Wind power potential – 'higher than current estimates'

A recent Harvard-led research project suggests the potential of wind energy could be considerably higher than previous estimates by both wind industry groups and government agencies. In this exclusive extract, PES looks at the report, garnered from the Proceedings of the National Academy of Sciences of the United States.

Using data from thousands of meteorological stations, the Harvard team estimated the world wind power potential to be 40 times greater than total current power consumption. A previous study cited in the paper put that multiple at about seven times. In the lower 48 states, the potential from wind power is 16 times more than total electricity demand in the US, the researchers suggested – significantly greater than a 2008 Department of Energy study that projected wind could supply a fifth of all electricity in the country by 2030.

Further afield, while remote regions of Russia and Canada have the greatest theoretical potential, the Harvard study pointed out that there are real gains to be made in high-emission nations, especially China, which has been rapidly constructing coal plants. "Large-scale development of wind power in China could allow for an 18-fold increase in electricity supply relative to consumption reported for 2005," the Harvard study said.

The findings are "further validation of what we've been saying – that the US is the Saudi Arabia of wind," said Michael Goggin, an electricity industry analyst for the American Wind Energy Association (AWEA). The authors based their calculations on the deployment of 2.5- to 3-megawatt wind turbines situated either in accessible rural areas that are neither frozen nor forested, or relatively shallow offshore locations. They also used a conservative 20 per cent estimate for capacity factor, a measure of how much energy a given turbine actually produces. In an example of how renewable energy potential can be a moving target, Mr. Goggin explained that the growth in the forecasts could be attributed to the increasingly common use of very large turbines that rise to almost 100 meters. Wind speeds are greater at higher elevations. Previous wind studies were based on the deployment of 50- to 80-meter turbines.

"As turbines start to get taller," predicts Mr Goggin, "we'll see a lot more capitalization of the resource."

Curiously, the new research surfaced just months after T Boone Pickens – citing rising financing costs – scaled back his plans for the world's largest wind farm in west Texas.

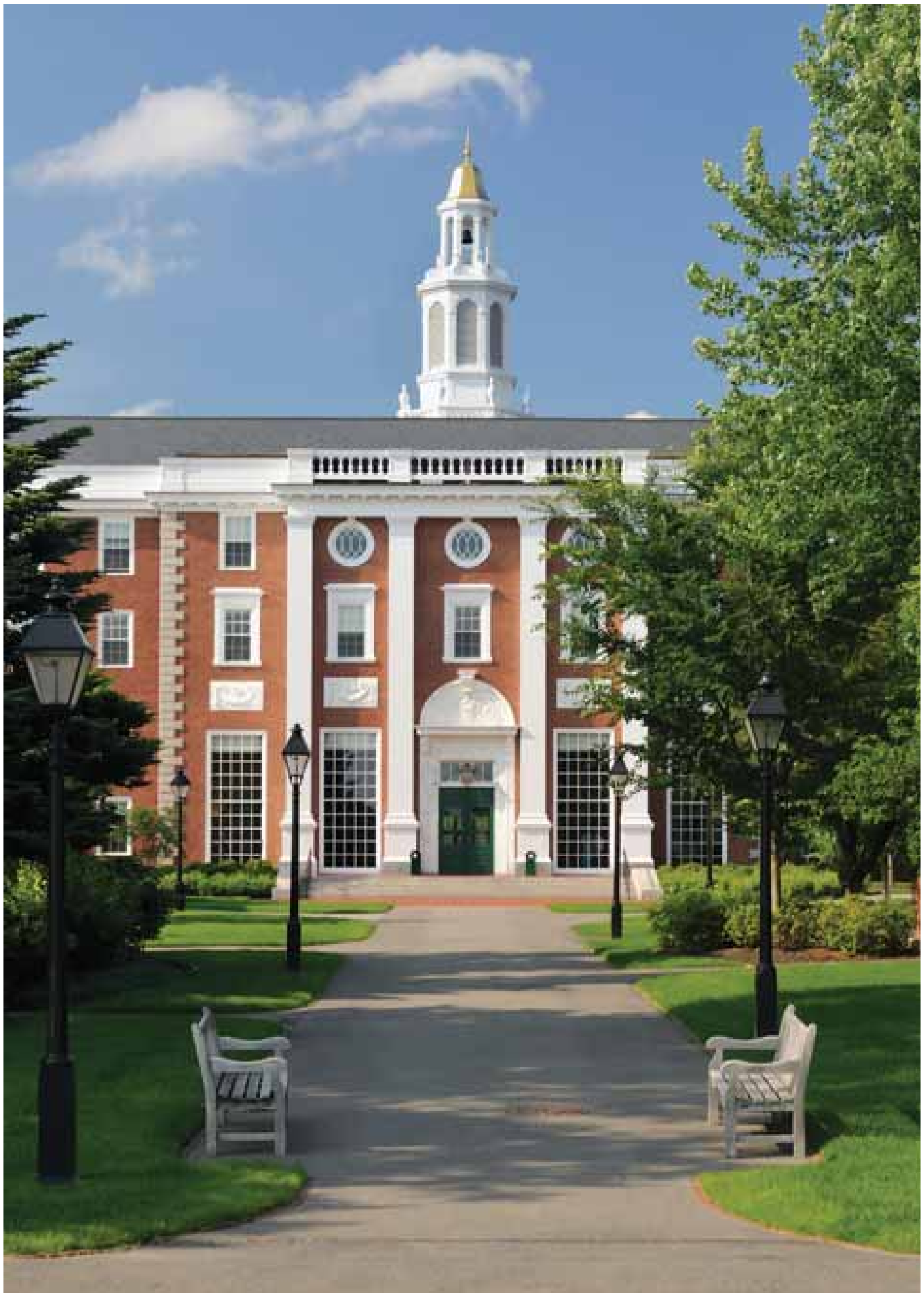
Wind power accounted for 42% of all new electrical capacity added to the US electrical system in 2008 although wind continues to account for a relatively small fraction of the total electricity-generating capacity (25.4 gigawatts (GW) of a total of 1,075 GW). The Global Wind Energy Council projected the possibility of a 17-fold increase in wind-powered generation of electricity globally by 2030, using the National Renewable Energy Laboratory'sWinDs model, concluded that wind could account for as much as 25% of US electricity by 2050 (corresponding to an installed wind capacity of 300 GW).

Other researchers estimated that 20% of the global total wind power potential could account for as much as 123 petawatthours (PWh) of electricity annually [corresponding to annually averaged power production of 14 terawatts (TW)] equal to seven times the total current global consumption of electricity (comparable to present global use of energy in all forms).

Their study was based on an analysis of data for the year 2000 from 7,753 surface meteorological stations complemented by data from 446 stations for which vertical soundings were available. They restricted their attention to power that could be generated by using a network of 1.5-megawatt (MW) turbines tapping wind resources from regions with annually-averaged wind speeds in excess of 6.9 m/s (wind class three or better) at an elevation of 80m. The meteorological stations used in their analysis were heavily-concentrated in the US, Europe, and Southeastern Asia. Results inferred for other regions of the world are subject as a consequence to considerable uncertainty.

Tracking changes

GEOS-5 (Goddard Earth Observing System Model) winds were obtained through assimilation of meteorological data from a variety of sources, in combination with results from an atmospheric general circulation model. Transport in the boundary layer was treated by using two different formalisms, one applied under conditions when the boundary layer was stable, the other under conditions when the boundary layer was either unstable or capped by clouds. The variation of wind speed with altitude was calculated in the present study by using a cubic spline fitted to the three lowest layers (central heights of 71, 201, and 332



m) of the GEOS-5 output to estimate wind speeds at the rotor heights of the turbines considered here (100 m).

The rotors of the turbines modeled in the study are of sufficient size that as the blades rotate, they traverse significant portions of the two lowest layers of the GEOS-5-simulated atmosphere. Use of wind speed for a single level (100 m) must be consequently subject to some uncertainty. To assess this uncertainty results were explored derived with an alternate approach. The power intercepted by the blades of the rotors passing through the separate layers was calculated initially on the basis of the reported average wind speeds for the involved layers. Adopting a typical value of 135 m for the height of the boundary between the first two layers, given a rotor diameter of 100m as appropriate for the assumed onshore turbines, it follows that 99% of the area swept out by the rotors would intercept air from the first layer, with only 1% encountered in the second layer. The power intercepted by the rotors may be calculated in this case by averaging appropriately the power intercepted in the two layers. Implementing this approach yielded results that differed typically slightly lower, by 15% for onshore results, by less than 7% for the offshore results.

The GEOS-5 data had a spatial resolution of 66.7 km - 50.0 km. It is clear that wind speeds can vary significantly over distances much smaller than the resolution of the present model in response to changes in topography and land cover (affected in both cases by variations in surface roughness). In general, it was expected that the electricity yield computed with a low-resolution model to underestimate global distribution of onshore capacity factor (%) for winds at 100m with exclusion of permanent snow/ice-covered areas such as Antarctic and Greenland.

The GEOS-5 data is expected to provide a useful representation of winds on a synoptic scale as required for example to describe the transport between adjacent grid elements. They would not be expected to account for subgrid scale variations in wind speeds even though the latter might be expected, at least under some circumstances, to make a significant contribution to the potentially available wind power.

To test this hypothesis, the implications of a high-resolution wind atlas available for an altitude of 100m for Minnesota (20) was explored. Wind speeds indicated by the high-resolution database are higher than the wind speeds indicated by GEOS-5, supporting the hypothesis. The close association of wind speed with surface land classification implied by the high-resolution Minnesota wind atlas suggests that land classification data could provide a useful basis for at least a preliminary downscaling of the relatively coarse spatial resolution of the potential wind resources in the present study. We elected in this study to exclude forested, urban, permanently ice-covered, and inland water regions. Given the relatively coarse spatial resolution of the GEOS-5 database, it is possible that this approach may have failed to identify localized environments where wind resources may be unusually favorable and where investments in wind power could provide an acceptable economic return.

To explore this possibility, a global land-based map of the efficiencies with which turbines with rotors centered at 100m might be capable of converting wind energy to electricity was developed. All land areas with the exception of regions identified as permanently ice-covered (notably Greenland and Antarctica) were included. Regions with particularly favorable capacity factors, even though forested, urban, or occupied by extensive bodies of inland waters, might be considered as potential additional targets for development.

It is apparent, for example, that the low-resolution GEOS-5 record underestimates the wind resource available in, for example, Spain and Portugal (a consequence most likely of the complex terrains present in these regions). Sweden is another example where wind resources indicated with an available high-resolution wind atlas are significantly higher than those implied by GEOS-5.

The discrepancy in this case may be attributed to the extensive forest cover of the region and the decision to neglect such regions in the present global study. Assessment of the potential of mountainous or hilly regions is also problematic. On average, wind speeds in these regions may be relatively low. Particularly favorable conditions may exist, however, on mountain ridges or in passes through mountainous regions. The Appalachian mountain range offers a case in point. In general the low-resolution results tend to slightly overestimate wind resources in regions of flat terrain, while underestimating the potential for regions defined by more complex topography. The analysis in this article suggests that a network of land-based 2.5-MW turbines operating at as little as 20% of rated capacity, confined to non-forested, ice-free regions would be more than sufficient to account for total current and anticipated future global demand for electricity. The potential for the contiguous US could amount to 16 times current consumption.

Important additional sources of electricity could be obtained by deploying wind farms in near-shore shallow water environments. An extensive deployment of wind farms may be considered as introducing an additional source of atmospheric friction. For example, if the entire current demand for electricity in the US were to be supplied by wind, the sink for kinetic energy associated with the related turbines would amount to 6% of the sink caused by surface friction over the entire contiguous US land area, 11% for the region identified as most favorable for wind farm development.

The potential impact of major wind electricity development on the circulation of the atmosphere has been investigated in a number of recent studies, which suggest that high levels of wind development as contemplated here could result in significant changes in atmospheric circulation even in regions remote from locations where the turbines are deployed. They indicate that global dissipation of kinetic energy is regulated largely by physical processes controlling the source rather than the sink.

An increase in friction caused by the presence of the turbines is likely to be compensated by a decrease in frictional dissipation elsewhere. Global average surface temperatures are not expected to change significantly although temperatures at higher latitudes may be

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expected to decrease to a modest extent because of a reduction in the efficiency of meridional heat transport (offsetting the additional warming anticipated for this environment caused by the build-up of greenhouse gases).

In ramping up exploitation of wind resources in the future it will be important to consider the changes in wind resources that might result from the deployment of a large number of turbines, in addition to changes that might arise as a result of human-induced climate change, to more reliably predict the economic return expected from a specific deployment of turbines.

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