

**Options for future generation:
can new renewable technologies provide a large scale economic and reliable supply?**

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Abstract

This paper takes an international view and reviews the technologies and costs of the new renewable technologies.

Many people have been led to believe that the large scale adoption of new renewable energy technologies such as windpower, solar power wave and tidal stream power will provide a low-cost reliable supply of electricity while, at the same time substantially reducing - or even eliminating - dependence on fossil fuel power generation and its associated emissions of carbon dioxide.

The paper shows that, before this can happen, three major problems must be solved. The first is the lack of a low cost efficient technology for storing large amounts of energy for periods of weeks and months. No such technology is available and, to my knowledge, no promising technology has even been identified. The second is the fact that no new renewable technology can be relied on to produce anything near to its maximum output when needed. The third is the high cost of these technologies compared to well established alternatives.

In order to highlight the magnitude of the storage problem, the paper compares a hypothetical isolated 10,000 MW power system powered either by nuclear power plus pumped storage or by windpower backed up by a storage system that can store large quantities of electricity for long periods.

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Introduction

Modern power systems are huge, complex and inherently unstable. Few people understand the problems of ensuring that the total generation in a power system matches the fluctuations in load on a minute by minute basis. If the fluctuations are excessive, the lights go out. New intermittent energy technologies such as windpower, solar power and marine power add a new source of major fluctuations and add to the difficulties of keeping the lights on.

All the new renewable technologies share the characteristics of a low capacity factor¹ and an output that is intermittent and, in most cases, unpredictable. Tidal power alone has a predictable output that varies twice a day with the tides and also monthly with the difference between spring and neap tides. Solar power is predictable in that no power is generated at nighttime and unpredictable because a band of clouds crossing the sun can reduce output by up to 80%. It is also seasonal with maximum output in the summer and less in the winter.

Windpower is unpredictable in the short term and seasonal in the long term. In New Zealand, it is about 10% above average in the springtime and about 10% below average in the autumn and early winter when it is most needed.

For the above reasons, none of these technologies can provide the reliable supply needed by modern power systems until we develop a technology that will provide low cost and efficient energy storage for periods of days, weeks and months.

Wind power

Wind power is the most highly developed of the new renewable energy technologies. The technology is well proven and competition between manufacturers is fierce so there is not much scope for further improvements in efficiency – other than a change to two bladed turbines – nor much scope for a dramatic reduction in costs². Because the technology has developed very rapidly over the last few years and ratings have increased from 1 MW to more than 3 MW in a relatively short time there is still no background of experience to draw on to determine the ultimate life and long-term maintenance costs of large modern wind turbines. This is not helped by the fact that wind turbine manufacturers and developers appear to be most reluctant to release information on what are rumoured to be widespread problems with gearboxes, blades and metal fatigue.

¹ The ratio of the average annual output to the installed capacity

² The share values of major wind turbine manufacturers have dropped by a large amount recently. This indicates that they are not making huge profits and, as result, there is little scope for them to reduce their prices. Some reductions will result from a reduction in the cost of steel and copper.

A change in the output of large windfarms of 50% in a few minutes is not unusual. Attempts to predict the output of wind farms more than an hour or so ahead have not been successful³. Capacity factors vary from 18 - 20% in Germany to 37 - 40% in New Zealand. At a typical 25% capacity factor windpower costs about 20 NZ c/kWh at the station gate. At 37% capacity factor, the cost is 12 c/kWh⁴. In the US, current coal and nuclear power generation costs 2-4 US c/kWh. A recent Finnish study⁵ calculated a cost of 3.5 Euro cents (5.25 US c) for new nuclear and 4.5 Euro cents (6.75 US c) for coal.

Solar Power

The capacity factor of solar power is around 20%. The output varies predictably every day and unpredictably every time a cloud passes over the sun and drops the output by as much as 60%. The capital cost of solar photo voltaic is in excess of \$5000 per peak kW. The unit cost is around 40 cents.

Grid connected solar power is seriously uneconomic and only exists because of massive subsidies or a desire to appear to "carbon neutral". The current "boom" in solar power is driven purely by subsidies. For example, in Spain, solar power installations are paid more than 400% above the current electricity price and this is guaranteed for something like 20 years.

The most widespread technology for solar power is photo voltaic – the use of solid-state silicon cells to generate electricity from sunlight. Most large installations are fixed and therefore generate maximum power in the middle of the day when sun is in its most favourable position. Some solar farms use tracking but it seems that the cost, complication and maintenance problems of thousands of tracking devices offsets most – if not all – or the advantage of increased output.

The other solar technology is solar thermal power. This has a large number of reflectors focussing sunlight on a heat exchanger mounted on a tower, or a tubular heat exchanger at the focus of a channel type reflector or a heat exchanger at the focus of a large steerable dish.

It is often claimed that huge solar of farms in the desert areas such as north Africa or Central South-West USA could provide huge amounts of power for Europe or the rest of the USA. Apart from the obvious problem of transmission, and seasonal energy storage, the problem of operating and maintaining complex and delicate equipment in a desert environment appears ot have been ignored. Most deserts are subject to sand storms that will damage reflectors, equipment housings and even plastic cables by sandblasting. Even if sand blasting is not a problem, and is still a problem of dust and dirt fouling the reflectors. Cleaning thousands of hectares of reflectors after every dust storm will not be easy and will not be cheap⁶.

³ Download report from <http://www.windaction.org/documents/461> "E.ON Netz GmbH, the largest grid operator in Germany, reports in its Wind Report 2005, that "Wind energy cannot replace conventional power stations to any significant extent...The more wind power capacity [on] the grid, the lower the percentage of traditional generation it can replace." The report can no longer be found on the E.ON website.

⁴ Based on a 20 life and a 10% discount rate.

⁵ Comparison of electricity generation costs Tarjanne Risto, Kivistö Aija Lappeenranta University of Technology Research report EN A-56 2008.

⁶ The California Public Utilities Commission estimates that 100,000 to 160,000 desert acres would be needed to meet the state's goal of increasing renewable energy by 33 percent by 2020.

Regarding the cost of solar power, a paper presented at a recent electricity industry conference in Queensland discussed costs and problems of replacing diesel generators supplying remote settlements with solar power. Although the cost of diesel generation was in excess of 50 Australian cents per unit the best available solar power (thermal reflector) was even more expensive.

The rapidly declining cost of solar cells is often used as a basis for claims that photo voltaic solar power will soon become competitive with grid generated power. These claims appear to ignore the costs of collecting the low voltage direct current from the cells and converting it to high voltage direct current to charge batteries and to supply the inverters that supply the load. Because at least 300 kW of solar cells operating at 20 per cent capacity factor will be needed to supply a 100 kW load at 60 per cent capacity factor, it is inevitable that the cost of the installation and of the conversion and storage equipment will be high compared to conventional generation.

While there is no doubt that solar power has its place where there is ample sun and alternatives are very expensive, it is hard to see how large-scale solar power can compete with conventional alternatives.

Marine power

There are three main forms of marine power:

Tidal power generation using a barrage is a well established technology but there are only two large tidal power stations in operation. The first is at La Rance in France which has been in operation for more than 40 years and the second is a recently commissioned station in South Korea. The Korean station was built at the site of an existing barrage built to store freshwater. Unfortunately there were major problems with water quality so the pond was to be opened to the sea via a tidal power scheme. As the barrage and most of the civil works were already built, the extra cost of tidal power generation was not excessive.

Other large tidal power schemes are being contemplated. One is the 5800 MW Kalpasar scheme on the Gulf of Khambat in India. The scheme is associated with large scale fresh water storage. The latest indications are that the tidal power component will be abandoned because of the high cost of the civil works and generating plant and the problems of managing the Indian Grid with a fluctuating input of up to 5800 MW every day. Calculations have indicated that scheme would generate power at a much higher price than could be achieved with coal-fired generation so it is likely that the tidal power component of the scheme will soon be abandoned in favour of a smaller scheme purely for fresh water storage.

Wave power has been investigated for many years. A very early proposal was for a wave power installation on the south east coast of the island of Mauritius in the late 1950s. This was abandoned because of the huge problems of building civil works on top of an existing coral reef. The scheme envisaged an inclined barrage that allowed the waves to spill into an elevated lagoon to supply a conventional low head hydropower station.

The OPEC crisis of the 1980s led to many investigations into wave power. Professor Norman Bellamy of Coventry University investigated many wave power options. He built working

prototypes of “Salter’s Ducks” and was the original inventor of the “Pelamis” sea snake which has recently been re-invented. According to Professor Bellamy, almost all the devices he investigated generated much less power than expected and turned out to be seriously unreliable. The fact that the Pelamis prototype off the coast of Portugal has recently been abandoned because of technical and financial problems, reinforces his conclusions. Professor Bellamy did develop one promising technology which he called “Sea Clam” which showed some promise. No one else has taken this up and he has recently come up with an improved version. In his latest letter to me he said that he has come up with yet another device which holds even more promise.

Some wave power devices are built on the sea coast. In the 1980s, the Norwegians developed a system using a tapering channel that amplified the waves and spilled the water into an elevated pond. The system worked successfully until storms wedged boulders in the tapered channel so wrecking the amplifying effect of the channel. The project was abandoned. The other device they developed had a resonance chamber that pumped air through a bidirectional Wells turbine. It worked reasonably well until it was destroyed during a storm.

Experience so far indicates that while it is very easy to invent a device that will recover energy from waves it is almost impossible to invent a device that is economic, reliable and will not destroy itself in a storm. The problems of maintaining a large number of wave power devices in a stormy marine environment may turn out to be insoluble at an affordable maintenance cost. Even if it is affordable, there is sure to be a major problem in finding skilled and versatile technicians who are prepared to work in a very unpleasant and dangerous environment. Those who suffer from seasickness need not apply!

Clearly, wavepower has a long and rocky road ahead.

Marine current power is also a fertile field for renewable energy. Many devices have been developed but, it seems, none of them have yet demonstrated that they can produce electricity at an acceptable cost and without the need for frequent maintenance.

Most proposals involve turbines similar to wind turbines. One example is the SeaGen prototype, located in Northern Ireland’s Strangford Lough. By July 2008 it had briefly generated 150kW and was expected to reach full capacity (1.2 MW) a few weeks later. It seems that it achieved an output of 1.2 MW in January 2009.

An unusual option is the open centre a turbine which is proposed for Kaipara Harbour. Not much information is available on this turbine. The turbine appears to have magnetic bearings around the perimeter and a generator that has its rotor poles exposed to the sea. Both of these represent major technological challenges. It appears that at least one prototype has generated power.

Marine current power has a potentially major problem with marine fouling. Barnacles, weeds and slime will regard these turbines as prime habitats. With the best anti-fouling compounds available, large ships need to be repainted every five years. Fouling is much worse close to the shore and where there are tidal currents. Disconnecting and removing a marine current turbine, in an environment with very strong currents, taking it to a place where it can be overhauled,

cleaned and painted, returning it to the sea bottom and re-connecting it will be an expensive and complicated business.

Can new renewable energy technologies provide a reliable and economic supply?

New renewable energy technologies add to the cost and problems of operating a power system because they are intermittent and/or unpredictable and their output changes rapidly. To a power system operator, there is no difference between a major load change and a rapid change in the output of a large wind farm or solar power plant.

It is frequently claimed that it is possible to supply most of the load from wind power and other renewable technologies and that modern economies can make a massive reduction in energy consumption without any effect on the economy. Many of these claims come from organizations involved in carbon trading⁷ or the renewable energy industry.

For example, a recent report commissioned by Greenpeace and the European Renewable Energy Council⁸ (Europe's largest renewable energy trading association) claimed that it was possible to replace all United States power generation from coal, nuclear and oil fired power stations with low cost renewable energy. Most of this renewable energy - wind, plus some solar and ocean - would be intermittent and seasonal.

These claims all ignore:

- the huge – and unsolved - problem of storing the energy when it is available so that it can be used when it is needed;
- the very real problems of coping with the unpredictable and rapidly fluctuating output of the windfarms;
- the very high real cost of windpower;
- the potential for nuclear power – usually by claiming that it is too dangerous to be contemplated;
- the cost and problems of the large-scale long distance power transmission that would be needed.

To illustrate the problems listed above I carried out a desk study of a notional power system with a peak demand of 10,000 MW at a capacity factor of 60% giving an annual energy demand of about 55,000 GWh pa. I calculated the total cost of supplying this system from:

- the well proven combination of nuclear power and hydro pumped storage;
and,
- a combination of windpower and pumped storage.

⁷ “Carbon trading is the only commodity trading where it is impossible to establish with reasonable accuracy how much is being bought and sold, where the commodity that is traded is invisible and can perform no useful purpose for the purchaser, and where both parties benefit if the quantities traded have been exaggerated. It is an open invitation to massive fraud.” <http://www.scoop.co.nz/stories/SC0711/S00060.htm>

⁸ “energy [r]evolution; a sustainable energy outlook” <http://www.greenpeace.org/usa/news/energy-r-evolution>
“The report finds that off-the-shelf clean energy technology can cut U.S. carbon dioxide emissions from fossil fuels by at least 23 percent from current levels by 2020 and 85 percent by 2050 (equal to a 12 percent cut by 2020 and an 83 percent cut by 2050 from 1990 levels) – at half the cost and double the job-creation of what it would take to meet U.S. energy needs with dirty energy sources.”

I chose nuclear power because it is “carbon free”, has low fuel costs and the cost is much same all over the world. The nuclear-power based system could supply all the load without the need for support from adjacent power systems so, to make a realistic comparison between the costs and benefits of the two systems⁹, the same constraint was imposed on the wind powered system.

I assumed that the nuclear power based system would have 7 generating units each of 1050 MW to give a total generating capacity of 7350 MW. Because nuclear power is not well suited to following fluctuations in load it is normal practice to associate nuclear power stations with hydro pumped storage. This allows the nuclear power stations to run efficiently and economically at a steady output. The pumped storage schemes pump water into an upper reservoir when the load is low and uses this water to generate extra electricity when the load is high. For a nuclear based system these pumped storage schemes need to have sufficient storage for about 10 hours operation at maximum output. With 3500 MW of pumped storage, the nuclear based system could supply all the load even if one nuclear unit and one pumped storage unit was out for maintenance. My calculations allow for a 25% loss between pumping and generating. I assumed that 20% of the energy would be supplied by the pumped storage scheme.

For this option, transmission costs would not be very high because the nuclear units would be sited reasonably close to the load centres and lines would be heavily utilized.

Assuming a typical wind power capacity factor of 25% and allowing for pumping losses, the system supplied by windpower needed 31,000 MW of windpower to generate the required 68,000 GWh pa. The key criteria for determining pumped storage installed capacity was that it had be sufficient to absorb all the windpower generated when the system load was low (say 4000 MW) and the wind output was at its maximum. It is well established from aggregating existing wind farms that windpower output would seldom exceed 80% of installed capacity (25,000MW) so a pumped storage capacity of 20,000 MW was needed¹⁰. These pumped storage schemes must be able to store large amounts of energy for long periods¹¹. For the purpose of the exercise I chose to ignore the fact that, in reality, there is very little chance of finding suitable sites for these huge pumped storage stations and that there is no alternative storage technology available or under development.

The next step was to calculate the cost of generation from the two systems. I used a cost of \$US4000 per kW for the nuclear power stations quoted in the recent Finnish report¹². For windpower I used a cost of \$US2250 per kW for windpower from investigations I have carried out into the cost of recent wind farms worldwide. I used a cost of \$US1500 per kW for the

⁹ Most evaluations of windpower assume that surplus electricity can be exported to other systems when the generation is greater than needed and can be imported from other systems when the wind is not blowing. In general, they assume that this can be done at no cost. In reality the surplus power is exported at a very low price and power is imported at a very high price.

¹⁰ $31,000 \times .8 - 4000 = 19,800$ MW

¹¹ For example, in New Zealand, windpower is 10% above average during the spring time when the load is low, the snow is melting and it is raining and about 10% below average during the autumn and winter peak demand periods. There would be very few systems where the availability of windpower closely matched the seasonal and daily loading.

¹² Comparison of electricity generation costs Tarjanne Risto, Kivistö Aija Lappeenranta University of Technology Research report EN A-56 2008.

pumped storage schemes which, from my background in hydropower, is reasonable for schemes with 6 – 10 hours storage.

I assumed that the transmission cost would be directly proportional to the installed capacity. If anything, this is conservative because the wind farms would be widely scattered around the country and the transmission system would have to be able to transmit large amounts of power from regions where the wind was blowing - which could vary from hour to hour - to the load centres and the pumped storage schemes.

I have used the operation and maintenance and fuel costs of a nuclear power plant and windpower schemes from the Finnish report. The costs are adjusted to allow for the difference between the amount of power generated and the amount of power actually delivered.

My calculations showed that the nuclear powered system would have a total installed capacity of 11,900 MW, would cost about \$US46 billion and would supply power for about 9c/kWh. The equivalent wind powered system would have an installed capacity of 51,000 MW, a total cost of \$US128 billion and would supply power for about 26 US cents/kWh.

The conclusion is that the cost to the consumer of large scale windpower is two to three times as much as nuclear power.

If the same exercise had been carried out for hydropower stations with seasonal storage or coal-fired power stations instead of nuclear, the result would have been much the same. With solar power instead of windpower, the difference would have been several times greater because solar power is much more expensive and has a capacity factor of about 20%. While the solar capacity available during peak demand periods might be quite high in systems where the peak demand occurs on a hot cloudless summer day, it would be very low in systems with a peak demand that occurs on a winter's night.

Conclusions

Large-scale power from intermittent renewable energy sources is very expensive and will continue to be unachievable until an efficient, low-cost method of storing large amounts of electricity for long periods is discovered¹³. I am not aware of any technology that comes anywhere near to meeting this requirement.

None of these renewable energy technologies would exist without grants, tax breaks and massive subsidies for large and fundamentally uneconomic developments. In addition, consumers, taxpayers and ratepayers, not the generators, pay for the cost of transmission and backup power stations.

¹³ It is often claimed that electric cars can be connected to the system so that they will provide additional generation during peak demand periods and, it is hoped, recharge the batteries in the early hours of the morning. This seems to ignore the fact that, peak demand periods often occur at about the same time as the car's owner returns home from his daily commute – so that the battery is nearly flat – and that will always be possible to recharge the battery by morning. Few commuters will want to risk the possibility of finding that their victory is not charged overnight.

Comparison of the two systems (\$US)

Nuclear powered system

Total installed capacity	11,900	MW
Total system cost	\$45,850	\$m
Cost of power	9	c/kWh

Wind powered system

Wind capacity factor	25%	
Total installed capacity	51,000	MW
Total system cost	\$128,200	\$m
Cost of power	26	c/kWh
Cost % of nuclear	300%	