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The Importance of Accurate Wind Resource Assessment for Evaluating the Economic Viability of Small Wind Turbines

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Abstract

The techno-economic performance of a small wind turbine is very sensitive to the available wind resource. However, due to financial and practical constraints installers rely on low resolution wind speed databases to assess a potential site. This study investigates whether the two site assessment tools currently used in the UK, NOABL or the Energy Saving Trust wind speed estimator, are accurate enough to estimate the techno-economic performance of a small wind turbine. Both the tools tend to overestimate the wind speed, with a mean error of 23% and 18% for the NOABL and Energy Saving Trust tool respectively. A techno-economic assessment of 33 small wind turbines at each site has shown that these errors can have a significant impact on the estimated load factor of an installation. Consequently, site/turbine combinations which are not economically viable can be predicted to be viable. Furthermore, both models tend to underestimate the wind resource at relatively high wind speed sites, this can lead to missed opportunities as economically viable turbine/site combinations are predicted to be non-viable. These results show that a better understanding of the local wind resource is a required to make small wind turbines a viable technology in the UK.

Keywords: micro-generation; wind; resource

1.0 Introduction

In recent years there has been considerable interest in the potential of microgeneration to contribute to a future of distributed electricity generation (DECC, 2011). The UK government has promoted the growth of such technologies through a number of incentives, including the Low Carbon Buildings Programme, the Code for Sustainable Homes and the Feed-in tariffs Order (Allen et al., 2008; Walker, 2011). As a result there has been an increase in the number of small-wind turbines (typically defined as < 50 kW) installed across the UK (Bergman and Jardine, 2009; RenewableUK, 2012). The primary benefit of small scale wind energy systems is the potential to generate low carbon electricity close to the point of use, therefore significantly reducing the energy losses in generation, transmission and distribution, as well as the carbon intensity of the generated electricity. In addition, from the perspective of the owner, a small wind turbine can produce an economic return either as a result of displacing electricity imported from the grid and/or payment for the generated electricity.

To ensure turbines are located at sites at which they are economically viable, an understanding of the energy resource is required. This is not typically a problem for large-scale wind turbine installations as extensive wind monitoring can be conducted to identify potential sites. However, due to financial constraints this is rarely possible for small scale installations; hence there is a reliance on standard assessment tools. If these tools are too optimistic, people who install small-scale turbines run the risk of disappointment and financial loss. This could lead to reluctance to support future low-carbon technologies on the basis that they too might be oversold. If however, the tools are too pessimistic, there could be a significant reduction in the investment in small wind turbines.

Globally, there has been significant research assessing the wind resource in rural locations (Islam et al., 2011; Fyrippis et al., 2010; Jowder, 2009) and in recent years, due to increased interest in microgeneration, a number of studies have developed techniques for urban areas (Heath et al., 2007; Drew et al., 2013; Millward-Hopkins et al., 2013; Weekes and Tomlin, 2013). Despite this, local authorities currently rely on the predictions of low resolution wind speed databases. In the UK, the DECC wind speed database has been widely used by installers and planners for a number of years to evaluate the wind resource at potential sites for a micro-wind turbine (James et al., 2010; Walker, 2011). It provides estimates of the mean wind speed at a 1 km resolution at 10, 25 and 45 m above ground level. The database was produced by a mass consistent flow model, NOABL (Numerical Objective Analysis of the Boundary Layer), which interpolated wind speed data from 56 weather stations across the UK (Burch and Ravenscroft, 1992).

UK field trials carried out by Energy Saving Trust and Encraft demonstrated that the DECC database (hereafter NOABL) tends to overestimate the wind speed, particularly at locations at close proximity to buildings (Encraft, 2009; Energy Saving Trust, 2009). Consequently, this has led to a number of problems where consumers have been given an unrealistic expectation of the energy production and therefore the potential economic benefits of their installation. The Energy Saving Trust field trial showed that during a one year observation period, all 38 building mounted turbines monitored achieved a load factor of less than 8%. In comparison, the 17 free-standing turbines monitored performed considerably better but still only achieved an average load factor of 19%. In the Warwick wind trials showed a mean capacity factor of only 4.2% across 26 rooftop turbines.

In 2009, recognising the need to develop a tool to help local authorities and individual consumers improve the placement of small wind turbines, the Carbon Trust in collaboration with the UK Meteorological Office launched an online wind speed estimator. This provided an estimate of the mean wind speed at a site based on the postcode and a brief description of its characteristics. The model was based on the National Climate Information Centre (NCIC) dataset, which comprises of data from 220 sites over 30 years, (in comparison to a 56 site, 10 year dataset for the NOABL). The

NCIC was used to generate a large-scale wind climatology at a height away from the surface, which was then scaled down through the boundary layer taking into account the impact of the underlying surface using a blending height method (Best et al., 2008). Energy Saving Trust (2009) and Drew (2011) showed that the Carbon Trust tool provided more accurate predictions of the mean wind speed than the NOABL. However, this tool is no longer available and consumers are now recommended to use the Energy Saving Trust Wind Speed Prediction Tool (EST tool). The EST tool is freely available online and provides an estimate of the annual mean wind speed at a height of 10 m based on the site's postcode and land use type (either urban, suburban or rural). However, little information of the calculation process is provided.

The aim of this paper is to investigate whether the tools currently available to estimate a site's wind resource are accurate enough to ensure small wind turbines are only installed at locations at which they are economically beneficial. The first section highlights the importance of an accurate assessment of a site's wind resource when estimating the techno-economic performance of a turbine. The second section considers the accuracy of the current site assessment tools by comparing the predictions with wind data collected at 91 Met Office weather stations across the UK. The final section considers the implications of any errors in a site's wind resource for the predicted energy production and economic performance of 33 small wind turbines for a range of economic scenarios.

2.0 Assessing the techno-economics of small wind turbines

One metric frequently used to assess the techno-economic performance of energy production technologies is the levelised production cost, LPC (Heptonstall et al., 2012; Allan et al., 2011; Cockerill et al., 2001). This is defined as the cost of the electricity at the point of connection to a load, including the initial capital, discount rate and operational costs, and can be calculated from

$$LPC = \frac{C}{aE} + \frac{TOM}{E} \tag{1}$$

Where C is the total investment cost associated with the installation of the turbine, E is the annual energy production, TOM is the total annualised operation and maintenance (O&M) cost and the annuity factor, a, is calculated from

$$a = \frac{1 - \left(1/(1+r)\right)^{n}}{r} \tag{2}$$

where r is the discount rate and n is the economic lifetime of the turbine (in years). For all calculations described in this paper an economic lifetime of 20 years was assumed with a discount rate of 5% (IEA, 2005).

The capital cost of a wind energy project can be broadly broken down into equipment and installation costs. A number of the equipment costs, such as the turbine and the inverter, generally scale with the size of the installation (Simic et al., 2013). However, for other components such as the wiring, meters and isolation switches, the price is generally fixed (Bergman and Jardine, 2009). Consequently, there is currently a large range in the specific investment cost, I, of small wind turbine installations, typically between £2,000 – 6,000 per kW (Bortolini et al., 2014). In comparison, the on-going costs of an installation are relatively low, as maintenance checks are necessary every few year and are likely to cost approximately £100 (Energy Saving Trust, 2013).

The annual energy production may be represented as

$$E = 8760 f_{load} P_{max} \tag{3}$$

where f_{load} is the load factor of the turbine and P_{max} is its maximum power output. A turbine is considered to be financially beneficial to the owner if the load factor (energy production) is sufficiently high that

$$LPC < e \tag{4}$$

where e is the sale price of the generated electricity. In the UK, electricity produced by a small wind turbine is eligible for the Feed-in Tariffs, which as of March 2013 are set at between £0.23-0.326 per kWh for a period of 20 years, depending on the size of the installation (Ofgem, 2013).

Figure 1 shows the minimum load factor, f_{load}, required for a turbine to be economically viable for a range of values of I and e. At present in the UK, the best case economic scenario, (i.e. the cheapest available turbine and the highest feed in tariff rate, I=£2,000 per kW and e=£0.326 per kWh) requires a turbine to be installed at a location at which it will attain a load factor of 10%. However, none of the 38 building mounted turbines monitored in the Energy Saving Trust field trials achieved this level of performance. The figure also shows that based on the current average performance of small free standing wind turbines (i.e. a load factor of 19%), if the cost of a turbine reduced to £1,000 per kW, it could be economically viable with an electricity sale price of only £0.11 per kWh. In contrast, based on current performance (i.e. a load factor of 5%), building mounted turbines are not economically viable even when I=£1,000 per kW and e=£0.4 per kWh.

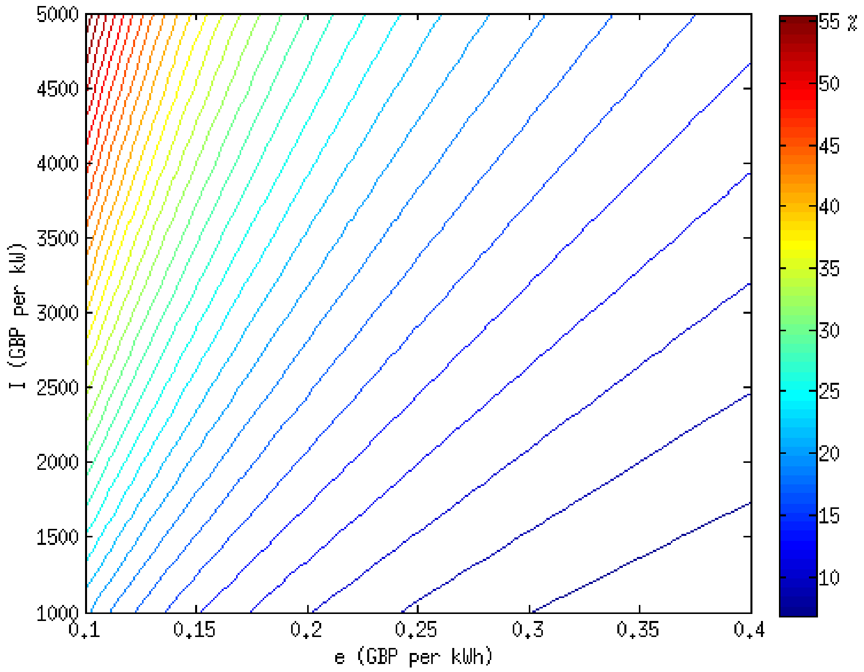

Figure 1 The minimum load factor required for a turbine to be economically viable for a range of turbine capital costs, I and sale prices of the generated electricity, e.

2.1 Estimating the load factor of a small wind turbine

Figure 1 shows that the techno-economic performance of a small wind turbine is very sensitive to its load factor. Estimating the load factor of a turbine at a given site, requires an understanding of both the available wind resource and the turbine's power output over a range of wind speeds. In general, when estimating the potential yield of a small wind turbine, the site's wind resource is represented by an estimate of the annual mean wind speed, U. A Rayleigh distribution is then assumed to represent the temporal variability of the hourly mean wind speed (Safari and Gasore, 2010; Seguro and Lambert, 2000). The Rayleigh distribution is a special case of the Weibull distribution, which has a probability density function given by

$$f(v) = \left(\frac{k}{\lambda}\right)\left(\frac{v}{\lambda}\right)^{k-1} exp\left[-\left(\frac{v}{\lambda}\right)^{k}\right] \tag{5}$$

where λ is the scale parameter, v is the hourly mean wind speed and k is the shape parameter (equal to 2 for the Rayleigh distribution). The annual energy production of a turbine can then be estimated from

$$E = \Delta t \int_{v\_cut\_in}^{v\_cut\_out} f(v)p(v)dv \tag{6}$$

where Δt is the number of hours in a year and $p(v)$ is the power output of the turbine at wind speed v. The power output of a turbine over a range of wind speeds is given by a power curve produced by the manufacturer. Figure 2 shows the normalised power curves of 33 small wind turbines using data obtained from the urban wind turbine catalogue (Wineur Consortium, 2006).

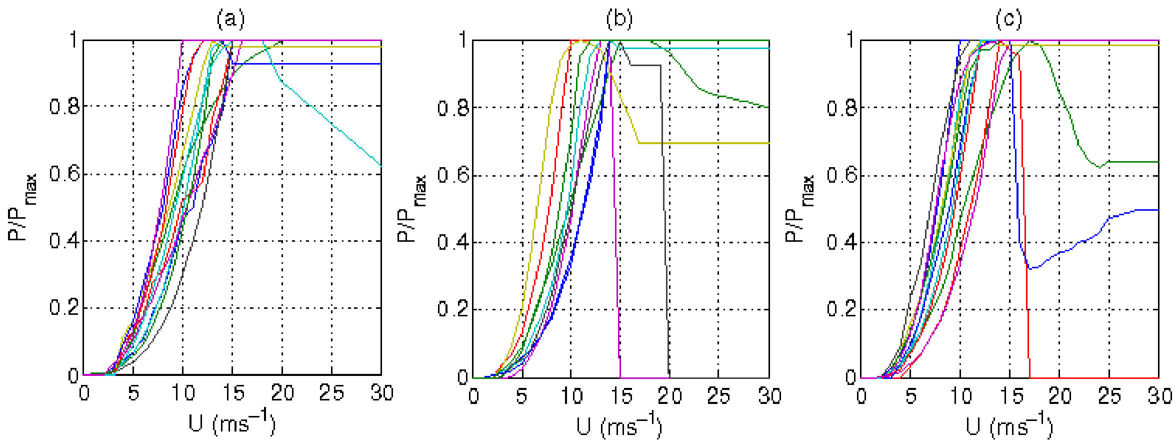

Figure 2The normalised power curves of 33 small wind turbine designs divided by the turbine's rated power (a) <1 kW (b) <5 kW (c) >5 kW (data obtained from Wineur Consortium (2006).)

Due to the non-linearity of a turbine's power curve, a small error in the prediction of a site's annual mean wind speed, U, can lead to a large error in the estimated annual energy production, E, and therefore load factor of a turbine. For example, for a site with an annual mean wind speed of 5 ms^{-1}, the median load factor across the 33 turbines is calculated to be 15%, however an uncertainty in the wind speed prediction of $\pm$0.5ms^{-1} results in a range of the median load factor of 11-19%. This shows that in order to determine whether a turbine is economically viable at a site, an accurate prediction of the annual mean wind speed is required.

3. Methodology

There are two main tools used in the UK to estimate a site's mean wind speed; NOABL and Energy Saving Trust Wind Speed Prediction Tool. This study investigates the impact of their accuracy on the estimated economic viability of a small wind turbine. The wind speed predictions of each of the tools have been compared with the long term mean wind speed, U, measured at a number of sites across the UK. Hourly wind speed data recorded at a number of UK Meteorological Office weather stations were obtained from the British Atmospheric Data Centre (UK Meteorological Office, 2012). The data is collected at standard exposure, which is defined as level, open terrain at a height of 10 m above the ground, where open terrain is defined as an area where the distance between the anemometer and any obstruction is at least ten times the height of the obstruction. Sites were only selected if data were available between 2000 and 2011 for a minimum of 90% of the time. Figure 3 shows that the 91 sites which met this criterion, are evenly distributed across the UK, with a mixture of coastal and inland locations.

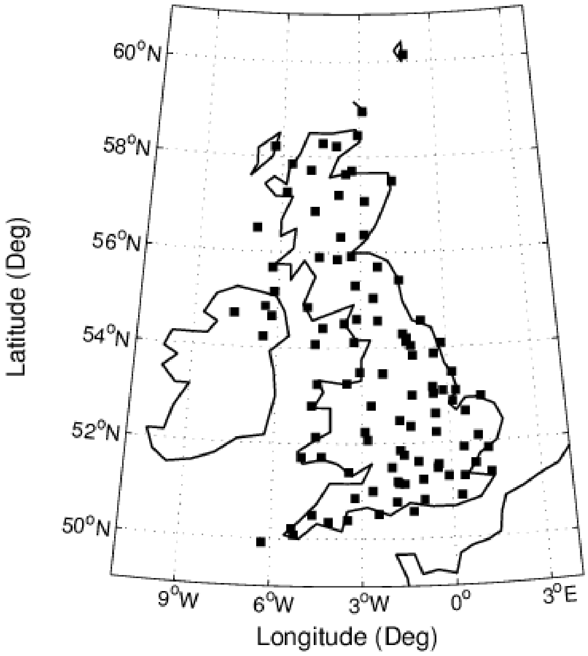

Figure 3 The location of the 91 Met Office weather stations from which hourly wind speed data has been obtained

At each of the 91 sites, the annual energy production of the 33 turbines (introduced in section 2) has been estimated using the measured wind speed data in conjunction with the manufacturer's power curve. The turbines have been selected to represent the full range of systems currently available, both in terms of the size and the design. Figure 4 shows that 24 horizontal axis wind turbines (HAWTs) and 9 vertical axis wind turbines (VAWTs), with a rated power ranging from 0.056 to 30 kW have been considered.

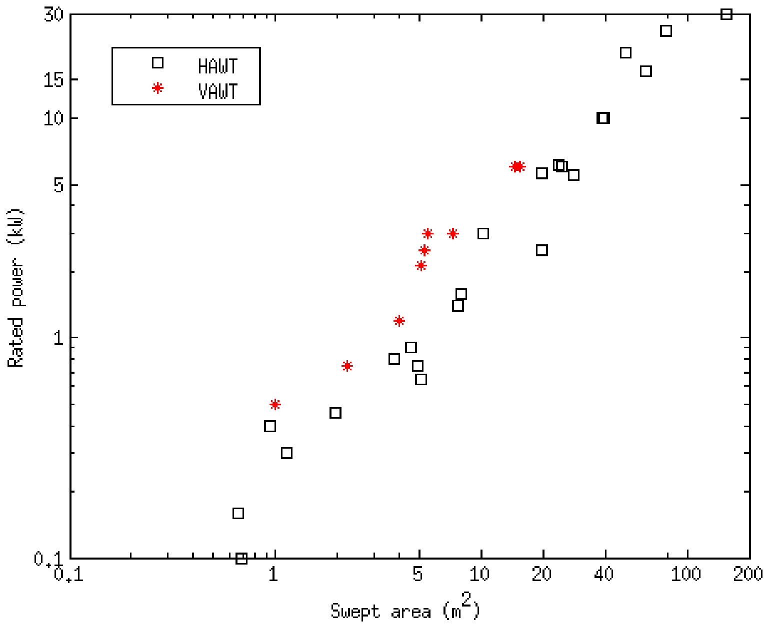

Figure 4 Details of the swept area, rated power and design of the 33 turbines considered in this study.

The economic viability of each turbine/site combination has then been calculated, following the method outlined in section 2. The analysis has then been repeated using the modelled wind data to investigate whether the same economic viability is predicted. Due to the current variability and future uncertainty in the specific investment cost of a small wind turbine and the sale price of the generated electricity, this study considers the techno-economic performance of the 33 small wind turbines at each site for a range of economic scenarios, detailed in Table 1.

Table 1 Details of the 12 economic scenarios considered

Scenario	Specific investment cost of the turbine (£ per kW)	Sale price of generated electricity (£ per kWh)	Minimum load factor (%)
1 a	1,000	0.1	22
1 b	1,000	0.2	12
1 c	1,000	0.3	9
1 d	1,000	0.4	6
2 a	2,500	0.1	41
2 b	2,500	0.2	22
2 c	2,500	0.3	16
2 d	2,500	0.4	9
3 a	5,000	0.1	72
3 b	5,000	0.2	39
3 c	5,000	0.3	27
3 d	5,000	0.4	15

4. Results

For the 12 economic scenarios, the minimum load factor required for a turbine to be economically viable has been estimated (shown in table 1). This has been calculated by finding the magnitude of the annual energy production (in equation 1) required to fulfil the criteria given in equation 4. The annual mean wind speed, U_{min}, required for each turbine to achieve this value has then been determined by assuming a Rayleigh distribution (equations 5 and 6). Figure 5 shows that for each scenario there is a wide range in U_{min} across the different turbine designs. For example, for scenario 1a, one turbine can achieve the required load factor of 22% at a site with a mean wind speed of only 4.4 ms^{-1}, while another turbine requires a mean wind speed of 7.6 ms^{-1}. It is also interesting to note that some of the turbines can be economically viable at relatively low mean wind speed sites. For 4 of the scenarios, there is a median value of U_{min} of below 5 ms^{-1}, and at least one turbine viable at sites with a mean wind speed below 4 ms^{-1}. In contrast, for scenarios 2a and 3b, a mean wind speed in excess of 8.0 ms^{-1} is generally required. For scenario 3a only 12 of the turbines are able to achieve the required load factor, all of which need a site to have a mean wind speed in excess of 11 ms^{-1}.

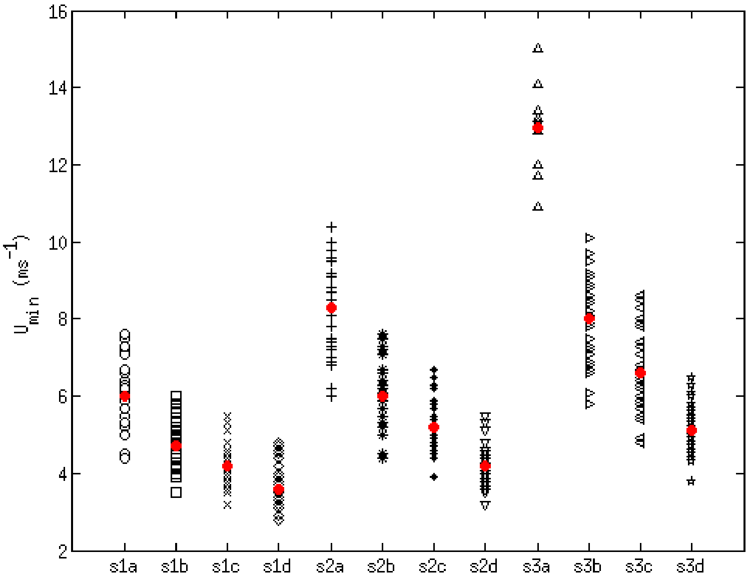

Figure 5 The minimum annual mean wind speed, U_{min}, required for each of the 33 turbines to be economically viable for each of the 12 economic scenarios, as given in Table 1. The red point indicates the median value across all turbine designs.

4.1 Performance of small wind turbines at 91 sites

At the 91 sites the load factor of each turbine has been calculated by combining its power curve with each of the measured hourly mean wind speeds. Figure 6 shows the median load factor across all of the turbines at each site. As expected, the load factor generally increases with the mean wind speed. However, for two sites with a similar value of U, there can be large variation in the derived load factor of a turbine. This occurs as a result of differences in the wind speed distribution and is particularly evident at a number of relatively low wind speed sites (U<4 ms^{-1}), where a small change in the wind speed distribution can lead to many more hours where the wind speed exceeds the turbine cut-in speed.

Figure 6 also shows that at a given site there is a large range in the load factor across the different turbine designs. The magnitude of this variation is such that at a given site some turbine designs are economically viable, while others are not. For example, for 7 of the economic scenarios considered, a load factor of 16% or more is required for a turbine to be economically viable (as stated in table 1). Figure 6 shows that averaged across all turbines a mean wind speed in excess of 5.3 ms^{-1} is required to achieve this threshold. However, with careful turbine selection, the required load factor can also be achieved at sites with a mean wind speed as low as 3.8 ms^{-1}.

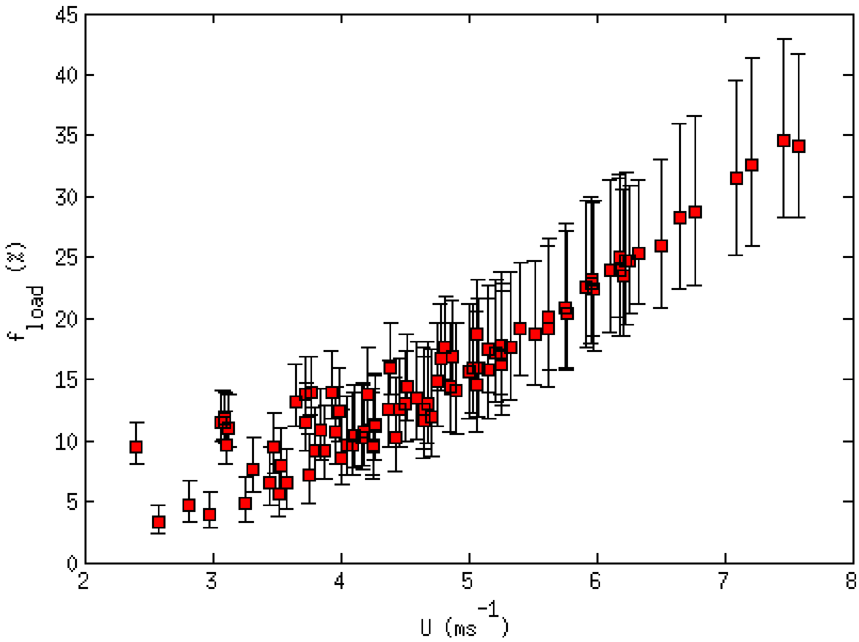

Figure 6 The median load factor across the 33 turbines at each of the 91 sites. The errorbars indicate the minimum and maximum values.

The number of turbine/site combinations which are economically vaible for each scenario, based on the measured wind data is shown in figure 7. For 7 of the scenarios, less than 50% of the turbine/site combinations are economically viable, which includes all 4 of the scenarios when the capital cost of the turbine is high, (I=£5,000 per kW). As expected, as the capital cost decreases or the sale price of electricity increases, more projects become viable. However, for all capital costs, when e=£0.1 per kWh (secnarios 1a, 2a and 3a), very few economically viable turbine/site combinations are shown; 25% when I=£1,000 per kW (scenario 1a), 4% when I=£2,500 per kW (scenario 2a) and 0% when I=£5,000 per kW (scenario 3a).

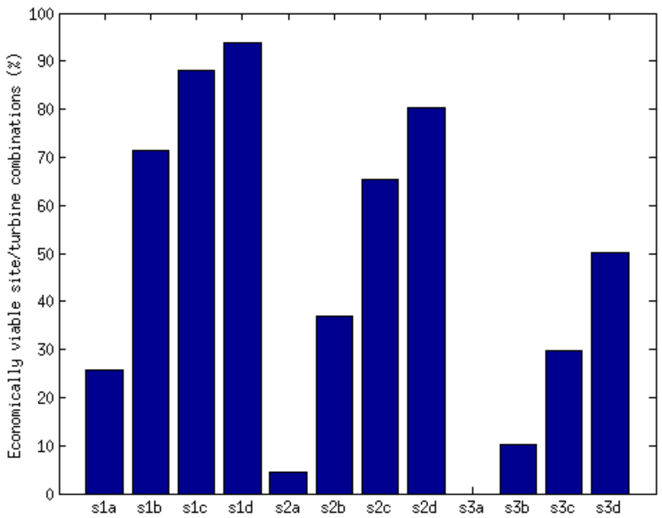

Figure 7 The percentage of turbine/site combinations which are economically viable for each of the economic scenarios listed in table 1.

4.2 Accuracy of Site Assessment Tools

Figure 8 shows that the NOABL database tends to overestimate the wind speed (73 out of the 91 sites). The magnitude of the underestimate can be quite large; the mean error is 23% and it is in excess of 20% of the measured mean wind speed at 35 sites. In comparison, for the 18 sites at which the resource is underestimated there is a mean error of 10%. The majority of the underestimates tend to occur at higher wind speed sites (15 occur at sites with a mean wind speed in excess of 5 ms^{-1}). The results shown here confirm the findings of the Energy Saving Trust (2009) and Encraft (2008), which performed a similar analysis but for a smaller sample of sites and a shorter period of time.

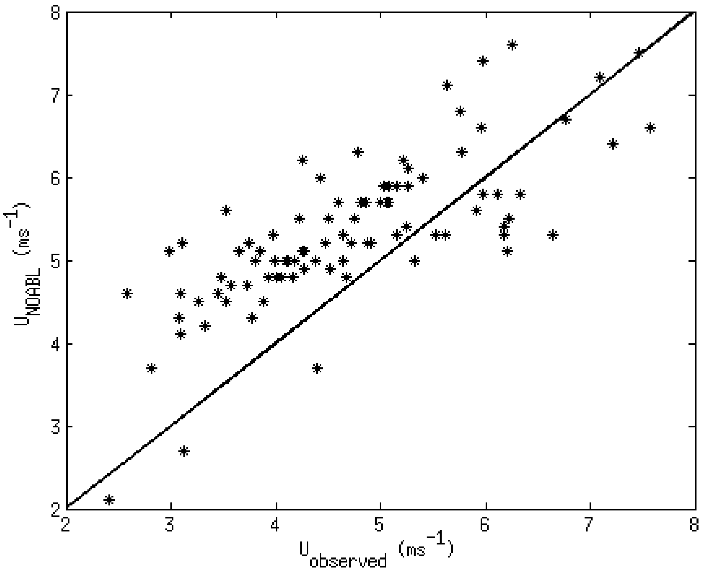

Figure 8 Comparison of the NOABL wind speed prediction and the measured annual mean wind speed at each of the 91 sites.

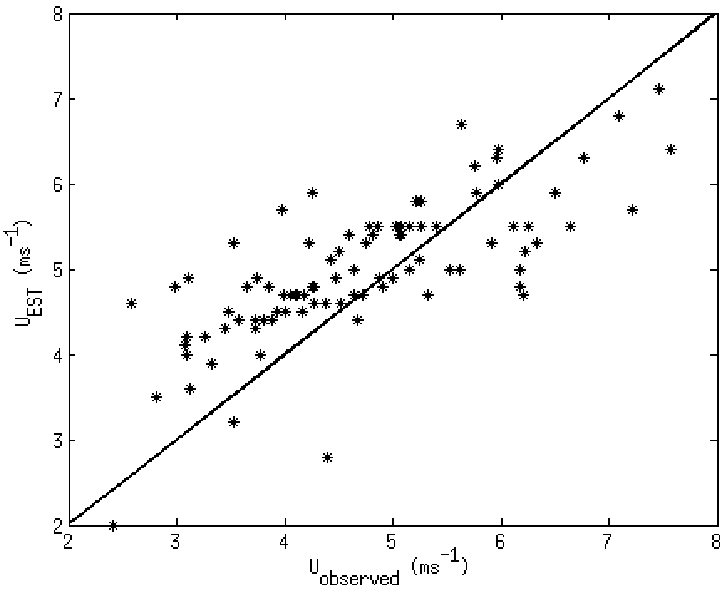

Figure 9 Comparison of the Energy Saving Trust tool wind speed prediction and the measured annual mean wind speed at each of the 91 sites.

Figure 9 shows a very similar relationship for the predictions of the Energy Saving Trust tool. However, the EST tool estimates lower wind speeds than the NOABL at 85 sites and therefore there is a reduction in the number of overestimates. The Energy Saving Trust tool overestimates the wind speed at 64 sites with an error in excess of 20% at 18 sites and a mean value of 18%. For the 27 sites at which the wind resource is underestimated, there is a mean error of 12%.

4.3 Implications of errors in the estimated wind resource on the economic viability of small wind turbines

The percentage of turbine/site combinations for which assessing the wind resource using the NOABL database yields the correct economic viability for each scenario is shown in figure 10. For 11 of the 12 economic scenarios, errors in the wind speed estimation tool can lead to the incorrect evaluation of the economic viability of turbine/site combinations. For the other scenario (3a), all turbine/site combinations were correctly shown to be not economically viable. The majority of the incorrect assessments occur due to an overestimate of a site's wind speed. This results in turbines which are not economically viable being predicted to be viable (grey bars). This occurs at up to 41% of turbine/site combinations depending on the economic scenario. However, there is also a number of economically viable projects being assessed as not viable (i.e. missed opportunities) as a result of an underestimate of the wind resource at relatively high wind speed sites (white bars). This occurs at up to 4% of turbine/site combinations for 8 of the economic scenarios.

Figure 11 shows similar results for the Energy Saving Trust tool. However, for all scenarios the Energy Saving Trust tool provides an accurate assessment for a greater proportion of turbine/site combinations than the NOABL database. A correct assessment was provided by the Energy Saving Trust tool for between 69-97% of turbine/site combinations across the scenarios (excluding 3a), in comparison to 58-94% for NOABL.

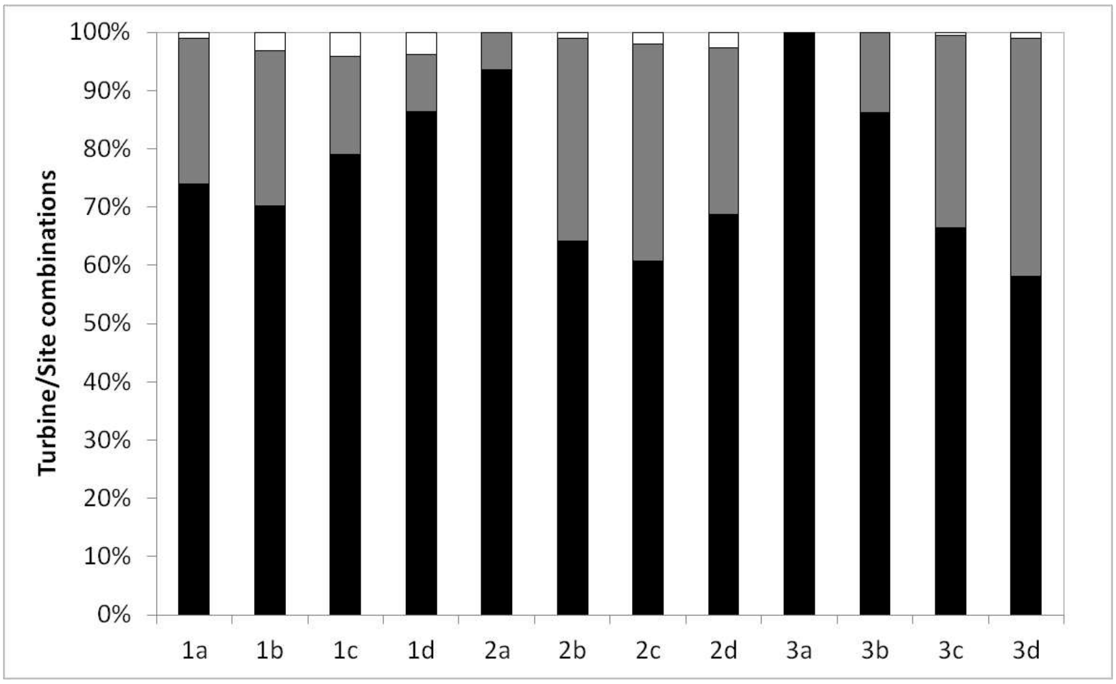

Figure 10 A breakdown of the economic assessment of the various turbine/site combinations made using the NOABL database for each scenario, listed in Table 1. Black indicates a correct assessment of a turbine/site combination. Grey denotes turbine/site combinations which the model incorrectly predicts to be economically viable. White shows the economically viable turbine/site combinations which are incorrectly shown to be not viable.

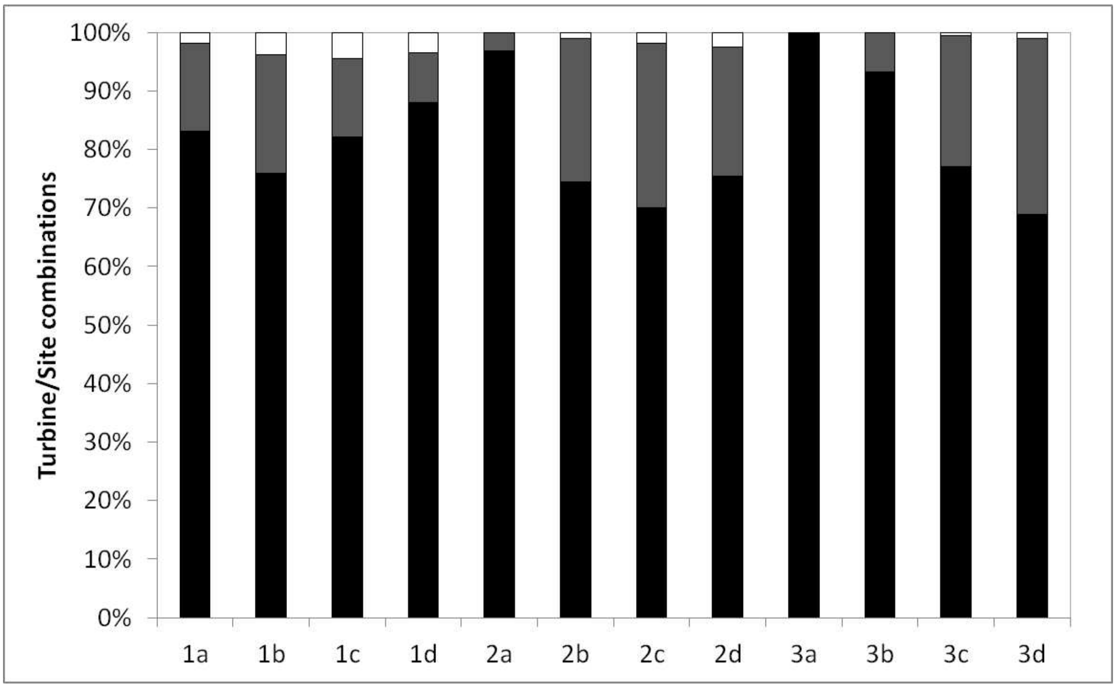

Figure 11 A breakdown of the economic assessment of the various turbine/site combinations made using the Energy Saving Trust tool for each scenario, listed in Table 1. Black indicates a correct assessment of a turbine/site combination. Grey denotes turbine/site combinations which the model incorrectly predicts to be economically viable. White shows the economically viable turbine/site combinations which are incorrectly shown to be not viable.

To investigate these results further the number of turbines for which the models incorrectly assess the economic viability at each of the 91 sites has been determined. Figure 12 shows the difference between the number of turbines estimated to be economically viable based on the model wind resource from corresponding value derived using the measured wind data. A positive number therefore indicates turbines which are not economically viable being shown to be economically viable by the models. In contrast, a negative number indicates economically viable turbines which have been calculated to be not viable (i.e. missed opportunities).

The analysis has been completed for each site and each scenario. When I=£1,000 per kW (scenarios 1a-1d), the overestimate of the wind resource by the models at the lower wind speed sites results in a number of turbines, which are not economically viable (according to the measured wind data), being shown to be viable. This problem occurs for all values of e, but occurs less frequently at higher values of e (scenarios 1c and 1d), as at these values the vast majority of turbines are economically viable, therefore the overestimate does not have an impact. For scenarios 1a-1d, the figures also show a number of sites at which the measured wind data suggests that a turbine would be economically viable but the tools underestimate the wind resource and consequently predicts that the turbine is not economically viable (i.e. missed opportunities). This occurs in two types of cases: (1) at relatively low wind speed sites, where a small underestimate in the wind speed can have a large impact, as it increases the frequency of time at which the turbine is not operating (the wind speed is below the turbine's cut-in speed). (2) At sites with a moderate mean wind speed ($5.5 < U < 6.5$ ms^{-1}), where a large underestimate in wind speed reduces the predicted energy production of the poorer performing turbines by a significant proportion. This second case only occurs at the lower values of e (scenarios 1a and 1b), at larger values (scenarios 1c and 1d) the magnitude of the underestimate is not sufficient to alter to the calculated economic viability. A similar relationship is shown as the capital cost increases (I=£2,500 (scenarios 2a to 2d) and £5,000 per kW (scenarios 3a to 3d)). However, due to the additional cost, the turbines are less likely to be viable at the lower wind speed sites and therefore an underestimate of the wind resource does not alter the economic viability. This is particularly evident at low values of e.

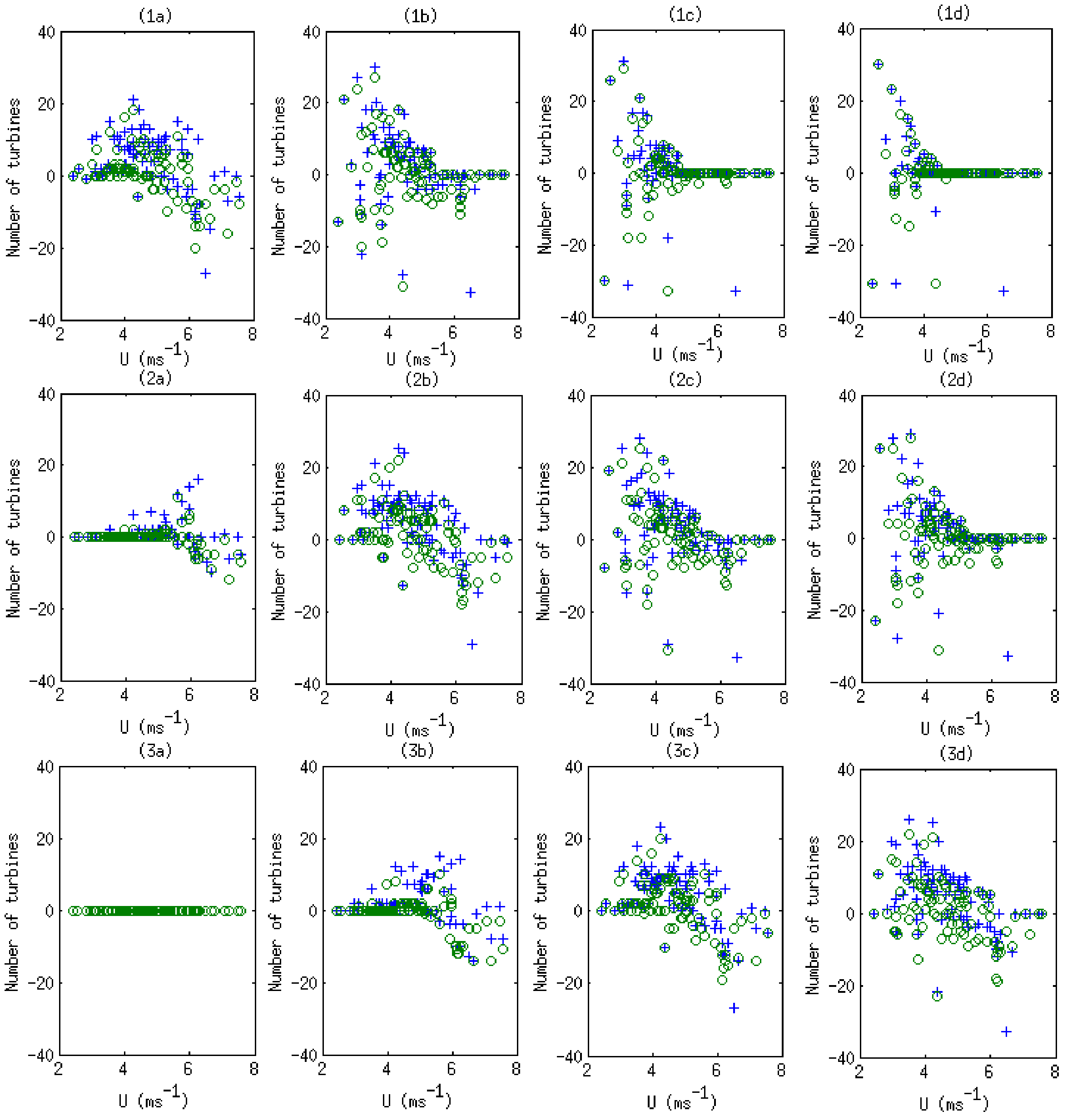

Figure 12 The difference between the number of turbines shown to be economically viable using the modelled wind data (NOABL (blue) and Energy Saving Trust tool (green)) from the number derived from the observed wind, at each of the 91 sites. Results are shown for each of the 12 economic scenarios given in Table 1.

5. Conclusions

The techno-economic performance of a small wind turbine is very sensitive to the site's wind resource. However, unlike large scale wind energy projects, due to financial and practical constraints it is not feasible to fit wind monitoring equipment at each potential installation site and therefore local authorities rely on low resolution wind speed databases to identify the best sites. In the UK, this is frequently either the DECC wind speed database (NOABL) or the Energy Saving Trust wind speed estimator.

The wind speed predictions of the two tools have been compared with data measured at 91 weather stations across the UK. In general, NOABL tends to overestimate the wind resource (73 out 91 sites). The magnitude of the overestimate can be quite large; there is a mean error of 23% over the 73 sites and it is in excess of 20% at 35 sites. In comparison, for the 18 sites at which the resource is underestimated there is a mean error of 10%. The majority of the underestimates tend to occur at higher wind speed sites (15 occur at sites with a mean wind speed in excess of 5 ms^{-1}). These results are in agreement with the findings of previous research. The predictions of the Energy Saving Trust tool showed similar results however the magnitude of the error was generally lower. The model underestimates the wind speed at 64 sites, with a mean error of 18%.

A discounted cash flow analysis of a range of turbine designs at each site has shown that the errors in the wind speed predictions using either the NOABL or EST tool can lead to the incorrect assessment of a turbine's economic viability. The majority of the incorrect assessments occur due to overestimates by the tools. This results in turbines being predicted to be economically viable when they are not. This occurs for up to 41% of turbine/site combinations (depending on the economic scenario) for NOABL and 30% for the Energy Saving Trust tool. This goes some way to explaining the poor performance of small wind turbines to date. A new insight from this work is that there are a number of missed opportunities. Whereby, due to an underestimate of the wind speed by the tools at relatively high wind speed sites, a financially beneficial turbine is shown to be not economically viable. However this only occurs for up to 4% of turbine/site combinations over all of the economic scenarios for both tools.

These results illustrate one of the big difficulties in the roll out of small-scale wind, specifically that the resource is highly localised and local authorities are making decisions using tools with an insufficient level of complexity and resolution. Consequently, there is a danger of supporting the installation of turbines at sites at which they are not economically viable. As it is not viable to collect very comprehensive local measurements, there is a need to develop a more accurate site assessment tool which can be used by both local planners and potential consumers.

Furthermore, planners and local policy makers should be aware of the high spatial variability of the production potential of small wind turbines, and should avoid blanket support or regulations that could result in turbines being installed in locations with a poor wind resource. In this respect, revenue based mechanisms, like the feed-in tariff, are preferable to capital grant schemes as they ensure the funding available is directed to the better performing turbines.

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