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Optimal over installation of wind generation facilities

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ABSTRACT

This paper evaluates the economic benefits to over-installing turbines on capacity-constrained wind farm sites in order to capture more energy at low wind speeds. Although this implies curtailment at high wind speeds, we show that over installing generation facilities can increase returns to investors and reduce system costs. A detailed model-based analysis is developed using British data, with variations in the range of over installation, the renewable policy support systems (fixed feed-in tariffs or green certificate premia to wholesale energy prices) and the extent of replacement of fossil generation in the technology mix with wind. In the cases of premia to market prices, we use agent-based, computational learning and risk simulation to model market prices. Not only is over installation beneficial under fixed feed-in tariffs, but is more so under premia to market prices and increasingly so as wind replaces fossil generation.

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1. Introduction

For industrial supply chains in general, it is often the case that production capacities are installed at different levels to their distribution channels. Usually, inventories play a key role in balancing these operations, but even with products than cannot be stored or services that cannot be delayed, and in network industries where production and distribution are integral parts of one system, this mismatch between production and distribution capacities commonly occurs for various reasons. For example, if a network infrastructure is difficult to adapt, it may be oversized to accommodate future growth in production. Alternatively, production facilities may be oversized if their output quantities are unreliable. In the particular case of investment in wind turbines, both of these reasons could apply. Whilst it might generally be expected that it would be more beneficial for wind farm developers to retain a future expansion option by securing a larger transmission connection agreement than is required from the outset, in this paper, we explore the opposite specification of over installing production capacity in relation to a transmission or contractual constraint. Using a model-based analysis, calibrated to British data, we analyse in detail the circumstances under which this over installation may be profitable.

With government imperatives to meet targets for renewable energy as well as carbon emission reductions, e.g., European Commission (2013), substantial expansion of transmission grids and interconnections are generally regarded as pre-requisite. To the extent that these are long-term and expensive infrastructure commitments, they have become one of the limiting factors in the development of wind resources (EnerNex, 2010; GE Energy, 2010; Mills et al., 2009). Thus, it is recognised that not only do the best sites for wind generation get developed first, it is often more convenient to prematurely re-power at existing locations than develop new sites (Jensen et al., 2002; Energy Wind Power, 2010; del Rio et al., 2011; Mauritzen, 2014; Staffell and Green, 2014). Even where land is available, objections to wind farms can limit their development. Barclay (2012) observes that, of the total number of applications for onshore wind farms per year in the UK, on average up to 50% of these do not pass the planning process. Grid connections are often allocated on a queue system and, as specified by their "maximum export capacities" (MEC), wind farm developers will clearly seek to maximise use of their MECs, once acquired. Furthermore, where government subsidies are required to support the economic case for

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investment, these awards are increasingly being allocated through auctions in which bids stipulate a per MWh delivery price and a maximum (MW) output (DECC, 2014). Once awarded, developers may choose to over install, to the extent allowed, in order to increase output at low wind speeds, but curtail output in high wind conditions to remain within their contracted maximum. Evidently, from a public policy perspective, the efficient use of existing grid infrastructure through higher load factors should be encouraged.

Over installing a wind farm implies the construction of more turbine capacity at the site than the MEC could allow under high wind speeds. With high wind conditions, therefore, output will be curtailed and the generators will not be fulfilling their output potential. The intuition, however, is that most of the time wind speeds will be lower, and by having more turbines on the site, for a fixed MEC, average output will increase. It is possible therefore, to envisage that profit contributions may be higher through increasing the average capacity factor[1] of the wind farm (MEC load factor) at the site (even though the capacity factor of the individual turbines, or turbine load factor will be lower), despite the opportunity cost of curtailing above MEC. Furthermore, if wind generators are exposed to market prices, then as spot prices tend to be lower (or even negative) under high wind conditions (Hirth, 2013; Sensfuß et al., 2008; Munoz and Bunn, 2013), this opportunity loss of curtailed revenue would be reduced to a possibly negligible amount. The attraction of over installing therefore depends not only on the investment costs and wind speed distributions, but also upon the type of subsidy regime (full, partial or no exposure to market prices) and the market structure itself (ownership and penetration of wind technology) to the extent that market concentration influences market prices. Furthermore, where the MEC is a binding constraint (and connection cables do come in "lumpy" sizes), over-installation can be the logical response. Nevertheless, over installing implies greater capital investment and more capital at risk. To be clear about the intuition, it is not being suggested that a higher NPV can be obtained by over-installing on a constrained site compared to an alternative project with the same capital commitment on a larger unconstrained site (if that were possible); rather that, given the site constraint, the NPV of the project can be improved by over-installation. The transmission owner and system operators' perspectives may also be favourable, since any increased load factor will also apply to the transmission assets and system operations.

The benefit of over installing turbines on a wind farms site is best understood in terms of energy output[2]. Table 1 shows the variation in energy output with over installation. We see in Table 1 the distinction between the individual turbine load factor and the MEC load factor: while over installing turbines in excess of the MEC reduces the load factor of each turbine, the overall MEC load factor of the wind farm is increased. We refer to capacity factor throughout the paper as the overall wind farm MEC load factor.

For a "normal" 100 MW wind farm a developer might choose to install 40 × 2.5 MW turbines which would produce 253.4 GWh annually (40 turbines × 6.3 GWh/turbine). If he over installs the number of turbines on site by 10%, he would install 44 × 2.5 MW turbines (for total 110 MW installed) and while the maximum output of each turbine will be constrained or turned down to 2.27 MW (100/44), the total wind farm output is increased by 6.67% to 270.4 GWh (44 × 6.1 GWh/turbine). Further details are provided in Appendix 1.

The potential economic benefit of over installation has been noticed by both the Irish and UK regulatory bodies. In 2014, the Irish Commission for Energy Regulation, (CER, 2014), decided to allow wind generators to over install by up to 20%, updating an earlier decision, CER (2011), whereby generators were permitted to over install

Table 1
Energy output with over installation.

Optimisation with GE 2.5 MW/100 rotor @ 7 m/s					
Level of Installation	100%	105%	110%	115%	120%
Installed capacity (MW)	100	105	110	115	120
Capacity constrained turbine rating (MW)	2.50	2.38	2.27	2.17	2.08
Net energy per turbine (MWh)	6,335	6,248	6,145	6,027	5,919
Number of turbines	40	42	44	46	48
Total wind farm energy (MWh)	253,419	262,424	270,378	277,243	284,107
Unconstrained wind farm energy (MWh)	253,419	266,090	278,761	291,431	304,102
Increase in wind farm capacity factor		3.6%	6.7%	9.4%	12.1%
Energy constraint		1.40%	3.10%	5.12%	7.04%

by 5% of MEC for technical reasons (to compensate for losses). CER (2011) noted that 50% of transmission connected projects and 27% of distribution connected projects had over installed for technical reasons by averages of 2% and 1.8% respectively. Both MEGAWIND (2014) and DNG (2014) highlight the over installation of turbines in excess of MEC on offshore wind sites, a practice known as "overplanting" in that industry. The rationale for overplanting in the offshore context is related to dynamic line rating and reliability but nonetheless highlights industry practises of over installing. In the UK, the provision for 25% over installation was anticipated in the UK Contract for Difference (CFD) scheme which is supported by the Levy Control Framework, DECC (2014). Over installing turbines can also lead to reduced transmission use of system charges which are levied based on the MEC, or Transmission Entry Capacity in the UK, National Grid (2015).[3] In manufacturing processes, redundancy is often created to provide for outages and maintenance. Given turbine contract manufacturers typically guarantee 95% availability,[4] over installation provides a buffer for production down time due to maintenance and faults. Staffell and Green (2014) show that wind turbine output declines with age at a rate similar to other rotating machinery and showed the UK fleet of wind turbines lost 1.6% +/ 0.2% of output annually between 2002 and 2012, so there is a natural depreciation of wind turbines over their useful economic life which over installing could mitigate.

A more subtle impact of over installing wind turbines is the reduction in correlation of individual wind farm wind output and system peak wind output. Under Feed in Tariffs, wind generators are indifferent to wholesale market prices and so are less likely to be concerned with this effect (assuming wind generation is not curtailed). However, if exposed to market prices, a generator is likely to see higher prices if it is generating when the system-wide wind is below maximum. If more wind is generated when wind is below its peak, in systems with least cost dispatch, this is likely to reduce prices for consumers.

In this paper we seek to clarify the economic, rather than technical, drivers for more substantial over installation, how they may depend upon the nature of the subsidy and the evolution of renewable penetration into the market, as well as evaluating the benefits of the increased MEC capacity factor to (1) enhance system reliability, (2) ease system balancing challenges, (3) increase the return on existing grid infrastructure and (4) reduce the risk of outages. These system considerations invite the question of whether there should be further policy incentives for over installation.

In the context of previous research, analysis of the optimal sizing of wind farms has not explicitly appeared and indeed Sturge et al. (2014) observed that "*questions of energy yield are notably absent from the growing literature on planning for wind turbines*". This is despite an extensive literature of the investment case for wind (e.g. Venetsanos

[1] Here we interpret capacity factor in its conventional way as the power produced over a period of time expressed as a percentage of the maximum power that could have been produced, Boccard (2010).

[2] Full details on assumptions are provided below in Section 1.1 Over installation with a Fixed-Price Feed-in Tariff

[3] Mott McDonald (2010) estimates these at £10,000/MW/pa of total annual operating costs of £34,203/MW for onshore wind.

[4] SEAI http://www.seai.ie/Renewables/Wind_Energy/Wind_Farms/Wind_Farm_Development/Wind_farm_Contracts_and_Agreements/.

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