WIND FARM SITING ISSUES IN AUSTRALIA

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This document is a detailed briefing paper discussing the siting issues associated with wind farming in Australia. This paper was prepared as background information for the preparation of a fact sheet for dissemination to the general public. As a result this document, any related documents (listed below) and the fact sheet itself attempts to be as non-technical as possible and sometimes goes to great pains to explain what may appear to be quite obvious to someone intimately involved in either wind energy or specific environmental issues.

However, as is often the case, such attempts may unintentionally oversimplify the issue or present information in a distorted way. We may also have made errors or omissions in the preparation of this document. Please do not hesitate to forward any suggested changes or additions to this document to Grant Flynn at Sustainable Energy Australia (Grant@SustainableEnergyAustralia.com.au).

Where possible footnotes have been provided within the text to allow the reader to consult the source article directly.

This document should be read in conjunction with the following sub-documents;

- None

This document has also been distilled into a very brief fact sheet of just 2 pages which can also be downloaded from the AusWEA: Australian Wind Energy Association web site at www.auswea.com.au.

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TABLE OF CONTENTS

SOURCES OF INFORMATION

- American Wind Energy Association
  http://www.awea.org/faq/noisefaq.html
- Wind Energy Conversion Systems
  NMIT Course Notes
- Danish Wind Energy Association
  www.windpower.org

SUMMARY

What is a Wind Farm Developer Looking for in a Site?

The sites selected for wind farm development need to have many positive attributes including;

- Superior wind speeds
- Close to suitable electrical grid
- Privately owned freehold land
- Land use is primarily for grazing or cropping
- Community Acceptance
- Low population density
- Good road access to sites
- Suitable terrain and geology for on site access
- Significant tourism infrastructure in place
- Good industrial support for construction and ongoing operations
- Significant potential for revegetation
- Minimal risk of agro-forestry operations

The selection of wind farm sites is not simply a matter of ticking off against desirable features. As with most things in life, it is a matter of compromise and finding the best overall outcome in the face of competing factors.

It is perhaps obvious that a wind farm relies on a site with a good wind resource. However, what is perhaps not so obvious is the great importance of wind speed to a wind farm's financial success. It is technically feasible to build a wind farm anywhere; given enough time and money almost any technical obstacle can be overcome. However the reality is that a wind farm needs to be financially successful. The wind resource is the primary siting issue and will certainly be a dominant criterion.

So just how windy does it have to be, to be windy enough? It will vary according to circumstances of each site but on the whole they will need to be very windy locations here in Australia.

The main reason for this is the cubic relationship between wind speed and the energy in the wind. If you double the wind speed then the energy available in that wind is increased eight fold. Just a 15% percent increase in wind speed adds 50% to the energy available and only a 26% increase is required to double the energy available. Likewise, a halving of the wind speed reduces the available energy to an eighth. Just a 20% reduction in wind speed means a halving of the wind energy.

A wind farm will cost essentially the same to build in a calm location as it will in a windy location. However the more electricity a wind turbine can produce the lower the price that needs be charged per unit of electricity to recover costs and earn a profit for the investors. This means that in a windy place a wind farm operator can sell the electricity for a lower price while still being able to pay back its loans, pay its bills and make its profits.

A large infrastructure project, like a utility scale wind farm, is financially quite complicated but in simple terms the financial success of a wind farm relies on a balance between the capital costs of the project against the volume of electricity sold. Seemingly minor variations in wind speed have a dramatic impact on the financial success of the wind farm because of the dramatic impact on revenues.

In a location where relatively high prices can be charged for electricity (e.g. remote communities, islands, etc) it is possible to build small, expensive wind farms in low wind regimes. In the case of these remote locations it is simply that the alternative (e.g. diesel fuelled generation) is so expensive that wind becomes a simple choice based on cost. On the whole, Australia enjoys one of the lowest prices for electricity in the industrialised world. It is in this context, that wind farms will usually be constructed.

The Mandatory Renewable Energy Target sets a price cap or a limit on the price at which electricity can be sold. This, combined with the limited scope for supply of renewable energy into our fossil fuel dominated system, means that competition is exceedingly high and prices must be quite low. The result is that wind farm developers are driven to finding sites with excellent (very high) wind regimes.

Factors Affecting Wind Speed

Wind speed is affected by several factors including;

- Geographic location
- Regional Terrain
- Surface Roughness
- Obstacles to the Wind

Geographic Location: The details of why this is important is beyond the scope of this document but suffice it to say that it is better to locate a wind farm in the southerly latitudes of the roaring forties rather than in the doldrums regions at the equator. The prevailing synoptic weather pattern is very important and heavily influenced by geographic location. However the influence of other factors such as surface roughness, terrain and obstacles becomes important near the surface of the earth where we build wind farms.

Regional Terrain: Hills, ridges and mountains can speed up the wind speed. A ridgeline across the prevailing wind, forces the wind to squeeze over the top of the ridge and speeds it up. This speed up effect of elevated terrain can be very important and can make a region that would otherwise be uneconomic for wind farm development into a suitable site.

Surface Roughness: The interaction between the free flowing atmosphere and the surface of the earth is very important. The roughness of the surface has a significant impact on wind speed, turbulence of the wind and the vertical wind speed profile. The rate at which wind speed increases with increasing elevation is determined mainly by the roughness of the surface of the earth over which it is flowing.

The impact of surface roughness is greatest in the lowest layer of the atmosphere where we will locate a wind farm. Very smooth surfaces (e.g. sea or ice) have only a minor impact. This is why off-shore and coastal sites are sought as potential wind farm sites – the wind has very low turbulence and the speed is typically quite a lot higher than inland sites.

Rougher surfaces can significantly slow the wind and introduce significant turbulence into the flow of air (further reducing the ability of a wind turbine generator to capture its energy). Even a mature wheat crop will slow the wind down more than closely grazed pasture. Scattered trees will have an even greater effect.

The worst case is that of dense buildings seen in city centres. While tall buildings can funnel the wind down city streets at very high speeds, the wind is very turbulent (as many an umbrella holding city worker can attest!). The influence of the city buildings is seen very high above the ground.

The further the wind travels over rough surfaces the more it will slow down the wind in the lower layer of the atmosphere. This is why the wind is much calmer at inland sites and why these sites are generally not as attractive to wind farm developers.

The influence of surface roughness on the vertical wind speed profile (wind shear) varies from place to place and needs to be measured using instruments at various heights above ground level. The difference between the wind speed at 10m above ground and 60m above ground can be quite significant and differences in excess of 20% are not uncommon.

Obstacles to the Wind: Any obstacle will cause the wind to slow down and introduce turbulence into the wind. The impact of an obstacle will be determined by its height, its width and its porosity to the wind. Turbulence will be seen all around the obstacle not just downwind. While the largest influence is seen in the downwind direction turbulence will also be introduced up wind, either side and across the top of the obstacle. This is analogous to placing a large stone in a steady flowing stream - we can see the turbulent flow all around the stone with the greatest impact downstream.

Wind farm developers will endeavour to avoid buildings, large windrows, forests and any other large obstacle to the flow of the wind. To give an idea of how dramatic the impact can be consider a site with open pasture and a single row of pine trees that are about 20m high and 100m wide. A wind turbine on a 50m high tower, placed 500m downwind of the windrow will experience an 8% reduction in energy. Even if at 750m downwind a 5% reduction in energy is still seen.

The factors described above explain why wind farm developers will generally look for sites near the coast, but also why this is not always the case. Other geographic features can be important such as land sea interface (to take advantage of sea breezes, etc).

Other Siting Issues

Close to Grid: A wind farm produces a large amount of electricity and the interconnection power lines to the existing electricity grid are quite expensive. The further we go away from the grid the more expensive the connection becomes. The added expense of long interconnections is “dead” money in that it does not increase the earning potential of the wind farm.

Unfortunately not all the places close to power lines are as windy as those that aren’t. Sometimes it is better to move away from the power line to take advantage of stronger wind speeds.

Sparse Population: Sparsely populated areas are more attractive as it ensures fewer people are involved in or directly impacted by the wind farm. Wind farms are spread over large areas of land and the layout design process is complicated enough without having to dodge residential buildings.

Private Land: While there is usually no specific reason against the use of public land the decision making process of “land holders” is often more complex and protracted in the case of public land. This makes privately owned land more attractive to a developer. Wind farm developers will on the whole disregard out of hand sites in world heritage areas, national parks, state parks, flora and fauna reserves, etc. However this may not mean that wind energy cannot be used in these areas. For example wind turbines are progressively being installed at our Antarctic bases so as to reduce the use of diesel power generation and several National Parks have small wind turbines for the generation of electricity or water pumping at camp sites, etc.

Road Access: Accessibility to a wind farm site is important for construction and for the ongoing operation and maintenance of the wind farm. Construction access is usually more problematic because of the large vehicles and loads that need to be brought onto site. Steep gradients and unstable surfaces are avoided where possible so as to minimise construction costs.

Low Environmental Impact: The ecological characteristics of a wind farm site are an important consideration and so it is an issue that is taken into consideration from an early stage in the development process. It is important to identify potential impacts and to allow determination of the options for mitigation of adverse impacts and maximisation of benefits. The clearing of vegetation is avoided as much as possible even if studies indicate that it is low scientific significance.

Soil / Ground Conditions: Wind turbine generators require very solid foundation to secure the large structure in high wind conditions. The location, type and cost of the foundation is largely determined by ground conditions. Clearly swampy or unstable ground is not likely to be acceptable.

Soil Erosion and Water Quality: With proper construction techniques and good maintenance a well designed wind farm should have no adverse impact on soil erosion and water quality. Control of these issues is a part of normal best industry practice. Where possible all removed soil is used on site and run off is controlled and diverted away from disturbed soil.

Community Acceptance: An important criterion is landowner support and general acceptance by the local community. Having a majority of the community in support of a proposal is important in the planning stage of a wind farm to maximise local benefits through constructive negotiation.

Wind farms enjoy widespread support in the wider community and engender a great deal of interest with thousands of visitors a year. Education of the public in regard to renewable energy, local Landcare and revegetation programmes and the regional history and culture is highly desirable. It is important that the local tourism infrastructure is able to cope with the tourists (or can be made to do so) to allow interpretation of and interaction with these aspects of the project.

Cultural Resources and Values: Typically a study will need to be undertaken of the general area and the proposed wind farm site itself to identify any sites of cultural, archaeological or historical significance. Initially a “desktop audit” is conducted by recognised specialists who have a sound knowledge of the region are used to conduct these studies. Where there is a possibility of unknown cultural artefacts being discovered a qualified archaeologist will carry out surveys on site during construction to ensure sites of cultural or archaeological important are treated appropriately.

Land Use and Local Amenity: Proximity to local facilities such as airports is important when siting a wind farm and land use is a key issue in determining the layout of a wind farm. The long life span of a wind farm means that it is important to consider not just the present uses but also the future uses of the adjacent land when selecting a site.

While wind farming is compatible with many land use activities, agro-forestry is not an ideal partner for wind energy. This is because trees interfere with the flow of wind – slowing it down and causing turbulence. Wind energy is however a very good partner with grazing, cropping and rehabilitation of coastal vegetation. This means that there is often a good fit with the existing land use of grazing and cropping and with the aspiration of rehabilitating the indigenous vegetation.

The revenues derived from the wind farm operation may allow some easing of the agricultural pressure on the land (i.e. reduce stock loading or revegetation of sensitive areas) Revegetation will usually be acceptable to the developer as it does not have the same scale of impacts of agro-forestry. Sites with established revegetation projects may be quite attractive to some wind farm developers as this can be an indication of increased environmental awareness.

Sufficient Land: Wind turbines need to be spaced some distance apart so a large area of land is required. However the actual area covered by the turbines and associated infrastructure is small (typically less than 1%). The remainder of the site can be used for farming or grazing as per usual.

Often a developer will accept an area that involves more than one landholder, however this becomes problematic if each individual land holding is too small – the number of landholders involved simply becomes too difficult to manage. Furthermore not all the land on one particular property might be suitable for wind farming. For example a developer may be trying to place their wind farm across a ridge where the ridge is only a small part of the holdings of several owners. In this case the amount of land involved and the number of owners may become quite large.

Residential Dwellings and Noise Emissions: Wind farms are very quiet machines, however the rural setting in which they are often built means that to comply with the very strict noise emission levels imposed on wind farms in Australia (some of the most stringent in the world) the relative location of residential dwellings becomes important in selecting a wind farm site.

Adequate separation distances are the primary tool for preventing noise problems. Just how far away from a dwelling the wind turbines need to be can really only be determined on a case by case basis but ranges from 300m to 800m according to a variety of features including the total number of wind turbines near the dwelling.

Why are Wind Turbine Generators so High?

Obviously we need to make sure the rotor is high enough above the ground to allow it to rotate without hitting the ground. The longer the blades, the greater the area swept by the rotor and the more energy the wind turbine generator is able to capture. However it is a square relationship and only a small increase in rotor blade length is required to dramatically increase the power of the wind turbine generator.

Capacity (MW)	Radius (m)
0.25	14
0.50	21
0.75	22
1.00	27
1.50	32
2.00	36
2.50	40

Wind shear is also important in determining the height above the ground. The higher we go the faster the wind speed. However, taller towers cost more to build. This extra cost must be balanced against the revenue gains from the increased wind energy.

Another important factor is the aesthetics of the wind turbines themselves. Generally a large utility scale wind turbine generator will look properly balanced if the blades come about half way down the tower. If the tower is too short, then the machine appears squat, if the tower is too tall it looks to be disconnected from the ground.

Why are Wind Farms Where They Are?

Tops of Hills? The wind speed is significantly higher at the top of a hill than it is in the valley below. This is because of the speed up effect of the hill itself and also because the hill will help place the wind turbine higher up in the vertical wind speed profile. Even quite modest increases in wind speed gained from being on the top of a hill can make the difference between a financially successful wind farm and an abandoned site.

Why Not Inland? Wind farms are generally sited near the coast to take advantage of the stronger winds. The smooth surface of the sea means the wind is not slowed down very much. Near the coast the wind farm may also take advantage of sea breezes especially on hot summer afternoons. Generally an inland site will need significantly elevated terrain to be acceptable.

Off-Shore? At this stage off-shore wind farms are still quite rare with only a handful around the world today. However a significant number of offshore projects are proposed in some countries.

Off-shore wind farms are very expensive to build and here in Australia our electricity prices are very low. This means that few if any developments can carry the added cost of off-shore construction. There are suitable sites on shore with comparable wind speeds to what might be found offshore.

We have very few wind farms in Australia and there is still plenty of room for development on shore. For comparison, in 2002 Germany installed 3,248 MW of wind energy to bring them to a total of 12,001 MW compared to Australia's total of 105 MW). For the time being wind farm development in Australia will primarily be located on-shore.

In the Out-Back? Australia has many remote areas where concerns of noise or visual amenity may not be an issue. In general though, the wind speeds are rarely sufficient and the cost of building very long power lines to connect the wind farm to the existing electricity network is prohibitively expensive. So while technically feasible it would not be financially sensible.

In remote communities where electricity is supplied from diesel power, wind turbines can be used to reduce diesel consumption. However theses wind farms supply only the needs of the community itself and consequently tend to be quite small.

How Far Apart and Why?

A variety of factors come into play in determining the distance between turbines and between turbines and other structures. The development of a wind farm is a complex and iterative process where a compromise must be found amongst several competing factors.

Inter-Turbine Separation: is determined by several factors. At the extremes they need far enough apart to allow the turbines to follow the wind (yaw) without colliding with each other. Likewise we do not want them so far apart that the cost of the interconnecting cables is prohibitively expensive.

So where is the happy medium? The main determinant of separation distance is wind speed and turbulence. A wind turbine generator necessarily removes some of the energy from the wind and causes turbulence. So downwind there is an area in which it would not be economic to place another wind turbine generator.

The surrounding unaffected wind will impart some of its energy to this slow and turbulent wind and the turbulence will be dampened and the wind speed will come back to that of the surrounding wind. We normally will wait until it comes back up to about 98 or 99% of the original power level before placing another machine downwind. The volume of air that is affected is determined by the diameter of rotor so separation distances can be expressed in multiples of the rotor diameter.

The rule of thumb used is for a downwind separation of wind turbine generators of between 5 and 7 rotor diameters. The influence of a wind turbine generator across the wind is no where near as great and could place a wind turbine as close as one rotor diameter apart across the wind. However the wind does not come from only one direction so we cannot do this in real life.

The detailed wind monitoring conducted on a site gives us a very good understanding of the prevailing wind energy direction for a site (may be different to prevailing wind direction). In general wind turbine generators will be separated by 3 to 5 rotor diameters across the prevailing wind energy direction and by 5 to 7 rotor diameters with the prevailing wind energy direction.

Layout Issues: involve more than inter-turbine separation, otherwise all wind farms would be simple rectilinear arrays. In most cases the development of a wind farm layout will be much more complex. Again several factors will come into play to varying degrees according to site conditions.

One factor is changes in elevation of the area. For example a ridgeline that spans across the prevailing wind direction may result in a line (or lines) of wind turbine generators following the contours of the ridge. In undulating areas, there is no point placing a turbine behind a small hill where wind speeds will be significantly lower simply because you have reached an appropriate inter-turbine separation distance if moving another 100 metres or so can significantly increase the wind energy the machine will be exposed to.

Other factors include (but are not limited to) the noise (sound pressure levels) to which nearby residences are exposed, aesthetic appearance of the wind farm (e.g. following natural contours in the landscape rather than straight lines), avoiding areas of important native vegetation (either for its innate or habitat value) or avoiding sites of cultural or archaeological significance.

Complicated three dimensional computer models help us to see how the air flows over the site, how noise propagates, estimate energy production, etc. The many complex, and often competing issues involved in a wind farm development can be plotted to form a geographical information systems (GIS) which allows for thematic mapping of the site according to various criteria.

How Much Land Do I Need for a Wind Farm? This is a simple question but is quite difficult to answer. Wind farms today are not as large as they once were. During the 1980’s very large wind arrays were built (e.g. San Gorgonio Pass - Palm Springs, nearly 3,000 machines; Tehachapi Pass - over 6,000 machines!). Today a large utility scale wind farm will typically involve in the order of 20 to 50 wind turbines. How they are located across a site will vary according to the site itself and the needs of the developer.

A wind farm with twenty 1.5MW wind turbine generators could be placed in an area of just 100 Hectares. However the local terrain, etc will probably mean that a larger area will be required. Often a developer will accept an area that involves more than one landholder, however the more landholders involved the more difficult it is to manage.

Furthermore not all the land on one particular property might be suitable for wind farming. For example a developer may be trying to place their wind farm across a ridge where the ridge is only a small part of the holdings of several owners. In this case the amount of land involved and the number of owners may become quite large.

MAIN DOCUMENT

What Are Developers Looking For in a Wind Farm Site?

The sites selected for wind farm development need to have many positive attributes including;

- Superior wind speeds
- Close to suitable electrical grid
- Supportive landholders
- Significant tourism infrastructure in place
- Good industrial support for construction and ongoing operations
- Privately owned freehold land
- Land use is primarily for grazing or cropping
- Significant potential for revegetation
- Low population density
- Minimal risk of agro-forestry operations
- Good road access to sites
- Suitable terrain and geology for on site access

The selection of sites for wind farm development is not simply a matter of ticking boxes on a list of desirable features. As with most things in life, it is a matter of compromise and a cost benefit analysis of positive features against negative ones.

In the following sections a number of the key issues are discussed in detail; however the iterative nature of the development process and balancing of a site's attributes needs to be kept at the forefront of our minds.

Wind Resource

It is perhaps obvious that a wind farm relies on having access to a good wind resource and that a wind farm site needs to have a relatively high average wind speed to be successful. However what is perhaps not so obvious is the very great importance of wind speed to a wind farm's financial success. In fact the wind resource is almost always the primary siting issue and will usually dominate over all other selection criteria.

So just how windy does it have to be to be windy enough?

The answer will depend upon a number of factors. To human perception, two sites that are both quite windy will seem the same but a small difference in the wind regime can have a dramatic effect on the energy captured and converted into electricity. Sophisticated instruments and long periods of detailed recording are required to differentiate between a suitable and unsuitable site.

The reason for this is the cubic relationship between wind speed and the energy in the wind. This relationship means that if you double the wind speed then the energy available in the wind is increased eight fold. In fact, just a fifteen percent increase in wind speed will result in a 50% increase in the energy available for conversion to electricity and a 26% increase in wind speed will double the energy available.

Of course this relationship works the same way for a decrease in wind speed. A halving of the wind speed will reduce the available energy to one eighth. Even a 20% reduction in wind speed will result in a halving of the wind energy available for capture.

A critical aspect of any capital-intensive project is to establish long term revenue flow to justify the investment of the capital. As for any business, the banks will not lend money to a business unless they are sure that the business has a good chance of repaying the loan principal and interest.

For an electricity project the revenue comes from the sale of electricity and the security comes from reliable technology and good market analysis. It is important that long term contracts to sell the electricity, at agreed prices, are established prior to the construction of a wind farm.

The wind regime of the wind farm site is very important in the economic success of the project. Wind farms are very capital intensive. The construction costs, or the servicing of debt incurred as a result of the construction, are the principle cost of wind generated electricity. The cost of operating and maintaining a wind farm will vary according to the wind regime of the site. The windier it is, the quicker service intervals will occur (similar to the more you drive a car the quicker the service intervals will occur). However the cost of operating and maintaining a wind farm is relatively low compared to the capital expenditure.

A wind turbine will cost essentially the same to build in a calm location as it will in a windy location. The more electricity a wind turbine can produce, the lower the price that need be charged per unit of electricity to recover costs and earn a profit for the investors. This means that in a windy place a wind farm operator can sell the electricity for a lower price while still being able to pay back its loans, pay its bills and make its profits. Therefore a key issue is the relationship between wind speed and energy generated (i.e. revenue). Because of the sensitivity of revenues to wind speed, seemingly minor variations in wind speed have a dramatic impact on the financial success of the wind farm.

In simple terms, the financial success of a wind farm relies on a balance between the capital cost of the project against the volume of electricity sold and the price at which it can be sold. As the gross revenue rises for the electricity a wind farm produces (either by an increase in price or an increase in volume or both) the wind regime that is acceptable becomes calmer or a more expensive a construction cost can be borne.

A large infrastructure project like a utility scale wind farm is more complicated than this of course with issues such as government policy, electrical grid strength and geometry, economies of scale, foreign exchange hedging, debt servicing costs, etc becoming important. However for the sake of this discussion we will keep the scenario fairly simple.

Different approaches have been adopted for wind farm development in different parts of the world based on the relationship between price and wind regime. In a location where relatively high prices can be charged for electricity (e.g. remote communities, islands, etc) it is possible to build small, expensive wind farms in low wind regimes. In the case of these remote locations, it is simply that the alternative (e.g. diesel fuelled generation) is so expensive that wind becomes a simple choice based on least cost.

Even in less extreme cases the price of electricity is very important. In European countries the price of electricity is significantly higher than here in Australia. This allows them to construct wind farms in regions with significantly calmer wind regimes or in places where the cost of construction is quite high (e.g. offshore wind farms). Many European countries have also made significant commitments to a shift away from fossil and fissile fuels and toward renewable energy resources such as wind. The resulting policies are also instrumental in increasing the uptake of wind energy and making the development of less windy places financially successful.

Australia enjoys one of the lowest prices for electricity in the industrialised world. It is into this context that the Australian wind energy community is attempting to develop an industry still in its infancy (relative to other countries). Here in Australia the Mandatory Renewable Energy Target – established through the Renewable Energy (Electricity) Act (Cth) - sets a price cap or a limit on the price at which electricity can be sold. This, combined with the currently limited scope for supply of renewable energy into our fossil fuel dominated system, means that competition is exceedingly high and prices must be quite low. The result is that wind farm developers are driven to finding sites with excellent wind regimes.

Factors Affecting Wind Speed

Wind speed is affected by several factors including;

- Geographic location
- Regional Topography
- Surface Roughness
- Obstacles to the Wind

Geographic Location

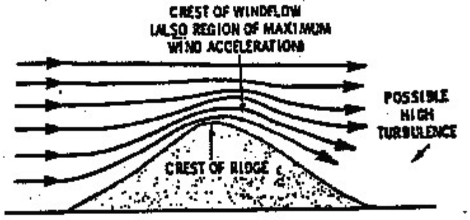
The latitude of the area is quite important because different parts of the globe are exposed to different wind regimes. The details of why this is the case is beyond the scope of this document but suffice it to say that it is better to locate a wind farm in the roaring forties (latitudes around 40 to 50 degrees) rather than in the doldrums regions at the equator.

Latitude is one of the most important factors in determining the influence of the global circulation of air in the upper atmosphere. The prevailing synoptic weather pattern is very important however the influence of other factors become important near the surface of the earth. Of course this is where we propose to locate a wind farm and so they are important for wind farming too.

The main issues are regional orographic features (terrain), surface roughness and obstacles to the wind.

Regional Terrain

Hills, ridges and mountains have an important impact on wind speed. Quite often a ridgeline or a mountain range will act as a barrier to the prevailing wind and it forces the wind to squeeze over the top of the ridge, requiring it to speed up in the process.



This speed up effect of elevated terrain can be very important. It can make a region that would otherwise be uneconomic for wind farm development into a suitable site.

Surface Roughness

The interaction between the free flowing atmosphere and the surface of the earth is very important to wind farming because it is in this, the lowest layer of the atmosphere, that we will locate a wind turbine generator. The roughness of the surface has a significant impact on wind speed, the turbulence of the wind and also on the vertical wind speed profile. The rate at which wind speed increases with increasing elevation is determined mainly by the roughness of the surface of the earth.

Very smooth surfaces, such as the sea or ice, have only a minor impact on wind speed and do not slow it down very much. This is why off-shore and coastal sites are sought as potential wind farm sites – the wind has very low turbulence and the speed is typically quite a lot higher than typical inland sites.

Rougher surfaces can significantly slow the wind near the surface and introduce significant turbulence into the flow of air (further reducing the ability of a wind turbine generator to capture its energy). Even differing lengths of grass can have a noticeable effect on wind speed. A mature wheat crop will slow the wind down more than closely grazed pasture and scattered trees will have an even greater effect. The worst case is that of dense buildings seen in city centres. While tall buildings can funnel the wind down city streets at very high speeds the wind is very turbulent (as many an umbrella holding city worker can attest!). The influence of the city buildings on wind speed is felt very high above the ground.

The further the wind travels over rough surfaces the more it will slow down the wind in the lower layer of the atmosphere. This is why the wind is much calmer at inland sites and why these sites are not as attractive to wind farm developers (though orographic features can improve the situation as discussed in the previous section).

The influence of surface roughness on the vertical wind speed profile explains why wind farm developers need to install wind monitoring masts to a height equivalent to the proposed hub height of the wind turbine generators (or as close as they can get it). The wind profile (called wind shear) varies from place to place - even within the wind farm site - and needs to be properly measured. This is done using instruments mounted on the monitoring mast at various heights above ground level. The difference between the wind speed at 10m above ground and 60m above ground can be quite significant - a difference in excess of 20% is not uncommon.

OBSTACLES TO THE WIND

Any obstacle will have an influence on the wind and will cause the wind to slow down and introduce turbulence into the wind. The impact of an obstacle will be determined by its height, its width and its porosity to the wind. This is something that we experience in every day life. Standing close by, and in the lee of, a building on a windy day might mean that we experience no wind at all. The wind effectively blocks all the wind. However standing in the lee of a sparsely treed windrow, while reducing the wind speed, will still leave us blown about because it allows some of the wind to flow through the trees (i.e. it is porous). At a short distance from a building – even in its lee – we will find it hard to escape the wind and it may seem to be blowing from a variety of directions at the same time. In this case we are experiencing turbulence.

What is perhaps not so obvious is the extent to which obstacles affect the wind. Turbulence will be seen all around the obstacle not just downwind of the obstacle. While the largest influence is seen in the downwind direction, turbulence will also be introduced up wind, either side and across the top of the obstacle.

This is analogous to placing a large stone in a steady flowing stream (the wind is less dense, but still a fluid just like water). We can see the turbulent flow around and over the stone and travelling a great distance downwind.

Wind farm developers will endeavour to avoid buildings, large windrows, forests and any other large obstacle to the flow of the wind. To give an idea of how dramatic an impact an obstacle can have on the energy in the wind consider the following example. The area is completely open pasture but with a single row of pine trees that are about 20m high and 100m wide. A wind turbine on a 50m high tower is then placed 500m downwind of the windrow. Would you expect there to be any influence on the wind energy at the wind turbine? In fact the wind energy is only 92% of normal because of the row of pine trees. Even if we were to move the wind turbine back so that it is 750m downwind of the windrow the wind energy is still only 95% of what it would normally be.

The factors described above explain why wind farm developers will generally look for sites near the coast, but also why this is not always the case. Other geographic features can be important such as land sea interface (to take advantage of sea breezes, etc).

OTHER FACTORS AFFECTING SITING

For a wind farm here in Australia, there is a certain cost associated with the construction and operation of the wind farm. That cost must be recovered by selling electricity, for which the price is severely limited. There are therefore only two ways to improve the competitiveness of a wind farm (i.e. reduce the cost of the electricity being sold to acceptable levels);

1. Find high wind speed sites (i.e. maximise sales), and / or
2. Reduce the capital cost of the wind farm construction (i.e. minimise costs).

As has already been mentioned the sites selected by developers of utility scale wind farms have excellent wind speeds with consistently strong winds. This increases the volumes of their sales.

The other component of the equation here in Australia is the capital cost of the wind farm. The capital cost has several components; the most significant is the cost of the wind turbine generator nacelles and blades; however other important costs are those of the foundations, towers, roads, transport and connection to the electricity grid.

Currently the wind turbines must be imported from overseas, thereby incurring further costs (import duty, exchange rate risk, etc). This is changing as the level of activity in Australia increases, the industry is able to attract the foreign manufacturers to our country and domestic production will soon dominate the market. To reduce the capital costs wind farm developers will aim toward larger projects to achieve economies of scale. The sites selected will also need to have good road access and be in close proximity to large electricity grid infrastructure. These and several other issues are evaluated by the developer against the backdrop of the wind resource of the sites and are discussed in more detail below.

CLOSE TO GRID

A suitable grid connection is vital for a wind farm. Because they produce large amounts of electricity the interconnection from a wind farm's switchyard to the existing electricity grid of a typical wind farm is by three phases, at 66,000 Volts using overhead power lines. These typically cost between $100,000 and $200,000 per kilometre. So if a wind farm is not close to the grid there is a large cost associated with the construction of new lines. The further we go away from the grid the more expensive the connection becomes. The added expense of long interconnections is "dead" money in that it does not increase the earning potential of the wind farm.

Much of rural Australia has quite weak power lines (though often adequate for the small number of customers they supply). These "weaker" (lower capacity) power lines are not suitable for commercial, utility scale wind farms.

Unfortunately not all the places close to power lines are as windy as others. Sometimes it is better to move further away from the power line, despite the increased cost, simply because the more distant site is so much more productive.

SPARSE POPULATION

Wind farm developers will always prefer to site their wind farm in relatively sparsely populated areas. This is mainly to ensure that fewer people are involved in, or directly impacted by, the wind farm. Because wind farms are spread over large areas of land (for inter- wind turbine generator separation), areas that have a lot of residences will involve more people in the planning process and make the location of wind turbine generators within the site quite complex.

PRIVATE LAND

Developers will prefer to restrict their wind farm development to private land. While there is usually no specific reason against the use of public land, the decision making process of "land holders" is often more complex and protracted in the case of public land. Usually public land is owned by either local, state or commonwealth governments however they may be managed by one or more government departments or authorities or community members through complex management committees. The issue of native title may not have been resolved for the land and so further complicate the control of the land.

Wind farm developers will on the whole disregard out of hand sites in world heritage areas, national parks, state parks, flora and fauna reserves, etc. However this may not mean that wind energy cannot be used in these areas. For example wind turbines are progressively being installed at our Antarctic bases (a World Heritage Area) so as to reduce the use of diesel power generation and several National Parks have small wind turbines for the generation of electricity or water pumping at camp sites, etc.

ROAD ACCESS

Accessibility to a wind farm site is important for construction and for the ongoing operation and maintenance of the wind farm. Construction access is usually more problematic because of the large vehicles and loads that need to be brought onto site. The turbines are brought onto site in large sections and erected using very large cranes. Local roads need to be sufficient to allow the delivery of the turbine components and construction equipment.

During the life of the wind farm the access tracks to each wind turbine, established during the initial construction, would be maintained and are sufficient for the service vehicles (usually a commercial utility, van or light truck).

Steep gradients and unstable surfaces are generally avoided because of the added cost of cutting suitable gradients and stabilising loose surfaces.

LOW ENVIRONMENTAL IMPACT

The ecological characteristics should be taken into consideration in the siting of a wind farm and the wind turbine generators within it. Consequently this is an issue that is taken into consideration from an early stage in the development process so as to identify potential impacts and to allow determination of the options for mitigation of adverse impacts and maximisation of benefits.

The plants and animals that use an area for which a wind farm is proposed and how they use it are carefully studied. Important in these studies is determining the level of scientific and cultural significance of the species involved. Sometimes the importance of native grasslands or seemingly insignificant species is not fully appreciated unless detailed studies are undertaken. A proper understanding of the ecology of the site and how this interacts with the larger scale ecological system is an important part of windfarm development.

The clearing of vegetation is generally avoided as much as possible, even if studies indicate that it is low scientific significance.

SOIL / GROUND CONDITIONS

Wind turbine generators require very solid foundations to secure the large structure in high wind conditions. Therefore soil conditions must be assessed to determine the stability of the ground. The location, type and cost of the foundation are largely determined by ground conditions.

SOIL EROSION AND WATER QUALITY

With proper construction techniques, and good maintenance, a well designed wind farm should have no adverse impact on soil erosion and water quality. Control of these issues is relatively well understood and a part of good practice in the civil construction industry. On site inspection of the soil and ground conditions is used not just for the design of roads and foundations but also in the development of the environmental management plan for the project which will implement the techniques appropriate to the site for the control of soil erosion and maintenance of surface and ground water quality.

Where possible all removed soil is used on site. Run off is diverted away from disturbed soil and controlled using artificial barrier or existing vegetation.

COMMUNITY ACCEPTANCE

A key criterion in the selection of a site by wind farm developer is landowner support and general acceptance by the local community. While it is often difficult (if not impossible) to engender universal support from the community, having a majority of the community in support of a proposal is important in the planning stage of a wind farm.

In the broader community wind farms enjoy widespread support and engender a great deal of interest from the community. The wind farms that already operate around Australia attract many thousands of tourist each year (e.g. Esperance (WA) wind farms receive 40,000 cars per annum, Windy Hill (Qld) received over 60,000 visitors in its first few months of operation).

Education of the public in regard to renewable energy, local Landcare and revegetation programmes and the regional European and Indigenous culture is highly desirable. So it is important that the local tourism infrastructure is able to cope with the tourists (or can be made to do so) and also that it is able to provide interpretation of and interaction with these important aspects of the project.

CULTURAL RESOURCES AND VALUES

Typically a study will be undertaken of the general area and the proposed wind farm site itself to identify sites of cultural, archaeological or historical significance. Initially this may simply be a matter of conducting a "desktop audit" to identify any issues that need to be addressed during the wind farm planning. Recognised specialists who have a sound knowledge of the region are used to conduct these studies.

Where there is a possibility of unknown cultural artefacts being discovered, a qualified archaeologist will carry out surveys and be present on site during construction to ensure sites of cultural or archaeological important are treated appropriately.

LAND USE AND LOCAL AMENITY

Proximity to local facilities such as airports is important when siting a wind farm. Land use is often a key issue in determining the layout of a wind farm. The long life span of a wind farm means that it is important to consider not just the present uses but also the future uses of the adjacent land when selecting a site. The need for a strong wind regime has meant that wind farm development has primarily occurred in rural and relatively open areas. These lands are often used for grazing, cropping, recreation, nature reserves and more recently forest management (or agro-forestry).

While wind farming is compatible with many land use activities, agro-forestry is not an ideal partner for wind energy. This is because trees interfere with the flow of wind – slowing it down and causing turbulence. This is not surprising given that we have been planting trees as windbreaks for generations. What may be surprising is that because of the sensitivity of energy on wind speed, agro-forestry has a measurable negative impact on wind energy for several kilometres downwind.

Wind energy is however a very good partner with grazing, cropping and rehabilitation of coastal vegetation. This means that there is a good fit with the existing use of grazing and cropping and with the aspiration of rehabilitating the indigenous vegetation. The sites therefore have significant potential for positive social and environmental outcomes.

The revenues derived from the wind farm operation make the land more fiscally productive. This can allow relief of the agricultural pressure on the land (i.e. reduce stock loading or revegetation of sensitive areas) and financial pressure on landowners.

Revegetation of coastal flora does not have the impacts of agro-forestry on wind. Coastal vegetation tends to be low, dense and shrubby. While this does reduce the energy in the wind compared to open grazing land or flat water, the reduction can be within acceptable limits.

Sometimes a developer will be attracted to a site where revegetation programmes are already underway, as it can be an indication of increased environmental awareness.

SUFFICIENT LAND

Wind turbines need to be spaced some distance apart therefore a large area of land is required. However the actual area covered by the turbines and associated infrastructure is quite small (typically less than 1%). The remainder of the site can be used for farming or grazing as usual.

At the Codrington Wind Farm the fourteen wind turbine generators are spread across an area 2,400 metres long and 500m wide and also spreads across two neighbouring properties.

Often a developer will accept an area that involves more than one landholder, however this becomes problematic if each land holding is too small – the number of landholders involved simply becomes too difficult to manage.

Furthermore, not all the land on one particular property might be suitable for wind farming. For example a developer may be trying to place their wind farm across a ridge where the ridge is only a small part of the holdings of several owners. In this case the amount of land involved and the number of owners may become quite large.

Residential Dwellings and Noise Emissions

Wind farms are very quiet machines. However the rural setting in which they are often built means that to comply with the very strict noise emission levels imposed on wind farms in Australia (ironically some of the most stringent in the world) the relative location of residential dwellings becomes important in selecting a wind farm site.

The only noise from a wind farm that is audible at any great distance (i.e. more than 100m from the base of the tower) is the aerodynamic noise of the blades as they move through the air. Much of this noise is masked by background noise (e.g. the wind moving through grass and trees etc) and noise of all kinds falls off sharply with distance. Adequate separation distances are the primary tool for preventing noise problems.

Just how far away from a dwelling the wind turbines need to be can really only be determined on a case by case basis but ranges from 300m to 800m according to a variety of features including the total number of wind turbines near the dwelling.

Why Are Wind Turbines on the Tops of Hills?

As discussed in the previous sections, the wind speed is significantly higher at the top of a hill than it is in the valley below. This is because of the speed up effect of the hill itself and also because the hill will help place the wind turbine higher up in the vertical wind speed profile. The sensitivity of the energy in the wind to the speed of the wind means that even quite modest increases in wind speed that are gained from being on the top of a hill can make the difference between a financially successful wind farm and an abandoned site.

Why Are Wind Turbines So High?

There are two main reasons for the height of wind turbines. The first is fairly obvious – we need to make sure the rotor is high enough above the ground to allow it to rotate without hitting the ground. The longer the blades, the greater the area swept by the rotor and the more energy the wind turbine generator is able to capture. Because the relationship between the rotor blade length and the area swept by the rotor is a square relationship [the area of a circle is given by $\pi(\text{radius})^2$] only small increases in rotor blade length is required to dramatically increase the power of the wind turbine generator. From the table below we can see that doubling the rotor radius from around 20 metres to 40 metres has quadrupled the power capacity of the wind turbine generator. This means that modern machines are not that much bigger than their predecessors and yet produce considerably larger quantities of power.

Turbine Capacity (MW)	Rotor Radius (m)
0.25	14
0.50	21
0.75	22
1.00	27
1.50	32
2.00	36
2.50	40

The second factor that is important for wind turbine height is the vertical wind speed profile of the area. The higher above the ground we go the faster the wind speed. The rate at which the wind speed increases with increases in altitude will depend mainly upon the surface roughness of the area. Again the sensitivity of the energy in the wind to small changes in wind speed means that manufacturers will try to build as tall a tower as possible so as to expose the wind turbine generator to the highest wind speed they can.

Other factors come into play however. The higher the tower the more expensive it and its foundation become. This is because it must be built stronger to hold up the extra weight of tower and because the moment of the tower is greatly increased (the tower is like a long lever and the push of the wind is the thrust on the top of the lever). This extra cost must be balanced against the revenue gains from the increased wind energy.

Another important factor is the aesthetics of the wind turbines themselves (i.e. the visual impact of the machine). While wind turbine generators are necessarily very large machines, most people will find it very difficult to tell the difference between a 1 MW machine on a 50m high tower and a 1.5 MW machine on a 65m high tower However because of our ability of comparison and pattern matching a large utility scale wind turbine generator will generally look properly balanced if the blades come about half way down the tower. If the tower is too short, then the machine may appear squat and if the tower is too tall the machine may appear “disconnected” from the surface.

Why Are Wind Farms on the Coast

Wind farms are generally sited near the coast to take advantage of the stronger winds that are experienced here. The winds are stronger on the coast mainly because of the lower surface roughness - i.e. the wind is not slowed down much by the water air interface.

Another advantage of being near the coast is that the wind farm is able to take advantage of sea breezes that are caused by the differential heating of the land compared to the heating of the water. Land heats up more quickly than water and the warm land causes the air to rise, thereby drawing the air above the cooler water on shore. This can provide a good steady wind, especially on hot summer afternoons. This can be important in increasing the value of the wind energy to an energy retailer because it may to some extent deliver more power at the time of day when demand for electricity is higher.

Why Not Put Wind Farms Out to Sea?

About two thirds of Australia’s territory is actually covered by the sea because of our control of waters to 200km from our shores. One might therefore think that we have the ideal conditions for off-shore wind farm development. While the wind resource is much greater out to sea - because of the relatively smooth surface of the water and lack of obstacles to the wind - the cost of construction of a wind farm out to sea is significantly higher.

In some countries (especially in Europe) most of the windy places on land have either already been taken up by wind farms or are precluded from development for other reasons (many European countries are densely populated making wind farm development difficult). Added to this, is the relatively high prices for electricity that can be obtained in these countries and significant government incentives for the construction of renewable energy projects.

As a result there is a move toward the development of wind farms out to sea in these countries. At this stage, off-shore wind farms are still quite rare; with only a handful of such projects in existence around the world today. However, a significant number of new projects are being proposed in some countries for development off-shore.

Off-shore wind farms need to be located in relatively shallow water and where wave energies are low - to reduce the cost of the construction of the foundations and mounting platforms for the wind turbine generators. The wind farm itself also needs to be located relatively close to shore at a point where a connection to a part of the electricity grid with suitable capacity can be achieved. This helps to control the cost of the electrical interconnection of the wind turbine generators (submarine cabling is very expensive). These factors make finding a suitable location more problematic.

Most of Australia’s waters have water too deep, waves too strong or are simply too far from grid connection points to make it worthwhile. Furthermore, our electricity prices are very low and this means that few if any developments can carry the added cost of off-shore construction. Essentially there are suitable sites on shore with lower construction costs and comparable wind speeds to what might be found offshore.

We also have very few wind farms in Australia. There is still plenty of room for development on shore. For comparison, in 2002 Germany installed over 30 times the total amount of wind energy capacity in Australia (3,248 MW installed in 2002 alone to bring them to a total of 12,001 MW compared to Australia’s total of 105 MW).

For the time being wind farm development in Australia will primarily be on-shore.

Why Not Put Wind Farms Out in the Desert?

Sometimes when confronted with concerns of noise or visual amenity, people wonder why wind farms are not built out in the “desert” (or the “outback”) away from people and where these concerns may not be as important an issue.

Such locations are not suitable because the wind speeds are rarely sufficient and because the cost of building very long power lines to connect the wind farm to the existing electricity network is prohibitively expensive. So while it might be technically feasible to build a wind farm in such remote locations it would not be financially sensible to do so.

A minor exception to this might be at remote communities where electricity is supplied from diesel power and wind turbines can be used to reduce diesel consumption or provide a cheaper alternative. However the wind project can only be as big as the needs of the community itself and so is only financially acceptable because of the comparatively high price of diesel power electricity in these areas.

How Far Apart Do Wind Turbines Need to Be Apart and Why?

Without a proper understanding of wind energy technology one might think that wind turbines can be packed into quite a small area. However this is not the case. A variety of factors come into play in determining the distance between the turbines and between the turbines and other structures. The development of a wind farm is a complex and iterative process where a compromise must be found amongst several competing factors.

Inter-Turbine Separation

The separation distances between each of the turbines are determined by several factors. Clearly the wind turbines need to be separated sufficiently so as to allow the turbines to follow the wind without risk of colliding with each other. Furthermore we do not want them so far apart that the cost of the interconnecting cables is so expensive that it makes the project uneconomic.

So where is the happy medium? The main determinant of separation distance is wind speed and turbulence. A wind turbine generator necessarily removes some of the energy from the wind (to convert to electricity). Downwind of a wind turbine generator the wind is therefore slower. However it is also more turbulent than it is upwind of the turbine because the wind turbine generator essentially acts like an obstacle to the flow of wind.

The surrounding unaffected wind will impart some of its energy to this slow and turbulent wind behind the wind turbine generator. In this way the turbulence is gradually dampened and the wind speed will come back to that of the surrounding wind. However a finite distance is required for this to occur. While it might be nice to wait until it comes back to its full strength, we will normally wait only until it comes back up to about 98 or 99% of the original power level.

The volume of air that is affected by a wind turbine generator is determined mainly by the diameter of the wind turbine generator's rotor. As a consequence separation distances are usually expressed in multiples of the rotor diameter. In this way we can develop rules of thumb that can be applied to any machine.

Generally, the rule of thumb calls for a downwind separation of wind turbine generators of between 5 and 7 rotor diameters. This will allow the wind to come back to almost its free flow wind speed by the time it reaches the next wind turbine generator. The influence of a wind turbine generator across the wind is no where near as great and we can essentially place a wind turbine as close as one rotor diameter apart across the wind. However the wind does not come from only one direction, and while we might be able to arrange wind turbines in this way if the wind were only to come from one direction, we cannot do so in real life.

The detailed wind monitoring conducted on a site prior to construction allows us to determine very precisely how the wind will flow over the site in three dimensions and to consider the prevailing wind energy direction over the site. The prevailing wind energy direction is not necessarily the same as the prevailing wind direction. The cubic relationship between wind speed and wind energy can mean that while the wind blows more often from one direction, there may be another direction from which most of the available wind energy comes. Given that it is the wind energy that we are really concerned with, this is the direction that we will wish to find in our layout procedure. Once we know where most of the wind energy comes from we can then separate wind turbine generators appropriately. In general, wind turbine generators will be separated by 3 to 5 rotor diameters across the prevailing wind energy direction and by 5 to 7 rotor diameters in line with the prevailing wind energy direction.

Layout Issues

In developing a wind farm layout, if all we had to worry about was the inter-turbine separation then all wind farms would be simple rectilinear arrays (i.e. a simple rectangular shape with wind turbine generators a set distance apart). While this might be possible on very simple sites where the land across the site is of almost identical elevation, and with no other issues needing to be considered, in most cases the development of a wind farm layout will be much more complex.

One factor that will significantly adjust the layout of the wind farm will be the changes in elevation of the area. Higher areas will usually experience stronger winds and so will be attractive to wind farm development. As a result, a ridgeline that spans across the prevailing wind direction may result in a line (or lines) of wind turbine generators across the top of the ridge. Likewise in undulating areas the wind turbines will be preferentially placed at the top of a hill rather than simply following the standard inter-turbine separation distances. There is no point placing a turbine behind a small hill where wind speeds will be significantly lower simply because you have reached an appropriate inter-turbine separation distance if moving another 100 metres or so can significantly increase the wind energy the machine will be exposed to.

Other factors that will influence the layout of the array include (but are not limited to) the noise (sound pressure levels) to which nearby residences are exposed, aesthetic appearance of the wind farm (e.g. following natural contours in the landscape rather than straight lines), avoiding areas of important native vegetation (either because of its innate significance or importance as habitat) or avoiding sites of cultural or archaeological significance.

To help in this process, complicated computer models are developed that are based upon three dimensional models of the proposed wind farm site. These models allow us to see how the air flows over the site and how noise propagates from the wind turbines. Nearby residences will be marked in the model (for noise assessment) and areas precluded from development (for whatever reason) will also be marked. It is then possible to place virtual wind turbine generators into the model and determine the electrical energy output of the generators, the noise emissions across the site and, in very basic way, to assess the visual appearance of the wind farm array.

The many complex, and often competing, issues involved in a wind farm development can be plotted in geographical information systems (GIS) which allows for thematic mapping of the site according to various criteria. You will often see these sorts of thematic maps in more detailed environment effect statements.

How Much Land Do I Need for a Wind Farm?

This is a common question and unfortunately is quite difficult to answer. With the increased efficiency of today's wind turbines, wind farms no longer need to be as large as they once were. One well-known wind development in the San Gorgonio Pass near Palm Springs in the USA contained nearly 3,000 turbines and another at Tehachapi Pass contained over 6,000 wind turbines.

Fortunately things have changed dramatically and, to a large extent, arrays of wind turbines this large no longer exist. During the mid to late 1990’s many of these exceedingly large wind farm arrays were “re-powered” with modern machines. In the re-powering process 6 to 10 old wind turbines were replaced with a single newer machine[1] while still maintaining (if not increasing) the energy production of the wind farm.

Large utility scale wind farm developments around the world today typically involve in the order of 20 to 50 wind turbines. However the actual number of wind turbines and where they are located will vary according to the area and the needs of the developer.

A wind farm with twenty 1.5MW wind turbine generators could be squeezed in an area of just 100 Hectares. However the local terrain, etc will probably mean that a larger area will be required.

Often a developer will accept an area that involves more than one landholder, however this become problematic if the each land holding becomes too small – because the number of landholders involved simply becomes too difficult to manage.

[1] Oak Ridge II Repowering Project Summary (www.awea.org/projects/summaries/oakridgeII.pdf)

Furthermore not all the land on one particular property might be suitable for wind farming. For example a developer may be trying to place their wind farm across a ridge where the ridge is only a small part of the holdings of several owners. In this case the amount of land involved and the number of owners may become quite large.