Small-scale wind energy

Policy insights and practical guidance

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Front cover photography courtesy of Andy Tanner, Plug into the Sun

Preface

Small-scale wind energy covers small wind turbines rated less than 50 kW, generally intended to supply electricity to buildings. Such systems are receiving increasing interest in the UK as one of a number of microgeneration technologies with potential to reduce carbon emissions. Recent years have seen new turbine products being brought forward and made available on the market, supported by grant schemes such as the BERR[1] Low Carbon Buildings Programme[2].

However, the overall potential of small-scale wind energy to reduce carbon emissions, and the conditions under which maximum carbon reductions can be made, have not been entirely clear. Recognising this, the Carbon Trust commissioned research from the Met Office and Entec to determine:

- The overall UK carbon prize associated with small-scale wind energy; and
- How small wind turbines[3] can best be sited to save most carbon.

This report, prepared with the assistance of Arup, draws conclusions from this study. It is primarily intended for government policy makers and organisations considering installing small wind turbines at their sites, but will also interest other readers.

In addition, the Carbon Trust and Met Office are jointly publishing a companion Technical Report, which provides a review of existing scientific literature and engineering methods for calculating energy yields. This is for engineers and scientists working in the field. Furthermore, as a follow-on piece of work, the Carbon Trust has commissioned a new yield estimation tool, which is based on the Met Office NCIC[4] dataset. This will be available on the Carbon Trust website later in 2008.

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[1] Department for Business, Enterprise and Regulatory Reform.

[2] For details, see www.lowcarbonbuildings.org.uk

[3] This report uses the term 'small' to mean all sizes between 500 W and 50 kW installed capacity. This is for brevity since the report does not distinguish between turbines within this size bracket. However, where distinctions are necessary, definitions preferred by the BWEA are as follows: 'Micro' wind turbines: swept area less than 3.81m^2 and/or power rating less than 1.5 kW; 'Small' wind turbines: swept area and/or power rating above these thresholds. This report does not cover architecturally integrated turbines; that is, turbines incorporated within the structures of buildings.

[4] National Climate Information Centre.

Executive summary

The potential UK carbon savings from small-scale wind energy

In theory, small-scale wind energy has the potential to generate 41.3 TWh of electricity and save 17.8 $MtCO_2$ in the UK annually. However, given current costs of small wind turbines and electricity prices, it is economic to achieve only small proportions of these figures. If 10% of households[5] installed turbines at costs of energy below 12p/kWh (indicative of the current retail electricity price), up to 1.5 TWh could be generated and 0.6 $MtCO_2$ saved. Relative to total UK electricity consumption and emissions from power generation, these figures are fairly low.

The majority of electricity and carbon savings are available from small wind turbines in rural areas – four times as much as urban areas irrespective of costs, and considerably more given economic drivers. This is mainly due to wind speeds generally being higher in rural areas. Some rural installations could have costs of energy competitive with grid electricity. But it appears that in many urban situations, roof-mounted turbines may not pay back the carbon emitted during their production, installation and operation.

A range of policies is encouraging the development of small-scale wind energy, including the Low Carbon Buildings Programme (LCBP), Permitted Development Rights (PDRs) for domestic microgeneration and the Code for Sustainable Homes. Based on this study, it is recommended that:

- In any future grant schemes, a criterion is used to measure the likely carbon savings of small wind turbines. This is to help ensure grants are awarded to installations which save reasonable amounts of carbon;
- Wind turbine manufacturers develop and adopt a carbon labelling system for their products, to enable consumers to estimate the lifecycle emissions of their installations;
- Should PDRs be reviewed in future, the Department for Communities and Local Government (CLG) gives serious consideration to setting a height limit for stand-alone turbines of more than 11m to the blade tip for open, exposed sites of a rural character; and if similar rights are later introduced for non-domestic buildings, sets a height limit of more than 11m for stand-alone turbines generally. This is to maximise the carbon savings of small-scale wind energy, given the sensitivity of generation to height; and
- An improved carbon saving estimation methodology is adopted for building regulations to give more accurate results than the current SAP and SBEM approaches[6]. This could be based on the new Carbon Trust yield estimation tool (see below).

Evaluating the potential of small wind turbines at specific sites

Due to the variability of winds across the UK, plus local effects such as sheltering and turbulence, only certain sites are suitable for small wind turbines. An initial evaluation of a site's suitability – sufficient for a 'move forward/no go' decision – can be made following simple rules of thumb.

The principal factor affecting the amounts of electricity generated and carbon saved by a small wind turbine is wind speed. This can be assessed in several ways, including by reference to the NOABL database[7] and applying a methodology developed for the Microgeneration Certification Scheme (MCS). The Carbon Trust is developing a new yield estimation tool which is based on a wind speed dataset preferable to NOABL. The tool also improves on the MCS methodology.

Organisations considering installing small wind turbines are recommended to:

- Use the Carbon Trust yield estimation tool to obtain initial quantitative estimates of a site's potential; and if the site appears attractive,
- Install anemometry equipment and take measurements to give the greatest degree of certainty about potential energy yields and carbon savings.

The yield and carbon savings of a turbine can be estimated using a measured or assumed wind speed distribution and the turbine power curve, obtained from the turbine manufacturer or installer.

Combining a yield estimate with cost data, it is possible to make an economic assessment. In doing so, it is important to take account of the amount of electricity likely to be exported (potentially 50%), since otherwise, the value of the yield must be reduced by the exported amount.

Other considerations include planning, the structural integrity of the supporting building if the turbine is to be roof-mounted, and grid connection.

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[5] Or an equivalent number of turbines supplied houses and commercial buildings.

[6] SAP is the Standard Assessment Procedure for energy ratings of dwellings and SBEM is the Simplified Building Energy Model for non-domestic buildings.

[7] See box on page 12.

1. Introduction

This section gives an introduction to small-scale wind energy and the Carbon Trust's work in this area.

1.1 Background

Small wind turbines have been available for several decades and are in widespread use today, with reportedly over 150,000 machines installed and operating worldwide[8]. Historically, fewer turbines have been sold in the UK than other countries (e.g. the USA), but a recent market survey suggests the UK market is growing[9]. This is likely to be due in part to increasing awareness of climate change and the potential of wind turbines to decrease the carbon emissions associated with electricity generation. Many individuals and organisations are now considering installing small turbines to supply electricity to their houses and commercial buildings[10].

In UK government policy, small-scale wind energy is often considered as one of a number of microgeneration technologies. In its 2005 Microgeneration Strategy, the Department of Trade and Industry (DTI, now the Department for Business Enterprise and Regulatory Reform, BERR) referred to an Energy Saving Trust (EST) study which suggested that by 2050, 'widespread installation of microgeneration could be reducing household carbon emissions by approximately 15%'[11]. Various estimates have been made of the carbon saving potential of small-scale wind energy specifically, including one by the British Wind Energy Association (BWEA) which indicated that 2.8 $MtCO_2$/year is possible. Other sources[12] have suggested figures between 0.7 $MtCO_2$/year and 9.9 $MtCO_2$/year, based on different assumptions.

Viewing small-scale wind energy as a microgeneration technology implies that its main use is to directly supply buildings, and following this is the important consideration of where the buildings are located.

While in general, the suitability of microgeneration technologies depends on building type and energy demand profile[13], few types of microgeneration are affected significantly by the built environment in which they are installed. Small wind turbines, by virtue of needing to be exposed to high wind speeds, are affected in this way. While there is considerable experience of successfully installing turbines in open, exposed rural areas, understanding how they will perform in urban locations is technically challenging.

This was a key conclusion of an internal scoping study carried out for the Carbon Trust in 2006 by Entec and Paul Arwas Associates. The study also found that, overall:

- There has been limited research into urban small-scale wind energy, and both theoretical and empirical evidence of performance is limited; and
- While much can be drawn from existing theory, the best methods for assessing the performance of small turbines in urban areas are unclear.

1.2 Scope and approach

To address these points, the Carbon Trust tendered for a research project and appointed the Met Office to conduct this during 2007. Objectives of the project were to:

- Establish the extent of current knowledge about small-scale wind energy in urban locations;
- From first principles and using appropriate meteorological data, develop a detailed estimate of the UK carbon savings achievable by small-scale wind energy, for the benefit of policy makers[14]; and

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[8] Source: American Wind Energy Association.

[9] Source: BWEA.

[10] And to meet other needs – e.g. powering remote telecommunications facilities. For case studies of potential uses, see the BWEA and American Wind Energy Association websites.

[11] Recently, in a project funded by BERR and various other organisations, Element Energy has estimated that microgeneration technologies could save up to 30 $MtCO_2$ by 2030, equivalent to a 5% cut in total 2006 UK emissions. See "The Growth Potential for Microgeneration in England, Wales and Scotland", Element Energy, June 2008.

[12] Including the Energy Saving Trust and Council for the Central Laboratory of the Research Councils (CCLRC) Energy Research Unit. See "The Feasibility of Building Mounted/Integrated Wind Turbines (BUWTs): Achieving their potential for carbon emissions reductions", CCLRC (part funded by the Carbon Trust), 2005.

[13] For example, the Carbon Trust recently made findings about the suitability of Micro Combined Heat and Power (CHP) systems. For details, see the Micro-CHP Accelerator Interim Report.

[14] This work was supported by Entec.

- Translate relevant parts of the scientific theory of wind energy into practical guidance for consumers considering installing small turbines to supply their premises.

The scope also included a review of existing scientific literature and engineering methods for calculating energy yields.

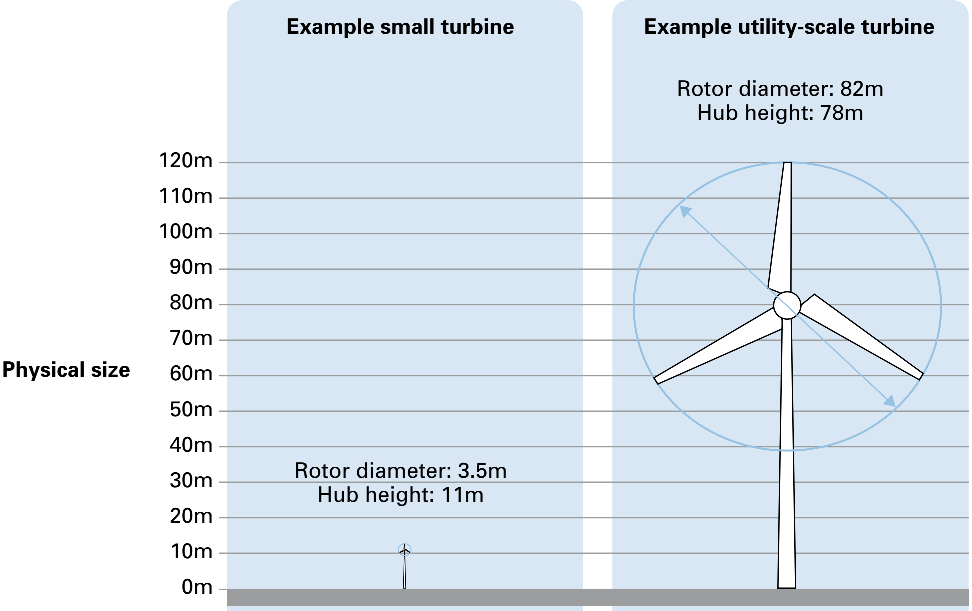
Small-scale and utility-scale wind energy

Small-scale wind energy refers to wind turbines rated less than 50 kW which are generally intended to supply electricity to buildings, and which may or may not be connected to the grid. This is distinct to 'utility-scale' wind turbines, generally rated between several hundred kilowatts and a few megawatts each, which form wind farms onshore (predominantly in rural areas) and offshore, and are almost always grid-connected.

Practically speaking, small wind turbines require many of the same conditions that utility-scale turbines do. Notably, they ideally need locations which are open, exposed and experience high wind speeds, which generally tend to be found in rural areas. However, an interesting alternative application for small wind turbines is urban locations. While these tend to have less ideal conditions, they are by definition where most candidate buildings for microgeneration lie.

The physical size, electricity generation potential and carbon savings of small and utility-scale turbines differ greatly. To illustrate this, an example of each type is shown in *Figure 1*. The differences between the yields and carbon savings are largely due to scientific relationships between a) wind power and rotor size and b) wind speed and height. These are explained in Section 2.

Figure 1: *Generation and carbon savings of a small turbine and a utility-scale turbine*



	Example small turbine	Example utility-scale turbine
Rated capacity	2.5 kW	1.650 kW
Energy yield	3.3 MWh/year Equivalent to 0.7 household	4,300 MWh/year Equivalent to 970 households
Carbon savings	1.4 tCO_2/year	1,900 tCO_2/year

Diagram approximately to scale. The figures are indicative only of order of magnitude, and are intended to enable general comparisons between the two example turbines. They should not be taken to imply how much power either turbine would produce, and therefore how much carbon would be saved, at any particular site. This is strongly site-dependent, as Section 2 discusses.

Assumptions: Capacity factors: Small turbine: 15%, Utility-scale turbine: 30%; Average annual household electricity consumption: 4,457 kWh/year (Source: BERR Energy Trends, December 2007); Carbon factor: 430 gCO_2/kWh.

Rural and urban sites for small turbines

This report makes frequent reference to rural and urban wind energy sites. In reality, since wind conditions vary considerably according to local conditions, there is no such thing as a typical site in either case. Nevertheless, it is useful to identify general characteristics of the two types, as illustrated by the photos in *Figure 2*.

- Rural sites are open and exposed, largely free of obstacles in all directions. Good sites tend to be found in areas of high ground (such as the tops of hills) and around the coasts. Due to the lack of existing structures, turbines will be mounted from the ground on dedicated poles.
- Urban sites are within built-up areas. They are likely to be quite close to buildings and other ground features, perhaps in many sectors of the compass. Turbines may be mounted on dedicated poles from the ground or relatively short masts on the roofs of buildings.

***Figure 2:** Photos of example rural and urban sites*

a) Example rural site b) Example urban site

Photos courtesy of Entec and Arup

Theoretical and experimental investigations

A feature of the research on which this report is based is its theoretical nature. The intention was to:

- Understand small-scale wind energy from a scientific perspective, and
- Assess the technology's potential by modelling a large number of turbine installations across the UK, rather than gather empirical evidence about a set of turbines installed at specific sites.

This is reflected in the report's coverage.

Empirical evidence is vitally important, however, both to verify the theory and take account of practical considerations which theoretical concepts cannot. Several field trials are currently underway to demonstrate how well small wind turbines perform in practice. The largest, which will involve up to 100 installation sites, is being run by the EST[15] with funding from various private sector partners. Other testing and monitoring activities include the Warwick Wind Trials[16], led by Encraft, and BEAMA's work to meter and monitor small wind turbines[17] in a study part-funded by the Technology Strategy Board[18].

A fuller picture of the performance of small-scale wind energy systems, incorporating both theoretical concepts and experimental results, is likely to emerge later in 2008 and during 2009. In the meantime, it is hoped that the theoretical results in this report will usefully inform ongoing experimental investigations, for example by indicating where it is best to situate field trial installations.

[15] See www.energysavingtrust.org.uk/aboutest/news/pressreleasesarchive/index.cfm?mode=view&press_id=552

[16] See www.warwickwindtrials.org.uk/

[17] Amongst other microgeneration technologies.

[18] Project K/EL/00312/00/00, Metering and Monitoring of Domestic Embedded Generation.

2. The wind resource and power generation with small wind turbines

This section gives background information on wind conditions and the power generation of wind turbines. It is not comprehensive but serves as an introduction for general readers[19] and as the basis for technical discussions later in the report.

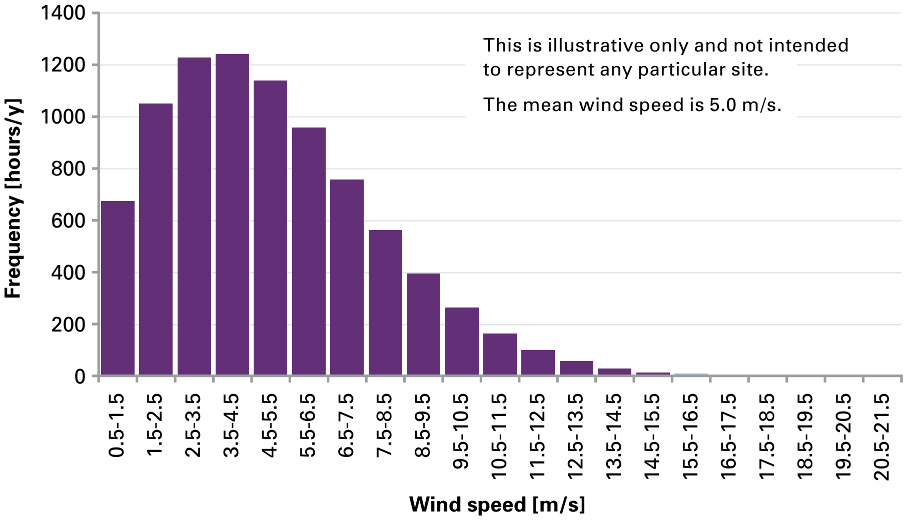
2.1 Describing the wind resource

Winds vary considerably around the world and across individual countries such as the UK. From a UK perspective, experience tells us it is generally windier in Scotland than parts of England, and wind speeds around the coasts are typically higher than inland[20]. Since wind speed is the key determinant of power, the performance of wind turbines is very sensitive to their location.

Wind speed also varies continuously over time at any point in space. Since for wind energy generation we are less interested in instantaneous wind speeds than average conditions, it is typical to take a statistical approach, for example by counting the numbers of hours during which ranges of wind speed (wind speed 'bins') occur. This is illustrated in *Figure 3*, which is an example UK wind speed distribution. Note that the bar chart is skewed to the left[21], indicating a tendency towards lower wind speeds. The mean wind speed for this distribution is 5.0 m/s, which is just to the right of the peak.

The number of hours represented in *Figure 3* amounts to one year, and to obtain a good view of average conditions, it is generally wise to measure wind speeds for at least this long. This is because as well as varying by the second, minute, hour and day, wind speeds vary over the seasons; for example, it is generally windier in winter than summer. However, wind speeds also vary from year to year, and the annual mean speed of one year may differ significantly to that of the next. The best single indicator of the windiness of a site is its long-term annual mean wind speed, averaged over several decades[22].

Figure 3: *Example wind speed distribution*

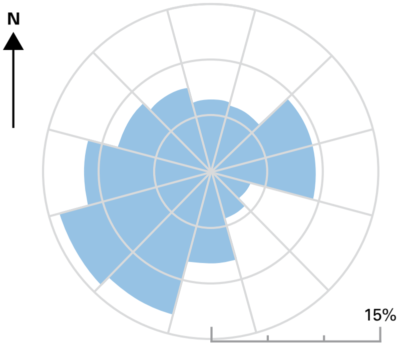


This is illustrative only and not intended to represent any particular site.

The mean wind speed is 5.0 m/s.

Source: Entec

Figure 4: *Example wind rose*



This is illustrative only and not intended to represent any particular site.

The predominant direction is southwest.

Source: Entec

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[19] For a more in-depth treatment, see the Technical Report or text books on wind energy, e.g. "Wind Energy Handbook" by Burton et al.

[20] For more about the diversity of wind conditions, including statistical characteristics, see "Wind Power and the UK Wind Resource", Graham Sinden, University of Oxford Environmental Change Institute, 2005.

[21] This form is often found to fit the Weibull continuous probability distribution, which is a function of two parameters, scale and shape.

[22] Note that the long-term historic annual mean wind speed is not necessarily representative of the long-term future wind speed. We usually want to know the latter but make do with the former.

As well as varying by speed, winds vary continuously by direction. Again, a statistical treatment is preferable, and for any point in space one can count the numbers of hours during which the wind blows from particular sectors of the compass. The result can be displayed as a wind rose, from which the predominant wind direction – typically southwest for UK locations – is easily discernable. *Figure 4* illustrates this, with the length scale representing the percentage of time over which measurements were taken.

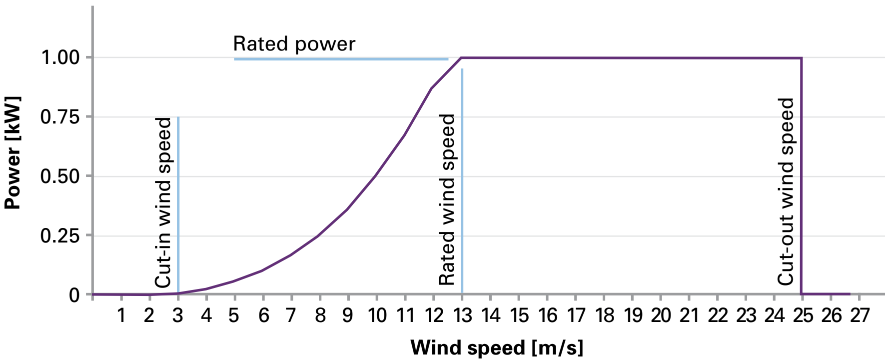
2.2 Describing wind power generation

In addition to the statistical characteristics of a site's wind conditions, one can consider the relationship between wind speed and power for a turbine. Most commonly, this is presented as a power curve, such as the example in *Figure 5*. This has three main parts, differentiated by their positions on the x-axis:

1. Speeds between nil and the cut-in wind speed – the lowest speed at which the turbine is able to generate any power. Most small turbines have a cut-in speed of around 3 or 4 m/s;
2. Speeds between the cut-in speed and the rated speed[23] – the speed at which the turbine produces its rated power, typically around 11-12 m/s. The relationship linking wind speed and power in this region is approximately cubic, as governed by the formula in the box overleaf;
3. Speeds between the rated speed and cut-out speed, beyond which the turbine is not able to generate – often about 25 m/s. Here, a constant[24] amount of power is produced despite the wind speed continuing to increase.

Generally, a site's wind characteristics and a turbine's power curve are used in combination to determine how much energy the turbine will generate at the site over a period of time. If the period is one year, the result is known as the annual yield. Section 4.3 explains how an annual yield estimate can be made. When considering how well a turbine performs at any particular site, or compared to other sites, a convenient term is the capacity factor. This is the ratio of the amount of electricity actually produced in a certain period to the amount of electricity that would have been produced over the same period had the turbine been generating continuously at its rated power. For UK utility-scale wind farms, capacity factors in the range 25-35% are common. Anecdotal evidence suggests that capacity factors for small wind turbines are generally lower, at around 15-20% or less[25].

Figure 5: *Wind turbine power curve*



This is only illustrative and does not represent a particular turbine make or model.

Source: Entec

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[23] The rated speed is the speed at which the turbine produces the rated power.

[24] In practice, this may be only roughly constant, vary or even reduce due to the way the turbine is designed and controlled.

[25] These figures are being investigated in the field trials mentioned in Section 1.

Power of the wind

In theory, the power P of the wind is governed by the relationship $P \propto v^3 A\rho$, where v is the wind speed, A is the swept area (πr^2 if the turbine is a horizontal axis machine, where r is the radius) and ρ is the density of air. This tells us that:

- If the swept area is doubled, so is the power. Looked at another way, doubling the rotor radius of a horizontal axis wind turbine increases the power by four times;
- If the speed is doubled, the power is increased eightfold. This demonstrates how sensitive power is to wind speed; high speed winds are very much more powerful than low ones.

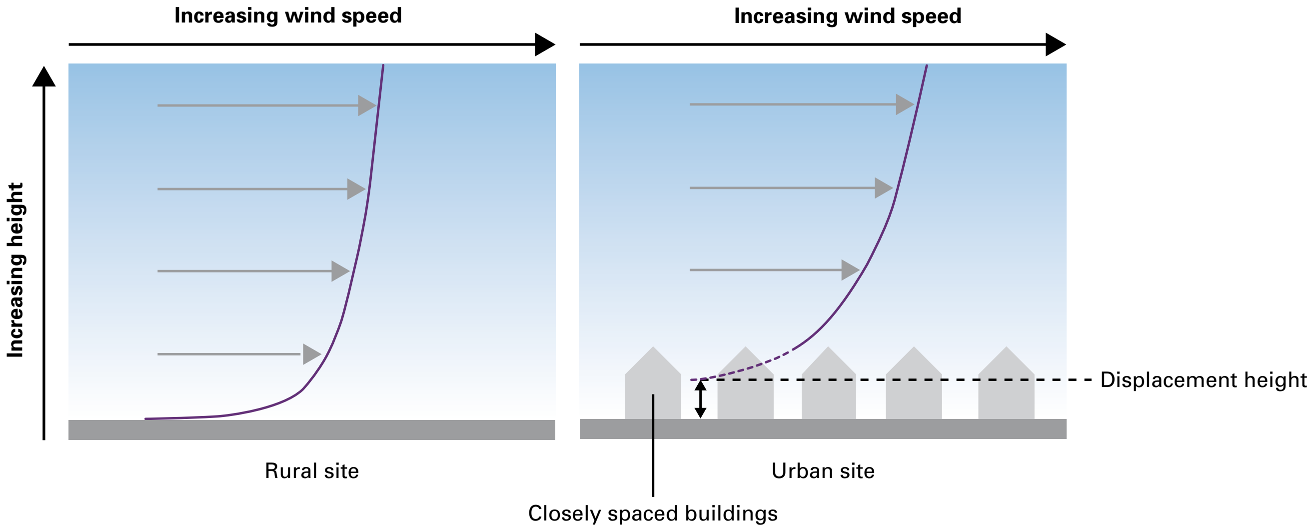
It can be shown that the maximum power it is possible to extract using a wind turbine situated in a free stream is $\frac{16}{27}\left(\frac{v^3 A\rho}{2}\right)$, where the constant 16/27 (0.593) is known as the Betz limit.

2.3 Significance of height and effects of orography

High up in the air, winds are generally at their fastest since there is nothing to slow the air down. But close to the ground, wind speeds are practically zero due to drag effects caused by the ground's 'roughness'. Generally, what happens in between is a logarithmic increase in wind speed with height; that is, a marked acceleration over a small distance above ground and a more gradual speed-up thereafter. This is known as the shear effect. The practical upshot is that generally, the higher a turbine is mounted, the greater the power that can be generated.

Figure 6 illustrates in simplified terms typical shear profiles for rural and urban sites. A key observation is that, compared to the rural profile, the urban profile is shifted upwards by a distance known as the displacement height. This is because from the wind's perspective, the closely spaced buildings represent a raised surface. This is sometimes termed the canopy, by analogy with large forests.

Figure 6: *Simplified shear profiles for rural and urban areas*



Source: Entec

As well as generally increasing with height over flat land, wind speed is affected by the shape of the land (orography). In particular, winds tend to speed up over hills, and it is therefore generally best to site wind turbines on or close to hill tops[26]. In addition, funnel effects can occur between adjacent hill peaks[27], accelerating the wind locally. These effects are sometimes important for utility-scale wind farms but are less relevant to small-scale wind energy due to the likely proximity of most small turbines to buildings on low-lying land.

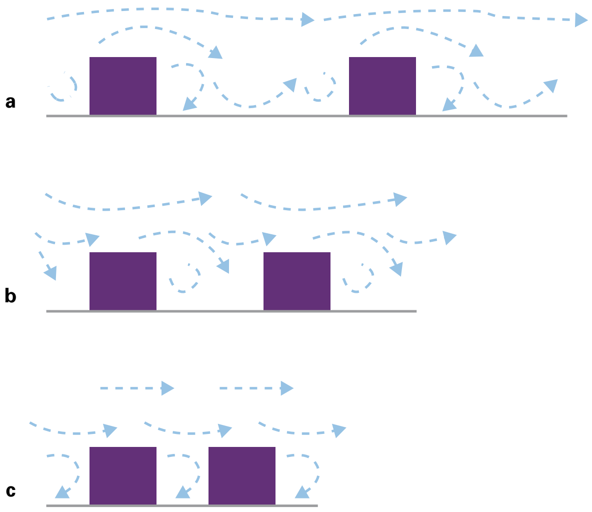
2.4 Effects of ground features

Obstacles such as buildings and trees in the path of the wind cause it to flow around or over the obstacles, often with turbulent (disturbed, relatively slow moving) air in its wake. After encountering isolated obstacles, the wind will quickly re-establish its speed and evenness of flow. But where obstacles are close together, the wind may not be able to recover in this way, and the flow behaviour can be very complex[28]. *Figure 7* illustrates three typical situations. A further case is where an obstacle is very close to a turbine, meaning there is practically no wind flow and the turbine is said to be sheltered. Generally, the effects of obstacles depend on their distances from the turbine and their heights relative to it.

Two special situations are:

- Where a very tall building is situated amongst shorter ones which are generally closely spaced. Here, the wind's behaviour may be similar to that when encountering an isolated obstacle in a rural environment.
- At the edge of a built-up area. Here there are transitional effects which impact the shear profile downstream; the profile is displaced upwards and changes shape. Such effects generally occur over quite short distances, as little as three streets. Wind speeds decrease further as one moves towards the centre of the built-up area.

Figure 7: *Wind flows around building obstacles*



a) Buildings act as isolated obstacles.

b) Flow around the downstream building is affected by the wake of the upstream building. This is known as wake interference.

c) Buildings are sufficiently close that the flow above rooftop level skims over the tops of the buildings; it appears that the ground level has been raised.

Source: Met Office (after Oke)[29]

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[26] The hill tops should ideally be smooth, since steep gradients and cliff edges cause turbulence.

[27] Funnel effects also occur between large buildings. For details, see the Technical Report.

[28] For a detailed discussion, see the Technical Report.

[29] See "Boundary Layer Climates", Timothy Oke, 1987.

2.5 Summary

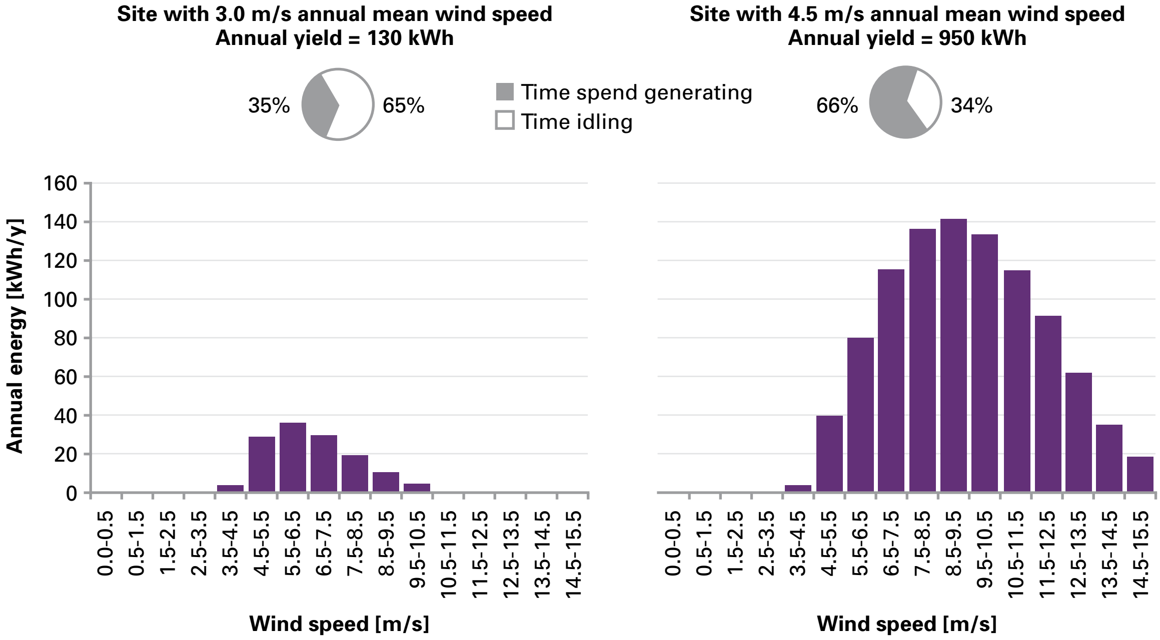
- Winds vary considerably across the UK. Since wind speed is the key determinant of power, the performance of wind turbines is very sensitive to their location. The best single indicator of the windiness of a site is its long-term annual mean wind speed.
- Wind speeds increase with height above ground, so the higher a turbine is mounted, the greater the power that can be generated. Obstacles such as buildings and trees can cause sheltering and turbulence, depending on their distances to the turbine and relative heights.

Sensitivity of small turbines to cut-in speed

At utility-scale wind farms, the annual mean wind speeds at the hub heights of turbines are usually somewhat higher than the turbines' cut-in speeds. But because small turbines are mounted at relatively low heights, their mean hub height[30] wind speeds may be close to their cut-in speeds. The implications are that, for long periods of time, a small turbine may not operate at all, or if it does operate (and visibly spin), it may not generate much electricity.

Figure 8 illustrates this sensitivity by showing the times spent generating and the annual yields of two identical small turbines installed at different sites. One site has an annual mean wind speed of 3 m/s while the other has a speed of 4.5 m/s. One can see that the turbine at the 4.5 m/s site generates more often than not and produces around seven times more energy than the 3 m/s site turbine.

***Figure 8:** Generation of small turbines at two sites with different mean wind speeds*



Site with 3.0 m/s annual mean wind speed
Annual yield = 130 kWh

Site with 4.5 m/s annual mean wind speed
Annual yield = 950 kWh

In each case, the total area of the bars represents the total electricity generated.
Seven times more energy is generated at the windier site.

Source: Entec

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[30] Most small turbines on the market are horizontal axis machines, for which 'hub height' means 'height of axis of rotation'. References to hub height in this report can also be read as 'rotor mid height' for vertical axis turbines.

3. The potential UK carbon savings from small-scale wind energy

This section outlines the methodology used to assess the amount of carbon which may be saved by small-scale wind energy and presents the results of applying this to the UK. It then outlines the UK government policy and regulatory landscape and considers implications of the results for policy measures such as grant support and planning.

3.1 Assessment methodology

Calculations of the potential carbon savings of low carbon electricity generation technologies are often based on the power that the technologies displace from large fossil fuel power stations; that is, abated carbon. This was the approach adopted in this research project for small-scale wind energy. However, the total carbon emitted and avoided over a turbine's lifetime (including manufacturing, installation and operation), known as the lifecycle carbon, is also important and discussed in the box on page 16.

Previous estimates of the UK carbon abatement potential of small-scale wind energy have been based on simple estimates about the annual yields of turbines, often involving assumptions about capacity factor. While reasonable to give a preliminary view, a problem with this approach is that one cannot generalise about capacity factors due to the variability of winds and local effects (see Section 2). It is therefore difficult to judge whether the assumed values are fair.

For the first time, this study has modelled the carbon abatement potential, or 'carbon prize', using a scientific approach which takes the variability and local effects into account. In outline, the methodology was as follows:

1. Identify and prepare an appropriate source of wind speed data at a very high height above ground;
2. Transform this in certain ways to estimate the wind speeds at the actual hub heights of turbines, effectively 'zooming in' through layers of the atmosphere;
3. Use the wind speed data and selected turbine power curves to estimate the annual yields of turbines, assuming they are widely deployed without any economic constraints; and
4. Apply economic constraints to give a realistic estimate of how much energy might actually be produced, then convert this into carbon savings.

The appendix expands this with a technical description of each step, referring to the box overleaf which describes two sets of reference wind speed data.

In following the methodology, several intermediate results were obtained which have important implications for the carbon prize. These include the following observations:

- Small turbines in rural locations may achieve capacity factors of around 15-20%, but urban turbines are likely to have significantly lower factors, with less than 10% being common.
- Generally, the choice of turbine type is much less important than the installation situation and mounting height. For roof-mounted turbines, height above roof level is critical; for example, increasing the hub height from around 2m to 9m above roof level can increase yields by a factor of three or more[31].

See the Technical Report for more details.

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[31] Source: Met Office.

NOABL and NCIC wind speed data

NOABL[32] is a public domain reference dataset used widely in the UK wind industry. Originally packaged as a simple PC programme, the data are now incorporated into a variety of computational tools, some for professional users and others for the general public[33]. The dataset comprises long-term annual mean wind speed estimates for each 1 km grid square of the UK[34], at three heights above ground level: 10m, 25m and 45m.

The Met Office National Climate Information Centre (NCIC) holds alternative wind speed data which are currently available under commercial licence. The Met Office is able to provide the data in several forms, including in sections split by geographic region and month. Like NOABL, the data consist of long-term annual mean wind speed estimates for kilometre grid squares across the country, which in original form are at 10m above ground level but can be scaled to other heights.

The NOABL and NCIC data have some features in common. One is that, while orography is taken into account, local variations in roughness and ground features are not. This means that both models give a very limited representation of local topography, and except for open, exposed rural sites surrounded by grassland, the data are unlikely to be representative. Various adjustments are needed, particularly for built-up urban areas.

However, a number of factors distinguish the NOABL and NCIC data. Some relate to how the data were formed and others concern how they compare in practice to real observations from meteorological stations.

- NOABL is based on observations for the 10 year period 1975-1984 for 56 stations, while NCIC takes into account 30 years of readings between 1971 and 2000 for approximately 220 sites. The longer time period implies that the NCIC data are more representative of long-term conditions, and the higher number of stations means the data are also less reliant on interpolation.
- Compared to actual measurements, both NOABL and NCIC provide fairly good estimates in general. However, analysis by the Met Office suggests that NOABL tends to underestimate slightly for higher wind speed sites and overestimate for lower ones, including sites found in urban areas. This means that it might tend to over-predict the amount of power it is possible to generate with small turbines in built-up areas.

In combination, these factors were considered sufficient to prefer the NCIC data as the basis for the carbon prize estimate.

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[32] NOABL is short for Numerical Objective Analysis of Boundary Layer. It was developed by Science Applications Inc. in the early 1980s, and in the early 1990s adapted by the UK Energy Technology Support Unit (ETSU) to calculate UK wind speeds in a project funded by the Department of Energy. As well as the name NOABL, the UK wind speed dataset is also commonly known as the DTI Wind Speed Database. It is available free on the BERR website.

[33] For example, Encraft's "WindPower Calculator". www.encraft.co.uk/ws/P/Calculators/HomePage.php

[34] According to the Ordnance Survey grid systems for Great Britain and Northern Ireland.

3.2 Results and analysis

The main result of the carbon prize assessment is *Figure 9a*, which is a cost-resource curve for UK small-scale wind energy. For any threshold cost of energy[35] (point on the x-axis), this shows the total energy (on the primary y-axis) that can be generated below the threshold. Also, by converting the energy figures into abated carbon (the secondary y-axis), one can tell how much carbon could be saved at different costs of energy. *Figure 9b* gives a selection of data from the curve. These data are for two costs of energy, 12p/kWh, which is indicative of the current retail price of grid electricity[36], and 100p/kWh, an arbitrary high cut-off; and two levels of market penetration, 100% and 10% (see Appendix).

Key conclusions to draw are that if 10% of households installed turbines[37] with costs of energy below 12p/kWh, up to 1.5 TWh/year could be generated and 0.6 MtCO_2/year saved. These figures are equivalent[38] to 0.4% of electricity consumption and 0.4% of carbon dioxide emissions due to power generation in the UK.

Further comparisons can be made to UK utility-scale onshore wind energy generation. In 2006, this was 4.2 TWh, which abated 1.8 MtCO_2[39].

The coloured regions of *Figure 9a* distinguish between rural and urban sites. One can see that:

- At low cost thresholds, only rural sites are viable. Practically no urban sites have costs of energy below 25p/kWh.
- At 100p/kWh, the energy that could be generated at rural sites is about nine times that of urban sites; i.e. the split is 90% rural:10% urban. If one extends the x-axis to account for the complete resource at any cost of energy (i.e. the resource irrespective of costs), the split becomes 81%:19% – roughly four to one.

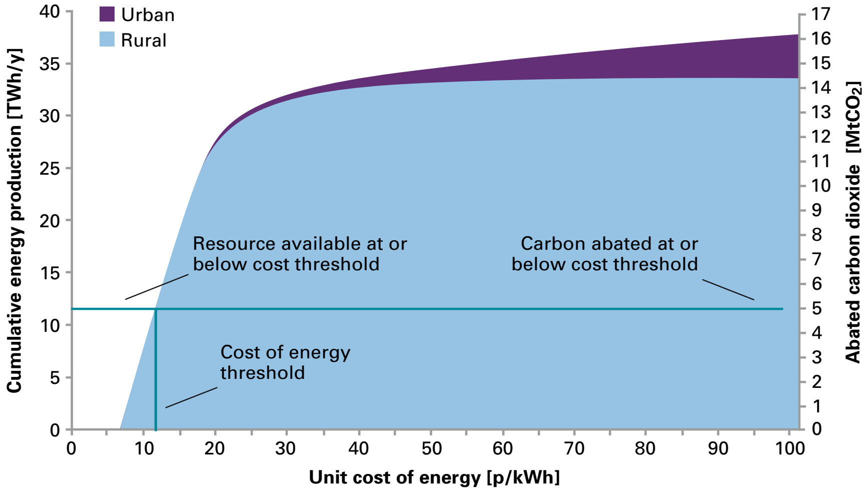
The total energy resource at all costs of energy is 41.3 TWh/year, which is equivalent to 17.8 MtCO_2/year.

These results reflect current costs of turbines, installation and operation. The box overleaf explores how the results could change if costs were reduced in future.

Figure 9: *Cost-resource curve and selected data for UK small-scale wind energy*

a) Cost-resource curve

The chart is based on 100% market penetration. In the table, the 100% market penetration bracket means 'if every turbine at or below a given cost of energy were installed', while the 10% bracket means 'if 10% of turbines at or below a given cost of energy were installed'.



b) Selected data from cost-resource curve

Sources: Met Office and Entec

		Cost of energy	
		<12p/kWh	<100p/kWh
Market Penetration	100%	15 TWh/year 6.3 MtCO_2/year	37 TWh/year 16 MtCO_2/year
	10%	1.5 TWh/year 0.6 MtCO_2/year	3.7 TWh/year 1.6 MtCO_2/year

[35] Cost of energy is the sum of upfront capital costs and the present value of future annual operating and maintenance costs divided by the present value of the annual yield. Assumptions used in the calculations are described in the appendix.

[36] This study has not explored the effects of changes in electricity prices. However, results at different prices can easily be determined from the cost-resource curve.

[37] Or an equivalent number of turbines supplied a combination of houses and commercial buildings.

[38] Percentages based on BERR energy statistics for 2006.

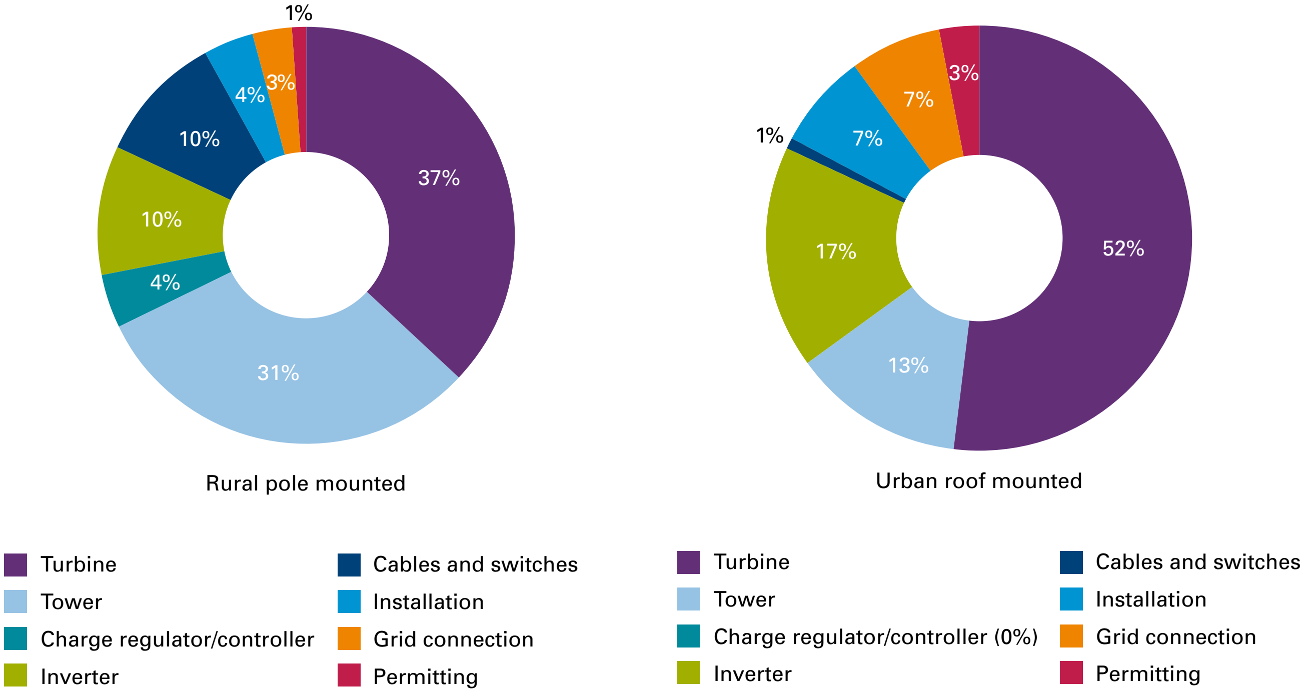
[39] According to BERR energy statistics and a carbon factor of 430 gCO_2/kWh. This factor is different to the one traditionally used by the UK wind energy industry, but is chosen for consistency of comparison in this context. The BWEA and Advertising Standards Authority are currently discussing a carbon abatement calculation methodology for wind energy.

Cost reduction

As the assessment methodology implies (see the appendix), the total UK small-scale wind energy resource reflects a combination of wind conditions and the performance of wind turbines. While the former is not controllable, some improvements to the latter are possible and could lead to marginal increases in energy generation.

However, such increases are unlikely to reduce costs of energy to a significant extent. To do this, one needs to reduce the costs of turbine installations. Since the costs of maintaining turbines tend to be low, upfront capital costs are the primary drivers of costs of energy, and capital cost reductions are most likely to lead to cost of energy reductions. The main items making up capital costs are shown in *Figure 10*.

Figure 10: *Typical capital cost breakdowns for rural and urban small turbine installations*



Rural pole mounted

Urban roof mounted

Source: Entec

Currently, small wind turbines of up to 1 kW installed capacity cost upwards of £1,500, while larger units from 2.5 to 6.0 kW tend to cost between £10,000 and £25,000 fully installed. Some lower priced models have much shorter design lifetimes than their higher priced competitors; figures quoted by manufacturers vary between 10 and 25 years. Some manufacturers specify that annual services are required for their turbines. The costs of services vary, but are generally likely to be between a few tens and a few hundred pounds per year.

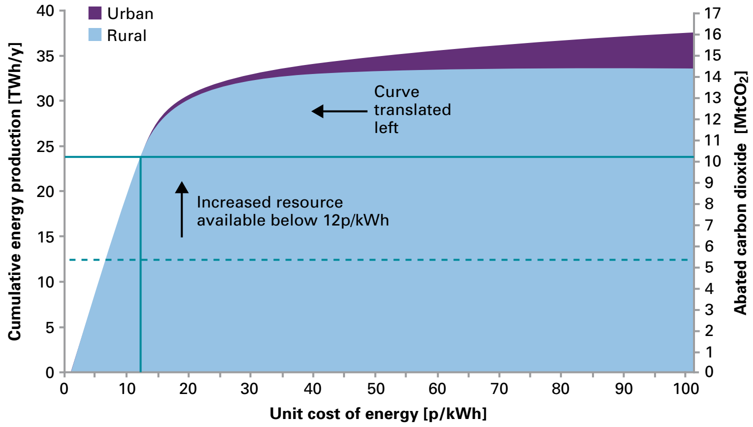
Analysis by Entec suggests that the main ways in which costs could be reduced are:

- Improvements in the engineering design of turbines; and
- Greater efficiency and increased economies of scale in turbine manufacturing.

Lower cost inverters and efficient installation techniques also have promise. The net potential for cost reduction varies between turbine types and installation situations, and is therefore difficult to tell on a general basis. However, using the cost-resource curve (*Figure 9a*) one can consider the effects of a general level of cost reduction in theory.

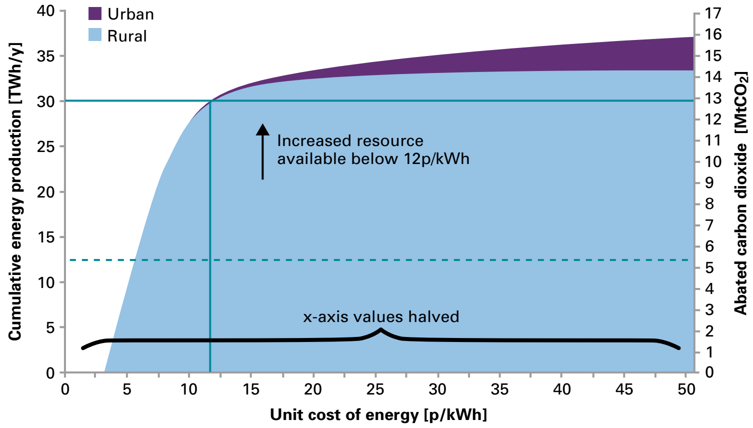
- A fixed reduction in costs of energy of up to a few p/kWh would cause the curve to translate left along the x-axis. For example, a decrease of 5p/kWh, as shown in *Figure 11a*, would mean that the energy and carbon currently available below 17p/kWh become available below 12p/kWh. These are 2.5 TWh/year and 1.1 MtCO$_2$/year at 10% penetration.
- A proportional reduction would scale the x-axis by the same proportion. So a 50% decrease in costs of energy (*Figure 11b)* would mean the x-axis values halve, and the energy available below 12p/kWh becomes that previously shown below 24p/kWh. This is 3.1 TWh/year, equivalent to 1.3 MtCO$_2$/year, again at 10% penetration.

Figure 11: *Effects of general levels of cost reduction*



a) Fixed reduction (5p/kWh reduction)

		Cost of energy <12p/kWh
Market penetration	100%	25 TWh/year 11 MtCO$_2$/year
	10%	2.5 TWh/year 1.1 MtCO$_2$/year



b) Proportional reduction (50% reduction)

		Cost of energy <12p/kWh
Market penetration	100%	31 TWh/year 13 MtCO$_2$/year
	10%	3.1 TWh/year 1.3 MtCO$_2$/year

Source: Entec

Lifecycle carbon

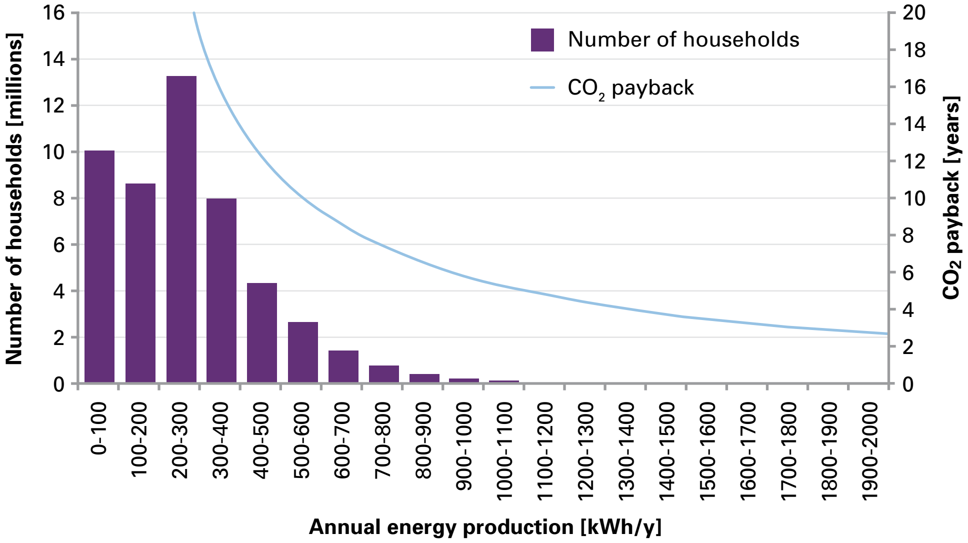
The lifecycle carbon of small-scale wind energy – that is, the entire carbon emitted during manufacturing, installation and operation of small turbines and abated during their operation – has been previously studied by various investigators. A paper by Edinburgh University[40] reports that the SWIFT turbine, a 1.5 kW machine intended to be roof-mounted and grid connected, has a carbon payback of between 13 and 20 months, based on a range of annual yields between 2000 and 3000 kWh[41]. Recently, BRE[42] – looking at three types of turbine and following a different methodology – found that turbines in 'suitable wind conditions… can generate sufficient energy to pay back their carbon emissions within a few months to a few years'[43].

Both studies comment on the potential to reduce the carbon footprints of small turbines, for example by using different materials and recycling. Notwithstanding this, however, the primary driver of lifecycle carbon is the amount of electricity generated.

The carbon prize assessment discussed here can be extended to tell how yields are distributed across installation sites, and therefore how many turbines are likely to pay back their embedded carbon over their lifetimes.

Using data from the Edinburgh paper, *Figure 12* gives a case study for the SWIFT turbine, assuming that the entire household population of UK urban areas has this machine installed. One can see that in the majority of cases (over 80%), yields are less than 500 kWh/year. This is equivalent to a carbon payback of 135 months, or over 11 years, as the secondary y-axis shows. Also, over 50% of installations have a carbon payback of more than 20 years, which is beyond the expected life of the turbine[44] and where the carbon payback curve terminates. While this analysis is only indicative, it suggests that in many potential installation situations, roof-mounted turbines may not pay back the carbon emitted during their production, installation and operation.

***Figure 12:** Distribution of yields for installation of SWIFT 1.5 kW turbine*



Assumptions: Lifecycle emissions of turbine: 2428 kg CO_2; Hub height above roof level: 2m; Carbon factor: 430 gCO_2/kWh.

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[40] "Energy and carbon audit of a rooftop wind turbine", Rankine et al, Proc. IMechE Vol. 220 Part A: Power and Energy, 2006.

[41] Assuming parts are recycled.

[42] "Micro-wind turbines in urban environments – An assessment", BRE, November 2007. This refers to lifecycle assessment analysis by Bath University, funded by the EPSRC Supergen Highly Distributed Power Systems programme. Further work is underway at Bath.

[43] Note that utility-scale wind farms typically have carbon paybacks of a few years or less.

[44] Source: Manufacturer's data.

3.3 Policy and regulatory landscape

A range of policies are currently being introduced in the UK to encourage the growth of small-scale wind energy. In addition, certain regulations are being reformed to facilitate the installation of small turbines at specific sites. The mixture of relevant policies and regulations can be considered in three main categories:

- Fiscal, concerning the economics of installation;
- Planning regulations and guidance; and
- Building regulations.

Fiscal instruments supporting UK small-scale wind energy fall into two types: capital- and revenue-based. The Department for Business, Enterprise and Regulatory Reform (BERR) Low Carbon Buildings Programme (LCBP)[45] is the main capital measure. In offering grants to householders, public sector bodies and charitable organisations[46], it effectively reduces capital costs to consumers. At the time of writing, householders can apply for grants of up to £1,000 per kilowatt of generating capacity, £2,500 in total or 30% of total eligible costs[47] (whichever is lower) per property. Public sector and charitable organisations, meanwhile, are eligible for support of up to 50% of project costs or up to £1 million per site[48]. Although the LCBP website[49] urges caution in the selection of sites, grant funding for householders is not conditional on the site wind resource or estimates of generation and carbon savings[50]. In contrast, grants for organisations may be rejected or limited if certain cost of carbon thresholds (which in principle can be used to tell if a site is poor) are exceeded. As a microgeneration technology, small turbines also qualify for reduced levels of VAT: 5% for existing properties and nil for new builds.

In terms of revenue support, the electricity generated by small turbines is exempt from the Climate Change Levy[51] and eligible for support from the Renewables Obligation (RO)[52]. At present, this is at the level of 1.0 Renewable Obligation Certificate (ROC, currently worth around £45) per megawatt-hour of electricity, but, with the introduction of banding in April 2009, this is expected to change to 2.0 ROCs/MWh. Since the RO is intended mainly to stimulate utility-scale renewable energy projects, and most small-scale installations produce only enough electricity for a small number of ROCs per year[53], Ofgem has made special provisions to make it easier for small-scale generators[54] to claim ROCs[55]. In addition, since April 2007, generators have been allowed to appoint agents to administer ROCs on their behalf, which is sensible to minimise transaction costs[56]. Despite this, however, some people believe that the RO is inappropriate to support microgeneration technologies. The EST and other bodies have advocated feed-in tariffs instead[57], which BERR is considering[58].

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[45] Similar schemes are the Scottish Community and Household Renewables Initiative (SCHRI) and the Environment and Renewable Energy Fund (EFEF) in Northern Ireland.

[46] Grants for not-for-profit organisations are also available from the Community Sustainable Energy Programme, www.communitysustainable.org.uk

[47] This has a specific meaning defined in the programme's terms.

[48] See www.lowcarbonbuildingsphase2.org.uk for further details.

[49] www.lowcarbonbuildings.org.uk

[50] The same is true of grants let under the SCHRI and other schemes.

[51] That is, eligible to receive Levy Exemption Certificates (LECs). See the guide "Microgeneration and the Climate Change Levy", produced by HM Revenue and Customs and DTI (now BERR).

[52] For details of the Renewables Obligation, see the Ofgem website.

[53] For any generator to receive ROCs, it must produce at least 500 kWh per year. Analysis by Entec indicates that less than 40% of all potential small wind turbine installations will achieve this.

[54] Defined as below 50 kW Declared Net Capacity in this context. Declared Net Capacity is the actual generating capacity reduced by a factor to account for the intermittent nature of the energy resource. For wind, the factor is 0.43.

[55] See Ofgem documents "Renewables Obligation: Guidance for small generators (50kW or less)" and "Frequently asked questions for generators 50kW or less", available from the Ofgem website.

[56] According to Ofgem (March 2008), twelve agents are currently operating on behalf of small-scale generators.

[57] Amongst other policy options. See "Generating the Future: An analysis of policy interventions to achieve widespread microgeneration penetration", EST, November 2007, and the similar report published by EST Scotland in May 2008. For further analysis of microgeneration policy, see also "The Growth Potential for Microgeneration in England, Wales and Scotland", Element Energy, June 2008; and "Unlocking the Power House: Policy and system change for domestic micro-generation in the UK", Sussex Energy Group, October 2006.

[58] See the "UK Renewable Energy Strategy consultation", BERR, June 2008.

A key consideration for the installation of small turbines is land-use planning. Various restrictions apply, and at the time of writing, all installations require planning permission. However, domestic installations are soon expected to benefit from new Permitted Development Rights (PDRs), which reduce the need for site-specific planning processes. The Department for Communities and Local Government (CLG), which has responsibility for planning in England and Wales, intends[59] that the PDRs will cover:

- Turbines on buildings that are less than 3m above the ridge (including the blade), with a blade diameter of less than 2m;
- Stand-alone turbines that are less than 11m in height (including the blade), again with a diameter less than 2m, and which are at least 12m from a boundary.

Restrictions will also apply to the acoustic noise of turbines and installation in conservation areas and heritage sites. The Scottish Government launched a consultation about microgeneration PDRs in Scotland earlier in 2008[61], and similar discussions are underway in the other devolved administrations. In future, non-domestic buildings may also benefit from PDRs.

Linked to planning, UK regulations are set to require increasingly high sustainability standards in the design, construction and operation of buildings. The current policy centrepiece is the CLG Code for Sustainable Homes, use of which to rate new domestic properties became mandatory in May 2008. Amongst other low carbon technologies, small wind turbines (below 50 kW) are eligible for credits under the Code's category of Energy and CO_2 Emissions, providing they can be shown to reduce emissions by a certain extent (at least 10%). The carbon estimation methodology for small turbines is part of SAP 2005[62], which is discussed further in the box on page 26. In future, non-domestic buildings may also be affected by regulations similar to the Code for Sustainable Homes, and both domestic and non-domestic buildings are already subject to Energy Performance Certificate regulations[63]. While the carbon reductions from small turbines supplying domestic buildings are again covered by SAP, a different methodology, SBEM[64] applies to non-domestic properties. This is also discussed on page 26.

Planning guidance and the Merton Rule

A range of planning guidance is relevant to small-scale wind energy. In England, the main documents are Planning Policy Statement (PPS) 22, Renewable Energy (for which a helpful Companion Guide is available), and a Climate Change Supplement to PPS 1, Delivering Sustainable Development. Similar documents are available in the devolved administrations.

In some areas, small wind turbine installations may be affected by the Merton rule[60] or equivalent policies. These require developers of new large buildings to install renewable energy generation equipment to either:

- Meet a fraction of the building's predicted energy requirements, often 10% or more; or
- Reduce the carbon dioxide emissions associated with these requirements, again typically by 10% or more.

The BWEA is preparing a guidance document on planning for small-scale wind energy for publication on its website.

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[59] See "Permitted Development Rights for Householder Generation: Government Response to Consultation Replies", CLG, November 2007.

[60] See www.themertonrule.org

[61] Permitted Development Rights for Domestic Microgeneration Equipment: Consultation Paper", Scottish Government, March 2008.

[62] The Standard Assessment Procedure for energy rating of dwellings. See the Technical Manual published by BRE (latest edition January 2008).

[63] These stem from the European Commission Directive on the Energy Performance of Buildings (Directive 2002/91/EC), and for domestic properties have been implemented as part of the Home Improvement Pack scheme.

[64] Simplified Building Assessment Methodology. See the SBEM Technical Manual published by BRE (latest edition December 2007).

3.4 Policy implications and recommendations

The first conclusion to draw from the carbon prize results is that, at current turbine costs and electricity prices, the potential of small-scale wind energy is fairly low relative to total UK electricity consumption and emissions from power generation. Even if the costs of small-scale wind energy were halved, the potential generation and abated carbon would still be less than already achieved by UK utility-scale wind energy (which is growing rapidly).

Further important conclusions concern the relative potential, economics and carbon savings of rural and urban sites:

- Irrespective of costs, about four times as much electricity and carbon savings are available from rural sites than urban ones. The multiple is considerably higher if economic drivers are applied;
- Some potential rural installations have costs of energy below 12p/kWh, suggesting their electricity is competitive with grid electricity; but
- It appears that in many potential urban installation situations, roof-mounted turbines may not pay back the carbon emitted during their production, installation and operation.

Given the sensitivity of small turbines to siting, a point of concern is that some government grants are not conditional on site wind speed and electricity generation potential. This carries the possible risk of grants being awarded to installations which save little carbon.
It is recommended that:

- In any future grant schemes, a criterion is used to measure the amount of carbon likely to be saved in operation of a turbine. Guidance on how to do this is given in Section 4.3;
- In grant applications from both householders and organisations, this figure is compared to the carbon emitted during manufacturing, installation and operation of the turbine; and
- To facilitate this comparison, turbine manufacturers develop and adopt a system of carbon labelling for their products[65].

Overall, this will enable consumers to estimate the lifecycle emissions and carbon paybacks of their installations.

A key aspect of the sensitivity to siting is height. Clearly, the hub heights of small turbines affect things other than the amounts of electricity generated and carbon saved, such as visual amenity[66], and the limits proposed by CLG for PDRs must be a compromise between these factors. However, it is important to recognise the implications of the height limits for carbon savings.

- For urban roof-mounted turbines, a hub height of 2m above roof height was set in this assessment. This is equivalent to CLG's proposed 3m limit to the blade tip for a 2m rotor diameter turbine. The analysis shows that only a relatively small amount of carbon dioxide[67] will be saved at this limit.
- For rural pole-mounted turbines, hub heights of between 11m and 15m above ground level were applied in the assessment. These imply heights to the blade tip of more than 11m. Consequently, if all rural turbines were installed according to the PDRs, less carbon dioxide would be saved than the assessment indicates.

Since rural areas offer the greatest potential for carbon savings, it would ideally be recommended that a greater height limit, such as 16m to the blade tip, should be applied in PDRs to stand-alone turbines in rural locations. However, following discussions with CLG, it is understood that this may be less easy to implement than the current provisions because whether a site is 'urban' or 'rural' is sometimes arguable. Also, CLG has already announced the 11m height limit to the blade tip for stand-alone turbines in general.

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[65] This could be based on the new Publicly Available Specification for the assessment of the life cycle greenhouse gas emissions of goods and services (PAS 2050), co-sponsored by the Carbon Trust and Defra. For details, see www.carbon-label.co.uk

[66] Other practical concerns associated with small wind turbines and other microgeneration technologies are discussed in the BRE report for the Scottish Buildings Standards Agency, "Building integration of low and zero carbon technology systems, including micro-renewables", November 2007.

[67] Up to 1.6 $MtCO_2$ below a cost of energy of 100p/kWh at 100% market penetration.

Consequently, it is recommended that:

- Should the height limit for stand-alone turbines be reviewed in future, CLG gives serious consideration to increasing it for sites which, by virtue of characteristics already defined or readily definable in national or local planning policy, are clearly of a rural character; and
- Should PDRs later be introduced for non-domestic buildings, many of which are likely to lie in more open and exposed sites than houses, CLG sets a height limit greater than 11m for stand-alone turbines generally.

Finally, the sensitivity to siting and the lifecycle emissions of small wind turbine installations have implications for buildings regulations. In particular, a robust methodology is required to estimate the emissions abatements of small turbines to prove the extent to which they allow the buildings to have low carbon footprints. The box about SAP and SBEM (see page 26) raises concern that their approaches to estimate the annual yields and carbon savings of small turbines are not particularly robust, and recommends that an improved methodology is adopted to give more accurate results. This could be based on the new Carbon Trust yield estimation tool.

3.5 Summary

- In theory, small-scale wind energy has the potential to generate 41.3 TWh of electricity and abate 17.8 $MtCO_2$ in the UK annually. However, at current costs of small wind turbines and electricity prices, it is economic to achieve only small proportions of these figures.
    - If 10% of households installed turbines at costs of energy below 12p/kWh (indicative of the current retail electricity price), up to 1.5 TWh could be generated and 0.6 $MtCO_2$ saved. Relative to total UK electricity consumption and emissions from power generation, these figures are fairly low.
    - To decrease costs of energy, it is necessary to reduce the capital costs of turbines. If such reductions caused costs of energy to halve, the figures above could change to 3.1 TWh and 1.3 $MtCO_2$. These are less than the amounts already achieved by UK utility-scale wind energy.
- The majority of electricity and carbon savings are available from small turbines in rural areas – four times as much as urban areas irrespective of costs, and considerably more given economic drivers. Some potential rural installations have costs of energy below 12p/kWh, suggesting they are competitive with grid electricity. Practically no urban sites have costs of energy below 25p/kWh.
- The primary driver of lifecycle carbon for small wind turbines is the amount of electricity generated. It appears that in many potential urban installation situations, roof-mounted turbines may not pay back the carbon emitted during their production, installation and operation.
- A range of policies is encouraging the growth of small-scale wind energy in the UK, including the Low Carbon Buildings Programme, Permitted Development Rights (PDRs) for domestic installations and the Code for Sustainable Homes.
- It is recommended that:
    - In any future grant schemes, a criterion is used to measure likely carbon savings;
    - Turbine manufacturers develop and adopt a carbon labelling system for their products;
    - Should PDRs be reviewed in future, CLG gives serious consideration to setting a height limit for stand-alone turbines of more than 11m to the blade tip for open, exposed sites of a rural character; and if similar rights are later introduced for non-domestic buildings, sets a height limit of more than 11m to the blade tip for stand-alone turbines generally; and
    - An improved methodology to estimate the annual yields and carbon savings of small turbines, perhaps based on the new Carbon Trust yield estimation tool, is adopted for building regulations.

4. Evaluating the potential of small wind turbines at specific sites

This section explains how, from a practical perspective, one may evaluate whether or not a site is suitable for the installation of a small turbine, and how to determine the site’s wind conditions. It then discusses how the carbon savings and economics can be assessed, and outlines other relevant considerations such as grid connection.

4.1 Assessing site suitability

Due to the variability of winds and local effects (see Section 2), only certain sites amongst all places where small turbines could possibly be installed are actually suitable for installation. Judging the suitability of a site is best done by engineers, but an initial evaluation sufficient for a ‘move forward/no go’ decision can be made by the layman following simple rules of thumb.

Visual inspection is the first step. A lot can be told from the site’s position in the local landscape, including:

- The site’s elevation above sea level, and, if urban, its location within the town or city boundary. Generally, highly elevated sites, or sites on the edges of built-up areas exposed to the predominant wind direction (typically southwest in the UK), are likely to experience the highest wind speeds; and
- To what extent the site is surrounded by ground obstacles such as buildings and trees, and the heights of these obstacles. Sites in open terrain generally experience the highest wind speeds at any height. Where a site has obstacles nearby, a turbine needs to be sited higher than those obstacles.

These points, which are largely intuitive, are illustrated in *Figure 14a*.

Having decided that a site is potentially suitable, one can begin to consider choosing a turbine (see box on page 24) and take steps to optimise its generation and carbon savings. These include:

- Maximising the hub height above ground or roof level;
- Locating the turbine so it is exposed to the longest possible fetch (distance over which the wind flows uninterrupted) in the predominant wind direction; and
- Avoiding turbulent regions close to the edges of flat roof buildings, and, for pitched roofs, setting the hub height above the peak and/or so that the rotor is well exposed in the predominant wind direction.

Figure 14b illustrates these points and others.

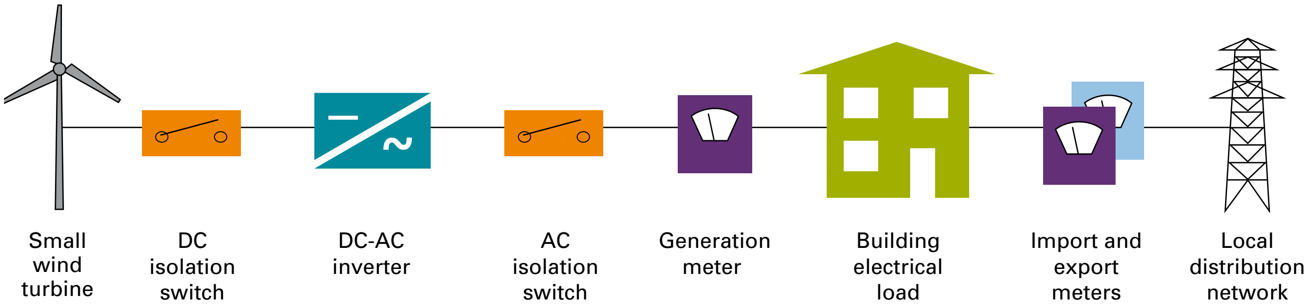
Ways of employing small wind turbines

Small wind turbines can be used in a number of ways, including:

- In places off the electricity grid, to charge batteries (possibly alongside other generators);
- For buildings on the electricity grid, to displace grid electricity and also export to the grid; and
- To provide space heating and hot water.

The overall manner of installation and equipment required in addition to the turbine vary between these options. For example, *Figure 13* shows the main parts of a grid-tied system.

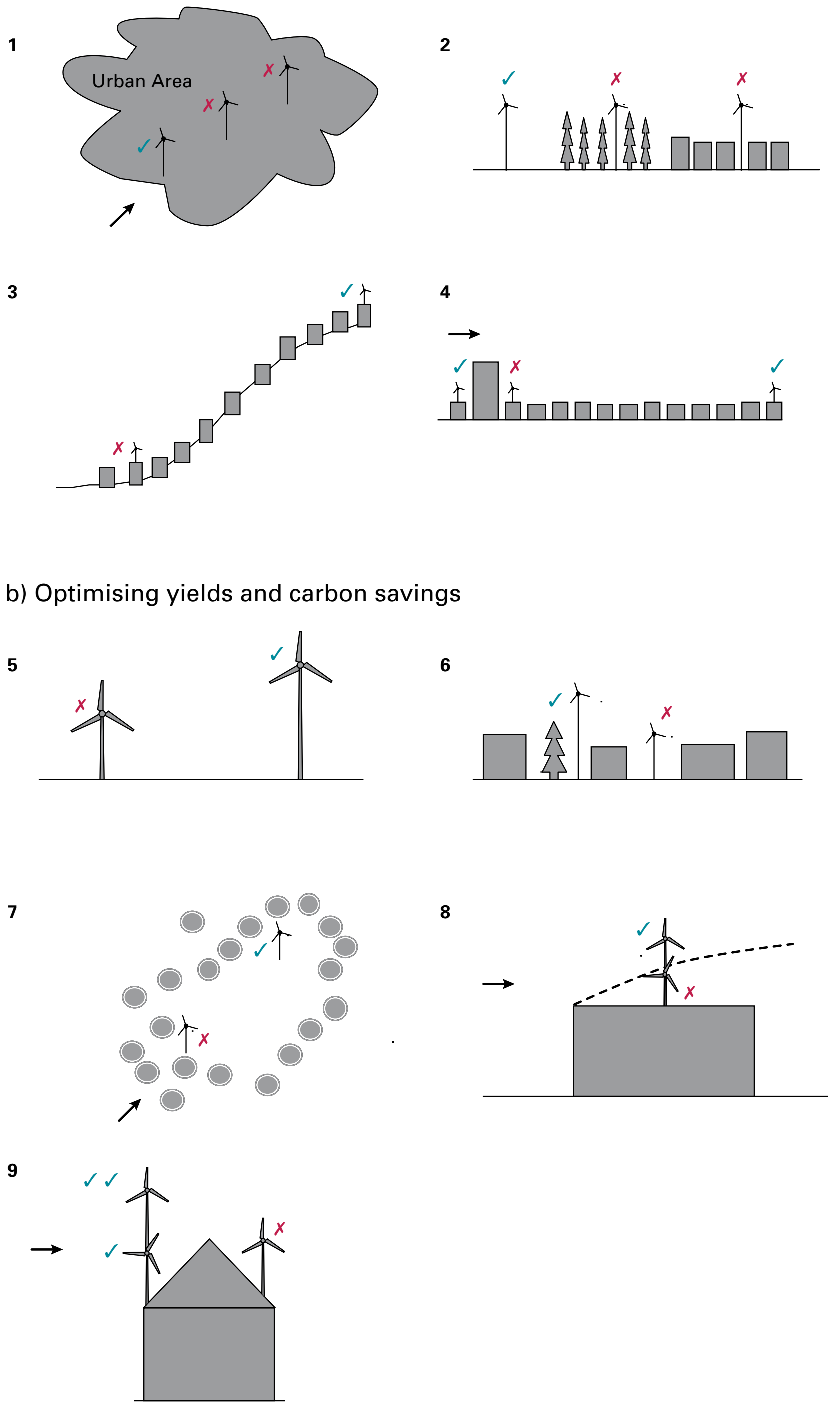
***Figure 13**: Simplified schematic of a grid-tied small turbine installation*



Many grid-tied systems also include a consumer control unit.

Systems vary between manufacturers and installers so this is an example rather than typical case.

***Figure 14:** Guidelines for siting and micro-siting of small wind turbines*



a) Deciding whether a site is suitable

b) Optimising yields and carbon savings

The arrows indicate wind direction

Source: Met Office

1 Turbines should be sited near the edge of built up or forested areas in preference to central locations. It is best to choose a location on the side of the prevailing wind.

2 Locate the turbine over a rural, non-forested area in preference to built up or forested areas.

3 Site turbines near the top of smooth hills. Sharply changing gradients, such as cliff tops, can cause turbulence and may not be suitable. For steep hills, the turbine should be placed at the highest point or on the side of the prevailing wind if the summit is not an option.

4 For each obstacle that protrudes above the general level of the roughness elements (e.g. a tower block within an area of generally one or two storey housing), try to ensure that the turbine is located.

Either further away than 3 to 10 times the obstacle height (larger factors applying to wider obstacles as seen from the turbine location) and further still if possible, up to 30 times;

Or higher than 1 to 1½ times the obstacle height (larger factors applying when the obstacle is a pitched roof building or a building with an along-sight length viewed from the turbine location which is less than the height) and higher still if possible, up to 1¾ to 2 times.

5 Position the turbine as high as practically possible or allowed.

6 Position the turbine above the height of nearby trees or buildings.

7 If practical considerations prevent the turbine being mounted above the height of nearby trees or buildings, ensure there is a clear view on the side of the prevailing wind direction (typically south-west in the UK).

8 Turbines mounted on flat roofs should be placed above the turbulence in the wake of the air stream.

9 For turbines mounted on pitched roof buildings that extend above the surrounding obstacles (e.g. other buildings, trees, etc), ensure that:

Either the turbine height above the roof peak is at least half the vertical depth of the roof (base to peak);

Or the turbine is mounted in front of the peak from the perspective of the prevailing wind direction (and ideally both).

Choosing a turbine and relevant standards

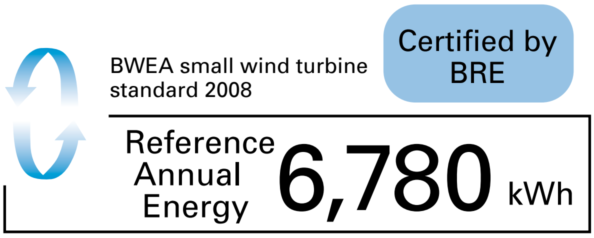
A variety of small turbines are now on the UK market, designed for different sites and applications. Some products have been available for many years while others are the result of recent research and development.

When choosing a turbine, the guidelines in Section 4.1 will initially be useful to decide whether it should be free standing or roof-mounted. Some manufacturers offer turbines suitable for both applications, while others focus on one or the other. Turbine manufacturers and installers[68] can provide various information about their products, including:

- Physical size and installation options, including heights;
- Costs, for the turbine itself and installation (see notes to *Figure 10*); and
- Electricity generation performance – notably turbine power curves[69].

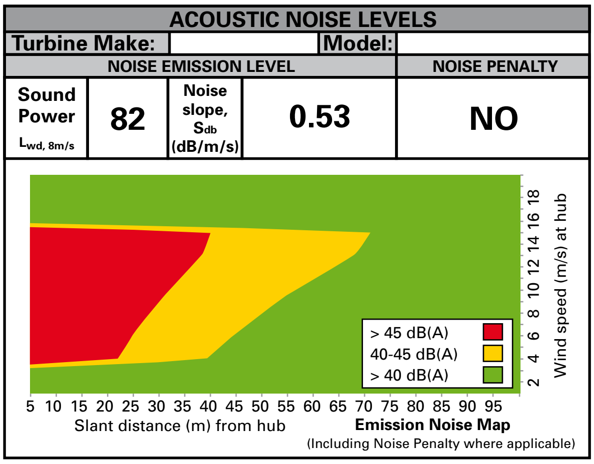
***Figure 15**: BWEA Performance and Safety standard labels*

Example performance label



Annual average wind speed of 5 m/s (11 mph). Your performance may vary.

Example noise label



ACOUSTIC NOISE LEVELS				
Turbine Make:		**Model:**		
NOISE EMISSION LEVEL				NOISE PENALTY
Sound Power $L_{wd, 8m/s}$	**82**	**Noise slope,** S_{db} **(dB/m/s)**	**0.53**	**NO**

Emission Noise Map
(Including Noise Penalty where applicable)

These data can be used to estimate how much electricity will be generated at a particular site and how much carbon will be abated (see Section 4.3). A variety of other information is also available. Some manufacturers and installers (e.g. Proven Energy and Segen) provide a comprehensive range of technical specifications on their websites.

To protect consumers and help them choose between turbines, several standards have been developed.

- One was produced by BRE on behalf of BERR as part of the Microgeneration Certification Scheme (MCS). This is linked to the Low Carbon Buildings Programme and sets standards for microgeneration products and installation services. Microgeneration Installation Standard (MIS) 3003 concerns small-scale wind energy[70] and sets requirements for companies involved in the supply and installation of small turbines.
- Another standard is the REAL Assurance scheme, developed by the Renewable Energy Association (REA). This sets a voluntary consumer code for companies involved in the sale and leasing of microgeneration equipment, including small wind turbines. The scheme web site lists companies which agree to the code, including small turbine manufacturers and installers.
- A third standard has been produced by the BWEA. This is a performance and safety standard, which refers to previously developed standards for utility-scale turbines but has new information to cater for certain special characteristics of small turbines. The standard sets out testing methodologies to assess a turbine's ability to generate power and the noise produced during generation, and also defines performance and noise labels[71] for turbine products, as illustrated in *Figure 15*. Note that the energy figure in the performance label does not reflect the amount of electricity that could be produced at a particular site; rather, it is a marker to distinguish between different turbine models, assuming that each operates under the same, standard conditions.

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[68] Lists are available from the BWEA and Renewable Energy Association, REA.

[69] To facilitate energy yield estimates, one can ask for power curves in tabulated rather than graphical form.

[70] The latest issue is 1.2, February 2008, and is available from www.greenbooklive.com

[71] The noise label was developed by TUV-NEL.

4.2 Determining site wind conditions

For any given turbine, site and installation setting (including height), the principal factor affecting the amounts of electricity generated and carbon saved is wind speed. There are several ways of assessing this, which vary in complexity and accuracy[72].

Ideally, one would like to know the actual wind speed distribution and wind rose (see Section 2.1) at the exact location the turbine is to be installed, since this enables the most accurate yield and carbon saving estimates to be made. In utility-scale wind farm development, there are several ways of doing this, commonly involving wind speed and direction data obtained from anemometers and wind vanes erected on a mast at the development site (ideally in the actual position of a turbine)[73]. Wind measurement campaigns can also be undertaken in small-scale wind energy, although some people may find the costs and time associated with erecting an anemometry mast and processing data from it unattractive.

As an alternative to measurement, one can use an existing source of wind speed data – typically a dataset containing annual mean wind speeds – and make assumptions about the distribution. A simple example is taking a wind speed figure for a particular kilometre square from NOABL (see box on page 12) and assuming the distribution has a standard shape[74]. This is fine for a first approximation, but since no information about local site conditions has been used, it could be highly inaccurate.

A further alternative is to assume a distribution but take local site conditions into account. A methodology developed by BRE for the Microgeneration Certification Scheme (MCS – see box on the previous page) does this, notably for roof-mounted turbines located a distance of less than ten times the height of the nearest obstacle away from that obstacle. After obtaining a wind speed estimate from NOABL (10m above ground level), one multiplies the estimate by a certain correction factor, selected according to:

- The overall nature of the installation setting – three options being 'dense urban', 'low rise urban/ suburban' and 'rural' (with typical building heights assumed); and
- The distance from the roof ridge to the lowest point of the turbine blades.

The corrected wind speed is then used to read from an 'Annual Energy Performance Curve' for a particular turbine.

The fundamental approach here of adjusting a reference wind speed according to some characterisation of local site conditions is reasonable. However, the MCS methodology has some limitations:

- Wind speeds can be estimated only at a limited range of heights; and
- Roughness is considered only at the immediate turbine site rather than around the local neighbourhood.

A new yield estimation tool being developed by the Carbon Trust addresses these points and makes other enhancements to the estimation process. The tool is introduced overleaf.

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[72] On this point, see also "Urban Wind Resource Assessment in the UK – an introduction to wind resource assessment in the urban environment", IT Power, 2007.

[73] Since wind speed varies over the seasons, measurements for utility-scale wind farm sites are typically made over at least one year. Often, the measured data and long term data for a nearby reference site (e.g. a Met Office station) are combined in a Measure-Correlate-Predict (MCP) calculation to produce a long-term distribution for the site in question. See the Technical Report for details.

[74] Such as the shape of the Rayleigh distribution, a special case of Weibull distribution with shape factor 2.

New Carbon Trust yield estimation tool

Recognising the limitations of existing wind speed and yield estimation techniques, and following development of the UK carbon prize assessment methodology (see Section 3.1), the Carbon Trust has commissioned the Met Office and Entec to transform the methodology into a new yield estimation tool for potential installation sites.

The tool will improve upon the MCS approach methodology by:

- Using the NCIC wind speed dataset as its basis rather than NOABL. See the comparative discussion on page 12;
- Taking into account roughness in the local neighbourhood, not just at the immediate turbine site, based on land use data;
- Covering a more comprehensive range of installation settings, including some involving commercial buildings; and
- Allowing wind speeds to be estimated at any height.

Operation of the tool will involve entering details of a location (UK post code or Ordnance Survey grid reference), intended installation situation and turbine (height and power curve[75]). Using this information, the tool will estimate the long-term annual mean wind speed, the potential annual yield and potential carbon savings.

The Carbon Trust is currently consulting industry representatives about the tool and plans to make a version available later in 2008.

Other calculation methodologies worth mentioning are:

- Those of SAP and SBEM (see Section 3.3) for estimating the carbon savings achieved by buildings employing small turbines. See the box below; and
- Techniques based on Computational Fluid Dynamics (CFD), which can be used to model how winds flow around buildings (using previously established input data). This is useful to tell where wind speeds are likely to be greatest and therefore where it is best to place a turbine. Several academic studies (including by Loughborough University – see *Figure 16*) have applied CFD to small-scale wind energy. However, the technical complexity of CFD and its subsequent costs of analysis mean that it is generally not suitable to assess installation sites.

SAP and SBEM methodologies

The SAP and SBEM methodologies for estimating the carbon savings achieved by buildings employing small turbines were mentioned in Section 3.3.

The SAP approach is very simple, using a number of pre-defined factors to produce a basic estimate. However, while advocating the same set of wind speed correction factors as the Microgeneration Certification Scheme methodology, these factors are applied to a fixed value of 'average wind speed', 5.0 m/s, which may bear no relation to the actual long-term annual mean of a real site in question. The approach also ignores height. This means that for the purpose of estimating the generation and carbon savings of a small turbine, it is not robust.

The SBEM methodology is more involved in the respects of defining factors to account for local roughness, selected in relation to the real site, and also allowing for wind shear. Also, rather than being fixed, the 'mean annual wind speed' is selected according to a site's location in the country – specifically its proximity to a reference site. However, since only fourteen such sites are defined, the wind speed is again unlikely to be representative of a real site's long-term mean. Again, therefore, the methodology is not particularly rigorous.

It is recommended that an improved methodology is developed and adopted in SAP and SBEM. This could be based on the new Carbon Trust yield estimation tool (see left).

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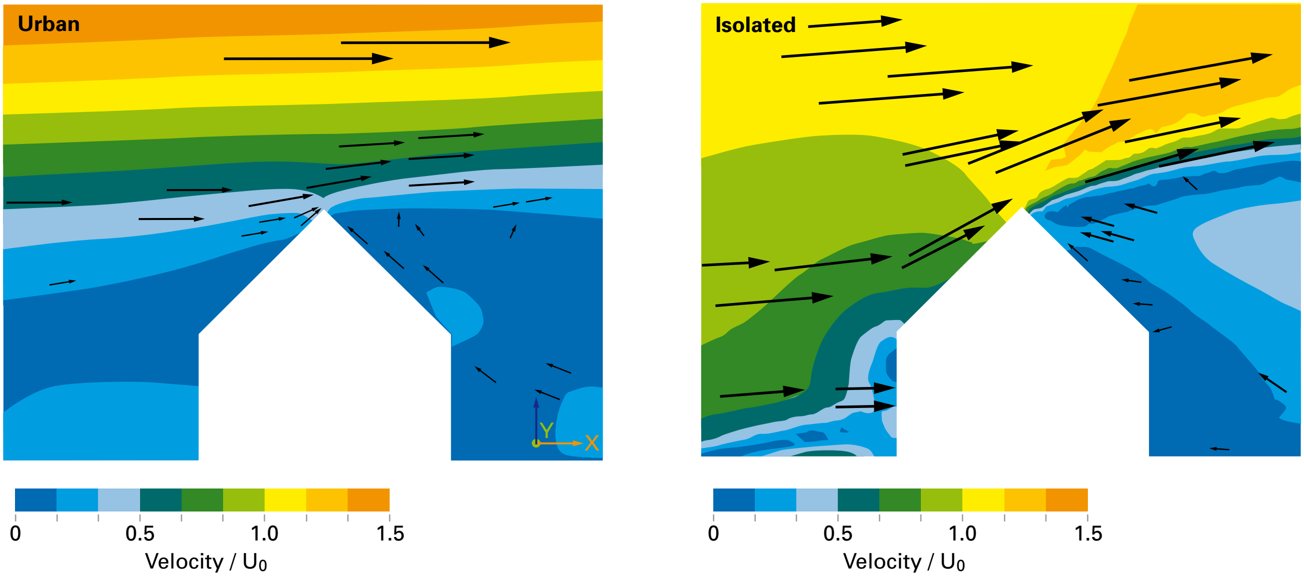
[75] Options for advanced users will be to enter the carbon factor and Weibull shape parameter, overriding default settings.

***Figure 16**: Results of CFD modelling of wind flows around buildings*



The warmer the colour and longer the arrow, the greater the wind speed. The 'Isolated' case is equivalent to a rural setting in context of this report, while the 'Urban' case depicts a building in an urban environment with other buildings nearby on either side (not shown).

Source: Centre for Renewable Energy Systems Technology (CREST) at Loughborough University.

Ultimately, the choice of method to assess wind speed depends on the certainty[76] to which generation and carbon savings must be known, and more than one method can be applied. It is recommended that:

- Following visual inspection of the suitability of a site, the Carbon Trust yield estimation tool is used to obtain initial quantitative estimates of its potential; and
- If these suggest the site is likely to be attractive for generation, anemometry equipment is installed[77] and wind speed measurements are taken[78].

If turbines are installed without taking measurements, it should be borne in mind that the generation and carbon savings obtained in practice may be lower than those predicted or required, with subsequent impacts on the financial and environmental cases for installation. Deciding not to take measurements amounts to accepting a lower degree of certainty than is technically achievable for the benefits of saving costs and time.

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[76] MIS 3003 currently recommends that consumers be advised that "the performance of wind systems is impossible to predict with any certainty" due to the spatial and temporal variation of winds. This could be taken to imply that any prediction will be completely uncertain and the consumer should have no confidence in it. In fact, yield and carbon saving predictions based on historic measured data can generally be stated within finite error bands, and this is done routinely for utility-scale wind farms. It is recommended that the standard's advice is updated to reflect this.

[77] It is advisable to install at least one anemometer and wind vane, the latter being particularly important if a site is partially sheltered or for some other reason it is necessary to determine the wind rose. Installing multiple anemometers at different heights allows wind shear, and the potential benefits of installing a turbine at one height rather than another, to be evaluated. However, for small turbine installations, just a single anemometer at the intended turbine hub height may suffice. Various companies (e.g. Better Generation) sell anemometers and masts.

[78] Although measuring for at least one year is generally preferable, this is not the only option. At certain partially sheltered urban sites, for example, data collected over just a few days may be highly illuminating, particularly if these data are compared to conditions at a well exposed nearby reference location (such as a Met Office station). This research did not extend to defining a reduced rationale for small-scale wind energy measurement campaigns, but this is recommended for further work. Amongst other aspects, assessment could be made of the potential to use low cost anemometry equipment instead of the high specification instruments typically used for utility-scale wind farms; and commercial or government-supported models to provide temporary access to the equipment – e.g. rental or loan schemes. Anemometry loan schemes have been operated in the USA.

4.3 Estimating turbine yields and carbon savings

Starting from a wind speed distribution based on measurements over the course of a year (or an assumed distribution matched to an annual mean wind speed), it is possible to estimate the annual yield of a turbine by:

- Multiplying the number of hours that the wind speed is within each wind speed bin with the power that the turbine would produce at that speed; and
- Summing the products across the range of power curve speeds from cut-in to cut-out.

Figure 17 – which combines *Figures 2 and 4* – illustrates this process. The result is known as the gross output. Realistically, the turbine will have some downtime for maintenance, and some energy is likely to be lost in the cables and inverter. Collectively, these could reduce the output by 5-15%. The gross output factored down by these losses is known as the net output. The net output can be converted into carbon by multiplying by a carbon factor, such as the Defra policy marginal factor of 430 gCO_2/kWh.

Alternatively, if one is following one of the BRE MCS, SAP or SBEM methodologies, the yield is estimated within the methodology and the carbon savings may be too. The MCS approach embeds an assumed wind speed distribution within the Annual Energy Performance Curve for a specific turbine. Effectively, this pre-computes the energy that would be produced for a Rayleigh distribution at the corrected mean, less an allowance for losses.

4.4 Assessing the economics of installation

Having obtained cost data from the turbine manufacturer or installer and estimated the net yield, it is possible to make an economic assessment of the potential turbine installation. This can be done in the following stages:

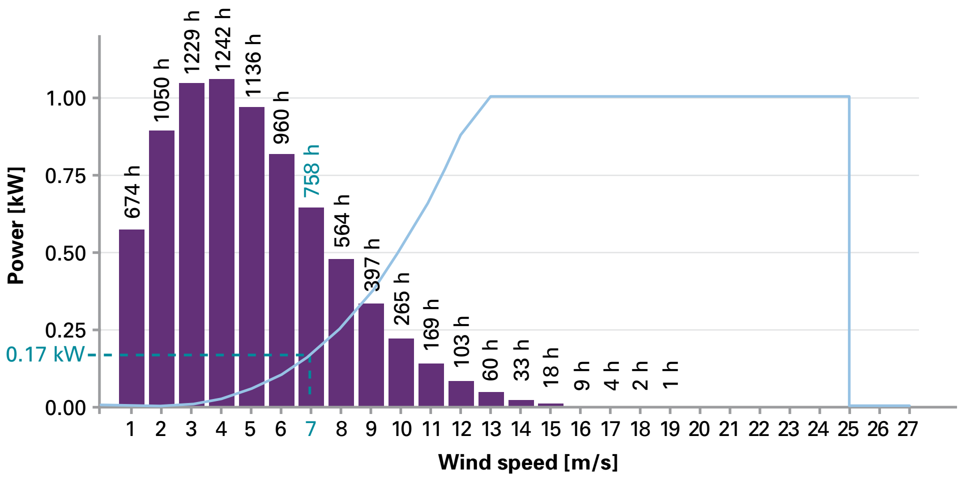
- Estimating the value of generated electricity;
- Computing the simple payback; and if necessary
- Making a discounted cash flow calculation.

The value of the electricity will be a function of the cost of energy displaced by the turbine. If the turbine is grid-connected, this has two main components:

- The value of electricity generated by the turbine and used locally. Since the turbine's electricity is replacing electricity from the grid, it is reasonable to apply the price of grid electricity set by the electricity supplier.
- The value of electricity exported. This is discussed on page 29. Note that if any significant fraction of electricity is likely to be exported, it is essential this is rewarded; otherwise, the value of the yield must be reduced by the exported amount.

On top of both these components are the values of ROCs and LECs (see Section 3.3).

Figure 17: *Illustration of yield calculation process*



The figures above the bars show the number of hours in the year that the wind speed is within each wind speed bin. For example, shown in light blue is the number of hours at 7 m/s. From the power curve, we find the turbine would produce 0.17 kW at this speed. Multiplying the two gives 129 kWh.

Source: Entec

Strictly, one should consider how much electricity will be exported from the turbine using data describing the demand patterns of the supplied building, and employ predictions of the future values of electricity and ROCs. However, for a simple estimate, one may assume 50% of the electricity is used directly and the other 50% is exported (see box below), and apply fixed, present day electricity and ROC values. *Figure 19a* illustrates this.

Bringing in cost data from the turbine manufacturer or installer, a simple payback calculation can now be made. The payback is the ratio of the total costs to the value of annual yield. If the installation is eligible for a grant (such as through the Low Carbon Buildings Programme – see Section 3.3), the total costs may first be reduced by the grant value. This is illustrated in *Figure 19b*.

Finally, the economic data can be put into a discounted cash flow calculation, to assess on a project basis the value of the investment compared to other uses of money. An example internal rate of return, taking the turbine service life as the investment period, is given in *Figure 19c*.

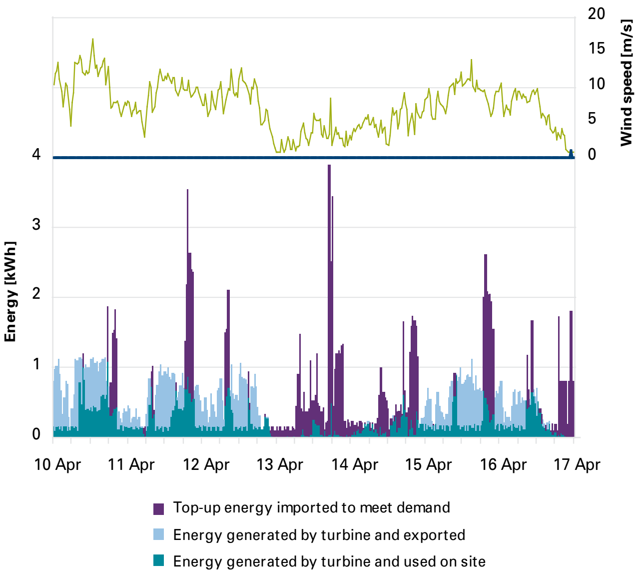
Electricity exports and value of generation

Due to the wind's variability, the amount of power generated by a small wind turbine varies over time. Because of this, the power at any instant may be in excess of the local electricity demand, sufficient to meet the demand or insufficient to meet the demand. If the turbine is grid-connected, then at times of excess, power will be exported (or 'spilled') to the grid; at times of sufficiency, power will be drawn from the turbine rather than the grid; and at times of insufficiency, the turbine's power will be 'topped-up' by grid electricity.

Important to the valuation of a small turbine's electricity are:

- The statistical match between the demand and supply, which determines how much electricity will be exported. *Figure 18* illustrates this, showing how in a randomly selected week a household uses electricity from its small turbine, exports electricity from the turbine and also imports grid electricity. A study by BEAMA (see reference on page 5) looked at the export characteristics of six small turbines installed in a range of UK locations, and found that over the period between June 2006 and May 2007, an average of around 50% of the generation was exported. This suggests that half the electricity from grid-tied small turbines may not supply buildings directly but instead supply the grid.
- Whether and how generators are paid for the exported electricity. The Climate Change and Sustainability Act 2006 introduced measures to allow the Government to change electricity suppliers' licences to require them to pay for electricity exports. At the time of writing, several suppliers[79] clearly advertise microgeneration tariffs to customers, and, in some cases, the price paid for exports is the same as the purchase price for grid electricity. In addition, electricity from small turbines is eligible for ROCs (see Section 3.3). Some suppliers with microgeneration tariffs offer to act as Renewables Obligation agents; that is, they will effectively pay generators for the value of both electricity and ROCs[80].

***Figure 18:** Local use and exporting of electricity for an example small turbine installation*



In this randomly chosen week, 58% of the household's electricity consumption is imported from the grid, 47% of the turbine's generation is used by the household, and 53% is exported to the grid.

Source: Entec

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[79] For example, RWE npower.

[80] Suppliers may also administer Levy Exemption Certificates (LECs) for organisations paying the Climate Change Levy.

Figure 19: *Example economic assessment for a pole-mounted turbine installed in a rural area*

a) Estimating the value of generated electricity and ROCs

Turbine capacity	2.5	kW	TC
Capacity factor	20	%	CF
Annual yield (net output)	4,380	kWh/year	Y = TC x CF x 8760 hours/year
Export fraction	50	%	F
Electricity exported	2,190	kWh/year	$E_{exp} = Y \times F$
Electricity used directly	2,190	kWh/year	$E_{dir} = Y \times (1-F)$
Total number of ROCs	4		$N_R = \frac{Y}{500\ kWh}$
Unit price of exported electricity	10	p/kWh	P_{exp}
Unit cost of imported grid electricity	12	p/kWh	P_{imp}
Unit value of ROCs	45	£/MWh	R
Value of exported electricity	219	£	$V_{exp} = E_{exp} \times P_{exp}$
Value of electricity used directly	263	£	$V_{dir} = E_{dir} \times P_{imp}$
Value of ROCs	180	£	$V_R = N_R \times R$
Total value of electricity and ROCs	662	£/year	$V_{tot} = V_{exp} + V_{dir} + V_R$

b) Estimating the simple payback

Total capital cost of turbine installation	10,000	£	C_C
Grant	2,500	£	G
Annual operating cost	100	£/year	C_O
Total capital cost after grant	7,500	£	C_C-G
Simple payback	13	years	$\frac{C_C-G}{V_{tot}-C_O}$

c) Estimating the internal rate of return

Turbine service life	20	years
Internal rate of return	4.2	%

The equation for the number of ROCs is based on 2.0 ROCs/MWh – see Section 3.3. For simplicity, LECs have been ignored in this example, but in practice their value could be added to V_R.

4.5 Other considerations

With the economic assessment complete, one can proceed to procure and install a turbine(s). But before an installation is made, it is necessary to consider:

- Whether planning permission is necessary;
- Structural integrity of the supporting structure, if the turbine is to be roof-mounted; and
- Arrangements to connect to the grid, if relevant.

While Permitted Development Rights (PDRs) for domestic properties are expected to be introduced soon, all small wind turbine installations currently require planning permission; and after PDRs are introduced, installations falling outside the provisions (including non-domestic buildings) will still need individual approvals. The process of obtaining permission is the same as for building structures, but planning officers are obliged to follow national guidelines specific to renewable energy and climate change (see box on page 18). *Figure 20* lists information which will need to be submitted with a planning application, and also items that generally should not be requested by officers, since they are not material to the planning decision. Consult your local council planning office for further advice.

The mast of a small turbine carries static and dynamic loads which, if the turbine is to be roof-mounted, need to be safely withstood by the roof structure. A structural survey and possibly engineering works to provide reinforcement may be necessary before erecting the turbine. Turbine manufacturers and installers have been investigating the best ways to roof-mount turbines and are able to advise on specific situations. Safe installation is also covered by the Microgeneration Certification Scheme (see page 24).

Figure 20: *Information required for small-scale wind energy planning application*

Information generally required for planning decision	**Information generally not required for planning decision**
• Planning application • Scale drawings of site and proposed installation, including site boundary • Supporting environmental information* • Planning fee	• Turbine generation capacity and power curve • Wind speed data, energy yield and carbon saving estimates, and results of economic and carbon assessments • Detailed Environmental Impact Assessment (EIA)

This is on the basis that the installation is not deemed to be an ‘Environmental Impact Assessment (EIA) Development’, which typically refers to large industrial installations.

*The supporting environmental information may refer to the turbine noise label, being introduced through the BWEA standard (see page 24). Generally it should not include a detailed noise assessment.

Sources: Department for Communities and Local Government and BWEA

Connection of small turbines and other microgeneration equipment to the grid is regulated to maintain the safety and quality of electricity supplies. Two sets of engineering recommendations[81] adopted by UK Distribution Network Operators (DNOs) are generally applicable to small turbines. One, known as G.83[82], is for turbines up to 16 amps per phase, while the other, G.59[83], is for turbines above this current rating. For installation to a typical house with a single phase supply, the 16A threshold is equivalent to a turbine of 3.8 kW rated capacity. Following G.83, the local DNO needs to be notified of the connection either before or at the time of commissioning. Such notification may form part of the service provided by the installer[84]. Further guidance on electrical connection is provided by DNOs[85] and the Electricity Safety Council[86].

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[81] Published by the Energy Networks Association.

[82] G.83/1 (2003): “Recommendations for the connection of small-scale embedded generators (up to 16A per phase) in parallel with public low-voltage distribution networks.”

[83] G.59/1, Amendment 1 (1995): “Recommendations for the Connection of Embedded Generating Plant to the Regional Electricity Companies” Distribution Systems.”

[84] In practice, it is likely to involve submission of a short form with simple details of the site, equipment and installer’s qualifications.

[85] For example, clear guidance is provided by Scottish Power Energy Networks. See www.spenergynetworks.net/newconnections/microgeneration.asp

[86] “Connecting a microgeneration system to a domestic or similar electrical installation (in parallel with the mains supply) – Best Practice Guide, Electrical Safety Council.”

4.6 Summary

- Due to the variability of winds across the UK, plus local effects such as sheltering and turbulence, only certain sites are suitable for the installation of small wind turbines. An initial evaluation of a site's suitability – sufficient for a 'move forward/no go' decision – can be made following simple rules of thumb.
- The principal factor affecting the amounts of electricity generated and carbon saved by small wind turbines is wind speed. This can be assessed in several ways, including by reference to the NOABL database and applying a methodology developed as part of the Microgeneration Certification Scheme (MCS). The Carbon Trust is developing a new yield estimation tool which is based on a wind speed dataset preferable to NOABL. The tool also improves on the MCS methodology.
- Organisations considering installing small turbines are recommended to:
  - Use the Carbon Trust yield estimation tool to obtain initial quantitative estimates of a site's potential; and if the site appears attractive,
  - Install anemometry equipment and take measurements to give the greatest degree of certainty about potential energy yields and carbon savings.

  Deciding not to take measurements amounts to accepting a lower degree of certainty than is technically achievable.
- The yield and carbon savings of a turbine can be estimated using a measured or assumed wind speed distribution and the turbine power curve, obtained from the turbine manufacturer or installer. Combining a yield estimate with cost data, it is possible to make an economic assessment. In doing so, it is important to consider the amount of electricity likely to be exported (potentially 50%) and how this will be paid for, since, otherwise, the value of the yield must be reduced by the exported amount.
- Other considerations include planning, the structural integrity of the supporting building if the turbine is to be roof-mounted, and grid connection. Some domestic installations may soon benefit from Permitted Development Rights. If planning permission is required, only certain information should be requested by planning officers, based on national guidelines. It may be necessary to conduct a structural survey and notify the local DNO before installing and connecting a turbine.

Figure 21 shows the information in this section in the form of a flow diagram. This is a summary rather than exhaustive advice, and other sources of guidance[87] may be consulted in addition.

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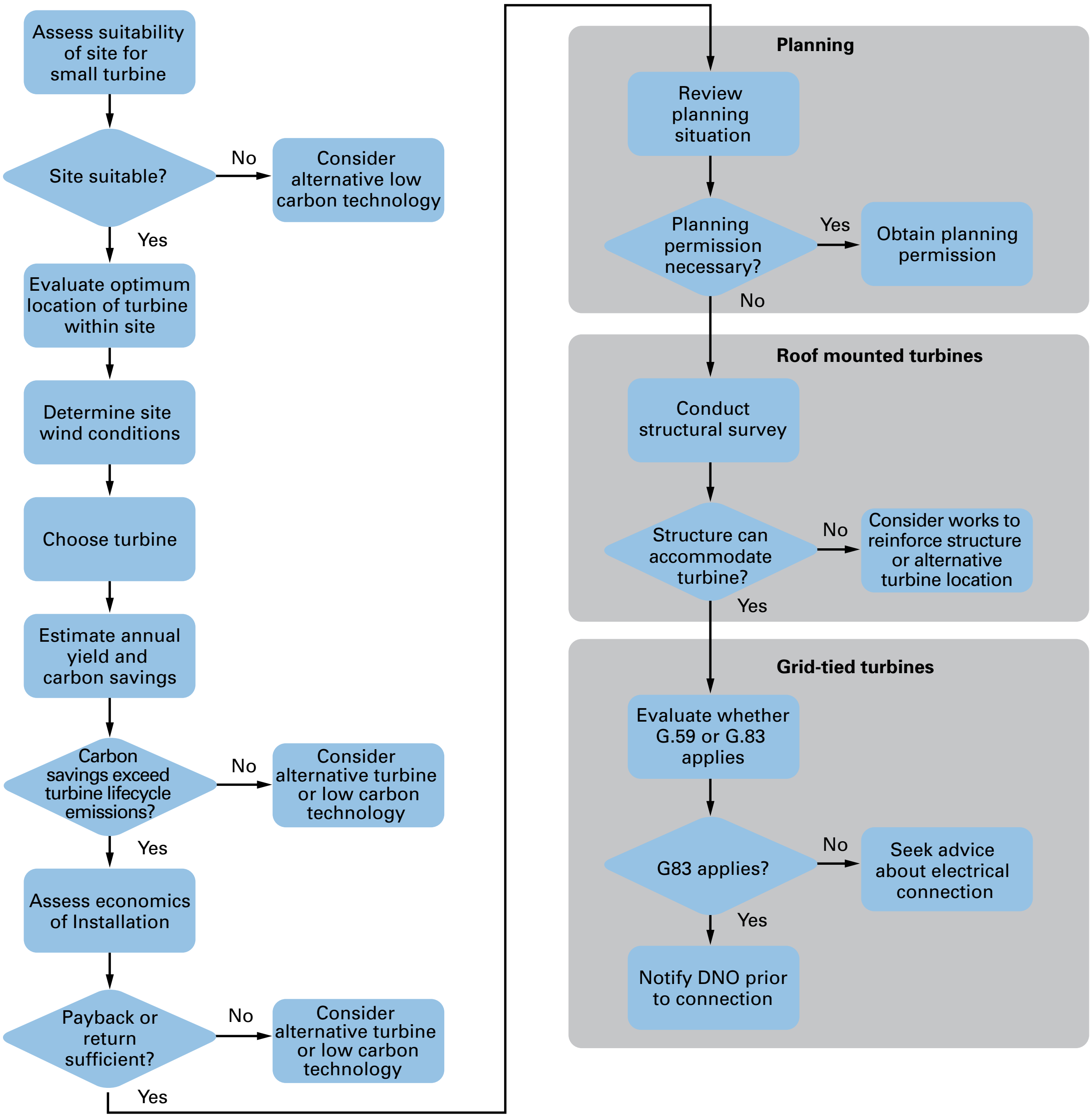
[87] Provided by the BWEA, for example.

Figure 21: *Summary flowchart for organisations considering installing small wind turbines*

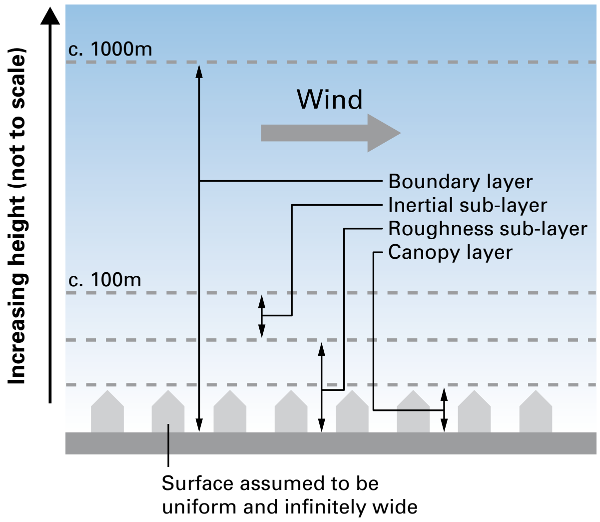


In practice, some of the steps may be taken by an installation company acting on a site owner's behalf, actions in the second column may be done in parallel with those in the first, and the order of actions in the second column may vary. Items not shown but which require consideration include:

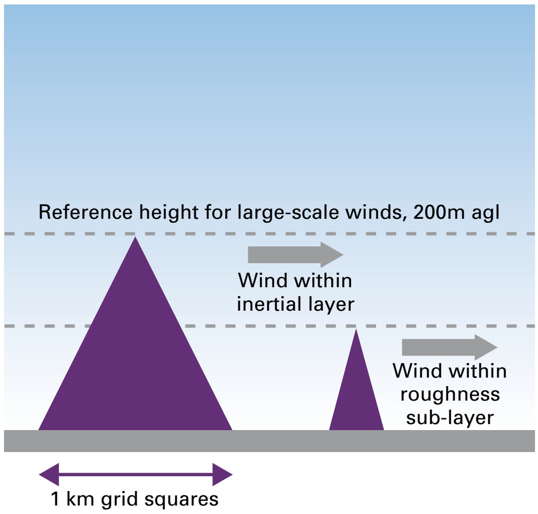
- Consulting neighbouring households and organisations in the context of planning;
- Arranging an export tariff; and
- Registering with Ofgem to receive ROCs and LECs, or appointing an agent to do this.

Appendix: Technical description of carbon prize estimation methodology

Main layers at which winds behave in different ways



Representation of layers in Carbon Trust methodology



Here is an overview of the methodology used to assess the carbon prize of UK small-scale wind energy. For further details and references to the sources of data, see the Technical Report.

The two charts above help illustrate steps 1 and 2 of the methodology.

- The left hand chart illustrates a number of conceptual layers in the air, at each of which the wind can be considered to behave in a certain way. At the top of the boundary layer, the ground and its features have very little impact on wind conditions. But close to the surface, their effects are very significant. The closer one moves towards the ground, the more wind conditions change over small distances.
- The right hand chart illustrates how the layers were represented in steps 1 and 2.

1. Identify and prepare an appropriate source of wind speed data at a very high level above ground.	• The starting point was a reference wind speed dataset whose data are uniformly valid across the country, at a certain height and over a standard surface. For the UK, two such datasets are readily available: one known as NOABL and the other held by the Met Office National Climate Information Centre, NCIC. The box on page 12 introduces the two and explains why the NCIC data were chosen. • The first calculation step was to scale the 10m NCIC data up to a reference height of 200m. This was to represent conditions near the top of the boundary layer, assumed to be unaffected by local surface characteristics.

2. Transform this in certain ways to estimate the wind speeds at the actual hub heights of turbines, effectively ‘zooming in’ through layers in the atmosphere.	• The regional wind speeds were then adjusted to lower heights, known as blending heights, which are within the inertial sub layer and vary according to ground cover (tending to be higher in built-up areas). Generally, the blending heights are still well above the hub heights of turbines. • Following this, the speeds at the blending heights were adjusted further to represent conditions at turbine hub heights. This was by applying shear profiles representative of typical urban, suburban and rural sites. The profiles were selectively applied to each square kilometre area of the UK by considering the area’s ground cover, and therefore roughness, based on satellite-derived and land use data.
3. Use the wind speed data and selected turbine power curves to estimate the annual yields of turbines, assuming they are widely deployed without any economic constraints.	• With estimates of the long-term annual mean wind speeds at turbine hub heights, it was possible to estimate the power that could be produced by turbines installed in each square kilometre. For this purpose, six different types of turbine were selected, with a range of rated capacities between 1 kW and 15 kW. Three of the turbines are suitable for pole mounting in rural locations, while the other three are intended for urban areas, two by roof mounting. A realistic range of hub heights was considered. • The annual yields of the turbines were estimated by combining their power curves[88] with wind speed distributions based on the mean speeds[89]. This produced a set of ‘energy maps’ across the UK – 18 in total, allowing for various combinations of turbine, hub height and location type. To estimate the total energy producible across the UK, yield figures were selected from amongst the energy maps according to census data describing the geographic distribution of location types (rural and urban) and population densities.
4. Apply economic constraints to give a realistic estimate of how much energy might actually be produced, then convert this into carbon.	• The result of step 3 was a theoretical maximum energy yield for UK small-scale wind energy, based on the assumption that every household has a turbine installed. However, due to the costs of turbines and variations in the wind resource, some locations will be more economically attractive than others. To reflect the range of economic attractiveness, discounted cash flow calculations[90] were made for all potential installations to estimate their costs of energy. The result was the cost-resource curve shown in *Figure 9a*. • Due to economic attractiveness and other factors, not all households are likely to install turbines, and penetration of the domestic market will therefore be less than 100%[91]. The same is true of the market for commercial buildings, occupied by businesses and public sector organisations. Data limitations meant that it was not possible to explicitly model installations of small turbines supplying commercial buildings. • To give an indication of the total generation and carbon savings that might realistically be achieved by UK small-scale wind energy, including both domestic and commercial buildings, it was assumed that the total number of domestic houses and commercial buildings likely to install turbines is equal to 10% of the total number of households; that is, 10% penetration of the domestic market. This is equivalent to dividing the figures based on every household having a turbine installed by ten. In future, this assumption could be updated by further research incorporating market analysis.

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[88] Provided in the turbine manufacturers’ sales literature.

[89] Generally assumed to be Weibull with a shape factor of 1.8.

[90] Using a 5% discount rate, chosen to represent the opportunity cost to consumers of not investing in a typical consumer financial product.

[91] This assessment did not extend to market analysis to estimate a likely level of market penetration, although work of this kind has been published by the Energy Saving Trust. See “Generating the Future: An analysis of policy interventions to achieve widespread microgeneration penetration”, EST, November 2007.

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Micro wind turbine, Northumberland
SIMON FRASER/SCIENCE PHOTO LIBRARY

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