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Issues with levelised cost of electricity

Why a simple metric cannot determine our energy future

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Foreword

Proponents of the policy of net zero emissions by 2050 in Australia regularly parrot the line that renewable energy is the cheapest form of energy. This statement is based on a measure, used in the annual Commonwealth Scientific and Industrial Research Organisation (CSIRO) GenCost report, namely: the Levelised Cost of Electricity (LCOE).

The LCOE is a measure of the average net present cost of electricity production for a generating asset over its lifetime. It does not tell us the *full* cost of electricity generation. Neither does it tell us the cost of the poles and wires that deliver the electricity. Moreover, LCOE does not tell us the cost of other power supplies—mostly coal and gas—that must be there as a backup to support variable renewables when the wind doesn't blow or when the sun doesn't shine.

LCOE accounting fails to explain the actual cost of electricity seen in Australian families' ever-increasing energy bills. And it says nothing about the value of being able to produce electricity on demand. Put another way, LCOE says nothing about the value of being able to turn the air conditioning on at 8pm on a hot summer night.

Instead, Australian energy ministers—and the full range of vested interests in the renewables sector, academia, and energy companies—have relied on LCOE accounting to defend what is increasingly indefensible. More renewables have not led to lower power bills; on the contrary, they have only made electricity more expensive. Australians have already experienced multiple increases in power bills. The federal government's promised $275 per annum reduction has disappeared.

The fundamental problem with the current approach to estimating the cost of energy by generation is that LCOE is a project-level metric, and one that is easy to manipulate to deliver a desired outcome. It does not scale up to reflect the complexity of Australia's electricity markets. Therefore, different tools are urgently needed to inform policy decisions.

Instead of trying to develop an energy system that delivers the lowest cost and highest level of reliability, policy makers have been promoting a system, on the basis of LCOE accounting, that has had the effect of increasing cost and lowering reliability.

To assist in better understanding what sits behind the claims about renewable energy being the cheapest energy source, this paper explains:

- what LCOE actually is (i.e., a variation on the net present value calculation used in financial analysis to look at specific investments),
- its fundamental shortcomings (it does not account for the real-world costs of delivering electricity to consumers),
- how it can be easily manipulated to provide the desired conclusion, and
- why LCOE should not be used as the basis for designing an energy system when superior modelling tools are available.

In discussing these issues, this report aims to clearly explain the folly behind the mantra: 'renewable energy is the cheapest form of energy'—and why Australian governments, renewable activists, and big renewable companies are responsible for delivering an energy system that cannot do its job, which is to provide secure, reliable, and affordable power.

1 Introduction

The Commonwealth Scientific and Industrial Research Organisation's (CSIRO) 2022-23 final GenCost report, released in July 2023 stated:

> Onshore wind and solar [photovoltaics] without transmission or storage costs are the lowest cost generation technology by a significant margin. Offshore wind is higher cost but competitive with other alternative low emission [electricity] generation technologies …[1]

The finding, which mirrored the previous year's conclusion, was seized upon by Climate Change and Energy Minister Chris Bowen, who reasserted in a speech to the Australian Business Economists in Sydney:

> The AEMO and CSIRO GenCost report has made clear the hierarchy of costs: renewables being the cheapest and nuclear being the most expensive.[2]

This was not the first time that the minister claimed renewables to be the cheapest source of energy, based upon the CSIRO's GenCost annual report.

Renewable and net zero advocates, such as Renew Economy and the Australian Energy Council, subsequently parroted the line that renewable energy is the cheapest form of energy. This is despite the fact that the increase in the share of electricity generated by wind and solar has been accompanied by a sharp increase in power bills and a sharp decline in energy reliability, as the energy supply crises of 2019 and 2022, and AEMO's future reliability gap warning demonstrate.[3]

But if the GenCost report is to be believed, then the opposite should have occurred. That is, consistent with Reputex' Powering Australia Plan, Australian families and businesses should have seen a **decrease** in power bills along with an increase in renewable penetration—leading up to a fall of $275 per annum by 2025.[4] Instead, Australians have experienced a 20 per cent annual **increase**, not decrease, in power bills.[5] Findings by successive GenCost reports seem to contradict the lived experiences of everyday Australians, and it has done so consistently for years. The reason lies in the flawed assumption of the CSIRO's analysis.

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[1] Paul Graham, Jenny Hayward, James Foster and Lisa Havas, *GenCost 2022-23: Final Report* (CSIRO, July 2023) 54, accessed 21 February 2024: https://www.csiro.au/-/media/EF/Files/GenCost/GenCost2022-23Final_27-06-2023.pdf.

[2] Chris Bowen, 'Speech to the Australian Business Economists, Sydney' (Sydney, 15 August 2023): https://parlinfo.aph.gov.au/parlInfo/search/display/display.w3p;query=Id%3A%22media%2Fpressrel%2F9321535%22;src1=sm1.

[3] Australian Energy Market Operator, *2023 Electricity Statement of Opportunities* (August 2023) 1-88.

[4] RepuTex Energy, *The Economic Impact of the ALP's Powering Australia Plan: Summary of modelling results* (RepuTex Energy, December 2021) 5, accessed 21 February 2024: https://www.reputex.com/wp-content/uploads/2021/12/REPUTEX_The-economic-impact-of-the-ALPs-Powering-Australia-Plan_Summary-Report-1221-2.pdf.

[5] Colin Packham, 'Electricity bills rose between 9 and 20 pc over the past 12 months, says energy regulator,' *The Australian,* 5 October 2023 (accessed 22 February 2024): https://www.theaustralian.com.au/business/mining-energy/electricity-bills-rose-between-9-and-20pc-over-the-past-12-months-says-energy-regulator/news-story/776789008a4aa810d5e47bad8f5d6fed.

Fundamental to the aforementioned report, and its conclusion about the cost-effectiveness of renewables, is a reliance on Levelised Cost of Electricity (LCOE) accounting. LCOE is a measure of the average net present cost of electricity production for a generating asset over its lifetime. It is a measuring tool to account for the cost of a project at the asset level, which does not necessarily scale to the system as a whole.

Critically, LCOE does not present the *full* cost of electricity generation.

What directly affects a consumer's power bill is not so much the cost of energy at the time of production (which LCOE measures), but the total system cost including back-up generation, transmission, and distribution networks. This is at the heart of the issue surrounding LCOE accounting.

Moreover, LCOE is biased towards those technologies that have relatively low upfront capital costs such as renewables, and against those which have long operating lives like coal and nuclear.

This metric has been used and weaponised by those advocating for a rapid renewable energy transition, including the federal government, to justify renewable energy targets on the basis that wind and solar are supposedly the cheapest form of energy. But this claim is not just flawed; it is fundamentally misleading.

The flaws in the approach are already well known among energy policy insiders and academics.[6] The Independent Review into the Future Security of the National Electricity Market, headed by then Chief Scientist Alan Finkel, for example, acknowledged that 'LCOEs do not include transmission or distribution costs' or indeed any 'costs incurred elsewhere in the system' external to the specific asset.[7] It can only therefore be an incomplete measure of the cost of energy generation, a point which is supported in the academic literature.

The following was noted in a 2021 paper co-authored by Ryan Coe, a marine energy expert based at the Sandia National Laboratories 9 (citations omitted):

> Although a "dollars-and-cents" metric like LCOE would seem to give the final verdict on a generation technology's viability, this is an oversimplification of the drivers at work upon a modern electrical grid. Quoting directly from the US Energy Information Administration (EIA): "LCOE does not capture all of the factors that contribute to actual investment decisions, making the direct comparison of LCOE across technologies problematic and misleading as a method to assess the economic competitiveness of various generation alternatives". As noted throughout literature, variability is a critical factor in determining the real market value of all energy generation technologies. Accordingly, an analysis based solely on LCOE will often tend to over-estimate the market viability of variable renewable energy (VRE)

[6] E.g. Wei Shen, Xi Chen, Jing Qiu, Jennifer Hayward, Saad Sayeef, Peter Osman, Ke Meng, Zhao Yang Dong, 'A comprehensive review of variable renewable energy levelized cost of electricity' (2020) *Renewable and Sustainable Energy Reviews*, 133, 110301; Soojin Park, Antony Langat, Kyuhwan Lee and Yongbeum Yoon, 'Measuring the impact of risk on LCOE (levelized cost of energy) in geothermal technology' (2021) *Geothermal Energy*, 9(1), 27.

[7] Alan Finkel, Karen Moses, Chloe Munro, Terry Effeney, and Mary O'Kane, *Independent Review into the Future Security of the National Energy Market* (Commonwealth of Australia, June 2017) 37, accessed 21 February 2017.

> generation. Thus, it follows that using an estimate of LCOE that does not factor in the effects of variability will lead to suboptimal design solutions and/or siting decisions.[8]

The outcome of relying on LCOE accounting to plan Australia's energy future is to grossly underestimate the cost of renewable energy generation and renewable transition. Ultimately, Australian families and businesses have had and will continue to pay the price of this oversight through higher energy bills and lower system reliability.

Put another way, Australian are being short-changed by the push to impose an energy system that is and will continue to be more costly than advertised.

2 Understanding LCOE: A comprehensive overview

Energy is essential in modern society and rightly carries a leading role in the agendas of both businesses and policy makers. Concerningly, pivotal discussions on energy, which should ideally be well-based in the realms of engineering and economics, have in recent years seen an unsettling shift towards politicisation and domination by ideologues.

The pressing objective of transitioning Australia's economy to zero carbon emissions has disrupted the delicate equilibrium between free market operations and government intervention. Consequently, governments at both the state and federal levels have assumed a more pronounced role in shaping the nation's energy trajectory.

This transformation has coincided with a significant deterioration in the quality of analytical discourse, with a pivot towards soundbites rather than substantive planning and investment deliberations. At the epicentre of this newfound political rush toward achieving a net zero carbon economy is a heavy focus on a singular investment metric—the LCOE. It has become the ubiquitous figurehead, on which energy policy documents, politicians, and media outlets rely to justify a sprint towards unreliable renewable technologies.

However, LCOE accounting is far from the holy grail of energy economics, engineering, or strategic planning. What may initially appear as a straightforward and widely accessible number is being employed in profoundly inappropriate ways to manipulate a pivotal debate regarding Australia's future energy landscape.

LCOE is an assessment tool based on the financial framework for assessing a project's net present value. This widely used financial metric calculates the present value of expected future profits from an investment or project by expressing them in today's dollars using a given interest rate. It takes account of the time value of money—that is, a dollar today is more valuable than a dollar in the future because you can invest it and receive interest over time that allows a greater quantity of future goods to be consumed.

Rather than model the expected profits of a project, an LCOE calculation rearranges the terms of the net present value calculation to yield an estimate of the average electricity price that a generating asset must command throughout its operating life to break-even. This

[8] Ryan Coe, Seongho Ahn, Vincent Neary, Peter Kobos and Giorgio Bacelli, 'Maybe less is more: Considering capacity factor, saturation, variability, and filtering effects of wave energy devices' (2021) *Applied Energy* 291, 116763.

calculation considers various factors such as initial investment, ongoing operational and maintenance costs, investment returns, and energy output.

A simple representation of the LCOE formula from the Australian Energy Regulator looks like this:[9]

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

Where:

r = discount rate (percent);

n = life of the asset (years);

I_t = Investment expenditure in the year t;

M_t = Operations and maintenance expenditure in the year t;

F_t = Fuel expenditure in the year t; and

E_t = Electricity generation in the year t

LCOE accounting offers certain advantages. One of its key strengths is its simplicity and accessibility, particularly in comparison with other intricate financial and economic tools. Consequently, it serves as a user-friendly metric that can provide high level guidance to investors and policy makers evaluating individual energy projects. Its very simplicity has contributed to its broad appeal and frequent citation in contemporary energy analyses, thereby elevating the prominence of energy-related discussions—a positive development for public discourse on this critical topic.

But LCOE accounting remains widely misunderstood. While it facilitates sensitivity analysis within a single project, allowing for the exploration of various cost scenarios, it cannot stand alone when comparing different types of energy projects. Many vital factors that influence investment decisions are beyond the remit of LCOE calculations.

Furthermore, electricity networks and markets are complex systems. The cost data of individual projects do not scale up to provide an adequate working model for the entire electricity grid. More detailed information on network, storage, firming, frequency management and back up costs must be considered along with the potential economic consequences of unreliable energy supply disrupting business activity.

Put simply: one project does not a market make.

Foremost among Australia's energy policy challenges is the fact that LCOE has been weaponised as a political, public relations and social tool. LCOE figures are often misconstrued, often misused, and susceptible to manipulation to serve political agendas.

As a result of these limitations, growing opposition has emerged against the excessive reliance on LCOE estimates. Engineers, economists, community groups, and energy analysts are increasingly highlighting the flawed methodologies employed by government planners in

[9] Australian Energy Regulator, *LCOE and LCOS modelling approach, limitations and results* (Commonwealth of Australia, December 2020) 7, accessed 21 February 2024.

their policy decisions and political advocacy.[10] Moreover, evidence from Australians families' lived experiences suggest that the transition to renewable energy sources, often touted for their low LCOE estimates, is not delivering the promised reductions in electricity prices.

This discrepancy between LCOE projections and real-world outcomes raises critical questions about the effectiveness of using LCOE as the primary determinant on which energy policy and investment decisions are based. Clearly, there are sources of potential bias in the CSIRO's GenCost, LCOE-based calculations that must be addressed.

3 LCOE estimates can be easily manipulated

There are many ways in which LCOE can be calculated depending on the different assumptions made around it. Different independent variables can enter the calculation to produce a more detailed analysis of a project's viability. These variables can be broadly classified as either cost inputs, which include capital expenditure, fuel costs and maintenance costs—or modelling parameters—including the discount rate, the capacity factor of an asset and the said asset's operating life.

The cost inputs are often a point of public debate, particularly in the endeavour to forecast future trends in LCOE. But the modelling parameters used in LCOE can have a significant impact on the output of an LCOE calculation and, through simple adjustments, create significant bias in the results of an LCOE study.

The following analysis is not intended as a source of LCOE estimates for the different generators analysed. But using a simplified form of LCOE calculation, it shows how easily LCOE estimates can be manipulated even without making variations to cost inputs. The modelling provided is based on inputs used in the CSIRO's 2023 GenCost study and the Simple LCOE Calculator from the United States (US) National Renewable Energy Laboratory.[11]

3.1 A baseline LCOE estimate

Table 1 below provides a baseline estimate for three different electricity projects: an onshore wind project, a solar farm, and a black coal-fired power station. While the cost inputs and modelling parameters were derived from the 2023 GenCost study, due to the application of the simple LCOE method, here, the final LCOE estimates vary from the outcomes modelled by CSIRO.

[10] Save Our Surroundings, *Save Our Surroundings (SOS) GENCOST SUBMISSION to Draft Consultation Documents: 2023 Inputs Assumptions and Scenarios Report* (February 2023), 1, accessed 21 February 2024: https://aemo.com.au/-/media/files/stakeholder_consultation/consultations/nem-consultations/2022/2023-inputs-assumptions-and-scenarios-consultation/submissions/save-our-surroundings.pdf?la=en; Aynsley Kellow, 'Dateline Glasgow: the real costs of renewable energy,' *The Spectator* (2 November 2021) accessed 21 February 2024: https://www.spectator.com.au/2021/11/dateline-glasgow-the-real-costs-of-renewable-energy/.
[11] National Renewable Energy Laboratory, 'Simple Levelized Cost of Energy (LCOE) Calculator Documentation,' accessed 21 February 2024: https://www.nrel.gov/analysis/tech-lcoe-documentation.html.

Table 1: Baseline LCOE estimates.

	Onshore wind	Solar PV	Black coal
Interest rate (r)	5.99%	5.99%	10.99%
Operating life (n)	25	30	30
Overnight capital cost ($/kw)	2,642	1,572	5,398
Fixed O&M ($/kw)	25	17	53
Capacity factor	48%	32%	89%
Fixed cost sub-total	55	47	86
Efficiency	100%	100%	40%
Fuel cost ($/GJ)	0	0	7
Fuel cost ($/MWh)	0	0	17
Variable O&M ($/MWh)	0	0	4
Variable cost sub-total	0	0	21
Total LCOE ($/MWh)	**55**	**47**	**108**

A quick review of these modelling outputs shows the LCOE of solar and wind being both significantly lower than coal's. The principal driver is the relatively much lower capital costs of wind and solar projects. Neither wind nor solar has fuel or variable costs while coal power stations do. This often gives rise to the misleading statements that wind and solar energy are free. Wind and solar may have zero fuel cost, but without large capital expenditures these sources cannot be harnessed for use in an electricity system.

This paper will not delve into the detailed issue of input costs, but rather evaluate the impact of assumptions used to set LCOE modelling parameters. The capacity factors, interest/discount rates, and operating life of electricity projects vary significantly. It is often questionable how closely these parameters align with real-world experiences and can be a significant source of bias that ultimately discredits the use of LCOE analysis beyond the assessment of a single project.

3.2 The impact of capacity factors

The first parameter that will be varied in this analysis is the capacity factor. The capacity factor is the equivalent of the percentage of time a generator is running at its maximum capacity in a period (usually a year). Alternatively, it describes the proportion of an asset's maximum output that it is expected to produce over the course of the said period.

In this analysis the capacity factor for each project is given as a constant over the project's lifetime. In practice, this does not happen. Wear and tear reduces the output of thermal generators even with regular maintenance. There is also now a growing research effort examining wind turbine performance over time showing similar output degradation.[12] Additional analysis on the capacity factors of solar panels in the US also indicates a strong tendency to underperform against expected output.[13]

[12] Davide Astolfi, Ravi Pandit, Ludovica Celesti, Matteo Vedovelli, Andrea Lombardi, and Ludovico Terzi, 'Data-Driven Assessment of Wind Turbine Performance Decline with Age and Interpretation Based on Comparative Test Case Analysis' (2022) 22(9) *Sensors (Basel)* 1-22.
[13] kWh Analytics, '2022 Solar Generation Index: Quantitative Insights from Leading Asset Owners,' accessed 21 February 2024: https://www.kwhanalytics.com/sgi.

Changing the capacity factor in an LCOE calculation has a significant impact on the outcome.[14] A lower capacity factor indicates the project is producing less electricity over its operating life. The LCOE, which is the average cost per unit of electricity, goes up with a decreased capacity factor.

This is captured in Table 2, where the LCOE of the wind and solar projects have been reduced to levels more consistent with the average capacity factor for each type of asset in Australia.[15]

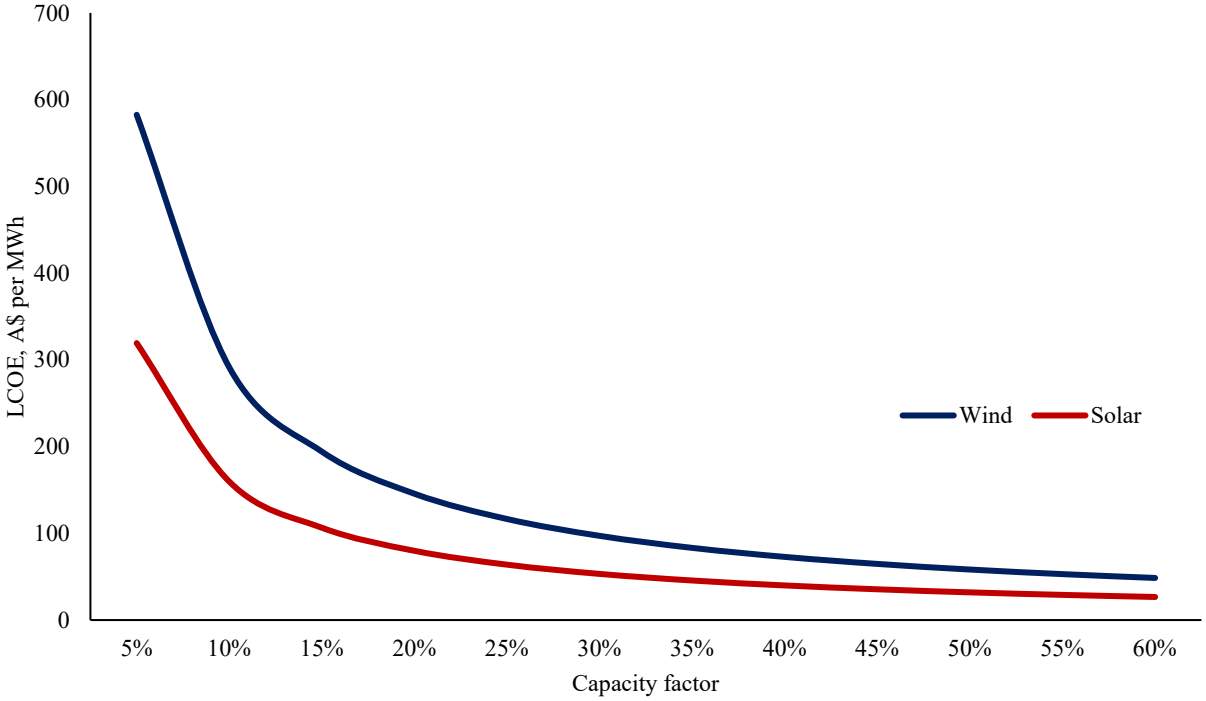
Table 2: The impact of using average capacity factors for renewable energy projects.

	Onshore wind	**Solar PV**	**Black coal**
Interest rate (r)	5.99%	5.99%	10.99%
Operating life (n)	25	30	30
Overnight capital cost ($/kw)	2,642	1,572	5,398
Fixed O&M ($/kw)	25	17	53
Capacity factor	32%	22%	89%
Fixed cost sub-total	83	68	86
Efficiency	100%	100%	40%
Fuel cost ($/GJ)	0	0	7
Fuel cost ($/MWh)	0	0	17
Variable O&M ($/MWh)	0	0	4
Variable cost sub-total	0	0	21
Total LCOE ($/MWh)	**83**	**68**	**108**

The impact on LCOE of each asset is significant. Simply aligning the capacity factor of wind and solar projects with the national average for each asset resulted in LCOE increases in the order of 50 per cent. This is widely understood, and most studies provide an LCOE band to reflect the different potential output of electricity projects. Nevertheless, energy industry advocates tend to focus on the low end of the band which often represents the optimal generating conditions that can only be achieved at a small portion of assets. As this analysis and Chart 1 show, there is a strong inverse relationship between capacity factor and LCOE. This relationship gives industry advocates the incentive to overstate asset performance.

[14] Sadik Kucuksari, Nuh Erdogan, and Umit Cali, 'Impact of electrical topology, capacity factor and line length on economic performance of offshore wind investments' (2019) 12(16) *Energies* 3191.
[15] Paul Graham et al., *GenCost 2022-23: Final Report* (CSIRO, July 2023) 80, accessed 21 February 2024: https://www.csiro.au/-/media/EF/Files/GenCost/GenCost2022-23Final_27-06-2023.pdf.

Chart 1: The relationship between LCOE and capacity factor



3.3 The role of discount rates

The second modelling parameter that is prone to bias is the interest or discount rate applied to a project's cost.[16] It is common in LCOE studies to apply a risk premium to certain projects on the basis that investors would demand a high rate of return to account for climate, regulatory or market risks.

This may reflect current market practice, but it is greater indication of the impacts of policy contamination. To provide a comparable LCOE across all potential electricity sources, the calculation must be free of any policy-led risks. A similar treatment should also be applied to exclude any government subsidies which can take the form of low interest financing schemes, direct grants, or preferential market treatment (e.g., an 82 per cent renewable energy target by 2030 and legislated emissions reduction targets under the *Climate Change Act 2022*).

The results of normalising our LCOE estimates for the interest rate is shown in Table 3. The LCOE of the coal-fired power station has decreased from $108 to $79, a reduction of 27 per cent. With the baseline capacity factor and other input assumptions, however, it remains higher than both the wind and solar projects.

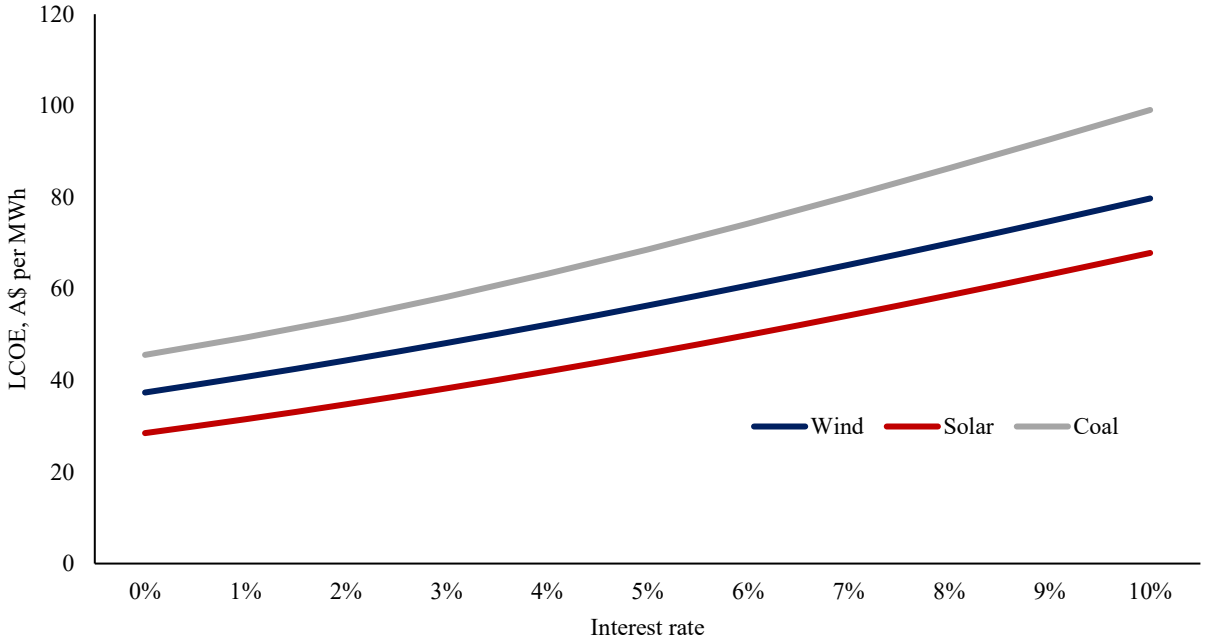
[16] See for e.g., John Aldersey-Williams and Tim Rubert, 'Levelised cost of energy–A theoretical justification and critical assessment' (2019) *Energy policy* 124, 169-179.

Table 3: The impact of standardising interest rate on LCOE estimates.

	Onshore wind	**Solar PV**	**Black coal**
Interest rate (r)	5.99%	5.99%	5.99%
Operating life (n)	25	30	30
Overnight capital cost ($/kw)	2,642	1,572	5,398
Fixed O&M ($/kw)	25	17	53
Capacity factor	48%	32%	89%
Fixed cost sub-total	55	47	57
Efficiency	100%	100%	40%
Fuel cost ($/GJ)	0	0	7
Fuel cost ($/MWh)	0	0	17
Variable O&M ($/MWh)	0	0	4
Variable cost sub-total	0	0	21
Total LCOE ($/MWh)	**55**	**47**	**79**

Unlike capacity factor, there is a strong and **positive** relationship between interest rates and LCOE. As interest rates are a project financing cost, higher rates result in increased LCOE estimates. It is no surprise then, that renewable energy proponents continuously lobby governments to provide subsidised financing schemes to support renewable projects while simultaneously advocating that no other class of generators, be it nuclear or coal-fired, be worthy of such access due to their higher costs.

Chart 2: The relationship between LCOE and interest rate



3.4 Asset life

The operating life of an electricity project can have substantial impact on its commercial returns. Large, baseload generators in particular are designed with long lives in mind and intended to maximise their output throughout their lifetimes by running nearly non-stop (thus their high capacity factors). Once such assets pay off their initial investments, their costs of generation are substantially lower; hence, keeping the assets running for as long as it is safe to do so makes commercial sense.

In comparison, renewable energy projects' operating lives remain somewhat unknown. Though they are designed to operate for between 25 (onshore wind) and 30 (solar PV) years, it remains to be seen if they can meet such expectations. There is mounting evidence that wind assets are experiencing higher fail rates, greater degradation than anticipated and may not reach their target lives without additional maintenance or replacement of parts. In December 2021, *The Daily Mail* reported:

> Chinese-made wind turbines on Australia's biggest wind farm have cracked, sparking outrage that the project didn't use locally made machinery. Nineteen of 40 turbines inspected at the Stockyard Hill wind farm, in Victoria's central highlands, are defective and will take months to fix, according to the Australian Manufacturing Worker's (sic) Union. Another 109 turbines were yet to be inspected and it was feared they could also be damaged.[17]

China dominates the market for wind turbines, solar panels, as well as much of the raw material production and processing necessary to manufacture wind and solar assets.[18]

In June 2023, turbine manufacturer Siemens' share price crashed 37 per cent in a single day in response to technical problems in its products and a costly repair program.[19]

To reflect this potential difference in operating life, Table 4 has varied the wind and solar projects' operating lives by reducing them by 5 years. In contrast, the coal-fired project has increased its assumed operating life by 10 years to 40 years. This parameter is well supported by experience in Australia that shows many coal-fired power stations continue to operation well beyond 40 years. For example, the recently closed Liddell power station operated for over 50 years, albeit at lower output rates towards the end of its life.

[17] Peter Vincent, 'Turbines made in China for Australia's biggest wind farm have CRACKS in them sparking outrage they weren't made locally to better standards,' *Daily Mail Australia* (15 December 2021) accessed 21 February 2024: https://www.dailymail.co.uk/news/article-10311315/China-wind-turbines-crack-sparking-outrage-werent-Australia.html.

[18] Yasuki Okamoto, 'Chinese manufacturers dominate wind power, taking 60% of global market,' *Nikkei Asia* (19 August 2023) accessed 22 February 2024: https://asia.nikkei.com/Business/Energy/Chinese-manufacturers-dominate-wind-power-taking-60-of-global-market; Reuters, 'China will dominate solar supply chain for years – wood Mackenzie,' *Reuters* (8 November 2023) accessed 22 February 2024: https://www.reuters.com/world/china/china-will-dominate-solar-supply-chain-years-wood-mackenzie-2023-11-07/; Alan Finkel, *Powering Up* (Black Inc, 2023).

[19] Wilfried Eckl-Dorna, 'Siemens Energy Falls by Record After Wind Unit's Woes Deepen,' *Bloomberg* (23 June 2023) accessed 22 February 2024: https://www.bloomberg.com/news/articles/2023-06-22/siemens-energy-shares-fall-after-company-withdraws-outlook?sref=fo3Pgvks.

Table 4: The impact of operating life on LCOE

	Onshore wind	Solar PV	Black coal
Interest rate (r)	5.99%	5.99%	10.99%
Operating life (n)	20	25	40
Overnight capital cost ($/kw)	2,642	1,572	5,398
Fixed O&M ($/kw)	25	17	53
Capacity factor	48%	32%	89%
Fixed cost sub-total	61	50	84
Efficiency	100%	100%	40%
Fuel cost ($/GJ)	0	0	7
Fuel cost ($/MWh)	0	0	17
Variable O&M ($/MWh)	0	0	4
Variable cost sub-total	0	0	21
Total LCOE ($/MWh)	**61**	**50**	**106**

The change in asset operating life adds a further $6 per MWh to the LCOE of the wind project and $3 per MWh to the solar project. The impact on the coal project is negligible, but as previously highlighted the simple LCOE estimation method is not the best tool to assess the commercial returns of extending a generator this far out. As will be discussed in the next section, LCOE in general is not a suitable tool for assessing the value of baseload generators that operate for many decades and produce substantial benefits long into the future.

3.5 Putting it all together

Bring together the changes in modelling parameters into a single scenario produces the most significant results, as shown in Table 5.

Table 5: The combined impact of capacity factors, interest rates and operating life on LCOE

	Onshore wind	Solar PV	Black coal
Interest rate (r)	5.99%	5.99%	5.99%
Operating life (n)	20	25	40
Overnight capital cost ($/kw)	2,642	1,572	5,398
Fixed O&M ($/kw)	25	17	53
Capacity factor	32%	22%	89%
Fixed cost sub-total ($/MWh)	91	73	53
Efficiency	100%	100%	40%
Fuel cost ($/GJ)	0	0	7
Fuel cost ($/MWh)	0	0	17
Variable O&M ($/MWh)	0	0	4
Variable cost sub-total ($/MWh)	0	0	21
Total LCOE ($/MWh)	**91**	**73**	**74**
Base case ($/MWh)	55	47	108
Variation ($/MWh)	36	26	-34
% change	65%	54%	-31%

Without a single change to input cost, the LCOE of the wind project has increased 65 per cent to $91 per MWh and the solar PV project increased 54 per cent to $73. In comparison, the coal-fired generator's LCOE went down 31 per cent to $74 per MWh. Notably, the coal-fired generator project now sits on-par with the solar PV project as having the lowest LCOE in the group.

3.6 Bias is inherent to LCOE analysis

As this analysis demonstrates, LCOE estimates can produce many scenarios. Even without questioning the validity of cost inputs or forecasts of which capital costs will reduce further over the next 20 years, it is easy to manipulate the modelling to produce a desired outcome through simple assumptions.

Quantitative analyses, such as LCOE estimates, are widely believed to be objective and conclusive. This is not necessarily the case. LCOE estimates are increasingly becoming subjective, insufficiently scrutinised and overly relied upon.

Such modelling bias is just the starting point to the argument for why LCOE should not be the metric used to determine our energy future. More of these reasons will be considered in the next section of this report.

4 Broader issues with LCOE

In private sector electricity project development, accuracy in financial estimates matters. There is a strong incentive for electricity project developers to produce accurate financial estimates, including LCOE, to inform their business decisions. Poor practices, such as modelling biases, ultimately create unprofitable businesses that rarely last long without some form of government support.

LCOE is increasingly employed beyond its original scope of assessing individual projects. It is now widely used to compare electricity project types and for forming the basis of energy policy decisions, especially those involving financial support for renewables. There is, therefore, now a strong incentive for data modellers to resort to some of the biases highlighted in the preceding section when producing LCOE estimates.

This alone should suffice as a reason to reconsider the use of LCOE estimates in comparing electricity projects. But there are also additional issues that must be considered when undertaking detailed analysis of large energy systems, which provide further support to the argument that using LCOE estimates is not appropriate for informing public policy on energy.

4.1 Missing costs

An electricity grid is a large and highly complex feat of engineering. While we think of electricity as a homogenous product, the reality is not so simple. Anyone who has tried to plug in their mobile phone charger in another country would have experienced a hassle associated with this complexity first hand.

The electricity grid has strict standards, each of which feature minimal tolerance for variation. Frequency, voltage and current must all be maintained for the system to work. The generators supplying them must also adhere to these standards.

LCOE estimates rarely compare projects based on their ability to meet these standards. In many cases, particularly with renewable energy projects, grid stability is left as an externality: a cost for other generators, the grid, or storage assets to cover. While this practice may reduce one project's cost, it contributes to the overall cost borne by consumers in the energy system.

It is now widely acknowledged that LCOE estimates exclude many cost inputs that are essential for making projects comparable. To put it mildly, a wind farm is not a direct substitute for a coal-fired power plant even if they have the same generating capacity. Voltage fluctuation in wind farms, for instance, is a perennial challenge. Furthermore, with a capacity factor roughly half that of a coal-fired power plant, a wind farm will rarely, if ever, generate electricity at its maximum capacity. In peak demand periods, it may even produce no electricity at all.

Similar issues exist with solar farms. Without frequency control systems, additional energy storage or firming capacity, such as back-up gas or diesel generators, a significant penetration of solar risks destabilising the power grid. The associated additional costs all drive up the comprehensive system cost paid by Australian families and businesses.

Nonetheless, the overwhelming of the energy grid by wind and solar still created significant supply and reliability risks.

South Australia, like many energy markets that have pursued renewable energy policies, has already encountered this phenomenon. The state has witnessed a surge in frequency management issues and now bears the highest residential electricity bills in the country, as shown in Chart 3 below.[20] Notably, since 2016, South Australia no longer host any coal-fired power station and is therefore reliant on interconnectors to other states in the national electricity market for imported supply of baseload power.

Chart 3: Residential electricity median market and standing offer prices

Source: AER

[20] Australian Energy Regulator, *Annual Retail Markets Report 2021-22* (Commonwealth of Australia, 2022), 36, accessed 22 February 2024: https://www.aer.gov.au/publications/reports/performance/annual-retail-markets-report-2021-22.

These performance standards matter significantly, and many engineering requirements essential for creating comparable projects are typically excluded from LCOE calculations. Increasingly, this issue is gaining the attention it merits, with public scrutiny of CSIRO's GenCost 2023 report revealing that even when firming and integration costs are added to variable renewable energy LCOE estimates, most of the additional capital expenditures required are still omitted.

4.2 Value matters, not just cost

A metric that primarily analyses project input costs, rather than performance, may not be best suited for informing decision making regarding complex energy systems. While low production costs are important in an economy or market, they are not the sole consideration.

Mark Nelson, a nuclear energy advocate and investor, provides a fitting analogy:

> Imagine you are standing in Manhattan and need to get to London in the most cost-effective way. We would find that swimming is the cheapest! By the cost per mile of swimming, it is far cheaper than building a boat, and the infrastructure needed to use a plane would be very expensive; swimming is clearly the cheapest way to get to London.[21]

LCOE and associated net present value calculations primarily assess the financial returns of a single project. Energy policy should aim to maximise economic value for all stakeholders in the market—of which the consumer is the most important—and not just one part of it: i.e., renewable investors and renewable companies. Value considerations have a more substantial impact on investment decisions.

The US Energy Information Agency now recognises this principle in its regular reports on generator costs. In its 2022 report, the agency highlighted the limitation of relying solely on LCOE:

> LCOE and LCOS [Levelised Cost of Storage] by themselves do not capture all of the factors that contribute to actual investment decisions, making direct comparisons of LCOE and LCOS across technologies problematic and misleading as a method to assess the economic competitiveness of various generation alternatives… solar LCOE, on average, is lower than natural gas-fired combined-cycle (CC) LCOE in 2027. However, more CC generating capacity is installed than solar PV between 2025 and 2027. We project more CC capacity to be installed than solar PV capacity because the relative value of adding CC to the system is greater than for solar PV, which LCOE does not capture.[22]

Part of the challenge to the value proposition of renewable energy projects is their intermittency. Since their generation cannot be timed to coincide with peak demand periods or easily controlled to match the short-term fluctuations in load, they have less value in an

[21] Joshua Antonini, 'Nuclear Wasted: Why the Cost of Nuclear Energy is Misunderstood,' *Mackinac Center for Public Policy* (25 July 2022) accessed 22 February 2024: https://www.mackinac.org/blog/2022/nuclear-wasted-why-the-cost-of-nuclear-energy-is-misunderstood.
[22] US Energy Information Administration, *Levelised Costs of New Generation Resources in the Annual Energy Outlook 2022* (March 2022) accessed 22 February 2024: https://www.eia.gov/outlooks/aeo/pdf/electricity_generation.pdf.

electricity grid. To address this issue, Dr Finkel proposed an 'incentive payment' made to consumers, for instance, so that they 'might agree to postpone using the dishwasher and washing machine' at peak periods.[23]

LCOE measurements do not account for this. Professor Paul Joskow from the Massachusetts Institute of Technology was among the first to identify this issue back in 2010, stating:

> While levelized cost calculations may be a simple way accurately to compare different dispatchable base load generating technologies with different capital and operating cost attributes it is not a useful way to compare generating technologies with very different production profiles and associated differences in the market value of the electricity they produce. When these kinds of comparisons are at issue, as they now frequently are given the public policy and regulatory pressures to increase investment in renewable energy technologies with intermittent output characteristics, a different set of methods is required to better understand what the true costs are for different generation technologies.[24]

Joskow made the following recommendation:

> A good starting point would be to evaluate all generating technologies, both intermittent and dispatchable, based on the expected market value of the electricity that they will supply, their total life-cycle costs and their associated expected profitability, rather than focusing only on the levelized cost per unit of output. Such an analysis would reflect the actual expected production profiles of dispatchable and intermittent technologies, the value of electricity supplied at different times, and other costs of intermittency associated with reliable network integration. That is, abandon levelized cost comparisons and adopt more standard economic evaluation methods for new generating capacity.[25]

A key issue in the value of renewable energy is that electricity prices are determined by the demand-supply balance in the market at any given period. When wind or solar availability is high, all competing wind turbines and solar PV enter the market together. Energy storage projects such as batteries, pumped hydro schemes, and hydrogen production, may be able to take this boost in electricity output, but the likely resulting abundance of supply will inevitably drive market prices down to unsustainable levels below the LCOE threshold for renewable energy projects.

The wind and sun may be free but wind and solar farms still require sufficient revenue streams to recoup their construction costs and provide a return on capital expenditure. The sole reliance on LCOE estimates is not properly assessing this revenue risk.

4.3 Comparing projects with significantly different operating lives

The single dollar figure provided by LCOE estimates conveys limited information about an asset's economic value, especially regarding how long it can provide electricity. This is crucial for long-term planning because generators have vastly different operating lives. While a wind

[23] Alan Finkel, *Powering Up* (Black Inc, 2023) 150.
[24] Paul L. Joskow, 'Comparing the Costs of Intermittent and Dispatchable Electricity Generating Technologies,' (2011) Vol 101 No 3 *American Economic Review*: 238-241.
[25] Ibid.

turbine may have lower capital costs than a nuclear reactor, the former is expected to operate for 20-25 years, whereas the latter may extend its useful life beyond 60 years if regulators permit it to do so.

Assessing the total capital requirements of an energy system over an appropriate time horizon provides a more comprehensive view of investment value. To equate the investment decision between a wind turbine and a nuclear power plant, a replacement program must factor into planning considerations. The initial wind farm would need to be replaced twice to match the long-term availability of the nuclear power plant.

This is where net present value analysis, and LCOE by extension, faces a challenge. The use of discounting rates significantly diminishes large future costs and the significance of future benefits.

Consider the cost of wind farm replacements over a 60-plus year horizon. The CSIRO GenCost report estimates capital intensity for onshore wind projects in 2022 at $2,642 per kW of capacity. Therefore, the total construction cost for a 300 MW wind farm would be approximately $793 million for the initial build.

GenCost anticipates substantial reductions in onshore wind farm technology costs in the future, with capital intensity falling to $1,720 per kW of capacity by 2040. For a replacement project, this translates to a total cost of $516 million. Assuming a capital intensity of $1,642 per kW in 2050 for the final replacement, an additional $493 million would be spent.

Across these three phases, a total of $1.8 billion would need to be invested in building wind farms over 60 years. However, when these costs are discounted, their net present value is reduced to only $1 billion, eliminating almost half of the long-term expenses.

Contrast this with a nuclear power plant project, where the discounting effect operates inversely to reduce its long-term benefits. A nuclear power plant does not require complete replacement like a wind farm and has minimal fuel and variable maintenance costs. As a result, analyses often show that existing nuclear power plants, once their initial capital costs are recovered, often have among the lowest LCOEs, even before accounting for grid, storage, and firming costs incurred by renewable energy projects.[26]

Consequently, the nuclear power plant receives a significant boost in its net cashflow later in its operating life, but these payments are heavily discounted. At an interest rate of just 5.99 per cent, all benefits beyond year 20 would be discounted in the net present value calculations to less than 30 percent of their actual value.

While such analytical methods are suitable for cashflow analysis aiming to capture the time value of money, they introduce another source of bias when LCOE is used to inform energy system planning, especially in studies that consider the long-term value of energy security.

These results underscore the issue highlighted earlier concerning modelling parameters, which indicated that assumptions regarding asset operating lives and interest rates can combine to produce significantly different LCOE estimates.

[26] George Bilicic and Samuel Scroggins, *LCOE+ 2023* (Lazard, April 2023) accessed 22 February 2024, https://www.lazard.com/media/2ozoovyg/lazards-lcoeplus-april-2023.pdf.

The Organisation for Economic Co-operation and Development's (OECD) modelling, as documented in its 2020 report on the Projected Costs of Generating Electricity, demonstrates this effect, as summarised by the World Nuclear Association:

> The 2020 edition of the OECD study on Projected Costs of Generating Electricity showed that the range for the levelized cost of electricity (LCOE) varied much more for nuclear than coal or CCGT with different discount rates, due to it being capital-intensive (see above). The nuclear LCOE is largely driven by capital costs. **At a 3% discount rate, nuclear was substantially cheaper than the alternatives in all countries**, at 7% it was comparable with coal and still cheaper than CCGT, at 10% it was comparable with both. At low discount rates it was much cheaper than wind and solar PV.[27] (Emphasis added)

This analysis underscores the influential role that governments can play in energy system development. Low-interest loans for energy projects with high capital costs can lead to lower project costs and improved business cases for many different electricity projects. Conversely, depriving competitors of access to such financial arrangements can practically prevent them from happening.

4.4 Summary

There are clear limits to what LCOE can be used for when analysing energy policy. Such estimates are prone to bias, omit key costs and cannot be used to assess the merits of projects that have vastly different values.

Australia needs a different approach to informing its energy debate.

5 Rethinking energy policy analysis

Criticisms over the use of LCOE in energy system analysis have been voiced for some time, yet the transition away from its exclusive application has been slow. In Australia, policy inertia continues to pose a significant challenge to reshaping energy policy. Although government agencies have acknowledged the limitations of LCOE and started to offer other metrics in their reports, there is room for further improvement by adopting innovative methods developed by energy experts worldwide.

5.1 Levelised Cost of Storage

Perhaps the easiest approach to addressing issues associated with LCOE accounting as it pertains to variable renewable energy projects is the augmentation of LCOE with a method to assess the costs of energy storage. LCOS accounting provides a break-even price that an energy storage system must achieve to justify an investment.

[27] World Nuclear Association, 'Economics of Nuclear Power' (August 2022) accessed 22 February 2024: https://world-nuclear.org/information-library/economic-aspects/economics-of-nuclear-power.aspx.

It treats electricity costs as an input similar to the cost of fuel and then factors in the capital expenditures, operating costs and maintenance expenses necessary in the same way as an LCOE calculation.[28] The formula is as follows:

$$LCOS = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

Where:

r = discount rate (percent);

n = life of the asset (years);

I_t = Investment expenditure in the year t;

M_t = Operations and maintenance expenditure in the year t;

F_t = Fuel expenditure in the year t; and

E_t = Electricity generation in the year t, which is calculated as the number of trading days (between 12 and 365) multiplied by a daily discharge of 400 MWh

The drawback of LCOS accounting is that it encounters some of the same limitations as LCOE. Notably, it often fails to account for the diverse benefits associated with different types of energy storage systems. For instance, comparing the LCOS of a lithium-ion battery with that of a large pumped hydro system overlooks the latter's superior grid stabilisation capabilities.

While pumped hydro synchronises with the electricity grid's frequency using turbines, the lithium-ion battery offers flexibility and different grid management advantages. LCOS, unfortunately, does not consider these aspects, thus the pitfalls of relying on a single metric for electricity system analysis.

Moreover, if LCOS estimates derive their electricity input costs from modelled LCOE figures rather than market pricing, then they risk perpetuating the biases inherent in LCOE.

5.2 Levelised Avoided Cost of Energy

To address the problem of LCOE not capturing the use value of a project, the US Energy Information Administration has developed the concept of Levelised Avoided Cost of Energy (LACE) to supplement their analysis of electricity market dynamics.

Whereas the LCOE of a project assesses its input costs to evaluate the minimum price it must achieve to make the project feasible, LACE instead determines the value that a project creates in a grid with a fuller analysis of what price it can charge for its output at a particular time. At its core, LACE is an assessment of the revenue that a project can raise. This addresses one of the fundamental issues in comparing variable renewable energy sources with dispatchable electricity generators. The US Energy Information Administration formula for LACE is:[29]

[28] Australian Energy Regulator, *LCOE and LCOS modelling approach, limitations and results* (Commonwealth of Australia, December 2020) accessed 22 February 2024: https://www.aer.gov.au/documents/wholesale-electricity-market-performance-report-2022-lcoe-lcos-modelling-approach-limitations-and-results.
[29] US Energy Information Administration, *Levelised Cost of Electricity and Levelised Avoided Cost of Electricity Methodology Supplement* (July 2013) accessed 22 February 2024, https://www.eia.gov/renewable/workshop/gencosts/pdf/methodology_supplement.pdf.

$$LACE = \frac{\sum_{t=1}^{Y}(Marginal\ generation\ price_t \times Dispatched\ hrs_t) + (Cap\ pymt\ \times Cap\ credit)}{Annual\ expected\ generation\ hours}$$

Where:

Y = the number of time periods (t) in a year;

Marginal generation price = the cost of serving load to meet the demand in the specified time period;

Cap pymt = capacity payment, namely the value to the system of meeting reliability reserve margin;

Cap credit = capacity credit, namely the ability of the unit to provide system reliability reserves; and

Annual expected generation hours = the number of hours in a year that the asset is assumed or expected to operate.

Rather than rely on one metric over the other, the US Energy Information Administration uses a ratio of LACE to LCOE to inform its analysis. This method shows that projects that create more value (based on LACE) than their cost (LCOE) are more desirable. The outcomes of such analysis have more closely explained energy investment in the US, particularly with regard to ongoing investment in combined-cycle gas turbines which have higher LCOEs than wind and solar projects. This approach has some shortcomings—it is still pegged to the LCOE and its potential biases—but it delivers an improved understanding of project investment decisions.

5.3 Full system costs of electricity

In the last decade, there has been a growing international effort to evaluate all costs involved with transforming an electricity system to address the problems of LCOE. New approaches that better integrate generation, network, and system management are emerging, but no method has become universally accepted as a replacement to LCOE as yet.

In 2018 the CSIRO released its own discussion paper on other methods that could be applied with the aim of addressing issues pertaining to LCOE accounting.[30] Yet the organisation has been hesitant to follow its own advice and continues to release its annual GenCost studies with few credible advances in addressing LCOE deficiencies.

In the 2023 GenCost report, the CSIRO provided a supplementary set of LCOE estimates that it claimed include integration costs as a step toward addressing the aforementioned issues. While admirable in its intent, this has proven to be another misleading set of costs that have perpetuated the myth of renewable energy being cheap, contrary to the observed reality.

The CSIRO's method has only included a portion of the additional grid, storage, and network management costs in its estimates by assuming that almost all investments needed in these areas will occur prior to 2030 and is essentially a 'sunk cost'. Therefore, any project built after 2030 need only consider the additional grid, storage, and network costs from that point onwards. What effectively amounts to a marginal additional cost approach in no way makes

[30] Paul Graham, *Review of alternative methods for extending LCOE calculations to include balancing costs* (CSIRO, December 2018) accessed 22 February 2024: https://publications.csiro.au/rpr/download?pid=csiro:EP187001&dsid=DS3.

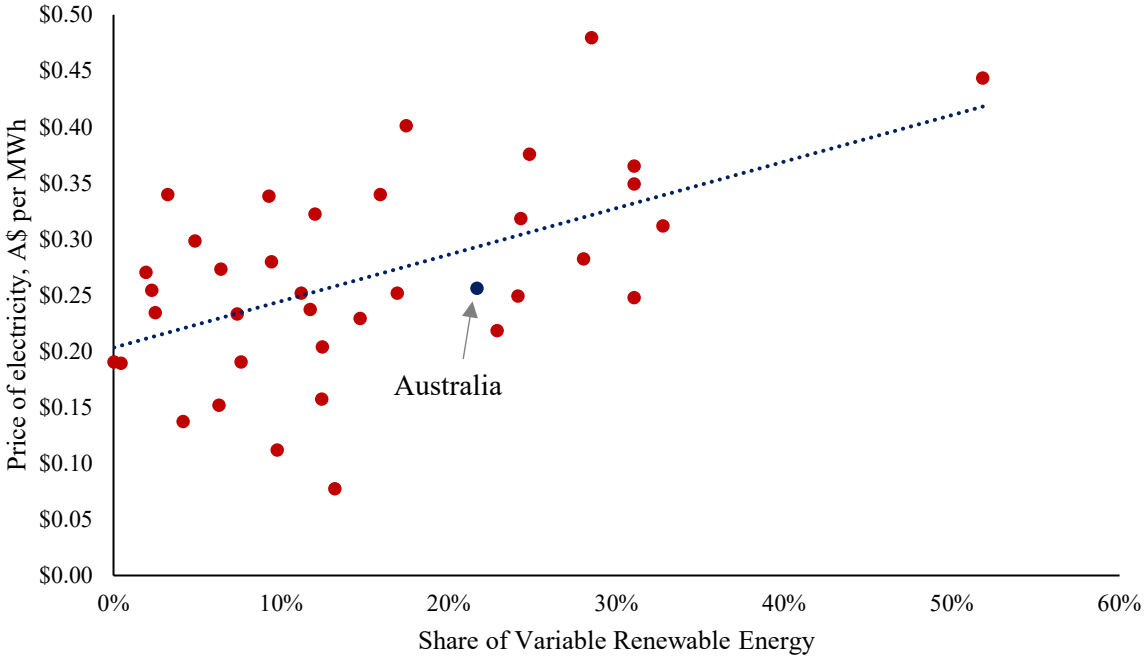
the LCOE of variable renewable energy projects comparable to dispatchable energy sources such as gas, coal, and hydro.[31]

In their 2021 book, Decarbonised Electricity: The Lowest Cost Path to Net Zero Emissions, energy experts Dr Geoff Bongers, Andy Boston, Stephanie Byrom, and Nathan Bongers highlighted the problem with the CSIRO's GenCost approach:

> … As a technology is added to the grid, the impact on TOTAL SYSTEM COST may well be non-linear. The system can become "saturated" with a particular technology and further additions then result in diminishing returns or incur increasing costs within the grid. For example, if solar PV is added to a grid with little current solar generation, then it is likely that most of the output will be of high value and all of its generation consumed. However, if the grid already has a large share of solar PV, then the addition of extra capacity will tend to generate in times of surplus when all the other solar PV plants are generating. To maintain the grid's stability, either its output will be curtailed, or extra costs will be incurred, such as the deployment of new storage to capture lost production or synchronous condensers to provide grid services.[32]

The authors also provide a comprehensive analysis of their total system cost approach using a bespoke energy market model. The results clearly indicate accelerating electricity prices with increased renewable energy shares in the energy mix, which is far more aligned with the experience of nations that have pursued such as energy policies (as illustrated in Chart 4).

Chart 4: Variable renewable energy reliance vs retail electricity prices in the OECD in 2021



Source: AEC, BP

[31] Hydropower or hydroelectricity; not to be mistaken with pumped hydro, which is a storage mechanism that does not produce power in isolation.
[32] Geoff Bongers, Andy Boston, Stephanie Byrom, and Nathan Bongers, *Decarbonised Electricity. The Lowest Cost Path to Net Zero Emissions* (Gamma Energy Technology P/L, February 2021) 6, accessed 22 February 2024: Available from https://www.powerfactbook.com/downloads/energy-reports.

There is a growing effort to produce similar models that capture the full cost of an electricity network rather than simply estimate the individual pieces. More work is needed to perfect these approaches and improve their user-friendliness. While they may deliver more complex models and outputs than policy makers may find desirable, they present a step in the right direction.

6 Conclusion

The reliance on LCOE as the primary metric for comparing classifications of energy projects to guide the deconstruction and reconstruction of Australia's energy networks is dangerous. LCOE accounting oversimplifies complex energy systems and overlooks crucial factors that need to be considered in making investment and policy decisions. LCOE's focus on production cost alone neglects performance, broader system integration, and value creation, rendering it inadequate for informing energy policy decisions.

One of the fundamental issues with LCOE is its inherent bias towards projects with lower upfront costs and inadequacies in comparing projects with significantly different operating lifetimes. This may conveniently align with the short-term goals of political actors; but it does not necessarily align with the long-term goals of an energy system. Furthermore, LCOE does not adequately address the intermittency of renewable energy sources and their inability to match supply with peak demand periods, leading to supply and reliability risks in an electricity grid. This is the reason for why the increase in the penetration of variable renewable energy, mistakenly dubbed the most affordable sources of energy in Australia based on LCOE accounting, has come hand in hand with increased risks of blackouts.

In response to these limitations, complementary metrics have been designed and publicised, such as LCOS and LACE. While these metrics offer valuable insights into energy storage and project revenue generation, their application would still involve LCOE in some capacity. Consequently, they do not entirely address its biases and shortcomings.

There is a growing effort to evaluate the full system costs of electricity, incorporating all the costs associated with transforming an energy system. However, a universally accepted alternative to LCOE is yet to emerge. Therefore, policy makers should be mindful of the pitfalls associated with a reliance on LCOE accounting when making and evaluating claims about the cost-effectiveness of energy production.

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