SUBMISSION FROM PROFESSOR ANTHONY TREWAVAS

Reconciling Government Insistence On Using Wind Energy Whilst Minimising Environmental Impacts.
Ten Metre-High Turbines, Ten Fold-Higher Energy Generation

Summary

The conventional wind farm uses propeller-style, 100 metre high turbines that rotate on a horizontal axis (figure 1). Professor John Dabiri (California Institute of Technology) has creatively exploited the use of ten metre high turbines that rotate on a vertical axis (figure 1). By understanding the nature of the turbine-generated turbulence, he has shown that these ten metre-high turbines can be packed close together and generate ten times more wind-generated electricity per square metre of land area, than the conventional wind farm. Ten metre-high turbines being the height of most mature trees, would obviate most public objections based on landscape impact. Ten times more wind generated electricity would reduce the land required by wind farms enormously. Placing ten metre turbines in already working or consented wind farms would probably obviate any further need for land for wind farms.

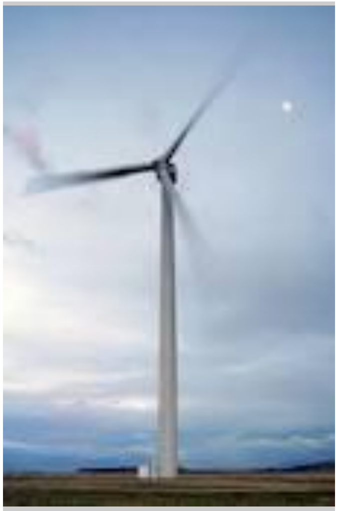
The problems with conventional wind farms.

Conventional wind farms use the familiar propeller-style turbine that rotates about a horizontal axis (figure 1). These turbines generate substantial and disruptive turbulence that requires each to be separated from its neighbour by 7-10 rotor widths to avoid damaging interactive turbulence. (A picture of this turbulence is provided on page 4). For a hundred metre high turbine, the rotor is generally 70 metres in diameter and thus the separation distance is anywhere from 500-700 metres and thus each turbine of necessity occupies 20 acres of land. [In the appendix I have given simple calculations of the land needed to generate 7GW of electricity, the Scottish winter requirement, by on shore wind only]. The consequence is that each turbine acts in effective isolation. Most of the wind that blows on the wind farm passes through the gap between these turbines and is not intercepted. Conventional wind farms are thus extremely wasteful in their collection of wind energy. This inefficient collection has led to the construction of larger and yet larger turbines to simply collect energy from the higher wind speeds encountered at height. But the increased size requires more land area and results in increased costs, difficulties in engineering, and impacts badly on visual and acoustic grounds as well as killing more bats and birds. Current wind farm construction is an excellent example of a ‘conventional wisdom’ whose inertia constrains innovative thinking.

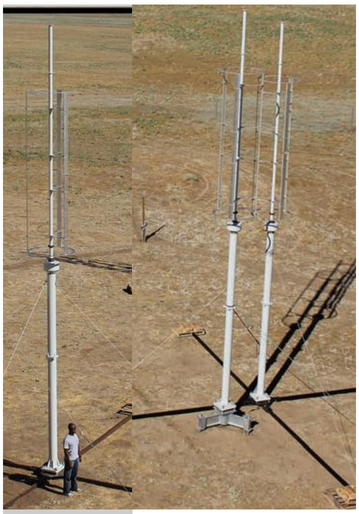
But the Scottish government insists on using wind energy. The difficulties can be resolved by a wind farm construction that all but eliminates landscape and environmental problems by using very small turbines. A great increase in efficiency would reduce the land required and minimise countryside damage. Solutions to both problems have emerged.

Imaginative insight solves the problem.

The ‘conventional wisdom’ has been challenged by Professor John Dabiri and others at the California Institute of Technology [Cal Tech] (Dabiri 2011). By imaginative thinking, they sought to understand how shoaling fish that swim through a medium (water), relatively-speaking far more viscous than air, do so **very close together** and at very considerable



A



B

Figure 1. Typical horizontal axis propeller-style wind turbine (A) and the type of vertical axis wind turbines used by Professor Dabiri, one of many commercial designs (B).

relative speeds. These fish do so, despite the turbulent vortices that each fish generates as it swims. Why then does this turbulence not interact with each neighbour and disrupt shoal formation? The answer is simple. Each fish generates turbulent vortices whose direction is complementary to its nearest neighbour and those downstream. By this means turbulence actually aids rather than disrupts shoal formation (Whittlesey et al., 2010).

Dabiri and co-workers then imaginatively applied those observations to wind farm construction. Replace each individual fish by a turbine that rotates about its vertical axis (figure 1). Ensure the rotation mimics the turbulence generated by swimming fish and is thus complementary. When that is done the vertical axis turbines can be packed very close together. With this construction Dabiri and others measured **a remarkable ten to fifteen fold increase in wind generated electricity on a square metre basis** compared to a conventional wind farm.

How can this happen? The vertical axis rotors have a rotor width of only just over a metre. The measured optimal separation distance they measured by experiment to be about two metres. In a conventional wind farm, turbines are separated from their neighbour by about 500 meters. In that space, Dabiri’s method would permit the placement of up to 250 turbines. This procedure thus intercepts virtually all the wind lost in a conventional wind farm construction.

Ten metre turbines were all that was necessary to achieve this big increase in electricity generation.

If near-ground wind energy can be harnessed much more efficiently than winds at higher altitudes then there is no need for the hundred metre-high wind farm turbines as presently used. To quote Dabiri, “The global wind power at ten metres exceeds global electricity usage several times over”. So the CalTech, wind farm design, instead uses a commercial, ten metre-high, vertical axis wind turbine. Advantageously these turbines do not need a gear box or yaw drive, the cause of many failures in the propeller style turbine. A hundred metre turbine requires a crane for gear box maintenance. Being small and near the ground, these ten metre turbines are easily serviced and being cheap are easily replaced. The very low height enormously reduces all environmental impacts including noise. A ten metre-high turbine is similar in height to ordinary mature trees. It would not be difficult to landscape it out altogether. Furthermore high wind speeds are reduced near the ground. Switch-off periods in times of high winds are reduced. Vertical axis wind turbines start rotation at lower wind speeds.

An early generation of vertical axis wind turbines suffered from materials problems, now solved, by using better construction materials. Again to quote Professor Dabiri “ Advances in materials and in predicting aerodynamic loads have led to new designs that are better equipped to withstand fatigue loads”. (Dabiri, 2011; Whittlesey et al., 2010). **The critical measurements have been made by Dabiri and others in the field. They showed over a season that the electricity /square metre collected is at least 10 fold higher** than conventional wind farms, despite the turbines being much smaller in height.

Dabiri concludes that **“this alternative approach to wind farming has the potential to reduce the cost, size and environmental impacts of wind farms”.**

The gross benefits from this wind farm design.

- Suppose Whitelee wind farm (nr Glasgow) had been constructed with the CalTech design. Instead of just generating one tenth the electricity of a gas-fired power station, it would now generate, on average, the equivalent of a gas-fired power station. Of course, wind unreliability would remain a problem, as would the electricity-generating difficulties of managing an unreliable source of energy. However five or six uncontroversial sites like Whitelee would generate, on average, Scotland’s electricity requirement, probably the maximum any stable electricity supply could tolerate. The environmental impact that is spreading over Scotland’s countryside from increasing numbers of turbines would be abrogated. Theoretically tenfold less land would be required to satisfy government targets. If most sites were located south of the Grampians there would be no need for Beauly-Denny either.

- With appropriate remote landscaping by trees or by earth barriers on a flat wind farm, nothing would be visible from outside. The foundation requirements for ten metres turbines are tiny unlike the huge concrete blocks used for 100 metre propeller style turbines. Long term damage to the soil is minimised.

- There would not be any need to put turbines at sea and generate the very expensive electricity paid for by the consumer. Dabiri points out that CalTech designs are equally applicable to underwater turbines in the seas. This has considerable bearing on attempts to harness Pentland Firth tidal energy?

- I have discussed with Dabiri the possibility of placing ten metre turbines on a conventional wind farm and there is no fundamental reason that they should not be located there. Given the present constructed and consented wind farms, there would be little requirement for further land use.

- Anyone facing wind farm applications should inform their local council of this revolution in wind farm design. In an inquiry applicants should be asked why they have not suggested use of the Dabiri style wind farm instead of the obsolete conventional hundred metre and environmentally-impacting turbines.

- The example above is innovation in action and indicates clearly how the conventional wisdom of a government-inspired, effective monopoly on wind farm construction, places blinkers on imagination. Competition would change attitudes but there isn't any.

- I don't expect industry to go along easily with Dabiri's revolution. All companies (and land owners) are grossly overpaid for what they do and what they are forced to do, by government diktat on ROC's. Why bother to change if you are doing nicely?

Common questions.

1.Why are wind energy companies not rushing to use this method?

Dabiri's last paper, with measurements, was only published in July 2011 so it is early days. Also the last 20 years has seen huge financial investment into optimising the construction of propeller-style turbines. There are therefore many vested interests in keeping things as they are. Who likes to be told that time and money have been wasted for at least two decades because something simpler and cheaper has emerged? There will be reluctance and opposition to, change.

2. I don't understand how complementary turbulence actually aids this wind farm construction?

If a vertical axis wind turbine is constrained to rotate in only one direction then the turbulence or wake that it generates can actually be used by the next turbine downstream, providing it too is constrained to rotate in the same direction. Imagine the first vertical axis wind turbine rotated by electricity. In the absence of wind, the turbulent wake generated would start to rotate the next turbine downstream.

3. I don't understand the turbine arrangement?

When a fish swims through water it generates turbulent vortices on its two sides. The left hand side generates vortices with an anti-clockwise direction; the right hand side clockwise. Dabiri ensured that turbines could only rotate in one or other direction. Two adjacent turbines rotate in opposite directions mimicking the two sides of a fish. Those downstream rotate in the same direction as the leader. This recognition was key to this wind farm construction. The turbulence formed from each is thus complementary instead of disruptive.

4. Won't it damage more birds?

On the contrary vertical axis turbines will act like scarecrows. Not ideal, but all renewables have a low density of energy collection and are thus land hungry. This is the best to date.

References.

Dabiri J.O (2011) Potential order-of-magnitude enhancement of wind farm power density via counter rotating vertical axis wind turbine arrays. *Journal of Renewable and Sustainable Energy*. **3**: 043104.
Whittlesey, R.W., Liska, S., and Dabiri, J.O. (2010). Fish schooling as a basis for vertical axis wind turbine farm design. *Bioinspiration and Biomimetics* **5**:035005.

A video by Dabiri is available on you-tube at:
http://www.youtube.com/watch?v=kz6dw_BIdNA

If that doesn't work go to Google and type in John Dabiri wind farm and look for youtube.

APPENDIX

*__Picture of the Horns Rev wind farm taken at dew point clearly showing the production of turbulence as condensation__ [http://www.ict-aeolus.eu/about.html].

As the propeller-style, rotor blade moves, it generates low pressure, turbulent vortices moving downwind because the blade tips can move up to 300km/hr. Bats caught in these low pressure vortices suffer explosion of their lungs, killing or severely injuring them. Although birds have different lung structures they too are subject to the laws of physics. Caught suddenly in a low pressure vortex, bubbles of gas (the bends) are likely, causing illness even death. Detailed observations at upland wind farms has shown that the great majority of bird species stay well away from wind farms, no doubt from experience. But since food availability determines local bird density, displacing some means death for others. Collision of birds with turbines is familiar.

****Calculation of land required to provide 7 GW of electricity (normal winter requirement) by onshore wind alone**.

100 metre turbines normally require 20 acres of land each to avoid serious interactive turbulence. A single 100 metre turbine normally generates, on average, about 0.7 MW. The number of turbines required to generate, on average, 7GW would therefore be about 10,000. However there would have to be more turbines than this to account for downtime and repairs. But as a straight calculation this would require 200,000 acres of land. However with necessary separation distances from roads, villages, towns and cities and unsuitable terrain and an 8-900 metres separation from individual houses to reduce damaging turbine noise and effects on human health, this area should be increased by at least five fold. That is 1,000,000 (one million) acres of land and about 1600 square miles but bear in mind that in this area every available piece of land would be occupied by a turbine; no-one would be out of sight of a turbine or a pylon. Using the Dabiri method this would reduce to 100,000 acres or less.

Turbines are easily visible given the right terrain on tops of hills for ten miles in all directions. The visibility area occupied by turbines by one wind farm alone in this case is 300 square miles. The land area of Scotland is 30,000 square miles. 100 wind farms each with 100 turbines to generate 7GW, if evenly placed, would potentially render all of Scotland as containing visible turbines and therefore changed to an industrial landscape rather than the natural version that attracts many but not all tourists.

With Dabiri's method the problem largely goes away because hill tops are not needed and at 10 metres high, visibility is correspondingly reduced.

Professor David McKay FRS,chief scientist at DECC provides an alternative calculation in his book “Sustainable energy without the hot air” (free on the web) and indicates that there is insufficient wind energy to generate UK requirements for electricity. I have checked my calculations with him.

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