**CO2 emissions resulting from wind farm construction**

**By Paul Miskelly**

1. The inherent intermittency of wind and solar PV, the enormous mechanical damage the dealing with this has on real generation assets, and of course
the impact of grid controllability. You have my paper, and no doubt others, that address these issues.
2. Not properly addressed in any way by the likes of the renewables advocates is the concept of Energy Return on Energy Invested, ERoEI.
The proper consideration of the matters raised in any such study would, I believe, have very serious implications as to the viability, both economic,
and, far more importantly, the use of these technologies in the context of any serious attempts at decarbonisation.

That there is now clearly demonstrated a need for the continuous provision of backup of intermittent renewables by fast-acting, therefore fossil-fired, generation,
shows that these renewables are hardly CO2-neutral.
This lead me to give serious consideration to what might be the amounts of the CO2 emissions generated during the entirety of a typical wind farm project.
After all, as it is now clear that the actual operation of a wind farm is not CO2-emissions-free, then, if there are CO2 emissions resulting from any phase of the
wind farm development, whether it be during construction, operation, or final demolition and site remediation, then, given that the emissions credit is now known
to be lowered by the need for backup during operation, then it is even more important to identify any additional emissions debits
that might arise during other phases of the lifetime of the plant.

While I am not proposing to attempt to quantify these emissions here, I suggest that those identified here might be raised before the Lords as matters
to be subject to critical assessment, by such as civil engineers and others who are expert in project management.

**CO2 emissions resulting from wind farm construction**

Seemingly overlooked by wind protagonists are the amounts of CO2 that must necessarily be produced by wind turbines during both the generation of electricity
and the prior civil works construction phase.
I was prompted to consider this while reading an excellent article on the present state of small nuclear reactors for power generation,
published recently in an electronics magazine here in Australia, (Silicon Chip, June 2016.
What is clear from the photos and diagrams is that a reactor delivering up to 100 MW continuously, if so required, that is, 24/7, for, typically, three years before refuelling,
would occupy a volume not much larger than a standard shipping container and could sit on a concrete foundation that is smaller in size than that
of just one pad for a typical 3 MW wind turbine.
Given that this is an extremely small footprint, I thought then that it might be useful to consider the scope and size of the material requirements for a wind farm
that provides what is, nominally, 100 MW on average of intermittent, all-over-the-place output. It is not the best comparison, but, in so proceeding,
it is one that massively favours the wind farm.

Here in Australia we do see wind farm capacity factors of around 35 percent. So, I will use that figure as my basis.
For some 100 MW nominal output, there is required some 100/35 = 285.7 MW installed capacity.
Presuming that we use off-the-shelf 3 MW wind turbines, we need 96 (rounded up) 3 MW wind turbines.
Given that the impact of the intermittency makes any such choice of numbers meaningless, it is not unacceptable
to round up this figure a little further to 100 wind turbines.
Using this latter figure obviously eases my computational burden, without significantly affecting the resulting data.

So, if you can continue to bear with me, note that so far in our comparison, our nuclear reactor, the complete package sans foundation,
which my article tells me is small enough to fit into a truck-transportable container,
easily fits onto a concrete pad the size or a single pad for one 3 MW wind turbine.
So, the site construction CO2 burden for the nuclear plant includes the excavation of the hole for the concrete pad for the foundation,
the concrete pour, including the steel reinforcement, an ancilliary building, and an employee carpark.
Both the nuclear reactor and an "equivalent" wind farm would require an on-site electricity substation so we can leave that out of any comparison.

Now, for comparison, let's have a look at the wind farm civil works requirements.
For 100, 3 MW wind turbines, there is required 100 reinforced concrete pads, each the size of the single pad required for the 100 MW nuclear plant.
So that multiplies our pad requirement by 100 against the wind farm.
The excavation of the pad site, the concrete pour, including the provision of the steel reinforcement bars, all of these activities result in a massive release of CO2.
The manufacture of both cement and steel each involves a massively CO2-producing process, thus multiplying the CO2 production against the wind farm.
We're not finished yet, although I think that if any such analysis is conducted by a wind farm proponent, and it gets this far, this is where it stops.

This system of pads is very interesting, and its construction is even more hugely CO2 intensive.
To begin, the pad system requires a system of access roads so that:
1. The pad site can be excavated, then the cement trucks and other transports carrying the steel reinforcement can access the pad site
to lay the pad foundation.
2. The roads are also required so that the components for the steel towers, and the wind turbine nacelle itself, can be transported to the site ready for erection.
Remember that the nacelle can weigh up to 200 tonnes.
3. The nacelle erection process requires a special nacelle-lifting crane, the vehicle for which must be some 1000 tonne-plus in dead weight,
(remember the principle of levers?), to lift the turbine nacelle to the 80 metres or more height of the wind turbine tower.

Therefore, given the weight of the vehicles, particularly the giant crane, these roads can be no mere, temporary, "dirt tracks".
No, each of these roads requires a major civil works programme, a programme that requires very substantial amounts of earthmoving operations,
crushed rock for the road base, etc.
All of these operations require the consumption of very substantial amounts of, usually, diesel fuel. That's more CO2 to add to the CO2 burden.

What length of substantial road is required for our 100 MW -nominal wind farm?

Here is where, I think, the story gets to be very interesting indeed. Let's put in place some known constraints.
In order to ensure that the output of each wind turbine is not affected by turbulent wakes generated by its neighbours,
the turbines have to be separated by a certain minimum distance.
The distance set by the manufacturer for 3 MW turbines to by about 500 metres.
For a wind farm comprising 100 wind turbines, then, this minimum spacing of 500 metres requires a network of roads, with turbines set appropriately,
that is a minimum total length of 50 kilometres, (that's 100 times 500 metres).
That's the minimum length of the network of substantial roads within the wind farm.
Remember, this length does not include the length of the access road back to the nearest main road.

What is the first requirement in the building of 50 kilometres of roads? Well, after the necessary excavations of the landscape to remove the vegetation,
(at Taralga this comprised assemblages of critically-endangered species), smooth out the peaks and troughs (all requiring the consumption of lots of diesel fuel),
the main emissions-producing requirement is lots and lots of gravel.
How much gravel and how is is best sourced?
To produce the gravel, preferably granite has to be sourced, and again, preferably, the source of the rock should be near-at-hand.
(No doubt, Dr Sarah is reminded of the cruel destruction of the Gardners sheep enterprise because the wind farm proponent built a rock-crushing plant
right next to their precious sheds - the rock-crushing plant being required as the first step in construction - to build the roads.)

So, how much gravel is required?
Is it merely many tens of thousands of tonnes? It is well over one hundred thousand tonnes?
I don't know, because I do not have the civil engineering expertise to do the calculations.
But someone must. And that calculation will reveal, I believe, a set of CO2 emissions whose size may not be ignored.

But, the hidden CO2 emissions story does not stop there.
These wind turbine things are made of some very exotic materials, some of which have very significant CO2 emissions costs in their extraction and refining,
and, incidentally, whose mining poses an ongoing environmental catastrophe at those sites from which they are removed.

Remember, we are still doing a comparison with our little nuclear reactor.
Our little reactor will come preloaded with several tonnes of enriched uranium, and after three years will require refuelling. The several tonnes will have become
several tonnes of very nasty radioactive material, material which will be sent off to safe storage of some sort. Note, I am not avoiding the radioactive waste issue.
I am also not avoiding the fact that the uranium will also require energy for its mining and enrichment, all of which will involve CO2 emissions.

What about our wind farm?
Well, each wind turbine has bound up in its permanent magnets some amount of the rare-earth metal Neodymium. There is at least half a tonne,
an estimate which I believe is a low estimate.
We can say that our wind farm has at least 50 tonnes of Neodymium embedded in its operations.
What is involved in the provision of this 50 tonnes of Neodymium?
Has the energy and CO2 emissions required for its extraction and fabrication into rare-earth magnets been factored into the CO2 emissions burden of the
wind farm by wind farm proponents?
I doubt it.

What is involved in the mining of Neodymium?
Because it is one of the "rare-earth" elements, it is generally found at very low assay levels. Our 50 tonnes of Neodymium at, say, 250 parts per million
of rock represents many thousands of tonnes of rock that must be mined, crushed, and disposed of.
(Check my figures: (1000000 parts divided by 250) x 50 tonnes is 200,000 tonnes of waste rock)
Some say that Neodymium is as abundant as Copper, in which case the assay can be much higher, leading to lower quantities of waste rock.
But, when I go searching around for information on commercially-feasible deposits, the answer somehow ends in China, with a whole suite of stories
alleging gross environmental and social damage to nearby human communities. Whatever the truth of these allegations, it would seem that the sweeping
statement that "Neodymium is as common as Copper" is one of those urban myths spread by such as renewables advocates.

It might help to understand that the extraction process is complex and dirty, and hence thoroughly toxic to both workers in extraction plants,
and to the environment if thoroughgoing environmental protection processes are not put in place. We need to understand that the rare earths nearly always
occur with Uranium and Thorium. The presence of significant quantities of both, and particularly Uranium, means that not only will the tailings always
be radioactive, but, there will be significant quantities of the Uranium and Thorium "daughter" elements, radioactive elements along the radioactive decay
chain, some of which, such as Radium and Radon, are extremely nasty as regards both occupational exposure and environmental contamination.

All of these environmental and occupational health issues are addressed in properly-managed Uranium mining and Thorium deposit operations,
but not necessarily in other heavy-metal mining operations such as that for rare earths where at the often lower assay levels,
these extraction of these radioactive elements is not economically feasable, and so they are treated as waste products.

A relatively recent article highlights the issues in a fairly readable, and non-alarmist, non-sensational, form:
<http://e360.yale.edu/feature/boom_in_mining_rare_earths_poses_mounting_toxic_risks/2614/>
and the following takes a sensible look at the potential for recycling Neodymium:
<http://arstechnica.com/science/2014/03/rare-earth-recycling-is-it-worth-it/>

<http://instituteforenergyresearch.org/analysis/big-winds-dirty-little-secret-rare-earth-minerals/>
A quote from this latter article is the sort of "quick bite" item that ought to go before the Lords:
*"For perspective, America’s nuclear industry produces between* [*4.4 million and 5 million pounds*](http://www.nei.org/Knowledge-Center/Nuclear-Statistics/On-Site-Storage-of-Nuclear-Waste) *of spent nuclear fuel each year.
That means the U.S. wind industry may well have created more radioactive waste last year than our entire nuclear industry produced in spent fuel.
In this sense, the nuclear industry seems to be doing more with less: nuclear energy comprised about* [*one-fifth*](http://instituteforenergyresearch.org/energy-overview/nuclear-2/) *of America’s electrical generation in 2012,*
*while wind a*c*counted for just* [*3.5 percent*](http://instituteforenergyresearch.org/energy-overview/wind/) *of all electricity generated in the United States."*
(My underlining for emphasis)
There is no point in any apologist for wind energy saying that the radioactive waste released from the mining of Neodymium and Dysprosium is "less dangerous"
than that in reactor spent fuel. The fact is that the release into the environment of the former is completely uncontrolled while the latter is held indefinitely
under very strict, international, safeguards.
For an indication as to the amounts of Uranium that occur in the commercially mined rare-earth deposits, the following article from
The World Nuclear Association is helpful:
<http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/uranium-resources/uranium-from-rare-earths-deposits.aspx>

Earlier in the same article the following statement appeared:
*"The wind industry requires an astounding amount of rare earth minerals, primarily neodymium and dysprosium,
which are key components of the magnets used in modern wind turbines.
Developed by* [*GE*](http://www.robotxworld.com/topics/robotics/articles/334705-hr-mp20-helicals-wireless-climbing-robot.htm) *in 1982,* [*neodymium magnets*](http://www.wisegeek.org/what-are-neodymium-magnets.htm) *are manufactured in many shapes and sizes for numerous purposes.
One of their most common uses is in the generators of wind turbines.

Estimates of the exact amount of rare earth minerals in wind turbines vary, but in any case the numbers are staggering.
According to the* [*Bulletin of Atomic Sciences*](http://thebulletin.org/myth-renewable-energy)*, a 2 megawatt (MW) wind turbine contains about 800 pounds of neodymium and 130 pounds of dysprosium.
The MIT study cited above estimates that a 2 MW wind turbine contains about 752 pounds of rare earth minerals.

To quantify this in terms of environmental damages, consider that mining one ton of rare earth minerals produces about one ton of* [*radioactive waste*](http://fmso.leavenworth.army.mil/documents/rareearth.pdf)*,
according to the Institute for the Analysis of Global Security. In 2012, the U.S.* [*added a record 13,131 MW*](http://www1.eere.energy.gov/wind/pdfs/2012_wind_technologies_market_report.pdf) *of wind generating capacity.
That means that between 4.9 million pounds (using MIT’s estimate) and 6.1 million pounds (using the Bulletin of Atomic Science’s estimate)
of rare earths were used in wind turbines installed in 2012. It also means that between 4.9 million and 6.1 million pounds of radioactive waste were created
to make these wind turbines."*

**Summary**
This little collection shows that, to generate an average of 100 MW of erratic, unpredictable, chaotic, intermittent electricity and to dump it into the grid,
a typical wind farm with a real capacity factor of 35 percent, such as occurs in Australia, generates of the order of at least some one hundred thousand
tonnes of waste rock. This tonnage results from the building of the access roads within the wind farm and in the mining of certain elements
that are essential to a wind farm's operation.
All of this rock has to be crushed, and transported, resulting in the burning of diesel fuel, thus releasing significant amounts of CO2.
Some of the rock, in addition, has to be chemically treated to extract essential elements such as Neodymium and Dysprosium, etc.

Whether the source rocks contain radioactivity in large quantities or not (remember, all rock contains radioactivity - that's the principal source of natural,
background radiation), all waste rock, and the quarries from which it is mined, constitute an environmental hazard.
One of the principal, universal, hazards is that of acid mine drainage: all rock contains significant quantities of sulphur and on contact with air and rainwater,
this sulphur mineralisation oxidises to form both sulphurous (H2SO3) and sulphuric (H2SO4) acids. Needless to say, these are major environmental
contaminants of waterways, etc., unless properly contained. This last paragraph comes from my own background expertise: I once did a lot of work
examining the dynamics of mine waste rock heap oxidation, hence my knowledge of CO2, SO2 and acid waste production from mine waste rock dumps.)

(Note: I haven't included estimates for the, additional, emissions resulting from the mining and processing of iron for the steel, that for the copper, etc.,
used in the wind turbines.)

**Some references**
Other useful articles on the impacts of the mining of Dysprosium and Neodymium:
<http://www.windfarmaction.com/neodymium-mining.html>
<https://stopthesethings.com/2014/03/24/more-facts-about-wind-turbines-and-rare-earths/>
<https://www.theguardian.com/environment/2012/aug/07/china-rare-earth-village-pollution>
<http://www.news.com.au/travel/world-travel/asia/baotou-is-the-worlds-biggest-supplier-of-rare-earth-minerals-and-its-hell-on-earth/news-story/371376b9893492cfc77d23744ca12bc5>
<http://www.windpowerengineering.com/uncategorized/rare-earths-minerals-used-in-windpower-technology-could-fall-into-short-supply/>
<http://min-eng.blogspot.com.au/2013/02/the-real-cost-of-using-neodymium-in.html>
<http://www.dailymail.co.uk/home/moslive/article-1350811/In-China-true-cost-Britains-clean-green-wind-power-experiment-Pollution-disastrous-scale.html>
<http://www.frontierrareearths.com/demand-for-neodymium-from-wind-turbines/>
There is even some useful information from the fanboys:
<https://yes2renewables.org/2012/03/06/rare-earth-magnets-not-all-new-turbines-are-using-them/>
<http://www.renewablesinternational.net/neodymium-a-bone-of-contention-in-wind-turbines/150/435/31015/>
(Of course, if the design does not use permanent magnets it is heavier, and consumes more power from the grid.
A heavier wind turbine requires larger foundations, a stronger tower => even greater CO2 emissions.)

The predictable grid instability from too great a penetration of renewables (specifically wind power in South Eastern Australia) was predicted a few years ago by Electrical Engineer Paul Miskelly's analysis published in a peer reviewed journal (accessible here:  <https://stopthesethings.com/2013/09/04/where-will-you-be-when-the-lights-go-out-for-good/> )