Published paper

Sturge, D., While, A. and Howell, R.J. (2013) *Engineering and energy yield the missing dimension of wind turbine assessment*. Energy Policy. Available online 5 November 2013. ISSN 0301-4215 (In Press)
http://dx.doi.org/10.1016/j.enpol.2013.10.052

Engineering and Energy Yield: The Missing Dimension of Wind Turbine Assessment

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Abstract

The goal of optimising the energy yield of renewables sits uneasily with the politics and processes of planning for wind turbines. In countries such as the UK the land-use planning consent regime is not concerned with the energy yield of proposed wind developments. This is a matter for the developer rather than the regulator, which might seem curious given the policy commitment to maximising the potential for renewable energy generation and the need to weigh up local environmental impacts with emissions reduction. In this paper, we highlight and investigate the implications of the exclusion of energy yield from wind turbine regulation. The case is made for increasing the weight given to energy yield within Environmental Impact Assessment and the land-use planning process.

Keywords

Wind turbine; energy yield; impact assessment

1 Introduction

Planning consent for onshore wind farms has become a contentious issue in the UK as the push for renewable sources of energy comes up against intense community resistance on grounds of visual impact and potential impacts of noise, and on health and safety. At the very least this can lead to considerable delays and often rejection of applications for wind farm developments. Of the total number of applications for onshore wind farms per year in the UK, on average up to 50% of those do not pass the planning application stage, as shown in Table 1. UK governments have used a range of mechanisms to help stimulate wind farm development as part of a broader strategy of market-based energy decentralisation. Initiatives include: a generous Feed in Tariff (FiT) introduced in April 2010 (but reduced after August 2011 because of concerns the coalition government had with the disproportionate amount of funds that developments in England would receive in comparison with the rest of Europe (DECC 2011)); and greater support for renewable energy development in national planning policy, including regional targets for renewable energy generation and targets for on-site renewables in major new developments.

Table 1. Total number of wind farm applications accepted and rejected per year in the UK from 2006 – 2011, from (Barclay 2012)

Year	Number approved	MW approved	Number rejected	MW rejects
2011	84	1109	84	860
2010	82	1357	83	1238
2009	97	1324	67	760
2008	72	1780	51	1563
2007	63	1145	48	869
2006	38	877	31	669

Given the emphasis on visual amenity, with some consideration of noise and wildlife as the main source of public opposition and planning application refusal, wind turbine impact has tended to be seen primarily as the domain of landscape assessment and local environmental impact. This is perhaps understandable given that those impacts tend to determine whether wind turbine planning applications are refused or accepted, but as we shall see, that also reflects the fact that questions about viability or efficiency of the development is left as a matter for the developer. This has been reinforced by difficulties in bringing climate change mitigation impacts into established Environmental Impact Assessment (EIA), either because calculating the prevision greenhouse gas reduction is fraught with difficulties or there is resistance to including detail on climate change mitigation (Gerrard 2008). Even where CO_2 emissions could be calculated, there would still be difficulties in weighing this environmental benefit against other environmental or ecological impacts. This issue is compounded by the fact that in countries like the UK, engineering aspects, and specifically the energy yield, is neither a matter for public debate nor consideration in the process of planning consent. This is curious as it might be expected that from the perspective of efficient decentralised energy investment, the energy output of the wind farm should have some bearing in determining whether or not a proposal is appropriate. This is especially the case where a trade-off is being made between visual amenity and renewable energy generation (siting arrangements and energy yield), particularly in a country with a high population density such as the UK.

Questions of energy yield are notably absent from growing literature on planning for wind turbines. Our aim in this paper is to consider whether and how questions of energy yield and especially the optimisation of favourable sites should be brought into the consent regime for wind turbine development. This analysis covers Environmental Impact Analysis and broader land-use regulations and reflects a concern that public policy should aim to maximise the return from wind turbine developments both in terms of the sunk costs invested in the turbines and the limited resource of land. The focus for our investigation is the UK planning system. As planning theorists are quick to point out, national planning systems are all distinctive, if not idiosyncratic, in their regulatory emphasis and legal basis. The context for decentralised energy provision also varies widely between countries in terms of incentive structures and ownership rules, though the remit of state regulation of wind turbines is broadly similar. While the focus is on the UK planning system, the issues described may be of relevance for other nations in the world.

This paper begins by first looking at the UK planning consent regime from the 'engineering perspective' of energy yield. Energy yield as a developer's responsibility and the effect this can have on siting decisions is then analysed. From this, arguments for changing the consent regime are made by drawing on examples from Denmark and Scotland. The paper draws on a policy analysis and interviews with local planning officers in England and Scotland.

2 Placing energy yield within the UK wind turbine consent regime

In countries such as the UK, wind turbine development has been highly controversial. This controversy reflects concerns about potential visual, noise and health impacts in a context of significant level of societal and political opposition, especially to the visual appearance of wind turbines. In this context of broad opposition, the process and methodology of impact assessment has become crucial for those seeking to develop or prevent wind farms. As Selman (2010) argues, the UK may be entering an era in which it is gradually “learning to love” the low-carbon landscape, but this is a slow process.

The UK planning system is a discretionary system in which individual applications are assessed by weighing up impacts and other material considerations. This is currently a plan-led system strongly influenced by national guidance within the National Planning Policy Framework (NPPF) (DCLG 2012), which replaced the previous system of national planning policy guidance in 2012. Decisions are taken locally by elected members acting on officer recommendations, but applicants can appeal to national government. In general, the UK government policy has become more supportive of wind farm development, and this is reflected in the 2012 NPPF. The environmental role discusses the responsibility of mitigating and adapting to climate change including moving to a low carbon economy (DCLG 2012). The current coalition government has also been seen to be strengthening its current policy views by the removal of John Hayes from the Department for Energy and Climate Change (DECC) due to his very vocal opposition of onshore wind turbines (Wintour 2013).

In adherence with EU regulations, wind turbines will be expected to have an Environmental Impact Analysis (EIA). The EIA is now a well-established method used around the world and is a tool that takes into account the likely significant effects of a development and are objectively analysed, playing an important part in determining the final decision.

For a wind farm the EIA is likely to cover (Stevenson 2006):

- Construction and infrastructure impacts;
- Landscape and visual impacts;
- Noise impacts;
- Ecological impacts;
- Hydrological impacts;
- Archaeological impacts;
- Electromagnetic interference;
- Public health and safety;
- Socio-economic effects both positive and negative;
- Wider global environmental benefits.

Our concern in this paper is with the assessment of energy yield from a wind turbine or wind farm. In assessing applications, planning authorities weigh up the costs and benefits, however, the 'benefits' is in the general contribution of decentralised energy. Whilst, in theory the specific energy contribution in terms of energy yield might be cited as a material consideration in favour of the development, it can also be placed under the EIA criteria of 'Socio-economic affects both positive and negative' and 'Wider global environmental benefits.' Therefore, the issues with the energy yield element of the equation raises concerns to what extent is it seen to be mitigating some of the other impacts, such as visual intrusion. There is suggestion that the EIA should not consider climate change as the environmental impact is negligible (Gerrard 2008). The issue of mitigation extends to how a single wind development can have an effect on the overall reduction of global greenhouse gas emission, when on this scale any net reduction is deemed insignificant. This approach is somewhat constrictive, as only focusing on a single development is compounded by the fact that impact assessments are reviewed on a local case-by-case basis rather than within a cumulative regional or national framework. Therefore, while the topics covered by the EIA are crucial for the wind farm planning process, the EIA framing of wind turbine development impacts is likely to mitigate against climate change goals.

The EIA process raises questions about the weight given to energy yield in conflicts over wind turbine development. However, in most marginal cases where considerations of maximising energy yield might make a difference, it is prevailing planning policy guidance that determines the weight that can be given to various arguments for and against wind turbine development. It might be expected that where governments are seeking to facilitate renewable energy development but face intense opposition, policy-making ought to include some consideration of energy yield from wind turbines. This might indicate whether a sensitive site is being used effectively or indeed, whether a developer should be given state subsidy in the form of a FiT or such like. This is where the issues of energy yield and ultimately, engineering play a key role, because from an overall perspective it fundamentally determines the viability of a development, not only financially, but environmentally too.

However in countries like the UK, questions of energy yield from wind farm developments are in effect a matter of development viability that is left to the developer. Moreover if the UK is moving to a system in which energy yield was a material consideration in EIA or development control, it raises questions about how this should be achieved and also the capacity of the regulators to assess the potential energy yield. This issue is explored in more detail in the following sections, which looks at current developer's responsibilities and how siting decisions are made.

2.1 Energy yield as a developer responsibility

The UK planning system has tended to become reactive and market-driven (Fraser 2002). For wind turbines, developers apply for planning permission by providing the fixed locations for wind turbine placement and infrastructure. This siting is primarily based on developer understanding of wind direction, turbine performance and the ability to be connected to the grid. It is also essential that a siting layout must be optimised, as it will minimise the need for repowering (the process of replacing multiple turbines with a single more efficient one), which would prove expensive. However, within the UK system, the precise location of wind turbines has to be fixed and agreed prior to development. Altering the siting of wind turbines to improve efficiency and output in response to site conditions would require a new planning application. This approach sits uneasily with the difficult task of predicting the aerodynamics of the terrain and atmospheric conditions of the region.

There has been considerable research into optimising the power output of a wind farm via the placement of the wind turbines themselves (Chowdhury et al. 2012; González et al. 2011; Husien et al. 2013; Magnusson & Smedman 1999; Meyers & Meneveau 2012; Politis et al. 2012; Røkenes & Krogstad 2009) and most notably the work carried out from Risø National Laboratories in Denmark on the European Wind Atlas, providing comprehensive wind statistics (Troen & Petersen 1989). The issue of wind turbine siting is important for overall energy yield and relies heavily on how each turbine is placed with respect to its surroundings and more importantly, other turbines. The turbulent air that the rotating blades produce is known as a wake; this low wind speed region greatly affects the performance of the downstream wind turbines. However, the problem lies with the difficulty of calculating the potential energy yield due to the complex nature of the turbulent air. It begins with the sheer size of wind turbines and with rotor diameters exceeding 150 m, it is impossible to test full size models because of impracticality. Therefore, the next best option is to test scale models in wind tunnels, however, due to scaling effects there are a lot of 'real' characteristics lost in the process. This then leads onto the use of Computational Fluid Dynamics (CFD), which allows engineers to model and simulate using computers, large wind farms on terrains based on actual locations. However, this process is an extremely demanding one that requires people with a high level of engineering expertise as well as weeks and possibly months of computational simulation time to determine an optimal layout of a farm within a predetermined area (Bechmann & Sørensen 2011; Montavon et al. 2009). Even then, the data that is produced is not necessarily of sufficient accuracy and may need revising further down the line. Therefore, it is engineers that will decide on an optimal layout to site the wind turbines and it is the result of this work that is put forward for planning approval. Should an application be denied on basis of the other impacts it may cause, engineers must start the whole process over again.

The importance of using the designed siting configuration is of paramount importance, as it will determine the total power output, which ultimately affects the ability for the wind farm to succeed. To emphasise the sensitivity of wind turbine siting, this area of research has been reviewed. An example is the work carried out by Husien et al. (2013) which found that a wind farm consisting of 16 wind turbines aligned in a single row, with all facing the optimal wind direction is 20% more efficient than if the same 16 turbines were placed in a 4x4 square arrangement. Another example looks at how the terrain plays an important role for efficiency; Røkenes & Krogstad (2009) shows that placing a wind turbine on top of a hill can yield an increase in wind speed of up to 15%, which is advantageous for maximum power output (for example a doubling in wind speed gives a factor of eight increase in wind power). In this case a 15% increase in wind speed yields a 50% increase in power in the wind due to the cubic relationship between wind speed and power in the wind. Meyers & Meneveau (2012) looked into the optimal spacing between wind turbines and found that for realistic cost ratios (land surface and turbine costs), the ideal average spacing is 15 rotor diameters (D) apart, which is considerably higher than the current 7D often used in wind farms. This distance allows for the wake caused by the rotating blades to dissipate enough that it has a minimal effect on downstream turbines. Therefore, an ideal layout would be a single line of wind turbines facing the oncoming wind placed on top of a hill; however, this is the configuration most likely to meet opposition for reasons on visual intrusion if nothing else.

2.2 Case studies of Barnsley Council wind developments

In order to illustrate the impact that the lack of an energy consideration has on scheme approval, the following section examines three case studies of wind development planning applications in Barnsley, England.

Case study 1: 12.5 MW five turbine wind farm (2009)

This particular planning request had a divided opinion within the local community due to its sensitive location within view of the Peak District National Park. The application was for the erection of a five-turbine wind farm with a height of 125m to blade tip and a potential energy yield of 12.5 MW. Unusually, the project had approximately the same number of letters of objection as letters of support at 1075 and 1037, respectively. The reasons for objection cover a range of issues, however, almost all refer to landscape and visual impacts. In contrast, there are also arguments that there is potential for an adverse impact on the Peak District National Park and local bird populations due to climate change itself, which is much greater than the threat posed by the wind farm. It is also worth noting that Kirklees and Sheffield councils objected due to the potential impact on visual amenity. Despite the 12.5 MW meeting over a third of the 2021 target of 34 MW for Barnsley, the application was ultimately refused because of significant harm to the character and appearance of the nearby National Park.

This is an example that can be put into the broader context of the limits of the English planning system. It illustrates the issue that decisions are taken on a case-by-case basis without an understanding of whether it is a regionally optimal site and how it fits into overall renewables strategy at local, sub-regional and regional levels. Further, it contradicts the scope of the NPPF, which it to support the move to a low carbon future (DCLG 2012).

Case Study 2: Single wind turbine – amended plans and reduction in height of turbine (2012)

The initial planning application by Empirica Investments was for a single wind turbine of a 67m height to blade tip, to be located in a field associated with Ringstone Hill Farm. The surrounding fields are crossed by footpaths and a byway runs adjacent to the site. The application was then amended, with the assumption being that a smaller wind turbine has a greater chance of gaining approval due to proposed location within the Green Belt. As a result the height of the turbine was reduced to 55m to blade tip and the output reduced from 0.9 MW to 0.3 MW. Despite this, the conclusion was that even though the scheme would make towards reducing CO_2 emissions, there are more significant landscape and visual impacts. Ultimately, the wind turbine application was refused, even with compromises made by the developer.

Case Study 3: 6 MW three turbine wind farm (2009)

E.ON Energy Company applied for planning permission for a three-turbine wind farm with a height of 101 m to blade tip in 2008 to be located on Blackstone Edge, Barnsley; it was granted planning permission in 2009 subject to 27 planning conditions. The developers applied for an amendment to one of the conditions regarding operating noise levels. The original condition limited the maximum noise level to 43dB during the day and 35dB at night as observed from two locations. However, the applicant advised that this condition would have significant restrictions on energy output. Therefore, the application sought to vary the condition to permit the noise level limit to be increased as recommended in the Planning Policy Statement (PPS) 22 Companion Guide (ODPM

2004). It was decided that the original condition was restrictive, therefore, significantly reducing the energy output and a reasonable justification for the amendment.

In this case diminished energy yield meant that the enforced conditions for the development were altered. However, the amendment was only accepted because the noise level limit was more restrictive than the government's suggestion and not solely due to the reduced energy output.

The capacity to manage siting decisions

So far the argument has been that the UK consent regime is inflexible when it comes to the detail of site location, but the detail of site location can have a significant impact on the energy yield of wind farms. In the UK the tension between these issues has tended to be played out around the dispute of minimum distances between dwellings and wind turbines on grounds of visual and noise impacts. Local authorities seeking to constrain wind farm development have sought to impose minimum distance requirements and wind farm developers have challenged this. Milton Keynes Council is an example of this; they tried to set a minimum distance of 1000 m for wind turbines over a height of 100 m (Anon 2013). However, RWE NPower challenged this motion as they were looking to build two wind farms in the area, arguing that the local authorities had no power to do so.

Our argument in this paper is that wind turbine siting might need to be more flexible if energy yield is to be maximised. However this poses challenges of technical capacity within the regulatory regime. All the planning officers interviewed during this study agreed that the level of knowledge provided by the government is sufficient, despite stating that the guidance is a bit "woolly." Notwithstanding the recent introduction of the NPPF (DCLG 2012), planning officers rely heavily on the PPS22 Companion Guide (ODPM 2004), which is out-dated. However, it is still the best guidance available, inhibiting energy yield consideration further. However, there is a desire for better clarity on siting issues such as a minimum distance between wind turbines and dwellings, as in the UK none exist at present. In most UK local authorities there are technical trained staff within local councils who can assess noise impact, landscape impact and environmental health, but often there is no in house professional engineer to consult on wind turbine placement and maximising energy yield. Some local authorities do offer relevant courses for their staff to gain knowledge in this area, but it is not a necessity and one planning officer was even said to use "Google" as a final resort in solving engineering related issues. Introducing a stronger regulatory emphasis on energy yield either through planning consent or EIA would require access to technical knowledge and expertise that is currently beyond local authorities, especially if developers were to be held to account on promised generation capacity.

2.3 Argument for changing the consent regime

Our argument is that planning policy could become more interventionist in identifying optimal wind turbine developments and ensuring that prime sites are maximised in terms of energy yield and the overall use of land. To some extent this is already achieved through the market-based system given the incentives on developers to maximise the returns on their investment (if a wind turbine farm is inefficient it will generate less revenue under a FiT scheme and so be less of a financial burden on government revenues). Yet to the extent that wind turbine development often depends on some sort of state subsidy, then governments might have an interest in ensuring that wind farm efficiency is optimised. It might be a case that the yield from wind turbines is something that should be weighed up against other impacts in planning decisions (such is described in the EIA section above). Finally, the lack of flexibility present also means that developers cannot put multiple potential layouts forward; so should one arrangement be refused, the planning officers cannot currently move onto a provided 'Plan B'. A backup option would allow developers to devise alternate plans that engineers have established as a reasonable compromise in the event there is local opposition.

International Comparison

As seen previously, the UK consent regime has a particular approach to wind turbine regulation. This section looks at the approach used in Scotland and Denmark; Scotland because land-use regulation has a common basis with England, but a different system of land-use planning regulation; and Denmark because it is often seen as an exemplar in onshore wind turbine development (Fraser 2002).

The System for EIA in Scotland and Denmark is similar to that of England. In those countries, energy yield (i.e. climate change offsetting) is generally not a detailed consideration for EIA. What is however noticeable is that onshore wind turbine development is more supported within national planning policy. Of particular interest is how Denmark and Scotland use land zoning to steer siting decisions. The issue of zoning is relevant because it involves a strategic decision about where the presumption should be in favour of wind turbine development and areas that should be avoided. This sort of approach had started to be introduced in English regional planning during the early 2000s with regional planning authorities required to identify sites for a certain level of renewable energy generation (ODPM 2004). The shift away from regional planning has removed requirements for regional planning and regional renewable energy targets, but the zoning approach is hinted at in the NPPF under section 10, "consider identifying suitable areas for renewable and low carbon energy sources" (DCLG 2012).

Scotland has perhaps been more proactive than England on wind turbine development, reflecting a strong emphasis on national energy security via renewable resources and the country's potential for wind power (SNH 2009). Scotland, like England, has sensitive landscapes. One way of reconciling increased renewable energy generation and landscape protection has been for Scottish Natural Heritage to set out a system of zoning for wind turbine developments with a three-zone sensitivity approach (SNH 2009). Zone 1 represents the lowest natural heritage sensitivity; these areas are least sensitive to wind farms with the greatest opportunity for development (70% approval rate) and covers 15% of Scotland's land area. Zones 2 and 3 represent medium and high sensitivities respectively, with applications unlikely to be accepted (a maximum of 30% successful applications in zone 3). Zone 2 comprises of 55% of Scotland's land area with Zone 3 the final 30%. However, these zones do not take any consideration of energy yield, wind speed and direction, and siting optimisation; instead, visual amenity and landscape heritage are the primary concern.

The Danish government identified renewable energy sources as an important policy and used incentives and subsidies to encourage development (Fraser 2002). Denmark began with clear objectives in terms of renewable energy in the 1990s, which allowed for potential development zones to be established (Meyer 2007). This reflects a clear understanding between the general public and the drive for sustainable energy sources, especially as an Energy Agreement in Denmark means developers must offer at least 20% of the ownership to people living within 4.5km of the site (Sperling et al.

2010). This cooperative ownership contributes significantly to the success in securing public support and acceptance.

Denmark also reviews and updates its wind turbine development plan (to achieve set renewable energy targets) every four years, as it is recognised that the correct regional locations must be identified because wind strength has direct economic implications for energy yield and minimising the number of turbines required in a development area (Fraser 2002). This process of 'zoning' means that different areas are designated as appropriate for the following types of development: individual wind turbines, local wind farms and clusters, and large-scale region wind farms as well as zones where development is strictly prohibited. The zones are clearly laid out and remove certain subjective arguments from the planning process. The public are also encouraged to directly enter debates on all aspects of wind development planning issues, with the relevant authorities holding seminars and meetings and even allowing those who are interested in helping select potential development sites (Fraser 2002).

However, one particular area that relates directly to the energy yield and efficiency of wind farms is the repowering scheme that Denmark has introduced. This scheme was implemented to reduce the total number of wind turbines by replacing an array of small turbines with a single larger and more efficient one. As a result of the repowering subsidy in addition to the FiT, a total of 1208 wind turbines were removed between the years 2000 and 2003, but with an overall increase of 202 MW in capacity (Sperling et al. 2010). This clear appreciation of technical knowledge from the national and local governments means that wind developments are kept as viable as possible, along with providing the public with benefits and assurance for their support.

3 Conclusion

The aim of this paper has been to promote debate on the 'engineering dimension' of wind turbine assessment, highlighting shortcomings in the current approach. The particular concern has been about optimisation of the potential for energy generation and energy yield issues in the planning consent for wind farms. Our argument is that this dimension is somewhat marginalised in EIA and land-use planning consent regimes. The energy yield gap runs counter to the ideal of maximising investment in energy decarbonisation, as local authorities have less concern with optimising wind farm layouts, despite having to meet local renewable energy targets. We have suggested that there are various reasons why regulators might seek to integrate planning with energy yield more centrally into the consent regime. The advantages would include being able to weigh up energy yield against oppositional factors, and also using energy yield considerations to inform a more flexible approach to siting. If access to technical knowledge for planning officers could be increased, this will allow the engineering aspect of an optimal energy yield to determine whether a development is viable and, therefore, beneficial to the nation. As well as removing some of the more subjective reasons for rejection, such as visual and noise impacts. However we also point to some of these challenges this might pose.

It is concluded that the current approach of the EIA and land-use planning is somewhat constrictive, as the focus is on the impacts of a single wind development. Therefore, a more universal approach to renewable energy developments is required; this would take into account regional, national and, potentially global implications. The solution would be to situate wind turbine development within a process of energy zoning in which priority locations are identified on the basis of their potential energy yield, including or excluding areas that pose difficulties in terms of landscape/visual amenity or wildlife protection. Those sites would have a degree of flexibility for detailed wind turbine design and location within an overall brief that would set the parameters for development. Such an approach would imply a more strategic method than the current EIA, capable of weighing up the environmental benefits and disbenefits of wind turbine development within a long-term framework of land-use regulation.

Our concerns are grounded in the specific context of the UK, but are more broadly applicable because the energy yield gap is a broader reflection of fault lines in state regulation of renewable energy generation.

Acknowledgements

This research was funded and conducted as part of the WindNet research group at the University of Sheffield, UK. The authors would like to thank all those who have reviewed and contributed to this paper for their valuable assistance.

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