Limitations of 'Renewable' Energy

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Introduction

Anyone who is intimately familiar with a field finds, after a time, that aspects of that specialist knowledge become encapsulated in specialised terms whose meaning is acquired by long familiarity with the application of that field, and whose application enables the analysis of the field far more rapidly and accurately than the means available to the layman.

For example a physicist confronted with the proposition that it is possible to build a perpetual motion machine, can, without actually having to investigate the detail of the proposed project, declare with complete certainty that it is impossible, since it would ***necessarily*** violate the laws of known physics. The physicist does not need to build it and test it in order to make that statement.

But to the layman, confronted with a (deliberately) complex object which, on the face of it *seems* to embody the principle, without the viewpoint acquired through years of studying physical systems in detail, the possibility seems to be there, and, indeed he can equally well conceive that opponents of it are **not** stating as near to a fact as science can get, but are *merely offering an (ego driven?)* ***contrary opinion.***

Against this challenge, there is, in the limit, no real hope of offering refutation to someone who firmly believes (and will not be dissuaded from) an opinion that contravenes fact. Men have, and still do, die, rather than relinquish strongly held beliefs. Even clear factual evidence can be distorted by 'confirmation bias' to the extent that, in the face of evidence that would clearly refute a proposition, they will still cling to it and construct fantastic and complex scenarios to explain why, *in this particular case, and this alone,* the experimental results fail to support their proposition. And of course if the proposition is essentially metaphysical, it is in any case irrefutable[1]. Absence of evidence, is not evidence of absence, to be sure, but an entity that stubbornly refuses to leave any discernible trace of its existence is , in scientific terms *not useful* and in philosophical terms may be expressed as *having zero truth content*. That is, the fact of its existence (or not) adds nothing to the task in hand.

So it is against this backdrop of extreme emotional attachment to 'renewable energy' and extreme ignorance of the principles underlying power generation, and in the face of extreme opposition to any contradiction of its precepts, that we have to - perhaps vainly - attempt to lead those who are prepared to be led, down a path of a somewhat technical nature, in order to understand why, despite its seeming usefulness, it is in the end a deeply disappointing, wasteful and ultimately fruitless exercise.

And why simply spending *more* money on it will never achieve the hoped for results.

In this case the Devil is firmly in the detail. hiding in tacit assumptions about the nature of power and energy and electrical systems, that are simply *wrong* by any technical engineering standards, and yet look superficially to be mere details.

Leonardo Da Vinci, sketched out designs for aircraft - some of which would conceivably have flown. But they never did. The reason is simple: no power source sufficiently powerful and light was available to him to propel them with. We had to wait 450 years for the arrival of the oil based internal combustion engine. The Devil was in that one detail.

So now we should examine the devils in the details of so called renewable energy.

1 For a full treatment of the nature of irrefutable metaphysical statements and pseudo science, the seminal work is Karl Poppers 'Conjectures and Refutations, where he argues that the inductive reasoning of science is nothing but 'inspired guesswork' that happens to both fit the facts, and yet be conceivably refutable by other testable facts.

The three necessary concepts

In order to bring the strengths and weaknesses of all power generation systems, and in particular 'renewable' technologies into sharp relief, a basic understanding of the crucial elements of any system of generating electricity has to be arrived at. This necessitates introducing some basic concepts - shorthand terms used to describe physical parts of, or aspects of, electrical power generation.

At its simplest a useful electrical system consist of a means of generating electrical power - a generator, or a battery for example, connected by wires to a load, which then takes that electrical power and does something useful with it. Lighting a bulb, heating a kettle or driving a motor. In terms of national and international systems the system that has evolved is (for very sound reasons) to have a multiplicity of generators connected to a mesh or **grid** of wires that distribute the power to a multiplicity of **loads** over a wide geographical area.

The reasons why there are more than one power station, are redundancy, and geographical limitations[2]. The reason why there are not as many generators as loads, is economic. In general the cost of generating plant, both in financial and in terms of materials is considerably in excess of the cost of distributing the power. Generators are expensive. Wires are cheap. Also, by using a broad geographical grid to interconnect generators and loads, the demand can be somewhat 'averaged out'. That means that whilst one region may be having higher demand than another, no extreme generating capacity is needed as the imbalance is catered for by the relatively efficient[3] flows around the whole grid[4].

So we see that the traditional grids that we have, are optimized to connect large power stations located reasonably close to demands and interconnected into national (Europe) or region (USA) sized grids, using interconnects that are not too large, as they are only balancing systems, not designed to connect large amounts of generation in one place to large loads elsewhere. Under certain fault conditions they *do* need to do that, and rolling blackouts have occurred when grid elements get overloaded.

One misconception that has been voiced is that somehow the grid represents a *store* of electrical power. Nothing could be further from the truth, indeed one of the hardest technical jobs the grid and power station operators face is that at any given instant the power they are generating must ***exactly*** match the power that is needed. There is simply no storage on the grid itself in any shape size or form. At best there are a **few seconds** of power in terms of the flywheels comprised by the spinning rotors in the generators before grid power is completely lost if one or more generators lose their power input.

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2 Although power transmission is efficient, the efficiency drops with distance, unless the wire size (and cost) is increased. This leads to the generalised idea that the grid is **not** to be used for mass transfer of power from one end of the country to the other, but is to be used to balance supply and demands. The grid by and large (at remote locations from the power stations) only carries the **differences** between local area supplies and demands. Renewable energy, which tends to concentrate generation capacity where the renewable resource is, not where the demand is, destroys the efficiency of this model, and requires considerable grid upgrades for this and (as shown later, by dint of poor capacity factors), other reasons.

3 In the UK the general efficiency of transmission is of the order of 95%-98%. Its better at lower loads.

4 There are limits to grid sizes. Grids of continental size start to suffer from a subtle issue related to the speed of light! In brief if you connect a load by both a short piece of wire and a very long piece of wire to an alternating current (AC) generator, it results in current not used by the load flowing around the whole ring Imagine a circular ,oat round a castle and at one point you are jumping up and down in it. Ripples will spread around the whole pond and result in a complex pattern of standing waves at any given point. Some of these will be larger and some smaller than the original waves you made, and energy will be lost moving them round the circuit. It is for this reason (as well as another) that long distance power transmission is done using direct current (DC) which, although it creates losses in itself in the equipment that is used to turn it from and to AC at each end, is, nevertheless lower in losses than AC would be over the same distances.

Prior to the use of electronic loads, a sudden loss of generating capacity or a sudden increase in load would result in a lowering of voltage and frequency on the grid[5]*, and electric motors connected to it would slow down, reducing power demands, and lights would dim. However modern electronic power supplies do not respond to lowered voltage by reducing power demands. They draw what they draw over a wide range of input voltages, and this may in time be an added problem to grid engineers as traditional filament lighting is replaced by electronically controlled CFL and LED lamps, and directly connected motors are replaced by electronically controlled ones. Part of the drive towards 'smart grids' is for this very reason: To identify non-critical equipment that can be reduced in power in conditions of temporary power shortage. As we will see later, renewable energy makes these problems far far more serious.*

So because the grid can store no energy at all, and power must match demand at all times, there is a need to have a multiplicity of 'hands on the throttles' of all the power stations, to adjust power at all times to match the demand, and since demand is only predictable to a certain level, this means that some power stations are at all times 'throttled back' from what they might be producing - and indeed some are throttled back so far that they are generating nothing at all, a condition known as **spinning reserve** - such power stations are ready to take up the load at short notice, but are essentially burning fuel, doing nothing. And this brings us to the first important concept that is unknown to most outside the generating business, the concept of **dispatch** which is used to describe the processes involved in adjusting generator output to match demand.

This is such an important and relevant - possibly the most important and relevant - issue when it comes to analysing renewable energy, that its full discussions is given a complete section in itself. Suffice to say that the key issue is that, lacking any ability to store electricity on the grid itself, there **is no alternative** but co-operation with dispatchable power sources[6], when attempting to match generated output to actual real-world demand. And that technologies that render this more difficult, are in general to be shunned. The problems of fluctuating demand is, so to speak, bad enough already without making it far, far, worse..and that is precisely what renewable energy - of the more popular sort - does.

Which brings us neatly to the second issue that needs to be understood. The issue of **intermittency.**

Intermittency is, quite simply, the fluctuating *availability* of an energy source. All power generating technology suffers from it. Things break and need mending. Supplies of fuel can get interrupted. Routine maintenance can shut down a plant for weeks. But where we are considering conventional power stations that rely on stored energy fuel sources - coal, gas or uranium and the stored renewables of hydroelectricity, geothermal[7], and biofuels - such loss of availability is the *exception* to the rule, and equally as importantly, generally characterised by being both infrequent and of significant duration. Taking down a coal plant for a boiler inspection is a week or more to let it cool down, inspect it and restart it. But it happens only once a year (and generally in summer when demand is lower anyway).

By contrast, when considering the intermission of 'intermittent' renewable energy - that is wind, solar, tidal and wave power (which is really a sort of wind power by proxy!) the intermittency is characterised by being persistent and of short duration. Solar power varies from nothing at night to full power during the day *every day* , tidal does similar twice a day (roughly) . Wind power fluctuates randomly but with a general period that approximates to 3-5 days, that being the average time it takes for a low pressure system with associated wind to pass over a reasonable geographical area.

5 And indeed a fault surge flow as other parts of the grid attempt to compensate for the sudden loss or demand elsewhere

6 Essentially any source of stored energy which can supply it at variable and **controlled** rates.

7 It is arguable as to whether geothermal energy is 'renewable' . In fact there is no 'renewable' energy in the universe. Thermodynamically there was one Big Bang and we live off the echoes...

But it is far from a smooth curve, for reasons to be touched on later.

Finally the proposed mass adoption of renewable energy on a hitherto undreamed of scale has made another issue that was unimportant with conventional power stations, extremely relevant, and that is **energy density,** or rather **power density.** In its simplest terms what power density means in the context of electrical power generation is 'how *big* does my power station have to be, in order to generate the power I want? With the most useful metric being how much land (or sea) area it is going to use up. How much real estate. And here we encounter the most easily understood, and the most insoluble of renewable energy's - including the 'stored energy' renewable sources like biofuel and hydroelectricity - its power density is very very low.

What is energy and power density, and why is it important?

This is perhaps the easiest concept that one can grasp to apply to 'renewable' energy, and of and by itself it delivers a crippling, (but not quite lethal) blow to the whole issue. In fact it was the first thing I personally started to calculate when the suspicion began to form that renewable energy was not all it was cracked up to be, and I was delighted to find that someone else - Professor David McKay, then merely a physics professor at Cambridge University[8], had already spent several years analysing and documenting what energy we use and how much of it, if any, could be supplied by 'renewable' means. David is beloved by the green faithful, because he really sincerely does want renewable energy to work. He is beloved by us who doubt it can, because of the ruthless honesty with which he has explored the power density issue, with such famous statements as 'the government would need to entirely cover the country of Wales[9] with wind turbines, in order to meet its renewable target ' and latterly 'the pumped storage needed to back these up could be achieved by damming and flooding the entire Lake District[10] to a depth of 500 feet' . The tragedy is that people take these as serious statements, and, mindful of not getting a brick through his window, David never disabuses them of this notion. The results of his research are available at his website at http://www.withouthotair.com and also in a book from UIT publishing - an international best seller - called 'Sustainable Energy - without the hot air'. Suffice to say that what follows is no more than a precis of that material, and credit is duly given.

If we construct a table of the average power output of an area of land planted with biofuels, with windmills, with solar panels, and with a conventional fossil or nuclear power station we get the following :

Technology	**Power density W/sq. m.**	**Size for 35GW average output**
Biofuel	~0.2-0.4	87,500-175,000 sq km
Wind power	~1-2	17,500-35,000 sq km
Solar power	~25	1400 sq km
Coal or nuclear power station	~4000	8.75 sq km

The United Kingdoms electricity demand is around 35GW on average. Wales has a land area of 20,000 sq km. The entire area of Great Britain is only 244,800 km² Very little of it is suitable for high efficiency biofuels like canola (rape seed) that goes to make biodiesel.

Sometimes its easier to make up trite little factoids to illustrate these points.

8 Now chief scientific advisor to the U.K. Department of Energy and Climate Change (DECC)

9 A small country tacked on the left hand side of England ...

10 An Area of Outstanding Natural Beauty much beloved by hill walkers, Romantic Poets and Paragliding Enthusiasts.

- If the entire agricultural land area of the United Kingdom were dedicated to growing biofuel, it wouldn't be enough to even provide electricity , let alone run cars.

- If a power station the size of Fukushima (4.7GW) were to be replaced with a wind farm of the same **average**[11] output, it would render an area larger than the current **temporary** exclusion zone (about the size of Greater London in which ~10m people live) **permanently uninhabitable.**

In essence it can be seen that renewable energy competes directly with other uses that the land, the sea and the spaces above it, have need to *also* utilise. We need farming, fishing, we employ air transport, we rely on sunlight hitting the ground to have an ecosystem, we rely on the wind to stabilise temperatures. Our wildlife uses these spaces and has its habitats in these places. Our line of sight radio and radar transmissions operate through these spaces. Our very vegetation needs the sunlight that solar panels have to block, to work, to trap carbon dioxide!

The cry of the renewable energy lobby is that we need to extract less than one percent of the energy from the sun falling *on* the country to *run* the entire country. This is completely true. The problem is that to get that one percent at the sorts of lousy efficiencies we can achieve - even with solar, is *radically* modifying the environment we are supposed to be protecting! We are concerned (or some people who espouse renewable energy are concerned) with a change in composition of 60 parts per million of the earth's atmosphere. The cure is, it seems to reduce the amount of sunlight reaching it by at least 10,000 parts per million. And turn it onto electrical power.

And the final point which cannot be emphasised enough, is that the **power density of renewable energy is not something we can change by any alteration of the technology that we have**. Perhaps we can genetically engineer better biofuel crops - algae perhaps, but we can't improve wind capture except by building higher, because essentially, all the energy there is in the wind to be harvested[12], is already being extracted by the turbines. Solar PV is already pushing 30% efficiency or more. There is no way that it will ever exceed 100%! That's a perpetual motion machine if it does!

In real terms that means that **renewable energy necessarily has a massive impact on the environment, simply because the scale of it has to be so large to collect what is - any way you look at it - a very diffuse and fleeting amount of energy.**

As said earlier, these are devastating , but not quite lethal blows to the dream of renewable energy. On the face of it solar, at least, looks like it would be possible to fit into a crowded island, even if windmills can't be. And these problems *only* become apparent once the woolly qualitative spin applied to renewable energy is dissected down into not 'is it possible to build it' (the theoretical physicist's approach) but 'how can we build it, and what will be the impact if we do?' Hard engineering, social and environmental questions.

We must wait until we examine the other issues of renewable energy to see where we can administer the final *Coup de grâce.*

The important problem of intermittency

Of all the aspects of renewable energy, none is greater in impact or less well understood by the lay public than the question of intermittency, and how it relates to dispatchability, capacity factors, and affects the whole idea of trying to incorporate renewable energy cost effectively into the demand patterns that we have for power. It has been already stated that intermittency is a name applied to

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11 Bearing in mind that sometimes it output would be essentially zero, and sometimes 4 times as much. See intermittency, etc.

12 'All there is to be harvested' is a significant point. Its not possible to stop the wind in its tracks so you can never get the full energy that is in it, out. The analysis of how **much** you can get is encapsulated in a formula called the Betz law - see http://en.wikipedia.org/wiki/Betz'_law. In fact its a respectable 59.3% of which the average wind turbine can get 75% to 80%. Giving an overall efficiency of 45% or thereabouts for the turbine.

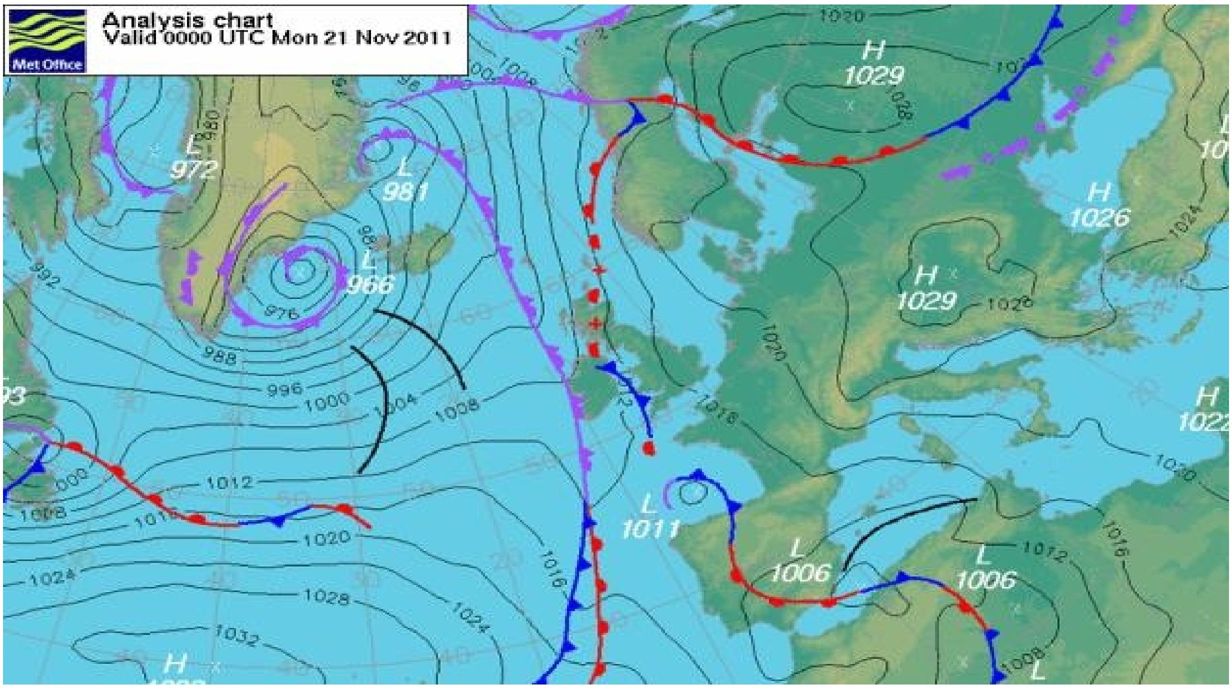
the availability - or lack of it - of any power generating source of electricity. That much is easy to grasp.

The first thing to say, is that it has nothing whatever to do with *predictability* or otherwise of that power source. That is, the fact that a conventional power station has *scheduled* down time is helpful, but does not negate the fact that it *has to have* that downtime. The fact that tides are predictable - highly predictable - does not remove the problem of dealing with e.g. lack of tidal power at high and low tides (in tidal stream power stations). As previously noted it is already an issue - a big issue - to deal with demand fluctuations in electricity, and the easiest way to consider intermittency is to regard it as a negative demand fluctuation on the grid, that is, it just subtracts from the demand in a more or less random way.

And again, note that whilst intermittent renewable energy obviously (in this way of looking at it), reduces the *average total demand* on the conventional power stations, it actually ***increases the dispatch demand.*** That is, there is - when seen from the perspective of the conventional power stations - an increase in *variability* of demand , overall. And the key thing to be understood here, is that we have no way to compensate for intermittency except by dispatching power stations that can be dispatched. Even if those are pumped hydroelectric storage 'batteries' .

What we find is that coping with generator intermittency is the same as coping with demand fluctuation, and requires exactly the same generic solutions to it as following the demand curve. That is :

1. We can try and average out the fluctuations over a wide geographical area. The classic phrase here is '*the wind is always blowing somewhere*' Except that it is not true.

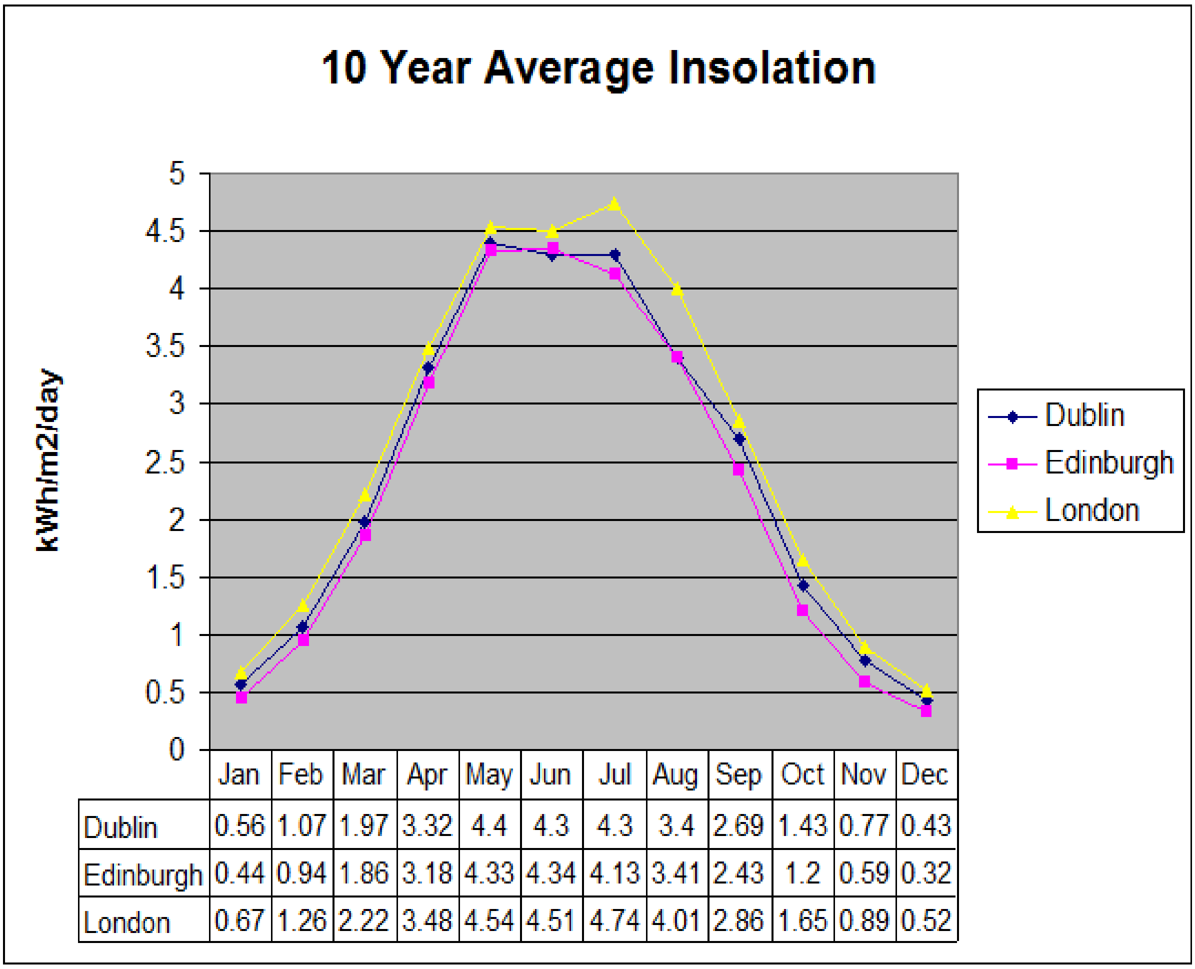


High pressure over the whole of N Europe creates almost zero output from any wind turbines on a continental scale

Furthermore, as explained earlier, the benefits of transmitting power over long distances are nullified the longer the path lengths get.

In respect of Solar PV of course no diagram is needed to point out that at night - and in the UK the worst case electricity requirements are just after sunset when lights are on, and TVs are on, and people are still active - there is no solar power whatsoever. Geographic dispersion would require that we build a cable, capable of running the entire country off, that stretched to somewhere 12 hours offset in timezones. Somewhere in the middle of the Pacific. The cost of such a system, and the vulnerability of it to failure with nationally disastrous consequences is something that seems to utterly escape those who propose it with a straight face as a viable solution.

2. We can use surplus electricity to 'pump up' some kind of storage system, The favourite is pumped storage. When its dark, or the wind isn't blowing, or its winter and the Solar PV is pathetically useless due to 6 months of not much sun at all, we will tap into these reservoirs of water to run hydro plant and seemingly have our dispatchability provided that way. So how big will these reservoirs have to be?



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dublin	0.56	1.07	1.97	3.32	4.4	4.3	4.3	3.4	2.69	1.43	0.77	0.43
Edinburgh	0.44	0.94	1.86	3.18	4.33	4.34	4.13	3.41	2.43	1.2	0.59	0.32
London	0.67	1.26	2.22	3.48	4.54	4.51	4.74	4.01	2.86	1.65	0.89	0.52

(Solar insolation by time of year: graph courtesy http://contemporaryenergy.co.uk/solarmap.htm)

Well, judging by that, something like 3 months of summer 'charging up', 6 months of more or less neutral and 3 months of winter 'discharging' would be required. to make solar PV fully dispatchable. So let's say we have 10GW of solar on our grid, how much water up how big a lake up a hill do we need to store - say - 3 months of solar energy? We aren't looking to the nearest square meter, just roughly, a square kilometer, 1000 sq kilometers?

The amount of electricity we want to store is 3x30x24x10 GWh approximately 21.6TWh[13]

Worth a tidy sum that - in UK terms about £10bn, wholesale. It's about 20 megatons of energy too. So about 400 Hiroshima sized atomic bombs if the dam breaks.

Carrying on with the calculations, at 500 meters average depth that requires a lake surface area of 15,858 square kilometres give or take. To store one third or less of the UKs electricity for 3 months. Oh I forgot, At 75% efficiency it had better be 20,000 square kilometres of lake, Or about the size of Wales. Its a pity we already covered that in wind turbines. Never mind, its a third of Scotland, and no one would miss that, would they?

13 Terawatt hours - a triillion watt hours or a billion units (kWh) of electricity

3. Build so many renewable energy plants that we can achieve dispatch simply by throwing the surplus electricity away. Since we know that the worst case for solar is zero power at all when its dark, that doesn't work at all. No matter how many solar panels you install they will still produce zero nocturnal output.

In the case of wind the worst case is about 1% of the average, so all we need to do is simply build 100 times as many windmills covering an area 100 times the size of Wales, and considerably bigger than the entire country, and arriving at a per unit electricity cost of around £9.95, by my estimation. Or around $16 or so. Compared with £0.06p (10c) for conventional power.

4. Smart grids. Only use electricity when its available, which means essentially if its a cold winters night with a heavy frost and not a breath of wind, you had better stay and home and hope the pipes don't freeze, because for sure there wont be any electricity to even make a cup of coffee with..

5. Do what we do now, and use dispatchable conventional power sources to make up the difference. . And that realistically is all anyone can do to match intermittent renewable energy to a given demand - fill the gaps with a dispatchable power station running on stored energy. The *only* time that gets you to a 'all renewable grid' is of your dispatchable power station is in fact 'renewable' - typically hydroelectric.

To summarise, the methods of dealing with intermittency all lead to non ideal solutions. Using geographical dispersion needs transcontinental power links of massive cost and low efficiency to transport huge amounts of power from 'where the wind is blowing/sun is shining' to 'where its needed' . Storage requires country sized installations of phenomenal potential destructive power and devastating environmental impact even if they don't disintegrate in a tsunami size dam burst. Oversupply of generating capacity to cover 'worst case' scenarios inflates the cost and environmental impact to the sorts of levels that would destroy a nation before it got the job half done. And moving from a 'demand dictates supply' to a 'supply dictates demand' grid would in the end equally disrupt society to a totally unacceptable degree.

The renewable lobby response to this is to hand wave it away with statements like 'well that's why we need diversity' and 'we simply need to build the storage', despite the fact that the actual numbers are nowhere to be seen, as to what the building of that storage would cost, or what impact it would have, over and above the massive costs already involved in 'renewable energy.'

The reality is that there is only one way to realistically add dispatch to large numbers of renewable power sources, and that is through **co-operating** them with conventional power. The renewable lobby use the term **backup** but I prefer to call it **co-operating,** to make the point that its not an occasional thing, its a 24x7 balancing act between dissimilar power sources both of which need to be built and operated - instead of just the one.

*Note that **if** you happen to live in a country that has a lot of hydroelectric installation (or potential) and you find you are running out of rainfall, then in that case, and that case alone, you can extend your already renewable grid without becoming any less renewable, and by about 25% , using wind and solar to essentially conserve rain fall and use the hydroelectric potential you have when the 'intermittents' fail you. It is still expensive, and very poor value for money compared with - say nuclear - but its not such a total unmitigated disaster as e.g. using coal fired power stations to co-operate with, as is done in e.g. Germany.*

In conclusion, what I have tried to demonstrate in this section is two things: firstly that intermittency is *not unpredictability*, but simple *variability in output* that is a **necessary and intrinsic** problem, of all types of renewable energy that do not in some way store energy - as biofuels and hydroelectric dams do . And that secondly there is no magic way to deal with it, except to regard it as additional demand for dispatchability on a range of conventional power stations that may or may not include hydro and pumped storage. Unless you count hydro, **this completely**

destroys any hope whatsoever of an 'all renewable' grid. At least not one that allows you to access electricity when you need it, rather then when it happens to be there,. like some third world Banana republic.

Furthermore it relegates intermittent renewable energy to a far more lowly role. **As a bolt on fuel saving device that may or may not save fuel. One that depends on conventional energy for its consistent operation.**

Without some form of low cost, efficient, high capacity small footprint, safe, electrical or otherwise storage system[14] an all renewable grid is simply total fantasy.

That still doesn't entirely administer Euthanasia to the concept however. Indeed one renewable proponent I spoke to said 'well at least it *saves fuel'*- and presumably Dangerous Emissions™, too.

But does it, *does it actually save fuel?* With luck the necessary concepts are now in place to address that important question, and reply to the rhetorical:

> *'Well if we are generating less electricity with gas and coal we must be saving fuel, right?'*

with the surprising and considered response of :

> '***No, not necessarily'.***

And once again there is a nasty little devil in the detail. We have the necessary ideas in place to demonstrate that renewable energy by dint of its intrinsic nature is big, and hence expensive, impracticable, and environmentally unpleasant in its use of space, that it increases problems for conventional power stations, rather than replacing them altogether, that it can't exist alone, but only in partnership, that all of the ideas that are touted to render it effective are either impossible or totally impractical, but hey it still saves fuel doesn't it?

> '***No, not necessarily'.***

What is dispatch, and why is it important?

To this point, I hope that the core concepts of why renewable energy must of necessity involve huge installations - on account of its low power density - and also must be interoperated with other technologies to the point where it may be considered as little more than bolt on fuel saving devices - by reason if its intermittency, are in place. And that, additionally the notion of any un-dispatchable intermittent generator on a grid, appears to the conventional generation fleet as just a greater need for dispatch. Albeit superimposed on a slightly smaller average demand. If these concepts are in place the next section should make sense.

Firstly :

Will the average decrease in demand (as seen by conventional power stations) afforded by intermittent generators reduce overall demand and fuel?

In isolation the answer has to be **yes**. This is the whole thrust of the case for renewables.

But the next questions are ones that are never asked by the renewable lobbies, and seldom by anyone else.

Does an increase in dispatch requirements (output variability to match demand) ***increase*** *fuel usage for the same level of average demand?*

That is a bit akin to saying 'will a car that is constantly stopping and starting accelerating and decelerating use more fuel than one driven at a steady speed, even if it arrives in exactly the same time?'

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14 Which if it existed already, would have been leapt on, as it would already reduce generating costs by easing the dispatch demand imposed by normal load demands on conventional power stations.

And the answer to that is of course another resounding 'yes!'

So the net result of placing an intermittent renewable on the grid, is, by dint of its contribution to average electricity generation, to *lower* the overall fuel burn, but at the same time by increasing the variability of output demanded from conventional fuel stations to also *increase* it.

The real question is

Overall, is the gain in average electricity generated by intermittent renewables greater than the losses incurred in dealing with their intermittency?

And the answer is:

No one really knows

No real studies have ever been done that measured real world effects

It depends on what you are co-operating it against

It depends on non-engineering factors such as economics and political interference, or lack of it.

It depends in the exact nature, magnitude, and time values of the intermittency.

And if this sounds complicated, trust me, it is.

This is a really nasty problem, one that has occupied me for several years, and essentially I have found no complete answer to it. The opacity of the problem is *convenient* for renewable proponents, who hand wave it away with an appeal to reason, and say that the variability imposed by renewable energy is much less than that imposed by demand, and therefore its insignificant. In the beginning this was true, but as renewable capacity of truly monumental proportions is starting to be imposed on - especially - German and Danish grids, it is no longer the case.

I have no better answer - lacking the political ability to actually require fossil stations to record their actual fuel burn against their generated output and search the data for correlations with wind and solar availability - than to attempt to explain in what way dispatch adversely affects power station efficiency, in various ways, and how economic policy and reality can drive higher fuel burn solutions into play when renewable energy makes its appearance.

But first a diversion to eliminate one thing from the discussion, and make a point that is worth making.

Nuclear power, dispatch and co-operation with intermittent renewables.

It is a commonly held belief that nuclear power is suitable only for baseload[15] operation, by dint of its being un-dispatchable. This is simply not true in principle. Nuclear reactors can be turned down, and are turned down, and the evidence shows that its common practice in the most 'nuclear ' country in the world - France - that they *are* turned down[16]. Its not that good to do it, only ones with fresh new fuel rods are able to do it well, as the process of reducing the power poisons the nuclear fuel with unwanted products, and in the end that limits how much it can be done, but done it can be, and done it is.

Why then is nuclear power most often revealed and discussed as a baseload only technology? The answer is simple.

Nuclear fuel costs represent at most 15% of the cost of electrical production of a nuclear plant. All

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15 Base load is that part of the demand that is always there, day and night where a power station can be used in undispatched mode at its peak efficiency (or its peak rated output depending on which is most profitable) for the longest periods of time.

16 There is a good paper on this at http://www.templar.co.uk/downloads/0203_Pouret_Nuttall.pdf

the rest is fixed overheads and capital cost,. so the opportunity cost of running the plant overnight even into cheap electricity prices is almost zero. Almost no fuel is saved by turning nuclear power down at night, and much potential revenue is lost. As long as nuclear power does not grow to beyond the baseload level on a grid, it will always be in a position to be the cheapest on the grid at night, simply because it never makes *more* money by *reducing* output. Likewise there is no economic incentive to *build* nuclear plant for high dispatch mode operation. So it's never going to be used to co-operate with intermittent renewables, for that reason alone, but, finally, in a holistic analysis, if you have the nuclear capacity already, and there is no economic or emissions benefit to co-operating it with wind or solar, why would you even build the wind or solar in the first place, except as a purely political gesture?

Dispatching with hydro electricity or pumped storage.

If you have to co-operate with intermittents these (hydroelectric storage systems) are definitely the best technical solution. Although cost and environmental impact are poor. As with all 'renewable' technologies you need a **big** lake up a **big** mountain to do much of use.

But hydro schemes have a massive advantage - two if you count the zero carbon nature - over conventional plant used for dispatch, and that is that they are extremely rapid to get started and the startup and shut down phases do not waste much water power. For that reason, in the UK, where hydro potential is geographically extremely limited it is used as a very fast response to rapid fluctuations in demand. Due to the way the UK market works, sudden shortfalls can be auctioned off, and hydro operators are in a position to sell into the top end of a sellers market, at high prices. If they have low water levels, that's what they do. After heavy rain, they sell at lower prices as well..they are prepared to undercut conventional power stations as the water, if it threatens to spill anyway, represents lost income. In similar fashion the pumped storage units of which there are a few, pump water up at night to arbitrage the cheap night electricity rates by selling into the high demand market at higher prices by day.

However in the UK at least, hydro power is already fully occupied doing this and has no spare capacity to dispatch on the behalf of any other renewables. Sadly its influence beyond mere grid stabilization, is fairly negligible.

This is not the case elsewhere. Other countries with good established hydro power are able to bolt on wind (typically) and conserve water thereby. New Zealand is an example. And one or two Scandinavian countries, though oddly there and elsewhere - Switzerland being a prime example - the trend has been to add nuclear power to water instead, a combination which allows the nuclear to run as baseload, or long period dispatch (you take down the plants in summer to maintain and refuel, and then run them hard in winter) with the hydro being used as part baseload, and part load following dispatch.. Countries with this policy show historically ultra low emissions in respect of carbon emissions.[17]

Obviously adding intermittent renewables to hydro power won't lower emissions that are essentially zero to start with! But they can avoid increasing emissions if more generating capacity is required. And in particular if the dams are there, and the capacity is there but the rainfall is not, they can definitely work well. The *opportunity* cost of the extra capacity then becomes quite low. Similar to nuclear power, and if the area is sparsely populated and has suitably uninteresting places to plant wind turbines onshore, it can almost compete with nuclear power. However it must be emphasised that these countries are the exception[18], not the rule, and for the remainder of the world the choice is

17 See http://carma.org/ - although getting to the exact information you want is a nightmare, the data is there .

18 Another potentially cost effective place to deploy wind power is in the Mojave desert - where there always seems to be wind and there is almost no population - in the vicinity of the Hoover dam. The Hoover dam itself and Lake Mead represent exactly the situation that suits wind. That is, the dam is able to deliver more power than it has water to supply it with. It can generate high and sustained peaks but not continuous power. Especially if winter rain and snow is low in the Rockies. It already has a high power link to California and Los Angeles, so the perfect

to co-operate with fossil fuels alone, and this is the real area that needs to be understood.

Dispatching with fossil fuelled power stations.

For the vast majority of countries, this is realistically the only way they can generate the dispatchability that intermittent renewables intrinsically lack. For although you can obviously turn down a windmill or solar panel, as with nuclear power, the high capital cost/low fuel cost argues for using them to the maximum. Indeed without generous effective subsidies in the form of market rigging, they are not economic to compete, even into peak demand scenarios, against conventional stations. A factor which will be addressed later.

Given the intrinsically high cost, the question raised earlier takes on even greater importance, namely: does the increased fuel burn of running conventional power stations out of baseload type operation into high dispatch mode, negate the fuel gains resulting from lower overall fossil generated electricity? And as previously stated, that depends. In order to understand what it depends on, and in what way, a necessary digression into some theory of heat engines is necessary, because a fossil fuelled power station is in essence a big heat engine with a generator stuck on the back. And these have very well defined characteristics.

When a heat engine is running, it is accepting heat (typically from burning something) and losing energy in three main ways. The one you want, is that associated with the expansion of a working fluid - hot steam (or hot turbine gas in a gas turbine), which cools as a result of the expansion, and that expansion drives a mechanical rotor - a piston and crank on a conventional steam engine or a turbine - a sort of windmill in a pipe[19] - and that drives an alternator - essentially a dynamo. As with a wind turbine, however, all the energy in the working fluid is not available to drive the shafts. Simply because the gas coming out is never quite as cold as it was when it went in to the boiler or turbine intake. So a proportion of the energy in the steam or hot gasses is lost as exhaust heat. By strapping condensers and cooling towers on the back, the temperature of the final stages of a multi stage turbine can be lowered, but even so some heat is always lost to the atmosphere. The harder you drive the turbines in terms of putting in more hot gas, usually the more hot gases and the hotter the gases (or steam) come out the back. So that means the harder you drive the turbine to some extent, the less efficient it is. So if you want high power you need **big** condensers (cooling water or cooling towers) on the back, or you will end up burning more fuel proportionately to run the thing in terms of what it produces.

So these losses tend to **increase** with high power, faster than the power itself increases. If that were all the losses there were, it would indicate the most efficient point is at the lowest output possible,but it is *not* the only losses there are: there are, in addition 'fixed' losses that are there, no matter *how* much power the station is producing. If the boiler is hot, no matter how well lagged it is, heat is escaping from it. The bearing friction in the moving parts - and there will be water pumps to inject the boiler with water and so on that must run all the time as well as the main bearings on the rotating shafts - all represent a source of power loss that turns into general heat and noise inside the power station, and is lost. Regardless of what power the plant is operating at.

In essence it is possible to design a heat engine such that its peak efficiency is almost anywhere on the power curve: it is for example useful for an auto-mobile engine to exhibit maximum efficiency at low throttle cruising (where the manufacturer knows it will be rated for m.p.g.) yet to have available much higher power - albeit at drastically reduced efficiency. The converse , however, tends to apply to fixed generators in power stations: they are optimised for best efficiency at or around full power, with the efficiency tailing off until at drastic levels of reduced output, fixed losses start to dominate, and the efficiency drops to zero as they go into 'spinning reserve' mode.

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infrastructure exists to utilise the isolated nature and the existence of the dam to deploy a considerable amount of wind power, with the only objection being the total ruination of the desert skyline.

19 although is a lot more specialised than that, its an accurate enough description to get the point across.

Essentially idling, but still burning fuel. What engineers cannot do, is design heat engines that are uniformly efficient from low to high power.

However - and its hard to find the data outside of specialist engineering publications - it seems that mostly efficiency is well preserved until quite low power output levels are reached.

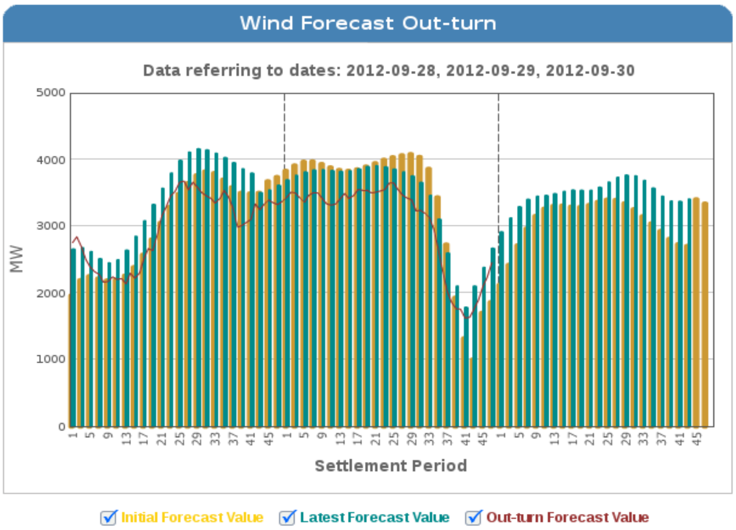
This leads to one reasonably important conclusion. **That intermittent renewable energy on a grid (that does not increase spinning reserve requirements) will not increase fuel burn per unit generated too much. Although it does increase it somewhat.**

However there *are* conditions in which it may lead to more spinning reserve:

If there is an anticipation of a rapid increase in demand caused by an expected rapid fall in intermittent power being generated, in order to cope with that, a prudent grid operator will commission spinning reserve to be there to come on stream when it does.

Likewise if intermittent power suddenly and unexpectedly does appear on the grid, there will be a need to shut down conventional power into spinning reserve mode. The evidence is that for two reasons at least - if not three, the predictability of (especially wind power) is less than ideal.

1. The wind turbine is massively sensitive to wind speed. Below its maximum output, power varies as the cube of wind speed. This means that minor errors in forecasting wind speed lead to quite large variations in actual power from what was expected.



Analysis of actual UK wind data shows that in general the actual wind output versus what was predicted shows at least a 10% error in any given period. When wind output is small, that is insignificant, and is absorbed by the normal dispatch capability of existing power stations, but when intermittent renewable energy reaches a significant proportion of the grid, it starts to be extremely relevant. The UK only has about 5-6GW of wind capacity at the moment, but if it were as high as 20GW that 10% error amounts to several conventional gas power stations that would have to be kept on spinning reserve to cater for variations in wind against forecast, alone.

2. Under conditions of high wind, sometimes wind farms must shut down in order to avoid turbine damage due to over stressing the gearbox and bearings. Failure to do that can and has resulted in turbine fires or even turbine destruction, so a higher than safe wind speed will tend to see whole bank of turbines going into safety shut down, pulling extremely high amounts of power off the grid, suddenly. Not only must this eventuality be catered for by extra spinning reserve, it is also liable to destabilize the grid and place unacceptable ' brown outs' or short duration low power events on the grid.

3. Contrariwise resumption of normal operation of wind farms in high wind conditions can

create the opposite effect, a power surge that can trip the grid, and must be met with immediate shut down of whatever fast acting conventional power is available.

With solar power, there are also effects. Although average solar energy is quite predictable and generally slower in variation time wise, it is guaranteed to fail completely at sunset after a very fast drop in the late afternoons, and show the reverse at sunrise. Predictable or not, this still means that power stations either have to be kept - if not on spinning reserve all day, at least on **hot standby**[20], and that means for coal stations a significant coal burn And the more solar power there is, the more stations are sitting there burning coal, generating nothing at all. . Gas power stations are much faster to start up, and can be online in 45 minutes operating at full efficiency, nevertheless every single start of a gas turbine burns a significant amount of fuel[21], energy that is irrevocably lost when its switched off and cools down again. And that means that gas is a two edged sword. Yes it can be held in cold reserve and still be operating in less than an hour, but, conversely if its offline all day it's going to be cold on restart and will need nearly as much fuel to start up as it would have burnt all day in hot standby mode.

Once again, the more starts and stops there are, the more energy is lost, with solar - being exactly too long between periods of no output to justify keeping gas on hot standby, being as bad as it gets.

There is a final issue, raised very clearly by Professor Hughes in the so called 'Hughes report' [22]that is even more worrying. Namely that the economics of fossil generation favour using the cheapest least fuel efficient plant for occasional use, to cover short term shortfalls in generating capacity. We will address that in more detail later, but essentially the rationale is this: intermittent renewable energy will inevitably displace not the cheap coal with low fuel costs and high investment in expensive plant, off the grid. Instead it will displace the high fuel priced but lower capital value CCGT [23]. Operators who cannot be guaranteed a reasonable amount of use out of capital plant, will install whatever is cheapest regardless of efficiency, knowing that in periods of peak demand, they can sell into a market of high electricity prices and recoup their minimal investments that way. In these cases fuel cost is less significant: the selling price is sufficient to cover the additional fuel burn.

All of these factors are compounded by yet another issue, which will be covered in more detail later when the economics of renewable energy are considered: Namely that in order to meet pre-defined political targets of renewable energy, - say an *average* of 30% or more of 'renewable energy' on the grid - especially a grid that is - say - 17% comprised of nuclear power which will be generating irrespective of market conditions - then there *will be times when the peak output of the intermittent renewables will exceed the total national demand:* At this point all dispatchable plant will be in hot standby or spinning reserve, or turned off, and there will be no option but to simply shut down wind and solar farms - although under the current terms, they will still get paid to **not** generate power that would otherwise be surplus to requirements and cannot be stored.

Denmark has already encountered this issue[24]. It often generates power it cannot use and this power

20 Hot standby. *Following a generator's start up preparation, it may be necessary to hold it for a period of time in a 'state of readiness' to generate at short notice. Under these circumstances, fuel will be used or energy taken to maintain this state of readiness. National Grid will offer 'hot standby' contractual terms to Generators who are able to maintain such a state of readiness and hence provide flexibility in the provision of timely energy utilisations, synchronised reserves or frequency response services.* (http://www.nationalgrid.com/uk/Electricity/Balancing/services/balanceserv/reserve_serv/bmstartup/)

21 I had a reference to € 10,000 being the cost of the gas to start up a medium 600MW gas turbine from an Irish paper, but the reference has been lost, sadly.

22 http://www.templar.co.uk/downloads/hughes-windpower.pdf

23 CCGT Combined cycle gas turbine. This uses a gas turbine as the primary generator, but the hot exhaust gases are used to drive a secondary steam plant, thereby gaining extra efficiency. CCGT can be up to 62% efficient. OCGT - open cycle gas turbines - are far cheaper to build but burn 60% (or more) fuel again.

24 See 'Wind Energy - the case of Denmark (http://www.cepos.dk/fileadmin/user_upload/Arkiv/PDF/Wind_energy_-

is either exported (at well below cost) to neighbouring countries who can use it to offset hydro electric power in 'low rain' years, or if their dams are overflowing, they simply refuse to import it at *any* price. It is essentially dumped. It is for this reason that whilst the adherents of renewable energy were able to claim that '20% of Denmark's electricity came from renewable sources' the detractors countered with the statement that whilst that might have been true, it had only resulted in something like 6% to 9% reduction in the actual fuel used to run their national grid. The benefits had been largely exported, at a loss.

In the case of the UK, we do not even have that option of selling surplus electricity below cost. Our links are to France, which has plenty of nuclear power, and Holland, which has its own wind farms that tend to be running hard when ours are. Even if the proposed link to Norway was built, there is no guarantee that the Norwegians would either pay what it costs us to generate it, or would even take it - they already are well able to buy Denmark's surplus and the link in any case would not be of sufficient capacity to absorb all our surplus.

There is a final point to make, and although its chiefly a financial one, it does have a fuel burn implication. It is an example of the way also that renewable energy companies can claim success whilst passing increased fuel burn and cost onto others. It is this. Increased high dispatch on conventional power stations means increased heat cycling and increased mechanical stress. Which leads to shorter lifetimes and more energy used on repair and replacement of capital plant. As does the installation of very low capital cost plant for peaking demand.

What can we say in conclusion?.

Well, the balance of probabilities is that renewable energy of the intermittent kind probably does result in a net reduction of fuel used. But it is certainly less than the headline figures used by the renewable industry to justify their products. At the very best we can probably say with certainty that **at least 15% of intermittent renewable energy results in no net carbon reduction, probably the true figure is somewhere between 40% and 60%,** and, it is possible to construct **entirely plausible scenarios where overall, analysed holistically, it actually results in no net benefit whatsoever**.

So although it probably does justify itself as a carbon reduction measure, it does start to make it very expensive indeed.[25]

Furthermore the low net reduction in fuel burn and the absolute necessity of co-operation with fossil plant to balance the intermittency and provide the dispatchability that it lacks, engenders **no increase in energy security and very little insulation from fuel price fluctuations.** Two reasons that are often upheld as reasons for its adoption.

Intermittency is in every way not a detail to be brushed to one side when discussing renewable energy, it is, with low power density, the core of the whole case against renewable energy.

It makes an 'all renewable ' grid completely impossible in countries that do not have extensive hydro electricity.

It makes nonsense of claims that intermittent renewable energy improves energy or price security.

Wind energy the case of Denmark.pdf) which is an interesting study that detours into socio economic analyses as well as pure analysis of renewable energy.

25 see http://www.templar.co.uk/downloads/cocu07.pdf This report compares cost of carbon reduction for various approaches, some of which - like house insulation and energy efficiency actually show cost reduction. per unit emissions saved. Others like nuclear are broadly neutral. 'low penetration wind 'is seen as expensive,. No figure for high penetration wind is included at all....

It reduces by anything up to 100% or more the claims that intermittent renewable energy reduces emissions.

It means that the more renewable energy you attempt to employ, the less effective it is and the more expensive it gets.

Is the renewable energy bull dead yet? Perhaps its tail still twitches, so the matador with a swirling cape must step in for the last Veronica and deliver the death blow, by means of systematic economic analysis...

Capacity factor, and cost benefit analysis

One has to ask the question that, **if there was no concern about climate change would anyone employ renewable energy (beyond a bit of cost effective hydroelectricity and biofuel) at all?**

Now, amongst the faithful it is held that, even in the absence of climate change, world shortages of affordable oil and so on means it is still a Good Idea, because it will replace carbon based fuels.

And yet the issues of Intermittency shows that on grid, it cannot. In the absence of hydro power or fossil fuel, intermittent renewables could provide, at best, emergency power for some functionality and only 'consumer and general industrial power' at certain times. And that not for long: without transport fuel able to go off grid, remote installations of wind turbines would be unmaintainable, and would last at best a few years. This especially applies to offshore installations.

So in this scenario we must also conclude that renewable energy of the intermittent kind, is ultimately about as useful as a chocolate teapot. In short the answer is:

Without the (presumed) existence of anthropogenic climate change, no rational reason exists to pursue a policy of intermittent renewable energy whatsoever in any country that has not got a large installed base of hydroelectric power..

That leaves the sole justification of renewable energy (of the intermittent kind) as a kind of fuel saving bolt on to conventional power stations.

And yet we have seen that even there, the gains are marginal and the costs are extremely high.

In short in the final analysis the pro-renewable argument must boil down to :

Are intermittent renewables *the*, or even *a*, cost effective way to reduce carbon emissions?

Because if they are not, we have to ask the question why on earth we are messing around with them at all.

And certainly many people have concluded that they are in fact *not* a cost effective way to reduce emissions. Vis this gem of sarcasm from a report by AF Mercados [26]

> *It is often not clear whether the aim of that (having a renewables target, over and above an emissions target, alone) policy is to reduce carbon dioxide emissions, or to deliver renewables for their own sake.*

Or this equally pithy report[27] from Professor Hughes, writing on behalf of the United Kingdom 's The Global Warming Policy Foundation

> *The casual assumption that expenditures on green technology represent an efficient and economic use of scarce resources is little more than a* ***convenient fairy tale for troubled times.***

Both reports make the point that if carbon reduction is the aim of the policy, renewable energy for its own sake is an extraordinarily expensive way - in terms of materials, direct and indirect costs, and environmental impact - to achieve remarkably little.

26 http://www.templar.co.uk/downloads/Powerful_Targets.pdf

27 http://www.templar.co.uk/downloads/hughes-windpower.pdf

In a recent report[28] that sets out to demolish Sterns conclusions on policy related to anthropogenic global warming Peter Lilley of The Global Warming Policy Foundation had this point to make:

> *Even in rich countries it may be more sensible to invest in general economic growth which will increase the resources available to future generations to tackle climate change rather than diverting it to projects which will only marginally reduce climate change.*

and

> *The government is required to publish an Impact Assessment of the costs and benefits of any legislation it introduces. The purpose of this requirement is to enable Parliament to "determine whether the benefits justify the costs".*
>
> *The Government duly produced an Impact Assessment of the Climate Change Bill as it passed through Parliament, showing that the potential costs - £205 billion - were almost twice the maximum benefits of £110 billion. Moreover, these cost estimates excluded transitional costs which were put at about 1% of GDP until 2020, omitted the cost of driving carbon intensive UK industries abroad, which was said to be significantly likely, and assumed that businesses would identify and implement optimum new carbon-efficient technologies the instant they become available. Nonetheless, Ministers ignored their own figures, refused to discuss them and proceeded to drive the Bill through. This must be the first time any government has recommended Parliament to vote for a Bill that its own Impact Assessment showed could cost far more than the maximum benefits.*

Furthermore he also makes the clear case that unilateral action by any country or economic or political bloc is so much pissing in the wind if the major emitters - China, India and the USA, fail to follow suit, although his language is much more polite

> *Indeed, the Impact Assessment was quite explicit:*
>
> *"Where the UK acts alone, though there would be a net benefit for the world as a whole, the UK would bear all the cost of the action and would not experience any benefit from reciprocal reductions elsewhere. The economic case for the UK continuing to act alone* ***where global action cannot be achieved , would be weak****."*
>
> *The UK's contribution to world emissions is tiny – barely 2% of the total and less than the increase in China's emissions in a single year. Even if the EU as a whole were to act unilaterally, the reduction in global warming as a result of our sacrifice would be far smaller than if the rest of the world did likewise.*

Why then are the costs of renewable energy so high? Once again, the devil is in the detail, and the detail is glossed over by it proponents.

Where capacity factor originated

Firstly we have to once again take a detour into tedious technical definitions, and revisit the whole intermittency issue, and see how it impacts not just the necessity of providing (expensive) but needful dispatch through fossil power co-operation, but also how it impacts on every single aspect of the costs both direct, and indirect, associated with intermittent renewable energy.

In the days before power generation became a political hot potato, commercial builders of generating equipment needed a yardstick to assess the economic viability of their generating plant, and obviously, the amount of time a plant actually runs in a year and at what level of output, determined the gross income that could be derived from it, so they started to talk about something they called **capacity factor,** which was, broadly, the amount of units of electricity it actually

28 http://www.templar.co.uk/downloads/Lilley-Stern_Rebuttal.pdf

generated (for whatever reason) divided by the amount it *could* have generated over the same period of time if it was working flat out.

In essence this was and is the combination of two things: the **availability** of the plant - the amount of time it was actually in service (thus excluding maintenance and breakdowns) - and the **dispatch factor** which reduced its output still further by dint of it not operating at full power all the time that it might have. Dividing the actual average output of the plant by the **nameplate capacity**[29] gave them a factor that they called **capacity factor,** and that was, in general, a good measure of the plant quality and operating environment and a good guide as to its likely income stream in a given period.

And with fuel a high proportion of the running costs, the variable costs would track with the capacity factor with not a huge impact on overall profitability.

Then nuclear plant was built. Here the cost metrics are subtly different as already mentioned. The high capital cost and low fuel cost necessitated that the plant be targeted firmly at the baseload market, and the capacity factor ceased to be an issue of *dispatch*, but became a mark of *availability*, alone. (And profitability). That is, with high fixed costs and very low fuel costs, and the expectation of either operating at full capacity, or being shut down for periods of time for maintenance, capacity factor ceased to be about dispatch into a demand led grid. Capacity factor was still a measurer of profitability but not a measure of dispatch.

Then came intermittent renewables. And yet another spin of the meaning of capacity factor. Instead of it being a metric of plant availability, as with nuclear, or a mixture of that, and dispatch demand as with fossil plant, it now became primarily a **measure of the availability of the 'fuel '.**

Which is another way of reflecting the refutation of the notion introduced earlier - and its a myth that people hold dearly - that somehow the problems of intermittency can be solved by better engineering design. As if the lack of availability was somehow due to the actual engineering structure - the windmill or the PV panel, rather than an issue with *fuel availability* - something that is beyond the remit of the plant designer.

Also, because its obvious that - say - gas plant that is used to cover periods of peak demand will be deliberately operated at a low capacity factor *because its is deliberately being used under high dispatch regimes* it is possible in a totally disingenuous way to say the (completely undispatchable) intermittent renewable energy 'has just as high a capacity factor as this fossil plant'

Apples and oranges. Capacity factor is a useful metric, but it can be royally abused. And it is.

Hopefully the preceding paragraphs will have introduced the idea that whilst capacity factor is a useful metric, it has different meanings in different applications, and different implications, but it still is a useful metric to have, and it can be summarised as

1. Capacity factor is a metric of both plant availability and dispatch, in fossil plant (and biofuel)
2. Capacity factor is a metric of plant availability alone, in a baseload power station like nuclear power.
3. In the case of hydroelectricity it's a metric of dispatch and fuel (rainfall) availability.
4. With intermittent renewables it is a little bit of plant availability, and a massive amount of fuel (wind, wave,. tide, sun etc.) availability that it measures. In short, with intermittent renewable power **capacity factor is almost 100% a metric of the availability of the energy source, not the plant quality, or the dispatch.**

In engineering term, capacity factor of *intermittent renewables* is the mean-to-peak ratio of the energy source .

Why is all this tedious technical speak necessary? Simply because capacity factor has deep implications for cost and quantity of materials involved in the overall design of the Grid.

29 Nameplate capacity. What the plant is capable of delivering, on a 'good day' with a following wind', essentially.

The cost of variability

To understand why variability in operating conditions increases costs, a simple fact of engineering has to be understood. Engineering consists in building purposeful systems and structures that *persist*. They do not break, fall down or wear out instantly. And that means that they should survive the worst that can be thrown at them, up to and including likely overloads, extreme conditions of usage and extreme conditions of the environment.

However their use, and their income streams, especially, do *not* correspond to the extremes of operation, but only to the mean. When you buy - say - a car, you are interested in how well it gets you from, one place to another, and what it costs to perform that function, and how long it will last. All those things can be plugged into a spreadsheet to give you a total cost of ownership and a cost per mile.

What is hidden in that calculation is how much of that cost represents things that aren't even on the spreadsheet: Namely how likely you are to survive an auto accident in that car. Or whether it will start if driven to Alaska and parked outside in sub zero temperatures, or whether it will break down in Death Valley. Or whether it will break down if driven at a steady 130mph down the (unlimited) German Autobahns.

All of these things you hope it will do, in addition to getting you from A to B in a more normal situation. And yet all of these things add to the cost of delivery of the cars main function. It will be bigger, heavier, more fuel hungry, use more materials and cost more to build simply because it has to cope with extremes of conditions and usage.

This can be summarised in one sentence

The capital cost of producing an engineering service (and some of its running cost) depends on the *worst* or *peak* case, the value of the service and its income stream however depends on its *average* or *mean* usage pattern.

This has deep implications for electrical power generation and distribution. The whole grid and its attendant generation sources have to be built to withstand the worst case, at considerable extra cost to simply providing the *average* requirements. In the case of the UK grid, it has, for example, something approaching 70GW of actual potentially available generation capacity, right down to emergency diesel generators, that can be brought into play if an unusually cold period, or two or three power stations breaking down simultaneously, necessitates that they are. And yet the *average* demand, the demand on which money is paid to suppliers, to supply, is only around 35GW.

In this case, we might say that our whole national grid[30] overall, is operating at 50% capacity factor. What this means is that twice as much material and twice as much cost than we would on average need to spend to get the electricity we want, has been spent so that the lights don't go out in winter.

Now, if some of this is capital cheap (but fuel expensive), it doesn't add much to the bills, since its unlikely to ever be used. We have, as I said, some pure diesel generating capability that is simply never used beyond testing to see that it *could* be used. Likewise fuel hungry single stage gas turbine sets are very cheap to build, but cost a lot to run.

But in the case of the actual grid as a transmission and balancing device, we have no option but to use - in crude terms - 'fatter wires' to carry the peak power that might be needed. And fatter transformers. In short our *distribution* system must be about twice as 'material intensive' as it needs to be *on average,* to carry *peak* demands.

Now when considering the overall costs of supplying national electricity, all these things must be taken into account, and what analysis leads to, is the fact that we already pay a premium to be able to supply winter peak demands, over and above average demand.

30 Namely, everything involved in the production and distribution of electricity.

In short **dispatchable power requirements add to the cost of electricity.** And intermittent renewable energy adds to that dispatch requirement...

The marketing of renewable energy completely ignores this, comparing intermittent un-dispatchable power with reliable dispatchable power, on an averaged basis, to arrive at costs that simply bear no relation to the overall cost of supplying reliable dispatched 'renewable' power to the grid. This is in essence fraudulent - the costs are taken off the balance sheet of 'renewable energy', deliberately, and in the end, appear on the costs of the suppliers of the dispatch - namely the grid operators and the operators of the plant that is required to provide that dispatch, instead. All of which, one way or another is paid for by the consumer.

It is possible to write some worked examples to illustrate this point. The actual costs are quite close to real world costs for the United Kingdom, but I do not claim they are exact: the point is to illustrate the principle.

Deriving costs of electrical generation.

First we will consider the costs of - say - providing a unit of electricity by means of a steadily operating gas power station, and then by means of an averagely similar, but intermittent offshore wind farm, (which neglects the intermittency, entirely, to produce its results) and then we look at the true cost of providing electricity with renewable energy that is backed up, including the cost of the backup, and using the difference between that and the gas only scenario to determine the actual cost of supplying the renewable part.

In all cases cost of capital is assumes to be 7.5%, cost of maintenance will run at 15% of capital cost annualised, and plant will be written down (amortized) linearly over a 20 year period. Cost of gas is taken as around 4p[31] per unit electricity generated. The capital cost of offshore wind is taken as £3m/MW[32] as is nuclear power, onshore wind is £1m/MW and the gas is £600,000 per MW[33].

A wind capacity factor of 25% is assumed, and for gas, 85%. We assume baseload for the gas with 15% downtime for maintenance.

The generalised formula used, is that annualised fixed costs are capital costs divided by amortization period (0.05) plus capital costs times cost of maintenance (0.15) , plus capital costs times cost of capital (0.075).

Those can be summarised as capital cost times (cost of capital plus maintenance plus one over amortisation period)

$Ca = Cx(0.05+0.075+0.15)$ where Ca is annualised fixed cost, and Cx is capital cost.

This comes to, for gas, £165,000 per MW ***capacity*** and for offshore wind ***capacity*** £825,000 or five times higher..

Now in terms of per unit electricity generated we need to take annualised fixed costs, and spread them over the amount of electricity units generated *on average* over that time. This is highly dependent on the capacity factor. We can then add in the fuel contribution. It is assumed there are 8766 hours in a year. (365.25 x 24 hour days to allow for leap years!). Since there are 1000 units of electricity in a MWh and our plant prices are on a per-MW basis, we need to include that as well.

So $Uc = \frac{Ca}{(8766\, x\, Cf\, x1000)} + Fc$, where Ca is the annualised fixed cost of running the plant and Cf is the capacity factor it is run at and Fc is the fuel cost of the fuel needed to generate a unit of

31 For a 62% efficient CCGT generator. Obviously if less efficient plant is used, fuel costs would be higher.

32 This is the headline costs associated with the London Array - an offshore wind farm in the Thames estuary

33 Information is hard to come by on this cost, however this is the average of several costs I was able to find on the Internet.

electricity.

So for gas operating at or near baseload with a capacity factor of 85% the fixed costs per unit electricity delivered are £0.02214 per unit so about 2.2p per unit. Adding in the 4p for the gas, the final costs come out at a believable 6.2p per unit.

For offshore wind, ignoring the balancing costs, there are no direct fuel costs, so the contribution of fixed costs is all there is. But at a capacity factor of 25% the final cost is a staggering 37.6p a unit!

(Onshore wind is approximately £1m per MW capacity or exactly one third the price, leading to a headline cost for wind at 25% capacity factor of 12.5p, near enough.)

Now, before we move on to look at the real opportunity cost of renewable energy when co-operated with the gas, it needs to be emphasised that what the above formulae demonstrate, is that:

1. Capacity factor affects unit output levels directly
2. Plant with high fixed costs and low, or zero fuel costs[34] suffers dramatically from lowered capacity factor .

It also demonstrates why nuclear power gets cheaper if you use it for baseload: Baseload operation at the highest capacity factor possible - and if a proper schedule of maintenance can be implemented that capacity factor can be at least 80% and may well exceed 85% - means the capital costs are spread out over the greatest amount of electricity, and, with nuclear power plants having lifetimes of the order of 40-60 years and rather lower maintenance costs, the impact of the high capital costs are further reduced - even when decommissioning costs are taken into account.

E.g. Using the above formulae and working on a 40 year amortisation period and 10% maintenance, with a fuel cost around 1p per unit for nuclear with a capital cost for new nuclear at £3m/MW[35] (the same as offshore wind[36]) we get fixed costs per MW **capacity** per year of nuclear at £600,000 - less than offshore wind as the maintenance is less and the lifespan is greater - and at 85% capacity factor running into baseload, that gives a unit cost of £0.08p for nuclear power plus the fuel cost of 1p giving an **overall cost of nuclear power not greater than £0.09p mark in the UK[37]** under likely regulatory regimes. Still less than even the most optimistic estimates for onshore wind **ignoring its intermittency**.

Costing mixed grids of medium intermittent renewable content.

Although it easy enough to calculate the levelised cost overall of a mixture of plant on a grid, it is not quite so obvious how to calculate the cost to ascribe to one particular component, particularly when its addition impacts the costs of the other part. And this is indeed part of the essential fraud[38] that exists at the heart of renewable energy costings: To take, in isolation, the renewable generator, and assume that simply adding more and more of it to a grid will not result in any costs being incurred elsewhere. And indeed, even if they are, to wash its hands of them.

The way this is approached here, is kind to renewable energy - kinder than it deserves. We are not

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34 I.e. renewable energy or nuclear power plants.

35 Broadly what new nuclear with cost overruns is coming in at in a heavily over regulated European environment.

36 Which the renewable lobby spin into 'nuclear is more expensive than onshore wind and just as expensive as offshore wind'

37 The staggering conclusion is that an all nuclear grid, operating at only 50% capacity factor in full dispatch mode could be built - a totally zero carbon grid - for a cost of £0.13p /unit fixed and £0.01p/unit fuel -that is £0.14p/unit in total . Although onshore wind would seem on the face of it to be cheaper, we cannot *build* a 100% renewable grid ...even if we took over the whole of Wales to build it on.

38 I have finally given up being polite about the renewable lobby. They are, I have concluded, simply a marketing lobby operating outside the legal constraints that would exist if they represented a particular company or product, and are free to say whatever they like, fact, spin or fiction, about renewable energy.

going to address social and environmental impact, costs of extra grid upgrades and so on (yet). and we are not even going to address the actual demand fluctuations on the grid. These all make things worse. Suffice to say that to illustrate how intermittency reflected as capacity factor affects costs, we will look at an idealised grid that has a steady demand of, for arguments sake, one MW of power, and attempt to work out the cost of supplying it using wind power and gas as a co-operating mixture.

Once that is achieved, we can look at the excess cost over supplying it with gas alone, by adding the renewable energy to it, and then by dividing that excess cost by the amount of electricity actually generated by renewable means, arrive at a figure for the holistic costs of that renewable energy.

That is, by regarding the cost of renewable energy component as an unknown but regarding the cost of gas generated baseload electricity as a known, we can see how much costs increase when that baseload gas is required to operate in high dispatch mode to accommodate intermittent wind power.

The general equation is

$$Utot = (Ugas\, x\, Gf) + (Uwind\, x\, Wf)$$

where Utot is the overall unit cost of the electricity, and Ugas is the unit price gas generated electricity *would* have cost in the absence of the wind, Gf is the fraction of gas generated electricity actually delivered, and Wf is the complementary amount of wind electricity generated, and Uwind is then the actual unknown cost of adding a unit of wind generated electricity to the grid

We will assume a capacity factor of wind of 25%. So that gas generated capacity represents 75% of the total grid. If we put more wind than that in, we will at times be throwing wind away, making it even more costly.

That means we have two unknowns left, the thing we want to know, what the cost of wind generated electricity really is, and what the cost of generating the total amount of electricity will be in this high gas dispatch scenario.

To establish the total cost of this particular mix of wind and gas - essentially a mix that represents the most wind we *can* put onto the fixed grid before we irretrievably have to discard the high wind events - we work out first what capacity of wind plant and gas plant we will need. We are no longer able to work in plant capacity directly yet, because we don't know how much of each will be required to fulfil the demand of a steady 1GW, but we know that we cant put *more* than a GW of wind in the grid So that's one thing we do know. One GW of wind capacity.

With gas, we have a more tricky situation. We know that our gas plant on average running into baseload achieves 85% **availability and capacity factor** - but sometimes its down for maintenance - 15% of the time in fact.

So we actually *need* a bit more than 1GW of gas, because

- sometimes some of it is not available and

- sometimes *the wind doesn't blow at all*[39]

Assuming we need to have a reliable 1GW of gas available at all times and its only taken down for routine maintenance so we never lose more than 15% at any one time, we need

$$\frac{1}{0.85} = 1.1765$$

GW of gas plant.

39 Worst case analysis of UK wind output data from NETA shows that there are times when wind is less than 1% of its average capacity, and significantly long periods where it is less than 5% - too long to be covered by any storage we have, which in any case we have left out of this scenario for simplicity.

Plugging that into the earlier equations we get a total capital cost of **onshore** wind and gas as £1.705m CapEx for a reliable 1GW of mixed source supply.

Since we already assigned the same amortization, cost of capital and maintenance costs to both, we can apply the formula again to the sum of the capital components to derive an overall fixed cost per annum of £469,117.

To arrive at the combined unit costs we need to divide this again by the hours in a year and the units in a MWh to get the contribution of fixed costs to final cost. The actual figure for onshore wind and gas comes out at £0.0535p per unit. Adding 0.75 x 4p for the gas fuel price need to generate 75% of it from gas[40], we get another 3p on that unit, taking the overall cost to 8.35p[41]

This nets us the last unknown apart from the 'real cost of wind' we can now start filling in the unknowns in the equation:

$$Utot = (Ugas\ x\ Gf) + (Uwind\ x\ Wf)$$

U*tot* is 8.35p, U*ga*s was, for baseload, 6.2p and we have the gas percentage of the total as 75%, and the wind total at 25%. So if we subtract 75% of 6.2p from our total and multiply by four, we get the 'true' cost of onshore wind. which comes out to be 14.8p.

That shows directly, that the effect of putting wind at a *headline* levelised cost of 12.5p onto a gas grid which is thereby required to operate less economically than it was doing by reason of having to dispatch, is to increase the holistic cost of the wind from 12.5p to 14.8p, with the extra 2.3p being passed onto the gas operators!

Worse, if we assume that we are losing - say - 20% of the putative fuel gains in the gas plant by dint of it having to operate outside ideal efficiency conditions and in high dispatch mode, and that is the most conservative estimate we can put on it, then instead of 4p gas cost per unit, we are looking at 4.8p and the U*tot* value will rise to 9p a combined unit. And then the actual 'cost' of the wind component rises to 18.66p

The minimum effect of the intermittency of wind in this scenario was to increase its impact on overall costs by 50% *more* than the calculated impact if intermittency is disregarded!

To put it simply, if you want to add 25% onshore wind to a baseload of gas generators, not only will you not be able to switch off a single gas generator permanently, but in addition to having to pay 12.5p for every unit of wind you generate, you will need to pay the ***gas*** operators a further 6.2p for every unit the wind operator generates, to compensate for *their* loss of revenue and less efficient fuel burn accommodating the dispatch that wind imposes on them.

Pausing to summarise these staggering answers, we can draw some generalised conclusions. Namely that while the renewable lobby methodology for calculating wind cost and other renewable costs are probably valid for very small penetrations into the grid, such that dispatch demands created by it don't actually overall increase the demand for dispatch on conventional power, once the intermittent renewable element starts to rise to the level where the capacity factors of the fossil plant start to fall *significantly*, then they have no option but to raise prices to cover their fixed costs, and given that the fuel savings will never be quite what the renewable energy component itself represents, then their fuel costs (per unit generated) will rise as well.

And that in the case of the *cheapest intermittent* renewable we have, onshore wind, the cost increase is considerable and could easily reach 50% at modest wind penetration.

This is exactly the sort of issue Professor Hughes meant when he said that more renewables would drive efficient gas plant off the grid: In the case of plant that is at the lowest capacity factors - and

40 Once again, being kind to renewables we assume every bit of wind cause an equivalent less amount of gas to be burnt, which we know to be more optimistic than the reality.

41 Note how close the price is, to nuclear power, of a gas grid with 25% wind added . But it only saves 25% of emissions, versus 100% with nuclear.

we can assume that in a mixed grid, the most efficient plant will operate when prices are lower, for longer, and the least efficient when prices are higher, when the high fuel cost on account of low efficiency, is less an issue than the ultra low capital cost of - e.g. Open Cycle gas turbine plant.

Which does little or nothing to improve emissions either. If the economic effect of adding onshore wind is to halve the efficiency[42] of the plant used to balance it with then it doesn't take long before any renewable emissions gains and fuel burn gains are entirely lost.

We can even put a figure on this. If we take our 25% wind example, and say that even disregarding reduced efficiency due to *dispatch* on the gas sets, we want to calculate how much of the CCGT would need to be replaced by cheaper OCGT in order to totally nullify any emissions gains, then it is a simple enough thing to do.

In essence, we want to know how much plant at 37% efficiency (OCGT), and how much plant at 62% efficiency (CCGT) but used only 75% (the 'with wind' case) , burns the same fuel as the plant needs at 100% operation at the full 62% efficiency (the 'no wind' case). That is, the case in which adding wind and replacing CCGT with OCGT results in *no fuel saving at all.*

So $(0.75)\,x\,(\frac{Fo}{0.37}+\frac{(1-Fo)}{0.62})=\frac{1}{.62}$ being the fossil capacity factor in the wind case, the fuel burn of the (Fo fraction) of OCGT units and the fuel burn of the CCGT units on the left hand side with the fuel burn of the CCGT without wind added, on the right hand side.

Rearranging gives

$$Fo\,x\,(\frac{1}{0.37}-\frac{1}{0.62})+\frac{1}{0.62}=\frac{1}{(0.75\,x\,0.62)}$$

and solving for Fo gives 49.3%.

If the economic result of adding 25% of wind to an all gas grid was to force replacement of 49% of the CCGT with OCGT, no net reduction in fuel used, would occur.

Once a government starts imposing conditions on a power generating system it has no choice but to keep on imposing conditions, and to require the tax payer or the consumer to pay the price of its meddling, or it won't see any benefit at all.

The purpose of introducing these formulae is not to necessarily give the correct answer, because power generation is a complex game, and in the case of an already fluctuating demand, and uncertainty as to the price of everything, it's not possible to do more than show how, in every case, the **intermittency of renewable energy results in worse results - often much worse results - than the simple one dimensional calculations used by renewable lobbies, ignoring its impact, would indicate to be the case.**

So hopefully this indicates how (if not exactly how *much)* intermittency is not a cost free exercise, and introduces indirect costs to other generators quite apart from the costs it imposes by dint of just being expensive in its own right.

Now we will examine what other indirect costs it imposes.

42 A slight exaggeration: CCGT in proper well maintained condition has around a 62% efficient, OCGT is around 37%.

Indirect social, financial, resource and environmental costs of intermittency

In the earlier section on power density, we discussed how the scale of renewable installations need to generate national scale electricity was of and by itself alone a deep and serious obstacle to its deployment. Even if unwilling citizens are simply coerced into accepting wind farms and PV panels, or bribed[43], there are still space limitations - especially with wind. Likewise there are deep and abiding concerns over noise, especially infrasound, and proven links to wildlife death with wind turbines, and proven interference with line of sight radio, radar and television transmission. Additionally other industries are impacted by loss of amenity - tourism for example - and power hungry industry suffers from the high price of energy. It is hard to say anything good about renewable energy - even the claims that it creates 'green jobs' have been refuted by replying that for every green job created. three move to china or India where (fossil) energy is cheaper to buy. The West is simply exporting its pollution to countries that are not part of Kyoto.

We have demonstrated absolutely that it does nothing to improve energy security in countries that don't have the ability to offset it with hydroelectricity. Lacking viable storage of a suitable capacity, cost, size and safety, intermittent renewable energy has no choice but to rely on fossil fuel co-operation.

When stripped back to its core concept - that it saves *some* fuel - we can see that although this is largely true in low penetration, it is less so as renewable capacity increase, especially in the sort of market where it is subsidised directly or indirectly, and other measures are not taken.

We have also introduced and emphasised repeatedly the concept that intermittent renewable energy, because its capacity factor reflects **'fuel' availability,** and not plant availability, or dispatched operation, **is not a stand-alone technology solution** when the problem is supplying a 24x7 demand. And this fact introduces the need for other plant - be it hydro, pumped storage or fossil plant that can operate off stored energy, to provide the dispatch capability that the renewables lack, as a **mandatory part of the system**: and that the cost of supplying that, and the inefficiencies it generates both increase the cost and reduce the beneficial reduction of fuel burn that is the ultimate (overt) *raison d'être* of renewable energy.

Worse yet,. the more renewable energy is deployed, the worse the dispatch problem for conventional power becomes, and the higher its costs and fuel burn rise as a proportion of the energy it actually provides. And doubly worse, if the capacity of renewable energy on the grid exceeds the total demand at any given time, (or, worse still, the total demand, *less* the un-dispatchable conventional power on the grid like some nuclear or, in the case of e.g. Denmark, CHP[44] heating systems that generate power as well), there is nothing else left to turn off, and the renewable energy that might have been generated has to be simply discarded. This effectively lowers the overall capacity factor of the renewable resource, and simply renders it more expensive per unit useful energy generated, and lowers the impact a given amount of renewable capacity has on actual emissions.

It also has other knock on effects on the grid itself. If solar PV and wind are - as is generally the case - remote from the centres of demand, not only must power lines be constructed to bring the power to the load, but, worse, they have to be constructed at such a size that they can carry the peak output of the renewable resource, even though on average they don't carry anything like that much, and occasionally will carry nothing at all. We have seen that the average capacity factor of the UK grid is about 50%: that is, it is sized to accommodate peak demand of about 70GW on an average

43 http://www.telegraph.co.uk/earth/energy/windpower/9311365/Bribe-residents-to-accept-wind-turbines-says-Tim-Yeo-MP.html

44 CHP Combined heat and power. Essentially boilers that run municipal heating schemes - often waste burners - and use the steam to drive generators, and the warm water left at the end to heat locks of municipally owned flats. The Danish renewable industry demanded that all these efficient schemes that save enormous amounts of fuel in heating be shut down and replaced with heat pumps to absorb more of the renewable energy surplus that no one otherwise wanted. What they would run on when the wind dropped was never discussed.

demand of about 35GW, but if renewable elements are introduced those elements *at least* would have to be - in the case of wind - operating at a capacity factor of 25% only, and in the case of solar PV, as low as 10% - (the difference between the **peak** summer midday output on a cloudless day, and the **average** operation over day and night, and including dull short winter days).

Worse, the nature of sun and wind (and tide of course) is such that on any given day the energy resource is often markedly localised to one area of the country. If its sunny down South, its raining in Scotland, and it its windy in Scotland its often still in the South. That introduces the need for not just isolated parts of the grid to be upgraded to take peak renewable flows, but large pan national trunks!

Of course the cost of this is never added to the cost of renewable energy, as defined by the renewable lobby. Like the co-operating fossil stations, it's someone else's problem.

The costs are not just financial, they are also environmental - pylons across the nation - and material. Aluminium and steel wires are not cheap. Neither is the necessary scurrying of wayleave negotiators, and environmental studiers and all the panoply of people who are directly and indirectly involved in getting planning permission for, and overriding local opposition to, large infrastructure projects, cost free in social, financial or energy terms. In short its a pretty unproductive way to waste money and create 'green' jobs..

Whether or not you consider the driving force to be a cost effective way to reduce emissions, or a replacement for fossil fuels in a resource stripped world, intermittent renewable energy fails to deliver much, if anything at all.

But there is a final sword to deploy to end its miserable existence. If there was no other alternative to renewable energy, although its terrifyingly expensive, it is conceivable that perhaps 10% of the worlds population could survive in some semblance of civilisation using renewable resources. It would for sure be a massively reduced population and an entirely elitist one - only the most important people could afford to have access to electricity and personal transport, when power was available - and for most their life would be a grinding existence of manual peasant labour tilling the fields and so on. More or less a mediaeval existence. But something would survive.

But there *is* an alternative.

The real economics of nuclear power.

If there is any area of power generation that has more hype and spin than 'renweables' associated with it, it is nuclear power. If someone drops a cigarette butt in a pot of paint thinners in a factory, and stars a fire, it rates two lines in the local paper. If two workers get blistered fingers in a **nuclear** power plant [45] it rates headlines internationally. Those whose job it is to promote renewable energy are well aware that the greatest threat to their narrative comes from real fact based analysis of nuclear power.

So leaving aside for now all the hype and concern about safety, decommissioning and waste disposal, how does nuclear power stack up? The worst case new nuclear build is at Okiluoto, and its been a fertile hunting ground for the anti nuclear campaign being used to show that 'nuclear is always more expensive that you think , and 'its way more expensive than wind'.

And yet,. those are the figures I used to estimate the cost of nuclear power. £3bn a GW. Leading to a cost of around £0.09p per unit, running into baseload. And if - unlike the cost of renewable energy, which stubbornly refuses to reduce its costs - more new generation reactors are built, those costs - which overran because of mistakes made in the construction - should be reducible by a considerable amount.

That is cheaper than even the headline cost of wind calculated by ignoring the intermittency and the

45 http://www.bbc.co.uk/news/world-europe-19494666

indirect costs. Even the costs of a totally nuclear grid running in dispatched mode at 50% average capacity factor would only double the cost to a similar figure to the true cost of onshore wind power when calculated as an adjunct to a gas powered grid.

Nuclear power beats onshore wind power on every single metric that I have ever seen used to advance the case for renewable energy

- Using similar costs of capital and reasonable maintenance costs, its cheaper than onshore wind. And way cheaper than solar PV, tidal, or offshore wind.

- It offers tremendous energy security by stockpiling, recycling or even breeding nuclear fuel. Renewable energy depends on fossil fuel to function.

- It has been (even with Chernobyl) the safest power generation technology in terms of associated death rates of any, per unit power generated. Way better than renewable energy.

- It completely displaces fossil power off the grid and offers high penetration zero carbon operation at reasonable costs. Renewable starts expensive, and gets more expensive the more its deployed, and can never realistically get to more than 30% grid capacity without spiralling cost and reducing efficacy. And requires that all fossil plant be retained and even more be built.

- Power density is high enough that, in the case of the United Kingdom only about 20 nuclear power stations could take care of the entire baseload, replacing coal, and reducing emissions on the grid by 50% or more. The actual footprint covered would be massively less than any renewable solution thus releasing land for other uses like agriculture, or human habitation. An all nuclear grid would require at most 50.

- Power stations could be sited close to where the demand is, eliminating or severely curtailing the need for any grid expansion. There simply isn't the space or the conditions to site 'renewable solutions' close to demand.

In short it is - apart from costing 50% more than coal or gas in today's heavily regulated environment - the ideal solution to zero carbon generation or generation in the absence of fossil fuels.

So why the witch hunt?

Cicero asks *Cui Bono?* And in the case of nuclear power being driven off the grid it is simply the gas and wind operators, and especially, coal. They stand to lose a huge market share, and renewable energy stands to be totally wiped out. If nuclear is - and on the evidence it is - simply a better cheaper way of generating low carbon electricity, it completely destroys the case for renewable energy. Furthermore, it sets a ceiling on the price that can be charged for fossil electricity as well. If gas cannot be delivered at a price low enough to make gas plant capable of matching an all-nuclear grid at a putative cost of 18p, then gas generation will also be wiped out. Apart from a very small amount needed to cover occasional peak demand.

Coal, gas and renewables all have common cause to use whatever means they can to suppress adoption of nuclear power.

Safety, waste disposal ,and decommissioning .

When people who are opposed to nuclear power are questioned, they raise the four horsemen of the alleged nuclear apocalypse, the cost, the safety, the disposal of nuclear waste, and the problem of decommissioning.

We have dealt with the raw costs of supplying nuclear power, and found it to be in isolation if not currently cost effective compared with current fossil prices, certainly far more cost effective than any renewable power alternative. And we have also shown that it represents a far lower impact on the landscape, environment and infrastructure than renewable energy..

Until, its detractors say, we look at safety, and the disposal of used nuclear plant and materials...

Now the first thing to be said, is that in total contrast to the insoluble problem of renewable power density, and the intrinsically insoluble problem of intermittency, the problems of safety, decommissioning and waste disposal of the nuclear power industry are soluble, if not absolutely, then to any level society would like, depending on how much they are prepared to spend on it. You want nuclear waste off Earth permanently? Fine, stuff it in a massively strong container and fire it into space. It's a lot less far fetched than some of the schemes the renewable protagonists come up with on a seemingly daily basis!

Let's look first at decommissioning. The cheap way to decommission a reactor and still keep any radioactive release to approximately zero, is first to remove the used fuel rods. As is done in any routine refuelling exercise. Those are then taken to interim storage - typically water tanks - where the highly radioactive by products of fission decay into stable compounds over a period of a few years. After which time the fuel rods are reprocessed into new fuel (most of the fuel in a fuel rod is not used: The reaction stops when they become poisoned by the creation of new elements that inhibit the reaction) and a small quantity of high level waste that cannot be reused in current reactor designs (although there is a strong probability that they can be burnt in 5th generation reactors that are under discussions). What is left over is either very very small (the odd long lived radio nuclide that can't be used as fuel) or not especially radioactive (the casings of the fuel rods are of course contaminated with various elements generated by being bombarded with neutrons, but mostly these decay rapidly to stable compounds). In fact the general principle is, the more dangerously radioactive something is, the quicker it decays into something that is not[46].

As far as dealing with the rest of the reactor - well there's a fair bit of water used in a reactor and that needs storing for a few years until its radioactivity subsides, and a few gases in it as well that need a few years to lose radioactivity as well. And likewise the containment vessels of concrete and steel contain transmuted elements that need to decay, but a few years - a decade or two - results in a reactor shell and materials that are so non-radioactive that its perfectly possible to go in with normal power tools and knock the thing down without having to take any special precautions beyond the normal ones in place for demolition of any other industrial structure[47].

The sane thing, since the reactor site is already a secure site with proper radiological monitoring and so on in place, is to leave all the medium level waste that it comprises right where it is, and, as is the case in many countries, the opportunity then exists to build a new reactor next door, when security and monitoring becomes part of the same site, and is achieved very cheaply. Once the reactor is sufficiently below standard radiation levels, it is simply taken apart and becomes (at worst) low level waste - which can be dumped in landfill quite safely, or if there are a few 'hotter' parts, treated to sealing in more secure places underground. In fact one of the cheapest options to decommission a reactor to a safe state is to fill it with concrete and heap soil on it. Which may yet be the final way that Chernobyl is dealt with.

In short there are plenty of ways to return reactors to green fields with blues skys and happy children dancing all over them, but the cheaper ways involve leaving them for a while. If you want

46 Which is spun by the anti nuclear movement into 'dangerous waste (which is very very small in quantity) that will stay dangerous for millions of years (untrue, if its around for millions of years its not very dangerous) and thousands of tons of it' (not true: the thousands of tons is low level waste which is so weakly radioactive it represents almost no threat even hypothetically, and in practical terms if stuck under a bit of soil and not actually ingested will be fine within a few years anyway).

47 Which is spun by the anti nuclear brigade into 'no one has ever decommissioned any reactor yet at all' (although in fact they have, one early Sellafield reactor at least has been returned to 'green field') and 'no one knows how much it will cost' (true, if you want it down to the last penny. It is after all something that hasn't been done before. No one has decommissioned a wind farm either yet, or knows how much it will cost.) and then the usual diatribe about 'leaving dangerous old reactors for future generations to deal with' as if every generation didn't have to deal with what its parents left behind. Like 19th century coal mines and factory sites that are far far more dangerous than old nuclear power stations.

it done quickly that means men in radiation suits doing it a bit at a time and that costs a lot. Naturally that is what the anti-nuclear movement focusses on.

In similar vein there are plenty of ways in which nuclear waste can be safely be disposed of, but once again the principle adopted by the anti-nuclear lobby is to refuse to contemplate every single one, leaving the whole question of waste disposal deadlocked. Nuclear waste is currently in storage waiting for some sanity and political will.

Whilst millions of tonnes of just-as-radioactive coal fly-ash is made into building bricks to construct houses.

There is no insoluble technical problems in dealing with radioactive waste of any grade. What there is is what seems to be an insoluble psychological problem, deliberately fostered by people whose position is irrational. And who use fear, uncertainty and doubt to destroy an industry that they fear, not because it represents a threat to life, but because it represents a threat to **profit.**

When discussing safety, of course everybody knows that at Fukushima, a tsunami that killed upwards of 20,000 people elsewhere killed two people. And crippled a reactor which subsequently killed no one, although a large area was evacuated as a *precaution*.

And, as previously pointed out, the whole of that evacuation area could have been covered in windmills and still not done the same job, rendering it **permanently uninhabitable.** You may be able to live *close to* wind turbines but no one lives under them.

Fukushima showed more than anything how **safe** nuclear power is, as every single system worked correctly: It withstood the earthquake and correctly shut itself down. It even withstood the tsunami. The sole failure was in fact the flooding of the diesel generators. The ensuing core meltdown was correctly contained. Warnings got out in time, iodine pills were issued. And evacuation was managed. Even though the calculations are that more people died from being forced to evacuate than would have died from any slight radiation[48].

Radiation is invisible - until you get to massive doses. Therefore its scarier than something you can see touch taste tor feel.

And therein lies the rub. Something invisible, that leaves no sign until years later you develop cancer? How creepy is *that!*

It's the stuff of nightmares, and of course if you are looking to discredit all things nuclear that's a perfect place to start.

Some sites were predicting cancer deaths in the thousands. The same sites predicted deaths from cancer at Chernobyl - still the worlds worst nuclear cockup - at something in excess of 200,000 world wide and yet...

> *2011 UNSCEAR report*
>
> *"The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) produced a report drastically different to many appreciations of the effects previously produced. The report concludes that 134 staff and emergency workers suffered acute radiation syndrome and of those 28 died of the condition. Many of the survivors suffered skin conditions and radiation induced cataracts, and 19 have since died, but not usually of conditions associated with radiation exposure. Of the several hundred thousand liquidators, apart from indications of increased leukaemia risk, there is no other evidence of health effects. In the general public, the only effect with 'persuasive evidence' is a substantial fraction of the 6,000 cases of thyroid cancer in adolescents[49] observed in the affected areas. By 2005, 15 cases had proved fatal.*
>
> *The total deaths reliably attributable to the radiation produced by the accident therefore stands*

48 http://www.forbes.com/sites/jamesconca/2012/07/20/fukushima-cancer-fears-are-absurd/

49 No iodine pills were issued to local inhabitants and nor were they evacuated, initially.

at 62 by the estimate of UNSCEAR."

Why is this massive discrepancy evident? The answer lies at the heart of nuclear safety regulation.

In the beginning of nuclear weapons and power very little was known about radioactivity's effects on cell mutation and health. What was known was that Radium glowed in the dark - and it was extensively used to make aircraft instruments clocks and watches that could be read by night - that Marie Curie after years of handling highly radioactive elements with no shielding, had died of cancer, and that an alarming prevalence of cancer of the lips and tongue were happening amongst the factory girls who were painting the radium dials and licking the brushes they were using. At the sort of radiation levels that would cause a national outcry today. Indeed old WWII aircraft scrapyards are enough to cause certain areas to be declared a 'radiological hazard'[50].

Out of this grew the realisation of a link between radiation and cancer. Radiation's high level effects were known - extreme doses suffered by experimenters working with nuclear materials had resulted in death - fairly quickly - and 'radiation sickness' was recognised. Post Hiroshima and Nagasaki - both sites that received a single massive dose and considerable fallout, (but show no cancer risk today, despite never having been cleaned up) it was realised that a single high dose could be lethal.

The radium experience showed that continued exposure to medium doses could also be lethal. Or at least cause cancers.

What no one knew what what short term exposure to medium doses could do, or long term exposure to low doses. There simply was no data. And that situation has persisted right up to Chernobyl.

There was clearly a need to restrict access to radioactive materials and to limit doses people received, but there was no real evidence to decide what was safe and what was not, and in the light of that almost total ignorance a model was constructed that made two basic assumptions:

- What counted was the **total** dose you received over a **period**, not whether it was short and fierce or protracted and gentle. Nor even what type of radiation it was or in what form of element.

- Your likelihood of getting cancer was in *direct proportion* to that factor.

The principle is known as the LNT[51] model

Armed with this model they set about establishing emission limits for the nuclear industry to such a level that it was inconceivable that any detectable increase in cancer could ever be seen.

The fact that this was an extraordinarily conservative way to manage nuclear safety didn't stop the anti nuclear movement from turning this from a commitment to public safety to 'a government admission of how dangerous radiation was' and in particular 'even the government admits there is *no safe dose* for radiation!'

And it is the results of applying the LNT model to nuclear accidents that gives predictions of tens or even hundreds of thousands of deaths, where the reality is that Chernobyl has direct clear evidence of less than a hundred deaths and, I think. between 4 and 6000 cases of non fatal thyroid cancer, due to radioactive iodine, and that's about it. Which is then spun *again* by the tinfoil hatters into 'clear evidence of high level cover ups[52]'. As if you could cover up 100,000 dead people without *someone* noticing.

Is the LNT model flawed? Almost certainly. There is a lot of evidence that short term high level exposure to radiation - as is used to kill some cancers - is likely to cause unrelated cancers a decade or two later. Other studies, from places where continuous exposure to high natural background levels is prevalent, suggest that below a certain level, radiation is simply something our bodies deal

50 http://www.bbc.co.uk/news/uk-17921639

51 Linear No Threshold: http://en.wikipedia.org/wiki/Linear_no-threshold_model

52 Note the doublethink inherent in 'the government's own regulations say' and 'the government is covering up...'

with. There is even a theory that below certain levels it *reduces* the chance of cancers[53]. Which has some evidence to support it.

It is in the end the misappliance of science. The LNT model was never established well enough to be a predictor of radiation damage, but it was a suitable tool to determine the regulatory framework surrounding nuclear power. And it has lead - instead of real dangers from radiation being ignored - to an imaginary perception of massive danger from it. If you treat radiation in a regulatory fashion as much more dangerous than it actually is, because in the absence of any better understanding, that is the responsible thing to do, people will be more scared by it than they need be. Even though that **is the safe and responsible thing to do**.

And its led to so many amusing anecdotes as well. A container of bananas is enough, apparently to set off radiation monitors at US ports[54].

There is apparently more radioactivity in the fly ash produced by burning (some) coal in a power station than a nuclear reactor produces to generate the same amount of power. Largely because it takes a **lot** of coal, and very little uranium..

Coal fly ash if it were produced *by the nuclear industry* would be classed as low level waste, and would need to be stored 'underground, for thousands of years' etc. etc. Instead its used to make lightweight constructional blocks.

During the Fukushima scare, some diplomats were advised to leave Tokyo for Europe to capitals that have a higher background radiation than Tokyo then did[55].

Day trippers enjoy an area slightly more radioactive than the ghost town near Chernobyl. and several times more radioactive than Fukushima's exclusion zone.

In the United Kingdom a nuclear power station could never be built on Dartmoor or Exmoor. The background radiation would exceed the maximum permitted dose for nuclear workers[56].

What can one say? A nuclear accident of some sort or another is always possible. Nothing is perfect, but the reality is that with the sole exception of Chernobyl, which was a poorly built reactor

53 Radiation hormesis: http://en.wikipedia.org/wiki/Radiation_hormesis

54 http://en.wikipedia.org/wiki/Banana_equivalent_dose

55 http://lapulcedivoltaire.blogosfere.it/2011/03/roma-piu-radioattiva-di-tokio.html

56 http://en.wikipedia.org/wiki/Background_radiation#Radon

to a flawed design that was handled totally incompetently, no one has died from **nuclear related** causes from the nuclear power industry.

And the lessons learnt from Chernobyl and Fukushima are not how dangerous nuclear power is, but how safe it is. Despite releases of stellar magnitudes, very few people have died at Chernobyl. That was a big reactor whose guts were totally exposed and burnt for several days. The hottest and most biologically active (radiological) parts of the release were gone relatively quickly. No one died at Three Mile Island and the radioactive release caused no real issues. A properly built reactor did what its designers intended, and contained a core meltdown as it should.

Nuclear materials are dangerous, but they are nowhere as dangerous as they are presented. Reactor design is better, with passive cooling (which would have eliminated Fukushima problems) being adopted in many designs, but the real lesson of Fukushima is how an incident that was, (in the context of the whole tsunami disaster), completely trivial, got world attention, and put the program of nuclear power back a decade. Causing countries to adopt fossil fuel solutions instead[57], increasing world emissions.

Meanwhile reactors in Japan are restarting and resuming construction[58]. Japan knows it has no real alternative. Hence the dithering[59] about policy.

A pessimistic view?

In the years since I was first tempted to engage in trying to understand the real issues behind power generation - especially electrical power generation - there is, above all, one salient feature that emerges across the board. Sanity and rationalism have been cast aside, and the whole arena is now a political and *ideological* battleground whose main protagonists understand little or nothing about the industry they seek to bend to suit their ideological (and possibly commercial) needs.

In short the world is *full* of people who have an *opinion* about power generation, who understand nothing about how it actually works or even **what** actually works. They will readily believe contrary things at the same time. They believe the governments when it tells them that climate change must be addressed by renewable energy, they disbelieve it when it quietly lets slip that nuclear disasters are not actually disasters on much of a scale at all. They believe scientists who tell them that climate change is a proven fact, and its all the fault of Big Oil, they don't believe scientists who tell them that if that is so, the remedy is in fact nuclear power.

Government policies are riddled with contradictions. Merkel shuts nuclear power stations and builds dirty brown coal ones, instead - the renewables don't work, and industry can't afford to continue funding the lost cause, but politically that can't be admitted, because with a PR system and enough Greens to hold the balance of power, the minority lunatic fringe must be kept appeased. The UK is in a similar position with a coalition comprised of people who know that nuclear power is needed, and are deeply sceptical of renewables, but are hamstrung by their coalition partners utter determination to drive it off the face of the planet and install windmills irrespective of their actual benefit.

Its a political minefield. One of the most telling statements I ever read, came from a Danish paper[60] some years back. It bears repeating.

> *Hitherto, the radical transformation of the Danish energy system has almost entirely been driven by economic considerations based on technical feasibility. The recent imposition of arbitrary targets by politicians that require unquestioning implementation by the infrastructure suppliers,*

57 http://www.bloomberg.com/news/2012-08-19/merkel-s-green-shift-forces-germany-to-burn-more-coal-energy.html

58 http://www.world-nuclear-news.org/NN-Construction_of_Japanese_reactor_to_resume-0110124.html

59 http://www.world-nuclear-news.org/NP_Japan_puts_off_nuclear_policy_commitment_1909121.html

60 http://www.templar.co.uk/downloads/Wind_energy_-_the_case_of_Denmark.pdf

without any apparent estimates of costs, is a relatively new and worrying departure for the way Denmark is organized.

The very fact that the wind power system, that has been imposed so expensively upon the consumers, can not and does not achieve the simple objectives for which it was built, should be warning the energy establishment, at all levels, of the considerable gap between aspiration and reality.

Denmark needs a proper debate and a thorough re-appraisal of the technologies that need to be invented, developed and costed before forcing the country into a venture that shows a high risk of turning into an economic black hole.

Rational scientific analysis shows conclusively that renewable energy *cannot ever* deliver on the very basis that it has been sold to the public. It's not cheap, it's anything but free, its not environmentally desirable, it offers no energy security, and it cannot exist in isolation from other technologies that are either even more costly than it itself is or have grave risks associated with them.

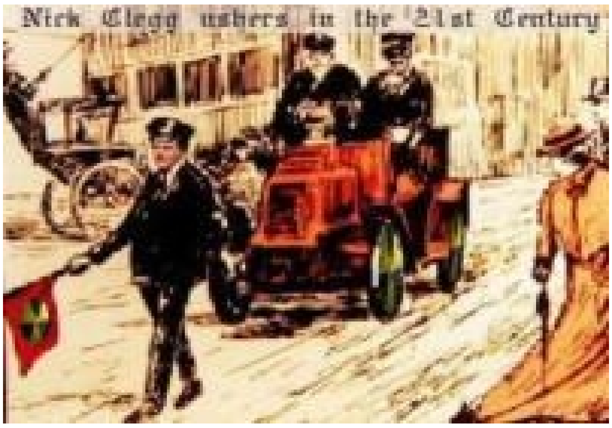
What we find when we analyse the intermittency problem, is that intermittent non-dispatchable power actually carries very little value at all. What society requires, is dispatchable power - power that can be on tap when its required, and turned off when it's not, and it requires in addition a large component of cheap baseload power, that never needs to be turned off. What it does *not* require is wilful power that's here today and gone tomorrow.

You cannot run a country on volunteers who turn up for work when *they* want to, and at other times don't (and take up 1000 times the office space of your normal workers *even when they don't turn up fat all*). If the power density of renewable energy makes it large, awkward, expensive, and environmentally challenging, the intermittency destroys its value completely. It is not something you can engineer out either: if the fuel supply is intermittent, lacking storage, so too will be the output. And the fond hope that engineers can build anything you want given enough time and money is total fantasy. We simply do not know how to build storage - we do not even know where to *begin* - that is better than fossil or nuclear fuel in terms of cost, size and safety considerations. If we did, we would long ago have done it - and halved the capital cost of the rest of the grid in the process.

The renewable lobby must know this. They simply seem not to care. If you look at the complete range of political pressures applied to the power industry worldwide, it benefits only one set of people: those engaged in the construction and supply of renewable technologies, and gas. Policies, when examined, result in no significant emissions reductions, but only increase profits for a minority. In fact, it makes more sense to regard the renewable energy business as a pure piece of cynical marketing with *only* profit in mind. They compare apples with oranges and the solution is bananas! The cost metrics and the utility of renewable energy are simply not comparable with conventional plant. But by pretending that they are, hidden costs are brushed aside, and conclusions reached that are plainly fraudulent.

Above all, this emotional narrative of renewable energy has to march forward on the fundamental assumption that it is, in the end, the *only* long term solution to global energy needs. That no matter how outlandish, or costly, or complex it gets, the alternative is a fossil stripped world with no power at all.

And yet, the actual reality that nuclear power can do everything that renewable energy claims to be able to do (but fails to achieve) at a fraction of the cost and far far better, must not be allowed to gain traction. Reason must not be allowed to prevail. Affordable zero carbon power that is clean safe and be tucked into a corner of the country and largely forgotten? No way! Not when you own a gas field in Azerbaijan, or Texas. Or your wife is on the board of a wind power company...



And if you are not Concerned About Climate Change (and let's face it, a world with no electricity at all is a lot more terrifying than one a degree warmer) there's several hundred years of coal, which the Chinese will be burning anyway.