HOUSES OF PARLIAMENT
PARLIAMENTARY OFFICE OF SCIENCE & TECHNOLOGY

POSTNOTE

Number 602 May 2019

Developments in Wind Power

UK power generation from wind has increased in recent years due to sharp reductions in the costs of constructing and operating wind power facilities. Onshore wind power provides the cheapest electricity of any form of new generation built, and offshore is expected to continue to reduce in cost. This POSTnote examines the innovations that have enabled wind power cost reductions, associated policy, and challenges for future deployment.

Overview

- Wind power has grown rapidly in the past 10 years. In 2018, onshore and offshore turbines generated 17% of UK electricity. Wind is a key part of UK greenhouse gas emissions reduction plans.
- Increasing turbine size, cheaper finance, and more efficient construction and operations have reduced costs substantially.
- The UK Government supports offshore wind with competitive subsidies, which have enabled cost reductions to date. Further support has been pledged in the 2019 Offshore Wind Sector Deal, and the sector is projected to continue growing.
- New onshore projects do not receive the same government support and are subject to more complex planning requirements. Onshore wind is not expected to grow by much without changes in these policy areas.

Background

Wind turbines are used to capture energy in the wind and convert it to electricity. Turbines can be built individually or as a group in a 'wind farm',[1] either on land (onshore), or affixed to shallow sea beds up to around 50m deep (offshore).[2] New designs for offshore 'floating' turbines, moored to the sea bed in deeper waters, are being installed in the UK.[3] In 2018, onshore and offshore wind farms generated 9% and 8% of UK electricity, respectively.[4] This has increased from almost zero in the mid-2000s. UK offshore wind power installation has grown the most in recent years (Fig. 1).[5]

Generating wind power does not directly emit greenhouse gases (GHGs), which contribute to climate change.[6] Recent increases in wind power have helped to reduce UK electricity generation GHG emissions by 65% since 1990, by partially replacing coal power plants that have closed.[7,8] Future growth would further help the UK meet its GHG emissions reduction targets under the Climate Change Act 2008,[9] and help mitigate the most dangerous effects of climate change (POSTnote 594).[6]

Total UK electricity demand is projected to increase by 2050, as a greater proportion of heating and transport will be provided by electricity (POSTnote 587).[10] At the same time, a large amount of electricity supply will be decommissioned (including all coal-fired power and most existing nuclear power) and additional electricity supply will be required in order to make up this shortfall.[11–13]

The UK has installed the largest offshore wind capacity in the world, aided by government subsidies and cost reductions as industry experience and efficiency have grown.[14] The UK Government has pledged further support as part of a joint government-industry programme, the Offshore Wind Sector Deal.[15,16] Potential challenges associated with wind deployment include impacts to marine habitats, bats and some bird species,[17,18] interference with aviation, and issues arising from wind power's variability.[19–21]

Factors Reducing the Costs of Wind Power

Recent growth in wind power has been driven by declining costs together with increases in the amount of power generated (Box 1). Cost reductions between 2015 and 2017 allowed developers to sell power from most new projects in 2017 at a price that was 50% lower than 2015 projects.[22,23]

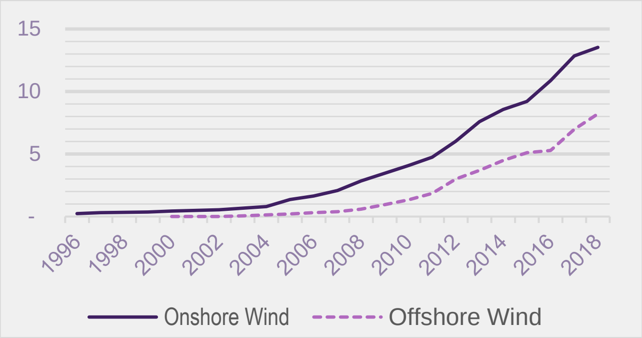

Figure 1: Total UK Wind Power Capacity (gigawatts, GW)[24]

Box 1: Types of Costs Associated with Wind Power
Costs exist at multiple stages of an electricity project, with developers requiring a measure that can be used to compare total costs (from construction to decommissioning) across the project. The 'Levelised Cost of Electricity' (LCOE) is a commonly used measure that incorporates:[25]

- **Development costs** from project planning and site selection
- **Capital costs**, including construction and financing costs
- **Operational costs**, including maintenance, management and fuel
- **The amount of electricity** generated over the project's lifetime. Producing more electricity reduces LCOE.

Developments in Turbine Design

A 'wind turbine' consists of all the components that are used to capture energy from the wind (such as rotors and blades) and convert it to electricity (such as drive-trains, gear systems and a generator).[26] Features such as turbine height and rotor diameter affect the amount of power that an individual turbine can produce. The maximum power output (capacity) is determined by the generator size.[27–30]

Industry commentators agree that the increasing capacity of new turbines has been the main driver of reduced costs.[27,30,31] The capacity of the largest UK turbines has increased from 1.5 megawatts (MW) in 2000 to 3MW onshore and 8MW offshore in 2018.[32] 12MW offshore designs are expected by 2021.[33–35] The largest designs currently in use are more than twice the height of the Elizabeth Tower.[16] The average offshore wind farm capacity has increased from 80MW in 2009 to 560MW in 2018, with some developments exceeding 1 gigawatt (GW:1000 MW, roughly the capacity of an average UK gas-powered station).[5,36–38]

Larger turbines have greater power output,[27–30] and capital costs do not increase proportionally when building larger turbines. These economies of scale have reduced the cost of building a wind farm, as farms consisting of fewer, but larger, turbines lead to savings in the costs of foundations, electrical cables and installation.[27] It is estimated that an increase in capacity from 4MW to between 6 and 8MW can reduce the Levelised Cost of Electricity (LCOE, Box 1) by up to 10%.[39,40]

Standardisation of turbine designs (manufacturing components to a set standard) and supply chain competition have also contributed to cost reductions.[41,42] Innovations throughout the rotor design can reduce LCOE by 5–6% through improved blade design, manufacturing and control; increasing power output from the turbine.[39,40]

New Construction Techniques

New projects use more efficient construction techniques, and component and process standardisation, which have reduced the costs. These include:

- Factory line assembly of turbine components, such as blades, which improves manufacturing efficiency and lowers construction and assembly costs.[42]
- Cheaper, easier-to-install foundation structures.[43,44]
- Vessels designed specifically for offshore wind construction and maintenance, which can operate under a wider range of conditions.[39,40,45] These have replaced the use of vessels originally designed for the oil and gas industry.
- Increases in the size of cables that connect turbines and substations on the shore, reducing the number of cables required and the associated installation costs.[40,43,46,47]

Some turbine components contain rare earth metals (such as neodymium, which is used in magnets). Some of these critical materials are produced in a limited number of countries and there are potential risks resulting from price variability and supply disruptions.[48] Switching to designs without these materials or their more efficient use during construction can mitigate some of these risks.[49]

More Efficient Operations

Operational costs are higher for offshore farms than onshore, as the marine environment degrades infrastructure quicker and presents challenges for maintenance.[25,28] Advances in turbine condition monitoring and data analysis mean that maintenance can now be undertaken only when required rather than at set intervals, reducing the number of offshore trips required and turbine downtime.[39,40] This has reduced LCOE by up to 3%.[45,47] Other developments, such as cheaper monitoring equipment,[50] increased component reliability and more efficient maintenance, have all contributed to reduced operational costs.[30,39–41] Improved access to technical turbine condition data (which is currently restricted) could enable further cost reductions.[51] An industry-wide monitoring scheme of UK offshore wind farms may increase technical performance and cost optimisation.[52] Reducing maintenance downtime of turbines increases the amount of electricity generated over the lifetime of a project, lowering LCOE.[25,53,54]

Increasing Power Production

Wind power depends on local wind conditions and how much of that energy can be extracted.[27,55] The capacity factor (CF) of a farm is the amount of energy that it generates in a year as a percentage of the theoretical maximum output that it could produce.[26] Annual CFs, and hence the amount of electricity generated over a project's lifetime, have increased. Offshore CFs have increased from 34% (for projects completed in 2016-2017) to 38% (in 2019-2020) and are projected to exceed 50% in 2022-2023.[53,56] Onshore CFs have more than doubled since 1990.[27] Other interventions include curtailing power from foremost turbines to improve overall power production from the farm.[45,57]

Box 2: Subsidy and Revenue Sources for Wind Power
The UK Government supports some projects through subsidy policies and other contracts:

- **Feed-in-Tariffs (FiTs)** are a subsidy paid to small-scale renewables (including wind projects of less than 5MW) for each unit of electricity they produce, as well as for each unit they export into the grid.[58] The tariffs paid have been greatly reduced since 2010 and were closed to new applicants in March 2019.[59]
- **Renewables Obligation (RO)** is a support mechanism established in 2002 for large-scale onshore and offshore renewable electricity that obliges UK electricity suppliers to source an increasing proportion of the electricity they supply from renewable sources.[60] It closed to new onshore wind capacity in March 2016,[61] and all other renewable technologies in March 2017.[62,63]
- **Contracts for Difference (CfDs)** are issued to developers of eligible low-carbon electricity technologies who win a competitive auction. CfDs provide a guaranteed price for the electricity that generators sell into the wholesale market, known as a 'strike price'.[64] When the wholesale price is below the strike price, generators are paid the difference. When it is higher, the generator pays the difference back.[54,65]

In the absence of government support, developers can sell power directly to large consumers under a Power Purchase Agreement (**PPA**), which can also provide a guaranteed price for a fixed period.[54]

Due to changing wind speeds, wind power provides a variable output (POSTnote 464). In response to growing variable supply, the UK electricity system is becoming more 'flexible', whereby more sources of electricity supply or demand can be modified in response to changing wind supply or prices (POSTnote 587).[12]

Costs of Financing
Wind projects require significant financing early on due to high capital costs, long before they generate electricity.[42] Higher financial risk to future revenues typically leads investors to require higher interest rates, increasing financing costs.[54] The combination of sector maturity, government support and regulatory certainty has lowered financial risk and interest rates in recent years, particularly for offshore projects.[5,42,54,66]

Policy Support
Power generators, such as wind farm owners, generally sell electricity into the wholesale electricity market. Emerging energy technologies are costly to build and the revenue they would earn from wholesale electricity prices alone will generally not be enough to cover those costs. Any new technology typically requires early-stage financial support to encourage initial deployment and reduce the costs of that technology. Efficiency improves as more projects are built and cost reductions are realised. Early government subsidy schemes can achieve initial deployment (Box 2). For example, subsidies for wind power have enabled significant cost reductions to the extent that some new onshore projects do not need a subsidy to be economic.[67,68]

In addition to increasing revenue (by providing subsidy), policy can support low-carbon technologies by reducing financing costs. As wholesale electricity prices can vary substantially, there is uncertainty for generators and developers around potential revenue. Contracts for Difference (CfDs) and Power Purchase Agreements (PPAs) (Box 2) provide a guaranteed price for electricity, reducing investor risk and financing costs. CfDs have significantly reduced costs as they are awarded on a competitive basis, increasing competition between developers and across the supply chain.[56] Offshore wind projects can be supported via a CfD.[76] However, new large-scale onshore wind projects have not been eligible for subsidy support since 2016,[77] and new installations have subsequently declined.[4,78] Some onshore projects on remote islands will be allowed to compete in the 2019 CfD round.[56]

Box 3: Public Attitudes to Wind Power
Survey evidence consistently suggests that national support levels for wind power are high and increasing in recent years.[69] In a 2019 government survey, 76% and 79% of respondents said they support onshore and offshore wind farms, respectively, with 66% saying they would accept large-scale renewable developments in their area.[70] Some local opposition exists, however.[71] Research suggests that increasing the public stake in projects by promoting community ownership and profit-sharing, and requiring meaningful public consultations (which provides an opportunity for participation) can build and maintain public support.[67,72,73] Less frequent planning refusals reduce development costs.[29] There is further evidence that consumers are generally willing to accept a share of their energy bills going towards low-carbon policy funding,[74] which form a lower proportion of UK bills than in other EU countries.[75]

Future Policy Priorities
The UK Government has encouraged onshore developers to develop new projects without subsidy.[79] Mechanisms that guarantee a price of electricity, such as PPAs (Box 2) and 'subsidy-free' CfDs (with strike prices at or below wholesale prices), would help developers to do so.[7,65,80,81] Some commentators suggest new approaches to supporting wind power. These include merging existing low-carbon and conventional power generation support schemes, or including wind power in the 'Capacity Market' scheme (designed to ensure security of supply, POSTnote 587).[82–84] However, academic researchers argue that changing existing policies would be disruptive,[85,86] and that consistent policy and regulatory certainty, along with long-term deployment targets, are key factors in encouraging cost reduction and wind power growth.[7,72,87,88] BEIS has advocated continuing proven policies such as CfDs. An Energy White Paper expected in summer 2019 will set out the future framework for energy and subsidy policy.[89]

Wind Farm Planning Process
Planning for offshore projects requires developers to acquire rights for construction through the Crown Estate and the Crown Estate Scotland, which manage the seabed around the UK.[90] The new leasing rounds of rights in 2019 will reduce risk for offshore investments by providing a certainty that new sites will become available.[16,45]

In contrast, planning for onshore projects is more complicated, and in England requires developers to locate farms in areas identified as suitable by local authorities and to have obtained the full support of local communities (Box 3).[91] In Scotland the final decision is made by the Scottish Government.[92] The 2017 Scottish onshore wind policy statement has set out its aim to increase the sector.[81]

Box 4: Potential Wind Farm Impacts on Birds and Bats

- **Collision mortality** occurs when birds and bats are lethally injured by colliding with rotors or towers; significant for some species.[93,94] Birds have been found to avoid turbines to an extent.[95]
- **Barotrauma** occurs when sudden air pressure changes associated with turbines blades causes damage to bats' lungs and ears.[96–98]
- **Displacement and barrier effects** during construction and operation.[93,99]
- **Habitat loss** risks arising from road and substation structures.[93,99]

A number of stakeholders argue that requiring English local authorities and communities to take deliberate action to 'opt in' (rather than to object), places an effective moratorium on onshore wind developments.[100] A convention among local authorities has been to restrict turbine heights to 125m, which limits wind farms' economic viability, though this convention is beginning to change.[29,101] These planning requirements do not apply to older onshore wind farms being recommissioned with new, often larger and fewer, turbines in a process known as 'repowering'.[36] Around a fifth of current UK onshore wind capacity (8GW) will be decommissioned before 2030, and repowering in this way could increase UK capacity by 1.3GW.[102,103]

Onshore and offshore developers must liaise with civil and military aviation authorities to minimise disturbance to air traffic control and radar technologies.[19–21]

Environmental Impact Assessment

Under current regulations, all projects with more than two turbines are required to undertake an Environmental Impact Assessment (EIA) during planning to identify potential environmental impacts on wildlife or habitats (Box 4).[104] Defra provides advice on impact monitoring methodologies for onshore farms,[105] while the Marine Management Organisation requires further monitoring of marine impacts during the operation of offshore farms.[106]

Climate change is the most significant threat to wildlife and wind power is a key way of reducing GHG emissions.[17] Wind power generation produces no GHGs, and life-cycle emissions (which also account for manufacturing and construction) are substantially lower than fossil-fuelled generation.[107,108] However, inappropriately sited wind farms can have impacts on bird and marine populations.[109] Suitable areas for wind farms, such as uplands and coastal areas, tend to be wildlife habitats,[17,110,111] while warning lights for aviation and shipping can attract and disorientate birds.[93] Some migratory species may face risks from large-scale offshore development across their range, but these are less certain and difficult to predict.[109] Wildlife groups are seeking to identify the most vulnerable species.[112] Evidence of impacts on marine species is scarcer. Some studies have shown temporary displacement of seals during noisier construction phases of an offshore farm, while similar effects on fish and mammals could also occur to a low extent.[113,114]

Effective impact mitigation measures include appropriate siting of farms that avoid migratory routes and breeding colonies,[17,94,97,109] as well as using fewer but larger turbines,[115,116] avoiding construction during breeding periods, and limiting noise during construction.[114,117] The RSPB publishes guidelines for wind farms on peat-lands.[111] Peat stores a substantial amount of carbon and building on them can lead to increased GHG emissions.[118]

Future Plans for Wind Power

Onshore Wind Power

Industry stakeholders suggest that without changes to planning and subsidy policy, deployment could stall and installed capacity could decline.[78,103] Some onshore wind projects can be delivered using the wholesale market alone or by agreeing PPAs with large consumers (Box 2).[119] However, analysts have stated that although PPAs can contribute to investor certainty,[67,68] they are unlikely to lead to growth outside of niche applications.[54] An alternate policy put forward by the Committee on Climate Change and the National Infrastructure Commission is to make CfD funding available for all onshore wind.[7,83,101,120] This is supported by research suggesting that because onshore wind is the cheapest form of new energy generation,[25] allowing it to compete for CfD funding would reduce financing costs and LCOE,[54] resulting in a net payback to the government over the contracts' lifetimes.[121,122]

Offshore Wind Power

Fixed

Fixed offshore wind has received substantial government support and is a central component of the UK Government's 2017 Industrial Strategy.[123] The 2019 Offshore Wind Sector Deal includes a number of aims for 2030: 30GW of total capacity installed, £250m of industry investment in the offshore supply chain, fivefold increase in exports (to £2.6 billion), increase of UK supply chain content from 48% to 60%, and £557m for further CfD auctions (which will be awarded to offshore wind and other technologies).[16]

Some commentators note that the 30GW capacity target will be exceeded through projects already in development,[124,125] and have recommended extending the target to 45GW.[126] Others suggest that refinements to CfDs, such as longer delivery deadlines, would enable further cost reductions.[83] Investment in the UK to date has been centred on new blade manufacturing sites, UK ports and offices supporting wind farms and cable and fabrication activities,[43] which can provide economic development to deprived areas.[42,127]

Floating

The UK has a substantial wind resource over deep seas,[45,128] and wind farms situated further offshore can access higher wind speeds and harness more power. However, deeper sea beds present substantial technological and economic challenges for building conventional fixed foundations. Developers have trialled floating turbine designs in Scottish seas for use in deeper waters, which are anchored to the seabed by mooring lines.[129] Floating wind could provide a significant amount of offshore UK capacity by 2030. It is currently at a pre-commercial demonstration stage, and large-scale deployment would require revenue and policy support. Academics suggest it would struggle to compete in CfD auctions for emerging technologies.

POST is an office of both Houses of Parliament, charged with providing independent and balanced analysis of policy issues that have a basis in science and technology. POST is grateful to Charalampos Michalakakis for researching this briefing, to the Engineering and Physical Sciences Research Council for funding his parliamentary fellowship, and to all contributors and reviewers. For further information on this subject, please contact the co-author, Jack Miller.

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