A checklist for renewable energy plans

Next Wednesday, Beyond Zero Emissions launches their Zero Carbon Australia 2020 Stationary Energy Plan. It will join a growing list of renewable energy plans - Desertec, Greenpeace's Energy [R]evolution, World Wildlife Fund Australia's Clean Energy Future, Peter Seligman's Australian Sustainable Energy, and others around the world.

The need to cut ourselves loose from our carbon based economy is urgent, and proponents of these plans are to be applauded. But, can they work? Many posts and comments at *Brave New Climate* have focussed on the hurdles facing large scale renewable power. Here I have tried to distill these points into a checklist to bear in mind when considering these plans. The list is followed by some brief exposition of each item. Some of these items refer to some Australian specifics, but similar questions will arise in other countries.

These items are not a set of pass/fail criteria, rather, they are prompts to ask "Did the plan address this point, and how?" The list is not exhaustive – many other questions could be raised, and hopefully will be in the comments. I have not really considered nuclear power in this list because I am not aware of similar comprehensive attempts to plan carbon free nuclear economies (perhaps there should be) – there would be questions, but unlike renewable energy, we have existence proofs that it can be done.

So, how does the plan check out?

0. The checklist

- □ What is the emissions reduction target?
- □ What is the budget for the plan?
- □ How is the plan to be financed?
- □ What is the cost of power if the plan is implemented?
- □ What is the CO_2 avoidance cost ($/t$CO_2$ avoided)
- □ Can the plan scale to 100% emissions reduction?
- □ What is the timeframe of the plan?
- □ What current and future demand is assumed?
- □ What efficiency improvements are assumed?
- □ Does the plan include power for electric vehicles, desalination, and industrial use?
- □ What are their worst case scenarios for solar and wind generation, and how have they been handled?
- □ Is enough wind and solar generation planned to cover their minimum capacity factors and longest outages?
- □ Do the wind and solar outputs account for dumped power due to production in excess of demand?
- □ Is enough energy storage planned to provide continuous power?
- □ Is enough generation capacity planned to charge storage in addition to supplying demand?
- □ Are wind and solar assumed to contribute to emissions reduction? If so, why?
- □ What lifetime of wind and solar plant is assumed? Can they be supported by data?
- □ What maintenance and decommissioning costs are assumed?
- □ Are all proposed generation and storage technologies mature?
- □ Can the plan meet National Electricity Market reliability standards?
- □ Does the plan increase the NEM mandated spinning reserve from the current 850 MW?

- □ Does the plan increase the NEM reserve generation capacity from the current 20% value?
- □ How much new hydroelectricity is assumed?
- □ How much new pumped hydroelectricity (GW) does the plan call for?
- □ How many hours storage does this provide?
- □ What sites are proposed for the pumped storage?
- □ What power source is proposed for pumping?
- □ How much new transmission infrastructure is planned?
- □ What power are the transmission lines rated for?
- □ How much steel, concrete, land and water are required?
- □ What are the proposed sites for the wind and solar installations?
- □ Has the availability and cost of labour been addressed? Does it consider transport to remote locations and accommodation?
- □ Have the ecological impacts of large scale wind and solar been assessed for the proposed sites?
- □ How much natural gas is used?
- □ Does the plan cost in large increases in the price of gas?
- □ How long is natural gas assumed to last?
- □ What will take the place of natural gas when it is no longer economically available?
- □ Was nuclear power considered as an option?

1. Scope of Plan

1.1. What emissions reduction is targeted? Is it sufficiently ambitious?

Climate change is a big issue, and we have to to think big. Unambitious targets will not solve our problem, and risk delaying effective action. Targets of 40% or 60% cuts to CO_2 emissions are not enough. The endgame is to completely decarbonize our energy system. Even if the plan does not reach that goal at once, it should have the potential to scale to 100% emissions reductions.

The preindustrial atmospheric CO_2 concentration was 280 ppm. It is currently about 390 ppm, and increasing at about 2 ppm per year. We need to bring it back down to 350 ppm or less, in a timeframe of decades. Failure will result in irreversible and extremely damaging consequences for human civilization and planetary ecology. The immediate goal, as proposed by James Hansen, should be to completely phase out coal power by 2030. An effective plan must be able to shut down coal plants, one by one, until they are all gone.

Unsurprisingly, these topics have been well covered on Brave New Climate:

Target atmospheric CO_2 levels, not vague carbon emissions

We need a real global plan for carbon mitigation

Managing catastrophic risk – the six step plan

How to get rid of existing coal

1.2. What is the budget for the plan?

No plan can be credibly advanced without a credible budget. Is this plan costed, not just for the direct generation plant, but also backup, storage, transmission, maintenance, decommissioning, and so on? Is the rising cost of the fuel for backup (gas especially) into the future considered? If not, pass.

1.3. How is the plan to be financed?

Having a budget is one thing. Knowing how the plan will be paid for is something else again. A plan that can't be paid for can't be built. There are many ways to do this – does the plan specify a financing model?

1.4. How cost effective is it ($/t$CO_2$ avoided)?

We don't have unlimited cash to spend on emissions reduction. We want bang for buck. We want to be able to measure value for money. And we want to shop around. Can I get better value with a different plan? So, what is the emissions avoidance cost, in dollars per tonne of CO_2 avoided?

Environment Victoria is campaigning to close down the Hazelwood coal plant. Their plan is to eliminate 12 MtCO_2 per annum with wind and gas at a cost of $64/t CO_2 avoided. Had they considered gas alone, they could have the same emissions reduction for $22/t CO_2 avoided. If nuclear were available it could be even cheaper. Choosing the more expensive option virtually guarantees their plan will fail. This is just one coal plant. Do we want to make the same mistake with nation scale infrastructure, and fail also?

Peter Lang has calculated the emissions avoidance cost here for a number of generation options.

1.5. Can the plan scale to 100% of demand (or more)?

Adding small amounts of renewable energy to the grid is relatively easy (albeit costly). But it gets harder as we add more. Can the plan take us all the way to 100% decarbonization? Or will we fall short, and be left with no other option than to bridge the gap with fossil fuels?

Each power source has its own limits. Hydroelectricity is limited by availability of suitable sites and adequate rainfall. Wind power penetration is limited by its effect on the stability and reliability of the grid. Even coal is limited to less than 100% by its slow response time to rapidly changing demand.

1.6. What is the timeframe of the plan?

Does the plan have a schedule? We should expect to see milestones in such terms as "20% emissions reduction by 2020 through to 80% reductions by 2050".

I do worry that such goals are a bit amorphous. Our power supply does not come in continuous percentages, it comes in discrete chunks – the power plants. So the best schedule would be a list of coal fired power plants, by name, with a date for closure. Energy Victoria have exactly the right idea with their campaign to close *Hazelwood* by *2012*. Now can we set a termination date for the rest of these plants?

1.7. What energy sectors are in scope?

Do we just consider the energy sectors that are visible to us as consumers, like household electricity, and driving the car? A plan that includes household efficiency, 'green' electricity, and reduced car usage might then look very appealing. But is it enough? Can the plan provide

- Household electricity
- plus commercial and manufacturing uses of electricity
- plus desalination
- plus electrification of transport

and perhaps more, including energy intensive carbon drawdown?

2. Demand and Efficiency

2.1. What current demand is assumed?

The electrical *energy* demand for Australia in 2009-2010 is a nice round 1.0 exajoule, according to ABARE. That's 10^{18} J, or 280 TWh (1 terawatt.hour is 10^{12} watt.hours). It's the equivalent of about thirty seven 1 GW power stations running for one year. We have 49 GW installed generation capacity (2008).

Peak *power* demand in the National Electricity Market is of the order 33 GW (2007).

This demand is not met just by generating this very large amount of energy. It is met by generating the total power demanded by all customers at all points in time and serving it to customers at the moment it is demanded. These figures are for electricity as a *product* which can be sold, not just energy which can be generated.

2.2. What future demand is assumed?

Our current demand will not stand still. The population will grow, and we will want more air conditioning and larger TVs! New uses will be found for electricity, including electric vehicles and water desalination.

ABARE projections have Australia's electricity production increasing to 366 TWh in 2030, without assuming significant adoption of electric vehicles. What future demand does the plan assume?

2.3. What demand reductions due to efficiency are assumed?

Of course, we could use less energy by being more efficient. However, plans that rely on a large efficiency component are due some close examination for a number of reasons.

The first is Jevon's paradox, which observes that when some technology becomes more efficient, the technology is more widely used because it becomes cheaper, and net energy use increases. Then there is the Khazoom-Brookes Postulate, which holds that energy efficiency allows increased economic growth, also leading to an increase in net energy use.

Efficiency only makes a big difference for uses that are already inefficient. But very energy intensive activities tend to be quite efficient, as there is a strong economic incentive for them to be so. Of our 280 TWh/yr of electrical energy, 43 TWh/yr is used in production of non-ferrous metals (29 TWh/yr just for aluminium). These processes are already close to optimal.

So we are looking for efficiency improvements down in the tail of the Pareto distribution - amongst a large number of smaller consumption categories. It is harder to achieve these efficiencies as improvements are spread over a diverse array of activities, each with its own special way of saving energy.

If we expect large efficiency gains from behavioural change, we will be disappointed. Few people are motivated to make large lifestyle changes to support deep cuts in energy usage. In the big picture, they are a hobbyist population that is of no consequence. The greater mass will resist inconvenience, strongly, and will resist any political move to coerce such inconvenience.

3. Generation

3.1. Wind and solar

3.1.1. How much redundant capacity will be built?

There are traps lurking in the average capacity factors of wind and solar that can lead us to underestimate the number of power plants required. Is the planned generation based on:

- The nameplate capacity?
- The annual average capacity factor?
- The capacity factor for seasons of lowest output (eg. the winter capacity factor for a solar plant)?

- Further derating the capacity factor to account for use of suboptimal sites, if very large scale generation is planned
- Further overbuild to cover extended periods of low generation that hide inside average capacity factors, such as a run of cloudy days or wind lulls?
- If we plan to store energy to cover these outages, we can't use the same generators to service demand *and* charge up the storage – is additional generation capacity included for the energy we want to store?

TCASE10 discussed a number of issues related to capacity factors and outages.

3.1.2. What are their worst case scenarios for solar and wind generation, and how have they been handled?

The sun does not shine at a constant average rate, nor does the wind blow at a constant average speed. Averages are not good enough for planning a power generation system. What is the longest period of low wind and zero wind power that the plan assumes? What is the longest run of cloudy days?

For instance, the Bonneville Power Authority in the US Pacific Northwest has 1.5 GW nameplate wind over four states, which in January 2009 ran for 11 continuous days at less than 50 MW (3% capacity). Or you might look at all the wind in Ireland through 2006-07, where you can pick out a number of periods of about a week running at about 10%. These low generation periods need to be covered by alternative generation, use of stored power, or backup generation.

The worst case for generation drives many critical assumptions around scale, storage, cost, backup and emissions. Does the plan explicitly state, and accommodate, the worst case?

3.1.3. Do the wind and solar outputs account for dumped power due to production in excess of demand?

With enough wind power in the system, sometimes output will exceed demand, in which case the energy is dumped, or sold at negative cost. This "spilled wind" reduces the capacity factor, or impacts the economics of the generator. It means that beyond point, perhaps 20% penetration if Denmark is typical, meeting demand by adding more wind to the grid is chasing diminishing returns. A similar effect is expected for high penetrations of solar power, although not enough solar power has been built to test this.

Does the plan account for this effect, or assume it can simply add wind up to 100% penetration without penalty?

3.1.4. How much storage is planned

How many hours of storage (for generation at full power) are planned? Is it enough?

For instance, a solar system should be able to provide some power throughout the night. You might guess this requires about 18 hours storage. The Spanish solar station Andasol 1 has 7.5 hours storage, which apparently gives "*almost 24-hour operation of the power plant during high sunshine periods.*" Or to put it another way, it can't provide a full day's power, even in high summer. How much storage is required to see us through a cloudy day? 24 hours? 36? How many continuous cloudy days might we expect? Better plan storage for those days too.

Similarly for wind, we need to ensure the storage can cover multi-day lulls. If it doesn't, we'll be burning some form of carbon instead. And the cost of the fossil fuel plant must be paid for by the small amount of energy generated, so the cost per unit energy is very high.

3.1.5. Are wind and solar assumed to reduce emissions?

How much does wind power really reduce CO_2 emissions? Does it even reduce it at all?

We currently back up intermittent wind with fossil fuel plants. As these plants idle in standby, or follow the variable wind output, they use more fuel, like a car in city traffic, idling and starting and stopping. Have these additional CO_2 emissions been accounted for? Is there a *net* reduction in emissions?

In fact, introducing wind into the grid may even increase emissions. A series of studies on wind integration for the Netherlands, for Colorado, and for Texas have all found increased overall emissions as more wind is added.

The same question has been considered here at *Brave New Climate*. Even if wind power does reduce emissions it is not on a watt for watt basis, and the cost of avoiding emissions is very high.

(I suspect a similar situation applies to solar power but to a lesser degree, but am not aware of any studies on this.)

So, does the plan attribute *any* emissions savings to wind power? If so, on what basis?

3.1.6. Maintenance, lifetime and decommissioning

Advocates of nuclear power have long been taunted by calls for decommissioning costs and full lifecycle analysis, and rightly so. And it's a question that should also be asked for other generators. So, what does the plan assume for:

- Lifetime of wind and solar generators
- Maintenance costs
- Decommissioning costs

Decommissioning is expensive. For instance, decommissioning for the Beech Ridge project (West Virginia) was estimated at ~US$100k per 1.5 MW turbine net of scrap value. With 119 turbines producing ~186 MW that's about $12m, or $60m/GW.

Offshore wind is more expensive. One UK study estimates £34m/GW nameplate capacity, or about £100m/GW average output.

Several comments here by bryen give a great rundown on a number of wind farm life cycle issues. To quote a few of his points:

"Wind industry developers suggest a 20 to 25 year lifespan for an industrial wind turbine .. However, due to the majority of these installations being new developments, few turbines have been around to test these lifespan assumptions under real world conditions .. Gearboxes in wind turbines are often replaced within the first 5 years .. Jan Pohl of insurance firm Allianz in Munich, who faced about 1000 claims in 2006 stated : 'an operator has to expect damage to his facility every four years, not including malfunctions and uninsured breakdowns.'"

3.2. Hydroelectricity

The Snowy Mountains hydro scheme can generate 3.8 GW sustainably for 1184 hours per year. It took 25 years to build, and we have neither the rainfall nor the sites for a large expansion of hydroelectricity.

Because of hydro's rapid response to power fluctuations, introducing variable generators like wind into the grid will increase the demand for hydro. Do we have enough hydro capacity to serve the proposed renewable generators?

3.3. Immature technologies

Geothermal power, wave power, tidal power, are all potential or actual sources of low carbon energy. Perhaps these and other generators are included in "the energy mix". Are they commercial? Or are they R&D projects? Is the plan deploying proven technologies, or R&D projects?

4. Grid Storage and Backup

4.1. System Reliability

The National Electricity Market must meet reliability standards. Unserved energy must not exceed 0.002 percent of total demand. The NEM is also required to carry 850 MW of spinning reserve power to ensure reliability.

Further, the grid carries about 20% capacity margin in reserve (Australia 2005, US 2004), which is 7-8 GW in Australia. Adding a large amount of intermittent generators to the grid would require an increase in the reserve power to ensure reliability.

Can the plan meet currently legislated levels of reliability? What happens if it can't? How much should the reserve power be increased to ensure reliability? Does the plan include this additional reserve power?

4.2. Storage with Pumped Hydroelectricity

Renewable energy requires energy storage, and the cheapest large scale storage is pumped hydro. Questions to consider for pumped hydro are

- how much power (GW) is needed?
- how much energy (hours of storage at full power) is needed?
- how long does it take to pump up the storage?
- what is the power source used for pumping?
- where will we put it?

Australia has 2.5 GW of pumped hydro. 1.5 GW of that is the Tumut 3 system which can generate full power for 6 hours. Then it requires 21 hours to pump it back up again.

The 0.5 GW Wivenhoe facility pumps from midnight to 6am. It generates for about 7 hours per day, and is on standby for 12 hours. During standby it provides some power to stabilise the grid. It can't pump up during daytime standby or generation periods.

Australia's pumped hydro capacity is a poor complement for wind or solar because pumping requires steady power – it can't start, stop or ramp quickly. This means you can't generate power while charging. So it generates power during the day, and is pumped up at night. This is obviously a poor match for solar, and it's also a poor match for wind. The power for pumping needs to be cheap. Coal fired base load works, wind and solar would be uneconomic. But the main limitation on expanding pumped hydro is the lack of suitable sites.

Peter Lang has analyzed a potential pumped hydro scheme using existing reservoirs in the Snowy Mountains scheme on Brave New Climate. It could provide 8 GW of power for 5 hours a day. It would cost ~$12- to $15-billion. There is much useful discussion in the comments to this post.

So, does the plan depend on pumped hydro to store energy generated by renewables? How much storage does it require? And where will we put it?

5. Transmission Infrastructure

5.1. How much new transmission infrastructure is assumed?

Long transmission lines are needed to collect power from generators far enough apart that local cloud or low wind is averaged out. The length scale is the size of the continent.

Each individual site will need a transmission link to the trunk, and each individual turbine will need to be connected. Additional switchgear and control systems will be needed.

So, does the plan have a comprehensive, costed, transmission infrastructure?

5.2. What is the capacity of the transmission lines?

The transmission lines must be sized to handle the nameplate capacity of any wind or solar plant, not the average capacity. Wind and solar need about three times the transmission capacity of a conventional generator (nameplate/average capacity).

Large scale weather systems impose greater transmission capacity requirements on wind and solar than conventional power plants. If the east coast is covered in cloud but West Australia is generating, the east-west transmission must be sized to carry the east coast load. There's a lot more power 'sloshing' across large distances.

So, are the transmission lines sized for the spatial load balancing and high peak loads of wind and solar, or does it just use capacities appropriate to our current generation system?

6. Resource Consumption, Land Use, and Ecological Impacts

6.1. Steel, Concrete, Land

TCASE4 considered steel, concrete and land usage for solar, wind, and nuclear power generation. The resource consumption of the renewables are stupendous, one or two orders of magnitude greater than nuclear power. Does the plan address the use of these resources?

6.2. Water for Concrete, Cooling and Washing

Renewable energy has large water requirements. Has water supply been considered?

Has the water supply needed to make the concrete during construction been factored in. Where will the water come from? What is the cost of supplying around 10 times as much water for the concrete for a solar thermal plant than for a nuclear plant of the same capacity?

As explained in TCASE6, all thermal power plants – solar thermal, coal fired, nuclear - have similar cooling water requirements, because they all produce power with steam turbines. For closed loop cooling, solar thermal and nuclear use about 3000 L/MWh. Open loop cooling withdraws much more water, about 100 000 L/MWh, which is returned to river, lake or ocean at a higher temperature. The water lost to evaporation is about the same as used in closed loop cooling.

A particular issue arises for solar thermal if the plant is to be located in the desert – where does this water come from? It is possible to use air cooling for thermal plants, but the cost is higher, and the thermal efficiency takes a hit, with less energy from a more expensive plant, so the cost effectiveness and investor return is reduced.

So, does the plan include a large amount of solar thermal power? If so, do the plants use open loop, closed loop or air cooling? Where does the water come from? Are costs and outputs appropriate to the cooling technology?

Finally, the mirrors in solar thermal plants require regular washing to remove dust, which blocks the sun. Does the plan describe the water supply for these plants, particularly if they are to be sited in the desert?

6.3. Gas

Large scale wind and solar requires lots of gas fired backup, and gas reserves are finite.

Professor Barry Brook has reviewed the availability of natural gas in Australia. He estimates that our reserves, less exports, if used to serve our full energy requirements, would last perhaps 20 years. How we actually choose to use it is an open question, but it is clear that gas as an energy source has a limited lifetime. Brook says:

"The UK is now paying dearly for their dash for gas, following the coal mine closures of the 1980s. Their once-abundant North Sea fields are rapidly depleting. Again, Australia should take note of this warning. We must not go down the natural gas-for-coal substitution route. It would be long-term economic suicide."

If we commit to renewables, we commit to expanded use of gas, at the same time as gas prices are expected to skyrocket. What happens to the price of electricity? Can we afford renewable power that commits us to dependence on a finite and increasingly expensive resource? And how long do we have before the gas runs out?

6.4. What are the proposed sites for the wind and solar installations?

Renewable energy takes up an enormous area because the power is so dilute. Meeting Austraila's energy needs with 2.5 MW turbines would occupy about 15 000 km^2 (a naïve calculation based only on the average capacity factor, without overbuilding). To give this some perspective, our best wind resource is on our 25 000 km coastline. Covering Australia's southern coastline a kilometre deep with windfarms would give us the required area. If you don't like this idea, where else should they go?

Similarly, meeting our needs with Andasol-class solar thermal would require about 2000 km^2. Where will these plants go?

What ecosystems will they impact? Who owns the land now? On what terms will we negotiate with existing owners for access to their land, or acquisition of it? What planning processes will be used? How long will this take?

6.5. Labour

Does the plan consider the workforce that will be required?

Renewable energy is labour intensive in construction as well as maintenance. And we don't just need to find the labour, we need to transport the workers to remote areas and accommodate them. In his Emissions Cuts Realities paper, Peter Lang writes:

"To construct the solar thermal power stations in areas throughout central Australia [*or remote wind power –jm*] will require large mobile construction camps, fly-in fly-out work force, large concrete batch plants, large supply of water, energy and good roads to each power station. Air fields suitable for fly-in fly-out will be required at say one per 250 MW power station."

Does the plan consider the labour resource for remote development? What cost of labour is assumed? Is it competitive with the mining industry in similar situations?

6.6. What are the ecological impacts?

Building wind power amounts to light industrialization of the landscape. The installation requires access roads for trucks, cranes and cement mixers, excavation of foundations and pouring concrete footings, construction of transmission lines and substations, and so on. The packing density estimated by Professor Brook for a typical turbine would give an average spacing of about 500 m. These activities are directly damaging to sensitive ecosystems, disrupting soils and causing erosion, and providing vectors for pest plants and animals

Solar mirror fields completely build over the area they occupy, which may mean local destruction of desert ecosystems.

Birds and bats are killed by blade strikes. While there are many sources of bird mortality, wind turbines appear to be particularly hard on raptors (eagles, hawks, falcons, etc.). Many other ecological effects have been reviewed in the report for the US National Academies, "*Environmental Impacts of Wind-Energy Projects*".

These impacts may appear trivial, or sound like NIMBYism. But for renewable energy deployments at very large scale, they may be devastating. Have the direct environmental impacts of the plan been considered?

7. Comparison to the Nuclear Alternative

Constructing a renewable energy plan is like composing a sonnet or a fugue. The constraints imposed by the form drive creativity and grand ambition. A fine thing for poetry, but what if we just want to *get the job done*?

The constraint accepted by so many of these proposals is that we design the system without nuclear power. What happens if you relax that constraint? Was this even considered?

If the goal is to avoid disaster in the biosphere, or to do an end run around peak oil, does the fastest, most certain path to a fossil fuel free future include nuclear power, or exclude it? Is our most effective course of action to pursue large scale renewables, or social and legislative change to enable rollout of nuclear power?

Were these questions even considered?