A Reliability Assessment of the AEMO 2022 Integrated System Plan for the National Electricity Grid

by independent engineers and scientists

14 November 2022

This reliability assessment report concerning the 2022 Integrated System Plan (ISP) of the Australian Energy Market Operator (AEMO) follows up the submission made last February regarding the draft ISP. That assessment found that the ISP could not meet any of the government's goals for reliability, affordable costs and emissions reduction.

Additional analysis focused on reliability has been conducted subsequent to the publication of the 2022 ISP on 31st June. This report also reflects communications in the last few months with AEMO, energy regulators AEMC, AER and ESB, the Department of Industry, Energy and Emissions Reduction (DIEER), Hon Chris Bowen, Minister for Climate Change and Energy and other ministers.

This report has been prepared by independent engineers and scientists who have no monetary, employment, political or ideological links to this subject matter.

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Executive Summary

AEMO's 2022 ISP Electricity Grid Design Cannot Provide Australians with Reliable Power

Using data from AEMO's Integrated System Plan (ISP), a top-down, whole-of-system analysis for years 2030, 2040 and 2050 shows that the ISP grid design fails to provide sufficient power for system reliability *regardless* of wind and solar operating conditions.

The primary reasons are:

- Inadequate levels of dispatchable power generation;
- Inadequate capacity of energy storage; and
- Over-reliance on geographic diversity and interconnector transmission lines to ensure reliability.

A top-down, whole-of-system analysis inherently assumes 100% connectivity and yet the results show power generation in the planned National Electricity Market (NEM) grid as a whole are simply insufficient to provide reliable power. It is impossible to distribute adequate power with interconnectors that simply does not exist.

Using AEMO's forecast for maximum power demand, the grid reserve margin for dispatchable power generators and energy storage systems falls from +20%, which has historically kept the NEM reliable, to highly negative levels ranging up to -53% in non-daytime periods when solar power is zero. Given the variability and intermittency of solar and wind, it is simply not possible the ISP will result in a grid meeting the 99.998% reliability standard (maximum grid outage of less than 10.5 minutes per year).

AEMO's published data over the last ten years shows frequent periods every year when wind power outputs fall to less than 10% and solar is zero every night for about 16 hours. Weather systems causing these conditions can affect very large regions at the same time, for example all of Victoria and NSW, which account for 60% of grid demand.

Adding more wind and solar power generation, as has been advocated by many, to address power shortages in the ISP when the root cause is low wind and no solar is completely illogical.

A primary outcome of the ISP design is large surpluses of solar power during daytime, which cannot be absorbed by inadequate storage systems. The result will be a collapse in wholesale power prices causing financial disaster for all power generators and high prices at night when large shortages of power make it difficult to generate revenue. This will be particularly acute for solar farms.

A top-down, whole-of-system analysis with 100% interconnectors shows that when solar and wind power conditions vary from substantial drought to well-above average, the grid fails to provide sufficient power throughout a 24 hour cycle to meet maximum demand and recharge energy storages. In solar and wind droughts resulting in just 10% outputs, the grid will experience widespread collapse with massive power shortages. Under average wind and solar conditions, frequent blackouts can be expected in non-daytime conditions. Even when solar and wind conditions are well above average, blackouts will persist in non-daytime periods.

Due to very high costs, current and proposed battery storages are feasible only for very short term (a few hours) smoothing of fluctuations in renewable energy outputs. They are minute compared to what is required to back up renewable energy over periods of days and they are prohibitively expensive. Snowy 2.0 storage capacity is 7 days but its power output is only 2 GW when peak and average grid demands exceed 40 GW.

Failure to meet a top-level whole-of-system power capacity versus forecast demands analysis makes the ISP unsuitable for consideration as national policy.

Not only will it lead to frequent and major energy shortages, it will make Australia completely dependent on China, which dominates the market for wind and solar equipment and materials, for our most critical infrastructure. Future trade sanctions by China would make our NEM unsustainable.

System Design Requirements

The NEM reliability standard is defined in the ISP (*Table 3 p19*) as 99.998%, a common standard for public utilities. It is a tough standard indeed – it requires total system outages in any year to be less than just 10.5 minutes. AEMO measures reliability, as described in their ESOO report of 31 August 2022 (*p17*), in terms of outages called Unserved Energy (USE) as a percentage of annual output. The bar for USE is therefore 0.002%.

The reliability standard is what applies to the operation of the electricity grid. It is not easy to determine except by measuring actual performance over time or running detailed and sophisticated statistical models. On the other hand, a design criteria that is widely used as an input to guide planning work and assess grid status is the "reserve margin". This is defined as *the percentage by which total dispatchable on demand power capacity exceeds maximum demand*.

This reserve margin is designed to cover facility outages for maintenance and repairs. In the past, the reserve margin has always exceeded 20% and ensured the reliability standard was met. This reserve margin was never intended for meeting the variability and intermittency of renewable wind and solar power, which is a far larger impact on the grid.

Maximum demand is based on past historical records and future forecasts. AEMO maintains such records and issues these forecasts. The maximum demand data used for the draft 2022 ISP was posted on its website in December 2021.

Since the June publication of the 2022 ISP, AEMO released its ESOO report in August, which defined maximum demand in statistical terms called Probability of Exceedance (POE). A 10% POE means a maximum demand that is exceeded only 10% of the time. That means over a year, the daily maximum demand will exceed 10% POE on 36 days! A healthy reserve margin is therefore critical to maintaining grid reliability.

However, communications with AEMO indicated their belief that a lower 50% POE maximum demand should be used. Comparison of the ESOO 50% POE data with the data AEMO used for the draft ISP showed it corresponded almost perfectly. The implications are concerning. A 50% POE maximum demand will be exceeded over 180 days every year – hardly an appropriate forecast to be using to design a reliable grid.

Table 1 shows AEMO's maximum demand forecast data broken down by state for years 2030, 2040 and 2050.

	ESOO 10% POE			**ESOO 50% POE**		
	2030	**2040**	**2050**	**2030**	**2040**	**2050**
Region	**GW**	**GW**	**GW**	**GW**	**GW**	**GW**
NSW	15.4	18.1	20.8	13.8	15.5	17.8
VIC	11.6	13.8	17.5	10.4	12.6	16.0
QLD	12.0	13.7	15.6	11.6	13.2	15.0
SA	3.9	4.7	5.5	3.5	4.3	5.0
TAS	1.9	2.0	2.2	1.8	1.9	2.1
Total Max Op sent out	**44.8**	**52.3**	**61.5**	**41.1**	**47.5**	**55.9**

Table 1 AEMO Maximum Demand Forecast *ESOO August 2022 A1 – A5*

The 10% POE maximum data is about 10% higher than 50% POE. This higher maximum demand by itself would reduce by half a 20% reserve margin, if the grid design was based on a 50% POE maximum demand.

A First Look at Reliability – Dispatchable Reserve Margin

The NEM has always met or exceeded the 20% reserve margin criteria and reliability has been excellent. Our analysis of planned reserve margin shows it plummeting far below maximum demand.

Our top-down reliability analysis is based entirely on data in AEMO's 2022 ISP for the planned capacities of all types of power generation sources and energy storage systems (*Figure 1 p9 and Figure 23 p54*) and AEMO's 10% POE maximum demand data as the most realistic approach to reliable grid system design.

Our analysis method constructs a NEM-wide power budget for a 24 hour cycle comprised of 8 daytime hours when solar and wind power are available and 16 non-daytime hours when solar is completely absent. The 16 hour period is further broken into 4 hours of peak demand requiring maximum energy storage outputs and 12 remaining hours of off-peak.

Unlike dispatchable power generators which can run 24/7 if necessary, *dispatchable energy storage* is limited by its maximum power output *and* its storage depth. It is not available during daytime when it is recharging. Except for Snowy 2.0, ISP energy storages such as batteries, do not have sufficient depth of storage to last much beyond the 4 hour peak period. Snowy 2.0 can last up to 7 days but its 2 GW output is only 5% of planned 2030 grid capacity.

The planned 2030, 2040 and 2050 dispatchable reserve margins shown in Table 2 are a grim result. Large negative reserve margins demonstrate a grid design that is inherently unreliable. Blackout risk will occur every day, usually in the early evening and early morning periods when demand is at a peak. This will occur even if all facilities in the grid are working perfectly.

Negative reserve margins are why the 2022 ISP grid design cannot possibly meet the Electricity Rules reliability standard. And this is confirmed by the ESOO report. It states (*p65*) that ***"…the 2022 ESOO identifies numerous reliability gaps over the 10-year horizon"***.

The power shortfall (the bottom line) shows what additional dispatchable power is required to restore the 20% reserve margin. The planned ISP dispatchable power is massively below the +20% reserve margin that is critical for NEM reliability.

Dispatchable Reserve Margin		**2030**			**2040**			**2050**		
		16 hrs		8 hrs	16 hrs		8 hrs	16 hrs		8 hrs
		Peak	**Remainder**	**Daytime**	**Peak**	**Remainder**	**Daytime**	**Peak**	**Remainder**	**Daytime**
	hrs	4	12	8	4	12	8	4	12	8
Dispatchable Generation	GW	28.3	28.3	28.3	16.9	16.9	16.9	16.5	16.5	16.5
Dispatchable Storage	GW	9.5	3.3		27.9	10.2		45.7	12.3	
Total Dispatchable	GW	37.8	31.6	28.3	44.8	27.1	16.9	62.2	28.8	16.5
Maximum Demand 10% POE	GW	44.8	44.8	44.8	52.3	52.3	52.3	61.5	61.5	61.5
Dispatchable Reserve Margin		**-15.6%**	**-29.5%**	**-36.8%**	**-14.3%**	**-48.2%**	**-67.7%**	**1.1%**	**-53.2%**	**-73.2%**
Grid Requirement with 20% reserve		53.8	53.8	53.8	62.8	62.8	62.8	73.8	73.8	73.8
Shortfall	GW	**-16.0**	**-22.2**	**-25.5**	**-18.0**	**-35.7**	**-45.9**	**-11.6**	**-45.0**	**-57.3**
	%	-35.6%	-49.5%	-56.8%	-34.3%	-68.2%	-87.7%	-18.9%	-73.2%	-93.2%

Table 2 Dispatchable Power Reserve Margin for 2030, 2040 and 2050.

The 4 hours of peak demand when storages start at full capacity show substantial negative reserve margins in 2030 and 2040 meaning blackouts are a high risk. Dispatchable reserve margins in the 12 hour period are massively higher because completely inadequate energy storages in the ISP are mainly exhausted. During this time period, blackouts are a certainty. Reserve margin in daytime falls even further because all energy storages are being recharged by renewable energy as a priority.

What this reserve margin analysis shows is a NEM that has no chance of providing reliable power on demand or any reserve to guard against facility maintenance and repair outages. It will be completely vulnerable to the vagaries of wind during the non-daytime period when maximum demands occur in early evenings and mornings.

Power from Renewables

AEMO will say that renewable energy will bridge the gap! Solar? Not during the 16 hours of non-daytime. Wind? It will vary up and down at all times of the day.

Solar power generation is concentrated every day – available only during daytime hours but also subject to cloud cover and remaining completely absent at all other times. Since the non-daytime period occurs across the entire NEM at about the same time every day, it means that solar power, which is two thirds of all renewables in the 2022 ISP, is severely restricted in the entire NEM. This leaves wind as the only renewable source to help meet maximum demand.

While average wind power output – its capacity factor - is estimated to be 29% (probably closer to 25% after accounting for transmission losses), a level of less than 10% is a very serious drought condition. Given wind generation is only one third of all renewables, a 10% wind capacity factor represents just 3.3% of all grid renewable capacity. And wind often drops well below that.

AEMO publishes daily, detailed operational data on all of its power generation facilities. Its large volume and detail have been processed by many websites in order to derive insights. Table 3 provides annual eastern Australia wind drought event data for the last 10 years.

This table shows the number of periods and their duration when total wind power is **less than 10% of maximum capacity** and breaks down this number of events when capacity factor falls lower than 10%. The table also notes the maximum duration of wind drought each year.

	Number of Events of Wind Drought								
	Length of Period when CF <= 10%					Annual	Capacity Factors		
Year	4-6 hrs	6-10 hrs	10-14 hrs	14-18 hrs	18+ hrs	Max hrs	0-6%	6-8%	8-10%
7mo/2022	9	14	4	1	2	20 h	3	18	19
2021	17	30	10	5	0	16 h	9	36	52
2020	22	27	14	4	4	34 h	21	21	53
2019	16	33	9	6	4	42 h	18	34	57
2018	28	34	9	5	5	57 h	17	51	54
2017	15	34	15	5	17	71 h	28	41	57
2016	24	17	18	2	6	62 h	17	35	64
2015	10	24	17	11	16	39 h	25	46	45
2014	29	29	22	2	13	46 h	19	51	77
2013	30	30	15	6	9	54 h	26	48	64
2012	20	33	12	6	19	66 h	36	46	59

Table 3 AEMO Wind Drought Data by Length of Period and Capacity Factor

The ESOO report and many public figures advocate increasing renewables to deal with power shortages – without explaining how adding more wind turbines when there is little wind will make any difference! And adding solar panels to back up wind droughts at night is farcical.

The 10 year data shows periods of widespread serious drought happen many times a year and the durations can last for up to several days. In addition, capacity factors vary to well below 6%.

It must be asked, in light of the preceding analysis on dispatchable design margins, can the grid be reliable when it experiences long 16 hour non-daytime periods every single day when dispatchable power and storages are so inadequate and renewable power falls to such low levels?

Common sense says the answer is no. When reserve margins of dispatchable power generators and energy storage are deeply negative (Table 2), it is most unlikely that wind power will reliably fill the gap. Table 4 shows the data.

Quite clearly, wind power does not come close to making up the shortfall in dispatchable power in the 2022 ISP grid design. Even when wind power is well above average at 40%, it is far less than needed to provide an adequate grid reserve margin.

The inescapable conclusion is that the 2022 ISP grid design is incapable of delivering a reserve margin even with wind power, which is critical to achieving reliability in line with the Electricity Rules Standard.

Wind	2030	2040	2050
Wind Capacity 100%	36.5	49.5	69.7
Capacity Factor 40%	14.2	19.2	27.0
Capacity Factor 25%	8.9	12.0	16.9
Capacity Factor 10%	3.3	4.8	6.8
Capacity Factor 5%	1.7	2.4	3.4
Shortfall from Table 2			
Below +20% Reserve Margin	-22.2	-35.7	-45.0

Table 4 ISP Wind Power GW vs Shortfall GW below 20% Reserve Margin in non-daytime

As a result, almost every wind drought will lead to blackouts. Plainly, the ISP is completely deficient in dispatchable power and energy storage. The ISP grid design is not off by a little, but by a lot. This does not call for tweaking the design – it needs a fundamental rethink.

This result calls into question the validity of the reliability modelling process used by AEMO. The ESOO report has plenty of description but little in the way of revealing the specific statistical models used for renewable energy generation and facility outages.

Another AEMO report, ESOO and Reliability Forecast Methodology Document August 2022, states (*p10*) that: "Planned outages are currently not modelled in the ESOO, because these are assumed to be planned in lower demand periods or to shift if low reserve conditions were to occur, and therefore not impact USE outcomes."

Surely, AEMO is aware that scheduled maintenance can sometimes take extended periods, even months? And power demand peaks twice per day – early evening and early morning during the 16 hour non-daytime period when solar is zero.

Interconnectors

AEMO's 2020 ISP, instead of including sufficient energy storage (probably because of its enormous cost) appears to adopt interconnector projects (costing $ tens of billions) which it hopes will improve reliability through geographic diversity of renewable energy supplies. Surely if one region is in wind and solar drought, AEMO hopes other regions will not be. Perhaps….they will generate enough surplus power to supply those regions that are short.

Given that interconnectors are such a critical factor in AEMO's plan, one would think the ISP would put forward the analytical studies and models to prove this will work. Not a word…

Geographic diversity is a popular idea among proponents for renewables but do the numbers stack up? For example when wind droughts hit Victoria and NSW (60% of NEM demand) at the same time, as shown in Table 3, will Queensland, South Australia and Tasmania with 40% of the grid size have enough surplus wind power to keep them afloat in non-daytime?

Unless wind generators are massively over-built in every region, standing by, ready for use when other regions run short during non-daytime and solar farms are overbuilt in all regions to support those regions experiencing daytime solar droughts from heavy clouds, there will simply not be sufficient power to share with the entire grid. How does this compute for capital costs, productivity and return on investment for huge assets which run at low utilisation? It simply does not.

Renewables already run at very low productivity (25-30% average) when compared with dispatchable generators (65-80%). How is it possible that investors could earn a viable return on investment, if large excess capacity is built into the grid? It would simply flood the market with surplus power during daytime driving wholesale prices to zero – as is already happening at certain times today. Savvy investors will shy away from such a plan and seek guaranteed returns from government regardless. This is not a market and the cost implications for consumers are incomprehensible.

Top-Down Power Budget Modelling

A top-level NEM power budget inherently *assumes 100% interconnectivity of the grid for transferring power from any place, to any where it is required.* It is therefore a somewhat optimistic analysis.

The previous dispatchable reserve margin analysis shows the impossibility of the ISP design to maintain an adequate dispatchable reserve margin. The next step in the analysis examines how variations in wind and solar power contribute to meeting grid demands.

The methodology used is the same as previously. A 24 hour cycle is broken into 8 hours of daytime and 16 hours of non-daytime, four of which demand peak power from energy storages. This analysis looks at three levels of NEM-wide renewables capacity factors: Substantial Drought at 10%, Average at 25%, and Above Average at 40%. Allowance is also made for the power during daytime dedicated to recharging the energy storage systems.

The details of this analysis are contained in Appendix 1. As before, the analysis is based entirely on data from the 2022 ISP and the maximum demand is set as 10% POE. The primary findings are as follows:

1. When **wind and sun are in substantial drought conditions** across the NEM (capacity factors of 10), catastrophic deficits occur continuously – often below minus 20% meaning ***major grid collapse***, despite all dispatchable sources, gas and hydro, running continuously at 100% capacity and all energy storage facilities being exhausted.
2. Under **average renewable energy conditions** across the grid (capacity factor – 25%), deficits occur continuously but for 2030, which still has a small amount of coal power, they are within the 20% reserve margin meaning the risk of blackouts due to facility breakdowns is increased. For the 16 non-daytime hours in 2040 and 2050, the deficit in power falls below minus 20% meaning ***frequent blackouts are inevitable***.
3. When a **surplus of wind and sun** occurs across the NEM (capacity factors of 40%), the daytime grid capacity is in surplus by large margins due to high solar and wind outputs. The result will be a ***collapse of wholesale power prices and large amounts of unsold power*** even when all dispatchable power is shut down. This will cause **substantial economic**

losses to both renewable energy and baseload generators. Yet the **grid is still unable to get through the 16 hour non-solar period without *significant deficits thus risking frequent blackouts***.

These dire results are a direct result of attempting to design an electrical grid with a vast majority of intermittent, highly variable, weather-dependent wind and solar generation with completely inadequate means for back up from dispatchable baseload power and energy storage systems.

No responsible power systems engineer would proceed with such a non-viable plan. Furthermore, the implications for the economy and for national security by relying on China, which dominates the market for wind and solar equipment and materials, is extremely negative.

A Closer Look at AEMO's 2022 ISP

1. Over the period 2030 to 2050, coal is eliminated, gas is reduced by 22% and hydro remains constant (no more dams). Therefore, *reliable baseload generation decreases by 41%.*
2. Snowy 2.0 provides a relatively low 2 GW of power compared to total grid design requirements (Table 2) of 54-74 GW in total. Its 7 day storage capacity will be useful over extended periods of wind and solar drought but many power system engineers think energy storage should be sized for at least twice that. To reliably firm up renewables in AEMO's grid design would require the equivalent of 20-30 Snowy 2.0 pumped hydro schemes, costing hundreds of billions of dollars. *Does Australia have the sites and environmental mandates to proceed with pumped hydro on this scale?*
3. DER Coordinated and Distributed DER are home storage batteries but only "coordinated" batteries are available to supply the grid directly. Distributed batteries are behind-the-meter and benefit the grid only by reducing possible grid demands from the specific residence. Strangely, the ISP forecasts 'coordinated' batteries to grow strongly by 800% while 'Distributed storages' stop growing completely by 2040 – *is this because regulations by 2040 will make "coordinated" home batteries mandatory?*
4. Home storage batteries cost about 5 times more per unit capacity than large utility batteries ($1500/kWh compared to about $300 per kWh). The total capital cost (paid by homeowners directly and by subsidies which are pare paid by all taxpayers) of the ISP's coordinated and distributed batteries is estimated at $135 billion and the lifetime of these batteries is about 10-12 years. By 2050, many homeowners will have bought two of them. Despite this high cost, AEMO's ISP is critically dependent on *consumers willingly paying for expensive home batteries*, because they account for 70% more than utility storages in 2030 rising to 175% by 2050. *How realistic is this assumption?*
5. Distributed PV in the ISP is home solar panel installations. They grow by 85% from 2030 to 2050 when they will be nine times more than today's capacity. They will exceed one third of the total renewable energy in the grid. That represents about 7-9 million homes and businesses. Without this assumed massive uptake in subsidised home solar, the ISP plan will fail to generate even the clearly insufficient power in its plan. In the face of rapidly rising costs for polysilicon and other materials to manufacture solar panels, *will this assumption hold up or will residents be forced to install solar panels?*

6. "Coordinated" means that homes are connected to control centres via the Internet. New technical standards adopted in 2021 require all new home installations to be internet capable. This will allow AEMO and its network providers, using artificial intelligence software, *to disconnect residential solar panels from supplying the grid during the day when massive solar power surpluses threaten to destabilize grid voltage*.

   It also will enable AEMO, under the Demand Participation Scheme (DSP) to turn off major home loads – heaters and air conditioners, hot water heaters and EV chargers when energy shortages exist – a frequent occurrence under this ISP plan. It will also allow AEMO to discharge a home battery, including an EV battery, into the grid to help compensate for power shortages. *How acceptable will DSP be for home owners or will it become mandatory?*

Some Answers to Frequently Asked Questions

1. **Why is the reliability number so high?** Public utilities such as water, power and telecommunications have long used this level of reliability as the criteria for delivering critical services to the public. 99.998% means service must not fail for more than 10 minutes per year! Partial failures may affect local areas for longer but over the year, total system shortfall must be less than 10.5 minutes of grid output. Yes, the reliability requirement is very strict – this is what consumers demand.

2. **Why is a 20% reserve margin necessary for reliability?** This is a grid design criteria to guard against power generation and transmission facilities being out of action for periodic maintenance and for repairs due to equipment failures. The NEM has always met or exceeded this criteria but the recent experience in June shows that when multiple unexpected facility repairs are needed *and solar and wind generation is at a low ebb*, the grid is at risk of blackouts. Europe has experienced months-long periods of below average solar and wind conditions. AEMO's public data shows the same thing.

3. **Why is solar only available for 8 hours?** Most solar panels are ideally mounted to face a northerly direction, where the sun is highest in the sky at noon, to produce maximum power. Most are firmly mounted for maximum strength against winds and lowest cost but some rotate in elevation to maximize output. In early morning, the easterly sun is rising at a low angle above the horizon, which provides little or no illumination of the panels. The same situation exists when the sun sets in the west. The effective period during which solar power is generated is about 4 hours on each side of noontime although seasonal variation occurs. Clouds also cause significant variation throughout the day and large weather systems can affect almost the entire NEM at the same time.

4. **Surely wind and solar will produce more power during the 16 hour period somewhere in the grid?** This is the major assumption of the ISP. However, the entire NEM grid experiences night at about the same time – every day. Hence total NEM solar generation is zero at night. Yet the AEMO grid design is for solar generation to be two thirds of all renewable power! Wind generated power varies at all times of the day and night. When atmospheric pressure gradients are low, wind decreases and at night it falls off in the absence of solar-induced thermal activity.

5. **Isn't a surplus of wind and solar power during daytime a good thing**? If it is captured and stored for use in the non-solar 16 hour non-daytime period it would be helpful but the cost of energy storage is far beyond economical. However, wind and solar is not in surplus every daytime – AEMO records data on all of its power generation outputs every few minutes of every day. The data shows that wind and solar generation frequently falls to almost zero over large areas, sometimes for days, for example in NSW and Victoria, which together account for 60% of NEM demand. In this situation, all other regions not only must have high capacity interconnectors, they must also massively overbuild wind and solar generators beyond their own needs in order to serve other regions. Over-capacity means a very low return on investment for wind and solar farms.
6. **Why doesn't AEMO's grid design use more energy storage?** AEMO's design has probably avoided adequate energy storage to meet reliability goals due to its enormous expense. To match Snowy 2.0's 7 day storage capacity, battery storage to back up the grid in 2050 (in excess of Snowy 2.0 and dispatchable power) would require at least 7980 GWh instead of the 319 GWh in the ISP. Cost estimates for this scale of battery back-up would be in the $5-7 trillion range, given the rapidly rising cost of lithium, cobalt and other battery materials - clearly an unaffordable cost which recurs every 10 years. Instead, the ISP focuses on interconnectors as the solution. However, interconnectors produce no additional power and the ISP design is clearly short of power generation. More wind and solar generation, as has been publicly advocated by many, does not add significant power at night when wind conditions are low and solar is zero.
7. **Do interconnectors lose some of the power being transmitted?** Yes, the longer the distance of transmission, the greater the losses due to resistance in the wires. Each interconnector will have its own characteristics but losses can be as much as 8-15%. The top-level power budget analysis optimistically makes no allowance for interconnector losses. Transmission losses of 0-3% in the power budget are for local distribution. Solar and wind farms in remote Renewable Energy Zones have higher losses than local baseload generators.
8. **Why doesn't AEMO's plan use nuclear energy to firm up renewables?** This idea, which has been advocated by prominent people, is rejected by climate activists and the renewables industry alike. Activists oppose all nuclear power on safety grounds but the renewable energy industry rejects it because it would be far more sensible and less expensive to run the "zero-emission" nuclear power plants 24/7 and eliminate the massive costs of wind and solar farms, energy storage systems, interconnectors and voltage stabilization facilities. Nuclear power is expensive in terms of traditional large scale custom-designed plants. Small modular reactors using modern technology for nuclear power plants are under active development in many countries and offer the promise of high safety, production line cost efficiencies with standard designs, flexibility in siting and expandability to meet changing requirements. By 2030, SMRs will be available and costs will probably be well known.
9. **What happens when more people buy EVs and want to charge them up at night**? The AEMO forecast for future electricity demand is partly based on increasing EV demand and recent studies have revealed that 95% of EV owners wish to recharge overnight. The analysis shows the non-daytime period of 16 hours when solar is not available is the period in which the planned grid is most likely to fail to meet demand. The prevailing reality that

peak grid demand occurs in early evening and early morning will likely be replaced by peak demand lasting through most of the night.

Appendix 1 AEMO 2022 ISP Top-Level Power Budget and Demand Tables

The tables on the next three pages provide the 2022 ISP top-level NEM power budgets compared to the design criteria for reliability, which requires maximum grid output to be greater than the maximum forecast design plus a 20% reserve to account for outages due to maintenance and repairs.

These tables assume that the grid has 100% interconnection. The explanation notes for various items in the tables is as follows:

Notes

1. Source power outputs from 2022 ISP Figure 1 for 2029-30, 2039-40 & 2049-50
2. Storage capacities from2022 ISP Figure 23
3. AEMO 10% POE Maximum Power Demand Forecast ESOO August 2022
4. Transmission losses are low for regional power supplies but higher for remote Renewable Energy Zones; losses for use of interconnectors are not included.
5. Distributed DER Storage (residential systems behind the meter) is not available to the grid but potentially reduce demands from their own installation.
6. Recharge efficiency accounts for transmission of power to storage sites, converting electricity to and then back from an alternative form.
7. It is assumed that all interconnector projects are implemented allowing all power generated anywhere to be delivered anywhere.
8. The 20% Reserve requirement guards the grid against transmission line failures and both scheduled and non-scheduled facility repairs and maintenance.
9. The power budget is for a 24 hour cycle broken into 8 hrs when solar is available and 16 hrs comprising 4 hours of peak demand and 12 hours of off-peak.
10. The power delivered to the grid is subject to a capacity factor - the percentage of maximum capacity that is dispatchable (baseload and storage) or available (wind/solar).
11. The capacity factor of baseload is adjusted downwards if a surplus of supply exists.
12. Preference is given to stored renewable energy over baseload.
13. The Energy Start and End lines record the stored energy levels before and after energy is delivered to the grid remaining in storage
14. Stored energy is allocated first to the 4 hour peak period; the remainder spread out over the 12 hour period.
15. The capacity factors for variable and intermittent renewable energy can be adjusted to reflect average grid conditions for wind and solar generation.
16. 25% is a nominal average daily capacity factor for wind and solar; daily solar output is focused to 8 hrs per day at 3 x the daily rate, average wind falls slightly at night.
17. Recharge power is calculated to restore full storage levels within the 8 hour window for solar energy generation.
18. A deficit exceeding -20% indicates blackouts are a certainty; blackouts may occur at any point of deficit if some generation facilities or transmission lines are inoperative.
19. A surplus indicates unsold energy; thus reducing the profitability of energy generators.

AEMO Forecast Maximum Demand Data

ESOO August 2022 10% POE Data

Step Change Scenario

Maximum Summer Demand	**Operational (Sent Out)**		
	2030	**2040**	**2050**
Region	**GW**	**GW**	**GW**
NSW	15.4	18.1	20.8
VIC	11.6	13.8	17.5
QLD	12.0	13.7	15.6
SA	3.9	4.7	5.5
TAS	1.9	2.0	2.2

Total Max Op sent out **44.8** **52.3** **61.5**

Table 1 Substantial Drought Wind and Solar Conditions

AEMO 2022 ISP Top-Level Power Budget														
Step Change Scenario with Complete Interconnection [7]						**Maximum Grid Power Inputs over 24 Hours Period - GW**								
Renewable Energy: Substantial Drought Conditions					**Period** [9]	**2030**			**2040**			**2050**		
Daily Capacity Factor: Solar	10%				**hrs**	16		8	16		8	16		8
Wind	10% Daytime; 10% Night					**Peak** [14]	**Remainder**	**Daytime**	**Peak** [14]	**Remainder**	**Daytime**	**Peak** [14]	**Remainder**	**Daytime**
AEMO 2022 ISP Sources of Power					**hrs**	4	12	8	4	12	8	4	12	8
Maximum Dispatchable Power [1]						**Operating Capacity Factor CF %** [10, 11]								
	2030	**2040**	**2050**	**Transmission**		**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
Dispatchable Sources	GW	GW	GW	**Losses** [4]		**GW**	**GW**	**GW**	**GW**	**GW**	**GW**	**GW**	**GW**	**GW**
Coal	9.0	0.9	0.0	1.0%		8.9	8.9	8.9	0.8	0.8	0.8	0.0	0.0	0.0
Gas	12.3	9.1	9.6	1.0%		12.2	12.2	12.2	9.0	9.0	9.0	9.5	9.5	9.5
Hydro	7.2	7.1	7.1	1.0%		7.1	7.1	7.1	7.1	7.1	7.1	7.0	7.0	7.0
Subtotal Dispatchable	**28.6**	**17.0**	**16.7**			**28.3**	**28.3**	**28.3**	**16.9**	**16.9**	**16.9**	**16.5**	**16.5**	**16.5**
Maximum Storage Power Output and Energy Capacity [1]				**Transmission**		**Maximum Available Power for Non-Daytime Periods** [12]								
Dispatchable Storage [2]	**2030**	**2040**	**2050**	**Losses** [4]		**GW**	**GW**	**GW**	**GW**	**GW**	**GW**	**GW**	**GW**	**GW**
Snowy 2.0 Power GW	2.1	2.1	2.1	3.0%		2.0	2.0		2.0	2.0		2.0	2.0	
Energy Start [13] GWh	349	349	349											
End Peak Period GWh	341	341	341											
End Remainder GWh	316	316	316											
Utility Storage Power GW	3.9	10.8	13.7	3.0%		3.7	1.3		10.5	8.1		13.3	10.3	
Energy Start [13] GWh	31	144	182											
End Peak Period GWh	16	101	127											
End Remainder GWh	0	0	0											
DER Coordinated Power GW	3.8	17.2	30.6	1.0%		2.0	0.0		11.6	0.0		26.7	0.0	
Energy Start [13] GWh	8	47	108											
End Peak Period GWh	0	0	0											
End Remainder GWh	0	0	0											
(Behind the Meter) Impact on Grid [5]				Effectiveness										
Distributed DER Power GW	5.5	14.6	14.4	50.0%		1.8	0.0		3.8	0.0		3.6	0.0	
Energy Start [13] GWh	14	30	29											
End Peak Period GWh	0	0	0											
End Remainder GWh	0	0	0											
Subtotal Storage Power GW	**9.8**	**30.1**	**46.4**			**9.5**	**3.3**		**27.9**	**10.2**		**45.7**	**12.3**	
Total Dispatch. Power GW	**38.3**	**47.1**	**63.1**			**37.8**	**31.5**	**28.3**	**44.7**	**27.0**	**16.9**	**62.2**	**28.8**	**16.5**
Variable/Intermittent Renewables Maximum Power [1]				**Transmission**		**Daily Capacity Factor % and Available Power GW** [15, 16]								
VRE Sources				**Losses** [4]				**10%**			**10%**			**10%**
Utility Solar GW	13.6	34.7	69.6	3%	GW			3.9			10.1			20.3
								10%			**10%**			**10%**
Distributed PV GW	37.2	55.0	68.6	0%	GW			11.2			16.5			20.6
						10%	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**
Wind GW	36.5	49.5	69.7	3%	GW	3.5	3.5	3.5	4.8	4.8	4.8	6.8	6.8	6.8
Total VRE GW	**87.3**	**139.1**	**207.9**			**3.5**	**3.5**	**18.7**	**4.8**	**4.8**	**31.4**	**6.8**	**6.8**	**47.6**
Total Supply Capacity - Dispatchable plus VRE GW					GW	**41.3**	**35.1**	**46.9**	**49.5**	**31.8**	**48.2**	**68.9**	**35.6**	**64.1**
Required Recharge Energy				**Recharge**		**Required Recharge Power GW** [17]								
Storage Recharge	**Required Energy GWh**			**Efficiency** [6]				**GW**			**GW**			**GW**
Snowy 2.0 GWh	44.2	44.2	44.2	75%				5.5			5.5			5.5
Utility Storage GWh	36.5	169.4	214.1	85%				4.6			21.2			26.8
DER Coordinated GWh	9.4	55.3	127.1	85%				1.2			6.9			15.9
Total Required Recharge Power GW								**11.3**			**33.6**			**48.2**
Total Available Customer Grid Power GW						**41.3**	**35.1**	**35.7**	**49.5**	**31.8**	**14.6**	**68.9**	**35.6**	**16.0**
Grid Power Demand and Reliability Reserve														
AEMO 10% POE Maximum Power Demand Forecast GW [3]						44.8	44.8	44.8	52.3	52.3	52.3	61.5	61.5	61.5
20% Reliability Reserve GW [8]						9.0	9.0	9.0	10.5	10.5	10.5	12.3	12.3	12.3
Total Grid Power Requirement						**53.8**	**53.8**	**53.8**	**62.8**	**62.8**	**62.8**	**73.8**	**73.8**	**73.8**
Surplus[19]/Deficit[18] (Avail. Power - Grid Power Demand + Reserve) GW						-12.4	-18.7	-18.1	-13.2	-30.9	-48.1	-4.9	-38.2	-57.8
Shortfall wrt Total Grid Power Requirement						-23.2%	-34.7%	-33.6%	-21.1%	-49.3%	-76.7%	-6.6%	-51.8%	-78.4%

Table 2 Average Wind and Solar Conditions

AEMO 2022 ISP Top-Level Power Budget

Step Change Scenario with Complete Interconnection [7]							**Maximum Grid Power Inputs over 24 Hours Period - GW**								
Renewable Energy: Average Conditions						**Period [9]**	**2030**			**2040**			**2050**		
Daily Capacity Factor:	Solar	25%				**hrs**	16		8	16		8	16		8
	Wind	25% Daytime; 25% Night					**Peak [14]**	**Remainder**	**Daytime**	**Peak [14]**	**Remainder**	**Daytime**	**Peak [14]**	**Remainder**	**Daytime**
AEMO Sources of Power						**hrs**	4	12	8	4	12	8	4	12	8
Maximum Dispatchable Power [1]							**Operating Capacity Factor CF % [10, 11]**								
		2030	**2040**	**2050**	**Transmission**		**100%**	**100%**	**55%**	**100%**	**100%**	**65%**	**45%**	**100%**	**0%**
Dispatchable Sources		GW	GW	GW	**Losses [4]**		**GW**	**GW**	**GW**	**GW**	**GW**	**GW**	**GW**	**GW**	**GW**
Coal		9.0	0.9	0.0	1.0%		8.9	8.9	4.9	0.8	0.8	0.5	0.0	0.0	0.0
Gas		12.3	9.1	9.6	1.0%		12.2	12.2	6.7	9.0	9.0	5.8	4.3	9.5	0.0
Hydro		7.2	7.1	7.1	1.0%		7.1	7.1	3.9	7.1	7.1	4.6	3.1	7.0	0.0
Subtotal Dispatchable		**28.6**	**17.0**	**16.7**			**28.3**	**28.3**	**15.6**	**16.9**	**16.9**	**11.0**	**7.4**	**16.5**	**0.0**
Maximum Storage Power Output and Energy Capacity [1]					**Transmission**		**Maximum Available Power for Non-Daytime Periods [12]**								
Dispatchable Storage [2]		**2030**	**2040**	**2050**	**Losses [4]**		**GW**	**GW**	**GW**	**GW**	**GW**	**GW**	**GW**	**GW**	**GW**
Snowy 2.0 Power	GW	2.1	2.1	2.1	3.0%		2.0	2.0		2.0	2.0		2.0	2.0	
Energy Start [13]	GWh	349	349	349											
End Peak Period	GWh	341	341	341											
End Remainder	GWh	316	316	316											
Utility Storage Power	GW	3.9	10.8	13.7	3.0%		3.7	1.3		10.5	8.1		13.3	10.3	
Energy Start [13]	GWh	31	144	182											
End Peak Period	GWh	16	101	127											
End Remainder	GWh	0	0	0											
DER Coordinated Power	GW	3.8	17.2	30.6	1.0%		2.0	0.0		11.6	0.0		26.7	0.0	
Energy Start [13]	GWh	8	47	108											
End Peak Period	GWh	0	0	0											
End Remainder	GWh	0	0	0											
(Behind the Meter) Impact on Grid [5]					Effectiveness										
Distributed DER Power	GW	5.5	14.6	14.4	50.0%		1.8	0.0		3.8	0.0		3.6	0.0	
Energy Start [13]	GWh	14	30	29											
End Peak Period	GWh	0	0	0											
End Remainder	GWh	0	0	0											
Subtotal Storage Power GW		**9.8**	**30.1**	**46.4**			**9.5**	**3.3**		**27.9**	**10.2**		**45.7**	**12.3**	
Total Dispatch. Power	**GW**	**38.3**	**47.1**	**63.1**			**37.8**	**31.5**	**15.6**	**44.7**	**27.0**	**11.0**	**53.1**	**28.8**	**0.0**
						8E+06									
Variable/Intermittent Renewables Maximum Power [1]					**Transmission**		**Daily Capacity Factor % and Available Power GW [15, 16]**								
VRE Sources					**Losses [4]**				**25%**			**25%**			**25%**
Utility Solar	GW	13.6	34.7	69.6	3%	GW			9.9			25.2			50.6
									25%			**25%**			**25%**
Distributed PV	GW	37.2	55.0	68.6	0%	GW			27.9			41.2			51.4
							25%	**25%**	**25%**	**25%**	**25%**	**25%**	**25%**	**25%**	**25%**
Wind	GW	36.5	49.5	69.7	3%	GW	8.9	8.9	8.9	12.0	12.0	12.0	16.9	16.9	16.9
Total VRE	**GW**	**87.3**	**139.1**	**207.9**			**8.9**	**8.9**	**46.7**	**12.0**	**12.0**	**78.5**	**16.9**	**16.9**	**119.0**
Total Supply Capacity - Dispatchable plus VRE	**GW**					GW	**46.6**	**40.4**	**62.2**	**56.7**	**39.0**	**89.4**	**70.0**	**45.7**	**119.0**
Required Recharge Energy					**Recharge**		**Required Recharge Power GW [17]**								
Storage Recharge		**Required Energy GWh**			**Efficiency [6]**				**GW**			**GW**			**GW**
Snowy 2.0	GWh	44.2	44.2	44.2	75%				5.5			5.5			5.5
Utility Storage	GWh	36.5	169.4	214.1	85%				4.6			21.2			26.8
DER Coordinated	GWh	9.4	55.3	127.1	85%				1.2			6.9			15.9
Total Required Recharge Power GW									**11.3**			**33.6**			**48.2**
Total Available Customer Grid Power GW							**46.6**	**40.4**	**50.9**	**56.7**	**39.0**	**55.8**	**70.0**	**45.7**	**70.8**
Grid Power Demand and Reliability Reserve															
AEMO 10% POE Maximum Power Demand Forecast GW [3]							44.8	44.8	44.8	52.3	52.3	52.3	61.5	61.5	61.5
20% Reliability Reserve GW [8]							9.0	9.0	9.0	10.5	10.5	10.5	12.3	12.3	12.3
Total Grid Power Requirement							**53.8**	**53.8**	**53.8**	**62.8**	**62.8**	**62.8**	**73.8**	**73.8**	**73.8**
Surplus [19]/Deficit [18] (Avail. Power - Grid Power Demand + Reserve) GW							**-7.1**	**-13.4**	**-2.8**	**-6.0**	**-23.7**	**-6.9**	**-3.8**	**-28.1**	**-3.0**
Shortfall wrt Total Grid Power Requirement							**-13.3%**	**-24.8%**	**-5.2%**	**-9.6%**	**-37.8%**	**-11.1%**	**-5.1%**	**-38.0%**	**-4.1%**

Table 3 Above-Average Wind and Solar Conditions

AEMO 2022 ISP Top-Level Power Budget

Step Change Scenario with Complete Interconnection [7]							**Maximum Grid Power Inputs over 24 Hours Period - GW**								
Renewable Energy: Above Average Conditions						**Period** [9]	**2030**			**2040**			**2050**		
Daily Capacity Factor:	Solar	40%				**hrs**	16		8	16		8	16		8
	Wind	40% Daytime; 35% Night					**Peak** [14]	**Remainder**	**Daytime**	**Peak** [14]	**Remainder**	**Daytime**	**Peak** [14]	**Remainder**	**Daytime**
AEMO 2022 ISP Sources of Power						**hrs**	4	12	8	4	12	8	4	12	8
Maximum Dispatchable Power [1]							**Operating Capacity Factor CF %** [10, 11]								
		2030	**2040**	**2050**	**Transmission**		**100%**	**100%**	**0%**	**100%**	**100%**	**0%**	**0%**	**100%**	**0%**
Dispatchable Sources		GW	GW	GW	**Losses** [4]		**GW**	**GW**	**GW**	**GW**	**GW**	**GW**	**GW**	**GW**	**GW**
Coal		9.0	0.9	0.0	1.0%		8.9	8.9	0.0	0.8	0.8	0.0	0.0	0.0	0.0
Gas		12.3	9.1	9.6	1.0%		12.2	12.2	0.0	9.0	9.0	0.0	0.0	9.5	0.0
Hydro		7.2	7.1	7.1	1.0%		7.1	7.1	0.0	7.1	7.1	0.0	0.0	7.0	0.0
Subtotal Dispatchable		**28.6**	**17.0**	**16.7**			**28.3**	**28.3**	**0.0**	**16.9**	**16.9**	**0.0**	**0.0**	**16.5**	**0.0**
Maximum Storage Power Output and Energy Capacity [1]					**Transmission**		**Maximum Available Power for Non-Daytime Periods** [12]								
Dispatchable Storage [2]		**2030**	**2040**	**2050**	**Losses** [4]		**GW**	**GW**	**GW**	**GW**	**GW**	**GW**	**GW**	**GW**	**GW**
Snowy 2.0 Power	GW	2.1	2.1	2.1	3.0%		2.0	2.0		2.0	2.0		2.0	2.0	
Energy Start [13]	GWh	349	349	349											
End Peak Period	GWh	341	341	341											
End Remainder	GWh	316	316	316											
Utility Storage Power	GW	3.9	10.8	13.7	3.0%		3.7	1.3		10.5	8.1		13.3	10.3	
Energy Start [13]	GWh	31	144	182											
End Peak Period	GWh	16	101	127											
End Remainder	GWh	0	0	0											
DER Coordinated Power	GW	3.8	17.2	30.6	1.0%		2.0	0.0		11.6	0.0		26.7	0.0	
Energy Start [13]	GWh	8	47	108											
End Peak Period	GWh	0	0	0											
End Remainder	GWh	0	0	0											
(Behind the Meter) Impact on Grid [5]					Effectiveness										
Distributed DER Power	GW	5.5	14.6	14.4	50.0%		1.8	0.0		3.8	0.0		3.6	0.0	
Energy Start [13]	GWh	14	30	29											
End Peak Period	GWh	0	0	0											
End Remainder	GWh	0	0	0											
Subtotal Storage Power	**GW**	**9.8**	**30.1**	**46.4**			**9.5**	**3.3**		**27.9**	**10.2**		**45.7**	**12.3**	
Total Dispatch. Power	**GW**	**38.3**	**47.1**	**63.1**			**37.8**	**31.5**	**0.0**	**44.7**	**27.0**	**0.0**	**45.7**	**28.8**	**0.0**
Variable/Intermittent Renewables Maximum Power [1]					**Transmission**		**Daily Capacity Factor % and Available Power GW** [15, 16]								
VRE Sources					**Losses** [4]				**40%**			**40%**			**40%**
Utility Solar	GW	13.6	34.7	69.6	3%	GW			15.8			40.4			81.0
									40%			**40%**			**40%**
Distributed PV	GW	37.2	55.0	68.6	0%	GW			44.7			66.0			82.3
							35%	**35%**	**40%**	**35%**	**35%**	**40%**	**35%**	**35%**	**40%**
Wind	GW	36.5	49.5	69.7	3%	GW	12.4	12.4	14.2	16.8	16.8	19.2	23.7	23.7	27.0
Total VRE	**GW**	**87.3**	**139.1**	**207.9**			**12.4**	**12.4**	**74.6**	**16.8**	**16.8**	**125.5**	**23.7**	**23.7**	**190.4**
Total Supply Capacity - Dispatchable plus VRE	**GW**					GW	**50.2**	**44.0**	**74.6**	**61.5**	**43.8**	**125.5**	**69.3**	**52.5**	**190.4**
Required Recharge Energy					**Recharge**		**Required Recharge Power GW** [17]								
Storage Recharge		**Required Energy GWh**			**Efficiency** [6]				**GW**			**GW**			**GW**
Snowy 2.0	GWh	44.2	44.2	44.2	75%				5.5			5.5			5.5
Utility Storage	GWh	36.5	169.4	214.1	85%				4.6			21.2			26.8
DER Coordinated	GWh	9.4	55.3	127.1	85%				1.2			6.9			15.9
Total Required Recharge Power GW									**11.3**			**33.6**			**48.2**
Total Available Customer Grid Power GW							**50.2**	**44.0**	**63.4**	**61.5**	**43.8**	**91.9**	**69.3**	**52.5**	**142.2**
Grid Power Demand and Reliability Reserve															
AEMO Maximum Power Demand Forecast GW [3]							44.8	44.8	44.8	52.3	52.3	52.3	61.5	61.5	61.5
20% Reliability Reserve GW [8]							9.0	9.0	9.0	10.5	10.5	10.5	12.3	12.3	12.3
Total Grid Power Requirement							**53.8**	**53.8**	**53.8**	**62.8**	**62.8**	**62.8**	**73.8**	**73.8**	**73.8**
Surplus [19] **/Deficit** [18] **(Avail. Power - Grid Power Demand + Reserve) GW**							**-3.6**	**-9.8**	**9.6**	**-1.2**	**-19.0**	**29.2**	**-4.5**	**-21.3**	**68.4**
Shortfall wrt Total Grid Power Requirement							**-6.7%**	**-18.2%**	**17.9%**	**-1.9%**	**-30.2%**	**46.5%**	**-6.1%**	**-28.9%**	**92.7%**