Research Projects

Wind Energy
A resource for the 21st century

Research Project information from CSIRO Land and Water

Sheet No.10
May 1999

CSIRO Land and Water scientists are playing an important role in developing the science and technology of wind resource assessment needed to harness the power of the wind. This is part of an ongoing project intended to help provide a clean, renewable source of energy through the combination of existing wind turbine technology and recent developments in the fields of meteorology and fluid mechanics.

The Kyoto climate change summit has given great focus to the issue of renewable alternative power sources. From it has emerged the Australian Government's Greenhouse Strategy that includes a commitment to source 2% of the nation's energy requirements from renewable resources by 2010. The community is increasingly aware of the role of renewables in meeting energy requirements with 'greenpower' schemes gaining support. The Australian Greenhouse Office projections for the expansion of the renewables industry lists large scale grid-connected wind as a major component of the renewable portfolio, with an annual contribution of 1000 gigawatt hours (GW.hr) per year from an installed capacity of 500 megawatts (MW) by 2010.

On the world scene, wind energy has become a major part of renewable energy resources. Twenty years of development, particularly in Europe, has seen the industry enter a mature phase with highly reliable, mass-produced turbines and wide acceptance of the technology. By the middle of 1999, over 10000 MW of capacity had been created.

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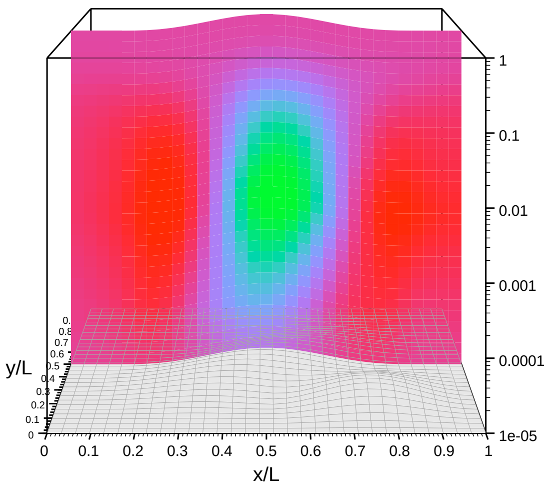
Germany, USA, India and the Scandinavian countries have led the way. Denmark already derives 7% of its power from the wind and plans to increase that to 40% by 2030 through extensive use of offshore wind farms. The cost of generation in Denmark is as low as (US) 4¢ per KW.hr, only slightly more expensive that the cheapest renewable, hydro power.

The modern wind farm has evolved as the capacity of the turbines steadily increases. Fewer, larger turbines are spaced further apart in an aesthetically pleasing arrangement. They occupy a very small 'footprint', allowing normal land use to proceed around them. Gone are the dense arrays of small machines spread across the landscape, which were the hallmark of the industry in the late 1970s.

Through advances in the aerospace industry and decades of experience, the turbines themselves have evolved into highly sophisticated, reliable systems. The most popular units have a maximum output in the range of 600 to 750 kW. These units are usually equipped with a three-bladed rotor, with a diameter exceeding 40 m and a hub height of between 40 and 55 m. The largest production units have a maximum output of over 1.5 MW, a blade diameter exceeding 60 m and a hub height of 65 m. These units stand as high as a thirty-storey building!

Grid-connected units use sophisticated computer controls and synchronous generators which allow the rotors to spin at a desired constant speed. Some units feature pitch control and viscous couplings to smooth output in turbulent winds. Modern composite technologies have made the blades highly efficient, lasting over twenty years through salt spray, ice and snow.

Normal grazing and most other agricultural activities can be carried on around modern wind farms, as can be seen here at Crookwell, NSW



Computer model simulation of airflow over topography, with green showing speedup

Defining the wind resources in Australia – how much is there and where is it?

The wind energy industry, like any other resource-based industry, requires detailed and accurate estimates of how much resource there is to harvest and exactly where it is, prior to investment. In the case of wind, the amount of power in the wind is proportional to the wind speed to the third power. For example, a thirty percent higher than average wind speed will more than double the amount of energy available. Hence, good estimates of potential yields are crucial to the economics of wind energy development. A 1% change in predicted output may be valued at $1m over the lifetime of a modest-sized wind farm.

The industry requires energy yield predictions at a number of scales. Firstly, broadscale predictions (~100 km) are needed to determine whether a region is windy in general and then if there are localised areas suitable for wind energy development. Secondly, they are necessary at the local scale (~10 km) to look in more detail at the possibilities for a wind farm in a promising area, taking account of where a wind farm might be located and its potential yield. Lastly, designing the layout of turbines in the wind farm itself requires highly accurate estimates of the potential energy yield every few metres over scales of a few kilometres.

Choosing the best site for the turbines not only requires a knowledge of the energy yield, but also of the potential interference between turbine units and a range of other factors such as aesthetics, noise propagation and cabling infrastructure.

The Crookwell wind farm

The Crookwell wind farm is Australia's first grid-connected wind farm. The site consists of eight Vestas 600 kW turbines with a total peak output of roughly 5 MW – enough to power 3500 homes and displace 8000 tonnes of carbon dioxide emissions annually. This joint project between Pacific Power and Great Southern Energy used CSIRO Land and Water science and technology to determine the optimum placement of the turbines, as well as to predict energy yield.

A careful blend of modelling and measurement

At first glance it may seem a simple matter to identify the ideal location for a wind farm: find a windy spot and begin construction. In practice it is far from this simple. In fact, the Crookwell wind farm (see inset) is the result of years of measurement and careful study of the wind flow in the region, undertaken by scientists at CSIRO Land and Water. The process of actually locating a wind farm begins with measurement of the *wind resource* at a number of locations, strategically distributed over the countryside. Meteorological towers are erected and the wind speed and direction is measured at several heights on each tower. This gives an accurate measure of the wind energy potential at these positions, yet tells little about the areas in between.

Atmospheric scientists play a crucial role in the siting of a wind farm. They do this by translating or extrapolating the results obtained from the meteorological towers to potential turbine locations between measurement sites. A combination of statistics and computer models are used which encapsulate many years of scientific modelling of the way air flows over hilly terrain, with surface cover varying from bare earth to forests. These models are used in a two-step process to fill in the gaps where there is no

Firstly, scientists use models to calculate how topography and surface characteristics have affected the wind at the points where measurements were actually made. Once these effects are determined, they can be subtracted from the measured wind. This reveals what winds in the region would be like if the surface were smooth and flat.

The second step is nearly the reverse of the first: the same computer models are used to calculate how this *idealised* wind is distorted by the topography and surface cover at any point in the region, particularly at a proposed turbine site. At this critical stage in the process, actual measurements are matched with computer predictions at a few specific locations, allowing predicted turbine power output at possible wind farm sites to be cross-checked against the on-site data gathered.

Improving the science

Computer models of wind flow are an integral part of the wind farm siting toolkit. Scientists at CSIRO Land and Water are constantly striving to improve the accuracy of the models by incorporating smarter mathematics and better descriptions of the physics of airflow. They use a three-pronged approach – utilising field experiments, laboratory wind tunnel simulations and theoretical studies – in an interactive blend of science and technology.

Computer flow models – riding the wave of increasing computer power

Scientists describe the way air flows in hilly terrain by means of a set of complex mathematical equations, which expresses the balance between all the forces acting on air molecules. The complexity of the potential siting scenarios means these equations can only be solved on powerful computers, and even then a number of approximations and assumptions must be made.

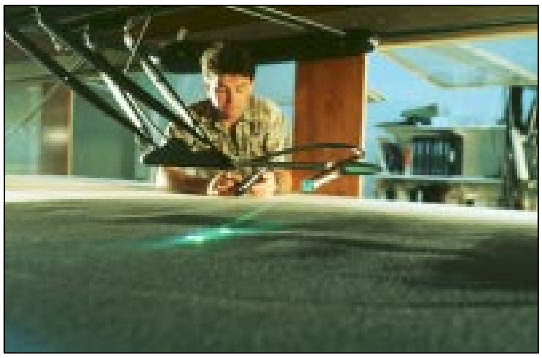
When constructing such windflow models, scientists must balance the need for accuracy against the desirablity of speedy results to enable investors to make timely and practical decisions about siting. This balance is continually shifting as the power of computers increases. Not only is greater computer power honing the accuracy of the current models that work best in gentle topography; it is also allowing scientists to extend the physics captured in the model equations, so they can predict the drastically altered airflows found in steep and craggy country.

Sampling the real world

In field studies, scientists sample the three-dimensional structure of the atmosphere from tall lattice towers supporting sonic anemometers: state-of-the-art instruments that have no moving parts. The instruments track the rapid fluctuations in the atmospheric wind, temperature and humidity by bouncing high frequency pulses of sound around a closed path. In complex terrain, however, even a large number of towers and sonic anemometers can provide only a sparse sampling of the spatially varying state of the natural wind. But armed with a greater knowledge of the dominant physical effects at play in the real world, scientists can study these processes in much greater detail in wind tunnel experiments.

Moving the wind indoors

Located in its Pye Laboratory in Canberra, CSIRO Land and Water has one of the largest 'Boundary Layer Wind Tunnels' in Australia: a facility is designed to simulate the natural wind with its complex turbulent and spatial structure.

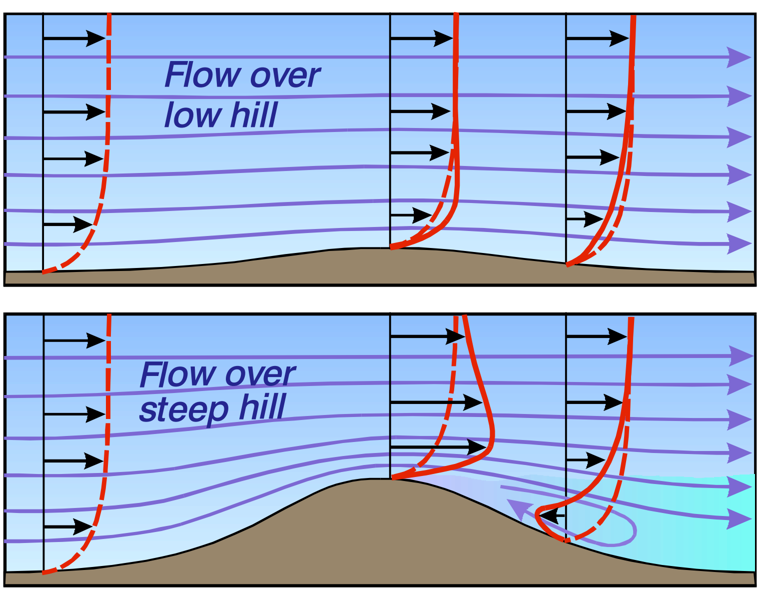


Within the tunnel, scientists can concentrate on particular features of the atmospheric wind that their field studies have revealed as important. A great advantage of bringing the wind indoors is that the same weather conditions can be re-run indefinitely, allowing wind structure to be sampled in exhaustive detail. To do this scientists use laser-doppler anemometers: instruments that track wind-tunnel flow by sensing the reflection of laser light from nearly invisible particles injected into the wind tunnel flow. Real topographical features of where turbines might be sited can be modelled, or scientists can investigate generic effects of surface roughness and steepness, which can then be translated into general rules for computer models.

The art of mathematical modelling – bringing it all together

Although scientists can construct equations that describe precisely the flow of air over topography, these are far too complex to solve – so in the models they must be replaced by simplified formulae. The art is to make the mathematical descriptions simple enough for rapid computation, yet at the same time faithful enough to the underlying physics to yield accurate predictions.

As an example, when air flows over low hills it smoothly follows the surface contours, speeding up at the crest and slowing in the wake of the hill. Current models predict this very well. Over steep hills, however, the air flow 'separates' on the downslope and instead of flowing smoothly downhill, it forms a large turbulent 'separation bubble' behind the hill, where the wind is just as likely to be gusting uphill as down. Predicting the occurrence and extent of these regions is very important when trying to estimate wind power potential in steep topography or the wind loads on turbine blades at such sites, yet there are no models that do this very well at present.



Separation in air flow is triggered when the pressure forces driving the air over the hill and the friction of the wind on the ground at the hill crest get out of balance. In the wind tunnel, hills of different steepness and roughness are being simulated to help understand more precisely how this balance is lost. With this knowledge, scientists can modify their model equations and use them to predict whether separation will occur at a 'real world' site. Then they will go back to field experiments to check if the prediction is correct. In this manner, a model is continually refined until it becomes accurate enough to guide the selection a wind farm site.

Through this three-way interplay of field tests, wind tunnel simulation and theory, scientists at CSIRO Land and Water are contributing to the viability of wind farms as a sustainable source of energy.

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