POWER FAILURE

AFFORDABLE RELIABLE RENEWABLES?

SOME INCONVENIENT REALITIES

Geoff Carmody

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Foreword

Note.

This booklet is neither a technical analysis nor a scholarly tome replete with numerous references to other work. Nobody commissioned or paid for it. It's based on a lot of reading and reflection. It's an economist's take on electricity in Australia. I've tried to write an easy-reading overview. I've failed. But I hope readers' interest is triggered a bit.

I apologise the booklet exceeds the 140 characters (now 280?) loved by social media. This note, alone, fails both tests. I know some heads of state tweet. I don't. Complex ideas – even real news? – suffer.

GFC
5 January 2018

Australia was regarded as a richly-endowed energy producer and net exporter. Along with agriculture, those endowments were a key factor in our comparative advantage, international trade success, and incomes.

In 1972-74 I was in Washington representing Australia at the IMF when the first 'OPEC oil shock' hit the world. Energy, especially oil, went from cheap to unaffordable or even unobtainable. World growth dropped, almost halting in 1975, as cost inflation soared. A new phenomenon was born: 'stagflation'.

In 1978-81 I was in Paris representing Australia at the OECD during the second 'OPEC oil shock'. I remember the enthusiastic welcome we received when arriving at a meeting considering how to respond.

Australia's energy resources were seen as part of the solution. We could help sustain world growth and living standards. We were an affordable energy antidote to the 'OPEC oil shocks'.

Things have changed.

In the 1970s, there was speculation about global cooling. In the 1980s and later, claims of human-induced global warming increased. From the early 1990s, if not earlier, Australia's 'fossil fuel' energy resources were increasingly targeted by some as a cause of global warming. 'Fossil fuel' became a pejorative term.

For those people, we've been downgraded.

According to them, we're no longer an energy powerhouse and income supporter. We're a pollution pariah.

Suppose anthropogenic global warming is realistic. The policies advocated by believers aren't.

They:
- have been silent, or, at best, vague, about the ***reliability*** of renewable energy in place of fossil fuels,
- ignore the relative importance of any net Australian contribution to ***emissions reduction*** globally, and
- have been increasingly dishonest about the ***affordability*** of ***reliable versions*** of their policies.

It's worth looking at the basic physics involved in rapid switching from current fossil fuel power to renewable energy alternatives, and its economic consequences, not least for affordability and/or reliability.

The political rush to greenhouse gas emissions reduction targets hitherto has ignored reliability. The costs of such targets, *assuming reliability standards comparable with fossil fuel sources*, need scrutiny too.

This booklet looks mainly at the broad physics, as understood by an economist. It draws some very broad conclusions about likely costs. Policy implications are at the end.

Geoff Carmody*
5 January 2018

**Geoff Carmody is Director, Geoff Carmody & Associates, a co-founder of Access Economics, and before that was a senior officer in the Commonwealth Treasury.*

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Summary

The problem

Electricity is more and more important for our power supply.

We debate power sources. But we rely a lot on fossil fuels. 'Green' car and other batteries, (such as the SA Tesla battery array), add power storage costs, whether re-charging using renewables or fossil fuels like coal.

Stated energy policy is to deliver affordable, reliable power, with lower greenhouse gas (GHG) emissions. Policy isn't delivery. Our electricity demand-supply balance looks wobbly on reliability, and is very costly.

We've only pursued lower emissions. Globally, we've gone backwards on these. For affordability and reliability, locally, likewise. Energy costs have soared. Local businesses are closing, and/or going offshore, taking emissions with them. Australian living standards have suffered, and will suffer more, as a result.

This is power failure.

The Government's stated policy goals provide the benchmarks for measuring failure.

Policy delivery has transformed us from a low-cost energy-competitive powerhouse to a costly-energy policy pauper. Global GHG emissions are still increasing. Nothing *we* do will alter this prospect much, if at all.

Why do we no longer deliver the two outcomes we once achieved: affordability and reliability?

The fundamental cause: politicians chased one new goal, and ignored the two old ones

The Government says we face an energy 'trilemma': supplying affordable, reliable, low-emissions electricity. They, the Opposition, and others, should know. They're all accomplices before, during, and after the fact.

Politicians put this 'trilemma' label on a problem of their own making over many years. It's become a policy excuse, in the last year or two, as adverse cost and reliability consequences of their blinkered energy policy have emerged. Blame-shifting is rampant.

These people didn't even talk about a policy 'trilemma' until recently. They only talked about reducing emissions. They hoped affordability and reliability would look after themselves – while denying they couldn't.

Affordability and reliability went backwards as the power grid staggered under a renewables policy onslaught that is also driving out lower cost dispatchable power supplies.

Some argue lower-emissions renewables like solar and wind are cheaper than fossil fuels like coal or gas. Really? Great news if it were true. Subsidies could stop. The market would switch to renewables unaided.

But these same renewables supporters won't let go of the subsidy teat. Why do they still want others to subsidise renewables? Because they know they're really *not* cheaper after all? They're right. They aren't.

It's worse. Such are the mixed policy signals and general uncertainty engendered by politicians that investment in dispatchable supply is under threat. That points to less affordability and reliability in future.

Politicians chose – and continue to choose – the costliest emissions reduction option

The focus on Australia's tiny contribution to reducing global anthropogenic emissions is worse. Politicians chose the costliest emissions reduction option: renewable energy targets (RETs). They still do.

Economically, this was the worst choice. Because costs are rising and reliability is falling, this will prove a poor choice politically, too.

Adding to costs, politicians ruled out some gas and all nuclear resources for lower-emissions power.

Simple physics shows renewables (solar, wind and hydro) are:

- Subject to weather, and water supplies, for power generation.

- Are thus *uncertain and intermittent* generators, not *continuously reliable dispatchable* power sources.
- Have *low energy densit*ies: large areas, volumes and weight are needed to generate modest power.
- As their share in power generation rises, they *raise total costs* of renewables/fossil fuel blends a lot.
- The Australian contribution to lower global emissions from RETs has been/will be insignificant.

Politicians ignored flow-on effects

Adding to power failure, being one-eyed on emissions, politicians ignored side effects. Modern power systems are interdependent. Increasing the renewables generation bit affects how other bits perform.

This is crucial for the back-up power needed for reliability. Back-up capacity requirements (extra generation plus storage) increase dramatically as the share of renewables in total power generation rises.

We have two choices for back-up power: fossil fuel or even more renewables.

NEM rules require all generators to supply power at lowest cost. The rules mean fossil fuels can't do so for much of the time, adding to their power dispatch costs when they can. But subsidised renewables require multiple generation capacity plus storage (batteries, etc). Multiplied capacity for the same power costs a lot.

Either way – indeed, with today's power grid, both ways – back-up costs of our blended fossil fuel plus renewables power system increase.

Against the three policy benchmarks, how does our power system score after increasing renewables' share?

Affordability = fail. Reliability = fail. GHG reductions = fail. Living standards = fail. More RETs = success.

Now what?

Insanity has been defined as doing the same thing (or even more of it) and expecting different results. Whether Einstein himself ever subscribed to this definition is debated. But Einstein wasn't dumb. Indeed, $E = mc^2$ gives us a clue to a 'trilemma' energy policy improvement.

On energy policy, Australian politicians haven't been smart. Power realities have been ignored.

We ***can*** reduce the inherent tension between affordability, reliability and lower emissions.

How?

1. Use nuclear fuels for peaceful power here. We already export them. It can be safe. Ask France.
2. Reverse state bans on gas development. These increase power costs. Give landowners a cut.
3. Phase out all RETs ASAP. On a *reliability-equivalent basis*, RETs are more expensive, not cheaper.
4. Require all power dispatch be on a *reliability-equivalent levelised lowest-cost basis* from now on.[1]
5. If we must price emissions, a comprehensive, uniform, national emissions consumption price is best.

We ***can*** choose a better path. If we want to. We ***may well*** choose more of the same. Power failure.

It's ***our*** choice.

Whatever the causes of any global warming, the consequences of our policy choices ***are*** anthropogenic.

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[1] Pending a full public review of NEM bidding rules, as a practical bidding approximation, a *reliability-equivalent levelised lowest-cost* bid to dispatch power might be defined as a bid valid for at least 24 hours. The ***generator-bidder*** would be required to stand in the market with a dispatch offer for a specified power quantity at the price nominated for one full 24-hour day. This would help to 'level the playing field' across all suppliers, while still allowing much higher peak demand offers to supply. See Figure 1 on page 26.

Full report

1. Do we have power failure?

This booklet is about ‘stationary’ electrical power in Australia.

Is power failure an issue?

With large endowments of fossil fuel energy, we once delivered two objectives: affordability and reliability. Generation intermittency wasn’t a problem. Source fuels were energy-dense, cheap, and always on tap.

Using coal or gas, we were to electricity what OPEC was to oil. We didn’t even use our nuclear fuels.

Concerns about anthropogenic global warming generated political pressure to reduce greenhouse gas emissions (GHGs). Energy policy supposedly has three objectives: affordability, reliability and lower GHGs.

These goals aren’t equal. Emissions reduction was given political priority. Affordability and reliability were left to fend for themselves. Reliability might now get more emphasis. Affordability probably won’t – or can’t.

We’ve set local GHGs reduction targets before assessing their full local costs and global benefits.

We’re paying for that.

We implicitly hoped existing fossil fuel energy generation would deliver affordability and reliability as back-up power. But our emissions reduction targets increased fossil fuel costs and stranded them as long-term assets. We banned some gas development. Climate policy flip-flops magnified ‘sovereign risk’ fears.

New fossil fuel investment froze. Existing coal-fired plants are closing. Renewables investment is surging.

The fossil fuels supply ‘squeeze’ – 100% policy-driven – is on.

Nuclear power? We export nuclear fuels to others – even NNPT non-signatories – but won’t use them here.

These decisions undermined Australia’s international competitive advantage. Global GHGs are still rising.

Affordability is a memory. *Reliability* has already become a headache in Victoria, New South Wales, Tasmania and, especially, South Australia. *Reducing emissions* is being modified now by desperate efforts to engage more fossil fuel power sources as back-up against more renewables failures (eg, the 9 diesel-powered generators imported by SA to back up power generation there as coal generators are closed).

If energy-rich Australia can’t achieve one of these objectives, still less two or three, that’s power failure.

If affordability and reliability are our biggest failures, our living standards will be our biggest loss.

2. Has reducing emissions disrupted energy policy?

Reducing GHGs is not business-as-usual with currently-used technologies in Australia.

Any costs of assumed global warming are broadly felt but privately non-chargeable.

Private markets can’t deal with this unaided. Reducing GHGs requires government taxes or subsidies.

Australian GHGs reduction policies using renewable energy targets effectively subsidise renewable energy and tax existing fossil fuels (both raising power costs, one way or another, for all).

Can governments tax or subsidise low-emissions power effectively? Evidence so far isn’t encouraging.

How governments intervene affects how businesses and individuals behave. ‘Good’ interventions reduce GHGs at least-cost both to living standards and access to affordable, reliable energy. Other interventions further increase costs of reducing GHGs and unnecessarily cut living standards. That’s where we are now.

Inevitably, reducing GHGs, *and* pursuing energy affordability & reliability, sets up a conflict between goals.

A year or so ago, the current Commonwealth Government labelled this our energy policy 'trilemma'.

With the energy resources we currently use (still mostly fossil fuels), and current technology, 'three into two won't go'. Some compromise between achievement of all three energy policy objectives is unavoidable.

Reality #1: Trade-offs between the three energy 'trilemma' objectives are unavoidable.

3. Price signals versus quantity targets: why did we choose targets?

The developing concern about global warming led to a basic question.

How much should anthropogenic GHGs be reduced relative to 'business-as-usual' (BAU) to avoid more than a specified amount of global warming (currently set by some at 1.5^0C-2.0^0C above 'pre-industrial' temperatures).

The 'right' answer also requires information about the percentage contribution of non-anthropogenic sources to warming or cooling (eg, volcanic activity). Natural causes can have big effects – in either direction.

That said, it was natural to quantify GHGs cuts relative to BAU and set these as climate policy objectives.

This led to proposals for 'cap and trade' Emissions Trading Schemes (ETS). The ETS label is distracting. It highlights buying and selling emissions permits, rather than the quantity of permits (the 'cap') available. This diverts attention from governments' role. With an ETS, governments are responsible for setting permit quantity 'caps'. Permit trading is then supposed to reduce GHGs at lowest cost in competitive markets.

ETS only reduce GHGs if governments make emissions permits scarce. Scarcity drives up prices for permits, cutting demand for them, and so cutting emissions. In Europe, GHG prices have been low. Governments haven't made permits very scarce. Elsewhere, GHG prices have been even lower, or zero.

An alternative is for governments to set an emissions price – a so-called 'carbon tax' – and allow the market to respond by finding ways to reduce emissions, avoiding or minimising the carbon tax liability. The GHGs reduction outcome is less certain. It depends on market responses. But the price is clearer.

Both approaches are inextricably linked. Governments/politicians (including our own) regularly deny this.

Reality #2: Reducing emissions permits increases permit prices, and vice versa.

There's another practical problem.

Measuring GHGs content through input-output production supply chains is hard. Changing technology, more globalised supply chains, and changes in energy inputs, complicate the accounting.

This was part of the rationale for ETS and 'carbon taxes' themselves. Leave governments to set the GHGs reduction quantity, or the GHGs price, and let the market sort out the detail. But, left alone, the market can't.

Policy compliance still demands good (and compulsory) emissions accounting and monitoring. If you can't measure, you can't monitor, and you can't manage. And all this must be done at individual emitter-level.

We've (sort of) ducked this fundamental problem, politically, so far.

When ETS and 'carbon taxes', as designed, were politically rejected or performed poorly, what did we do?

A simpler approach has found political favour: the renewable energy target (RET).

Why is this politically preferred?

There are several reasons:

- RETs are policy 'announceables' for the future. Announcing them makes sympathisers feel good.

- They side-step GHGs accounting issues. Renewables are simply *assumed* to be 100% GHGs-free.
- RETs can be used to 'rig' electricity market bidding in favour of renewables, seemingly 'cutting' GHGs.
- RET effects on costs – both for renewables and fossil fuel alternatives – are opaque and disputed.

Unlike ETS, the emissions quantity focus of RETs excludes broad-based processes to minimise GHGs reduction costs. The opposite cost outcome is likely. Energy reliability can also be compromised.

Reality #3: Alone, if RETs cut emissions, they also cut affordability and/or reliability.

4. Renewable energy targets for electricity

RETs focus on stationary electrical power. Renewables efforts for transport have been more limited.

Why the focus on stationary electricity?
- Centralised electricity generation plus transmission/distribution grids allowed increases in large-scale, RET-subsidised, renewables. Initially these appeared to have little cost effect on end-users.
- Marketing of 'green' generation sources, sometimes little more than 'green-wash', was facilitated. Users generally don't know how their electricity is generated. It's 'smeared' across total grid supply.
- Optional take-up of small-scale renewables (mainly rooftop solar energy) was made available for individual households, businesses, etc. Very generous 'feed-in' tariff incentives on long term contracts initially were offered for excess solar generation fed back into the grid.
- This small-scale 'distributed' generation model was so well-received governments soon cut back or terminated generous 'feed-in' tariffs. The cost of these concessions was smeared across centralised electricity supply tariffs. Those who couldn't afford solar panels, or chose not to, subsidised those who could or did. The 'feed-in' tariff policy was most strongly supported by Labor and the Greens. But its costs hit lower-income groups most. They couldn't afford to buy solar panels.
- Small- and large-scale renewables became so large they began to affect grid stability (both voltage and frequency). Investment to stabilise the grid added to energy costs but is essential to avoid power blackouts and grid damage. More on this later.

Renewable energy initiatives for transport have been slower to develop:
- Transport energy sources, (petrol, diesel, etc) are purchased directly by end-users.
- There is an expensive, geographically extensive, distribution system for such fuels already in place.
- Some renewable sources (eg, biofuels) are attempting to piggy-back on this distribution system. Biofuel supporters advocate legislated minimum proportions of such renewables in fuel blends.
- Battery development is proceeding. Availability of re-charging stations, the time required for re-charging, 'range anxiety' with use of all-battery vehicles, and other technical problems, remain issues to be resolved. In Australia most re-charging is still coal-powered. Worse than petrol, GHGs-wise?
- Energy density is a major problem. It's considered later in this booklet.

Australian RETs are justified as reducing Australian GHGs. This is seen as a local contribution to a global response to assumed global warming. As elsewhere (eg, the USA), state politics intrudes where states have power to restrict state GHGs and set state RETs. Different RETs multiply.

Australia has a national RET. State and territory governments each have their own. The *announced* RET state of play in Australia now is as follows (renewables as a % of total electricity power generation):
- **National RET: 23.5% by 2020.**
- NSW 'RET': state-wide, 'zero net emissions' by 2050 (ie, a target covering more than electricity).
- Victorian RET: 25% by 2020 and 40% by 2025 (and 'zero net emissions' by 2050?).
- Queensland RET: 50% by 2030.
- WA RET: 23.5% by 2020 (ie, the national RET).
- SA RET: 50% by 2025.
- Tasmanian RET: 100% by 2022.
- ACT RET: 100% by 2020.
- NT RET: 50% by 2030.

Some of these targets are legislated (eg, the national target and Victoria's). Others (eg, Queensland, South Australia and the ACT) are 'aspirational'. The national RET, for one, is not supported by all political parties.

The national RET is the lowest common denominator. States either match it (WA), or are more 'ambitious'.

Only two states – Tasmania and South Australia – are quite close to, or perhaps have achieved, their ambitious RET targets. These outcomes reflect very different situations:

- For Tasmania, its long-standing hydro power resources give it a renewables endowment advantage.
- For South Australia, a rush into solar and, especially, large-scale wind power, has been the cause.

The near-achievement of RET power generation objectives in Tasmania and South Australia relies on fossil-fuel back-up from the NEM (through Victoria), when hydro fails (eg, due to drought), or there's no wind, via:

- The Basslink undersea HVDC interconnector between Tasmania and Victoria.
- Mainly, the Heywood interconnector between South Australia and Victoria.

When Tasmania and South Australia have surplus hydro or wind power, they export it to Victoria via these interconnectors (eg, to meet Victorian or other peaking power demand). That's how the NEM should work.

When the interconnectors themselves malfunction or are shut down, all back-up bets are off.

The high share of renewables in Tasmania and South Australia has caused major power supply problems.

Drought, plus problems with the Basslink cable, saw Tasmania directly importing fossil fuels for power.

Excessive wind shutting down wind farms, storms bringing down transmission lines, plus shutting-down of the Heywood interconnector when South Australian demand threatened to overload it, blacked out that entire state in September 2016. Further supply problems, attributed to closure of coal power stations and non-operation of local gas power plants, have been evident. Imported diesel is now a back-up source there.

'Sleight of hand' is needed for delivery of the more ambitious announced state/territory RETs. Those for the ACT, South Australia, and Tasmania, for example, currently depend on cross-border 'deals' to use other states' renewables, or other states' (mainly fossil fuel) power sources as back-up.

Their *measured* state/territory-specific GHGs cuts mean more emissions, less GHGs cuts, for other states.

At present, such cross-border 'deals' are needed for reliability, even if they don't deliver affordability.

Reality #4: Large individual state renewables generation targets require interstate back-up.

The cost of renewables as a proportion of total NEM costs has been estimated by the ACCC and others.

Attachment A summarises recent estimates. As explained there, I think 'official' cost estimates substantially understate the cost of renewables, both in a static and a dynamic sense. They overstate other cost sources.

Two intrinsic features of renewable energy sources affect both affordability and reliability.

The first is *uncertain intermitt*ency.

The second is *low energy density*.

The next three parts of this booklet deal with these problems.

5. What's wrong with renewables #1: uncertain intermittency

Renewables (solar, wind, hydro) generate power when the sun shines, the wind blows, or water is available.

We can't control the weather, affecting sun or wind. Storing water for hydro is subject to droughts.

Renewables only supply power when weather or water say they can. Daily or longer supply cycles apply.

Electricity demand also has cycles: daily, weekly and longer. There's base-load and peaking demand.

The cycle for renewables power *supply* is not synchronised with the cycle for human power *demand*.

Renewables power is *intermittent*, and may not be produced, or produced enough, exactly when we want it.

In contrast, fossil fuels supply power pretty much when we want it. Intermittency is not an issue.

The problem is worse. Weather and drought are *uncertain*.

We can’t be sure when, or how much, the sun will shine, or the wind will blow, or dams will be full.

Renewables’ supply is *uncertainly intermittent*. Humans demand *reliable power supply certainty*.

Reality #5: We can’t control renewables’ supply. That’s up to the weather and water.

There’s another problem for centralised electricity grid systems with significant renewables supply.

Big fluctuations in renewables supply into the grid can disrupt both voltage (240 volts) and frequency (50 hertz). Synchronous grids must neutralise these disruptions. Otherwise the grid suffers damage (eg, transformers burn out) and/or end-users’ appliances are damaged (eg, computers fry).

Neutralisation requires new investment. That’s costly, but cheaper than replacing grid transformers, etc.

Reality #6: Intermittent power is a threat to grid stability without countermeasures.

6. What’s wrong with renewables #2: illustrating solar power intermittency

The impact of power supply intermittency can be illustrated using the daily cycle for solar renewables.

Similar conclusions, over cycles usually longer than a day, apply for wind and hydro power.

Power supply basics

Power can be measured in, say, kilowatts (kW), multiplied by hours supplied (kWh). Multiples can be expressed in megawatts (mW and mWh), or larger metrics.

Assume a base-load requirement of 100kW, every hour, 24/7. That’s 2,400kWh every day.

Generation *capacity* measures maximum generation possible; power *dispatched* is what’s actually delivered.

Fossil-fuelled base-load plant can generate the required power dispatch all the time if it has a capacity equal to that requirement (in our example 100kW). Indeed, continuous operation of such plant is usually most cost-effective. As we’ll see later, RETs can undermine this efficient operating mode.

Intermittent renewables can only deliver the daily 2,400kWh power required if generation/storage capacity is some ***multiple*** of the assumed 100kW fossil-fuelled power capacity. Here’s an example explaining why.

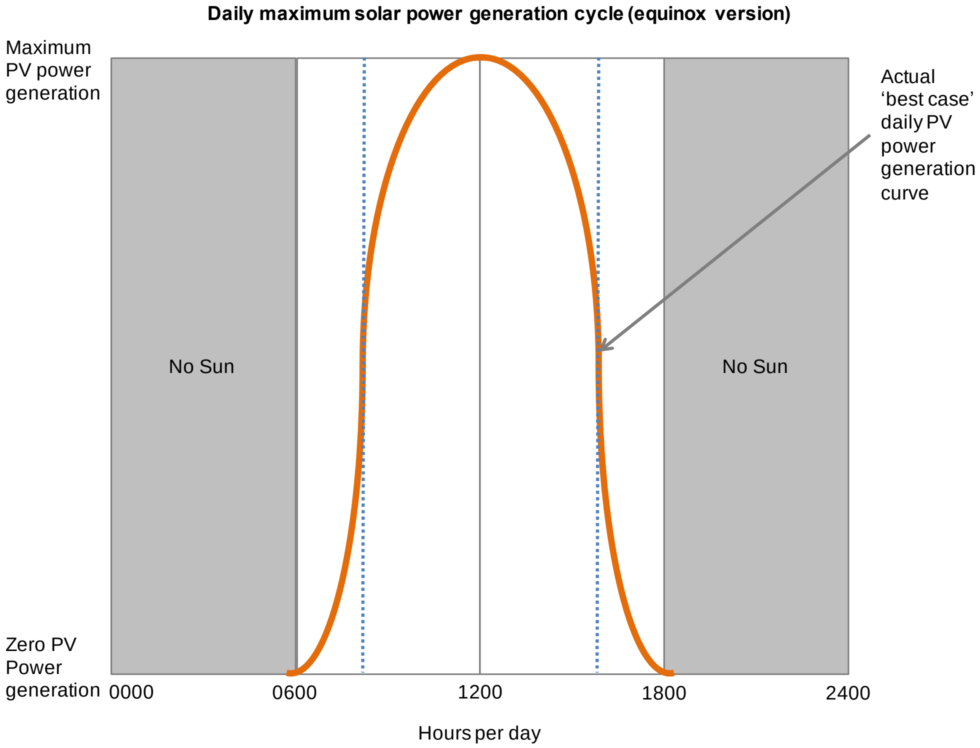
A simplified solar power scenario

Reality is more complex than the following example. But it demonstrates the basic point.

Assume no clouds, fogs or rain, and the same light intensity every day. This is a ‘best case’ solar power scenario (albeit probably not good for hydro!). Assume an ‘equinox’ period (day and night each 12 hours).

Daily solar power generation is illustrated in the diagram below.

‘Maximum PV power generation’ (the vertical axis) is 100kW.



The area of the 24-hour rectangle is our daily 2,400kWh requirement (24 hours x 100kW). The area under the orange bell curve is actual solar power generated each day.

12 hours have no sun. For the 12 daylight hours, the sun's intensity rises from zero to a maximum and then falls back to zero. Averaged, about half the daylight hours deliver 100kW power; the rest nothing.

In this scenario, how can solar power deliver the 2,400kWh needed each day? More capacity, and storage.

We need about *four times* the generating capacity for solar compared with a fossil-fuel plant. One-quarter of that is used as generated. Three-quarters must be stored for use when the sun is not shining at all (two-thirds of that) or when the sun is not shining strongly enough (the remaining third).

In total, we need *seven times* fossil-fuel generation capacity: *four times* as solar power generation, and *three times* as storage of some sort. (This ignores some solar panel, and all storage efficiency, losses.)

Solar power requires much more generation capacity than fossil-fuelled plant. It also requires storage capacity for dispatch when the sun is not shining, or not shining strongly enough. That's expensive.

The real world is worse

This scenario assumes an equinox daily sun cycle. What if solar power has to cope with the *least favourable* sunlight days each year? These vary by latitude, but they point to the location-specific winter solstice.

The ACT's winter solstice day is about 9 hours and 47 minutes. The night is about 14 hours and 13 minutes.

With no clouds, rain, fog, and unchanged light intensity, maximum solar generation capacity in the ACT averages a bit under 5 hours, with a bit over 19 hours requiring storage. Nearly *five times* the generation capacity of fossil-fuelled plant, plus nearly *four times* in storage capacity, is needed to do the same job.

Larger solar generation and storage multiples than in the 'equinox' case add to costs.

The further south, the larger this winter solstice effect.

The further north, the less so.

If assumptions about no cloudy, rainy and foggy days, and light intensity, are relaxed, the required solar generation/storage capacity multiples, and costs thereof, increase even more.

What about peak demand?

Daily and seasonal power demand cycles add peak demands to base-load. These include morning and evening peaks, plus different summer and winter demands (cooling and heating). More capacity is needed.

Generation/storage capacity multiples for solar, relative to fossil-fuel peaking supply, depend on how much demand peaks coincide with solar generation peaks.

In winter, demand peaks occur mainly when the sun is not shining, or shining very weakly.

Using solar generation to meet winter demand peaks increases required generation/storage capacity multiples relative to fossil-fuel capacity (eg, gas peakers).

What about wind, hydro and thermal solar power?

Wind, hydro and thermal solar renewables are also intermittent, but usually with longer cycles than solar.

The longer the non-power generation period in their cycles (no wind, no stored water, no sun/molten salt) the larger the generation/storage or other back-up capacity required.

A large grid, via spatial variations in renewable generation, can reduce required capacity multiples.

What about ‘pumped hydro’ (most recently, the mooted ‘Snowy 2.0’)?

This idea is old (Snowy 1.0). It might make sense (*ignoring* pros and cons of the initial capital investment) if arbitrage is possible between cheap base-load power in the small hours of the morning to pump water uphill, to be released (say) during peak power demand in the afternoon/evening of the following day or later on.

This model has (sort of) ‘stacked up’ relying on cheap ‘off-peak’ fossil fuels for pumping water uphill. Without such cheap back-up, pumping efficiency losses (between 10% and 30%?) make this a non-economic option.

What if pumping water back to the upper storage dams (even with Snowy 1.0) uses intermittent renewables?

Dispatching power as generated is cheaper than dispatching it after it has been stored/discharged first.

‘Pumped hydro’ would be pumping water uphill when the sun is shining strongly or the wind is blowing strongly (so other renewables are available at lowest cost to power the pumps). That increases re-charging competition with other renewable energy suppliers in their own generation re-charging/storage phases, competing with *their* generation/storage/discharge/dispatch cycles. Could this shrink arbitrage margins?

Could ‘pumped hydro’s’ basic cost arbitrage justification transform it from a peaking power supply complement (as now) to a renewables power re-charge demand competitor? What increased cost ensues?

The grid’s generation/storage renewables multiple could be further increased compared with fossil fuels.

Reality #7: Intermittent power multiplies the cost of generation and adds storage costs

These costs of multiplied capacity are complicated by the second renewables feature: low energy density.

7. What’s wrong with renewables #3: low energy density

Energy density affects generation and storage. With renewables, we need more of both. We need batteries.

What’s a battery? They’re everywhere!

We all know what batteries are, right? There are little cylindrical, rectangular, and pill-shaped ones. We put them in torches, remotes, mobile phones, tablets, laptop computers, etc. Bigger ones are used in cars. Still bigger ones are used in off-grid homes, and homes on the grid. Industrial-scale ones are used, too.

They’re modern versions of the ‘voltaic pile’, invented by Alessandro Volta and others around 1800.

There are other batteries. Some water heaters are batteries. Rainfall stored at a higher level can drive generators as it flows to lower levels. We can recycle water between higher and lower dams to supply renewable energy (pumped hydro). The sun can melt salt to store heat energy to drive generators.

But Volta and co. were latecomers. Natural battery power (not just electric eels) has been with us for ages.

Over millions and billions of years, nature has produced huge batteries spread all around the world.

Photosynthesis plus decay plus geological storage manufactured huge batteries available to be discharged. We call them fossil fuels, now with a pejorative tone. Exploding stars over the eons disgorged heavy radioactive elements, producing terrestrial nuclear fuel batteries. These have a mixed reception. We're happy to use nuclear fusion (called solar power), provided it's sourced 150 million kilometres away in the sun (and very diffuse when it gets here). Wind power depends partly on solar temperature differences.

Some batteries are discharged fully with one use. Others can be used more than once.

Wood's a battery, when burned. So's food, when consumed. Both are renewable.

In general, batteries store energy for use later. They're ubiquitous.

Actually, life couldn't exist without them.

Extracting energy: energy density realities

How efficient are different types of batteries/energy sources? A key metric is 'energy density'.

Broadly, energy density is a measure of how much energy/power you can stuff into how small a weight/volume/area. This can be used to rank alternative sources of energy.

Converting matter into energy is best, as Einstein worked out ($E=mc^2$ and all that). Anti-matter is top of the pops because, combined with matter, all of both are converted to energy. But anti-matter is a bit like 'unobtainium' in the movie *Avatar.* We can't get it or use it, at least at scale.

For currently-obtainable terrestrial sources, nuclear energy is the most energy-dense source. It converts a very small amount of matter into huge amounts of energy, as per Einstein. We're trying to develop cold fusion. But fission power currently is best (for peaceful purposes anyway).

This can be thousands of times (plus) more energy-dense than hydrogen and fuels like oil and gas, coal, charcoal and wood.

Fossil fuels can be 40 to 50 times (plus) more energy-dense than man-made batteries.

Battery technology is improving. Lithium-based batteries are more energy-dense than lead-acid batteries.

Renewables like solar, wind and hydro are by far the least energy-dense power sources. They are very diffuse, not concentrated. They require very large areas (solar and wind) and/or large volumes (hydro) for collection.

Measuring the differences involves a blizzard of different metrics. I'll leave them to qualified physicists.

But to illustrate, I've read statements like the following:

- Gasoline is one billion times more energy dense than wind and water power, and ten quadrillion times more than solar radiation.
- To store the energy contained in 1 gallon of gasoline requires over 55,000 gallons of water to be pumped up 726 feet (assuming 90% recycling process efficiency).
- Apple's 500,000 square foot iCloud data centre (an energy-dense storage facility) would require about 6.5 square miles of solar panels to power it.
- Using wind to fuel the Facebook data centre would require nearly 11 square miles of wind farms. This is about half the size of Manhattan Island or about eight times the size of New York's Central Park.

Basic physics tells us energy density is maximised using nuclear power.

Fossil fuels come a distant second, but still far ahead of renewables.

A couple of points on man-made batteries are in order.

One-use batteries beat rechargeable batteries. Recharging degrades battery efficiency.

One-use nuclear batteries can last a long time, have small volumes and modest weight (eg, those powering the still-going 1977 *Voyager* and the 1997-2017 *Cassini* space probes). While not as good as nuclear power, fossil fuel batteries can deliver much energy from relatively modest volumes over a short period.

Rechargeable batteries have different cycle tolerances that limit usability and battery life.

Lead-acid batteries can't be discharged much before the process greatly reduces their effective life. Lithium-based batteries are much better at cycling from low remaining charge to full charge on a regular basis, as we know from our mobile phones, etc. (But note Apple's current agonies about charges it has slowed down older, degraded batteries in products like its iPhone.)

Crucially, all rechargeable batteries require another source of energy (with its costs) to recharge them. In Australia, that's mainly coal-fired power plants.

Reality #8: Nuclear power is by far the most energy-dense source available

Our global warming debate has ignored energy density

For decades, we've debated energy and greenhouse gas emissions, energy and local pollution, energy and land and water appropriation and/or degradation, energy waste disposal and storage, and the like.

The conservation argument against energy-dense fossil fuels used to be that supplies would run out ('peak oil', etc). We're still waiting for 'peak oil'; still longer for 'peak gas' and 'peak coal'.

Now, apparently, we can't use *known* fossil fuel deposits. That would increase global warming, local atmospheric pollution, etc. They can't be *allowed* to run out. Instead, they must be left in the ground.

Global warming concerns have driven politicians to reverse historical trends raising living standards. Energy-dense power must be abandoned. Energy-diffuse power, or none, are needed to reduce GHGs.

Politicians assert taxpayers must, (and here they do), subsidise this switch.

Energy density *per se* hasn't got much consideration at all.

Emissions reduction – but only via lower energy density – dominates the political media.

Will voters accept the affordability and, quite possibly, reliability, consequences? We may soon know.

Low energy density supply is spread out. High energy density equipment (demand) is getting more compact

The low energy density of renewables mean they take up much more space, more volume, more weight, (or all three), than nuclear or fossil fuels generating the same power.

This weighs heavily on use of renewables for transport. For example, aircraft and cars are designed to minimise weight to enhance performance and economy. Batteries are relatively heavy (albeit getting lighter).

I've read some examples of how this applies. Here's one:

- The maximum take-off weight of a Boeing 737-700 is about 78,000 kilograms. This includes about 20,500 kilograms of jet fuel. Replacing that fuel with lithium ion batteries would require about 1,600,000 kilograms of batteries – a battery pack weighing about 21 times as much as the aircraft.

For electricity, we already see the large areas taken up by large-scale solar plants and wind farms.

We can't see the puny power they generate compared with much more compact fossil fuel plants.

And we can't see the cost of producing those renewables plants. I'll return to costs later.

We also cannot see the GHGs emissions involved in producing solar panels, wind turbines or hydro dams and turbines.

These are far from zero, involve considerable mining, cement and construction inputs, and, especially for solar panels and wind turbines, have quite finite lives, raising new investment and disposal issues.

Renewables and man-made batteries are much less energy-dense than nuclear and fossil fuel power sources. This disadvantage, *as well as* intermittency, must be offset to produce the same power:

- The capacity and space required for reliability-equivalent renewables generation plus storage is *many multiples* of that required for nuclear or fossil fuel power.
- These capacity multiples increase as renewables' market share rises.

Here's one more topical energy density example:

- Could an equivalent-power, solely renewables-fuelled, electricity generation/storage plant be installed, *whatever its cost*, within the footprint of the 2,000 mW Liddell coal-fired power station?
- With current technology, I don't think so.

Reality #9: Low energy density multiplies required generation and storage capacity

More generally, especially through RETs, *politics* is driving a supply-side shift towards lower energy-density. At the same time, technology, via increasingly-pervasive, numerous and more compact (energy-dense) computer technology, is driving an overall demand-side shift towards more electricity-hungry equipment.

Here are some more general examples:

- The global ICT system includes everything from smartphones to laptops to digital TVs to the vast and electricity-thirsty computer-server and data farms that we call 'the cloud'.
- Some estimates suggest that the ICT system now uses well over 1,500 terawatt-hours of power per year. That's over 10% of the world's total electricity generation or roughly the combined power production of Germany and Japan.
- It's more than the amount of electricity used to light the entire planet in 1985. We already use over 50% more energy to move data than we do in global aviation.
- The ICT system is largely on all the time. From computer trading floors or massive data centers to your own iPhone, there is no off period. That means a constant demand for reliable, dispatchable electricity. As 'the cloud' grows bigger and bigger, and we put more and more of our devices on wireless networks, we'll need more and more electricity.
- As the 'network of things' expands, the same conclusion will apply there too.
- So-called 'crypto-currencies', notably Bitcoin, apparently are very heavy electricity consumers.

How much energy smart phones, tablets, computers, etc, are using is not immediately obvious to the user. The electricity used to charge their batteries is often produced via centralised, remote, power grids. For our cars, the immediate cost of petroleum products reminds us we're consuming energy and paying for it. The digital economy's energy requirements are less obvious, but we still pay electricity bills later on.

There is a market collision on energy density under way. There seems no great concern about higher- and higher-density developments on the demand side – most seem to think it's great. But policy is driving the supply side in the opposite direction: more electricity from lower-density intermittent sources.

To misquote the title of Kev Carmody and Paul Kelly's great song: *'From little chips, big watts grow'.*

Reality #10: Energy density issues are driving us to a policy supply, technology demand, collision.

8. Renewables, reliability and affordability: the costs of back-up

Space and volume requirements for renewables compared with alternative fuels

For Australian electricity, some argue we have plenty of space, sun and wind (somewhat less so for water). The extra space, or volume, or weight, required for renewables therefore is of no consequence.

Economists would disagree:

- On space, volume or weight issues, there's no 'free lunch': cost-benefit analysis is still needed.
- For affordability (assuming the same reliability) the cost of renewables, properly measured, is needed.

The large areas, volumes or weight required for fossil fuel-equivalent renewables generation and storage capacity might be of less concern in remote areas than in congested urban areas. But what are the opportunity costs of alternative land uses?

Remote arid country might seem an Australian 'free lunch', but this should be assessed. Even there, surely green groups would want to evaluate the land's 'eco-system services' as part of any cost-benefit analysis?

In all remote supply cases, the costs of required extra power transmission investment needs to be added.

Competition for space and volume between alternative uses in urban areas is more intense. Rooftop solar panels might be the least congested, but even here 'over-shadowing' restrictions (and their costs) apply.

What does renewables generation and storage cost compared with fossil fuels?

How do we measure the cost of supplying electricity?

The 'levelised cost of electricity' (LCOE) is a widely-used metric. Roughly, it is defined as:

> *the average total cost to build and operate a power-generating asset over its lifetime divided by the total energy output of the asset over that lifetime. The LCOE can also be regarded as the average minimum cost at which electricity must be sold in order to break-even over the lifetime of the project.*

It's claimed LCOEs can be calculated for different fossil fuels and renewable energy sources, and compared.

Such statistics exclude important cost factors, such as:

> *wider system costs associated with each type of plant, such as long distance transmission connections to grids, or balancing and reserve costs. These items can be explicitly added as necessary depending on the purpose of the calculation.*

Can LCOEs (say per megawatt-hour) provide accurate comparisons between (continuous) fossil fuel electricity and (intermittent) renewables? Given sections 5 – 7 above, the answer, clearly, is 'no'

The LCOE definition above excludes, for example, 'reserve costs'. Assuming such costs cover consequences of intermittency, the *practical* question then is: of what use is the LCOE definition *at all*?

- The LCOE definition noted above makes no distinction between continuous and intermittent production. Having the same lifetime total energy output in the denominator of LCOEs is sensible. It's an 'apples versus apples' *power supply* comparison. But for the *power cost* numerator, lifetime costs to build and operate power assets makes no distinction between those producing power continuously or intermittently. These supply characteristics have big effects on affordability and reliability.
- Comparing fossil fuel supply with renewables supply using 'standard' LCOE measures biases cost comparisons in favour of renewables. Reliability is ignored, and reliable affordability suffers.

Attachment B shows how to make LCOE measures reliability-comparable across continuous and intermittent power sources. The example used compares continuous coal-fired power and intermittent solar power.

It shows 100% solar generation is competitive with 100% coal generation only if the cost per megawatt for solar generation is no more than 25% of the corresponding cost for coal. That ignores solar storage costs.

Why? Because all of the 24 hours of solar power supply must be generated in 6 hours (75% of which must then be stored), rather than spread evenly over 24 hours. Solar requires 4 times more generation capacity.

The solar power cost impediment versus coal is even larger. As noted near the end of Attachment B, additional costs (eg, for battery storage, grid stabilisation, bad weather, etc) must be added for solar power. Its cost per megawatt-hour must be even lower than 25% of coal costs.

Incidentally, the adjusted LCOE measures proposed in Attachment B do not add back the ultimate costs of implicit or explicit subsidies received by renewables (eg, under RET or feed-in tariff schemes).

Reality #11: Levelised cost comparisons are strongly biased in favour of renewables

Blending solar power and coal power: adjusted levelised cost comparisons

Attachment C builds on Attachment B by considering different blends of solar/coal power: 0%/100%, 25%/75%, 50%/50%, 75%/25% and 100%/0%.

The examples show that as the share of solar power in total supply increases, the competitive cost hurdle faced by solar power increases:

- from cost per megawatt-hour parity for a 25% solar power share;
- to solar hourly costs no more than 50% of coal costs for a 50% solar power share;
- to solar hourly costs no more than 33.333% of coal costs for a 75% solar power share;
- to solar hourly costs no more than 25% of coal costs for a 100% solar power share.

The solar power cost impediment versus coal is even larger than that. As noted near the end of Attachment C, additional costs (eg, for battery storage, grid stabilisation, bad weather, etc) must be added for solar power. Its cost per megawatt-hour must be even lower than each of the scenario numbers shown above.

Reality #12: The affordability hurdle faced by solar power increases with its market share

This section ignores possible costs arising from less efficient intermittent use of coal generation plants.

9. The effects of RETs on fossil fuel costs: the other blade of the RET scissors

RETs are intended to cut GHGs like a pair of scissors. They have two policy blades.

Explicitly or implicitly, they subsidise dispatch of renewables.

They also increase fossil fuels' unit power costs as their dispatch times shrink.

Attachment D adds to Attachment C a simple example of this dispatch time 'squeeze' affecting coal power.

Minimum daily costs spread over fewer hours increase dispatch costs. Net effects of (1) increased wear and tear due to intermittent plant operation *less* (2) savings from reduced daily coal inputs must also be covered.

Cutting dispatch hours per day raises hourly costs, as a result of blending solar with coal power supply.

Will increased wear and tear costs be larger than coal input cost savings? Two scenarios are conceivable:

- For smaller solar power market shares, it may be more efficient to keep coal generators running. In this case extra coal plant wear and tear costs might be minimised, as might coal input cost savings.
- For larger solar power market shares, coal generators might be operated more intermittently, adding wear and tear costs but saving on coal inputs.

Especially for *existing* coal-fired generators, capital costs might already be 'sunk' costs. Wear and tear costs may come later in the effective life of the plant and might be smaller. Coal input costs might be relatively low because coal is still a cheap power plant consumable. The net cost consideration might go either way.

But for *new* coal plant (if any) about to come into production, the net cost might swing from a saving (from less coal use) to a net cost (due to increased wear and tear on coal plant because of intermittent use of new plant). If so, solar power may have an even larger cost mountain to climb than suggested in Attachment C.

Reality #13: Solar power's affordability hurdle may increase even more as coal declines

10. Some cost numbers

Sections 8 and 9 can be fleshed out by adding cost per megawatt-hour estimates for solar and coal power.

Robert Bryce[2] has published estimates of electricity costs for generation entering service in the United States in 2018.[3]

These are expressed in US dollars per megawatt-hour for different energy sources.

Amongst these he states:

- Solar photovoltaic powered generation in 2018 will cost US$144.30.
- Coal powered generation in 2018 will cost US$100.10.

He also states:

- Natural gas powered generation in 2018 will cost US$65.60
- Nuclear powered generation in 2018 will cost US$108.40.
- Solar thermal powered generation in 2018 will cost US$261.50.
- Hydroelectric powered generation (I think natural, *not* pumped, hydro) in 2018 will cost US$90.30.

Attachment E summarises the effects of his solar and coal cost estimates on the competitiveness of each.

In summary, for cost parity with coal at US$100.10:

- For a 0%/100% solar/coal power blend, power costs US$100.10.
- For a 25%/75% blend, solar should cost US$69.47 *less* net costs of intermittent coal operation, not US$144.30.
- For a 50%/50% blend, solar should cost US$34.72 *less* net costs of intermittent coal operation, not US$144.30.
- For a 75%/25% blend, solar should cost US$23.15 *less* net costs of intermittent coal operation, not US$144.30.
- For a 100%/0% blend, solar should cost US$17.36 *less* net costs of intermittent coal operation, not US$144.30.

On any likely estimate of the net cost of intermittent coal plant operation, intermittent solar power supply, whatever the blend with coal power, is likely to be much more expensive *on a reliability-equivalent basis.*

There are three forces combining to produce this result:

1. On a per megawatt-hour basis, at present, in the USA, solar costs more ($144.30 versus $100.10).
2. As the proportion of solar power increases above 25%, extra solar generation capacity is needed to generate (and then store) power during the assumed 6 hours each day of maximum sunlight. This renewables generation back-up adds to total blended power system costs. Storage costs are extra.
3. As dispatch time for coal power falls below 24 hours each day, recovery of daily costs needed for plant viability requires hourly dispatch costs to increase to offset the reduction in hours dispatched. This dispatch time 'squeeze' applies in solar/coal power blends. It increases total blend cost above continuous operation of coal-fired plants.

Even if per megawatt-hour solar and coal dispatch costs are the same, the second and third forces just noted increasingly make 100% coal power relatively more affordable.

The solar power cost impediments versus coal are even larger than these estimates. As noted near the end of Attachment E, additional costs (eg, for battery storage, grid stabilisation, bad weather, etc) must be added. Solar power's cost must be even lower than in each of the scenarios shown above.

Reality #14: If power affordability is the question, renewables aren't the answer

11. The National Energy 'Guarantee'

On 17 October 2017, the current Federal Government announced a National Energy 'Guarantee' (NE'G') for *affordabl*e, *reliable* electricity, consistent with Australia's existing promises about *reducing our GHGs*.

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[2] *Smaller faster lighter denser cheaper*, Robert Bryce, published by Public Affairs, New York, 2014, page 241.

[3] As noted, these are $US cost estimates for new plant entering service in the USA in 2018. Costs for different energy sources can vary across countries. For example, gas prices may be higher in Australia. Coal prices may be lower. Variations in the costs of different energy sources generally will not affect the broad conclusions against renewables in this booklet. The costs of multiplied renewables generation capacity, plus multiplied generation-equivalent storage, will swamp any LCOE-based energy cost variations. Readers can plug their own preferred cost estimates into the formulae in Attachment E to test/confirm this statement. Specific rankings presented in section 17 below may vary, but not the broad conclusions about the high reliability-equivalent cost of renewables.

This reflected an eight-page 'advice' document from the Energy Security Board (ESB) on 13 October 2017.[4]

Of itself, the NE'G' guarantees *nothing* about any of the three policy objectives mentioned.

It's a largely specifics-free framework for negotiation with the states and territories through the Council of Australian Governments (COAG) in the first half of 2018.

At this stage:

- The current NEM reliability standard of 0.002% outages per region is not explicitly reconfirmed.
- The reliability and emissions reduction contract commitments on retailers are to be determined.
- Reduced electricity costs are to be determined.

Policy ends and policy means

Of the three NE'G' objectives, affordability and reliability are simultaneously achievable. We've had them before. They were a foundation for our international comparative advantage. Fossil fuels did the job.

Now we're adding reductions in GHGs. We're also ruling out low-emissions nuclear power, and some states are banning exploitation of some gas deposits even though these have lower emissions than coal.

The GHGs reduction objective is based on RETs: renewables like solar, wind and hydro power.

As sections 5 – 10 above show, for all sorts of reasons, *on a reliability-equivalent basis*, solar power is more expensive than coal. Similar conclusions apply for wind and new hydro power.

The *current* NEM reliability standard, plus renewables to reduce GHGs, cannot make electricity cheaper:

- This reflects *Economic Reality #1: Trade-offs between the three energy objectives are unavoidable.*
- Also *Economic reality #3: Alone, if RETs cut emissions, they also cut reliability, and/or affordability.*
- And *Economic reality #7: Intermittent power multiplies the cost of generation and adds storage costs*.
- And *Economic reality #9: Low energy density multiplies required generation and storage capacity*.
- And *Economic reality #13: If power affordability is the question, renewables aren't the answer*.

The trade-off between affordability plus reliability, and cutting GHGs, is inescapable. It's physics.

What to do?

- We can reduce reliability, or reduce affordability, or increase GHGs, or all three.
- With the current NEM reliability standard, we must choose less affordability or more GHGs.
- If we want cheaper power and the same GHGs reduction, reliability must suffer.

All three choices are options via COAG negotiations on the NE'G'.

One practical question

NE'G' detail is to be fleshed out, finalised and COAG-agreed. Practical questions arise now. Consider one.

The ESB advises electricity ***retailers*** should have contracts with electricity wholesalers that comply *both* with reliability *and* GHGs reduction standards (to be determined). Why retailers? Why not generators?

How will this work?

Retailers sell electricity supply to meet customers' demand at all times. They don't sell reserve capacity (well, any reserve capacity costs are opaque and smeared across supply charges and consumption tariffs).

Assume the NEM reliability standard (0.002% outages in each NEM region) is confirmed. Suppose a specified portion of retailer supply must be from renewables to meet our national 23.5% RET.

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[4] *ENERGY SECURITY BOARD ADVICE ON A RETAILER RELIABILITY, EMISSIONS GUARANTEE AND AFFORDABILITY.*

What supply would any retailer be required to contract to meet demand? Up to 100% (for reliability) plus 23.5% (for emissions cuts)? If this doesn't apply to all regions, doesn't it apply on average across Australia?

Anything above 100% of expected demand means an explicit, large, new reserve capacity obligation on retailers (in the first instance, anyway). From sections 5 – 10 above, that adds generation and storage costs.

Who pays for 'reserve capacity'? The customer. Whither (and wither?) affordability?

This underlines the tension between reliability plus affordability, and reducing GHGs.

Reality #15: A NE'G' imposing retailer 'guarantees' can reduce affordability

12. Charting a transition away from fossil fuels

We want cheaper, reliable, low emissions energy.

But we argue about how best to get all three.

Can we get to energy policy 'Dublin' from here?

Where is 'Dublin'? What's it like?

I define 'Dublin' as:
- Making progress supplying cheaper, more reliable, lower-emissions electricity.
- Ensuring that the first two of those objectives have at least the same policy importance as the third.

Some heavily emphasise the third objective. Others would delete it, given its global insignificance.

As costs and unreliability increase, average- and lower-income voters will opt for cheaper, reliable electricity.

For a collective view on where/what 'Dublin' is, assume *equal weights* for all three objectives.

Given 'Dublin', we must start from where we are now, and allow equally for all objectives as we proceed.

That requires us to preserve cheap, reliable existing power sources while allowing new sources to enter.

It requires us to deliver a declining emissions intensity mix as cheaper reliable sources come on line.

This seems not to be the transition path envisaged in the NE'G'. It won't get us to my definition of 'Dublin'.

Sure, the NE'G' transition is not yet detailed, but it probably involves higher costs and maybe less reliability.

If so, the NE'G' transition entails more power failure.

Reality #16: The NE'G' may exacerbate the 'trilemma'

13. Is killing coal fast an affordable transition option? Have governments chosen it anyway?

General answers

No and yes.

Three-word answers don't convey the detail.

Consider (i) existing coal generation, and (ii) new investments in coal.

For the former, plant owners need to assess the net costs of continuing operation versus closing down. This must weigh low coal input costs, and repairs and maintenance, against plant closure and/or sale.

If plant owners assess net present values (NPVs) from new non-coal generation investments, plus sale of existing plant, exceed those for keeping existing coal generation going, closure is the better option.

For new coal fired generation, the investment decision is the same. What delivers the best NPV?

Government policy and posturing affect these assessments.

For long-lived new power generation investments, expected returns dominate the spreadsheets.

When governments waffle about reducing emissions, impose and increase RETs or their like, and change their policy positions regularly, investors factor into their expectations uncertain future carbon prices over effective lives up to 40-50 years. Effective (usually opaque) subsidies for renewables are prominent, too.

These realities can have powerful investment effects.

When private finance institutions announce they will no longer lend for fossil fuel investment, and government-financed institutions target non-fossil fuel investments, these expectation effects are magnified.

My ‘no’ answer to the first question is negated by government and private lenders’ answer to the second.

Power costs for reliable supply are likely to increase.

If so, the ‘trilemma’ will continue.

Reality #17: Government policy statements, and private sector responses, extend the ‘trilemma’

The BHP position on coal

Apparently, BHP is about to leave the World Coal Association, the US Chamber of Commerce, and, in future, the Minerals Council of Australia (MCA). Why?

It argues:
1. The science of global warming should not be challenged.
2. For the ‘trilemma’, equal weight should be given to all three objectives.
3. Decisions on energy fuel input sources should be technology-neutral, and outcomes-focussed.
4. Governments should not ‘artificially’ favour one technology over another.
5. Energy policy should foster efficient allocation of energy resources.
6. MCA lobbying for ‘clean coal’, such as High-Efficiency Low-Emissions (HELE) plants, should cease.

This mixes-up sensible positions, and denial of energy policy biases in Australia. It should be challenged:
- The science of global warming *always* should be scrutinised, on the basis of the latest evidence.
- It’s nonsense in this, as in other fields, to assert ‘the science is settled’. It’s not. Remember Galileo?
- It might be (roughly) OK equally to weight affordability, reliability and lower emissions. We don’t.
- Australian policy concentrates on lower emissions, hitherto ignoring affordability and reliability.
- I agree energy policy *should* be technology-neutral. This gets lip-service in Australia, not adherence.
- Current policy favours/subsidises renewables, and actively penalises fossil fuels (via RETs, etc).
- Current policy ignores efficient allocation of energy resources. Affordability/reliability suffer.
- MCA lobbying for some can cause problems for other members. This association issue is common.
- It’s normal for an industry association to say nothing on policy issues dividing its membership.
- It’s not normal for these sorts of differences to be aired before resolution, with CEOs ‘resigning’.

What is the basis for BHP’s seemingly mixed-up position? I don’t know. But let’s look at its ‘book’ (to see if it’s talking that). I gather that, in 2017, BHP’s revenue sources are as follows (%share):

▪ Iron ore	38.0
▪ Copper	22.0
▪ Coal	20.0
▪ Petroleum	18.0
▪ Other (group)	2.0
▪ **Total**	**100.0**

Last time I looked, iron ore needs metallurgical coal to be refined into steel, etc. Ditto copper? Coal itself needs coal to extract? Ditto petroleum? BHP has a product portfolio mix that relies on fossil fuels – including coal – for extraction and refinement.

Why would BHP come out hard against coal? I don't know.

Two possibilities occur to me.

Both are due to government 'policy':

- Governments subsidise renewable energy. Energy companies become 'moths to the subsidy flame'.
- Politicians advocate 'closing coal'. Investors stop, and invest/advocate no further in/for coal.

But why would BHP, with one-fifth of its revenues coming directly from coal, oppose its expansion?

Is a high export share of BHP's revenue a reason? Why upset the locals if revenue is sourced offshore?

BHP earns most of its Australian revenue from exports. But why support substitution from local to foreign coal sources? Anti-coal advocacy here supports similar campaigns elsewhere, anyway.

Reality #18: BHP's position seems inconsistent.

14. 'Demand response' as a power failure solution

What is 'demand response'?

There are two notions of 'demand response':

- The first is medium/longer-term demand adjustment to higher power prices: price up, demand down.
- The second is emergency/short-term. Not enough supply? Cut demand to fit supply – right now.

The first is always there, but gradual, and related both to demand reductions induced by high prices, and, related to high prices, shifting to more energy-efficient equipment. I don't consider it further in this booklet.

The second involves power grid managers asking, telling, or forcing power customers to cut demand because total supply can't meet total demand in the next five minutes, hour, day, etc.

Bidding prices aren't allowed fully to balance demand and supply. Cuts to power quantity are used instead.

Short term 'demand response' is a euphemism for rationing. Why not be up-front about that? Politics.

Rationing is not new, even in the NEM. The NEM has a (high) regulated cap on prices, once called the Value of Lost Load (VoLL) and now called the Market Price Limit.

This price cap means the NEM does not balance demand and supply during demand spikes only by raising prices. The price 'cap' means, *in extremis*, the market is 'cleared' directly by cutting customers' demand.

This introduces another euphemism: 'load-shedding'. Load-shedding means those responsible for supply arrange for those demanding it not to receive some, or all, whether they are prepared to pay for it or not.

Is this a sensible solution to excess power demand? Is it efficient? Is it fair?

Very 'peaky' demand can overwhelm supply on a few extreme-demand days each year. This problem will get worse as we rely increasingly on weather-dependent renewables supply like wind and solar power.

It might be sensible not to invest huge amounts in capacity just to address these extreme days. That means reducing reliability. Accepting that, what are the alternative ways of balancing demand and supply?

1. Local, regional, state or larger blackouts: not a good idea, economically or politically.
2. Shorter 'rolling' blackouts spreading across regions: no choice, imposed by suppliers.
3. Power cuts for energy-hungry businesses: bad for industry competitiveness, jobs and incomes.
4. Selected customers (or all), are given a 'take it or leave it' price 'reward' for imposed power cuts.
5. Any or all customers are given an *optional* price incentive and can choose to accept power cuts or not.

We're familiar with options 1 – 3. We don't like them. Consumers suffer and industry competitiveness is cut.

Option 4 is a bit better, but *properly* valuing the cost of power cuts to customers is side-stepped.

Option 5 is best of this lot. Customers' acceptances reveal the marginal value of their power preferences.

Who pays for 'demand response'?

There's no 'free lunch'. Costs for all five options above must be paid by somebody.

- Option 1 smears supply cut costs arbitrarily across all blackout area customers.
- Option 2 does the same thing, albeit maybe more spread out over time and space.
- Option 3 targets businesses, jobs and industry competitiveness. It's then spread community-wide.
- Option 4 is a bit like options 2 or 3, but with bureaucratically-determined compensation paid by others.
- Option 5 is closest to a clean price-based market response to constrained supply versus demand.

Who actually pays?

- Under option 1, all customers pay.
- Under option 2, all customers pay.
- Under option 3, initially businesses, then employees, then communities (and their incomes) pay.
- Under option 4, some customers (a bit), and then all customers, or taxpayers more generally, pay.
- Under option 5, taxpayers or all power customers (if they finance the optional price incentive) pay.

None of these 'demand response' costs are advertised by politicians.

Politically, that's hardly surprising.

It's also wrong, if you believe in policy transparency.

Reality #19: In general, 'demand response' offloads supply failure costs to others

15. 'Contracting-out' supply as a power failure solution

So much for 'demand response' as a demand-supply balancing option. Could 'supply response' help?

In general, supply response can only work over the medium to longer term. I won't consider the pluses and minuses of supply privatisation in this booklet. I just note that the *act* of privatisation, rather than (i) the way governments selling such assets (understandably?) behave to 'puff-up' sales prices, and (ii) the subsequent competitiveness of the private markets so created, are more likely to be the culprits for any adverse results.

Privatisation of government-owned assets aside, 'contracting out' can involve:

1. Government incentives (appropriation of other users' funds) to finance installation of small-scale power generation systems. That's what 'feed-in' tariffs, and now, increasingly, battery subsidies, are about.
2. Government incentives via RET schemes to install large-scale renewable generation/storage capacity.

There's also an unstated policy 'incentive' inducing private provision of generation/storage capacity.

That is power failure itself: raising expectations that energy supply will be unaffordable and unreliable.

3. *Power failure* induces those who can afford it to take affordability and security into their own hands.

All three of these options are alive in Australia now. Option 1 is shifting from solar panels to batteries. Option 2 is thriving. Option 3 is up and running. We're all paying for all of them, one way or another.

Here are a few examples of option 3:

- In the ACT, a business called Solar Hub is advertising for residents to avoid 'bill shock' by installing solar panels. Rightly or wrongly, that's touted as an *affordability* option to avoid expensive grid power.
- The same business advertises solar plus battery storage installation as a *reliability* option to avoid the disruption of power blackouts. It's marketing a distributed power alternative to centralised grid failure.
- In South Australia, after the State-wide blackout in September 2016, the Energy Minister, Tom Koutsantonis, responded to complaints from BHP's Olympic Dam about power blackouts by asserting they should install their own back-up generation/storage capacity.

The markets for PV panels, batteries, and fossil-fuelled portable generators are rising strongly right now. That's an option 3 response to power failure.

The consequences of options 1 and 3, if not 2, for the centralised grid over time are not clear. Could the grid *itself* eventually become a 'stranded asset'? There's been talk about a grid 'death spiral'. Who pays for that? Who loses most? Probably lowest income groups. Whither (indeed, wither?) the NEM itself?

Could 'supply response' make things worse? On affordability, possibly.

Those paying for this because of concerns about grid affordability and reliability won't thank governments.

Reality #20: All versions of 'supply response' reflect power failure

16. Putting our national, state and territory emissions reduction efforts in a global context

Australia's share of global greenhouse gas emissions is less than 1.3% (and falling).

That's less than 5% of China's share (about 26%, and rising).

Consider a simple scenario involving Australia and China (ignoring USA, EU, India and all other emitters):
- Assume Australia cuts its emissions to zero by 2050 (in 32 years).
- Assume China records real GDP growth averaging 5% per annum over that period.
- Assume China halves its emissions intensity (emissions/GDP ratio) by 2050.

By 2050:
- Australian emissions fall from under 1.3% of the global total to zero.
- China's real GDP increases by 476.5%.
- China's emissions increase by 238.3%.
- China's emissions growth increases global GHGs at least 62% (even at 26% of global emissions).
- Our 'turning off the lights' efforts reduce them by less than 1.3%.
- Netting the China/Australia results out, global emissions increase by nearly 61%.

Suppose instead Australia maintains a 1.3% share of global emissions. In this case, the combined China/Australia emissions increase is around 62% by 2050.

Suppose Australia maintains a fixed *absolute amount* of global emissions. Its global share falls (say, roughly by half). In this case, the combined China/Australia emissions increase is still close to 62% by 2050.

In all of these scenarios, the range of outcomes from doing nothing to cutting Australian emissions entirely is a one percentage point difference in the *net increase* in China/Australia emissions. This allows nothing for the net emissions increase likely from the other 73% of global emitters.

At most, lower emissions as part of the 'trilemma' are a very small contributor to cuts in global emissions.

Reality #21: If Australia 'turns all its lights out', net global emissions still increase a lot

Should Australia do nothing?

Assuming anthropogenic global warming is real, the arithmetical reality is *global action* is needed.

Emissions abatement policy design must foster global action.

An anthropogenic cause – global emissions abatement policy design – is impeding global action.

Nearly a decade ago, I considered this policy design problem.[5]

If all countries reduce emissions at the same time and speed, a national emissions production focus is fine.

If different countries reduce emissions at different times and speeds, that focus actually undermines policy.

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[5] See Geoff Carmody, http://onlineopinion.com.au: *Effective climate change policy: the seven Cs.* Paper #1: *Some design principles for evaluating greenhouse gas abatement policies.* (July 2008.) Paper #2: *Implementing design principles for effective climate change policy.* (September 2008.) Paper #3: *ETS or carbon tax?* (October 2008.)

In fact, it's a policy incentive for countries not to take the lead, and for laggards to do nothing at all.

A production focus adversely affects competitiveness of leaders' exports and import-competing products.

Where countries act at different times and speeds, national emissions consumption should be the target.

Indeed, some countries have tried to 'carve out' so-called 'emissions-intensive, trade-exposed' industries.

These attempts have been partial approximations to a consistent national emissions consumption model.

The global focus on national emissions production has helped produce abatement policy failure.

If global warming is a problem, this is a global policy own-goal.

Policy makers could undo this mistake.

If they want to.

Reality #22: The national emissions production focus of abatement policies deters global action

17. Policy conclusions: some inconvenient realities

Diagnosis

We already have power failure. It's likely to continue.

We can expect less affordable, possibly more unreliable, electricity. We won't change global GHGs much.

It's worse.

The cause is anthropogenic: Australian energy policy own-goals.

It's worse again.

Politicians responsible for what the current Government dubs 'the trilemma' now claim to be able to solve it.

Will they? They've gone a long way down the wrong track.

How did they get into the current mess?
1. Australian politicians ignored the *basic physics* of different energy sources.
2. They ruled out *alternative energy sources* that could have helped, and opted for RETs.
3. Adverse market effects of these choices on power costs and reliability duly emerged.
4. They then actually 'doubled down' on both responses noted at 1. and 2.
5. They pushed *more* renewables, and *more expensive versions* (eg, Snowy 2.0), as the solution.
6. These people steadfastly ignored the First Law of Holes.

The First Law of Holes is: *'If you find yourself in a hole, stop digging'*.

With Australian energy policy, it seems, not a bit of it.

The light at the end of the tunnel needn't be an oncoming train.

If the 'trilemma' is anthropogenic, policy makers can reverse past policy decisions.

If they want to.

But to do so, they must absorb the lessons from past policy outcomes.

Policy options framework: the lessons of history

I think the following lessons should guide energy policy reform:

1. If legislation can't override laws of physics, allow for these laws fully in designing energy policy.
2. Renewable energy sources are both intermittent and uncertain. Policy should allow for this.
3. Energy density is a critical performance indicator. Policy should allow for this.
4. Affordability, reliability and lower GHGs point to energy-dense, dispatchable, lower emissions fuels.
5. Australia is less than 1.3% of global GHGs. Multiple state GHG policy targets make no sense.

Of course, energy policy decisions are in the hands of elected politicians, many of whom are in the 'doubling down' camp noted above. It's doubtful they will accept or absorb the lessons noted above.

In principle, however, energy policy development might proceed down one of two very different paths.

Policy option #1: More of the same, or more expensive more of the same.

The first path is more renewables, more expensive energy, and less reliability than we have now.

Along this policy path:

- Affordability is reduced, reliability may be as well, and direct GHGs reductions are small.
- Australia's international comparative advantage is further reduced as our energy costs increase.
- Shifting activity, jobs and living standards offshore may even increase global emissions (net).
- Australian living standards will be undermined.

Where's the sense in following this path?

The 'trilemma' becomes a trifecta.

Of failure.

Policy option #2: Switch to more energy-dense, dispatchable, lower emissions energy sources.

Learning the lessons from our past mistakes, a policy package promoting more affordable, reliable, lower emissions energy sources might proceed as follows. (Costs per megawatt-hour in US$ for 2018 are based on Robert Bryce.[6]) *Rankings ignore back-up costs associated with intermittency and low energy density*.

For *affordability*, we choose the cheapest energy sources. Bryce's top five for the USA are:

- Natural gas ($65.60)
- Onshore wind ($86.60)
- Geothermal ($89.60)
- Hydroelectric ($90.30)
- Coal ($100.10)

Natural gas is a clear cost winner. Nuclear power just misses the cut at $108.40.

For *reliability*, we choose continuous or dispatchable energy sources. In cost order, Bryce's top five are:

- Natural gas ($65.60)
- Geothermal ($89.60)
- Coal ($100.10)
- Nuclear ($108.40)
- Biomass ($111.00)

Natural gas again is a clear cost winner. No renewables make the cut because they are intermittent.

To *reduce emissions*, a transition to:

- Natural gas ($65.60) and then
- Nuclear ($108.40)

would minimise trade-offs between lower emissions versus affordability and reliability.

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[6] *Smaller faster lighter denser cheaper*, Robert Bryce, published by Public Affairs, New York, 2014, page 241.

Intermittent renewables are simply assumed to be emissions-free because the source of energy is assumed so. This ignores GHGs embedded in the production of generating and storage equipment, and disposal issues when plant is decommissioned.

Current policy favouring RETs is biased against affordability, and especially reliability, as policy objectives.

To eliminate this bias, Australian governments should:

1. Use nuclear fuels for peaceful power here. We already export them. It can be safe.
2. Reverse state bans on gas development. These increase power costs.
3. Phase out all RETs ASAP. On a *reliability-equivalent basis*, RETs are more expensive, not cheaper.
4. Require all power dispatch be on a *reliability-equivalent levelised lowest-cost basis* from now on.[7]
5. If we must price emissions, a comprehensive, uniform, national emissions consumption price is best.

On 1, opponents will cite accidents at Three Mile Island (1979), Chernobyl (1986), and Fukushima (2011).

What about the United States, France, Japan and other *current-technology* nuclear power users *today*?

The USA generates as much nuclear power as France and Japan combined. France is 75% reliant on nuclear power and is the largest net exporter of such power due to low generation costs. France is a nuclear back-up power source for Germany and other EU members. While cutting back, Germany is still 14% reliant on nuclear power, and about 43% on coal. While also planning to cut back (at least older generation plant designs), Switzerland is about one-third nuclear-reliant, plus, at present, about 55%+ hydro.

Australia is geologically stable, with large land areas relative to population, with nuclear source fuels.

Option 2 is obvious. Restricting local gas supply increases local expected gas prices, cutting affordability. Why can't Australian landowners get a cut of development revenues or profits? They do in the USA. Wind farm (and solar plant?) operators offer such deals here.

On options 3-5, this booklet argues renewables reduce affordability and reliability and do little to cut GHGs.

The transition path

We currently depend overwhelmingly on coal as our power source for electricity: black coal in NSW (and the ACT), Queensland and WA, and brown coal in Victoria. SA and Tasmania use back-up brown coal, too.

We cannot and should not change this overnight. Coal power in Australia is relatively cheap and provides reliable power (not least for base-load demand). It also fuels existing renewables' re-charging (eg, hydro).

In any sensible transition to natural gas and nuclear, our emissions intensity will decline while minimising damage to affordability and reliability.

This path won't *eliminate* the 'trilemma' (see *Economic reality #1* above).

It *will* make our energy policy much less a power failure than now.

Reality #23: We can't eliminate the 'trilemma'. We can and should make it less severe.

Attachment F presents a consolidated list of the 23 energy policy realities proposed in this booklet.

The policy debate context

International and local policy debates on energy and global warming have been unhelpful.

I'll end with two comments on the ranting passing for debate on global warming today. They're apposite.

The first is from Robert Bryce[8]:

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[7] Pending a full public review of NEM bidding rules, as a practical bidding approximation, a *reliability-equivalent levelised lowest-cost* bid to dispatch power might be defined as a bid valid for at least 24 hours. The ***generator-bidder*** would be required to stand in the market with a dispatch offer for a specified power quantity at the price nominated for one full 24-hour day. This would help to 'level the playing field' across all suppliers, while still allowing much higher peak demand offers to supply. See Figure 1 on page 26.

> *‘My position about the science of global climate change is one of resolute agnosticism. I’m not an ‘alarmist’ or ‘denier’. There’s no question that carbon dioxide is a greenhouse gas. What we don’t know for certain is the ideal concentration of that gas in the atmosphere. I can’t talk knowledgeably about polar vortexes, cosmic rays, ice cores, forcings, or aerosols. Nor can I be certain that the climate models being used are accurate. I’ve become bored by the arguments about ‘hockey sticks’, proper thermometer siting, and whether temperatures have levelled off in recent years. In my view, the media and the pundits are way too focussed on climate models and not nearly focussed enough on reactor, engine, and fuel cell models.*
>
> *Over the past few years, the discussion about climate change and carbon dioxide emissions has devolved into a hyper-partisan slugfest that’s obsessed with tribalism. ….*
>
> *I’m disgusted with the tribalism and the name calling. I am not interested in being part of anyone’s tribe. I am infinitely more interested in finding and exploiting the innovations that can help us surmount the challenges we face than I am in the endless accusations and name-calling generated by the cadre of self-appointed scorekeepers who spend their entire careers blogging about who might belong on Team Alarmist or Team Denier.’*

The second is from a novel by Michael Crichton about climate change[9].

These are the last words in his novel:

> *‘Everybody has an agenda. Except me.’*

Indeed.

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[8] *Smaller faster lighter denser cheaper*, Robert Bryce, published by Public Affairs, New York, 2014, page 236.

[9] *State of fear*, Michael Crichton, Harper Collins, London, 2004, *author’s message,* page 573*.*

Figure 1: A stylised illustration of the 24 hour-based bidding in recommendation 4

Figure 1A: Illustrating market-clearing price-quantity outcomes for base-load and peak demand

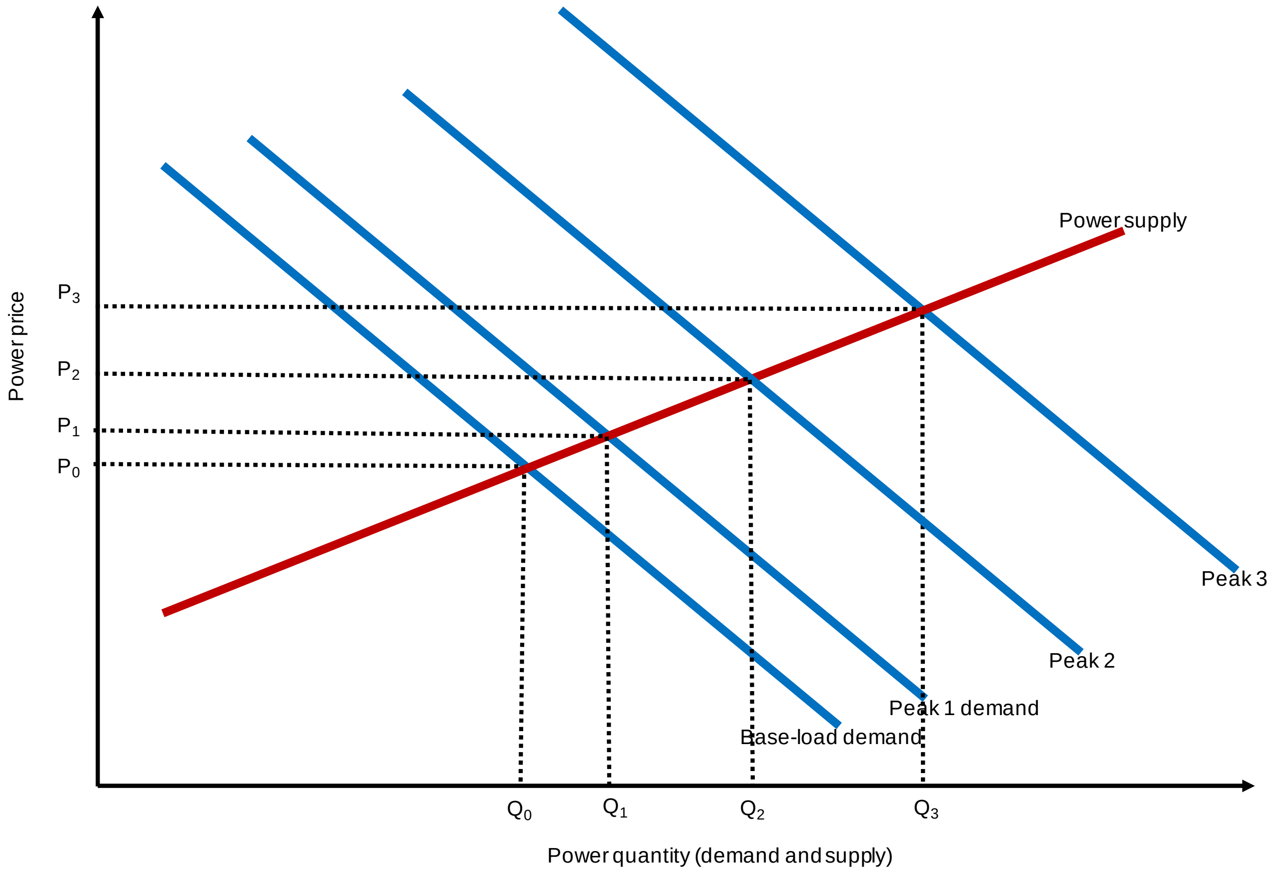


Figure 1A illustrates power market demand-supply balance for four NEM bidding periods:

- Baseload demand (market balance results in Q_0 dispatched at P_0).
- Peak 1 demand (market balance results in Q_1 dispatched at P_1).
- Peak 2 demand (market balance results in Q_2 dispatched at P_2).
- Peak 3 demand (market balance results in Q_3 dispatched at P_3).

For each of the four market scenarios illustrated, all buyers pay the same price and all generators receive the same price. There are producer and consumer surpluses for infra-marginal buyers and sellers. This is a standard product market result.

Figure 1A produces four price-quantity market-clearing results: base-load, peak 1, peak 2 and peak 3.

All bids to dispatch are binding on the bidders for 24 hours. Bid acceptance is the prerogative of AEMO.

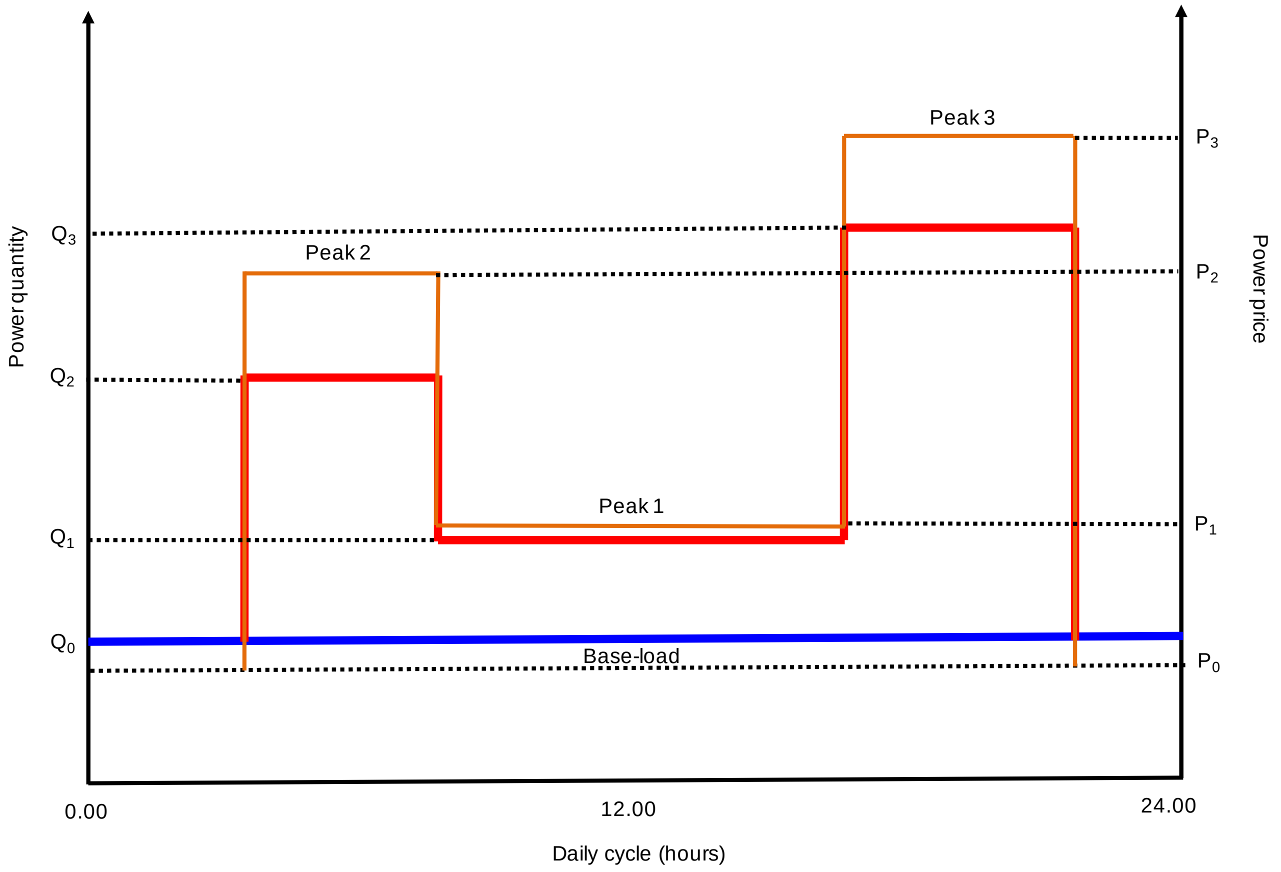
All accepted generator-bidder offers would be subject to heavy financial penalties for non-dispatch.

Peak demand periods will vary day-by-day, and season-by-season. Generator-bidders cannot know with certainty how long each day their dispatch bid will be required. Accordingly, they will have to organise their own extra generation and storage back-up (using whatever fuels they can contract) to cover up to 24 hours of dispatch. As a rough approximation, this requires renewables generators to offer supply on a reliability-equivalent LCOE basis, as do fossil fuel generators today.

As the share of renewables increases, the need for, and cost of, extra generation plus storage back-up, and the risk of heavy penalties for non-dispatch, increase. For fossil fuels, this risk is lower or absent.

The next step is to transfer the four illustrative market outcomes from Figure 1A to a chart illustrating how these might apply over a ‘typical’ 24-hour period (see Figure 1B below).

Figure 1B: Illustrating base-load and peak demand over a 24-hour period



Bidding results

Assume power demand = supply at all times, with power prices clearing the market, as in Figure 1A.

Bidding results as illustrated in Figure 1B are as follows:

i. Base-load supply generators stand in the market for 24 hours, offering Q_0 power at price P_0.
ii. Peak-demand supply generators stand in the market, *also for 24 hours*, offering extra power. This increases total supply on offer to meet increased demand:
    - Q_1 power at price P_1;
    - Q_2 power at price P_2;
    - Q_3 power at price P_3.
iii. In each 24 hour period, as illustrated in Figure 1B, AEMO accepts:
    - Q_0 power at the base price (P_0) for about 6 hours;
    - Q_1 power at a higher price (P_1) for about 8 hours;
    - Q_2 power at a higher price (P_2) for about 4 hours;
    - Q_3 power at a higher price (P_3) for about 6 hours.
iv. AEMO rejects all other bids.
v. All successful dispatch bids receive the accepted bid price. There is no VoLL, or Market Price Limit.

Attachment A. Electricity cost dissections: do they reveal – or conceal?

What's the 'official family' feeding the punter about cost increases within the NEM?

'Official' numbers for effects of different cost components on electricity prices within the NEM have been released.

In an opinion piece in *The Australian* on 21 August 2017 (provocatively entitled: *We're quickly reforming the energy markets with ideas, not ideology*), the Energy Minister provided a cost breakdown of Australian power costs.

The Minister apportioned electricity costs as follows:
- Transmission and distribution ('poles and wires'): up to 50%.
- Power generation: up to 30%.
- Power retailers: about 12%.
- Green schemes: up to 8%.

Others, such as the ACCC, have released broadly similar (but far from identical) cost breakdowns.

The ACCC has blamed transmission and distribution ('poles and wires') costs for most electricity cost increases.

Really? Hang on:
- Large-scale grid-based electricity systems like the NEM are, in the economists' jargon, *joint products*.
- Generation without electricity transmission, distribution, and retail sales is production without customers.
- Retail without generation, transmission, and distribution is customers without a product.
- Generation and retail without transmission and distribution is production with no link to customers.
- Generation, transmission, distribution and retail are inter-connected parts of an essential service.
- Eliminate one (or two), and the whole house of cards collapses. Really? Try SA in 2016.

These 'official family' statistics don't seem very useful. Do they conceal more than they reveal?

Is there a better way of breaking down sources of electricity cost increases?

The current policy debate about cost increases within the NEM has a few key components.
- What cost increases for electricity have we recorded?
- What parts of the electricity system are causing these?
- Are renewable energy sources a major source of cost increases?

These are inter-connected questions, because generation, transmission, distribution and energy retail are connected.

The quantitative answers provided by the Minister, the ACCC, etc, assume generation, transmission, distribution, and energy retail are separate boxes – cost 'silos' that can be dealt with separately. They assume we can apportion cost increases *exclusively* to one of these groups without allowing for how they interact.

This seems unhelpful.

It's worse.

The 'official' cost allocations include a *separate* category for 'renewable energy' or 'green schemes'. There is no information about how that is allocated to generation, transmission, distribution, or retail. (Is it all generation? Possibly.)

The basics of the NEM, in my opinion, are these:
- The electricity grid (in this case the NEM) is an *interdependent* system.
- Generation, transmission, distribution and retail are all links in the chain producing and supplying power.
- Bits (generation & retail) can be competitive if dividend-hungry governments get out of the way and cease being owners (and, instead, make the rules only).
- Transmission & distribution are 'natural monopolies'. They need to be regulated (as long as rule-making governments don't have dividend 'skin in the game' as government owners, corrupting their rule-making).

Splitting cost components as done now seemingly *ignores this fundamental interdependence*. They're *not* additive cost silos: they're connected all the way along the line every bit as intimately as a base-load generator and a home heater.

I suspect much new investment in 'poles and wires' is to connect new (often remote?) renewable generation to the grid.

Ditto retail costs?

'Green energy' ('green-wash'?) retail contracts involve a cost premium. But why? Is it more expensive (claimed to be cheaper?) 'green' generation? Additional cost recovery for new 'poles and wires'? Or just a 'feel good' retail mark-up?

Shouldn't we re-think how we quantify cost pressures in this area?

- For generation, split sources into fossil fuel (coal, diesel, gas, etc), or renewables (solar, wind, hydro, pumped hydro, thermal solar, etc).
- For transmission & distribution, split costs into (i) those *exclusively* attributable to fossil fuel generation; (ii) exclusively attributable to renewables; or (iii) those that can't be so apportioned, and must be regarded as 'joint' transmission costs (and split somehow between both).
- For retail, we need to do the generation and transmission/distribution cost allocations to get a sensible overall split between fossil fuel energy sources and renewable energy sources. Maybe we end up with three categories here too: fossil fuels, renewables, and 'joint'.

On this new (and I think more honest) basis:

- Cost increases attributable to fossil fuel power supply probably will be much less important.
- Cost increases attributable to renewable sources of power probably will be much more important.

My gut feelings aren't important, however.

In an evidence-based world (remember those?) what do the numbers say?

Let's see them.

And if we can't see them (because some claim it's 'too hard'?), are we rudderless in an energy cost allocation sense?

Can we measure renewables versus fossil fuels costs in a more transparent way?

If we can't see the 'official' numbers – because the 'official family' claim the numbers are not available – what can we do?

At the most aggregated level, we have a 'default' transmission/distribution/retail allocation that is a trivial calculation.

I think it's superior to what's being done now. If we know the generation split between renewables and fossil fuel sources of supply (and we do), why can't we use that same split for transmission/distribution/retail?

If we do, given the actual need for new investment in transmission/distribution related to (often remote) large-scale renewables relative to fossil fuel energy sources, won't we be understating the share of renewables in cost increases?

How much of the last decade's asserted poles and wires 'gold plating' *itself* is a response to the rush to renewables (plus government hunger for dividends in some cases)?

There's more.

Even if I'm right, this is a static accounting of the costs of what's in place. What about the dynamic effects of the investment environment on costs not directly attributable (but indirectly so) to renewables? For example:

- Cost increases attributable to fossil fuels may reflect state policy decisions to ban development of gas resources and some closures of major fossil fuel generators.
- NEM bidding rules (aided and abetted by the RET) might give first call to renewables, thus driving up needed rates of cost recovery over smaller operating times for other sources.
- More generally – and beyond the 'shadow carbon price' implicit in the RET and its ilk – there is the broader, longer-term 'expected carbon price' that long term investors must allow for and which, because of uncertainty about its level and likely path over time, must attract a large uncertainty margin on top.
- Surely all of these should be sheeted home to renewables? If so, the renewables cost share jumps.

I think a lot more transparency in this area is needed.

Attachment B. Adjusting the LCOE definition for intermittent versus continuous electricity supply

1. Notation

$LCOE_{0\text{-}t,\,i}$ = Levelised cost of electricity over period (0 – t) for energy source i.
$TC_{0\text{-}t,\,i}$ = Total capital plus operating cost over period (0 – t) for energy source i.
$TE_{0\text{-}t,\,i}$ = Total electricity generated over period (0 – t) for energy source i.
GC_i = Generating capacity (in, say, megawatts) for energy source i.
C_{mWhi} = Cost per megawatt-hour for energy source i.
Subscript 's' denotes solar power source.
Subscript 'c' denotes coal power source.

2. Current LCOE definition (simplified)

$$LCOE_{0\text{-}t,\,i} = TC_{0\text{-}t,\,i} / TE_{0\text{-}t,\,i} \qquad (1)$$

If $LCOE_{0\text{-}t,\,s} = LCOE_{0\text{-}t,\,c}$ then

$TC_{0\text{-}t,\,s} = TC_{0\text{-}t,\,c}$ assuming we are comparing costs for equal electricity generation using different energy sources (that is, we assume $TE_{0\text{-}t,\,s} = TE_{0\text{-}t,\,c}$) (2)

This definition ignores differences between continuously available, or dispatchable, power, and intermittent power.

3. Modified LCOE definition covering generation capacity adjusted for intermittent solar power

Define $TC_{0\text{-}t,\,i}$ as follows:

$$TC_{0\text{-}t,\,i} = GC_i \times C_{mWhi} \qquad (3)$$

Suppose solar power is a 100% substitute for coal power on a continuous basis:

$GC_s = 4 \times GC_c$ (ie, generation capacity for solar must be 4 *times* that for coal to supply power 24/7 – see section 6).

Where $TC_{0\text{-}t,\,s} = TC_{0\text{-}t,\,c}$

$$4 \times GC_c \times C_{mWhs} = GC_c \times C_{mWhc} \qquad (4)$$

$$C_{mWhs} = (1/4) \times C_{mWhc} \qquad (5)$$

In words, only if C_{mWhs} is *less* than one-quarter of C_{mWhc} will the levelised cost of solar be *less* than the levelised cost of coal, once allowance is made for the fourfold increase in solar generation capacity needed to deliver the same daily electricity supply 100% via intermittent solar power, as illustrated in section 6 of this booklet.

4. Further complications not covered here

Amongst other factors, section 3 of this attachment ignores the following additional costs:

- The costs of battery storage needed to spread solar power generation dispatch over a full day.
- The additional generation/storage capacity needed to allow for low-light weather during daylight hours.
- Lower solar intensity in winter and, for higher latitudes, shorter daylight hours around the winter solstice.
- The uncertainty of when solar power will be generated during daylight hours.
- Any additional transmission investment costs for new large-scale solar plants.
- Electricity grid stabilisation investment costs needed to sustain synchronous power (voltage + frequency).
- Any land use costs from large-scale solar plants.

There are other, additional, costs involved in scenarios where solar power is a partial substitute for coal power.

5. Cost-competitiveness conclusions: 100% solar versus 100% coal power

Even before allowing for all the additional costs noted in section 4 of this attachment, the additional generation capacity required to make 100% use of intermittent solar power cost-competitive with continuous coal power (equinox scenario) is four times that of coal, for the same power delivery. Only if solar generation costs are no more than 25% of the cost of coal power per megawatt hour can it be cost-competitive on generation alone.

In the real world, it must be much cheaper than that.

Attachment C. Broad cost implications of varying renewables' share of electricity generation

1. Notation & focus

Use the same notation as in Attachment B.

Attachment C illustrates the effects on LCOE of different solar renewables' shares of electricity generation, based on the solar power equinox example presented in section 6 of this booklet.

2. Solar power share is 25%

If intermittent solar power supplies the electricity market only for the assumed 6 hours per day of maximum sun, no back-up solar generation is required. Fossil-fuelled continuous generation supplies the remaining 18 hours each day.

In this case, adapting equation (4) from Attachment B:

$$0.25 \times GC_c \times C_{mWhs} + 0.75 \times GC_c \times C_{mWhc} = GC_c \times C_{mWhc} \quad (1)$$

$$GC_c \times C_{mWhs} = GC_c \times C_{mWhc} \quad (2)$$

$$C_{mWhs} = C_{mWhc} \quad (3)$$

In words, only if C_{mWhs} is *less* than C_{mWhc} will the levelised cost of solar be *less* than the levelised cost of coal. No allowance is needed for back-up solar generation capacity to deliver the same daily electricity supply 25% of each day via intermittent solar power.

3. Solar power share is 50%

If solar power supplies the electricity market for the assumed 6 hours per day of maximum sun, plus another 6 hours, back-up solar generation is required to cover the second 6 hours. Fossil-fuelled generation supplies the remaining 12 hours each day.

In this case, adapting equation (4) from Attachment B:

$$0.50 \times 2 \times GC_c \times C_{mWhs} + 0.50 \times GC_c \times C_{mWhc} = GC_c \times C_{mWhc} \quad (4)$$

$$2 \times GC_c \times C_{mWhs} = GC_c \times C_{mWhc} \quad (5)$$

$$C_{mWhs} = 0.5 \times C_{mWhc} \quad (6)$$

In words, only if C_{mWhs} is *less* than half of C_{mWhc} will the levelised cost of solar be *less* than the levelised cost of coal. Allowance is needed for back-up solar generation capacity (a doubling of solar generation capacity compared to the 25% solar share example) to deliver the same daily electricity supply 50% of each day via intermittent solar power.

4. Solar power share is 75%

If solar power supplies the electricity market for the assumed 6 hours per day of maximum sun, plus another 12 hours, back-up solar generation is required to cover the additional (non-sun) 12 hours. Fossil-fuelled generation supplies the remaining 6 hours each day.

In this case, adapting equation (4) from Attachment B:

$$0.75 \times 3 \times GC_c \times C_{mWhs} + 0.25 \times GC_c \times C_{mWhc} = GC_c \times C_{mWhc} \quad (7)$$

$$3 \times GC_c \times C_{mWhs} = GC_c \times C_{mWhc} \quad (8)$$

$$C_{mWhs} = 0.3333 \times C_{mWhc} \quad (9)$$

In words, only if C_{mWhs} is *less* than one-third of C_{mWhc} will the levelised cost of solar be *less* than the levelised cost of coal. Allowance is needed for back-up solar generation capacity (a trebling of solar generation capacity compared to the 25% solar share example) to deliver the same daily electricity supply 75% of each day via intermittent solar power.

5. Solar power share is 100% (the example shown in Attachment B)

If solar power supplies the electricity market for 24 hours each day, back-up solar generation is required to cover the (non-sun) 18 hours. Fossil-fuelled generation supplies no power.

In this case, as shown in equation (4) in Attachment B:

$$4 \times GC_c \times C_{mWhs} = GC_c \times C_{mWhc} \quad (10)$$

$$C_{mWhs} = 0.25 \times C_{mWhc} \quad (11)$$

In words, only if C_{mWhs} is *less* than one-quarter of C_{mWhc} will the levelised cost of solar be *less* than the levelised cost of coal. Allowance is needed for back-up solar generation capacity (a quadrupling of solar generation capacity compared to the 25% solar share example) to deliver the same electricity supply 100% of each day via intermittent solar power.

6. Further complications not covered here

Amongst other factors, this attachment ignores the following additional costs:

- The costs of battery storage needed to spread solar power generation dispatch over a full day.
- The additional generation/storage capacity needed to allow for low-light weather during daylight hours.
- Lower solar intensity in winter and, for higher latitudes, shorter daylight hours around the winter solstice.
- The uncertainty of when solar power will be generated during daylight hours.
- Any additional transmission investment costs for new large-scale solar plants.
- Electricity grid stabilisation investment costs needed to sustain synchronous power (voltage + frequency).
- Any land use costs from large-scale solar plants.
- Increasing RETs ‘squeezes’ dispatch time and costs of fossil-fuelled generators. See section 9 of this booklet.

As the solar generation share increases, in general so do costs of reliably addressing each of these additional factors.

7. Some broad cost-competitiveness conclusions

Attachment C shows cost-competitiveness for renewables, as measured by LCOE, becomes more difficult as the share of solar generation increases. This is *before* allowing for the complicating factors in section 6 above.

As the need for back-up solar generation increases, so does the LCOE cost-competitiveness hurdle for solar power.

Similar conclusions, generally over longer than daily cycles, apply to wind power and hydro power.

Some examples:

- For a RET of 25% (close to the national and WA targets) and focussing *only* on generation, the LCOE cost per mWh for solar power has to fall slightly below the corresponding LCOE for coal or other fossil-fuelled power for it to be more cost-competitive.
- For a RET of 50% (the announced targets for Queensland, South Australia, the Northern Territory and close to the 40% target for Victoria), the LCOE cost per mWh for solar power has to fall slightly below *half* of the corresponding LCOE for coal or other fossil-fuelled power for it to be more cost-competitive. To be fair, for South Australia, and to a degree Victoria, the economics of wind power, as well as solar, must be considered. For Queensland and the Northern Territory, it’s mainly solar power.
- For those announcing a 100% renewables target (Tasmania and the ACT), the LCOE cost per mWh for solar power has to fall slightly below *one-quarter* of the corresponding LCOE for coal or other fossil-fuelled power for it to be more cost-competitive. For Tasmania, the economics of hydro and wind power, as well as some solar, must be considered. For the ACT, some home-grown solar is relevant. The rest is imported from the states.

In the media, this type of analysis seems to get almost no attention.

Attachment D. Illustration of the solar RET ‘squeeze’ on coal power dispatch time and cost

1. Notation & focus

Use the same notation as in Attachments B and C, plus:

$WT_{0\text{-}t,\,c}$ = Increased wear and tear costs from intermittent daily use of fossil fuel (coal) over period (0 – t).
$FS_{0\text{-}t,\,c}$ = Fuel input cost saving from intermittent daily use of fossil fuel (coal) over period (0 – t).

Attachment C ignores cost effects on fossil fuel power due to increasing RETs (see section 9 of this booklet).

Coal fired generators often operate most efficiently on a continuous basis. Curtailing their dispatch to allow solar generation dispatch when the sun is shining (and/or to allow discharge/dispatch of stored solar power) has two effects:

- Any given minimum daily cost recovery (LCOE basis) must be recovered over less than 24 hours each day.
- Intermittent daily use of coal plant costs more via wear and tear, *less* savings from reduced coal inputs.

LCOE comparisons should cover these cost and saving effects from intermittent use of coal.

Attachment D roughly illustrates these cost effects.

Similar cost effects, over different time cycles, apply for wind and hydro power.

2. Solar power share is 25%

If intermittent solar power supplies the electricity market only for the assumed 6 hours per day of maximum sun, no back-up solar generation is required. Coal-fuelled generation supplies the remaining 18 hours each day. The 24 hour-basis minimum hourly cost recovery for coal must now be compressed into 18 hours, increasing the hourly cost by one-third.

In this case, adapting equation (1) from Attachment C:

$$0.25 \times GC_c \times C_{mWhs} + 0.75 \times [0.75 \times GC_c \times 1.333 \times C_{mWhc} + GC_c \times (WT_{0\text{-}t,\,c} - FS_{0\text{-}t,\,c})] = GC_c \times C_{mWhc} \quad (1)$$

Simplifying (1) and with some algebraic manipulation

$$C_{mWhs} = C_{mWhc} – 3 \times (WT_{0\text{-}t,\,c} - FS_{0\text{-}t,\,c}) \quad (2)$$

Note that

$$C_{mWhs} = C_{mWhc} \text{ if } (WT_{0\text{-}t,\,c} - FS_{0\text{-}t,\,c}) = 0\text{, as in Attachments B and C.} \quad (3)$$

In words, comparing the blend of solar plus coal power with 100% coal power, (2) shows that, only if C_{mWhs} is *less* than C_{mWhc} *minus* three times the net cost of additional wear and tear *less* coal input savings, will the levelised cost of solar plus coal be *less* than the levelised cost of 100% coal.

This makes intuitive sense. If solar has a 25% share and coal drops from 100% to 75%, the net cost of intermittent coal plant wear and tear *less* coal input savings must be offset by lower solar power costs. For that, the net extra cost directly attributable to intermittent coal power supply must be ‘allocated’ to one-third of that 75%: the 25% share of solar power.

3. Solar power share is 50%

If solar power supplies the electricity market for the assumed 6 hours per day of maximum sun, plus another 6 hours, back-up solar generation is required to cover the second 6 hours. Coal power generation supplies the remaining 12 hours each day. Twice the solar generation capacity (plus storage) is needed in the 6 hours of maximum sun.

In this case, adapting equation (1) above:

$$0.50 \times 2 \times GC_c \times C_{mWhs} + 0.50 \times [0.50 \times GC_c \times 2.00 \times C_{mWhc} + GC_c \times (WT_{0\text{-}t,\,c} - FS_{0\text{-}t,\,c})] = GC_c \times C_{mWhc} \quad (4)$$

Simplifying (4) and with some algebraic manipulation

$$2 \times C_{mWhs} = C_{mWhc} - (WT_{0\text{-}t,\,c} - FS_{0\text{-}t,\,c}) \quad (5)$$

$$C_{mWhs} = 0.5 \times C_{mWhc} – 0.50 \times (WT_{0\text{-}t,\,c} - FS_{0\text{-}t,\,c}) \quad (6)$$

In words, comparing the blend of solar plus coal power with 100% coal power, (6) shows that, only if C_{mWhs} is *less* than half C_{mWhc} *minus* half the net cost of additional wear and tear *less* coal input savings, will the levelised cost of solar plus coal be *less* than the levelised cost of 100% coal.

This makes intuitive sense. If solar has a 50% share and coal drops from 100% to 50%, the net cost of intermittent coal plant wear and tear *less* coal input savings must be offset by lower solar power costs. For that, the net extra cost directly attributable to intermittent coal power supply must be 'allocated' to the same 50%: the 50% share of solar power.

4. Solar power share is 75%

If solar power supplies the electricity market for the assumed 6 hours per day of maximum sun, plus another 12 hours, back-up solar generation is required to cover the additional (non-sun) 12 hours. Coal power generation supplies the remaining 6 hours each day.

In this case, adapting equation (1) above:

$$0.75 \times 3 \times GC_c \times C_{mWhs} + 0.25 \times [0.25 \times GC_c \times 4.00 \times C_{mWhc} + GC_c \times (WT_{0\text{-}t,\,c} - FS_{0\text{-}t,\,c})] = GC_c \times C_{mWhc} \qquad (7)$$

Simplifying (7) and with some algebraic manipulation

$$3 \times C_{mWhs} = C_{mWhc} - 0.333 \times (WT_{0\text{-}t,\,c} - FS_{0\text{-}t,\,c}) \qquad (8)$$

$$C_{mWhs} = 0.333 \times C_{mWhc} - 0.111 \times (WT_{0\text{-}t,\,c} - FS_{0\text{-}t,\,c}) \qquad (9)$$

In words, comparing the blend of solar plus coal power with 100% coal power, (9) shows that, only if C_{mWhs} is *less* than one-third C_{mWhc} *minus* one-ninth the net cost of additional wear and tear *less* coal input savings, will the levelised cost of solar plus coal be *less* than the levelised cost of 100% coal.

This makes intuitive sense. If solar has a 75% share and coal drops from 100% to 25%, the net cost of intermittent coal plant wear and tear *less* coal input savings must be offset by lower solar power costs.

For that, the net extra cost directly attributable to intermittent coal power supply must be allocated to the 75% share of solar power. It is spread over three times the coal generating capacity actually used (solar is 75%; coal is 25%). Coal also has one-third of the weight of solar in total supply. (However, the net extra cost of ($WT_{0\text{-}t,\,c} - FS_{0\text{-}t,\,c}$) presumably increases as coal's generation share falls). The weighting in (9) is therefore 1/9.

5. Solar power share is 100% (the example shown in Attachment B)

If solar power supplies the electricity market for 24 hours each day, back-up solar generation is required to cover the (non-sun) 18 hours. Fossil-fuelled generation supplies no power. Costs of stranded/closed coal plant aren't covered.

In this case, as shown in equation (4) in Attachment B:

$$4 \times GC_c \times C_{mWhs} = GC_c \times C_{mWhc} \qquad (10)$$

$$C_{mWhs} = 0.25 \times C_{mWhc} \qquad (11)$$

In words, only if C_{mWhs} is *less* than one-quarter of C_{mWhc} will the levelised cost of solar be *less* than the levelised cost of coal. Allowance is needed for back-up solar generation capacity (a quadrupling of solar generation capacity compared to the 25% solar share example) to deliver the same electricity supply 100% of each day via intermittent solar power.

This allows nothing for the cost of closing existing coal-fired power plants.

6. Further complications not covered here

Amongst other factors, this attachment ignores the following additional costs:

- The costs of battery storage needed to spread solar power generation dispatch over a full day.
- The additional generation/storage capacity needed to allow for low-light weather during daylight hours.
- Lower solar intensity in winter and, for higher latitudes, shorter daylight hours around the winter solstice.
- The uncertainty of when solar power will be generated during daylight hours.
- Any additional transmission investment costs for new large-scale solar plants.
- Electricity grid stabilisation investment costs needed to sustain synchronous power (voltage + frequency).
- Any land use costs from large-scale solar plants.

As the solar generation share increases, in general so do costs of reliably addressing each of these additional factors.

7. Some broad cost-competitiveness conclusions

Compared with Attachment C, attachment D shows cost-competitiveness for solar power, as measured by LCOE, becomes even more difficult as the share of solar generation increases.

This is *before* allowing for the extra complicating factors in section 6 above.

As the need for back-up solar generation increases, so does the LCOE cost-competitiveness hurdle for solar power.

Similar conclusions, generally over longer than daily cycles, apply to wind power and hydro power.

Attachment E. Coal versus reliability-equivalent solar/coal power blends: some numbers

1. Power cost estimates

Robert Bryce[10] has provided estimates of electricity costs for generation entering service in the United States in 2018.

These are expressed in US dollars per megawatt hour. They are LCOE-based estimates.

Amongst these he states:

- Solar photovoltaic powered generation in 2018 will cost US$144.30.
- Coal powered generation in 2018 will cost US$100.10.

He also states:

- Natural gas powered generation in 2018 will cost US$65.60
- Nuclear powered generation in 2018 will cost US$108.40.
- Solar thermal powered generation in 2018 will cost US$261.50.
- Hydroelectric powered generation in 2018 will cost US$90.30.

2. Applying these estimates to the findings in Attachments B, C and D

We can plug these estimates into the scenario formulae presented in Attachments B, C and D. Sure, they are estimates for the USA. But the results, allowing for multiplied solar power generation needed to cover intermittency, plus covering the net costs of extra wear and tear on coal generation plants less coal input savings, should be of interest in Australia.

Differences in energy source cost per megawatt-hour between the USA and Australia are likely to be overwhelmed as the market share for solar power rises and that for coal falls.

We start with 100% coal power at US$100.10 per megawatt-hour. Now increase the proportion of solar and cut coal.

2.1 25% solar, 75% coal power

From (2) in Attachment D:

$$C_{mWhs} = C_{mWhc} – 3 \text{ x } (WT_{0\text{-}t,\, c} - FS_{0\text{-}t,\, c}) \qquad (1)$$

That is, for competitive parity:

$$144.30 = 100.10 – 3 \text{ x } (WT_{0\text{-}t,\, c} - FS_{0\text{-}t,\, c}) \qquad (2)$$

Or

$$C_{mWhs} = 0.694 \text{ x } C_{mWhc} – (3/144.30) \text{ x } (WT_{0\text{-}t,\, c} - FS_{0\text{-}t,\, c}) \qquad (3)$$

For competitive parity, solar power must cost way less than 100% of coal power, but in the USA it costs over 44% more.

Only if there are huge *net* cost savings from reduced coal inputs would this conclusion be reversed.

2.2 50% solar, 50% coal power

From (5) in Attachment D:

$$2 \text{ x } C_{mWhs} = C_{mWhc} - (WT_{0\text{-}t,\, c} - FS_{0\text{-}t,\, c}) \qquad (4)$$

That is, for competitive parity:

$$2 \text{ x } 144.30 = 100.10 – (WT_{0\text{-}t,\, c} - FS_{0\text{-}t,\, c}) \qquad (5)$$

Or

$$C_{mWhs} = 0.347 \text{ x } C_{mWhc} – (1/288.60) \text{ x } (WT_{0\text{-}t,\, c} - FS_{0\text{-}t,\, c}) \qquad (6)$$

For competitive parity, solar power must cost less than half that for coal power, but (in the USA) it costs over 44% more.

Only if there are even larger *net* cost savings from reduced coal inputs would this finding be reversed.

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[10] *Smaller faster lighter denser cheaper*, Robert Bryce, published by Public Affairs, New York, 2014, page 241.

2.3 75% solar, 25% coal power

From (9) in Attachment D:

$C_{mWhs} = 0.333 \times C_{mWhc} – 0.111 \times (WT_{0\text{-}t,\, c} - FS_{0\text{-}t,\, c})$ (7)

That is, for competitive parity:

$3 \times 144.30 = 100.10 – 0.333 \times (WT_{0\text{-}t,\, c} - FS_{0\text{-}t,\, c})$ (8)

Or

$C_{mWhs} = 0.231 \times C_{mWhc} – (1/3) \times (1/432.90) \times (WT_{0\text{-}t,\, c} - FS_{0\text{-}t,\, c})$ (9)

For competitive parity, solar power must cost less than one-third of coal power, but (in the USA) it costs over 44% more.

Only if there are huge *net* cost savings from reduced coal inputs would this finding be reversed.

2.4 100% solar power

For the 100% solar scenario, there's no coal. The cost of coal power closures/stranded assets, etc, is ignored here.

Solar generation (producing 24 hours of power in 6 hours) must be 4 times the capacity for coal power generation.

As in (11) in Attachment D (and excluding closure, etc, coal plant costs):

$C_{mWhs} = 0.25 \times C_{mWhc}$ (10)

That is, for competitive parity:

144.30 = 25.03 (obviously ridiculous, even before allowing for coal plant closure costs) (11)

Or

$C_{mWhs} = 0.173 \times C_{mWhc}$ (12)

For competitive parity, solar must cost less than one-quarter of coal power, but (in the USA) it costs over 44% more.

3. How does solar power fare as a blend with, or substitute for, coal power (reliability-equivalent basis)?

The cost of solar power, we're told, is falling.

Using Bryce's 2018 USA-based cost estimates, competitive parity with coal:
- Is not achieved with a 25% solar/75% coal blend, unless there are large net coal input savings (unlikely).
- Is even less likely to be achieved with higher proportions of solar power in total power supply.
- For proportions of solar from 50% and higher, cost parity seems unlikely even if $C_{mWhs} = C_{mWhc}$ = US$100.10.

At present, if we wish to improve energy affordability, substituting solar power for coal power won't help.

That increases power costs.

4. Implications for RET aspirations

The implementation of RET aspirations substitutes more expensive renewables (in this case solar) for cheaper fossil-fuel power (in this case coal).

There are three forces combining to produce this result:

1. On a cost per megawatt-hour basis, at present, $C_{mWhs} > C_{mWhc}$.
2. As the proportion of solar power increases above 25%, extra solar generation capacity is needed to generate (and then store) power during the assumed 6 hours each day of maximum sunlight. This renewables generation back-up adds to total power system costs.
3. As dispatch time for coal power falls below 24 hours each day, recovery of daily costs needed for plant viability requires hourly dispatch costs (C_{mWhc}) to increase to offset the reduction in hours dispatched. Because this applies in solar/coal power blends, it increases total blend cost above continuous operation of coal-fired plants.

Even if $C_{mWhs} = C_{mWhc}$, the second and third forces just noted increasingly make 100% coal power more affordable.

5. Further complications not covered here

Amongst other factors, this attachment ignores the following additional costs:
- The costs of battery storage needed to spread solar power generation dispatch over a full day.
- The additional generation/storage capacity needed to allow for low-light weather during daylight hours.
- Lower solar intensity in winter and, for higher latitudes, shorter daylight hours around the winter solstice.
- The uncertainty of when solar power will be generated during daylight hours.
- Any additional transmission investment costs for new large-scale solar plants.
- Electricity grid stabilisation investment costs needed to sustain synchronous power (voltage + frequency).
- Any land use costs from large-scale solar plants.

As the solar generation share increases, in general so do costs of reliably addressing each of these additional factors.

Attachment F. Twenty-three energy policy realities: the consolidated list

Reality #1: Trade-offs between the three energy 'trilemma' objectives are unavoidable.

Reality #2: Reducing emissions permits increases permit prices, and vice versa.

Reality #3: Alone, if RETs cut emissions, they also cut affordability and/or reliability.

Reality #4: Large individual state renewables generation targets require interstate back-up.

Reality #5: We can't control renewables' supply. That's up to the weather and water.

Reality #6: Intermittent power is a threat to grid stability without countermeasures.

Reality #7: Intermittent power multiplies the cost of generation and adds storage costs

Reality #8: Nuclear power is by far the most energy-dense source available

Reality #9: Low energy density multiplies required generation and storage capacity

Reality #10: Energy density issues are driving us to a policy supply, technology demand, collision.

Reality #11: Levelised cost comparisons are strongly biased in favour of renewables

Reality #12: The affordability hurdle faced by solar power increases with its market share

Reality #13: Solar power's affordability hurdle may increase even more as coal declines

Reality #14: If power affordability is the question, renewables aren't the answer

Reality #15: A NE'G' imposing retailer 'guarantees' can reduce affordability

Reality #16: The NE'G' may exacerbate the 'trilemma'

Reality #17: Government policy statements, and private sector responses, extend the 'trilemma'

Reality #18: BHP's position seems inconsistent.

Reality #19: In general, 'demand response' offloads supply failure costs to others

Reality #20: All versions of 'supply response' reflect power failure

Reality #21: If Australia 'turns all its lights out', net global emissions still increase a lot

Reality #22: The national emissions production focus of abatement policies deters global action

Reality #23: We can't eliminate the 'trilemma'. We can and should make it less severe.

What are the broad take-away messages from these realities?

Unless it delivers affordable reliable power, centralised energy infrastructure will slowly die.
Alone, Australia can do little about global greenhouse gas emissions.
Energy policy must be shaped by these realities.
It's not. Changing that is our choice.