Submission on 23/24 GenCosts report

David Conomy, 08/02/24

The GenCosts approach

The CSIRO's GenCosts report has commendable aims to compare *"the relative competitiveness of generation technologies".* However reading it I was underwhelmed by what I felt was a flawed approach to the wrong question. The report's central finding - comparing the costs of variable renewables to conventional baseload forms of energy - is equally flawed and misleading. While baseload power generators could be compared on this basis, individual variable renewables surely cannot as they cannot by themselves provide baseload power. Instead they require a "system" of generation and storage technologies to provide the baseload power which could be relied upon to meet demand. The massive area requirements and geographical spread per unit energy of renewables would also require the network to be extended and upgraded to make use of this power. The GenCosts report attempts to deal with this problem by introducing the concept of VRE share, however the assumptions and results presented in the report suggest fundamental flaws in the underlying approach here too. Given that network reliability is a firm requirement, I suggest that the only way to meaningfully compare the costs of variable renewable technologies to baseload power sources, is to compare the total system costs of a scalable renewable system which can produce a comparable level of reliable baseload supply. I will refer to such a system as a baseload variable renewable energy (BVRE) system.

In this submission I will present an alternative approach and model to evaluate and optimise a BVRE system. This approach allows for the optimisation of a system which is scalable and does not rely on highly tenuous scenario narratives. The results of this model can then be used to provide meaningful cost comparisons to other baseload energy systems. My model results contradict the GenCosts report's central finding that a renewable energy system presents the lowest cost energy system. Furthermore, as I will outline below there are several reasons to believe that my model likely also underestimates the full costs of a BVRE system.

System requirements must meet network requirements

A key requirement for any reliable energy network is that it is able to meet demand at all times. The systems which make up the network must also meet network requirements as well as be scalable to meet changing demand. Australia's electricity supply sector only represented around 25% of Australia's 2020/21 energy use.[1] Continued electrification has the potential to massively increase electricity demand, by pushing transport and other sector's demand onto the electricity grid. These changes may also significantly alter the existing demand curves. For example, widespread uptake of EVs would massively push up night-time demand from overnight charging, a period where renewable supply is at a minimum. If we want to correctly understand the costs associated with scaling a BVRE system to meet both current and future demand, it's clear that it needs to be costed and optimised as a standalone system. Now the authors may argue that the report was aimed at investors and so total system cost was not a focus, however I believe this explanation is entirely unsatisfactory. Regardless of whether costs are borne by investors, private individuals/businesses, consumers or taxpayers, ultimately Australians pick up the bill. Therefore, all costs necessary for the operation of the BVRE system need to be included.

[1] https://www.energy.gov.au/sites/default/files/Australian%20Energy%20Statistics%202022%20Energy%20Update%20Report.pdf

Energy generation vs dispatchability

It is not possible or practical for me to assess the competency of the modelling undertaken by GenCosts or the ISP, particularly as only the outputs are publicly available. However, a fundamental flaw with the GenCosts approach seems to be its reliance on average energy generation (in the form of capacity factors) rather than baseload capacity for benchmarking variable renewables against conventional baseload energy sources. This erroneously conflates average energy generation from variable renewables with dispatchable energy, which incorrectly assumes that variable renewables can be turned on as required with a reliable supply. While a BVRE system could provide dispatchable energy, it could only do so at its baseload supply level. Systems therefore need to be benchmarked against their minimum dispatchable energy (i.e. baseload capacity) not their average energy generation.The timescale required to undertake this analysis is also at the hour (or less) timescale rather than the year average timescale adopted by the GenCosts report. To illustrate my point, consider the case where we rely on a wind farm which might produce vast quantities of energy in the morning while producing none later in the day. While the average energy generated over the day may meet the average demand, such variability would likely necessitate a conventional flexible baseload system running in parallel. Unpredictability would also complicate your ability to set baseload supply without risking a system failure. This means that baseload supply would likely need to be scaled to meet the vast majority of demand, while the renewable system simply floods the grid with excess energy that is ultimately wasted. The below figure shows that this problem can actually be seen on the aggregate scale of the NEM.

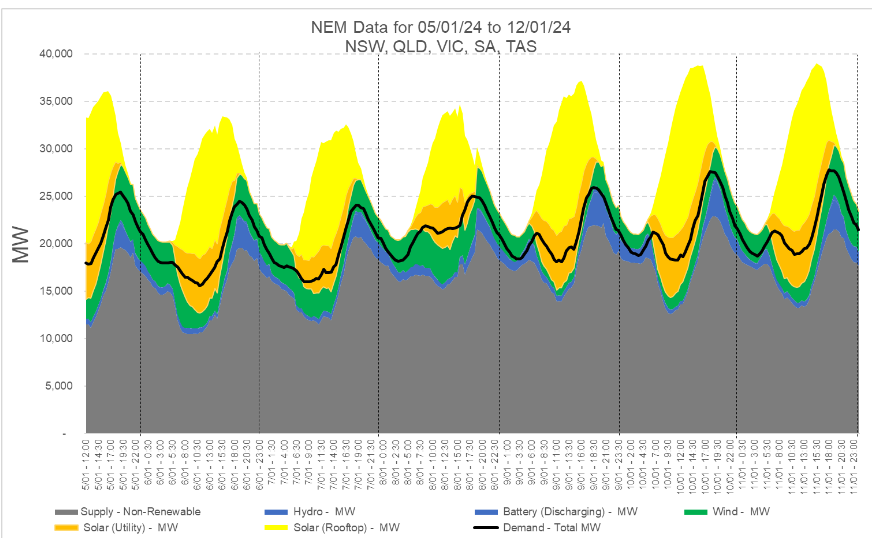

Figure 1: 7 day hourly NEM supply and demand data taken from OpenNEM and AEMO

An alternative approach and model for a BVRE system

Recognising this as an issue I instead built my own model to test the report's findings against competent BVRE systems. My model attempted to assess BVRE systems which consist of combinations of large-scale solar PV and onshore wind for energy generation. These technologies were chosen by GenCosts for their own VRE analysis, being identified as the lowest cost per unit of generated energy of other forms of renewable energy currently available.[2] Importantly, the two technologies also have somewhat complementary supply curves. Australia also has many real-world examples of projects for both technologies. For storage, BVRE systems utilised large-scale battery energy storage systems

[2] Aurecon 2023 estimates EPC cost per kW nameplate capacity of $2,875/kW for onshore wind, $1,440/kW for large scale solar as compared to $5,323/kW for Offshore wind and $14,670/kW for wave energy.

(BESS) as again this was considered the lowest cost per unit of energy storage capacity that is currently available. These systems are also suitable for use with solar and wind.

First I built stochastic numerical models to simulate the hour-to-hour variability of both onshore wind and solar generators. These generation models were fit and validated against statewide OpenNEM data for Victoria after being scaled for total state nameplate capacity for each technology. Models were fit and validated against actual data on the seasonal, day to day and hourly timescales. Statewide data was used so the model would accurately reflect collective supply rather than individual generators. For simplicity, the model assumed a “copperplate” network, which in reality would likely require either massive network upgrades or renewable systems to be co-located near the existing network. It is not clear that a “copperplate” model assumption would be appropriate for geographic scales beyond this, certainly not without incurring massive network upgrade costs. Additionally, as the NEM data at the hour-to-hour level shows similar variability to statewide data, it seems unlikely it would impact the conclusion even if the assumption was achieved in practice. So I then used these energy generation models as a supply input to a simple battery model which could simulate charge and discharge on a hour-to-hour basis to maintain a specified baseload power supply. Instantaneous ramping was assumed as an approximation to rapid ramping of BESS facilities.[3] A simple discounted cost model then provides a total system cost per unit of baseload energy for the chosen arrangement. The cost model makes use of either real-world Victorian projects (if available) or estimates from Aurecon 2023 (where real-world data is not available).[4] Unlike the GenCosts report, costs were on a total system basis including costs of land development in accordance with Aurecon 2023 as well as network connection cost estimates provided by AEMO 2021. This model was then used to compare BVRE system costs for different combinations of solar, wind and battery storage that were competent to produce reliable baseload power.

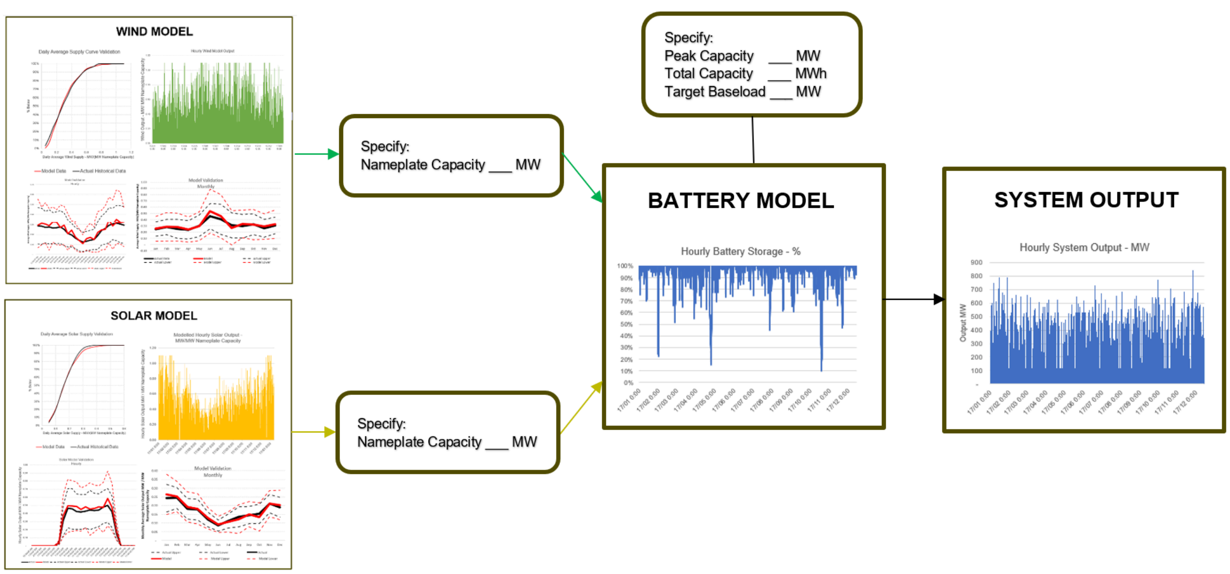

Figure 2: Schematic of showing structure of numerical model for BVRE system

[3] Aurecon 2023 estimates ramping rates of 10,000MW/min

[4] Real-world project costs were also checked against Aurecon 2023 estimates for consistency

An example of the model output is shown below for illustrative purposes. Put simply, at times where total generation is above the baseload demand threshold the battery charges, while it discharges to increase supply at times when total generation is below the baseload demand threshold.

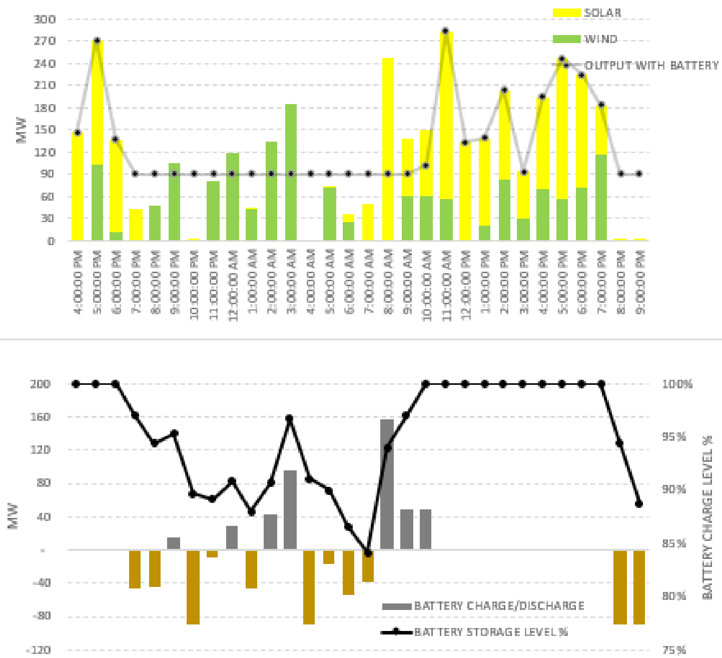

Figure 3: Example of model output results. Baseload demand threshold set at 90MW.

BVRE system optimisation

After inputting parameters for baseload supply, solar nameplate capacity, wind nameplate capacity and battery capacity, the model can be run multiple times to simulate multiple years performance. Systems were only considered competent to produce reliable baseload power if system output did not dip below the specified threshold baseload level demand for more than 12hours per year.[5] In reality such a result would translate to an uncontrolled network wide blackout, which may not be acceptable even at this level. However, given these constraints, iIterations of different proportions of solar,wind, battery size and baseload supply level can now be performed to determine an optimum BVRE system cost.

Initial system cost optimisation was performed on a 530MW onshore wind farm as this is the size of a recent large scale onshore wind farm project example at Stockyard Hill in Victoria. As expected, the analysis found that combinations of wind+battery and solar+battery produce lower baseload power levels and higher total system costs than when all three technologies are combined. This seems to be due to the technologies “filling in” for each other at times of low supply which lessens the requirement for battery storage. However, cost optimisation of the model also provides an insight into the interaction of system parameters on system cost rates. Generally it shows that systems with lower battery capacity produce lower baseload power outputs which increases the system cost rate. Baseload capacity level can be increased by adding more batteries but only up to an optimum baseload capacity (lowest cost), beyond this point battery storage requirements increase dramatically per unit of baseload power and system costs also rise sharply. Optimisation assumed BESS storage with a duration of 8 hours in line with the ISP’s

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[5] The model is stochastic so at least 5 model runs were used to test competence

definition and adoption of “medium storage”. Cost estimates for BESS systems were taken from Aurecon 2023.[6] A sensitivity check was also undertaken assuming BESS storage with 2 hour duration.

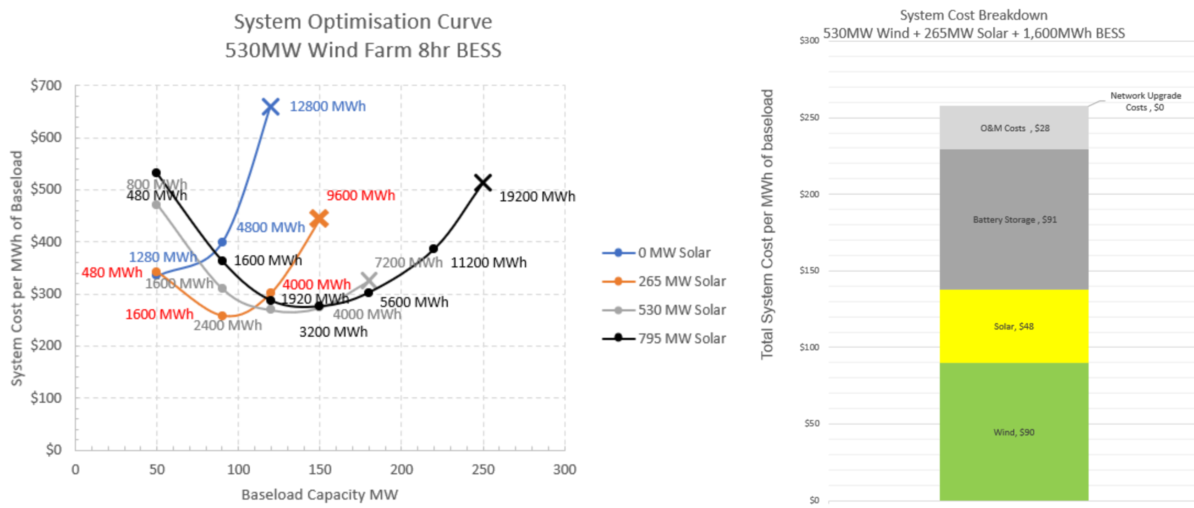

Figure 4: BVRE system optimisation curve (left), distribution of costs for optimum system (right)

The analysis found that the optimum BVRE system cost per unit of baseload energy occurs when the 530MW wind generator was coupled with a 265MW solar generator and supported by a 200MW battery with 8hr duration (1,600MWh capacity). This system can produce 90MW of reliable baseload power at a system cost of **$258 per MWh of baseload.** For scaling purposes this means for every **1MW of baseload** you need **8.8MW (5.9MW wind and 2.9MW of solar)** of nameplate capacity coupled with around **2.2 MW** of 8 hour duration battery storage. Sensitivity checks assuming a 2 hour duration battery produced similar results, although an optimum system cost was found with an equal mix of wind and solar at a slightly higher system cost. Sensitivity checks on systems with a larger share of solar were also found to require more battery storage and had higher optimum system costs. The performance of the optimised BVRE system was also subsequently tested and confirmed when scaled to meet higher baseload demand levels as well as using real world demand curves.

My model approach is useful for understanding the underlying drivers of BVRE system cost. It can be used to provide guidance on the cheapest mix of renewables to achieve the lowest overall system cost but it can also be used to estimate the effective system cost when other factors dictate the mix used.

GenCosts storage assumptions

The GenCosts report claims that *“ Integration costs to support renewables are estimated at $34/MWh to $41/MWh in 2023 and $25/MWh to $34/MWh in 2030 depending on the VRE share (Figure 5-3 and Figure 5-4).”*. In a response to prior feedback the report goes on to claim *“The modelling approach applied accounts for all of these factors across nine historical weather years. The result we find is that, in 2030, the NEM needs to have 0.28kW to 0.4kW storage capacity for each kW of variable renewable generation installed.”* These findings have not been substantiated in the report, however the explanations provided by the authors do provide some insight into the fundamental flaws in their approach. Firstly, the authors appear to base their conclusions on misleading comparisons between demand and supply on an annual average basis. If output from wind and solar farms only varied on a year to year basis this might be an appropriate comparison, however in reality supply from these sources varies significantly at the

[6] Aurecon 2023, table 9-3

scale of an hour or less. Secondly, the author's use of VRE serves only to obfuscate the author's analysis methodology. In reality the supply from a 100%VRE network would be weather dependent and not dispatchable. Careful attention therefore needs to be given to the dispatchability and reliability of the energy supply, and the magnitude thereof. Knowing the percentage of variable renewable energy in a network only tells you how much variability you have added to the system, it does not tell you how much dispatchable energy is available. As a result the approach by the authors to use VRE as a measure of network integration is also entirely erroneous and misleading. As I have already explained, only additions of reliable baseload energy added to the network should be considered additional dispatchable energy, as this is the only energy which can be relied upon to meet demand at any point in time. This can be done with renewables but it requires a BVRE system. This is the approach underpinning my model.

Contrary to the report's finding, when consideration is given to a system's competence to reliably meet demand at the hour-to-hour timescale, my model suggests **for every 1MW of baseload energy added an additional 2.2MW of 8 hour duration battery storage is needed** to maintain baseload supply at a level which provides lowest overall BVRE system cost. Further, systems with only solar or wind require more storage and have higher overall BVRE system costs. My analysis shows that it is possible to adopt a BVRE system with lower battery storage size, but doing so reduces baseload supply and reliability, while dramatically increasing total system cost.

Other assumptions affecting BVRE system costing
For simplicity network upgrade costs (including major transmission and distribution) were excluded from my costing calculations. The GenCosts report indicates that in 2023 these costs could be in the order of **$30 per MWh**. The report's finding that this cost would remain constant or even drop as the renewable share of the energy grid increases appears entirely inconsistent with the obvious impact that expanding renewables energy zones (REZ) would have on network expansion and associated upgrade costs. It is difficult to tell from what is presented in the report but this would suggest that such network upgrade costs have not been fully costed or costs have not been correctly incorporated into the unit cost of dispatchable renewable energy. Additionally if costs have been benchmarked against average energy rather than baseload energy, this would understate the unit cost. It appears that increased O&M costs for expanded network assets have also been excluded. Given the above it appears this estimate would be on the lower end of the real costs.

My model also excludes the costs of various renewable energy subsidies through the RET and other government initiatives. Some sources have reported the costs of these renewable subsidies in Australia as $2.8billion per year.[7]

My cost analysis utilised publicly available capital costs from large renewable projects completed in 2021. This was a conservative assumption to allow costs to be based on more mature current technology rather than older technology. However, since 2021 global supply chain disruptions have been reported to have led to significant cost escalations for renewables.[8] It is also not clear if these cost escalations will continue into the future. For this reason it is likely that my optimised cost estimates actually understate the true current day costs. For comparison, if we adopt cost estimates for wind and solar provided by Aurecon 2023 (which attempt to incorporate cost escalations) the optimum system cost would increase to **$307 per MWh of baseload**.

[7] https://www.afr.com/politics/renewable-energy-subsidies-to-top-28b-a-year-up-to-2030-20170313-guwo3t#:~:text=Renewable%20energy%20sources%20such%20as,Target%2C%20according%20to%20new%20research.

[8] Aurecon 2023

As my model operates at the hour-to-hour level it is also not competent to resolve system strength or frequency related network stability issues at the <1hour time scale. Network operators have flagged this becoming a growing issue of concern. For example NSW network operator Transgrid advised recently that *"Operating the NSW power system as it transitions towards 100% instantaneous renewable power is resulting in a grid that is sitting closer to its limits for stability and security"*.[9] Network upgrade costs to solve these issues have also been excluded due to the complexity of assigning costs. My battery model also assumed no reserve capacity either for stability or frequency correction. If included, storage capacity would likely need to be upsized at additional cost.

The ISP appears to assume that a major component of the battery storage will come in the form of behind-the-meter storage systems from customers, which they refer to as "distributed storage" and "coordinated DER storage". It is not clear that the ISP makes allowances for either the costs associated with these technologies nor the network upgrade costs to support such a system. However, the costs associated with small scale residential batteries is actually substantially higher than utility scale projects. So any scenario which calls for the use of these technologies would also result in a higher system cost. Aurecon 2023 provides an estimate for Residential Battery Storage Systems (RBSS) of $14,400 for a 5kW (10kWh) system with a life of 10 years.[10] If our baseload renewable system is assumed to rely on RBSS for storage, the storage component of the system cost increases from $91 per MWh to $407 per MWh of baseload, bringing the system cost to **$617 per MWh.** Network upgrades would also greatly increase the cost to the system.

Offshore wind projects have been proposed in several states although there are no completed projects in Australia for reference. Aurecon 2023 estimated the EPC costs of offshore wind projects as $5,323 to $7,356 per kW, which is significantly higher than onshore wind projects. O&M costs are also significantly higher.[11] Some have spruiked the benefits of their higher capacity factors than onshore wind projects, however these are still variable renewable systems and as my analysis reveals, average capacity factors is not a competent measure of a project's ability to produce baseload power. If integrated into a BVRE system, I estimated that it would bring the total system cost above **$500 per MWh of baseload**. Recently, significant concerns regarding environmental impacts of offshore wind projects have also been raised.[12]

What about Nuclear?

I'll leave it to others to properly present the case for nuclear energy, however I would echo what others have noted about the GenCost's problematic approach to costing nuclear technology. In 2023 there were over 400 nuclear power plants in operation around the world.[13] Interestingly however, the GenCosts nuclear energy cost estimate appears to rely entirely on a single example of a prototype plant (UAMPS project). As GenCosts notes this project was actually discontinued in 2023 due to project complications. The report goes on to dismiss contrary international experience with the extraordinary conclusion that *"overseas nuclear electricity costs may be referring to technology that is not appropriate for Australia, or assets that are not seeking to recover costs equivalent to a commercial new-build nuclear plant, there may be no meaningful comparison that can be made to Australia's circumstances which is the focus of GenCost."*. The suggestion that because it hasn't been done before in Australia (as it is currently banned), or to dismiss technology on your own preconceived judgement on whether it is *"appropriate for Australia",*

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[9] https://www.transgrid.com.au/media/avyondr4/system-security-roadmap-2023.pdf
[10] Aurecon 2023, table 9-9
[11] Aurecon 2023, table 4-8 and 4-9
[12] https://www.abc.net.au/news/2024-01-22/offshore-wind-project-environmental-laws-victoria/103356684
[13] https://www.statista.com/statistics/267158/number-of-nuclear-reactors-in-operation-by-country/#:~:text=Operable%20nuclear%20power%20reactors%20worldwide%202023%2C%20by%20country&text=As%20of%20May%202023%2C%20there,those%20connected%20to%20the%20grid.

is to suggest you know the answer before you've even asked the question. Moreover, by utilising the highest cost estimate you can find, on the worst case assumptions you can find, while largely ignoring international experience, does not seem like an objective exploration of all options for honest consideration and comparison.

In contrast to the figures in the report, the Barakah Nuclear plant in UAE was completed in 2022 with a nameplate capacity of 5,600MW at a total cost of $38billionAUD.[14] Including estimates for O&M over a realistic 60+ year lifespan[15], this equates to a system cost of $70 per MWh. Alternatively, look at the troubled Vogtle Unit 3 and 4 plant which was the first new nuclear plant in the USA in 30 years. Despite suffering multiple delays and cost escalations, it ended up costing around $53billionAUD for a 2,430MW capacity plant.[16] Again, when accounting for ongoing costs this equates to a system cost of $177 per MWh. Looking at other first-of-a-kind plants, Terrapower's Natrium reactor which is currently ongoing in Wyoming in the USA is specifically designed to integrate with renewable energy and provide 345MW fast ramping baseload capacity at an estimated cost of $6.1billionAUD.[17] Again after accounting for ongoing costs this equates to a system cost of $146 per MWh. The provider has also claimed that total cost could ultimately be reduced to $1.5billionAUD for future plants, which would bring a future system cost down to $53/MWh.

If a realistic lifespan and O&M costs are adopted it indicates a system cost less than $180MWh, with significant potential to bring this cost down for nth-of-a kind plants. This range is consistent with the findings from a recent University of Queensland report looking in depth at what would be required for nuclear energy in Australia.[18] Interestingly, while the GenCosts report takes a generous approach to price drops on nth-of-a-kind renewable projects, it appears to completely ignore the potential for nuclear system costs to decrease as the technology advances.

Comparing apples with apples

As previously noted, neither individual variable renewables nor the author's VRE estimates can be legitimately compared to the other baseload sources of energy provided in the summary. As a result the report's inclusion of this summary of costs is highly erroneous and misleading. My analysis instead considers BVRE systems which can be directly compared to other baseload power sources. My findings for a BVRE system are shown in red for illustrative purposes and comparison to GenCosts findings. I've also included updated nuclear estimates based on more realistic assumptions as noted by subject matter experts. Note my optimised estimate for BVRE should also be considered a lower limit due to several costs being explicitly excluded for simplicity. To deal with this I have added a range which covers a realistic spread of non-optimum mixes of technologies for adoption. It is also expected that the cost would tend toward the middle of this range, particularly if ISP scenarios are to be believed.

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[14] https://www.enec.gov.ae/news/latest-news/enec-and-kepco-announce-financial-close-for-barakah-nuclear-energy-plant/
[15] https://www.nuclearaustralia.org.au/wp-content/uploads/2023/12/Stephen_Wilson_WhatWouldBeRequired-FINAL.pdf
[16] https://www.eia.gov/todayinenergy/detail.php?id=57280
[17] https://www.cnbc.com/2021/11/17/bill-gates-terrapower-builds-its-first-nuclear-reactor-in-a-coal-town.html
[18] Wilson note 15

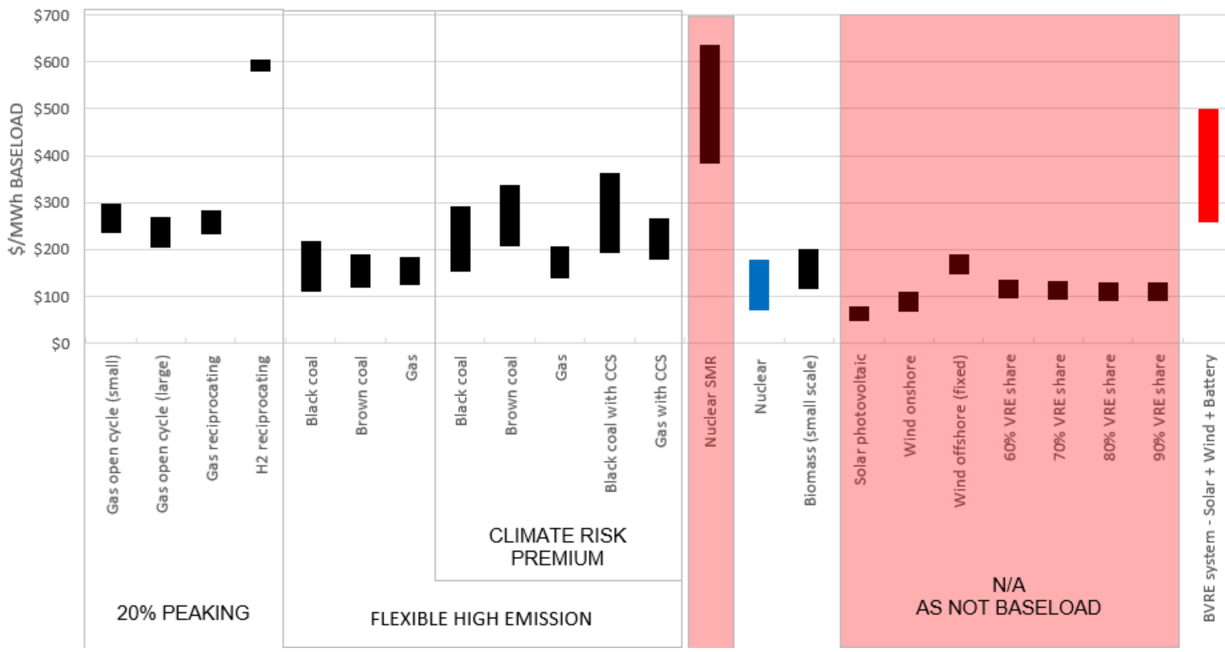

Figure 5: Black estimates are taken directly from GenCosts report. Red is my estimate for a BVRE system. Blue is the international cost range for nuclear projects considered.

Other costs and externalities not considered by GenCosts
I am a bit surprised that a report of such significance from our chief scientific agency did not give at least some consideration to other costs and externalities relating to the technology options they consider.

There's no doubt renewable energy sources have decarbonisation potential, estimates of lifecycle GHG emissions per unit energy generated from renewables like wind and solar are at least 12x lower than from coal and over 2x lower than natural gas.[19] It's not clear how a BVRE system would compare however it's likely that the difference would reduce. I'd note however that nuclear is estimated to produce around 2x less than solar and wind.

There is also no doubt renewables provide public health benefits over existing fossil fuel sources. Deaths associated with fossil fuel use is up to 1,636 times higher than for renewables. However, it should also be noted that death rates from nuclear energy are also similar to renewables.[20]

Renewables also require substantial quantities of material during their manufacture. Solar PV for example is estimated to require 16,447 Tonne of materials per TWh of energy produced, a large proportion of which is precious metals and minerals. Wind requires around 10,260 Tonne/TWh, mostly concrete and steel. Nuclear for comparison requires 920 Tonne/TWh.[21] Again, following my analysis, this discrepancy would be even more stark if we considered a BVRE system rather than individual renewables.

Renewables also require vast amounts of space. Yallourn Power Station - a coal fired power station in Victoria - is on a site approximately 55km^2 (all inclusive plant, mine and buffer zone) and produces

[19] https://unece.org/sites/default/files/2021-11/LCA_final.pdf
[20] https://ourworldindata.org/grapher/death-rates-from-energy-production-per-twh
[21] https://www.sciencedirect.com/science/article/pii/S2772783122000085

1,480MW of baseload power[22], or around 0.037km^2 per MW. Land use densities for solar and wind projects are estimated at 0.022km^2 and 0.37km^2 per MW of nameplate capacity respectively.[23] This equates to 2.25km^2 per MW of baseload at the optimum BVRE, around 60x more area per unit of baseload energy.[24] It is expected that a nuclear plant would have similar area requirements to a coal plant. Such vast area requirements will pose new environmental and cultural heritage challenges.

Renewables also have a relatively short life when compared to coal, gas and nuclear plants. While investments now in fossil fuel or nuclear plants would be expected to last in 60-80+ years, solar, wind and batteries all have lifespans in the order of 20 to 30 years. This will ultimately present unique challenges and costs for renewable system renewal, decommissioning and recycling into the future. Australia will be exposed to potential price escalations more frequently as we renew the assets more frequently and new industries would likely be required to manage the emerging waste problem. As renewables rely on imported components, Australians would also be exposed to energy security risks from lack of supply of critical components and parts. All of these present significant new risks and costs to Australians.

Conclusion:
We may expect politicians to be driven by ideology, however as our chief scientific agency, the CSIRO should be driven by a pursuit of the truth. Renewables are a fantastic innovation and will undoubtedly play a role in efforts to decarbonise the economy, however, I think we need to be honest about the clear limitations of the technology. If the aim is to ultimately fully decarbonise the economy with renewables, it is necessary to answer the following hard questions: is a baseload variable renewable energy (BVRE) system possible and what does it cost to build a scalable one? My analysis indicates that it should be possible to build a BVRE system but the total system cost is in excess of $258 per MWh. This analysis finds that when consideration is given to total system costs, a BVRE system will still be more expensive than both conventional fossil fuel and nuclear baseload energy systems.

Importantly, the analysis makes it clear that when evaluating energy options we must get out of the mind-set of just dumping more energy into the grid by focusing on average energy generation. If we want to ultimately achieve the lowest overall cost for a reliable energy system, we must instead consider new energy supply systems against their capacity to provide stable baseload energy to the grid. If we don't, as we follow the path of the ISP ultimately it will either lead to ever escalating costs or the plan will fail entirely.

As a final note, I fully support efforts to decarbonise the economy and improve energy security for Australia, I just think we need to be objective and level headed about how we get there. Mine isn't the final model, in fact I intend to further refine it in collaboration with others. Cooperation is key to Australia's success so I am happy to provide my model in full and to address any questions to assist.

Regards,

David

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[22] 5,500ha = 55km2
https://www.energyaustralia.com.au/sites/default/files/2022-11/SHEMS11-SHE-P015-L01%20-%20EnergyAustralia%20Yallourn%20Bushfire%20Mitigation%20Plan.pdf

[23] https://www.netzeroaustralia.net.au/wp-content/uploads/2023/04/Downscaling-Solar-wind-electricity-transmission-siting.pdf

[24] 5.9MW*0.37km2/MW+2.9MW*0.022km2/MW = 2.25km2/MW of baseload

Appendix 1. Cost model assumptions data:

Metric	Value
Assumed Cost of Capital	5.3%PA
Simple discount model	Repayment = P*r*(1+r)^n/((1+r)^n-1)

Onshore Wind Farm

Metric	Value	Reference/Comment
Stockhill Yard Windfarm	$1,698,113 per MW nameplate capacity	$900mil for 530MW nameplate capacity link
EPC Estimate	$2,875,000 per MW nameplate capacity	Aurecon 2023, table 4-3
Connection Costs	$144,000 per MW nameplate capacity	AEMO 2021, table 11, average in Victoria assuming 5-10km range to existing network
Land and development	2.5% EPC costs	Aurecon 2023, table 4-3
Lifespan	30 years	Aurecon 2023, table 4-2
O&M costs	$26,500 per MW nameplate capacity per year	Aurecon 2023, table 4-3

Large scale solar PV

Metric	Value	Reference/Comment
Numurkah Solar Farm project, Victoria completed 2021	$1,767,857 per MW nameplate capacity	$198mil for 112MW nameplate capacity link
EPC Estimate	$1,440,000 per MW nameplate capacity	Aurecon 2023, table 4-12
Connection Costs	$144,000 per MW nameplate capacity	AEMO 2021, table 11, average in Victoria assuming 5-10km range to existing network
Land and development	6% of EPC costs	Aurecon 2023, table 4-12
Lifespan	30 years	Aurecon 2023, table 4-10
O&M costs	$12,500 per MW nameplate capacity per year	Aurecon 2023, table 4-12

Battery storage

Metric	Value	Reference/Comment
EPC costs	$4,025 ,000 per MW nameplate capacity for 8 hour duration BESS	Aurecon 2023, table 9-3
Connection Costs	$84,000 per MW nameplate capacity	AEMO 2021, table 12, average cost rate, assumes 1km range to existing network
Land and development	$10,000,000 per 200MW BESS	Aurecon 2023, table 9-3
Lifespan	20 years	Aurecon 2023, table 9-2
O&M costs	$19,700 per MW nameplate capacity per year	Aurecon 2023, table 9-3
Extended warranty 20 years (excluded from analysis)	$19,600 per MW nameplate capacity per year	Aurecon 2023, table 9-3

Input Reference Documents:

Aurecon 2023, *2023 Costs and Technical Parameter Review*
Report (aemo.com.au)

AEMO 2021, *Transmission Cost Report, for the integrated system plan (ISP)*
transmission-cost-report.pdf (aemo.com.au)