Evaluating the feasibility of Nuclear and Solar Photovoltaic energy infrastructure.

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Background

In the current age, the use of fossil fuels is falling under increasing levels of scrutiny both due to dwindling supply and looming "net zero" deadlines. While nuclear energy is certainly a possible source of renewable energy in the future, the claim that **"In the future, nuclear energy is the best possible energy source for Australia"** seems to be an opinion of many in the space, and warrants investigation. By comparing nuclear energy options to the best options that are currently implemented, a comparison can be made.

Other energy sources currently implemented, such as hydroelectric energy, do not directly compete with Nuclear energy. Biomass in particular is limited in growth by the rate of biomass waste generated by industry (EIA, 2024). Therefore the scope of comparison is limited to the most abundant and fast growing energy sources that directly compete with nuclear.

Energy Generation Technology	Current Share (%)	Current Annual Growth (%)	Average growth over last 10 years (%)
Solar Photovoltaic (PV)	27.3%	21%	27.1%
Wind	20.4%	7.8%	14.7%
Biomass	32%	3.9%	-0.4%
Hydro	10.8%	-2%	-0.9%

Table 1: *Current share and growth of select energy sources in respect to total renewable share* (Australian Government, 2023).

Solar PV demonstrates the second highest share in electricity generation, and is currently the fastest growing renewable energy. Therefore it will be the alternative in this comparison.

Categories of comparison

Cost

Energy generation requires investment at many stages during a piece of infrastructures life cycle. Contributors to cost will be discussed. The cost per unit of energy produced should be considered as cost of living is a major issue in some parts of Australia (Potts, 2024).

Reliability

Critical sectors like healthcare and agriculture rely heavily on the grid, in addition to the millions of Australians who have improved quality of life because of it. If one technology demonstrates a increased reliability, this is a significant advantage.

Waste production

Looking towards the future, the waste product of each technology must be considered. These will accumulate during generation, and at the End Of Life (EOL) period of infrastructures lifespan. If one technology becomes the dominant power generation infrastructure, the long term impact of it's materials and processes must be considered, just as they were in the case of fossil fuels (DCCEEW, 2025).

Research question

Is Nuclear Energy more sustainable than Solar Photovoltaic (PV) in terms of cost, reliability and long term waste production?

Cost

LCOE (Levelised Cost of Electricity)

Initiating construction of electrical generation infrastructure is a capital intensive process. For a project to be successful, the money spent during construction operation, and generation must be lower than the total revenue generated by the infrastructure over its lifespan, and additional profit margins.
Since the sum of costs are recuperated over the lifespan of the infrastructure, comparing them against the sum of energy generated by the plant allows an average cost per unit of energy to be determined. This is known as the LCOE (Levelised Cost of Electricity) for that installation, and is usually measured in dollars per watt hour ($/Wh).

The CSIRO's GenCost report calculated, and predicted LCOE's for a number of technologies from the years 2024, to 2050, allowing for direct comparison of said technologies (Graham et al., 2024).

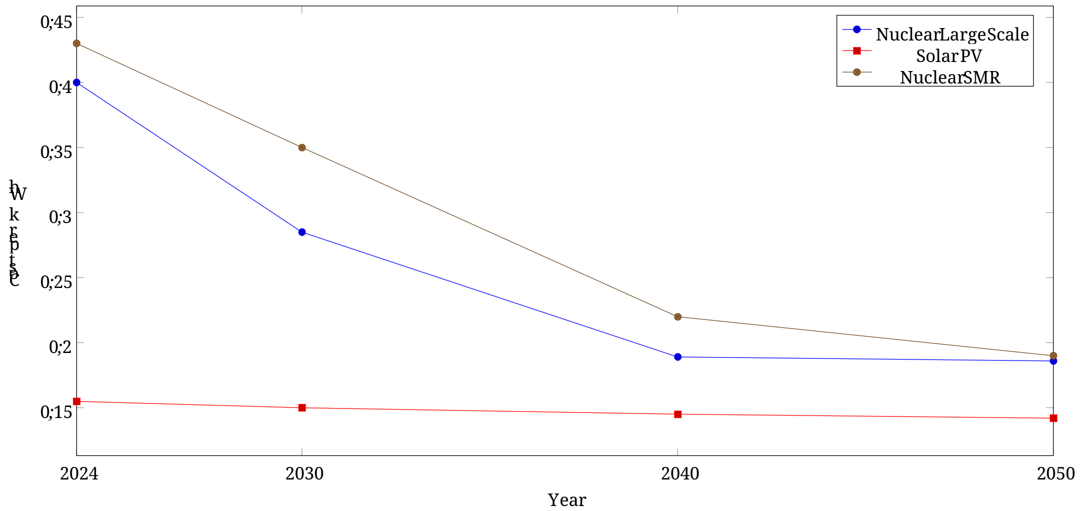

Figure 1: *Calculated LCOE by technology and category for 2024 to 2050 (AUD)* (Graham et al., 2024).

Limitations

These predictions are based on current policies and discounts applied to renewable infrastructures.

Clearly solar PV demonstrates the lowest LCOE, being 0.16 $/kWh (as shown in Figure 1). The closest nuclear technology to this is large scale nuclear, which is currently has costs of 0.40 $/kWh. While the gap between solar PV and nuclear facilities is predicted to shrink, solar is consistently predicted to be the cheapest option for the foreseeable future. This is likely due to higher capital, or setup, costs for nuclear infrastructure

Capital costs

TABLE 12-1 – BASE PLANT SITE CAPITAL COST ESTIMATE FOR AN

Technology:	AN	
Nominal Capacity (ISO):	2,234,000 kW	
Nominal Heat Rate (ISO):	N/A Btu/kWh-HHV	
Capital Cost Category		(000s) (January 1, 2016$)
Civil Structural Material and Installation		1,927,067
Mechanical Equipment Supply and Installation		3,782,925
Electrical / I&C Supply and Installation		700,954
Project Indirects [(1)]		3,029,122
EPC Cost before Contingency and Fee		9,440,067
Fee and Contingency		1,446,413
Total Project EPC		10,886,479
Owner Costs (excluding project finance)		2,395,025
Total Project Cost (excluding finance)		13,281,504
Total Project EPC	/ kW	4,873
Owner Costs 22% (excluding project finance)	/ kW	1,072
Total Project Cost (excluding project finance)	/ kW	5,945

(2) Includes engineering, distributable costs, scaffolding, construction management, and start-up.

Figure 3: *Capital cost estimates for Advanced Nuclear* (Leidos Engineering, LLC, 2016).

The U.S Department of energy's "*Capital Cost Estimates For Utility Scale Electricity Generating Plants*" further breaks down these capital costs.

While fresh fuel is benign, as fission has not yet been initiated, spent fuel requires specialised equipment and procedures to be safely handled. Spent fuel poses not just a hazard to people, but the plant. If fresh fuel is not isolated from spent, it can induce fission and begin a chain reaction.

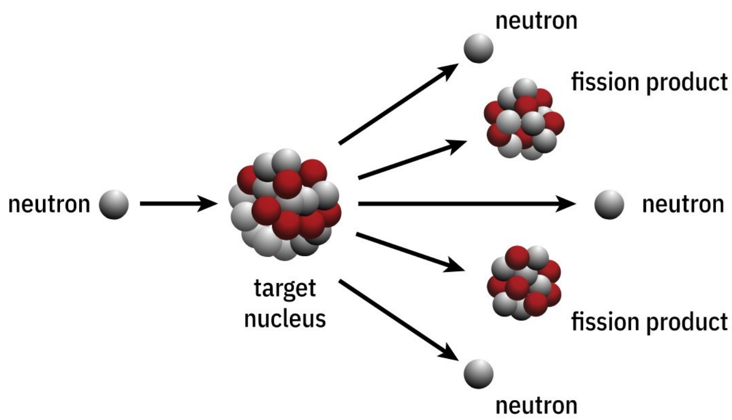

Figure 4: *Diagram of nuclear fission, or splitting of the atom* (Linquip Team, 2023).

When neutron-induced fission occurs, a neutron transmutes an atom from a stable isotope, to an unstable isotope, causing it to split and eject additional neutrons, as well as other nuclei. The splitting of the atom produces heat, and the ejected neutrons continue the reaction.

Neutron counters are placed throughout the plant in order to detect radiation contamination, and thick shielding is utilised to prevent beta minus decay (neutrons) or other radiation from penetrating through containment vessels, or into other sections of the plant (World Nuclear Association, 2022). This results in 38% of total costs being associated with engineering, materials and construction (excluding any mechanical or electrical equipment) (Leidos Engineering, LLC, 2f016).

The cost of large scale nuclear in Australia is currently predicted to be ≈ $9000/kW in capacity, and is expected to be as low as ≈ $8000/kW by 2050 (Graham et al., 2024).

The cost of uranium fuel in America was 0.46 cents/kWh in 2021 (Leidos Engineering, LLC, 2016). Acquiring fuel locally would hypothetically decrease costs further, however, the cost of fuel is a only minor contributor to LCOE. It is estimated that 60% of LCOE is attributed to capital costs (World Nuclear Association, 2020).

The largest capital costs in solar PV systems are the mechanical and electrical systems, and equipment. The procurement and instillation of these components account for ≈ 80% of capital costs (Leidos Engineering, LLC, 2016).

TABLE 15-3 – BASE PLANT SITE CAPITAL COST ESTIMATE FOR PV

Technology:	**PV - Tracker**	
Nominal Capacity (ISO):	**150,000 kW/AC – 180,000 kW/DC**	
Nominal Heat Rate (ISO):	**N/A Btu/kWh-HHV**	
Capital Cost Category		**(000s) (January 1, 2016$)**
Civil Structural Material and Installation		36,304
Mechanical Equipment Supply and Installation		193,336
Electrical / I&C Supply and Installation		53,818
Project Indirects (1)		13,991
EPC Cost before Contingency and Fee		297,449
Fee and Contingency		45,000
Total Project EPC		342,449
Owner Costs (excluding project finance)		37,669
Total Project Cost (excluding finance)		380,118
Total Project EPC	/ kW	2,283
Owner Costs 12% (excluding project finance)	/ kW	251
Total Project Cost (excluding project finance)	/ kW	2,534

(1) Includes engineering, distributable costs, scaffolding, construction management, and start-up.

Figure 5: *Capital cost estimates for Advanced Solar PV (with tracking)* (Leidos Engineering, LLC, 2016).

Solar PV installations are generally less expensive, and take less time to construct. This translates to lower financing fees, and an overall lower LCOE. The current capital cost of large scale solar PV in Australia is ≈ $1500/kW, and is expected to be ≈ $700/kW by 2050 (Graham et al., 2024).

Solar PV's 'fuel' is sunlight, which is a free resource. While land usage scales with capacity, solar PV installations generally are have lower owner costs with respect to the total cost of the installation. Owner costs cover development, property, and other miscellaneous factors (World Nuclear Association, 2024).

Reliability

Reliability is defined as "The ability of a system or device to carry out it's desired function under predefined circumstances for a certain amount of time" by the Institute of Electrical and Electronics Engineers (Obatola, 2024).
Availability is also a key factor in assessing a systems reliability. It is expressed as a fraction that describes a component or systems operating time in respect to its total lifetime. (Sayed et al., 2019)

$$\text{Availability(A)} = \frac{\text{Mean time to failure}}{\text{Mean time to failure} + \text{Mean downtime}}$$

Where:

- Mean time to failure is the amount of time the system operates for on average before a failure occurs
- Mean downtime is the time it takes for operations to resume after a failure occurs.

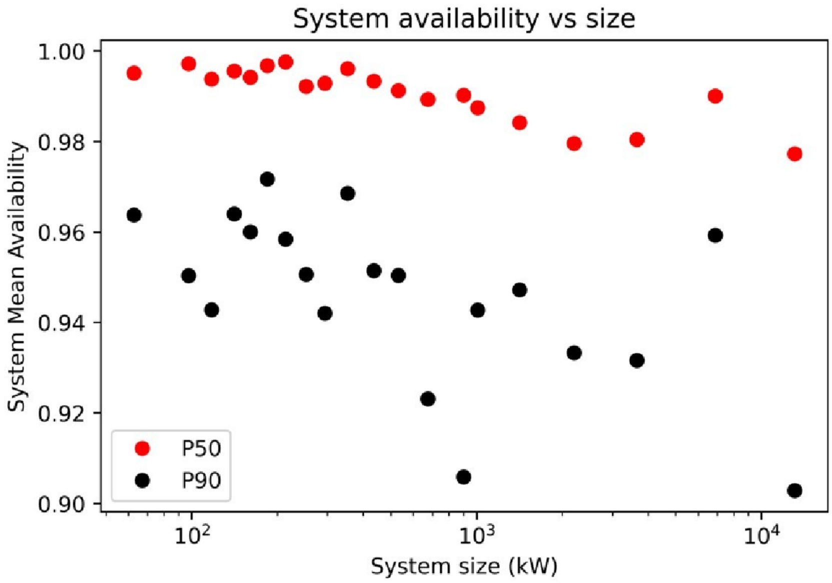

Figure 6: *System availability versus system size shows negative trend. P50 (red) and P90 (black) quantile values shown.*

"*Availability and Performance Loss Factors for U.S. PV Fleet Systems*" by Chris Deline et al. considered availability data from large scale solar PV systems up to ≈ 10 MW (10000 kW). Figure 4 suggests the median availability (P50) decreases as system capacity grows, however, even as the system capacity surpassed 10 MW median availability remained at ≈ 98% (Deline et al., 2024).

Limitations

It should be considered though that climate of America varies significantly from Australia in terms of temperature and humidity. This will affect the rate at which systems degrade and fail, therefore the applicability of this data is limited.

"*Availability factor of a PV power plant: evaluation based on generation and inverter running periods*" by Kumar, N. M., et al. considered inverter uptime in a 1000 kW plant.

The main contributor to the lowering availability was considered inverter modules, at ≈ 92% available in a 1000 kW system. Often there are many inverters operating in parallel, and the "Plug and play" nature of these components allow repairs to be completed quickly with minimal tools. This is also the case with many other less integral components, which results in relativity high availability for the entire system (Sayed et al., 2019)

Limitations

> System availability is affected by all components in the series from the PV modules to the grid. While considering a single component alone, the entire system's availability cannot be properly gauged

Nuclear infrastructure faces many of the same challenges in reliability and longevity as solar PV. IAEA's Power Reactor Information System (PRIS) is a database of statistics regarding the construction, operation, and capacity of global nuclear energy infrastructure. Extrapolating availability from their public dataset gives a global median of 85.05% (excluding South Africa) (Iaea.org, 2022).

This is significantly lower than solar PV systems, which seems unlikely due to solar PV relying on occasional daylight to function. However nuclear plants must abide by more stringent safety protocols, therefore more time is spent on both restorative and preventative maintenance as it must be carried out with greater frequency and meticulousness.

For a 1000 MW reactor, repair timelines range from 9, to 80 days depending on the severity of the fault (Shi & Wang, 2016). Additionally, nuclear plants must schedule downtime to replace fuel rods and handle spent fuel every 3-5 years.

Limitations

> It should be considered that the output of nuclear facilities is larger relative to solar PV infrastructure discussed by a factor of at least 100 times. Considering the decreasing trend observed in availability factor as scale increases, solar PV is hypothesised to have a lower availability at the same scale as nuclear.

Waste Management

Waste generated from electricity generation is generally in the form of solid waste such as aluminium, concrete, and glass, and greenhouse gas emissions (GHG) like CO_2.

The waste generated by solar PV systems is approximately 1.7-2 g of solid waste per kWh. In Australia, once recycling of these materials is complete, the lifetime CO_2 emissions are 46-59g of CO_2 per kWh (Barnard, 2025).
This is well below the internationally accepted limits of 50g of CO_2 (or equivalent) per kWh, or about what a tree would absorb in a day (EcoTree, 2022).

Waste generated by nuclear plants is much higher in density. A 1000 MW reactor creates roughly 10 cm^3 of waste per kWh, however due to the chaotic and heterogeneous nature of nuclear reactions, the composition of nuclear waste varies.

What remains constant though is the hazard and long lifetime of spent fuel. Fission products such as Strontium-90, and Cesium-137 have half lives of $\approx$ 30 years (World Nuclear Association, 2022). Spent fuel contains up to 50% of its original energy (World Nuclear Association, 2022). To minimise potential for irradiation, spent fuel spends up to 50 years in a shielded pool where they continue to undergo fission in a controlled environment.

Due to the density of the water and the inverse square law, the spent fuel is able to decay and release heat without causing harm before being sealed in a steel and concrete containment vessel. Overall this produces 110 g of CO_2 (equivalent)/kWh.

Discussion

Extrapolation/Summary of credible findings

In terms of cost, solar was clearly the better option. Nuclear energy is simply too complex and monolithic to be considered viable at this point in time.

Solar was found to be more reliable mostly due to its resilience against minor damage and its limited seriality. Nuclear energy is simply too bureaucratic and has too many risks, and therefore spends a larger portion of its lifespan managing them through preventative maintenance and diagnostics.

In terms of waste, solar PV is more sustainable as it's waste products are easily recycled and have smaller CO_2 emissions. Nuclear infrastructure appears to induce more costs while managing waste products than creating useful output for consumers. Increasing the output and number of nuclear plants will produce more waste, it is almost the antithesis of sustainability; there is an overabundance of waste product so that in the future, energy production may be limited not by lack of fuel, but waste containment saturation.

Improvements and extensions

While solar was found to be the more feasible energy source, it was hypothesized it might not be viable at scale. Investigation into larger, more relevant solar installations and their reliability could be worthwhile.

Furthermore, investigation of supplemental of hybrid infrastructure could be worthwhile. It is foolish to assume that grid systems can only contain a single form of energy generation technology, and the addition of other technologies in parallel would likely increase the reliability of both.

Conclusion

The idea of a "Nuclear fantasy" itself appears to be a reality. Solar PV infrastructure appears to have been implemented with its current magnitude for good reason. The claim **"In the future, nuclear energy is the best possible energy source for Australia"** has been disproven through answering the research question **"Is Nuclear Energy more sustainable than Solar Photovoltaic (PV) in terms of cost, reliability and long term waste production?"** with 'No'.

References

Australian Government (2023). *Renewables.* [online] Energy.gov.au. Available at: https://www.energy.gov.au/energy-data/australian-energy-statistics/renewables.

Barnard, M. (2025). *Solar Panel Waste is Tiny—Coal & Gas Emit Hundreds Of Times Mass Per MWh - CleanTechnica.* [online] CleanTechnica. Available at: https://cleantechnica.com/2025/04/19/solarpanel-waste-is-tiny-coal-gas-emit-hundreds-of-times-mass-per-mwh/.

Clark Public Utilities PowerZone. (n.d.). *Biomass Energy - How Do We Make Energy From Waste?* [online] Available at: https://powerzone.clarkpublicutilities.com/learn-about-renewable-energy/biomassenergy/.

DCCEEW (2025). *Net Zero.* [online] Department of Climate Change, Energy, the Environment and Water. Available at: https://www.dcceew.gov.au/climate-change/emissions-reduction/net-zero.

EcoTree. (2022). *How much CO2 does a tree absorb? Let's get carbon curious!* [online] Available at: https://ecotree.green/en/how-much-co2-does-a-tree-absorb.

EIA (2024). *Biomass Explained.* [online] US Energy Information Administration. Available at: https://www.eia.gov/energyexplained/biomass/.

Iaea.org. (2022). *PRIS - Last three years factors - Energy Availability.* [online] Available at: https://pris.iaea.org/PRIS/WorldStatistics/ThreeYrsEnergyAvailabilityFactor.aspx [Accessed 29 Jul. 2025].

Potts, P. (2024). *Record number of Aussies struggling to pay energy bills amid rising power prices.* [online] Sky News. Available at: https://www.skynews.com.au/business/energy/australian-householdscontinue-to-financially-struggle-to-pay-off-their-energy-bills-as-the-costofliving-crisis-worsens/newsstory/854599def1031ade38b3b42247f5452e.

World Nuclear Association (2024). *Australia's Uranium - World Nuclear Association.* [online] worldnuclear.org. Available at: https://world-nuclear.org/information-library/country-profiles/countries-af/australia.

Deline, C., Muller, M., White, R., Perry, K., Springer, M., Deceglie, M., & Jordan, D. (2024). Availability and performance loss factors for U.S. PV fleet systems (NREL/TP-5K00-88769). National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy24osti/88769.pdf

Graham, P., Hayward, J., & Foster, J. (2024). GenCost 2024-25: Consultation draft. CSIRO.

Kumar, N. M., Dasari, S., & Reddy, J. B. (2018). Availability factor of a PV power plant: Evaluation based on generation and inverter running periods. *Energy Procedia, 147*, 71–77. https://doi.org/10.1016/j.egypro.2018.07.035

Leidos Engineering, LLC. (2016). EOP III TASK 10388, SUBTASK 4 and TASK 10687, SUBTASK 2.3.1 – Review of power plant cost and performance assumptions for NEMS: Technology documentation report: FINAL - REVISED. Energy Information Administration Office of Electricity, Coal, Nuclear, and Renewables Analysis.

Nuclear Energy Agency. (2021). Small modular reactors COP26 flyer. OECD Nuclear Energy Agency.

Obatola, S. O. (2024). Reliability overview of grid-connected solar PV system: A review. *Archives of Advanced Engineering Science, 00*(00), 1–9. https://doi.org/10.47852/bonviewAAES42023083

Sayed, A., El-Shimy, M., El-Metwally, M., & Elshahed, M. (2019). Reliability, availability and maintainability analysis for grid-connected solar photovoltaic systems. *Energies, 12*(7), 1213. https://doi.org/10.3390/en12071213

Shi, J., & Wang, Y. (2016). Reliability prediction and its validation for nuclear power units in service. *Frontiers in Energy, 10*(3), 425–431. https://doi.org/10.1007/s11708-016-0425-7

World Nuclear Association. (2020). Economics of nuclear power. Retrieved from https://www.worldnuclear.org/

World Nuclear Association. (2022, January 25). Radioactive waste management. Retrieved from https://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-waste/radioactive-wastemanagement