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Evidence-based analysis that draws on peer-reviewed academic research and publicly funded studies to address issues such as bird-strike, shadow flicker, noise, impact on property prices and 'wind turbine syndrome'.

Centre for Sustainable Energy, May 2011

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This publication was written in response to requests from community groups for factual information about wind energy, in part to counter the many myths and misconceptions surrounding this technology. It was produced as part of **PlanLoCaL,** a project that aims to give communities the knowledge and confidence to influence local planning policy and contribute to a low-carbon future **(www.planlocal.org.uk)**.

Photo: Wind turbine near Sheffield by Kai Chan Vong

Centre for Sustainable Energy (CSE)

We are a national charity that helps people and organisations from the public, private and voluntary sectors meet the twin challenges of rising energy costs and climate change.

We share our knowledge and practical experience to empower people to change the way they think and act about energy. We do this by giving advice, managing innovative energy projects, training others to act, and undertaking research and policy analysis.

At any one time we have between 50 and 60 different and separately funded projects under way. All of these are helping people and communities to meet real needs for both environmentally sound and affordable energy services. You can read more about what we do at **www.cse.org.uk**

We are based in Bristol although much of our work has relevance and impact across the UK. Our clients and funders include national, regional and local government and associated agencies, energy companies and charitable sources.

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Centre for Sustainable Energy

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Introduction

The Centre for Sustainable Energy commissioned this research with the aim of explaining some of the concerns that typically arise in relation to wind power and other aspects of energy generation.

Of all renewable energy sources, wind power occupies a unique place due to a combination of two attributes: technological preparedness (wind is best placed of all existing renewable to contribute the electricity needs of the UK while simultaneously reducing its carbon dioxide, or CO_2, emissions); and the fact that it is inherently site-specific (making wind turbines strikingly visible additions to often previously undeveloped landscapes). The increasing presence of wind farms across the country means that communities everywhere will need to address the issues surrounding wind power.

In particular, an individual's attachment to the landscape and their concept of what constitutes 'unspoiled' countryside is inextricably entwined with the need to balance the transition to a low-carbon economy.

Wind power is not an all-encompassing solution, able to replace all other forms of electricity generation. However, it will play a significant role in the nation's policy toward helping divert the worst effects of anthropogenic (human induced) climate change, and to ensuring energy security in future decades.[1] Despite having fallen short of government targets, by the end of 2010 there was still more than 5GWe of installed onshore and offshore wind capacity in the UK. Given 2010 load factors (a year in which wind speeds were lower than average), this equates to roughly 10TWh of electricity generated in a year, which would allow for the annual displacement of some 5.98 million tonnes of CO_2 (MtC) were that energy to be otherwise supplied from fossil fuel generation.[1,2]

By 2020, wind power alone will be helping to displace over 50MtC, more than a third of the UK's current annual CO_2 emissions from electricity generation and over 10% of the UK's total CO_2 emissions for all forms of energy. Just one component of the renewable energy mix, wind power obviously has clear benefits.

Despite the advantages offered by wind power, its place at the centre of landscape development as outlined above often makes it a contentious issue. This is exacerbated by articles in the UK news media that continue to repeat misstatements put forward by opponents of wind power which are clearly contrary to the evidence and can easily be refuted (see sections on house prices, infrasound, net energy cost).

However, some of these issues are more subtle and critically dependent on the way in which they are presented. Emotive language is frequently employed by journalists to enhance the impact of a news story, and the authors of opinion pieces can 'cherry-pick' evidence to present a one-sided view.

As media platforms have to compete in a progressively more fragmented marketplace, creating a narrative that has an easily identifiable cause célèbre – in this case, wind turbines – helps attract fierce debate, thereby driving circulation and, increasingly, online traffic. On the reverse side, keen proponents of wind power are sometimes too quick to dismiss any problems raised, levelling the charge of 'nimby' at any concerned group who voice a protest over planned developments. While not willfully dishonest, both sides of the debate can be accused of reporting expediently to further their point of view.

In this document, we hope that pertinent research has been presented in a more balanced manner in anticipation that informed discussion can ensue. The reader will notice that it relies heavily on academic peer-reviewed publications and expert reports. Reading this is not intended to be the end of an interested person's research: rather, it should encourage further reading around the subject, casting a critical eye on the source of information. Casual assertions that unambiguously state wind power is good or bad without any supporting evidence should be judged accordingly. As is demonstrated throughout this document, the reality is frequently more complicated than that. The agendas of vested interests too often mean these subtleties are lost, and the subject descends into acrimonious debate.

What this document aims to show is that, implemented as part of a progressive energy portfolio, wind power can significantly reduce both the UK's carbon footprint, and its dependence on fuel sources that may become less secure in the future, or that present a costly and unacceptably hazardous legacy for future generations.

However, wind power is not appropriate everywhere, and we hope that by publishing this research communities themselves will engage constructively with the best available evidence to judge if there is a place for wind turbines in their own locality. To empower communities to make these decisions demands a more mature and responsible approach from the media, the wind industry and pressure groups on both sides of the debate.

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1

Wind turbines and energy payback times

Summary

Concerns about the amount of energy (and subsequent CO_2 emissions) involved in the manufacture, construction and operation of a wind farm are often voiced as an argument against its installation. It is true, of course, that some energy will be required over the whole life cycle of a wind farm. This includes the manufacture of materials; the transportation of parts to the site; construction of the turbines and supporting infrastructure like foundations; site operations and maintenance; and, finally, in decommissioning the site. However, this is true of all forms of energy generation.

The issue, therefore, lies in whether the plant will generate sufficient useable energy over its lifetime to justify the energy involved in its installation. In the case of wind farms, all the evidence suggests that this is the case: the average wind farm is expected to generate at least 20–25 times[1] the energy required in its manufacture and installation over its lifetime, and the average energy payback time for a wind farm is in the region of 3–6 months.[1,2] These figures compare favourably with other forms of power generation, as discussed in more detail below.

What is this based on?

Those opposed to wind power (be it onshore or offshore) often allude to the energy required in the construction and operation, with little consideration or comparison to other forms of large-scale power generation. The amount of energy required in installation is an important consideration when assessing the suitability and cost-effectiveness of any new energy development. As such, it is useful to be able to compare the amount of energy used in site installation with the amount of energy that the installation is expected to generate over its lifetime (i.e. the 'net energy' of the system – see the diagram in reference 1). This is often referred to as the 'energy balance' or 'energy return on investment' (EROI). The time taken for an installation to generate as much energy as was needed in its manufacture and construction is the 'energy payback period'.

A number of factors will affect the energy balance and energy payback period of a wind farm, including wind speed at the site and the size, number and type of turbines installed. Furthermore, in calculating the energy balance or payback period, a number of assumptions have to be made about, for example, the power rating, lifetime and capacity factor (section 3) of the turbines, and the 'system boundary' of the wind farm. The system boundary describes the number of different stages in the life cycle of the wind farm, all of which are taken into account when assessing a site's energy payback. These stages may include: business management; design and manufacture of component parts; transportation; construction; connection to the electricity grid; operation and maintenance; and final decommissioning and restoration of the site. These key steps are illustrated diagrammatically in reference 1.

What is current evidence?

Given the number of assumptions that have to be made in assessing and comparing the energy requirements of wind farms with the energy they generate, it is not surprising that a range of estimates exist about payback. However, a recent study provides a useful and comprehensive review of the net energy return for electric power generation by wind turbines.[1]

The review (published in 2010 in the journal Renewable Energy) includes data from 119 wind turbines, from 50 different analyses (of both real and conceptual wind farm sites), going back some 30 years. The range of assumptions (e.g. of power load, capacity, lifetime and system boundaries) and methods employed by the different studies is very evident – the review captures this breadth and helps in highlighting the impact of these assumptions and approaches on the resulting estimate of energy return.

The study refers to the 'energy return on investment' (EROI), which is simply the ratio of energy delivered by the technology to energy required in running the site over its lifetime (i.e. energy generated/energy required). A higher value indicates a better performing system. The results of the survey show an average EROI across all studies (operational and conceptual) of 25.2 (falling to 20 for operational only).

In other words, it shows that the average wind farm is expected to generate some 20-25 times more energy over its lifetime than was required in building and running it. This compares well with other forms of power generation systems. For example, coal offers a lower energy return on investment of around 8 and nuclear around 9.[3] The paper also shows the energy payback in years for the studies where this data is available. Figures referenced range from 0.29 to 0.53 years, or 3.5 to 6.4 months, suggesting on average a wind farm will have generated sufficient energy in just half a year to account for all the energy that is required in its construction and operation. This figure is broadly consistent with the 3–10 month payback period quoted by the Sustainable Development Commission.[4]

Conclusion

All electricity generation systems require some amount of energy for their manufacture, construction and operation. It is important to consider how this energy requirement compares with the expected energy output of the system over its lifetime. If the former is almost on a par with the latter, the system is clearly not a sustainable choice (environmentally or economically). In terms of energy payback, wind farms do compare favourably with other power generation systems. Furthermore, there is significant potential for technological development in wind energy – particularly relative to other, more mature systems – which could further improve the cost-effectiveness and performance of installations.

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[2] Milborrow, D. (1998). Dispelling the Myths of Energy Payback Time. Wind Stats Newsletter, vol. 11, no. 2 (Spring 1998).

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2
Wind turbines, costs and subsidies

Summary

It is often argued by organised groups opposed to wind energy – and repeated in the national press – that wind power is both expensive and is heavily subsidised by the taxpayer. In fact, onshore wind is already cost-competitive with conventional large-scale generation. And while it is true that all forms of renewable energy generation benefit from specific government support, it must be recognised that all forms of large-scale generation – whether low carbon or conventional – receive some kind of state support (in the form of subsidies, capital grants and allowances, etc). It is the case that, so long as the 'externalities' related to power generation from conventional fuel sources (from the plant itself or from the fuel supply chain impacts) are not included in the cost of those activities, government support will be needed to incentivise the low carbon but capital intensive forms of generation.

What is this based on?

Those opposed to wind power (be it onshore or offshore) often highlight the high costs involved in this form of large-scale electricity generation without consideration or comparison with other ways of generating power. These are then used to claim that wind power is an extremely expensive way of generating electricity and that without significant subsidies, ultimately from the tax-payer, wind power development would be unable to continue.[1, 2] In addition, there is a well organised opposition to the mechanisms by which all forms of renewables are supported – e.g. the Renewables Obligation (or RO) and, to a lesser extent, the exemption that all forms of renewables receive from the Climate Change Levy (CCL).

What's the current evidence?

Cost

Figures from the government-funded Sustainable Development Commission in 2005 showed that the generation cost of wind power was around 3.2p/kWh onshore and 5.5p/kWh offshore – this compared at the time to a wholesale electricity price of 3.0p/kWh. As an increasing amount of wind power is added to the system, there are some additional costs associated with accommodating it. These 'system costs' are estimated to be around 0.17p/kWh if wind power were to supply 20% of total output – this is equal to a 3.8% increase in the current cost of electricity, or £13 extra per year on the average domestic bill.[3] A previous government report in 2002 stated that onshore wind was competitive with new coal and cheaper than new nuclear.[4]

The generation costs of wind power have increased by 20% over the past three years due to increased demand and rising prices of key raw materials, though a European Commission Strategic Energy Review predicts a long term decline in capital cost.[5] This must be compared to increases in conventional fuel prices and the fact that there are no ongoing 'fuel' costs for wind power – as a renewable resource it will become comparatively even cheaper.

The most recent report looking at cost estimates of generating electricity from a range of large scale technologies commissioned by the Department of Energy and Climate Change in 2010 showed that estimates for onshore wind are now 9.4p/kWh. However, to put this in context electricity from nuclear power is estimated to be 9.9p/kWh and electricity from gas 8.0p/kWh. Offshore wind is estimated to be more expensive, with costs of 15.7–18.6p/kWh (depending on wind farm location), although this is expected to fall to 11.0–12.5p/kWh for projects commissioned from 2020.[6]

Subsidies

Claims that onshore wind energy is competitively priced only because of government subsidy, or that wind power is disproportionately subsidised, are not supported by the evidence. In order to meet the UK's targets for reducing carbon emissions electricity suppliers are required to purchase an increasing number of Renewable Obligation Certificates (ROCs) each year from renewable energy generators. A fine is paid by those suppliers who have not met their obligation, with the revenue being distributed to those suppliers who have (in proportion to how many ROCs they purchased) therefore rewarding those who are purchasing more renewable energy.[7]

The only financial support from government for the Renewable Obligation is the administration and regulation by Ofgem, which for 2008–09 was only £988,500, representing less than 0.1% of the scheme's total value.[8] While the costs are ultimately reflected in customer's bills, one aspect of the policy ensures that this is never more than an additional 3p/kWh on a maximum 10% of the customer's electricity use, meaning that 90% of a customer's bill is unaffected by the Renewable Obligation.[7] Furthermore, ROCs are a market mechanism and non-technology specific so it is most economical for suppliers to meet their Renewable Obligation by purchasing the cheapest renewable energy, thereby supporting the case that onshore wind is a cost-effective method of increasing renewable capacity.[7]

A different kind of subsidy which is inherently not accounted for is found in the externalities of fossil fuel and nuclear generation. Externalities refer to wider environmental, social and economic costs of an activity which are not accounted for in that activity's price. These costs, or impacts, are typically felt outside the traditional economic accounting system, or in what is often referred to as 'the commons', such as the atmosphere, land and water.[9] These costs include pollution, fuel spills, accidents, clean ups, health costs and, ultimately, climate change. Where the industry responsible does not fully cover these externalities, they are effectively subsidised by society through taxation.[9]

In an attempt to quantify these externalities, the EU's ExternE report claims that if all environmental and social costs of burning coal and oil were 'internalised', the price would double.[10] This assertion is made even though the impacts of natural resource depletion are not included in the analysis;[11] accounting for the full impacts of mining, processing and transporting the raw materials would internalise significantly more costs, particularly for coal and nuclear, given the processes involved (see also section 6).

A 2011 paper aiming to quantify the full costs of coal generated electricity uses a more comprehensive life cycle analysis than the ExternE report – which includes the impacts of natural resource depletion, wider ecological impacts and its contribution to climate change – and suggests that the true cost of coal generated electricity could be tripled.[12] And there are yet further impacts which are not accounted for, such as the long-term effects of toxic chemicals and heavy metals on ecosystems, the health and ecological risks posed by sludge and slurry, the full contribution of nitrogen deposition to eutrophication in fresh and sea water, the prolonged impacts of acid rain and the full assessment of impacts on an increasingly unstable climate.[12] As true cost accounting improves, the relative costs of fossil fuels compared to renewables will increase; however, there will always be impacts that cannot be adequately quantified.

While overall subsidies to conventional generation have been considerably greater than those to renewables, on a per unit energy basis renewables in general have received significantly more.[13] However, a comprehensive study into worldwide energy subsidies revealed that wind 'has registered a spectacular success story in reducing the need for subsidisation' and among renewables only hydro (which receives the least per unit of electricity of all generation types) receives less; moreover, coal-fired generation received the highest subsidies per unit generated, despite its widespread deployment[11]. Furthermore, this only includes the externalities as accounted for by the ExternE report, which does not represent the true overall cost (see above).

The bulk of subsidies to renewables go into research and development and the significant capital needed to bring emerging technologies into the market.[11] Not only were such subsidies necessary for the development of much conventional generation during its equivalent early years[11, 13] but the social and environmental costs of both the fuel supply chain and the resultant pollution of those energy sources are ongoing. Once wind farms are up and running, on the other hand, there is no fuel input or pollution and therefore no similar associated impacts.

Conclusion

A recent report for the Department of Energy and Climate Change (DECC) characterised the cost trade-off to be considered by stating that "Plant can be broadly categorised either as being expensive machines for converting free or low cost energy into electrical energy or else lower cost machines for converting expensive fuels into electrical energy. The former group comprises most renewable generation and nuclear plant, while the later group comprises plant running on fossil fuels."[14]

The evidence demonstrates that wind energy is already cost competitive with conventional electricity generation over the lifetime of the plant.[3, 14] Furthermore, there are no fuel costs associated with operating a wind farm, unlike fossil fuel plants. Fossil fuel prices are set to increase now that less accessible fuel reserves need to be extracted to meet global demand. This means the relative price of wind energy is likely to become even cheaper.

Much of the environmental and social cost of conventional fuels is not reflected in the cost of generating electricity from conventional large scale plant, and effectively amount to additional public subsidies. Internalising these costs completely would further increase the costs energy generated from conventional fuel sources.

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3

Efficiency of wind turbines

Summary

It is sometimes alleged that wind turbines are inefficient and 'only work 30% of the time'. This figure is based on the 'load factor' for onshore wind farms, but is erroneously used to imply wind power is inefficient. This is wrong – load factor and efficiency are not the same; in fact, conventional power stations in the UK run with an average load factor of 50–55%, but these are not described as running "half the time". Wind farms actually generate electricity around 80–85% of the time, and power is converted to electricity very efficiently, with none of the thermal waste inherent in fossil fuel plants. So, wind power is an efficient way to generate electricity, employing a free energy source that is also renewable.

What is this based on?

Any device capable of generating power is given a rating or 'nameplate capacity' measured in watts. This is simply how much power the device can produce at its full, or peak, capacity – it does not take into account how that power is converted into useful energy. The capacity factor, or 'load factor', is the average power output (i.e. actual output measured over a period of time, usually measured in hours) divided by what could have been produced had the generator run continuously at peak capacity over the same period. It is from this calculation that the 30% figure for wind turbines is drawn, but capacity factor should not be confused with efficiency; that is to say, this does not mean wind turbines are 70% inefficient, or that they only run for seven hours every day. No generator is designed to run at full capacity continuously, and conventional power plants as a whole usually run with an average load factor of 50–55%.

What is the current evidence?

Medium to large scale power generators of any kind (e.g. fossil fuel, nuclear, wind or hydro) have capacities measured in megawatts (MW). When discussing electrical power generation from power plants, it is common to draw a further distinction between megawatts electrical (MWe) and megawatts thermal (MWt). To give a few examples: typical capacity ratings for a large coal-fired power station or large combined-cycle gas turbine plant in the UK would be in the 1–2,000 MW range; nuclear power plants are around 1,000 MW; gas/oil plants go from 10–50 MW; and the ratings for individual modern large wind turbines are commonly between 1.5–3.0 MWe. Table 4.1 (overleaf) gives load factors for various conventional plants and renewable power sources in the UK for years 2007–09.[1]

Conclusion

When discussing wind power, load factor is frequently equated with efficiency. This is incorrect, and paints a misleading picture of wind turbines being inefficient compared to more traditional sources of power. Onshore wind power generation has a load capacity of around 27%, but this is not an indication that something is wrong with the functioning of the turbines, and is hardly calamitous when compared to the ~38% average load factor of conventional thermal power stations.

The UK continues to offer the best wind resource in Europe, and the power output from a wind farm can be calculated with considerable accuracy.[2] In fact, wind turbines typically produce electricity 80–85% of the time, and periods of peak generation from onshore wind can be used as an opportunity to sell electricity back to the national grid.[1,3] Furthermore, the efficiency of a wind turbine can be considered very good in comparison to non-renewable sources, as they are capable of turning a free resource (wind) into electricity without the considerable thermal inefficiencies inherent in most conventional plants that consume fossil fuels or use nuclear power.

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[1] National Statistics, 2010. Digest of United Kingdom Energy Statistics 2010. London: TSO. Published with permission of Department of Energy and Climate Change. www.decc.gov.uk/assets/decc/statistics/publications/dukes/348-dukes-2010-printed.pdf (accessed 23 Nov 2010)

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Table 3.1	2007	2007	2008	2008	2009	2009
Source of electricity generated	Installed capacity (MW)	Load factor (%)	Installed capacity (MW)	Load factor (%)	Installed capacity (MW)	Load factor (%)
Conventional thermal stations – of which coal-fired	36,658 23,008	44.3 66.0	35,145 23,069	39.1 59.9	35,151 23,077	32.9 49.8
Nuclear stations	10,979	59.6	10,979	49.4	10,858	65.4
Combined cycle gas turbine stations	26,930	64.3	28,593	70.9	29,878	62.8
Hydroelectric stations (natural flow)	1,419	36.3	1,519	35.7	1,526	35.0
Onshore wind – on unchanged configuration basis	2,083	27.5 27.3	2,820	27.0 29.4	3,483	27.4 26.9

Unchanged configuration uses load factors of wind turbines that have operated throughout the calendar year. This avoids biases created by the introduction of new turbines partway through the year. As this mainly applies to commercial scale wind farms, units of <100kW rating are excluded.

4

Intermittency of wind turbines

Summary

Weather patterns can be forecast with some degree of accuracy, but there is no denying that wind power is an intermittent source of energy when focusing on isolated sites. This notwithstanding, the problem of 'dispatch', whereby supply of electricity is tailored to meet constantly changing demand, is not new to the industry. Large unpredictable swings in the system are already balanced on a daily basis, and the grid is prone to critical failures for which significant reserve capability already exists. On balance of the evidence, there appears little need to expand this overall reserve in response to increased wind capacity.

The uncertainty of supply when considering wind is a problem of availability that presents novel statistical challenges to the transmission operator when compared with conventional generators, but not one that cannot be forecast and integrated effectively into the national grid. It should be made clear that these challenges do require a moderate financial cost, although the external benefits of reduced total CO_2 emissions from electricity generation and the resilience provided by a distributed network of wind farms should not be underestimated.

What is this based on?

One major disadvantage often stated for wind power is that this resource is not available as a smooth, uninterrupted supply, i.e. it is intermittent. This is a critical factor when dealing with electricity generation because output must be balanced exactly with demand (electricity, uniquely for a major energy supply, cannot be easily or efficiently stored). Traditional power generation in the form of fossil fuel plants operate in a load-following capacity, whereby output is lowered or "ramped up" according to the demand placed on the national grid. In the main, this role is performed by gas-fired power stations, which can be rapidly fired up to meet increased demand.

In the UK, peak demand – and thus, electricity production – is typically just below 80% of the nation's total capacity.[1] Therefore, no system of electricity generation is designed to run at maximum capacity, as it must have the flexibility to cope with fluctuations in demand at the same time as providing for unforeseen events such as plant failure. The variability of wind is a significant issue, but is not an unprecedented challenge for an industry that already copes with greater fluctuations in the national grid on a daily basis. The argument should be considered with regard to the cost society is prepared to accept for carbon-free electricity (of which wind is the major contributor at present).[2,3]

The UK is considered to have one of the best available onshore and offshore wind resources in Europe, with installed capacity notably higher than rates achieved with comparable facilities in Denmark and Germany.[4] Care should be taken not to extrapolate average data for wind resources across the entire country when discussing wind power.

However, this caveat should not be applied simply to argue that a UK wind power grid will be undermined by periods of inactivity (caused by low or high winds),[5] since this can also work in favour of wind power when implemented as part of a diversified network.[6] In the context of a nationwide, diversified system of wind farms the effect of this variability is largely evened out – the lack of control with regards to when the wind blows over a specific wind farm is what creates the perception of an insuperable problem.[2] A nationwide "geo-spread" of wind capacity, provided it is balanced across the whole grid, means that:

> *"...the sudden loss of all wind power over an entire power system at the same instant – due to a drop in the resource – is not a credible event."*[3]

To discuss the issues involved with intermittency, this section will deal mainly with wind generation as a whole (i.e. onshore and offshore) as this phenomenon is inherent in any form of wind power.

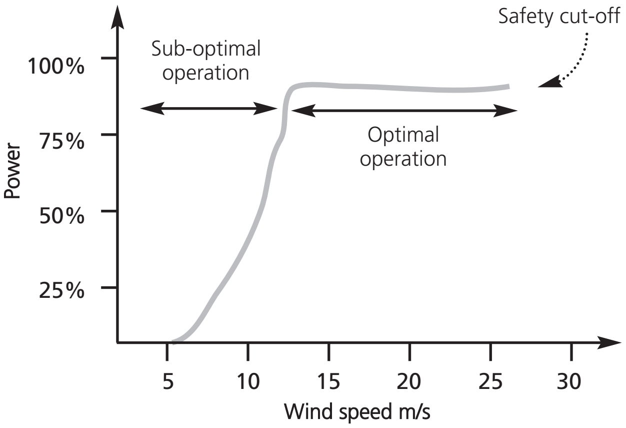
What is the evidence?

The output of electrical power across the grid must exactly balance the demand, as there are only very limited means to store electrical energy that is not used.[2] Onshore wind power generated 2% of the UK's total electricity production in 2009: this was 7,564 GWh (which can be expressed in terrawatt hours as 7.56 TWh) out of a UK total gross production of 359,189 GWh (or 359.2 TWh).[1] The UK target is for renewables to make up over 30% of the country's total electricity production by 2020, estimated to be a demand of 399 TWh.[7]

Conservative estimates say onshore wind will have an installed capacity of 11.5 GWe and offshore wind will rise to 21.5 GWe.[8] We have seen already (section 3) that power plants only ever provide a fraction of their theoretical capacity – the load factor – and this is around 30% for wind power as a whole. Given the 33 GWe capacity predicted above for 2020, wind will generate 86TWh of electricity. To put this in perspective, every TWh of electricity generated by wind in place of fossil fuels would displace 598,000 tonnes of carbon dioxide, saving over 50 million tonnes (MtC) in total if 2020 targets were reached.[1]

There is no denying that wind is an intermittent power source: the figure overleaf illustrates a typical power curve of a modern wind turbine, demonstrating that a wind turbine ramps up its output from <10% of its capacity to almost full capacity (>85%) between wind speeds of 4m/s (9mph) and 12m/s (27mph)[9]. This output tends toward

Fig 4.1
Indicative power curve of a typical modern turbine



maximum capacity between 12–25m/s (27–55mph), after which the turbine cuts out to prevent damage due to high wind speed. Weather patterns across the British Isles can often result in wind power output varying by 0–100% for a particular wind turbine (or wind farm) on any given day, since the window of operation is 4–25m/s; typically *individual* wind turbines are on average non-productive for 20% of the year, almost always due to lack of wind.[6]

What problems does this pose for managing wind power on a national scale? The present level of capacity in the UK system for wind in both onshore and offshore platforms is 4.4 GWe (around 5%), and any period when these installations are not providing enough energy can be easily adjusted for by the grid using more responsive plants such as natural gas-fired turbines. However, as wind penetrates the electricity generating capacity to a much more significant level (up to 33 GWe – 39% of the UK's total installed capacity[1]) then the fluctuations inherent in the system will require careful management to maintain security of supply.

Consider a future grid that contains 10 GWe of installed wind capacity. With existing conventional non-intermittent plant it is accepted that demand forecast over a half hour (0.5h) window will be subject to a 0.34 GW standard deviation (s.d.), but with 10 GW installed wind capacity there is also a calculated s.d. of 0.14 GW across the same period of time; adding these independent forecast errors together, that amounts to 0.37 GW [for combining s.d. values solve the formula √(3402 + 1402)]. Reserve capacity to deal with uncertainty between demand and output is taken to be three standard deviations of the overall forecast error: for our system here that contains 10 GW of wind capacity this is equal to 1.14GW (= 3 × 0.37).

In summary, a grid with 10GWe of installed wind capacity must be able to cope with a potential mismatch of 1.14 GW in every 0.5 hour period.[10] Across a 4-hour window these fluctuations amount to just under 3 GW. As the forecast window increases the s.d. for the forecast error levels off, so 0.5 hours and 4 hours are considered appropriate periods to take account of uncertainty in output.

The above example shows that, above a certain penetration, installing 1 MW of wind capacity does not necessarily equate to 1 MW of conventional plant being replaced. Due to the inherent uncertain availability of wind at various operating time windows, a high penetration of wind capacity places a significant burden on the grid operator to manage reserve capacity and ancillary services. This is not just for shortfalls in power output – it can also be the case that highly concentrated centres of wind power generation will cause other problems due to supply outstripping production.[5]

In large wind power systems in continental Europe this can largely be offset by exporting electricity to neighbouring countries via well-established inter-country networks; but this is not so straightfoward for the UK (although interconnected grids between the UK and Ireland offer a limited 'smoothing' facility).[9,11] The British Isles does have the advantage that summer and winter weather patterns broadly coincide with annual peak demand, i.e. wind capacity factor (load) is considerably higher than the yearly average during winter months, which is the period of highest demand. Aggregating wind power generation over the entire UK grid allows local supply/demand mismatch to be smoothed out and reduces the need for large levels of balancing capacity.[6] Indeed, the creation of continuous geographical 'balancing regions' allows more accurate forecasting to meet the needs of the transmission (grid) operator.[12]

As mentioned above, an increased wind capacity creates a special requirement for reserve capacity that can be easily brought into action or, alternatively, curtailed, to meet constantly fluctuating demand. Reserve capacity is traditionally heavily reliant on a synchronised or 'spinning' reserve, i.e. conventional thermal plant that is kept part-loaded (around 20% capacity) to be instantaneously ramped up when needed and subsequently returned to standby when demand drops. Additional capacity is provided by standing reserve, which, as its name implies, employs smaller generators (typically diesel) that are switched on and off. This is usually in response to a large drop in power caused by a power plant outage.

There are negative aspects to keeping spinning reserve as a backup to compensate for greater penetrance of wind power: power plants that run part-loaded are less efficient and thus create more CO_2 emissions per unit electricity; and the most efficient conventional thermal plants are not designed for 'load-cycling' at the degree needed to cope with demand/supply mismatch, which means they will run less reliably due to physical stress placed on these units[9]. Previous estimates of the cost of increased wind capacity may not have taken these factors into account; but, the underestimation of availability of wind-generated electricity at times of higher demand means that the need for spinning reserve has been overestimated as a result.[6]

In fact, the grid already has reserve in place to cope with existing intermittency – a fact often overlooked is that conventional plant can be the cause of unplanned, and at times very considerable, power loss.

The resilience of a distributed network of wind turbines can even be considered superior to large conventional plants that may go offline without warning, creating an instant gigawatt ‘hole’ in the national grid’s supply (for instance due to the inherent risk nuclear plants must shutdown completely if there is a serious fault).[6,13]

Conclusions

The increasing installed capacity of wind power across the UK poses a considerable technical challenge to ensure the balance of demand and supply is maintained at all times across the grid. However, while availability of wind is to some extent uncertain for any one area, coping with large swings in supply and demand is a problem transmission operators have been familiar with for some time. And while the requirement on existing plant to provide some extra reserve capacity causes some concern, it is clear that national installed wind capacity can form an aggregated ‘balancing region’ whereby its perceived unreliability due to site-specific variability has been overestimated.[6,9,10]

However, the need to create a diversified network of wind installations is essential, and the practical issues of distribution from low to high-load areas within the grid should not be underestimated.[5,11] The need for extra investment should not be dismissed. There will be additional costs to improve distribution infrastructure and maintain sufficient conventional reserve, although these are thought to contribute only a moderate increase (5%) to the cost of electricity generated by wind.[2,10]

The ‘social resource cost’ is arguably the most important consideration for the decision to commit to optimum penetration of wind power capacity across the UK (generally estimated to be 26–33 GWe).[2,8,10] Wind power currently offers the most commercially viable and well-established renewable resource for electricity generation to meet national targets for the reduction of CO_2 emissions, and attempts to compare its ‘capacity credit’ on a like-for-like basis with fossil fuels is misguided, not to mention largely unnecessary given the capability of the industry already to cope with uncertainty in supply and demand[2,6]. In fact, a diversified wind power network would go some way to assist the transmission operators in achieving an overall probability level of meeting demand throughout the year, meaning its capacity credit may be underestimated in any case.[3,6,14]

There are concerns that relying on more flexible gas-fired power plants to play a load-cycling role could create increased unreliability and inefficiencies in the operation of conventional plant, and this should be accounted for in any implementation cost estimates. However, the displacement of larger, inflexible baseload plant across the system goes some way to offset this.[6,9,10] It should not be forgotten that the UK government’s targets include all renewables contributing 127 TWh by 2020 – increasing investment in biomass and marine/tidal would create less volatile capacity that could be used in place of traditional fossil fuel reserve when needed.[7,8]

Wind farms offer a flexible, modular system that if implemented as a diversified resource with effective geographic spread can offer a reliable source of low-carbon energy, forming a core part of a mixed renewables portfolio in combination with a reduced platform of responsive conventional capacity.

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5

The need for onshore as well as offshore turbines

Summary

It is argued that because there is a superior wind resource off the coast of the United Kingdom that all efforts should go into offshore wind power rather than onshore. However, various reports maintain the importance of continuing onshore wind's expansion alongside the development of offshore wind.

What is this based on?

Opposition to onshore wind and the typically higher speed and regularity of the wind regime offshore leads to claims that the UK should not bother with onshore wind, and should put all its efforts into developing offshore wind capacity. The potential to generate substantial amounts of renewable energy from offshore projects is also used as a justification for setting much lower targets for onshore projects. Proponents of this view argue that, because the visual impact of wind turbines offshore is much reduced, this is the right location for wind power.

What is the current evidence?

Offshore wind is forecast to be a major component of our future renewable capacity and, while the UK is a leader in its development, it is in its early stages compared to onshore. Onshore wind is already cost competitive with conventional electricity generation without subsidies (see section 2) and is currently the cheapest way for electricity companies to meet their renewable obligations and for the UK to meet its legally binding commitments to cut CO_2 emissions. Given government projections that onshore wind will become the cheapest way to generate electricity by 2020,[1] it will remain a crucial component of the UK's renewable strategy.

Both the capital cost and ongoing operational and management costs of offshore wind are up to twice that of onshore[2]. The former is due to the considerable costs of foundations, submarine transmission cables and installation facilities, while the latter reflects the remote and harsh sea environment in which they operate. High capital costs demand government financial support for this developing industry, though the technology is established and it is believed that economies of scale will reduce costs as production and investment increases with rounds two and three of offshore wind development.[1,4] However, despite the higher energy generation per MW installed, a recent analysis maintained that overall, offshore wind will remain more expensive than onshore as operating costs will always be significantly higher for reasons of gaining access and maintenance.[1]

The fact remains that the UK will need to continue increasing onshore wind capacity alongside huge offshore development if we are to meet the ambitious targets of 15% renewable electricity by 2020.[2] The European Wind Energy Association's high capacity scenario predicts 20GW offshore and 14GW onshore,[3] so they are both essential for increasing renewable generation.

Conclusion

The evidence demonstrates that the capacity of both onshore and offshore wind needs to expand if ambitious renewable and carbon reduction targets are to be met. The cost-competitiveness of onshore wind mean its continued expansion can continue, and while offshore wind still needs significant government support, its development will be a core component of the UK's longer-term renewable generation capacity.

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6
Wind power and nuclear power

Introduction

There is a wide and respected body of analysis which shows that the UK needs to develop its excellent wind energy resources – both on and offshore – if the country is to achieve its ambition of significantly cutting its carbon emissions and improving energy security.[1] Indeed, there are precious few credible projections of UK energy supply and demand that meet these objectives which do not include a large tranche of onshore wind power over the next 20 years, whatever other energy sources they also include.

In spite of this evidence, there are some who argue that we do not need wind power because we could replace the low carbon electricity it produces by developing more nuclear power stations. These, it is argued, avoid the intermittency associated with wind power, producing steady ‘base-load’ electricity at a cost at least comparable with onshore wind power.

However, in the context of forward projections for UK energy supply, which include a large tranche of onshore wind power over the next 20 years (and, in some cases, an assumption of new nuclear power stations), this is not an argument against wind power but an argument in favour of nuclear power also making a contribution.

This briefing explores the validity of this argument that nuclear power can sensibly be considered a replacement to the development of wind power in the UK. It should be read as neither for nor against nuclear power. It is instead intended to provide evidence which challenges the assertions that form the basis of the argument that nuclear power is an alternative to wind power. These assertions are that: (a) nuclear power can contribute enough to UK electricity demand such that wind power is not needed to meet low carbon objectives; (b) nuclear power’s ‘low carbon’ status is reliable and equivalent to renewable energy sources such as wind power; (c) nuclear power’s own environmental impacts and safety risks are either resolved or resolvable and can therefore be dismissed in any discussion about its suitability as a sustainable electricity supply.

Summary

Nuclear power has been used to generate electricity since the 1950s, and purports to be a tried and tested method of power generation. The use of nuclear power stations has been hailed in recent years as the most efficient way to produce electricity without relying on traditional fossil fuels, thus creating a relatively ‘carbon-free’ grid. While not strictly renewable, the potential stockpile of nuclear fuel available for extraction means its supporters describe nuclear power as a viable means to meet the world’s energy needs for hundreds of years at least, based on the fraction of physical fuel (enriched uranium) required by a nuclear plant in comparison by bulk with coal or gas.

However, nuclear power’s status as a low-carbon source of electricity is doubtful: while it compares favourably to traditional fossil fuels such as coal, the logistical chain required for extracting and processing uranium, plant construction and plant decommissioning create a carbon footprint for nuclear power that is significantly greater than renewable sources. In addition, the nuclear power industry in the UK and abroad has been traditionally beset with problems involving the start-up, operation and decommissioning of nuclear plants, resulting in economic inefficiency and threats to public health. Despite decades of experience, the unique problem of storage and disposal of hazardous radioactive waste remains a concern for the nuclear industry, with the cost and potential health implications to be borne by future generations for centuries to come.

Even without the concerns already raised, the long start up time required to make a nuclear power station operational means that nuclear power is irrelevant to the UK’s target to cut CO_2 emissions by 2020. The cost of electricity per unit generated by nuclear power is currently no better than onshore wind power, without taking into account the future costs of cleaning up when a plant is finally decommissioned. In comparison, the generation of electricity from wind power poses an insignificant threat to public health, requires a fraction of the start up costs and is a true renewable energy source.

What is this based on?

A typical nuclear reactor will generate the same energy as a coal fired plant using less than 0.001% of fuel by weight. For example, a 1,000 MWe coal station will burn 3.1 million tonnes (Mt) of coal per year, compared with just 24 tonnes of enriched uranium oxide per year for a 1,000 MWe nuclear power station (although it should be remembered that this comes from 25,000–100,000 tonnes of mined ore).[2] The heat created in a nuclear fission reaction with uranium is used to generate steam which drives the plant turbine to produce electricity; hence, no CO_2 is emitted as a waste product, making nuclear electricity ‘on a par’ with renewables such as hydro and wind power.

The operating carbon footprint does neglect the life cycle analysis (LCA) of nuclear power created by the mining, construction and decommissioning activities necessary for a nuclear plant’s operation – an analysis that calls into question the nuclear industry’s low-carbon claims.[3] This is of particular concern if global installations of nuclear capacity increase: as the readily available uranium ore is used up, efforts to extract lower-quality ore will create even larger environmental burdens. When compared with fossil fuels, the relatively small amounts of uranium needed (once it is suitably enriched) does mean that nuclear power is less subject to market forces that affect fossil fuel prices; and the global nuclear fuel supply is, in the early 21st century at least, relatively secure.[4] It should be remembered that wind energy is also largely immune to market forces, since its 'fuel', i.e. wind, is free and renewable, and start-up costs are considerably less than for nuclear.

Nuclear power stations supply baseload capacity and typically run with a load capacity of more than 80% – although the UK's current nuclear plant actually runs between 50% and 70%.[5] Traditionally, nuclear power stations offer less flexibility during off-peak times because output cannot efficiently be adjusted to follow load, which is the main reason they are employed in a baseload capacity only.

There is one market that shows it is possible to manage load-following electricity generation through careful integration of a fleet of nuclear power stations: France. This model offers valuable insights to management, but it should be noted that as the plants get older they lose their flexibility and have to be operated at baseline load. Furthermore, the French system generates 78% of its electricity by nuclear power, and can call upon a large network of 58 reactors overseen by a centrally controlled (and largely state-owned) administrator to provide load-following capacity.[6] Even with existing conventional thermal plant (fossil fuel and nuclear) national transmission operators in the UK and elsewhere must always rely on a flexible reserve to cope with a constantly fluctuating demand, a role which nuclear power is not suited to. The issue of balancing electricity across the grid is dealt with in the section on the intermittency of wind (section 4).

In the UK the most recent nuclear power plant to be commissioned and built was Sizewell B between 1987–95. Since the privatisation of the UK energy industry it has been acknowledged that investment in new-build for nuclear plants has not been forthcoming.[7] The reluctance of investors in the UK has been blamed largely on negative perceptions of the economic and safety record of the industry in this country,[8] although even in European markets traditionally more open to nuclear power, the two most recent construction projects of new 'Generation III' reactors (Olkiluoto in Finland, and Flamanville in France) are bedevilled with safety issues and rising costs, causing repeated delays and leading to increased risk of electricity shortfalls in France at critical times of the year.[7, 9]

Despite high-profile incidents in the past, the nuclear industry safety record is in fact very good, with a worldwide fatality rate expressed as 0.048 deaths per gigawatt of electricity per year (0.048 deaths/GWey) due to accidents – a statistic that compares favourably with coal (6.921; although 90% of this is from China), oil (0.917), gas (0.197) and liquefied petroleum gas (15.058).[10] Wind power, between 1975 and 2010, has 44 recorded fatalities, an average of 0.054 deaths/ GWey[11] It should be remembered that the figure for nuclear energy drops to an estimated 0.02 deaths/GWey when discounting the much poorer safety record of non-OECD nations.[12]

What is the current evidence?

Since the Government's commitment to reducing the UK's carbon emissions, nuclear energy has gone through a turbulent period of initial optimism followed by despondency. Despite being a mature technology with low operating carbon emissions, the question of whether the UK should invest in more nuclear power is dogged by concerns about environmental impact, economic viability and implementation, and safety.[3, 8]

Environmental impact: is nuclear power a low-carbon energy source?

Nuclear energy's hoped-for renaissance was based largely on its role in the shift to low-carbon energy production, based on its negligible operational CO_2 emissions.[8] This selective view of nuclear power's carbon footprint has been questioned by recent research, which points out that the life cycle analysis (LCA) of the 'nuclear chain' does in fact create significant environmental burdens.[13, 14] The LCA of nuclear power must take into account both the 'front-end' (the mining of uranium ore, the milling process, chemical conversion, and enrichment through centrifugal treatment and construction and operating of the plant itself) and the 'back-end' (the spent-fuel processing, transport, interim storage, and eventual disposal. Finally, there is the decommissioning and dismantling of the retired power plant, a costly financial and environmental stage that places liability on future generations.

It should be noted that the CO_2 emissions (CO_2e) generated by nuclear power are still a tremendous improvement over traditional fossil fuels, at 66g CO_2e/kWh compared to 960g CO_2e/kWh for coal, but they are higher than the rate of CO_2 emissions from true renewable energy sources: e.g., biomass generators of various kinds have life cycle carbon emissions between 14–41g CO_2e/kWh; a 3.5MW hydroelectric reservoir generates 10g CO_2e/kWh; and a onshore wind turbine of 1.5MW also creates just 10g CO_2e/kWh.[13] Looking to the future, if nuclear power capacity increases worldwide the environmental impact due to its LCA will only get worse. The quality of uranium ore plays a significant part in the life cycle emissions of nuclear-generated electricity, a crucial factor as the easily obtainable stores of uranium are used up.[14] This is a reminder that nuclear power is ultimately neither carbon-neutral nor renewable.

Economics and efficacy of implementing new nuclear build

Supporters of nuclear energy point out that renewables receive a greater boost from the government under the Renewables Obligations (RO) scheme introduced in 1998, despite the fact that RO grew out of the Non-Fossil Fuel Obligations (NFFO), designed to bolster the nuclear power industry, following privatisation of energy markets in

1989.[8,15] Due to the private sector's reluctance to take on the risk of lifetime costs of the nuclear-generated electricity industry the state-owned Nuclear Electric received 95% of the funds (£1.2 billion) gathered from the NFFO levy on electricity bills. Renewables are therefore disadvantaged until further NFFO orders redressed the balance.[15, 16] In fairness, it was reported that across Europe (EU-15 nations), renewables enjoyed subsidies almost 2½ times those received by nuclear, amounting to €5.3 billion and €2.2 billion respectively in 2001 (although the nuclear industry was able to waive the cost of full-liability insurance cover for critical accidents as such risks are not commercially insurable according to international treaty).[17, 33]

One might also add that this subsidy share is unsurprising if you consider that renewable energy technologies are in their infancy compared to nuclear, and that, in its nascent years, nuclear power received enormous subsidies thanks to the weapons potential that came from it.[17]

In the UK, there has been no new nuclear capacity introduced since 1995, despite the retirement of nine plants since 1989 (not including research facilities such as Windscale and Dounreay), not to mention the projected retirement of more than 9 GWe of capacity by 2025 (the latter date being met by the extension of some of these power plants past their original scheduled retirement date).[18, 19] As already discussed, private investors are wary of spending huge amounts of money on new nuclear build given the UK industry's economic history and the difficulty of estimating the complete life cycle cost of a nuclear facility.[7, 15] These fears are being borne out by the recent experience at Flamanville and Olkiluoto.

In France – arguably the most experienced market when it comes to commissioning nuclear plants – the Flamanville reactor is due to come online in 2013, over a year late and with costs 50% above the original €3.3 billion. The situation with the Olkiluoto plant is worse, being at least four years overdue and having a final budget over double the original €3 billion forecast.[7] The hidden financial burden of decommissioning also inhibits investment, with the UK cost set by the Nuclear Decommissioning Authority (NDA) at £73 billion in 2007, representing an average increase of 9% every year since government estimates in 2002.[19, 20, 21] Although there is some merit in the idea that the UK nuclear industry as a whole can make a profit through spin-off technologies involved with commissioning and decommissioning, this contribution is small in comparison with the public cost to manage the legacy of existing UK plant.[22]

The barriers to new investment outlined above, coupled with the lead-time for new nuclear plants to come on stream (around 11 years) make nuclear power irrelevant to the government's 2020 carbon-reduction targets,[18] though not necessarily the 2050 ones. However, given the enormous technological and financial resources required, the capital-intensive start-up costs of nuclear power plants and the lengthy lead-times before shareholders begin to see returns, it is difficult to see how a genuinely private UK nuclear sector can function in today's liberalised electricity market. Continued calls for stronger government support will also mean, in the words of one commentator:

> *"...alternative options for meeting the policy goals of making electricity affordable, reliable and sustainable will not be vigorously pursued while the nuclear option is pre-empting the available resources."* [7]

Safety of nuclear power

In addition to the imposing financial cost of nuclear energy, there is the safety and environmental record to take into account.

Purely in terms of associated deaths, the nuclear industry has a safety record (calculated as 0.048 deaths/GWey.[10]) that compares favourably with other energy production methods. However, the failure of the nuclear industry (and government) to show to the public's satisfaction that it has a high degree of safety is one of the main mitigating factors preventing the acceptance of nuclear-generated electricity as a valid source of low-carbon energy.[8] This is not surprising: despite promises that things are now much safer, as recently as 2005 the Thermal Oxide Reprocessing Plant (THORP) plant at Sellafield was found to have leaked 83,000 litres of liquid containing 22 tonnes of uranium fuel into a sump for a period of eight months before being discovered; the leak only came to light at the plant because the follow up accountancy system noticed there was missing nuclear material. The contents did not escape into the environment, but the inspector's report made it clear that the plant operated under an "alarm-tolerant culture", at one point stating:

> *"The HSE investigation team found that there were significant operational problems with the management of a vast number of alarms in THORP, resulting in important alarms being missed."*[24]

The delays with the Olkiluoto plant are also caused primarily by safety concerns of the Finnish regulatory authority (STUK), although there was also some public disquiet among independent parties over why it took STUK so long to discover non-compliant components.[25, 26] Although it can be said that operational fatalities are relatively low for the nuclear power industry across its history, the consequences of failure can be catastrophic, causing not just immediate loss of life, but also 'latent' mortality of many others (although care should be taken not to overstate these figures).[27] To be considered "politically unremarkable"[8] the nuclear industry must maintain "the high standards demanded for the unique nature of nuclear operations".[12, 24]

The 2011 disaster at the Fukushima nuclear power station in Japan demonstrates just how difficult such 'politically unremarkable' status will be to achieve. An 8.9 magnitude earthquake and subsequent tsunami completely overwhelmed a highly sophisticated, multi-layered safety system and left the nation's technologically very capable nuclear industry improvising its response on an hour-by-hour basis. The Fukushima emergency shows that even the most considered 'belt-and-braces' safety system can be undermined by extreme natural events. It also illustrates how quickly the potential scale of the resulting nuclear risk captures public and political attention and how one high impact event focuses concerns on the continued operation of all nuclear power stations worldwide.

Radioactive waste

The problem of radioactive waste is another concern that impinges on both safety and the environment. Nuclear waste in the form of spent uranium contains a mixture of fission products, which can be grouped into either medium-lived or long-lived fission products. The medium-lived products have a half-life (t½) of up to 90 years; for example, iodine-131 (^{131}I) lasts for only eight days, whereas caesium-137 (^{137}Cs) and strontium-90 (^{90}Sr) both have half-lives of roughly 30 years. Those that are long-lived can last for 211,000 years in the case of technetium-99 (^{99}Tc), 2.14 million years for neptunium-237 (^{237}Np), 15.7 million years for iodine-129 (^{129}I), and 700 million years for any unspent uranium-235 (^{235}U) itself. Those listed here are some of the most problematic due to their activity in biological and geological systems, but it is by no means a comprehensive list.

The problem inherent with nuclear fission is that the waste produced must be isolated and contained for a sufficient period such that it no longer poses a threat to human health and the environment if exposed. In fact, the majority of what is termed radioactive waste is 'low-level' and can be safely stored for several decades to allow any contaminants to decay, after which point it can be disposed of reasonably safely.[28] However, long-lived fission products need to be treated and a solution found whereby they can be subsequently removed from the biosphere. In the short-term this is a troublesome issue itself, as the NDA is finding that many of the decommissioned sites around the UK contain a mixture of toxic and radioactive materials that generate a great deal of heat and require careful handling and storage to minimise the danger (a costly exercise, as discussed above).[19, 29]

Some fuel can be reprocessed and the reclaimed uranium put back into the reactor, although this itself is incredibly specialised and employs a range of highly toxic chemicals.[28] The UK's high-level waste is predicted to be 478,000 m^3 by the 22nd century[29] (equivalent to filling the Albert Hall five times over). This waste is highly toxic and must be made safe: it is generally solidified in borosilicate glass, a process called 'vitrification' that is mainly carried out at Sellafield.[19] What to do with this waste after that is still a moot point, and one that government and the industry have not been able to resolve completely.

The most attractive option for the nuclear industry in general appears to be a geological repository, and this is certainly the preferred recommendation of the UK government.[28, 29] However, the govenment's Committee on Radioactive Waste Management has taken pains to point out that the position adopted on the issue is presented to the public in terms that are too simplistic and optimistic, and that to date there has been just a single area of the UK to offer itself as a geological disposal facility.[30] Following the publication of this recommendation, the Scottish Parliament announced that it had opted out of the report as they have ruled out geological disposal as a method of long-term storage.[31] The most well known case study, that of the Yucca Mountain repository in the USA, has also suffered a setback despite billions of dollars spent on years of consultation and research by the US Department of Energy.[32] The current American administration has declared the Yucca Mountain site is now "off the table".

Conclusions

Investment in nuclear energy represents an enormous commitment, with any meaningful expansion of the UK's nuclear capacity likely to come from the public purse. The benefits of such a policy are by no means clear, but what is certain is that the legacy of such a policy would place a financial and environmental burden on future generations that is difficult to predict. Nuclear only contributes to the electricity energy needs of the UK – it cannot meet the demand for transport or heating which are dominated by fossil fuels. At most, this is a theoretical maximum of 20% of the UK's total energy demand.[5, 7] Much the same can be argued for wind power (and other renewables), but wind does not have the same safety and environmental problems, and can be removed more cheaply and quickly. Furthermore, in the words of one expert commentator:

"…the financial and political resources that [nuclear] consumes so voraciously can be diverted to the painstaking work that will be needed to ensure that the energy efficiency of every dwelling in the UK is transformed, ***as can readily be technically achieved.*** *"* [7] *[emphasis added*]

The flexible, modular approach that wind power and other renewables offer means that technology and policy can be fine-tuned or redirected as the situation requires, without entrenching UK energy sector in a costly and potentially risky enterprise that would draw on resources for years to come.

Notwithstanding the environmental concerns about the 'nuclear chain' and the long-term problems created by radioactive waste,[13, 14, 28–32] there are compelling arguments that modern nuclear reactors are both safe and exhibit a relatively low carbon footprint during their operational lifetime.[12] Despite this, the industry in the UK has not shown that it has learnt from mistakes of the past, and seems poorly placed to compete in the privatised electricity market of today.[7, 24] There is some hope that economically viable technologies can be encouraged through expertise in decommissioning and cleanup, including limited import and export arrangements of certain types of waste, but it is difficult to see how these will make up for the cost of operating and subsequently retiring the existing capacity.[19–21] Successful state-owned models of operation in France belie the free-market approach of the UK, which would require a centralising of the nuclear industry at the expense of less risky, low-carbon policies that seek to integrate efficiency savings and renewable energy effectively.

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7

Public acceptance of wind turbines

Summary

Attitudes toward wind *power* are fundamentally different from attitudes toward wind *farms*, a divergence that has created what is sometimes called the 'social gap'. Despite the broad public support for renewable energy (wind included), the development of wind farm projects is often met with stiff opposition at a local level. Although some opposition is based on misconceptions about wind power in general, local resistance to wind farms is a complex interconnection between a position of being 'for the greater good' and negativity toward what is seen as an unwelcome imposition on the visual landscape to which residents have a strong emotional attachment.

The pejorative term 'nimby' (from 'not in my back yard') has regularly been levelled at residents when negative opinions about planned wind farms have been raised. This term is inaccurate, unfair and has no explanatory value, serving only to increase antagonism if it achieves anything at all. Understanding the issues involved, namely what lies behind the concerns and preconceptions of residents, is crucial if a community is to accept and even welcome the installation of a wind farm nearby.

What is this based on?

Beginning with the 1989 Electricity Act, the UK government has steadily moved towards a policy of greater dependence on low-carbon energy generation. In its most recent policy statement (2009) the government hopes to achieve more than a one third reduction in CO_2 emissions from 1990 levels by 2020; a large part of this requires generating 30% of the nation's electricity needs using renewable energy.[1] Notwithstanding targets for 2020, it is clear that previous targets set by government for 2010 have not been met, despite large increases in installed renewable capacity.[2,3]

One of the key factors identified as necessary for the UK to meet its renewable energy targets is the support of local communities; conversely, failure of renewable energy projects to achieve planning permission in a streamlined and timely manner is identified as one of the major obstacles[2]. Wind power is not the only renewable energy source to have met with opposition: in Europe and the USA, biomass, geothermal and tidal energy projects have all met with resistance at a local level.[4] It is important to note that, contrary to initial assumptions by the industry, offshore wind power is also subject to opposition by local communities.[5,6]

Clearly, there is a need to address the concerns of local communities when a wind farm is being built; but, the community should be engaged from the start so that the pros and cons of local developments are fully discussed. The dismissing of the problem by regulators and the energy industry as 'nimbyism' reveals that a 'barrier-oriented' view prevails. This can leave residents feeling disempowered and unable to control their own landscape.[5,7] Balanced dialogue and direct community involvement to redress perceived inequities are needed if renewables are to realise national and international policy goals for cleaner energy.[1,8]

What is the evidence?

What lies behind the 'social gap' – the divide between the public's support for wind energy and its opposition to local projects?[9] This is not a new problem, as modern society has dealt with the integration of infrastructure for many years. A common theme for policy-makers and regulators is that local opposition is motivated by a selfish view that while society as a whole can benefit from the implementation of improved infrastructure, this is only welcome when these developments take place elsewhere.[7] This is epitomised by the term 'nimby'. Wind energy proponents have been guilty of this in the past, when developers found that local support did not reflect public opinion in favour of clean energy.[4,10] In the last decade, many commentators have rightly disparaged this view, which makes little attempt to understand the complex interaction of local communities with society and national policy.[4,7,9]

What is implied by the term 'nimby'? It is best defined as the dichotomy between the public good and an individual's attempt to maximise their own utility.[7] In this case, the implementation of wind power as a clean source of energy is the public good; and local opposition to wind farms is the manifestation of the individuals' desire to minimise the impact on them personally. However, studies on community views relating to the installation of wind farms reveal that opposition – while instigated largely by the announcement of an impending local development – is not driven by local considerations alone, but by the perceived gap in understanding how wind power will benefit society as a whole.

For instance, a major wind farm development off Cape Cod in the USA has been floundering at the planning stage for nearly a decade due to a highly-motivated and high-profile opposition campaign. A compelling statistic from the community involved reveals that when placed in the context of a nationwide move toward wind power that has a larger benefit to society as a whole, support for the Cape Cod project increased dramatically.[5]

While it can be asserted that some opponents of local developments gain from the 'free ride' to be had by strenuously arguing against a local development while at the same time supporting wind energy elsewhere, the significance of such self-interested groups should not overshadow the genuine site-specific concerns that residents might have.[4,9] It must be remembered that public opinion is consistently highly favourable toward wind energy, and only a tiny fraction of opposition by local groups can be attributed to true nimbyism, almost invariably by those who dislike wind power generally.[8]

As discussed elsewhere (sections 8 and 11), there are many negative preconceptions voiced when an installation is proposed and built, which decline once the wind farm is operational[11]. Concerns over noise and environmental impact are significant, but it is changes to the visual landscape that is believed to be the driving force behind additional objections surrounding the development of a new wind farm.[6,7] Although generally true, the maxim that public acceptance of a new wind farm follows a 'U-shaped curve' – i.e. broad support before planning, declining support during planning and construction, followed by rising acceptance afterwards – should be treated with caution, as this is by no means a universal response.[4]

In the UK, lack of community involvement is regarded as a contributing factor to the continuing difficulties wind farms face during planning applications. Elsewhere in Europe, where local authorities are often the motivating force behind wind farm developments (e.g. Denmark and Germany), direct involvement in the planning process – and a share in the economic benefits – mean that communities express fewer of the feelings of unfairness and inequity than communities in countries where the siting and construction of wind farms is largely driven by the private commercial sector (e.g. UK and Netherlands).[4,8] In particular, the adversarial style of the UK planning process means that local opinion only crystallizes in response to a planning application that is made public expressly to prompt any objections residents might have.[9]

Efforts by wind developers to address the root cause of local opposition to wind farms too often ends up with them stressing the 'greater good' but seemingly offering nothing but detrimental effects on the landscape.[4] What residents see is a developer's attempts to hide the turbines away:

> *"The wind industry adjusted to public resistance with a series of initiatives, ... pointing out that wind power produces no toxic waste, no radiation, no acid rain, no greenhouse gases, no thermal discharges, and no irreversible landscape changes. Though correct on all counts, there was still nothing the industry could do or say that would make the turbines invisible, and this left the most glaring infraction of wind power unresolved."*[10]

There is compelling evidence that most residents who come into contact with them on a regular basis do not find the presence of wind turbines objectionable[4,11]. Provided the benefits to both the community and wider society are properly explained and taken on board, most people display a surprisingly unselfish view of the need for such installations and close correlation is found between local community perspectives on wind farm developments and public support for clean energy as a whole[7,8]. Treating wind farms simply as a burden that must be imposed on local communities suggests that many proponents of wind energy are perhaps missing the point.[4,9,10]

Conclusion

The visual aspects of wind farm developments affect the fundamental views of local residents with regards to clean energy sources and the role they must play in society as a whole. The need for an increased reliance on wind energy continues to have widespread support, but the reality of a wind farm being built in any particular area often creates a marked divergence from this viewpoint. This gap between acknowledging the benefits of wind power whilst objecting to it on a local level has often been dismissed simply as nimbyism, but this fails to address the complex interactions between communities, national policy and the wider society, and is rightly seen as a defunct hypothesis.

Rather than focusing purely on 'free rider' motives that push the onus on clean energy to other communities, the objections to wind farm developments put forward by individuals are intimately tied up with their unique concerns about the local landscape and poor understanding of the principles of wind energy.

In the UK a top-down approach has driven much of the country's wind farm developments so far, creating a democratic deficit that is often filled by vociferous opposition groups. Involving communities in the decision-making and planning process for wind farms not only reduces the need to combat such opposition, but creates a better understanding of the wider issues involved in energy policy and the environment. An informed and motivated community with a real investment in a wind farm project will be well-equipped to integrate renewable technologies effectively in a manner that reduces social inequity.

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8

Wind turbines and property prices

Summary

As the number of proposals for wind farms across the UK increases, detractors fear that nearby residents will see their property values drop. Given the negative press that wind turbines often receive in the mainstream media, it is not surprising that this becomes a concern for local residents during the planning and development of a wind farm. In fact, a great deal of research in the UK and abroad shows that there is no devaluation in property prices nearby once a wind farm is operating. These fears are driven largely by the "anticipation stigma" found to exist during the planning and construction of wind farms, often bearing little relation to the actual community opinion or local property markets.

What is this based on?

This is a common objection raised against the siting of onshore wind farms. The premise seems obvious: why would someone be willing to pay as much for a property (inevitably in a rural area) that has wind turbines in view, when compared with a property that does not? As property is the single largest financial and emotional investment a person is likely to make, residents' concerns are legitimate and understandable. It is no great surprise that opponents of wind farms are quick to seize on this sensitive issue, but the evidence does not support the view that wind turbines will cause house prices in the surrounding area to fall.

What is current evidence?

Since the first UK commercial wind farm began operation in Delabole, Cornwall in 1991, wind turbines have become an increasingly common feature of the landscape in many areas of the UK, particularly Scotland.[1] In 2003 the Scottish Executive commissioned a study to assess the impact of wind farms on nearby residents, using ten major sites across the region.[2] This was an extensive survey that took into account how close to the wind farms residents lived, covering a surrounding 'zone' of 20km in total. Overall, only 7% of those questioned said their local wind farm had had a negative impact on the area; this is compared to 20% who said the impact was positive, and 73% who felt it had no impact either way.

Perhaps most surprisingly of all, respondents who lived closest to the wind farm (< 5km) and could see the turbines most often comprised the highest proportion of those who responded positively. Those respondents who were already living in their house prior to the wind farm being built were asked about house prices. Some 7% of them said that they had *anticipated* that house prices would be reduced by the wind farm; when asked about the *actual* effect, the number who said house prices had fallen dropped to 2%.

Further studies have been carried out on sites in Cornwall using actual selling prices. A preliminary study by the Royal Institute of Chartered Surveyors (RICS) in 2004 reported 60% of property professionals found new wind farm developments had a detrimental effect on residential property values.[3] These effects were stated by the respondents to occur overwhelming at the planning and construction stage, somewhat echoing the findings of earlier polls (discussed above). Since then, more rigorous research has been carried out.

In these later studies, the statistical samples are controlled so that other factors that may influence house prices (e.g., waterfront views, which can disproportionately enhance a property's market value) do not affect the relationship between the presence of a wind farm and house prices – this is generally known as the 'hedonic pricing method'. Initial data from these areas in Cornwall show no linear correlation between the presence of a wind farm on house prices in the immediate surroundings (within 5 miles).[4]

Further statistical analysis of the same area demonstrates that there was no causal relationship between distance to the wind farm and house price, or even visibility of the turbines themselves.[5] The largest statistical analysis to date uses data from almost 7500 sales across nine states in the USA.[6] This is an extremely thorough and rigorous study which summarises its main findings thus:

> *"Specifically, neither the view of the wind facilities nor the distance of the home to those facilities is found to have any consistent, measurable, and statistically significant effect on home sales prices."*

Conclusion

The installation of infrastructure relating to power generation and distribution is not a new issue. High voltage overhead transmission lines (HVOTLs, commonly known as electricity pylons) have also been the subject of extensive studies over the years, employing the same techniques of hedonic pricing.[7]

Increasingly, the installation of wind turbines at sites across the UK has prompted many surveys and studies to determine if nearby residents' property values are adversely affected.[2,3,4,5] There is no evidence that a causal links exists between house prices and the proximity of wind turbines, and this is borne out by larger studies carried out on transaction data in the USA.[6] What many of these studies have shown is an anticipation "stigma", whereby the perceived negative impact of wind turbines being constructed nearby causes a transitory drop in house prices, which quickly reverses when these negative affects fail to materialise post-construction.[6,8] This inflated anticipatory effect is also evident in the attitudes of local residents near large wind farms surveyed in Scotland.[2]

In many cases, the stigma is reinforced by the opinions of real estate agents when planning for wind farms begins, but this viewpoint is found to be misguided when post-construction data is available.[3,4] It is accepted that predictions by estate agents are found to be inaccurate (negative predictions in particular often being significantly inflated) when compared with actual transaction data and the views of the buyers themselves.[3,4,5,6,7,8,9]

Furthermore, the actions of groups inherently opposed to the construction of wind turbines can distort popular perceptions of how a community integrates a new installation – in the case of wind farms in Cornwall, 95% of objections raised during the planning stage originated from non-locals.[4] In recent years, estate agents and surveyors have begun to accept that data on house purchases clearly show there is no lowering of house prices caused by wind turbines.[10,11]

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9

Wind turbines and safety

Summary

All sources of energy supply, wind power included, can present a hazard to human health: fuel extraction and transport; construction and maintenance of plant and distribution networks associated with energy production; and the operation of such facilities; present a risk to human health, both to industry workers and, in rare instances, the public. In the energy industry, fatalities are measured in such a way as to show the cost/benefit for the energy produced, i.e. deaths per unit energy generated. This is usually given as deaths per gigawatt year (GWey). Wind energy enjoys one of the lowest fatality rates per GWey of any energy source, considerably lower than that for fossil fuels.

However, there is no escaping the fact that deaths occur due to the installation and use of wind turbines. These are overwhelmingly related to industry workers, although there are rare incidences of members of the public being killed: as with any industry, wind energy must strive to minimise or eliminate any fatalities where possible. When appraising wind energy, it must be remembered that wind continues to provide one of the safest forms of electricity generation available, without the additional environmental burdens that can impinge on public health, such as pollution or hazardous by-products.

What is this based on?

Despite having no requirement for large sources of fuel to be extracted (as with fossil fuels) or dangerous reactions to be controlled (as with nuclear reactors), wind turbines create hazards of their own. A typical commercial 2–3 MW turbine will have a hub height anywhere from 65–100m (roughly 215–330 ft) with blades around 45m (150 ft) in length. The risks of working on such high structures are readily apparent, not to mention the potential hazards created when transporting the component parts. Worldwide between 1975 and 2010, 23 workers have been killed while installing or removing turbines, and a further 16 people have been killed during operation and maintenance procedures (this does not include three recorded deaths that occurred on offshore installations).

In addition, there have also been four members of the public reported killed in accidents between 2000 and 2010. A parachutist in Denmark, a crop duster pilot in the US, a traffic accident in the UK involving a turbine transporter, and a child in Canada who was killed whilst playing around a residential turbine that was under repair.[1]

During operation a major hazard is also presented by the phenomenon known as 'blade throw', whereby a blade or piece of a blade becomes detached and is thrown clear of the turbine. Related to this, and a reported problem in areas prone to hard winters with icy conditions (e.g., Switzerland, Germany and Canada) is the occurrence of 'ice throw' – as the name implies ice accretes on the blade edge and is thrown through the air in chunks of varying sizes. These operational hazards are of particular concern as the distances travelled by blade parts or large pieces of ice can be considerable. There are concerns that the phenomenon of blade throw in particular is not being sufficiently addressed, with oversensitivity by the industry resulting in incidents not being openly reported.[2]

Perhaps partly due to this attitude of secrecy, the issue is further complicated by reports of blade throw that are difficult to corroborate. For instance, an extreme incidence of blade throw that occurred in 1993 is regularly cited as indicative of the large distances damaged blade parts can travel – up to 400m.[2] This figure should be treated with some scepticism: the mechanical failure was caused by a storm effecting an installation of small turbines (each 300 kW) and is referred to on a prominent anti-wind website.[3] Although the website carries a citation from an industry publication, the 400m distance is not mentioned anywhere in this reference cited,[4] nor is it mentioned in any related articles (in fact, no distances are mentioned at all). The website citation includes the fact that "An independent witness estimated the blade piece to weigh 1 tonne and travel almost 500m" but fails to mention any source for this additional statement. Care must be taken to ensure incidences such as these are not repeated without some basis in fact.

What is the evidence?

Modern societies have enormous and diverse energy needs. For instance, in the case of electricity, daily demand in the UK regularly fluctuates between 15–24kWh per person per day: taking the whole population this equates to some 40–60GWe of demand every day (the highest demand of the last decade occurred on 10 December 2002 and reached 60.12GWe).[5] Society derives its energy needs from a mixture of fossil fuels, nuclear and renewables, each with a cost to society through impacts on the environment or directly on human health.[6] In the dry language of economics these are termed 'negative externalities', but are more broadly known as social costs. The salient fact is that with all the above methods of delivering energy there is injury and loss of life involved. It is generally accepted that society strives to minimise these as much as possible, but such social costs are unavoidable.

There has been a considerable amount of data collected on the safety of conventional energy industries and hydroelectricity.[7,8,9] Taking figures from the start of the commercial wind energy industry in 1975 up to 2010, there have been 44 recorded fatalities (this includes a technician who reportedly committed suicide by hanging), an average of 0.054 deaths/GWey.[1] Conventional fossil fuel industries have considerably higher rates, ranging from 0.197/GWey for natural gas, to 6.921/GWey for coal and 15.058/GWey for liquified petroleum gas.[7] The outlier is nuclear energy, with just 0.048 deaths/GWey due to accidents – although it should be remembered that the hazards associated with nuclear energy are much greater in the event that something goes wrong, with 'latent mortality' difficult to quantify (see also section 6).[9] The data is summarised in the chart on the following page.

It is clear that maintaining an energy supply carries a human cost, but the superior safety profile of wind energy is evident. Going back to the UK's typical supply any one year: in 2009 natural gas was used to deliver some 19GWy of electricity[5] at a supposed rate of 17 fatalities, if taking the average accident risk calculated between 1965 and 2000.[7] An equivalent supply generated by wind power would, on average, result in one death.

But what of nuclear? It is, indeed, an impressively safe industry when the above figures are analysed. In fact, some recommend the risk element for modern nuclear reactors used in the OECD nations should be closer to 0.02 deaths/GWey.[9] The risk is low, but the hazard that nuclear power plants pose should something go wrong is considerable. A similar situation is demonstrated by the chart (next page), which shows the catastrophic effects of the Banqiao Dam disaster and how the safety profile of hydroelectricity has been distorted by this single incident.[7]

Finally, additional negative externalities exist that are not adequately captured by the data above, which simply focus on immediate fatalities. As well as being comparatively safe, wind power does not create air pollution or radioactive emissions, and has a significantly lower carbon footprint that any conventional thermal power source.[6]

Conclusions

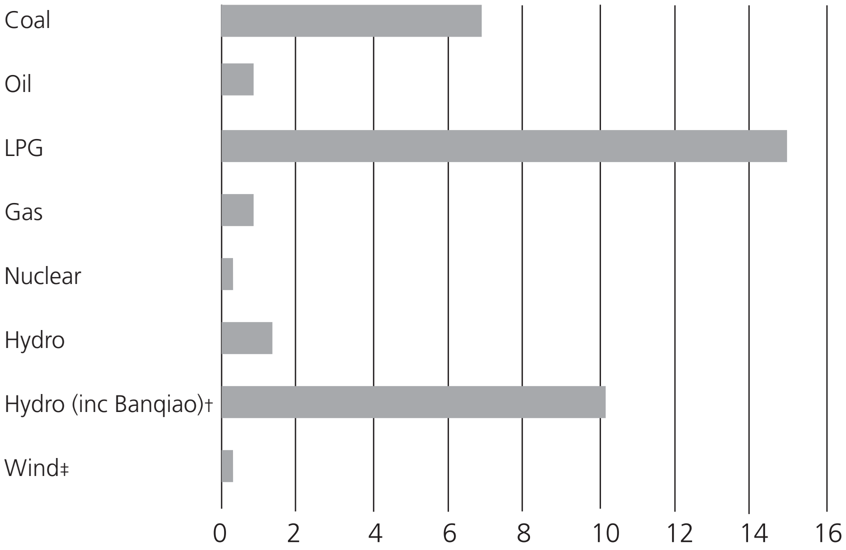
As with other features of modern life (e.g. air, rail or motor transport), society makes the decision to accept certain risks in exchange for the benefits that this development brings. Measuring one against the other is of paramount importance, as is a continual effort to minimise the risks along with any detrimental outcomes. This also implies that we should regularly re-evaluate the costs and benefits, so that we can be sure that what was once an acceptable cost is still the case and meets the increasing standards of safety expected in modern society.

Great care should be exercised when attempting to show wind-generated electricity is a benign source of energy.[10] There have been at least 44 recorded fatalities involving wind power since 1975 – very low by the industry standards, but the fact that lives are lost should not be ignored.

Analysing these statistics again reveals that the mortality rate per GWey has dropped ten-fold since the first commercial expansion of the wind industry in the 1980s.[1] However, wind turbines continue to suffer from faults which pose potential hazards to workers and the public. The problem of blade throw has been around for some time, and efforts by the industry to downplay this issue can only be detrimental.[2] It is telling that even very recent guidelines by pro-wind groups mention ice throw, but fail to address the much broader problem of blade throw.[11]

Much has been learnt in the last two decades as the wind energy industry has grown: more rigorous safety standards are being implemented in manufacturing, and work is being carried out to adequately model for risks such as blade throw to incorporate them into planning.[12,13] Although it could tackle some issues more openly, overall the wind energy industry has one of the best safety records of any energy industry, and has seen fatality rates decrease in the face of a rapidly expanding capacity. Wind continues to offer a clean, safe form of electricity supply, with considerably less cost and risk to society than either fossil fuels or nuclear energy.

Fig 9.1
Number of fatalities per GWey*



* Data for all energy types except wind taken from Burgherr & Hirschberg (2008)[7]: note that these data cover the period 1969–2000 and only include severe accidents with five or more fatalities (see note below for wind). Figures for wind cover the period 1975–2010 and are taken from Gipe (2010).[1]

† Figures for hydro are listed a second time to include the Banqiao Dam failure of 1975, which killed 26,000 people due to immediate flooding alone.

‡ Unlike data from Burgherr & Hirschberg (2008), data shown here for wind includes all recorded fatalities, not just severe accidents. In fact, each of the 44 accidents recorded resulted in a single fatality in each case[1].

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10
Wind turbines, shadow flicker and epilepsy

Summary

An effect known as 'shadow flicker' is caused when the rotating blades of a wind turbine cast a shadow on an observer. As the blades move they cause shadows on the ground or nearby dwellings to move too, giving rise to a flicker effect through windows and doors where the contrast between light and shade is most noticeable. An observer oriented so as to be looking in the direction of the sun's disc through the wind turbine's open face will also see a flicker effect as each blade transits the sun.

Because of the geometries involved, shadow flicker is an easily modelled property and can be accounted for during planning and development of a wind farm; indeed, UK government planning regulations stipulate that this must be considered. Due to the size and speed of modern commercial wind turbines, there is no risk of shadow flicker causing photo-epileptic seizures in vulnerable persons.

What is this based on?

Wind turbines are tall structures, and present an open disc in the form of rotating blades. Depending on the sun's bearing in relation to observers (this is the sun's azimuth) and the sun's altitude in the sky, wind turbines will cast a shadow over nearby ground – this can be a significant length at certain times of the day and at certain times of the year. An important factor in the case of wind turbines is that the rotating blades will pass in front of the sun's azimuth, giving rise to moving shadows that are particularly noticeable through windows and doors where the contrast between light and shade is most apparent. This shadow flicker effect would certainly present an annoyance to exposed residents, and some critics have predicted (wrongly) that sufferers of photosensitive epilepsy would be prone to seizures as a result.

What is the evidence?

The position of the wind turbine in relation to the observer is critical, both in terms of the sun's bearing and it's altitude, factors dependent upon the longitude and latitude of the location in question. In the UK, only dwellings sitting within 130° either side of north relative to the turbines can be affected (going clockwise, that is 230° to 130° from true north).

Research carried out at various wind farm installations across the UK has found that shadow flicker only occurs when the shadow is sufficiently in focus and lasts a certain duration, both properties that diminish rapidly with distance from the rotating blades. Thus, it has been calculated that distances up to ten times the rotor diameter can create the right circumstances to give rise to shadow flicker.[1,2] For example, a rotor diameter of 80m will potentially give rise to shadow flicker up to 800m away, if at the correct orientation. This ratio is used as part of the planning regulation guidelines for the siting of wind turbines in the UK.[3]

Since shadow flicker does occur, the optimum site for a wind farm may create the circumstances whereby nearby dwellings are affected. However, shadow flicker doesn't occur all the time; on many days the intensity of sunlight is diminished due to cloud cover or the time of year. For example, in winter months in the UK, the sun is lower in the sky and casts longer shadows, but 80% of the time the sun does not shine brightly enough to create the necessary contrast; even in summertime, the sunlight is not bright enough 60% of the time. The sun must also be at the correct bearing in relation to the turbine rotor face to cast a shadow across an exposed dwelling. Due to this combination of sunlight and bearing, these circumstances in reality only occur together for a fraction of the theoretical maximum – 15% in winter and 30% in summer.

Since it is possible to accurately model this phenomenon it is relatively simple to predict. In addition to re-siting, there are a number of other mitigation measures the developer can employ to protect residents. For example, it is possible to plant a screen of trees between the turbines and the affected properties to disperse the light. In addition, wind turbines are controlled remotely and can be easily programmed to stop operation in the brief window of time during which shadow flicker has been predicted to affect certain dwellings.

It has also been suggested that shadow flicker poses a threat to the small percentage of epileptics who suffer from photosensitive epilepsy, in which seizures are triggered by flashing lights or contrasting patterns of light and dark.[4] In the UK, the National Society for Epilepsy states that 1 in 131 people suffer from epilepsy during their lifetime, and about 5% of this group will have photosensitive epilepsy. Flashing or flickering at frequencies between 3–30 Hz are the most common form of photic stimuli known to cause photo-epileptic seizures – note that large commercial turbines have rotation speeds that result in frequencies below 2 Hz.[3]

Potential triggers for photo-epileptic seizures are well-understood and are commonly found in everyday life. Well-publicised instances of photo-epilepsy involving television broadcasts have led to stringent guidelines which have shown substantial success in reducing episodes in the vulnerable population.[5,6] Similarly, there has been recent research into the effect shadow flicker from wind turbines might have on photosensitive individuals.

There are some concerns that flicker can be apparent at greater distances than currently taken into account by planners and engineers; including flicker caused by sunlight reflecting off the blades (as opposed to the shadow cast by the blades). However, the parameters involved are applicable to the flicker rate produced by smaller turbines not found in wind farms. These smaller turbines have the compounded problem of greater number of blades and faster rotation speeds that create flicker above the critical frequency.[7]

The photo-epileptogenic potential of smaller turbines is still an important consideration, but it should be remembered that modern commercial turbines rotate more slowly (roughly 35 r.p.m.) producing a frequency of no more than 1.75 Hz, well below the threshold known to trigger photo-epileptic seizures.[8,9] In fact, largely due to atmospheric conditions, the contrast threshold between light and dark is significantly reduced with the end result that observed flicker will not have the capacity to induce epileptic seizures at distances greater than 1.2 times the turbine height[8]. Even for smaller turbines the hub height and rotor diameter will be less (typically hub height is < 45m), meaning their potential reach is not as great.

Government guidelines advise developers to minimise the specular properties of turbine blades to avoid light reflecting off the blades unduly; indeed minimising reflectiveness of the blades is something the industry has been carrying out for several decades already.[3,10]

Conclusion

Shadow flicker from the rotating blades of a wind turbine is a known, quantifiable effect. Large commercial turbines can create a flicker effect at frequencies up to 2 Hz, safely below the threshold that can cause photo-epileptic seizures.[3,4,10] While flicker can be annoying, there is no evidence that the operating characteristics of commercial wind turbines can induce seizures in the vulnerable population of epilepsy sufferers.[4,8]

Due to the precipitating factors, which involve turbine position in relation to the solar azimuth and sun's altitude above the horizon relative to an observer, this phenomenon can be accurately modelled and predicted. In practice, shadow flicker occurs within narrow spatio-temporal limits. This means that even if it is predicted to affect certain dwellings, shadow flicker is only apparent when the intensity of sunlight and angle of the blades to an observer combine with the sun's position in the sky to create a noticeable effect – this is effectively for short periods in any single day affecting those particular dwellings that are vulnerable during such periods.

The predictability and infrequency makes shadow flicker an eminently manageable problem: it can be curtailed by the introduction of various mitigation measures, among them re-siting of individual turbines, creating screening features such as treelines (or using existing ones), and programming the turbines to cease operation for the short time during which dwellings are affected.

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11
Wind turbines and noise

Summary

Wind turbines rely on mechanical operations to generate electricity. The movement of the blades through the air inevitably creates noise, and the increasing size of medium-to-large turbines (typically 2.3–3.6 MW rating, standing 65–105m tall) has prompted concern that they will generate an unacceptable level of noise for nearby residents.

In the UK, this phenomenon has been studied by a government working group, and detailed guidelines form part of UK planning regulations to prevent undue noise pollution. These, coupled with the quieter design of modern turbines, mean that the noise levels generated by wind farms are comparable to outdoor background noise. Studies have found topography and changing wind patterns at night can accentuate this noise in specific locations, but understanding this process means it can be correctly assessed during planning to ensure that properties that might be prone to these effects are not affected.

Experience of wind farms in Europe has shown that residents' negative perceptions of noise are reduced when they enjoy a direct financial benefit from the turbines, and also diminishes with time post-construction.

What is this based on?

Any large device that has moving parts will create some noise, and wind turbines of any size are no exception. Many people's idea of wind turbine noise is derived from small turbines mounted on houses (around 2.5–6.0 kW range) that cause vibrational disturbance, or from standing up close to a large megawatt turbine. Medium-to-large turbines (0.5–3.6 MW) commonly in use will generate significant levels of noise during operation if one is stood at the base, with typical noise output ranging between 97 and 107 dB(A) at 10m.[1]

It is apparent from this that wind turbines cannot be sited too close to residential dwellings. Excessive 'community noise', defined as traffic, industries, construction works, and the urban environment, can create a host of adverse effects on human health according to World Health Organization (WHO) guidelines.[2]

As the wind energy sector began to expand in the early 1990s the UK planning authorities recognised that the existing guidelines (BS 4142:1990) did not adequately cover the use of increasingly larger wind turbines in the megawatt range. A Noise Working Group set up to advise the government carried out detailed research to define the lower limits for noise emissions from wind farms, after which these recommendations were laid down in the ETSU-R-97 report and incorporated into national planning guidelines.[3]

Noise levels encountered in everyday situations are given in the table below. Note that noise levels are measured using an 'A-weighting' that emphasises those frequencies to which the human ear is most sensitive, hence sound pressure levels are given in dB(A). The A-weighting helps ensure measured sound levels are close to the perceived sound levels of the human subject. The dynamic range of human hearing is discussed in more depth in the section on low-frequency sounds (section 12).

Despite revised guidelines in the UK and other European countries with a high penetration of wind power (e.g. The Netherlands, Denmark and Germany), some researchers have reported that noise continues to be an annoyance factor for a significant number of residents living near wind farms.[4,5] At certain sites, noise emissions were found to be unexpectedly high at night time, but in other surveys many complainants stated various degrees of annoyance at sound levels no greater than ambient background noise caused by other factors, such as passing traffic.[6,7] Noise emissions from wind turbines can be problematic even when planning guidelines are adhered to, and there is some evidence that particular acoustic characteristics of turbines are more intrusive than previously thought.[7,8]

Table 11.1	Indicative noise level in dB(A)
Threshold of pain	140
Jet aircraft at 150m	105
Pneumatic drill at 150m	95
Truck at 30mph at 100m	65
Busy general office	60
Car at 40mph at 100m	55
Wind farm at 350m	**35-45**
Rural night-time background	20-40
Quiet bedroom	20

What is the current evidence?

Modern designs have seen the gear mechanisms and their housings producing progressively quieter wind turbines, and the latest generation of 'direct drive', or gearless turbines create even less mechanical noise.[7,9] In addition, blade design has constantly been refined to reduce the noise generated, which also creates a more efficient turbine as less energy is lost to acoustic energy.[9,10,11] However, one acknowledged feature of a wind turbine sound that is independent of mechanical noise are the broadband emissions caused by the rotating blades, particularly as they pass the turbine mast itself. This rhythmic 'amplitude modulation' is generally described onomatopoeically as a "swish", "swoosh", "whistle" or, at times of high activity, a "thumping" sound.[6,7,8] The phenomena associated with these aerodynamic sounds were discussed in detail by the UK working group in ETSU-R-97. They concluded that equating blade noise to background noises like wind blowing through trees is "perhaps an oversimplification".[12]

The discovery that a small but significant proportion of residents find audible emissions annoying and intrusive is surprising, as levels of noise have been repeatedly measured as falling inside accepted limits for ambient background noise (30–40 dB[A]).[5,7] It is thought that the characteristics of aerodynamic noise from wind turbines may be perceived differently depending on the sensitivity of individual residents[8].

After visual impact, noise is most frequently cited as the reason for complaints by nearby residents relating to wind farms, and a feature common to most studies into intrusive noise is that negative attitudes toward the siting of wind farms plays a large part in any individual subject's response to noise.[4,5,7,13]

Researchers into the peculiar noise characteristics of wind turbines and their affect on annoyance and disturbance have pointed out that if residents feel disconnected from decisions made by local government, or are generally unhappy with changes to their community space, then they are much more likely to be affected once a wind farm is installed. Profound changes brought about by the installation of wind farms in rural areas correlates with increasing sensitivity to noise-related disturbance.[7,13] Tellingly, a further field study in the Netherlands has shown that residents who enjoy a direct benefit from a neighbouring wind farm do not experience the same feelings of annoyance despite being exposed to the same level of noise.[14]

Conclusion

Renewables are essential for the move toward low-carbon energy sources and public attitudes on the whole are strongly in favour of their implementation. However, there is a striking divergence between overall support and more local opposition to the installation of renewable technologies.[15] Although wind energy is not the only renewable energy that produces divisive opinion, it is best placed to achieve the CO_2 emission targets set by the UK government and take on a significant proportion of the country's electricity needs by 2020.[16] An increasing number of installations will see an increasing number of challenges from concerned residents unless the causes of negative opinion are understood.

In spite of continual improvements made to turbine design, there is a significant body of evidence showing that the characteristics of noise emissions from wind turbines can affect a small proportion of the communities that are exposed.[4,5,7] Evidence also suggests that failure to take into account the topography of individual sites and the increased size of modern turbines can lead to unexpectedly high noise emissions.[6]

Accordingly, the issue of noise should be treated with due consideration, and guidelines must be strictly adhered to, or efforts made to revise them if necessary. There are some critics who point out the existing UK planning guidelines are in need of updating, and there is some justification for this when current planning regulations in 2011 continue to refer to a working group report released in 1996; indeed, the original reporters presciently aired much the same wish in the ETSU-R-97 document itself.[12] However, the report is still a well-grounded and thoroughly researched reference and it is clear that the recommendations on which planning regulations rely clearly stipulate that sound pressure levels, not distance, should determine the minimum setback from nearby dwellings:

> *"The difference in noise emissions between different types of machine, the increase in scale of turbines and wind farms seen today and topographical effects described...all dictate that separation distances of 350–400 metres cannot be relied upon to give adequate protection to neighbours of wind farms."*[12]

Day- and night-time levels should be set at 5 dB(A) above background ambient noise, with a fixed limit of 43 dB(A) for night-time use; an upper limit of 45 dB(A) is acceptable for a dwelling which derives a direct economic benefit. Guidelines also takes into account areas that might experience low levels of background noise and that absolute noise limits need to be set relative to this if necessary.[3,12]

It is important to note that the literature on the small but significant number of residents who are continually disturbed by perceived noise from wind farms almost invariably reveals that the propagated sound is not any higher than normal community background levels. Visibility plays a significant part in exacerbating disturbance due to sound, with affected respondents frequently already unhappy that their local setting has been marred by the introduction of wind farms, and the overall perception of intrusive sound is intimately associated with the feeling that the visible structures have been forced on the landscape without any say from them.[5,7,13] This lies at the heart of the divergence mentioned above (section 7).

Alienated residents (i.e. those not involved in decision-making, with no direct economic benefit, without a knowledge of how wind energy operates and suspicious of wind farms thrust upon them) will ultimately perceive any wind farm development negatively, regardless of public support in general.[15]

Accusations of nimbyism are unhelpful and irrelevant: it is up to the wind energy industry and its supporters to be honest about any noise concerns local residents might have, and to work with them to minimise these affects within the framework of the planning regulations (designed for exactly this purpose).[17] It is evident that residents who feel installations are forced upon their local setting will judge any subsequent noise accordingly, and it is cogent that clearly realised benefits for residents (direct financial benefit and a better understanding of how wind power contributes to a low-carbon economy) significantly mitigate this negative bias.[14,15]

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12
Infrasound from wind turbines and 'Wind Turbine Syndrome'

Summary

The subject of low-frequency sounds typically inaudible to the human ear (infrasound) has been posited as a hidden causative agent behind reported ill-health suffered by some individuals living near wind farms. This is based largely on the promotion of a small number of biased case studies by one self-published lobbyist which has garnered significant media attention, despite the overwhelming consensus in the peer-reviewed literature that there is no evidence such a thing as "wind turbine syndrome" exists. Repeated efforts have been made to measure the perceived effects of infrasound from wind turbines, with no positive results. Guidelines for environmental noise already exist both nationally and internationally. They take low-frequency noise into account, and are based on robust evidence from decades of research, and these continue to be refined.

The continuing coverage that "wind turbine syndrome" receives, obscures the much-better understood issues surrounding environmental noise, and the continued distraction hinders treatment for the small number of individuals who genuinely suffer from anxiety, stress and attendant health problems brought on by the perceived existence of negative environmental agents with no discernible physical cause.

What is this based on?

In 2009, drawing on a series of case studies from 10 families with a total of 37 subjects, a paediatrician in New York state attributed the following symptoms to low-frequency sound emissions from wind turbines: sleep disturbance, headache, tinnitus, other ear and hearing sensations, balance and equilibrium disturbances, anxiety, nausea, irritability, energy loss, motivation loss, memory and concentration disturbances. The author of this case series grouped these symptoms together under the umbrella of "wind turbine syndrome". These findings have been self-published in a book marketed by the author.[1]

What is current evidence?

Sound propagates as a pressure wave through vibrations in the air, and the number of vibrations – the frequency – is given in Hertz (Hz). The intensity of the pressure wave emitted is measured in decibels (dB), which is usually recorded as a logarithmic scale to account for the enormous range of frequencies at which sound is audible to the human ear, i.e. 20–20,000 Hz. Below the 20 Hz threshold is 'infrasound' – this low frequency sound outside the normal range of human hearing; however, it is accepted that frequencies below 20 Hz can be detected at high levels (>79 dB), although as the frequency decreases the level of sound required for auditory perception becomes very high; for instance, frequencies below 8 Hz must be at levels above 120 dB to be heard (akin to standing within 60m of a jet aircraft taking off).[2,3]

The effects of noise on human health and activities have been studied for many decades. Outdoor noise in modern society originates primarily from traffic (road, rail and air), industries, construction works, and the urban environment or neighbourhood: these sources of noise are commonly grouped under the term 'community noise'.[4] The World Health Organization (WHO) acknowledges that community noise guidelines should take into account the presence of a strong low-frequency component when assessing noise emissions,[4] but when dealing with very low-frequency sound emissions it should be remembered that in many cases these sounds, although low-frequency, still fall outside what can be correctly termed infrasound.[3]

Overall, the case series presents very weak evidence for anything akin to a definable syndrome. Following several years of campaigning after a wind farm was proposed next to her town in Malone, NY, the author asked for respondents who already believed they were suffering symptoms caused by nearby wind turbines. This self-selection bias makes it difficult to identify a causative agent. Many of the subjects suffered from pre-existing conditions including: mental health disorders, persistent migraines, continuous tinnitus and motion sensitivity, and several had a history of significant exposure to loud noise in the workplace. A similar report authored in the UK, published exclusively on lobby group websites, exhibits many of the same methodology flaws.[5]

To understand the recent accusation that infrasound can cause detrimental effects to health to residents living near wind turbines, it is useful to break down the hypothesis of "wind turbine syndrome" into its two main parts.[1]

1. Infrasound at 1–2 Hz from wind turbines propagating through the air directly affects the vestibular system of the ear. The vestibular system within the inner ear plays an important part in balance, and also works in combination with the visual system to maintain focus when moving. To do this, specialised hair cells suspended in fluid in the cochlea transmit mechanical fluid movement caused by sound waves to the brain via nerve cells. These inner hair cells, are responsible for almost all of the auditory capability of human hearing (i.e. sounds generally above 20 Hz), but are insensitive to frequencies in the infrasound range. A recent review suggests a possible link between the mechanical movement of other sensory hair cells that are more sensitive to infrasound, inferring that some physiological effect can be elicited by infrasound at levels below normal auditory perception.[6] Tellingly, the reviewers propose that these effects are only likely to appear in subjects who are susceptible to infrasound, i.e. people who

suffer from rare conditions affecting the inner ear. It should be remembered that the non-pathological inner ear is a poor detector of low frequency sound. In studies on normal subjects that aimed to produce ill effects from infrasound, the participants had to be subjected to very high levels of sound, considerably higher than those produced by wind turbines.[7,8]

2. Infrasound at the 4–8 Hz range enters the lungs via the mouth and then vibrates the diaphragm, which transmits vibration to the internal organs of the body. This internal vibration conflicts with auditory and visual signals received by the brain, causing agitation, anxiety, nausea and irritability. The author coins this phenomenon "visceral vibratory vestibular disturbance" (VVVD).

In addition to the vestibular system mentioned above, the internal organs (generally termed the viscera) can transmit information to the brain based on the body's position and motion. This sense is called proprioception, and is initiated by the balance organs in the inner ear and by 'proprioreceptors' found in the muscles and supporting ligaments; it is also thought to involve contact and vibration receptors in the skin, although these receptors are not sensitive to sound waves at infrasound frequencies. It is the effect of infrasonic vibrations on this visceral system that supposedly forms the basis of VVVD.[1] However, this hypothesis ignores several salient facts.

Transmission directly through the head does not occur, for the skull has to resonate at frequencies much higher than 20Hz to transmit the energy from a sound wave to vibrations within the body. Vestibular disturbance can occur at inaudible levels through bone conductance, but only at frequencies much higher than infrasonic sounds (around 100Hz)[9]; this independent research was misinterpreted by the creator of wind turbine syndrome to provide a "direct link" to VVVD – a fact later openly criticised in a public refutation by the lead researcher.[10] In addition, the natural resonant frequency of the viscera is around 4 Hz: infrasonic, but the wavelength at this frequency is so long (85m) that the sound pressure behaves as a compression wave of negligible force, acting on the body equally from all points and thus preventing any resonant vibrations in the viscera.[8,11] To cause noticeable sensation and unpleasant effects, infrasound must be at levels far exceeding the emissions measured from wind turbines.[7,8,11]

Conclusion

The evidence sited above does not confirm the existence of a "syndrome". The propagation and effects of low-frequency sound are well understood, and adverse effects on humans are only evident at infrasound levels far exceeding that generated by operating wind turbines.[3,7,11]

The UK Health Protection Agency welcomes additional research in the field of environmental infrasound, while acknowledging the lack of evidence supporting wind turbine-generated infrasound as a health risk.[8] Research into the effects of infrasound is ongoing to refine what is already known. Guidelines in the UK and internationally are clear that sounds at all frequencies must be taken into account when assessing the impact of environmental noise.[4,8] It is recognised that weighting should also be given to low-frequency noise, and government and industry continually incorporate this information into accepted guidelines for measuring the acoustic emissions from wind turbines.[3,4,12,13]

Claims that infrasound is "wind energy's dirty little secret"[14] are unfounded and ignore the existing body of evidence that states the opposite. An advisory expert panel goes as far to state that:

> *"Wind turbine syndrome," not a recognized medical diagnosis, is essentially reflective of symptoms associated with noise annoyance and is an unnecessary and confusing addition to the vocabulary on noise."*[11]

A 2006 report investigating complaints about nearby wind farms in the UK found that of the 126 operational wind farms, five complaints were made regarding low-frequency noise. At one location, a resident was found to have sensitivity to infrasound that made some emissions by the nearby wind farm audible, although the same resident was actually found to be awoken by the low-frequency noise from traffic, not the wind turbines themselves. In all the locations studied, infrasound was found not to play a part in disturbance to residents.[15] The confusion between audible sound and infrasound may have supported the argument for the "hidden effects" of wind turbines.[3,11]

The reporting of 'health scares' in the national media also perpetuates these myths, and may reinforce the pre-existing belief that wind turbines are the cause of underlying pathologies and contributing somatoform disorders brought on by negative anticipation.[11] This is unhelpful, and distracts from those truly susceptible to stress and anxiety, exacerbating the frustration at not being able to control their external environment and creating misguided fixation on the 'cause' of their suffering (i.e. wind turbines).[16]

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13
Bat and bird mortality in relation to wind turbines

Summary

Construction of large-scale wind farms first took place in the 1980s in California, and other similar locations in the USA and Europe. Unfortunately, the contemporary design of the smaller commercial wind turbines (with open-lattice towers), the greater number of such turbines required on a single site, and their placement across areas used by ecologically sensitive raptor populations have all conspired to cause an elevated rate of avian mortality, particularly affecting important populations of rare species. These unfortunate events form the basis of the misconception that new wind farms will cause disproportionate harm to bird populations.

In fact, wind turbines are responsible for less than 0.01% of avian mortality caused by humans, with by far the largest cause of deaths being standing buildings (more precisely, the windows), power lines and domestic cats. Considerable variation exists in the number of birds killed annually across different wind farms worldwide, and the industry now undertakes extensive surveying of avian populations and migratory routes to further minimise any detrimental effects before commercial turbines are sited. Modern, large-scale megawatt turbines in use for the past ten years have been found to result in a significantly lower rate of fatalities in most areas where they have been subsequently introduced. In terms of electricity generated, wind is substantially safer than fossil fuel energy when avian deaths per unit of electricity generated are compared.

Although avian mortality has received the greatest attention by far over the preceding three decades, there is increasing concern that bat fatalities may occur on a proportionally larger scale, and are potentially more damaging to the smaller number of species involved. The migratory patterns of bats are not well understood, but considerable variation in fatality rate also exists between different wind generation sites, as found with birds. Bats are typically adept at avoiding moving objects, and it is thought that the unexpectedly high mortality at some sites may be accounted for by altered behaviour during migration, and by the occurrence of ‘barotrauma’ caused by rapid air pressure reduction near the edge of the turbine blade as it moves through the air. In any case, it is clear that more data must be collected on bat populations if the wind industry is to repeat its success with reducing avian deaths.

What is this based on?

Avian mortality due to all sorts of human activity (anthropogenic causes) has been well-documented for many decades, and is an ongoing area of research.[1,2] Wind turbines have earned a bad reputation thanks to several large installations built in the early 1980s, most famously Altamont Pass in California (the Altamont Pass Wind Resource Area [APWRA]), and the Navarro and Tarifa regions in Spain. Early wind turbines were sited with very little consideration for the indigenous raptor populations in the APWRA, causing excessive fatalities in six raptor species. This effect is not observed to such a degree in similar wind farms sited elsewhere in the USA leading to the conclusion that poor planning and outmoded turbine design is largely responsible.[3]

In southern Spain, two large installations in the mountains of the Campo de Gibraltar region totalling more than 30 MW have also recorded a high proportion of raptor deaths, including the griffon vultures, a vulnerable species. In this case, the particular arrangement of turbines along ridges used by migrating raptors to gain height in the absence of thermals was thought to contribute to the high rate of fatalities, as little difference was seen between turbines of older and newer designs.[4] Similarly, the Navarra region was one of the earliest sites opened up in Spain for large-scale wind farms. Large numbers of the griffon vulture (63% of raptor fatalities) have been killed across this region in collisions with turbines, from installations that make up just 5% of the nation’s installed capacity at the end of 2010.[2,5]

Even smaller installations in Belgium (Zeebrugge harbour) and Norway (Smøla) have recorded large numbers of deaths per turbine in sensitive breeding populations of eagles and seabirds.[2]

Although a small but significant level of bat fatalities were known at wind farms in the USA as part of studies on bird mortality,[6,7,8] there was a surge in deaths recorded at several wind farms in the Appalachian Mountain region in studies between 2002 and 2005.[3] In particular, a small installation in Tennessee and a much larger wind farm in West Virginia both reported a worryingly high fatality rate in excess of 20–30 bats per turbine.[9,10] The figures for the southeastern US are alarming, but lower numbers of fatalities have also been reported at wind farms across America.[11]

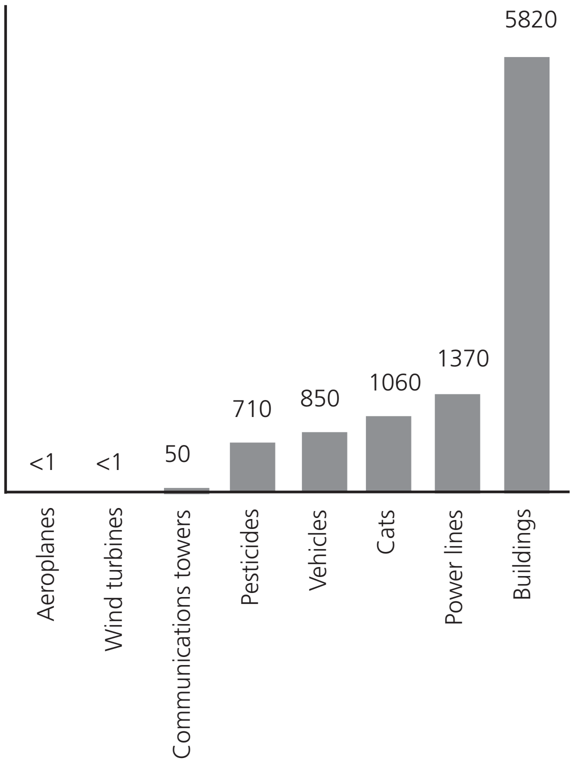
In Europe and the UK the problem has become apparent with over 1,500 fatalities recorded as of April 2009 and up to 21 species being affected. Some species on the European mainland are known to migrate notable distances, but data on UK migratory patterns is currently scarce.[12]

The discovery that bats are being killed by wind turbines has raised a number of questions as to why this should occur, since bats are known to be excellent at avoiding moving objects using their ability to navigate by echolocation. A recent review of the problem put forward no less than 11 hypotheses as to what might be contributing to these fatalities.[13] Clearly, a great deal of research is still needed.

What is current evidence?

The existing body of research into avian deaths caused by wind turbines over the last 20 years is extensive, and the literature on bat fatalities is increasing.[2,11,12] This increase in awareness has provided the wind energy industry with vital information that must be incorporated into planning and developing existing and future wind farms.[14] Indeed, planning regulations already exist in the UK to protect natural habitats and prevent damaging development that may harm protected species: these include the Natural Environment and Rural Communities Act 2006, and the Planning Policy Statement 9 on Biodiversity and Geological Conservation.[12]

Fig 13.1
Estimated annual avian mortality per 10,000 deaths
(Data taken from Erickson 2005[1])



There is little existing evidence for the UK that shows any detrimental effects to sensitive bird populations (although fatalities do occur);[14] bats, however, are protected species, and the government advisory body, Natural England, took immediate steps to provide guidelines for the installation of commercial wind turbines.[15]

It is clear that, while much research is still underway, there is a great deal of data available on the overall effects of wind turbines on bird and bat populations. Much of this information is collected on a site-specific basis and requires a great deal of assimilation to reach a perspective on the ecological effects of wind power generation.

As avian mortality has been continually researched for decades, it is worthwhile summarising this data. Doing this shows that the contribution made by wind turbines to avian mortality is negligible when compared to overall mortality from anthropogenic sources. Figures collected across the USA and Europe show that bird deaths caused by collisions with wind turbines make up less than 1 incident out of every 10,000 deaths from all causes: that is less than 0.0001%.[1]

The human activity estimated to cause by far the largest number of avian deaths is the erection of buildings, collisions involving birds accounting for over 58% of fatalities (see figure). This is thought to be largely due to windows, which birds seem poorly equipped to deal with, and artificial lighting.[2,16] Following this, transmission power lines and domestic cats account for >13% and >10% respectively.

In the context of overall human activity, the above statistics are compelling.

However, since wind farms are being introduced as a means to reduce CO_2 emissions, a more meaningful way to analyse avian deaths would be to compare wind power with non-renewable sources. The concept of comparing data by unit electricity produced is discussed above in relation to the risks to human health posed by different sources of energy (section 9). A preliminary study suggests that when the same principle is applied to avian mortality, existing fossil fuels are responsible for over 15 times the number of deaths for every GWh produced: that is 5.2 fatalities/GWh for fossil fuels compared with just 0.3 fatalities/GWh for wind. Nuclear power had a similar mortality rate to wind energy, with 0.4 deaths per GWh.[17]

Conclusion

Wind turbines represent an insignificant fraction of the total number of bird deaths caused by man-made objects or activities (e.g. building structures, transmission lines, and keeping domestic cats). However, the industry is well aware that fatalities do occur, and there is considerable interest in refining monitoring techniques to inform developers when planning wind farms. In the UK, wind farms are subject to an Environmental Impact Assessment, which must take into account any sensitive bird populations, including migratory species. The planning regulations and advisory guidelines ensure bird populations in areas affected are studied to best predict the influence siting a wind farm might have – and planning permission can be refused if the perceived detrimental effects are unacceptable or cannot be sufficiently mitigated.[14,18]

There are an increasing number of sophisticated models used to measure and track migratory bird populations, which are the most likely to suffer significant mortality from wind turbine collisions.[2,4,6,7] A great deal of data has been derived from long-established sites in California, namely the APWRA, and there is a consensus that replacement of older turbines with a smaller number of larger modern turbines (usually as part of 'repowering' the installation) is one way in which mortality can be reduced.[7,19] The excessive raptor fatalities recorded at the APWRA have mostly involved the 5,400 turbines (<250kW each) originally installed, the output of which could be theoretically achieved with a tenth of that number of modern turbines. Although this is an attractive idea, it should be remembered that raptor deaths recorded in similar landscapes in Spain did not appear to show any correlation with the turbine structure itself, merely the presence of wind turbines along a particular topographical bottleneck.[4]

It seems reasonable to assume that, while global mortality rates have decreased as wind turbines have grown to become taller, tubular structures, the impact of any wind farm can be significantly reduced through careful siting in response to data gathered on seasonal density in feeding and nesting areas, and on flight paths.[2,7,17] Meticulous collection of information can aid flexibility when developing sites for wind energy, using "micro-siting" so as not to disrupt flight paths.[2,20,21]

The plight of bats has come to light in the last decade, unfortunately due to a number of locations in the USA and mainland Europe that have suffered unexpectedly high fatality rates.[3,11,12] Unlike bird populations, bat migratory patterns are less well known, and in many cases it is not clear what causes such excessive mortality in certain areas.[13]

Although a great deal of monitoring is being done, there are possibly several confounding factors that lead to bat deaths at wind farm sites.[11] As well as striking the turbines blades directly, there is increasing evidence that barotrauma is brought on by the dramatic changes in air pressure around the moving blade edges.[22] Of some concern is the finding that the increased height of modern turbines contributes to fatalities in migratory bat populations.[23] There are theories that this effect is caused by the habit of migrating bats to fly higher than their usual foraging routine, and that some bats may not use echolocation when following migration paths.[13,23]

Co-ordinating the needs of both local and migratory avian and bat populations presents a challenge to the wind energy industry, and one that will have to be tackled on a site-by-site basis. The natural development of the commercial wind sector that has brought about turbines with taller, tubular designs that have slower rotating blades has mitigated avian deaths to some extent, although there is a risk this may actually increase the threat to vulnerable bat populations. The steady refinement of data collection methods, with regard to birds in particular, will help generate the information needed to correctly plan future sites for wind farms.

It is hoped increased research into bat populations will reap similar rewards. Positive developments, such as the finding that 'feathering' turbines to increase their start up wind speed can reduce both bird and bat fatalities, illustrates how the wind energy industry can respond (happily, the adjustment results in a minimal loss of power equal to less than 1% across a year).[2,24] It can certainly be stated that, for every unit of electricity generated, wind has a considerably lower avian fatality rate than fossil fuels, and this will only improve as planners and regulatory bodies learn from the mistakes first made in the 1980s.

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