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Is the Future Really Renewable?

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I was an early enthusiast for renewable, or 'alternative' as we then called it, energy. Since 1973 when interest in this area was triggered by the Middle East oil price crisis, I have looked into a wide range of technologies: waves, hydrogen, ocean temperature difference, carbon capture and bioenergy.

All of these failed to live up to initial expectations once carefully evaluated and when side effects were considered.

The fundamental problem with all forms of renewable energy is that in practice they consume the one totally non-extendable resource of the planet - space. A 2 GW nuclear power station occupies about 0.5 km^2. Even in windy Britain to produce the same average output we would have to cover 800 km^2 with wind turbines. Furthermore the issues of intermittent supply look insoluble with any technology on the horizon.

There are places and situations where the right kind of renewable technology can indeed be effective. However few of these are where politically driven investment is currently directed. The best location for most renewables is in sunny developing countries lacking a good existing energy infrastructure.

For a future world of nearly ten billion by 2050, renewables, appropriately chosen and located, will undoubtedly have a significant part to play, but dispatchable, high density energy sources, i.e. fossil fuels and nuclear, will remain essential.

1. They’ve Stopped Making it

Apocryphally, the American author Mark Twain was once asked for advice on investing money. He is reputed to have said “Buy land lad, they’ve stopped making it.” A characteristic of all renewable energy sources is that they actually consume large amounts of the planet’s one totally unextendable resource – land.

Estimates of the areas required to produce 1GW of electricity in the UK are as follows.

- 30,000 km^2 catchment area for hydro (very variable and approximate)
- 25,000 km^2 of arable land for electricity from biodiesel (50 % thermal efficiency)
- 10,000 km^2 of arable land for by product wheat straw co-fired (30 % efficiency)
- 4,200 km^2 of arable land for cereal biomass (30 % efficiency)
- 3,300 km^2 of sustainable woodland (Economist, 6/4/13)
- 400 km^2 of wind turbines at 25 % LF (4 × 2.5 MW turbines per km^2)
- 300 km^2 lakes for hydro (very variable, depends on annual rainfall patterns)
- 65 km^2 of solar panels at 10 % LF.

For comparison, the 1.36 GW nuclear power station at Torness in Scotland occupies less than 1 km^2 including offices and car park, as does the Sellafield site which processes all UK nuclear fuel. The reason for these huge areas is that ultimately all renewable energy must come from the sun. Solar radiation in the UK is just over 10 W/m^2, which puts a theoretical lower limit of 10 km^2/GW. It is thus clear that most natural processes for turning sunlight into other forms of energy are not very efficient. Solar PV would appear to be working quite well giving about 30 % efficiency during daylight hours.

The other issue of course, is what else can coexist in or near the areas required for renewables. This is very dependent on the technology. Thus most of the catchment area for hydro is still available for

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recreation (e.g. mountaineering in Norway) or, with reservations on water use, for agriculture. Arable land used for growing fuel crops is unavailable for food, but woodland can still be available for recreation. Solar panels on rooftops can occupy otherwise unused space although solar 'farms' may preclude other agricultural use. Most controversially in the UK and other densely populated countries is the coexistence of wind turbines with habitation and recreation.

2. The Good, the Bad and the Ugly

There is a strong tendency for renewable energy enthusiasts to overlook what they consider to be side issues and to exercise undue optimism. In the discussion below some of these are highlighted. I endeavoured to classify the technologies into three categories.

1. Good – efficient and reliable with a minimum of undesirable side effects.
2. Bad - inefficient and / or with undesirable side effects.
3. And Ugly.

However, I found that a fourth category was required – the Improbable.
I will discuss these in turn starting with the Ugly.

2.1 The Ugly

At first sight wind turbines appear to be an ideal source of energy. The wind is free and universally available, no chemicals are involved and the vision of blades turning gently in a rural landscape in developers' photographs appeals to many.

To deal first with the 'free' will also expose the key problem inherent in all intermittent renewables such as wind, solar and waves.

The wind industry (Renewable UK, 2015) puts the development and construction cost of cost of a MW of onshore wind at £ 1.47 M. (At May 2015 exchange rates £ 1 = $ 1.5 = € 1.4.). Using the UK average load factor of 27.9 % each MW would generate 2.44 GWh annually. An average wholesale electricity price of £ 40 /MWh leads to annual revenue from electricity sales of £ 97 k, giving a simple payback period of 15 y, hardly a very attractive investment.

However, current onshore wind developments receive a guaranteed subsidy of £ 45 /MWh and offshore receives £ 90 /MWh rather changes the picture for developers, and increases the cost to consumers by these amounts.

However, this is not the whole story. Consumers rather than developers have to pay the costs of expanding the electricity grid to take wind generated power from e.g., the north of Scotland to the main centres of consumption in the south of England, more than 1,000 km away. Further, there are the indirect cost impacts on the rest of the electricity system

These last should have been anticipated but were not either in the UK nor in Germany which faces similar problems. No one considered the impact on the rest of the electricity system of large amounts of near-zero marginal cost electricity appearing and disappearing essentially at random, and being given priority on the grid.

The UK currently has 12.2 GW of installed wind capacity, which produces on **average** 3.4 GW. The likely maximum output is around 10 GW. However the **minimum** can be essentially zero, e.g. at 2.20 pm on 4 April 2015 total wind generation from all this capacity was a mere 79 MW (Gridwatch, 2015).

Furthermore, the need to keep flexible generation capacity on standby at low efficiency can significantly reduce the carbon dioxide displacement which has been the main justification for renewables in Europe. This can mean that around 30 % of the claimed reduction is not achieved. (Wheatley, 2012)

It is also noticeable in the UK that wind tends to displace low CO_2 gas generation rather than coal, unsurprising as this is both more flexible and more expensive (Gridwath, 2015).

The consequences of this situation can be summarized as follows.

- No matter how much wind power you have, you cannot close down any significant amount of dispatchable generation.
- When wind is given grid priority, thermal generation must be turned off or down, leading to inefficient operation and uneconomic load factors.
- The cost of electricity to the consumer therefore rises still further.

These additional costs to consumers have been estimated to raise the effective cost of onshore wind generation to £190 /MWh and £ 265 /MWh offshore, compared with £ 6 /MWh for new combined cycle gas turbines (Gibson, 2011). UK consumers are thus paying at least £ 3.55 billion/y extra for wind power.

However, this is not what makes wind power really ugly. The problem lies not so much with the technology, but with how it is being delivered.

People who live in cities and see wind turbines at only at a distance, usually from their cars, believe that wind is a benign technology. It is not. Wind turbines are noisy and the larger turbines, up to 140 m high, create an overwhelming and oppressive visual impact on any property within 2 – 3 km, at which distance the noise can also become unbearable. Having wind turbines built near your home can make it both uninhabitable and unsaleable.

Since they are so profitable there will be some people in communities near wind developments who benefit from them, while those living near the turbines suffer. Wind power can thus destroy individual's lives and tear communities apart.

The solution would be either not to build turbines near habitation, difficult in a crowded country like Britain, or to compensate and relocate the people affected. The issue is thus a social and political rather than a technical one.

Is there then a sensible role for wind generation? Until the problem of large scale energy storage is solved, if it ever can be, it must be on a relatively limited scale unless the costs of maintaining essentially 100 % backup are acceptable. The human issue could be addressed by compensation or simply by building turbines only in uninhabited areas of small scenic significance – northern Canada and much of Australia for example. While these are remote from consumers, the same is true of many existing hydroelectric installations.

2.2 The Bad

Bio is bad. Or at any rate, this is the case with most currently promoted technologies.

Liquid biofuel production in temperate climates from grain or oil seeds is a demonstrable nonsense (Ponton, 2009) unless some cost effective method of converting cellulose to liquids can be developed, and so far this has not happened. Nor have alternatives such as bio-butanol or algal hydrocarbons yet proved practical. Sugar cane ethanol in the tropics, with increased photosynthetic efficiency and multiple annual crops may look better, but concerns remain about the long term sustainability of such monocultures.

In the UK, Drax, a 4 GW coal fired power station has been modified to fire biomass in two of its six units and there are plans to extend this to three or more. In 2014 it consumed 4 Mt of biomass, 97 % of it imported, mostly from the US and Canada. Biomass power has the great advantage of being dispatchable, it is the only significant renewable technology other than hydro which can be controlled. However it's short to medium term effect in reducing carbon dioxide emissions is questionable.

Burning wood to produce electricity releases about 25 % more carbon dioxide per MWh than coal. This is because being carbohydrate rather than carbon wood is a poorer fuel and burns at a lower temperature. Also, chopping down trees removes a carbon sink, the carbon they contain is released immediately, but new trees, if actually replanted, take up to thirty years to grow. Proponents argue that only timber waste need be used, and that this would otherwise end up anyway as carbon dioxide or, even worse from a greenhouse gas perspective, methane by anaerobic decomposition.

However, it is hard to see how large scale biomass firing could be accommodated solely by waste or even notionally sustainable woodland at 3,300 km^2/MW. The total area of woodland in England is about 13,000 km^2, which if managed sustainably (which would make it unattractive for recreation for which much of it is now used) would provide only 4 GW of power, about one tenth of the England's average demand. This is why the country's only large biomass station imports nearly all its fuel.

Small scale biomass using locally sourced material is a possibility for domestic heating in rural areas, but even here the logistical problems of delivering and feeding four or five tonnes of solids are significant.

Truly sustainable biomass from annual crops such as grasses similarly fails due to the land area required for large scale production. Burning all the UK's by-product straw would produce about 185 million GJ annually. However, if used to generate electricity at an optimistic 30 % thermal efficiency this would yield only about 5 % of annual requirements – ignoring the problems and costs of collection and delivery (Ponton, 2009).

2.3 The Improbable

Before considering the Good let us consider the Improbable. Besides the space they occupy, the fundamental problem with nearly all renewables is their intermittency, and for most, their unpredictability.

Intermittency and unpredictability could be overcome if there were a means of economically storing large quantities of electrical energy. Unfortunately, only one plausible technology is presently known – pumped hydro storage. Hydroelectricity is (usually) a Good renewable technology. Unfortunately it is very restricted by geography and topology, and pumped storage hydro is even more restricted. It requires two large areas to be occupied by lakes thus doubling the area occupied, unless one of these can be the sea. However unless the destruction of a fresh water ecology can be contemplated the sites available for large salt water lakes inland are even more restricted – there is only one in Europe, the Rance tidal power scheme in France.

Pumped storage thus requires the existence or creation of two freshwater lakes at different levels. There are four such storage systems in the UK with a combined energy storage capacity of about 27 GWh. This represents about 45 min of average UK demand. Only two or three other plausible sites remain in the country. At least 20 would be required to iron out the fluctuations of a mainly wind powered country. (Mearns, 2015)

Chemicals have the highest energy density of all non-nuclear systems. A m^3 of gasoline represents 8.88 MWh of thermal energy, while the same volume of water raised 300 m represents a mere 0.82 kWh of mechanical energy.

Unfortunately there is no easy or economic route to turn electricity into gasoline and few other chemical systems approach this density. The best lithium storage batteries can achieve a density of around 0.7 MWh/m^3. The idea that a national fleet of electric cars could serve as a distributed storage system suffers from two major flaws. First of all the cost of replacing most existing vehicles would be inordinate. Secondly if this were to supplement e.g. wind power, unpredictable demand could leave all the country's vehicles stationary. Backing up solar would not be very effective either as most vehicles are in use during the day and would want to be recharged at night.

The only chemical relatively easy to produce electrically is hydrogen and its high mass energy density (142 MJ/kg, 39 kWh/kg) looks superficially attractive. Unfortunately even when liquefied this represents only 2.76 MWh/m^3, or when compressed to bounds of safety, even less. In addition the overall efficiency of hydrogen storage with electrolysis and fuel cells both only about 70 % efficient, is around 50 % compared with more than 80 % for pumped storage.

Hydrogen is probably the worst fuel imaginable in terms of storage and transport due to this low volumetric energy density and its tendency to embrittle most metals. From a safety point of view it has the largest range of flammable and explosive limits. About the only disadvantage it lacks is toxicity.

2.4 The Good

From an engineer's standpoint, the best renewable energy is hydroelectricity. It is the most flexible – start-up and shutdown of even the largest installations takes only minutes at most. While the catchment area required is huge, the installation is compact and the areas occupied by storage lakes less than the space occupied by wind turbines.

However the possibilities for hydro generation are greatly constrained by geography. One has to be a large country with a small population and the right topology. Norway is the classic examples; its land area is 385,000 km^2, larger than Germany, and its population, 5 million, is less than that of Scotland. Norway produces more than three times as much electricity as a country with that population would normally consume.

So hydro is good if you are Norway, not so good if you are crowded China and have to displace large sections of your population. If you are Laos, upstream hydro developments on the Mekong are likely to have a disastrous impact on your horticulture along the banks of that river. However, the major constraint is the lack of possible sites. Although the world total of economically viable hydro could be doubled or tripled, from currently around 3.4 PWh/y, and this could represent nearly half of current electricity consumption, most of the potential expansion is not close where it is required. For example, Western Europe has very little unexploited hydro power, and the bulk of this is remote areas of Russia (INTPOW 2011).

Solar is good. Even in cloudy Britain it takes up less space than any other renewable technology. It is silent. Solar panels on roofs disturb no one and damage no views of the scenery.

However, not all rooftops are conveniently south facing and unshaded so the practical potential is significantly limited. Cost of panels themselves have fallen hugely in ten years and will fall further. However, the cost of installation and ancillaries such as inverters remain high. Unavoidable daily intermittency and a 3:1 difference between summer and winter mean that average load factors are at best 10 % in northern Europe, and surges on sunny mid-days have led to grid instability in Germany. A major beneficiary of European solar power investment is France which can turn down its own hydro and nuclear power to accept surplus, and thus free or cheap, solar (and also wind) generated power from Germany and Spain.

Solar can never be a major source of power in Europe, although one potential application does stand out. Air conditioning is becoming a significant consumer of electricity. Demand is maximum on summer days and so integration of solar technology, either photovoltaic or absorption heat pump, in air conditioning systems seems an obvious development. This would make even more sense in the US where peak electricity demand is actually for air conditioning in the summer.

The major payoff for solar is in sunny countries with a poor or nonexistent grid system where it can replace inefficient and damaging alternatives. A striking example of this would be replacement of about one billion kerosene lamps in developing countries with self contained solar lighting. There would be at least a triple payoff from this.

Firstly kerosene lighting contributes to greenhouse effects the equivalent of about 440 Mt of carbon dioxide. Half of this is due to carbon black (soot) particles emitted by inefficient and often home-made lamps.

(Jacobsen et al, 2013) These particles, emitted indoors, are a major health hazard, particularly to children, so a second significant benefit would be to public health.

Finally, even small solar lamps provide better light than all but the most expensive kerosene lamps, and their installation has been found to improve the educational attainment of children who can now study at night (SolarAid 2015).

Even if one simply considers greenhouse gas remission, the economic case for spending on solar to replace kerosene in Africa rather than, say, gas in the UK is overwhelming. A solar lamp costing about £5 can replace a kerosene lamp emitting the equivalent of about 450 kg of carbon dioxide a year. A solar 4 KW installation in the UK costs on average £ 7,500 and at best would remit 1,500 kg. £ 20 worth of solar lamps would remit 1,800 kg.

Germany spends about € 16 billion annually to subsidise renewables and its emissions have recently actually risen. A one-off investment of £ 5 billion, € 7 billion, could replace all the developing world's kerosene lamps making a permanent remission of nearly half a billion t of carbon dioxide a year.

One should not forget the very best option, which is to reduce energy consumption and so save the need for generating electricity of burning fuel in the first place. Average fuel efficiency of vehicles in Western Europe has more than doubled in the last twenty years. This has saved money, reduced dependency on imported oil and probably had more effect on reducing emissions than the billions spent on subsidising wind and solar.

3. Conclusions

- Renewable energy is a nice idea. However the reality is that all existing technologies occupy large amounts of space in a crowded world and can seriously damage the local environment. It is also the case that the production and disposal of materials involved (e.g. neodymium used in turbines) may have both immediate and long term environmental impacts.
- The fact that most renewables cannot be turned on and off to meet demand means that dispatchable generation is required to back them up almost on a 1:1 basis meaning that the capital cost of this capacity must still be met. While in principle this problem could be overcome by large scale energy storage, there is no suitable technology presently available or in immediate prospect. This adds hugely to real costs and reduces potential CO_2 savings.
- A rational renewables strategy would be to look at the most cost effective technologies and applications. This would involve their deployment in developing countries rather than in Western Europe, providing these countries with added health and social benefits.
- Unless and until the storage problem can be solved, the amount of intermittent renewables in the energy mix will have to be limited. Denmark, with nearly 40 % of its electricity from wind, is already well past this limit and has to import from Norway or Sweden at times of shortage, paying a premium price, while having in effect to give surplus electricity away when wind production greatly exceeds demand.
- However, in Europe there is scope to develop both shale gas, which in practice causes neither earthquakes nor water pollution, and safe nuclear power based on uranium today and thorium tomorrow to supplement a sensible amount of renewables.

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