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In Defence of Renewable Energy and its Variability

Mark Diesendorf

Globally, renewable energy has been a great success story over the past quarter century:

- Following the oil shocks of the 1970s, wind power experienced a renaissance in Denmark in the 1980s and then spread rapidly to many other countries. By early 2006 there were 60,000 megawatts installed globally, with the largest shares being in Germany, Spain, India and Denmark, in that order.
- Bioenergy---that is, energy from crops, crop residues and other organic materials---is well established in Finland and Austria.
- Solar photovoltaic electricity, despite its high price, is growing so rapidly in Japan, Germany and Spain, that there is a shortage of the appropriate grades of silicon. Research advances, that have already been made in thin films and Sliver cells, are now coming onto the market and will gradually bring down the price of solar PV electricity.
- Solar thermal electricity, after a long period of hibernation, is awakening in the USA.
- Wave power and tidal current converters are being installed on pilot scales in several countries.

Unfortunately, this success has attracted the hostile attention of the conventional energy giants, especially the coal and nuclear industries. Together with grass roots NIMBY organizations, these vested interests are spreading misinformation about renewable energy that sounds superficially plausible and is being parroted by journalists and others. Wind power, as the least expensive of the 'new' renewable sources of electricity, has received the worst attacks and misrepresentations.

In the UK, where nuclear power and wind power are now serious competitors for becoming the backbone of the national greenhouse response program, there are close links between the anti-wind movement and the nuclear industry. Vice-president of the peak anti-wind farm organization, Country Guardian, is Sir Bernard Ingham, who is also secretary of a leading nuclear power promotion organization, Supporters of Nuclear Energy (SONE).

Several public opinion surveys have found that the majority of respondents who originally opposed a wind farm in their district find them acceptable several years after their installation. Many respondents say that the alleged environmental impacts, noise and bird kills, are not a problem, despite initial fears.

Some environmentalists oppose bioenergy on the fallacious grounds that it can only be implemented by cutting down native forests, or by substituting for food production, or by using vast quantities of artificial chemicals, or by applying large inputs of fossil energy. While each of these adverse impacts is possible with inappropriate technologies and policies, bioenergy can make a substantial contribution to electricity generation without any of these adverse impacts. However, if bioenergy were used to substitute for petrol and diesel on a large scale, then it would take a significant land area.

With the failure of the environmental arguments against wind power and bioenergy, the two most economic renewable sources of electricity, a more subtle piece of misinformation is being disseminated against renewable energy. The method is to label renewable energy as 'intermittent' and then claim that it can never replace existing base-load power stations, such as coal and nuclear, which are described as 'firm' or 'reliable' sources of power. For renewable energy to become a significant energy source, the assertion goes, it would need a new kind of inexpensive long-term storage.

The short answer to the claim can be stated succinctly. There is no such thing as a totally reliable source of electricity. The distinction between 'intermittent' and 'firm' sources of power is arbitrary. Conventional power stations break down unexpectedly from time to time and are then generally offline for longer periods than calms in the wind or sunless periods. They just have a different pattern of variability than wind, solar, wave and run-of-river hydro energy. It is more appropriate to describe this kind of renewable energy source as 'variable', rather than 'intermittent', because the latter term creates the misleading impression that they switch on and off sharply. Some renewable energy sources, such as bioenergy and geothermal power stations, have similar patterns of variability to coal and are best described as 'dispatchable', rather than 'firm' or reliable'.

Having clarified our definitions, it remains to point out that electricity supply systems are already designed to handle variability in both demand and supply. They can integrate variable renewable energy sources by simply building on this basic property.

This article points out that the problem of integrating renewable energy sources into electricity grids has been mostly solved, both in theory and in practice. It also draws attention to scenario studies showing that renewable sources, based on existing technologies with small improvements, could provide over half the electricity generated from a state or national electricity grid.

Variability of demand & supply

First consider that demand for electricity varies on daily and seasonal basis, as well as having unpredictable changes. Because it is very expensive to store electricity on a large scale, electricity grids have a mix of base-load, intermediate load and peak-load power stations to meet changes in demand. It is a perpetual balancing act.

Base-load power stations in Australia are coal-fired. Since they have high capital cost and low running cost, they are operated 24 hours a day every day, except when they break down or undergo planned maintenance. Back-up is provided for base-load power stations by a combination of base-, intermediate- and peak-load stations.

In the absence of hydro-electricity, peak-load stations are gas turbines, which have low capital cost and high operating cost. Their fuel, usually natural gas, is much dearer than coal. Because peak-load stations can be turned on and off very quickly, they are valuable for 'balancing' fluctuations in demand and for rapidly covering the unexpected failure of a base-load power station.

So, variability is nothing new to fossil fuelled electricity generating systems. As a result of the variability of demand and supply, the reliability of the whole generating system can never be 100%. To achieve this would require an infinite amount of back-up and hence an infinite cost. In practice, reliability can be measured in terms of indicators such as the average number of hours per year that supply fails to meet demand.

Adding wind power

The integration of wind power into the grid adds a third type of variability. When wind power contributes only a few percent of total electricity generation, its variability is unnoticed among the fluctuations in demand. Under these conditions, it is easy to show that wind power can be treated statistically to a good approximation as a completely reliable source of power equivalent to its *average* power output, which is typically about 30% of its rated power capacity.

How big a contribution to electricity generation can wind energy make without introducing long-term energy storage? It turns out that the limitation is primarily economic rather than technological. In several isolated electricity supply systems, wind energy is already contributing more than 40% of the electricity generated: examples are Denham and Hopetoun in W.A. and the Australian Antarctic base at Mawson, where the variations in wind power are balanced by varying the outputs of the diesel generators. Because diesel fuel is expensive in these remote locations, wind energy can economically contribute a large fraction of total generation. In effect, the diesel fuel provides the long-term storage.

In a large-scale state or national electricity grid, the balancing of wind power is done primarily by peak-load plant.

The economics of wind power must take into account its effect in changing the economic *optimal mix* of conventional base-load and peak-load plant. If there is too much peak-load plant in the grid, the annual costs of the generating system are higher than optimal, because of the high fuel costs of the peak-load plant. On the other hand, if there is too much base-load plant, the annual costs are higher than optimal, because of the high annual charges on the capital cost of base-load. Optimal mix of base-load and peak-load gives the minimum annual cost.

When a large amount of wind power is introduced into an electricity supply system, this optimal mix changes. Using mathematical and computer models, it has been shown that wind power replaces base-load power stations with the same annual average power output[1,2]. For example, 2700 megawatts of wind turbines may have an average power output of about 850 megawatts, which is about the same as the average power output of a 1000 megawatt coal-fired power station. Therefore, such a power station could be retired at the end of its operating life and replaced with 2700 megawatts of wind power, which would generate the same annual average quantity of electricity.

As expected, the reliability of the generating system would decrease a little, but this is easily restored by installing a little additional peak-load plant, e.g. gas turbines. For an electricity supply system in which geographically dispersed wind farms contribute 20% of electricity, this additional peak-load plant is typically about one-quarter of the wind capacity (about 700 megawatts in the above example) and is only operated infrequently. Since its capital and fuel costs are both low, it plays the role of reliability insurance with a low premium.

By the way, the fact that the average power of a wind turbine is typically 30% of its peak power is not a serious problem -- it is taken into account as a matter of course in the economics of wind power.

Practice

Since 2003 Denmark has generated 20% of its electricity from wind power and this has permitting some coal-fired power stations to be retired. There have been no major problems resulting from wind variability, although there is a temporary problem resulting from the connection of a large bloc of wind power from off-shore wind farms to a single point on a weak section of the transmission network. Because Denmark is connected by transmission line to other European countries, it does not need to install additional peak-load plant to balance its wind power. Instead, it purchases additional power from its neighbours when necessary. In practice it makes little difference whether the back-up is purchased from other countries or from a local gas turbine.

With some strengthening of the grid, Denmark plans to increase wind's share even further. As this occurs, the costs of balancing the wind and of discarding wind energy during off-peak periods will gradually increase. Clearly, without long-term storage -- e.g. in the form of hydrogen or vanadium-redox batteries -- it is not possible to generate 100% of grid electricity from the wind. But, a mix of different kinds of renewable energy sources can provide a complete generating system.

Renewable energy scenarios

Graham Sinden from the Environmental Change Unit at Oxford University has investigated the potential contribution from several different, variable, renewable electricity sources in the UK. He finds that adding up different renewable energy sources with different statistical properties can substantially reduce the total variability and hence the need for back-up. Using real data spanning many years on winds, sunshine, waves and tides at multiple sites, Sinden concludes that the major proportion of UK electricity could be generated from renewable energy sources, with wind from dispersed sites being the biggest source[3]. As Sinden says:

> "…if you plan the right mix, renewable and intermittent technologies can even be made to match real-time electricity demand patterns. This reduces the need for backup, and makes renewables a serious alternative to conventional power sources."

In particular, it puts renewables ahead of nuclear power, which runs at the same rate all the time regardless of fluctuations in demand. Currently wind power is less expensive than nuclear power in the UK and the USA.

Some renewable energy sources are no more variable than fossil fuel power stations: for example electricity generated from the combustion of biomass is dispatchable, as is hot rock geothermal power, which is generally regarded as an honorary renewable energy source on account of its very low pollution and very large reserves in Australia. A combination of dispatchable and variable renewable sources could supply 100% of Australia's electricity.

The recent national scenario study, *A Clean Energy Future for Australia*, is based on small improvements to existing technologies and so has a more modest goal. In its principal clean scenario, renewable energy contributes 60% of electricity, as well as reducing the demand for electricity (by means of efficient energy use and solar hot water). The study finds that CO_2 emissions from Australia's electricity generation could be reduced by 78% compared with the 2001 level by 2040, given the political will.[4]

Clean energy futures, based on efficient energy use, renewable energies and natural gas (while it lasts) are technologically and economically feasible. The main barriers are institutional and the political power of the fossil fuel industries.

Dr Mark Diesendorf teaches at the Institute of Environmental Studies, University of New South Wales.

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