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V1851

LEVELISED COST OF ELECTRICITY

REVIEW

Prepared for
Clean Energy Council

CLEAN ENERGY COUNCIL

Document information

GENERAL INFORMATION

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Version	Final
Prepared by (author)	Isobel Hugall, Kevin Lee, Matthew Pinnegar, Abel Son
Reviewed by	Matthew Pinnegar, Abel Son, Bruce Wymond
Approved by	Abel Son
CRM number	V1851
Security classification	Client-in-Confidence

HISTORY OF CHANGES

Version	Date	Checked by
V01	2 April 2024	Matthew Pinnegar, Abel Son
V02	10 April 2024	Abel Son, Bruce Wymond, Matthew Pinnegar
V03	13 April 2024	Client
V04	16 April 2024	Matthew Pinnegar, Abel Son
V05	18 April 2024	Abel Son
V06	22 April 2024	Client
V07	30 April 2024	Client

Version	Date	Approved by
V03	11 April 2024	Abel Son
V05	16 April 2024	Abel Son
V06	18 April 2024	Abel Son
V07	22 April 2024	Abel Son
V08	7 Mary 2024	Abel Son

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Disclaimer

This report is an independent analysis based on a review of the following documents:

- CSIRO GenCost 2023-24: Consultation Draft 2023
- Lazard Levelised Cost of Energy Report Version 16.0, 2023; and
- Mineral Council of Australia 2nd Edition, 2022 of Small Modular Reactors in the Australian Context.

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TABLE OF CONTENTS

1 EXECUTIVE SUMMARY

The Australian Government has legislative commitment to move Australia towards achieving net zero emissions. This commitment is underscored by a substantial investment of nearly $25 billion[i] dedicated to advancing climate change and energy transformation initiatives.

Central to achieving this net zero commitment is the need to ensure that the transition builds a more reliable, affordable, and low-emissions energy system for all Australians. It is therefore important that the cost of delivering different forms of renewable generation sources is thoroughly considered both by investors and governments. The Levelised Cost of Electricity (LCOE), henceforth referred to as "the cost of electricity" or simply "the cost" is a metric frequently cited as a measure of cost for generation technologies. However, methodologies for calculating the LCOE vary across jurisdictions, and in terms of the assumptions and types of factors that are included.

The Clean Energy Council (CEC) has commissioned Egis to conduct a literature review of three reports that offer insights into the LCOE of different energy generation technologies.

- CSIRO GenCost 2023-24: Consultation Draft, 2023,
- Lazard Levelised Cost of Energy Report 16.0, 2023, and
- Minerals Council of Australia 2nd Edition, 2022 of Small Modular Reactors in the Australian Context.

This review analyses the methodologies and assumptions used in calculating LCOE and explores the implications of LCOE in the context of investment planning in Australian context.

1.1 Review findings

Our review of the above reports, and supplementary materials from other international resources led to the following findings:

1.1.1 The cost of renewables versus nuclear energy

- The three reports had varying LCOE calculation methodologies. Of those three reports, the GenCost 2023-24 Draft and Lazard Edition 16.0 reports provided LCOE for both renewables and nuclear energy generations. Both of these reports indicated that the cost of renewable energy is lower than that of the cost of nuclear energy. These reports highlights the economic competitiveness of renewables in the current energy landscape.
- The GenCost 2023-24 Draft and Lazard Edition 16.0 reports show nuclear energy to be up to six times more expensive at the highest end of cost estimates when compared to wind and or solar with batteries.

1.1.2 The cost challenges of nuclear energy in Australia

- The extent to which a nuclear industry is already established in a region will have a large impact on the potential for nuclear as a cost competitive energy source. Australia sits at one extreme end of the spectrum, with no nuclear energy industry as nuclear energy is currently prohibited by Commonwealth and State legislation.
- The waste management and decommissioning of a nuclear plant has been omitted from cost calculations in the major reports we considered. This is an issue not only from a financial standpoint but from a political, environmental, and social perspective.

1.1.3 Requirements for a nuclear industry in Australia

- A significant consideration for the Australian context is the suitability of nuclear to integrate into the existing and targeted existing generation mix and market structure. The economic viability of nuclear energy is diminished in a high variable renewable energy (VRE) grid – Australia's current VRE target is 82% by 2030, which is before any nuclear would theoretically be operational.

- Post the Commonwealth lifting the moratorium on nuclear energy, the repealing of several state legislations would be required, such as:
  - Victoria: *The Nuclear Activities (Prohibitions) Act 1983*
  - Queensland: *Nuclear Facilities Prohibition Act 2007*
  - Western Australia: *Nuclear Waste Storage (Prohibition) Act 1999*
  - NSW: *Uranium Mining and Nuclear Facilities (Prohibitions) Act 1986*
- Nuclear waste management is a particularly contentious issue in Australia, which currently has no permanent low-level waste repository.

1.1.4 Small modular nuclear reactors

- The Minerals Council of Australia report on Small Modular Reactors (SMRs) was based on the cost estimates of three projects in developmental stages. One of these projects, the NuScale Power Module, has since been cancelled due to large cost overruns far greater than those outlined in the MCA report. The assumptions around costs are therefore flawed.
- The GenCost 2023-24 Draft Report and the Small Modular Reactors (SMRs) in the Australian Context report did not anticipate a long delay to SMR projects around the world, making them too slow to market. SMR would be too late to contribute to 2030 Australian emissions reduction targets, and difficult to factor into the National Electricity Market (NEM) to meet the 2050 Net Zero Emissions (NZE) target.

2 INTRODUCTION

2.1 Project Background

The Australian Government has made a legally binding commitment to drive its transition to net zero. In 2022, Australia enshrined in law its targets of reducing greenhouse gas emissions by 43% from 2005 levels by 2030 and to net zero by 2050.

To achieve the emissions target, the Australian Government has committed almost $25 billion[ii] to deliver climate change and energy transformation priorities, including:

- Transforming Australia's electricity supply to run mainly on renewables
- Supporting the development of new, clean energy industries
- Supporting the decarbonisation of existing industries and the transport network

The commitment to net zero emissions has sparked debate regarding the cost of various electricity generation sources in Australia. One key discussion concerns the cost-effectiveness of nuclear power compared to other sources of power generation. Proponents and opponents of nuclear power often cite the Levelised Cost of Electricity (LCOE) as a key metric to support a nuclear energy industry in Australia.

To gain a deeper understanding of the LCOE and its implications, the Clean Energy Council (CEC) has commissioned Egis to conduct a literature review of three reports that offer insights into the LCOE of different energy sources:

- CSIRO GenCost 2023-24: Consultation Draft, 2023,
- Lazard Levelised Cost of Energy Report 16.0, 2023 and
- Minerals Council of Australia 2nd Edition, 2022 of Small Modular Reactors in the Australian Context.

2.2 Scope of Work

The scope of Egis' engagement is to:

- Conduct a literature review of three specified reports.
- Analyse the methodologies and assumptions used in calculating LCOE.
- Explore the implications of LCOE in the context of investment planning in Australia.

2.3 Overview of Reports

This Report will provide a literature review of the three abovementioned reports, highlighting the key insights, methodologies, and trends identified in the reviewed literature. It includes a brief overview of the significance of LCOE as a metric for comparing different energy sources.

2.3.1 CSIRO GenCost 2023-24 Draft Report

GenCost 2023-24 Draft Report is a collaboration between the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Australian Energy Market Operator (AEMO). The Report aims to deliver an annual, up-to-date economic report providing cost estimates of building new electricity generation, storage projects, and hydrogen technologies up to 2050. The report is used as an input into AEMO's Integrated System Plan (ISP), which then applies a system wide optimisation of the transmission and generation investment required to meet emissions targets at least cost.

2.3.2 Lazard Levelised Cost of Energy Report Version 16.0 2023

Lazard is a US-based financial advisory and asset management firm that produces an annual Levelised Cost of Energy Analysis. Lazard's analysis investigates various energy generation technologies and evaluates their cost competitiveness on a US$/MWh basis. The analysis is intended to provide industry insights, rather than specific financial advice. Data is based on their internal estimates and publicly available information.

2.3.3 2nd Edition, 2022, Small Modular Reactors in the Australian Context

SMRs - Small Modular Reactors in the Australian context 2nd Edition (2022 update) was commissioned by the Minerals Council of Australia (MCA). The Report highlights the potential benefits of Small Modular Reactors (SMRs) as a low-cost, reliable, and emission-free source of power for Australia.

3 METHODOLOGY

3.1 Overall Process

The methodology for reviewing the three reports is detailed in Figure 3-1. This methodology is designed with the aim of providing an unbiased and balanced review of the three reports.

FIGURE 3-1 REVIEW METHODOLOGY

Input Analysis	Analyse the inputs and available information.
Assumptions Testing	Identify and evaluate assumptions made surrounding input parameters. Characterise as valid, outdated, or requiring further investigation.
Bias Identification	Based on the assumptions, assess for any biases indicated. Analyse their impact on the outcomes.
Consistency Check	Verify the LCOE methodology, including inputs and exclusions, are consistent across sources. Highlight and investigate discrepancies and their impact.

4 LEVELISED COST OF ELECTRICITY

4.1 Overview

The Levelised Cost of Electricity (LCOE) is a measurement used to assess and compare the cost of various methods of energy production, such as wind, solar, coal, gas, and nuclear power sources. It can be used as a supporting tool for more detailed investment planning, and to consistently compare different electricity generation methods.

Broadly, the LCOE methodology is a discounted cash flow analysis that calculates the net present value of the total cost of building and operating a certain type of power plant and divides this by the total electricity that is generated over the plant's lifetime. It is a widely cited metric that provides an average cost value per megawatt hour that a given technology produces over its lifetime. As a result, LCOE is seen as an important metric in assessing the economic viability of various energy generation technologies.

4.1.1 Inputs

Several key parameters are considered when calculating LCOE. When evaluating the LCOE of an energy generation technology generally, the values for these inputs can be derived from a range of sources, including government or industry data, studies, or specific projects. The total inputs associated with the project generally will include:

- Capital costs
- Fixed and variable operating costs
- Fuel price
- Thermal efficiency
- Nominal capacity
- Capacity factor
- Discount rate
- Project lifetime
- Capital structure

As these inputs are variable and uncertain, common practice is to provide conservative and optimistic bounds for their values, and thus, given LCOE values fall across a range.

Other factors that can be considered in LCOE calculations include the impacts of carbon pricing and tax incentives. These are specific to particular jurisdictions, thus its inclusion can improve the accuracy of the LCOE results for a particular region but make comparison across jurisdictions difficult.

4.1.2 Exclusions

The LCOE is a simplified benchmark. There are several relevant factors when considering the costs and benefits of a generation technology that are typically excluded from consideration in LCOE analysis. The choice to include a specific assumption can depend on the context of the analysis.

To obtain non-site specific LCOE values, analysis typically calculates costs of electricity generation at the point of production, with the perimeter of the analysis at the plant scale level. Therefore, some aspects, such as associated grid upgrades and transmission costs, are excluded. Externalities, such as social or environmental costs and benefits, are also excluded. The costs of decommissioning and waste management are often omitted from analysis. Permitting/development costs and complying with various legislation and regulations are also often not included.

4.2 Limitations

The literature analysed in this report outlines several limitations of LCOE and the adjustments that have been made to attempt to overcome some of these limitations.

4.2.1 **Challenges of capturing system-wide and lifecycle costs in LCOE**

LCOE does not take a system-wide approach to costing analysis. This can make like-for-like comparisons between Variable Renewable Energy (VRE) and nuclear energy challenging. Nuclear plants optimally provide a stable baseload supply of energy, but their economic efficiency in a grid with a high proportion of VREs (as the Australian grid is on track to be) is negatively impacted. This is further explored in Section 7.1. This view of the energy system means that the interactions between different energy generation technologies with vastly disparate characteristics (such as VREs and nuclear) are not explored.

The LCOE analysis overlooks the different roles various energy generation technologies play in the energy system. Certain technologies are utilised nearly full-time to cover the base load, while others are activated for shorter durations or mainly during peak demand periods. This alters their cost hierarchy based on average production costs. Reduced utilisation results in a higher average cost per MWh, i.e. a higher LCOE calculation. The LCOE thus ignores the positive utility these technologies provide to an energy system, providing the energy needed in peak periods.

As energy generation sources can have vastly different characteristics, they have separate limitations in terms of how valuable an LCOE assessment of them can be. Renewable energy sources like wind and solar are inherently intermittent and variable. The integration of large quantities of these energy sources creates a need for flexible technologies – such as storage, demand side management and backup plants – to offset and maintain stability. In addition to the LCOE calculations, this requires an analysis of the cost of firming.

Whilst nuclear plants can provide a more stable energy supply[iii] and do not have the same associated firming costs as VREs, the waste management and decommissioning of a nuclear plant is a uniquely significant consideration that must be included in the discussion but is often omitted from LCOE calculations. This is an issue not only from a financial standpoint but from a political, environmental, and social perspective as well. For the Australian context, nuclear power also poses the issue of legislative requirements (discussed in Section 4.4). In addition, the high upfront costs associated with nuclear and higher perceived risk will mean that establishing this industry will require significant government, private sector and taxpayer support.

As stated, LCOE is a tool to standardise and compare different energy technologies. It does not provide the full picture of an energy system, and these specific issues cannot be adequately incorporated into an LCOE assessment. This tool can be used in conjunction with other analyses to rank and assess the costs of various energy generation technologies.

- *Key note: Lazard Report acknowledges the cost of firming intermittent resources and estimates this in addition to the LCOE.*
- *Key note: The CSIRO GenCost 2023-24 Draft Report includes an added cost to firm up renewable energy. The inclusion of these and other costs unique to variable renewables is done through a system modelling approach directly into the LCOE for a given projected share of VRE in the energy system.*

4.2.2 **Risk Profiles**

LCOE analysis often uses a uniform discount rate across generation technologies. In doing so, the analysis ignores the risk profiles of different energy sources, which can vary based on several factors such as how established the technology is, or the susceptibility of a technology to climate change policies. As the discount rate is impactful to the LCOE results, the choice of rate for each technology is an assumption that can produce significant variations in LCOE hierarchies.

- *Key note: Lazard Report uses a uniform discount rate of 7.7% across all energy sources.*
- *Key note: CSIRO GenCost 2023-24 Draft Report analysis notes that fuel technologies face a greater risk of being impacted by the introduction of current or new climate change policies. Thus, the analysis provides two sets of LCOE calculations for fossil fuel technologies, both with and without a risk premium.*

- *Key note: The SMR Report applied a discount rate of 5.9%, aiming to maintain consistency with the discount rate utilised by the Australian Energy Market Operator in 2020. However, there is ambiguity regarding whether this discount rate adequately incorporated appropriate risk factors in the Australian context.*

4.3 Sensitivities

4.3.1 Sensitivity to Assumptions

LCOE results are impacted heavily by the assumptions made about the input variables. Assumptions are 'best guesses'; and can be inexact, subjective, and easily outdated. When considering the complex and dynamic markets and technologies associated with the energy sector, different reports and interest groups use differing assumptions. Therefore, the assumptions underpinning given LCOE figures should be interrogated and understood rather than simply accepted, as further detailed in this report.

LCOE provides simplified metric that can be used to compare generation technologies on a somewhat like-for-like basis. But, as widely recognised in publications that utilise the LCOE methodology for analysis, it is not a replacement for the substantial financial analysis of a potential project. The LCOE metric is a useful standardisation tool to allow for comparison of energy sources, but it must be utilised with appropriate discernment and consideration of contextual factors with regard to inherent limitations and biases. This discussion requires a more nuanced and holistic analysis that includes the costs and benefits of integrating generation resources into future electricity systems, both financial and non-financial. Decision-making should include a discussion of positive and negative externalities outside of LCOE.

4.3.1.1 Discount rate

LCOE is a discounted cash flow analysis based on the time value of money. A higher discount rate negatively impacts the present value of a project with high upfront costs and longer-term revenues.

When determining the appropriate discount rate for a potential energy generation project, it is crucial to determine the source of the investment. Government versus private investors will evaluate projects using independent discount rates due to having different objectives, tolerance to risk, and funding supplies. As the LCOE outcomes are reliant on these discount rates, making assumptions about the type of investor will lead to varying LCOE projections.

The return expectations of the private sector are greater than that of the public sector, and thus private investors will select a higher discount rate for their investment decision calculations. Additionally, governments often have broader, non-financial objectives, can tolerate higher levels of risk, and have access to cheaper funding than private investors, which allows for a lower discount rate.

4.3.1.2 Investment period and project lifetime

The project lifetime of a nuclear power plant compared to a wind farm, for example, is vastly different. Nuclear power plants can operate for 40-60 years, whereas wind farms operate relatively less. If the calculation of the LCOE of these generation types is based on the same investment period, this can impact the results as the asset life will influence costs and revenues.

4.4 Regulatory Environment Considerations

When considering nuclear power generation, Australia's unique regulatory context must be addressed.

Two Commonwealth Acts of Parliament prohibit nuclear power – the *Environment Protection and Biodiversity Conservation Act 1999* and the *Australian Radiation Protection and Nuclear Safety Act 1998*. These acts ban the approval, licensing, construction, and operation of nuclear facilities for power generation, fuel fabrication, uranium enrichment, and nuclear waste reprocessing.

For an Australian nuclear industry to be established, these bans will have to be lifted with the support of the Australian Government and the Australian Parliament. Several states also have legislation that regulate and prohibit nuclear-related activities.

In Victoria, the *Nuclear Activities (Prohibitions) Act 1983* prohibits the establishment of nuclear activities in Victoria. In Queensland, the *Nuclear Facilities Prohibition Act 2007* prohibits the construction or operation of nuclear reactors, nuclear fuel fabrication plants, and other nuclear facilities within Queensland. It also prohibits the transportation and storage of nuclear waste in the state. In West Australia, the *Nuclear Waste Storage (Prohibition) Act 1999,* prohibit the construction and operation of a nuclear waste storage facility in Western Australia. In NSW, *Uranium Mining and Nuclear Facilities (Prohibitions) Act 1986,* prohibit mining for uranium, and prohibit the construction or operation of nuclear reactors and other facilities in the nuclear fuel cycle.

Along with the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*, ancillary state legislation would also apply to approvals for nuclear power generation as it does for other electricity generating infrastructure, including State and Territory planning, development, environment, natural resource management, and native title legislation separate from that of the Commonwealth.

This Report does not provide legal advice; however, it can be assumed that the Commonwealth does not have the authority to override the Australian Constitution powers of state jurisdictions as they pertain to state approvals.

Aside from removing the legislation expressly prohibiting nuclear activities, setting up a nuclear market in Australia would require a legal and regulatory framework through which to regulate the nuclear industry, as with other industries' activities and projects covered under the *Environment Protection and Biodiversity Conservation Act 1999* and supporting state and territory approval legislation.

The regulatory framework pertaining to developing, operating and/or deploying renewable energy infrastructure impacts the cost of building a power plant. For example, excessive regulatory barriers and red tape can increase the costs and maintenance associated with renewable energy and influence its competitiveness.

Using the United Kingdom as an example, their independent nuclear regulator, the Office for Nuclear Regulation, states five statutory purposes: nuclear safety, nuclear site health and safety, nuclear security, nuclear safeguards, and safety of transport of nuclear and radioactive materials. These are supported by an array of regulatory and legal frameworks which Australia does not currently have.

Developing relevant regulations for the Australian context and implementing them will take significant time. The *Australian Naval Nuclear Power Safety Bill 2023* and the *Australian Naval Nuclear Power Safety (Transitional Provisions) Bill 2023* are currently before the Australian Parliament as part of the AUKUS nuclear submarine arrangement with the United States and the United Kingdom. These Bills will legislate the establishment of a regulator, the granting of Australian naval nuclear power safety licences, and the monitoring and enforcement of compliance and safety. It is an indicator of a model the Australian Parliament could use to make nuclear energy lawful.

A whole-of-life nuclear energy industry would need to make provisions for design, construction, enabling infrastructure, operation and maintenance, decommissioning and site remediation, pre-disposal and storage. To secure planning and environment approvals for nuclear energy generation, a range of stage gates would need to be met under existing Commonwealth and state legislation, including:

- Siting studies, including transportation and logistics
- Stakeholder engagement
- Oceanography/ maritime studies
- Geotechnics, seismology and hydrogeology
- Flood risks
- Soil remediation
- Decommissioning
- Nuclear and industrial security and safety
- Waste management
- Local integration and acceptability

These matters fall outside the scope of an LCOE assessment, but in the discussion of the potential energy generation resource mix for Australia, it poses a considerable cost and time consideration alongside LCOE calculations.

Case Study: United Arab Emirates (UAE) Barakah Nuclear Power Plant

4.4.1 Overview

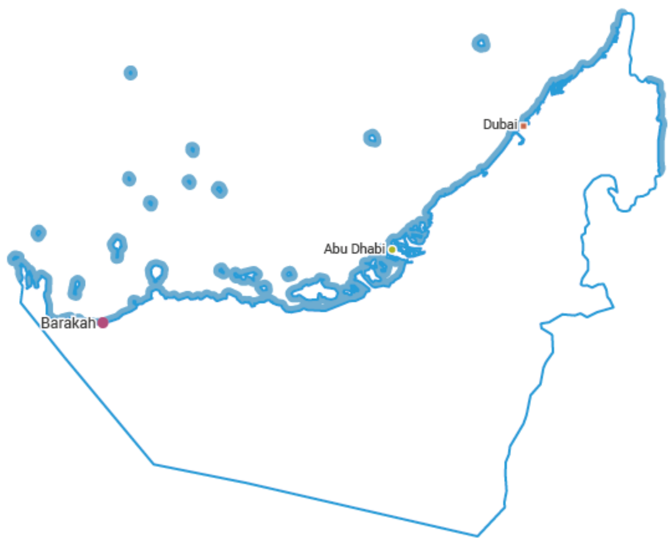
The Barakah Nuclear Energy Plant is the UAE's first nuclear power station, consisting of four identical reactors housed in four separate units, with a total generating capacity of up to 5,600MW[iv]. The power plants aim to supply up to 25% of UAE's electricity needs. As described by Emirates Nuclear Energy Corporation (ENEC), it is the first commercial nuclear power station in the Middle East. The APR-1400 is an advanced pressurised water nuclear plant is designed to help diversify the UAE's energy sources and reduce reliance on fossil fuels.

In December 2009, ENEC awarded Korea Electric Power Corporation (KEPCO) a $20 billion contract to build the first nuclear power plant in Barakah[v]. The construction of the Barakah Nuclear Power Plant began in 2012 and the final construction cost was estimated to be around $24.4 billion USD in 2020, $4 billion more than initially presumed. Construction of Unit 2, 3 and 4 were completed in 2021, 2022 and 2024 respectively with Unit 1, 2 and 3 now in commercial services. In March 2024, electricity generation for Unit 4 has started[vi].

UAE's Barakah Nuclear Power Plant project demonstrates the various aspects that are required to be considered for the development of a nuclear power plant. The following section outlines the associated considerations that may not be incorporated in the LCOE calculations.

4.4.2 Site Selection

FIGURE 4-1BARAKAH NUCLEAR POWER PLANT LOCATION



Source: World Nuclear Association, 2024

The Barakah Nuclear Power Plant is situated in the Al Dhafra region of the Emirate of Abu Dhabi, on the Arabian Gulf coast (see Figure 4-1). The site selection process was guided by best practices and standards from the Federal Authority for Nuclear Energy (FANR), the Electric Power Research Institute and the International Atomic Energy Agency (IAEA). The ENEC also considered various factors including geological stability, proximity to water sources, population density, and regulatory requirements. In July 2012, FANR and the Environment Agency – Abu Dhabi (EAD) granted final approval for Barakah to be the site for ENEC's first nuclear energy plant.

4.4.3 Regulatory Framework

The UAE established a multi-layered regulatory framework for nuclear energy, including the FANR, to oversee safety, security, and non-proliferation aspects of the program. FANR adopted international standards and practices to ensure the safe and secure operation of nuclear facilities. In addition, the UAE has entered into agreements with the International Atomic Energy Agency (IAEA) to implement safeguards to prevent the diversion of nuclear materials for military purposes.

4.4.4 Construction

Following the establishment of ENEC in 2009, a responsible body for the development, construction, and operation of nuclear power plants in UAE, the construction of the Barakah Nuclear Power Plant began in 2012 after receiving regulatory approval and international cooperation agreements[vii]. The project was led by ENEC in collaboration with the Korea Electric Power Corporation (KEPCO), which provided expertise and technology for the APR-1400 reactors. The construction of the Unit 1 took 9 years, excluding development and commercial approval.

4.4.5 Safety and Security

The plant adheres to relevant international safety standards and regulations, with oversight from FANR and international organisations such as the IAEA. The plant is equipped with multiple layers of safety systems to mitigate potential risks and ensure the protection of workers, the public, and the environment. The ENEC also developed an independent Quality Assurance program to ensure the Barakah Nuclear Power Plant is constructed, commissioned and operated in line with the best industry practices, governing codes and standards, regulations and license requirements.

4.4.6 Future Plans

The UAE aims to progressively increase the contribution of nuclear energy to its electricity mix, with the Barakah Nuclear Power Plant expected to provide up to 25% of the country's electricity needs once all four units are operational[viii]. The operator of the Barakah Nuclear Power Plant, Nawah Energy Company, submitted an initial decommissioning plan as part of its application for an operating license to the UAE's nuclear authority FANR. The plan envisages that decommissioning will be handled by Nawah and will begin five years after the final reactor is permanently shut down. According to the ENEC, the decommissioning process is forecasted to last around 13 years for each of the four units[ix].

5 LITERATURE REVIEW

5.1 GenCost 2023-24 Draft Report

The GenCost 2023-24 Draft Report is a collaboration between the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Australian Energy Market Operator (AEMO). The Report aims to deliver an annual, up-to-date economic report providing cost estimates of building new electricity generation, storage projects, and hydrogen technologies up to the year 2050. This includes, but is not limited to, coal, natural gas, solar photovoltaics, onshore and offshore winds, solar thermal, and nuclear small modular reactors.

Published annually since 2018, CSIRO has revised the cost estimation methodology and/or modelling in subsequent Reports to improve the cost estimation by including relevant costs of electricity generation.

The GenCost 2023-24 Draft Report received submissions during the six week consultation period from 21 December 2023 and 9 February 2024. The final GenCost 2023-24 Report is scheduled to be published in the second quarter of 2024.

5.1.1 Levelised Cost of Electricity

The GenCost 2018 Report and a supplementary report identified limitations relating to methods for calculating the additional costs of renewables, noting that:

- LCOE does not account for the additional costs associated with each technology, particularly the significant integration costs of variable renewable electricity generation technologies.
- LCOE applies the same discount rate across all technologies even though fossil fuel technologies face a greater risk of being impacted by the introduction of current or new state or federal climate change policies.

LCOE does not recognise that electricity generation technologies have different roles in the energy system. Some technologies operate less frequently, increasing their costs, but they are valued for their ability to quickly make their capacity available at peak times.

Accordingly, a new method was implemented in the GenCost 2020-21 Report. The LCOE included integration costs unique to variable renewables. In the GenCost 2020-21 Report, CSIRO developed a set of criteria to compare methods, these being:

- Include the full breadth of renewable balancing solutions,
- Include the capacity to recognise the context in which renewables are being deployed,
- Include the ability to draw conclusions about separate technologies as opposed to combinations of technologies, and
- Be transparent and repeatable.

CSIRO acknowledged that none of the system modelling approaches reviewed included all the major relevant firming solutions for variable renewables, which include transmission, storage, and other flexible generation. In response, CSIRO developed Spatial Temporal Analysis of Balancing Levelised-Cost of Energy (STABLE) model. The STABLE aims to enhance the assessment of integration costs for variable renewable energy sources via considering spatial and temporal variations in generation. This method was considered to offer a more holistic approach in understanding the overall cost and efficiency of the energy system.

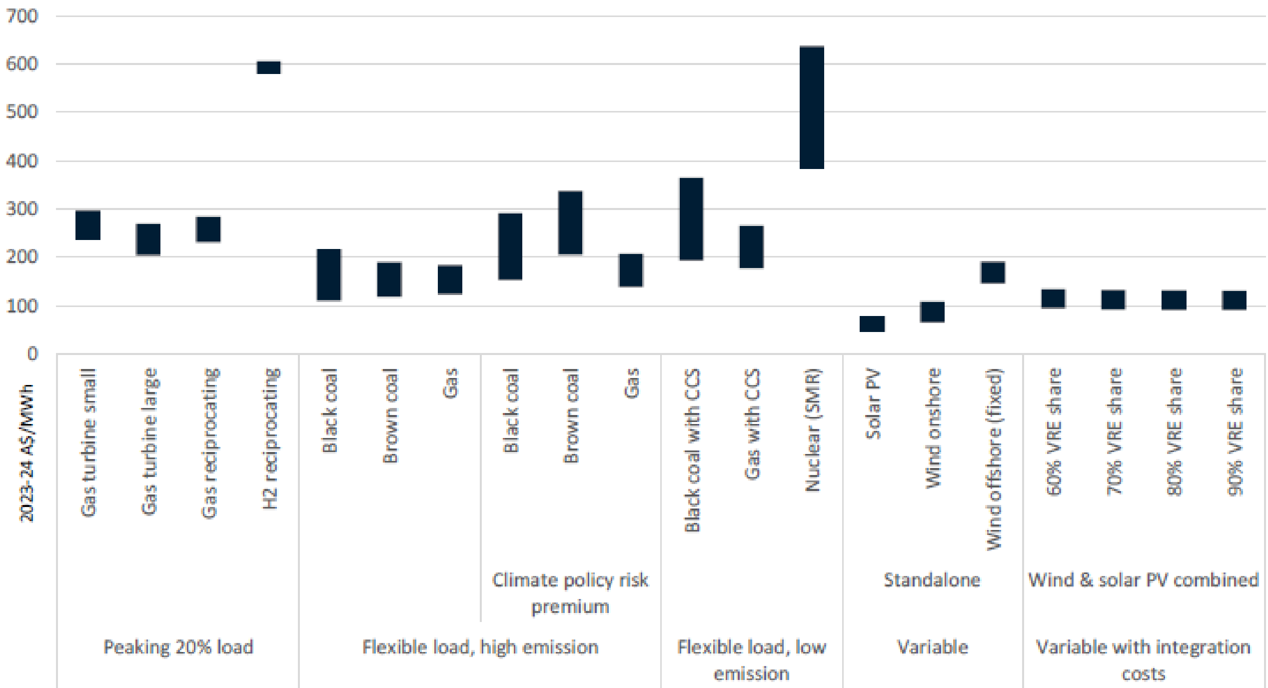
In response to feedback on the previous reports, pre-2030 integration costs were included into the LCOE calculation methods for the GenCost 2023-24 Draft Report. Pre-2030 integration costs include storage and transmission for Variable Renewable Energy (VRE). .This was an attempt to address the concern that leaving out pre-2030 projects under-estimates the cost of the renewable transition.

The GenCost 2023-24 Draft Report has incorporated an economic life tailored to the type of energy technology (for example, 25 years for wind and 30 years for nuclear SMR). This method differs from other LCOE calculations, as traditional LCOE methodology uses a uniform economic life across technologies. Whilst it is noted that some capital replacement costs are accounted for within the operational cost, the refurbishment turbines for example, is not incorporated within the LCOE calculations which could provide varying results depending on the energy. In addition, a consistent 5.99% discount rate was applied to all technologies with climate policy risk premium of 5% is added to fossil fuel technologies.

5.1.2 Impact of Variable Renewable Energy (VRE)

Variable Renewable Energy (VRE), such as wind and solar power, can have a significant impact on the calculation of the LCOE due to their intermittency and variability in generation. The GenCost 2023-24 Draft Report notes that the inclusion of costs of storage requirement and other backup generation capacity were particularly important to ensure all costs are accounted for when comparing with other low emissions technologies such as nuclear Small Modular Reactors (SMR). Subsequently, the GenCost 2023-24 Draft Report LCOE calculations included storage requirement costs and other backup generation capacity costs.

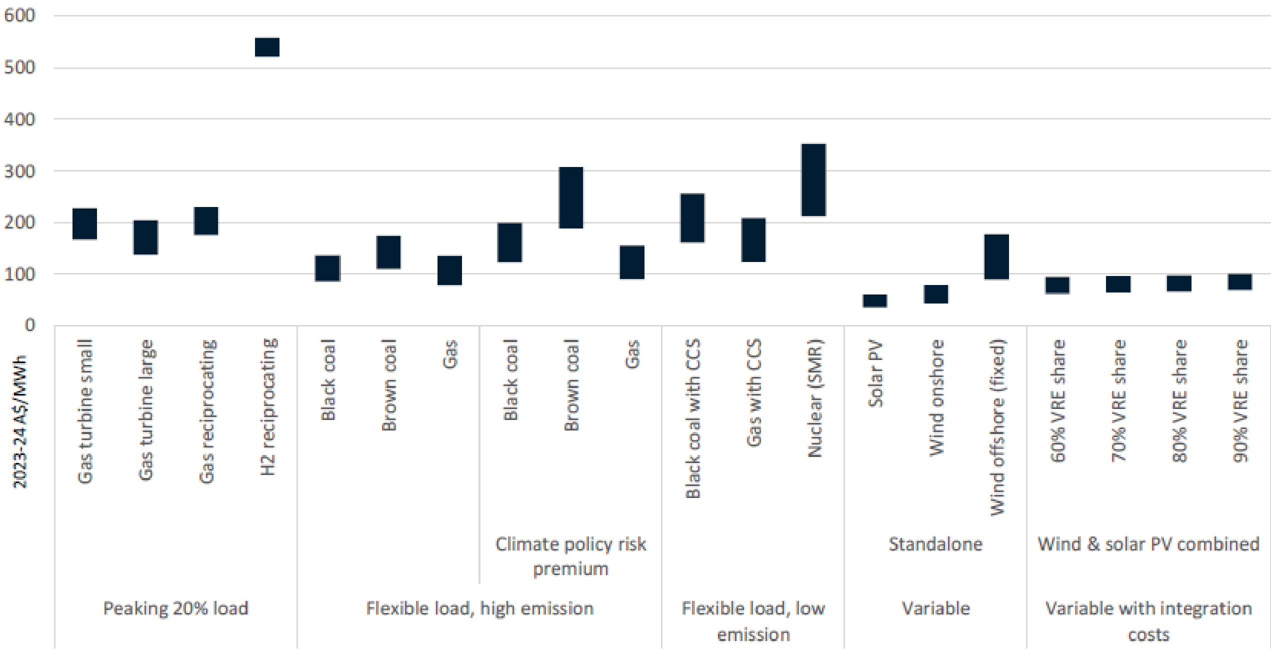
FIGURE 5-1 CALCULATED LCOE BY TECHNOLOGY AND CATEGORY FOR 2023



Source: GenCost 2023-24 Draft Report[x]

The GenCost 2023-24 Draft Report notes that new-build technologies, like renewables, can enter an electricity system and provide reliable power by relying on existing capacity already deployed. However, as its share increases, it forces the retirement of existing flexible capacity, and the system will find it increasingly difficult to provide a reliable power supply without additional investment. To address this issue, the report (as shown in Figure 5-1 and 5-2) calculates the additional cost to firm up renewables (the extra “integration costs” consist mainly of new storage and transmission costs).

FIGURE 5-2 CALCULATED LCOE BY TECHNOLOGY AND CATEGORY FOR 2030



Source: GenCost 2023-24 Draft Report[xi]

As shown in Figures 5-1 and 5-2, the GenCost 2023-24 Draft Report found that even when those integration costs were considered, the LCOE range for variable renewables was still the lowest of all new-build technologies in 2023 and 2030.

5.1.3 Nuclear Small Modular Reactors (SMR)

The GenCost Draft Report only assessed SMRs as the technology for nuclear energy in Australia. At the time of consultation, stakeholders indicated interest in SMR technology rather than large scale reactors.

- *Key note: CSIRO advised the details of stakeholders involved in the consultation are confidential.*

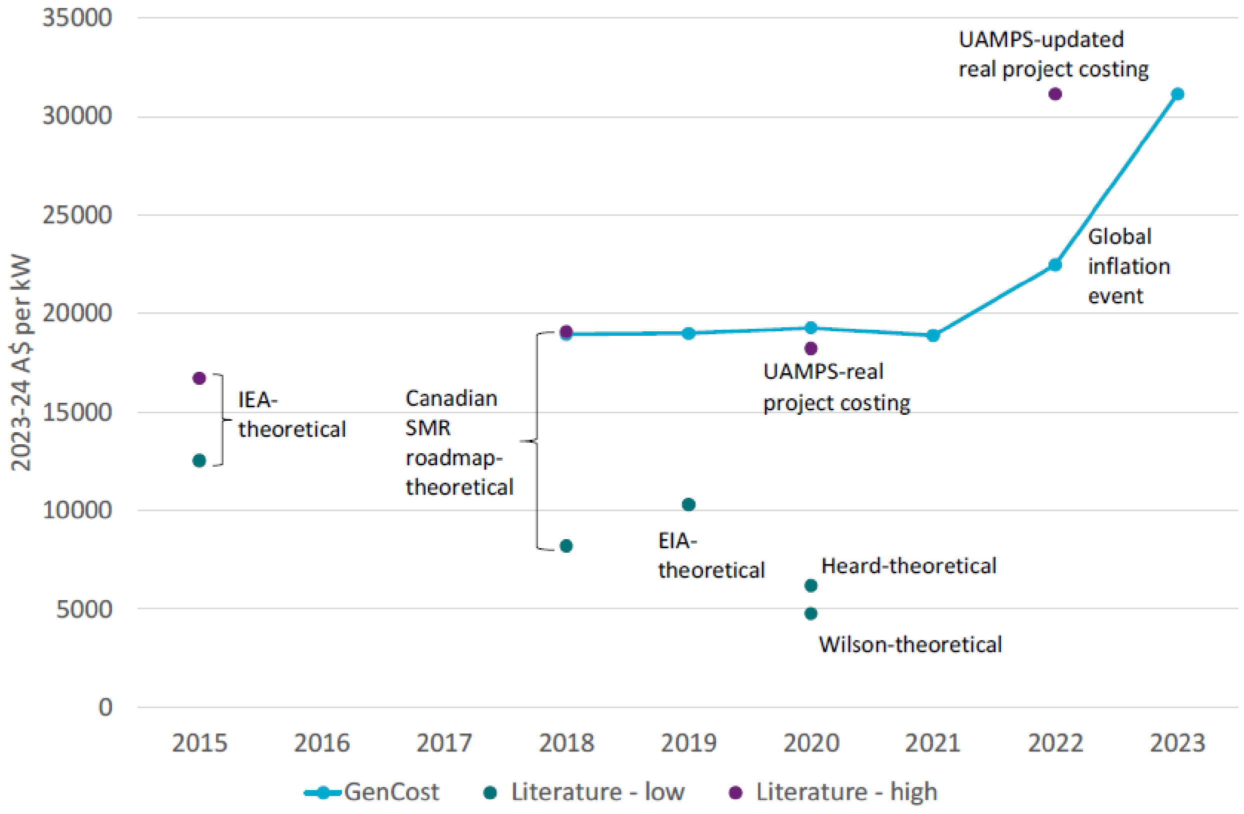
The GenCost 2023-24 Draft Report acknowledges that based on the information collected to date, the current nuclear SMR capital costs are significantly higher than any other technology included in the GenCost. Using the cost estimates from the Utah Associated Municipal Power Systems (UAMPS), a First of a Kind (FOAK) project in the USA, the estimated SMR LCOE for the Australian context are:

- 2020 – A$18,200/kW, rounded up to $19,000/kW in GenCost
- 2022 – A$31,100/kW due to inflationary pressures at UAMPS

The cost of nuclear was based on the NuScale SMR project in Utah, noting the cost escalations from being FOAK, inflation, R&D design and certification problems. Subsequently, the GenCost 2023-24 Draft Report notes the NuScale SMR project was cancelled in November 2023, likely due to this significant increase in costs.

As it was the only SMR project in the US that had received design certification from the Nuclear Regulatory Commission, it would be difficult to obtain ongoing nuclear SMR cost estimates. Notwithstanding, costs obtained from UAMPS are not considered to be representative of international studies of countries that have nuclear power.

FIGURE 5-3 TIMELINE OF NUCLEAR SMR COST ESTIMATES AND CURRENT COSTS INCLUDED IN EACH GENCOST REPORT



Source: GenCost 2023-24 Draft Report[xii]

It would be useful for a future LCOE to examine other nuclear options, including Light Water Reactors (LWRs), to address the nuclear energy question more comprehensively than it is covered in the GenCost 2023-24 Draft Report.

- *Key note: Light Water Reactor (LWR) is a type of nuclear reactor that uses normal water (light water) as both a coolant and a neutron moderator to sustain nuclear fission. LWRs are typically large-scale reactors that are built on site, with capacities ranging from hundreds to over a thousand megawatts electric (MWe). SMRs are smaller in size, with capacity usually less than 300 MWe. They are designed to be modular and can be built in smaller increments and possibly transported to the site fully assembled.*

5.1.4 Review Findings

Overall, the nuclear cost assumptions based on SMR costs from UAMPS are significantly higher and the GenCost 2023-24 Draft Report does not exhibit any other sources, including LWRs.

It is not clear how the GenCost 2023-24 Draft Report treated capital replacement costs for different technologies with less than 20-year lifespans such as solar or wind. In addition, the estimated LCOE did not include the expanded grid costs and port costs for offshore wind.

As the GenCost 2023-24 Draft Report is currently reviewing feedback from consultation, it is possible, post consultation, the findings in the Draft Report will change.

5.2 Lazard's Levelised Cost of Energy Analysis 2023

5.2.1 Overview

The Lazard Levelised Cost of Energy Analysis is a comparative study of various generation technologies on a US$/MWh basis. It is based on US data and includes sensitivities for inputs such as taxes, fuel, and capital costs, and is based on underlying assumptions.

5.2.2 Inputs and Exclusions

5.2.2.1 Technologies Assessed

The Lazard report assesses several renewable and conventional generation technologies. For the purposes of this Review, the focus will be on the following technologies:

- Solar PV – utility-scale
- Solar PV + Storage – utility-scale
- Wind – onshore
- Wind + Storage – onshore
- Wind – offshore
- Gas peaking
- Nuclear – Pressurised Water Reactor (PWR)
- Coal
- Gas combined cycle

5.2.2.2 Inputs

The key inputs included in the Lazard LCOE calculations are:

- Net facility output (MW)
- Total Capital costs (US$/kW)
- Fixed O&M (US$/kW-yr)
- Variable O&M (US$/MWh)
- Capacity factor
- Heat rate (Btu/kWh)
- Fuel price

Most inputs have conservative and optimistic values, providing lower and upper boundaries of the LCOE estimates. The assumed values of some relevant inputs for nuclear and renewable technology are outlined in Section 5.2.4.

5.2.2.3 Exclusions

There are several factors excluded from the analysis:

- Full scope of Inflation Reduction Act (US-specific)
- Network upgrades
- Transmission, congestion or other integration-related costs
- Permitting/other development costs
- Compliance costs (e.g. environmental regulations)
- Social or environmental externalities
- Nuclear waste disposal

As discussed in Section 4.1.2, to enable comparable benchmarking, LCOE calculations commonly exclude several relevant factors. The exclusion of the costs indicated in the Lazard report are found to be consistent with the generally accepted exclusions. As previously noted, this simplification means that other assumptions need to be considered along with LCOE to provide a full understanding of costs.

5.2.2.3.1 Nuclear Waste Management

Waste management for nuclear power plants is a significant factor to consider as it requires on-going security and maintenance management. After the onsite cooling process, fuel assemblies are moved to dry caskets for long-term storage. Caskets are located on site at nuclear power plants around the world, with steps underway in some countries to move this spent fuel to permanent repositories. In Australia, spent fuel from the Lucas Heights reactor (used for medical research, not energy production) is stored in cooling ponds and in dry storage at Australia's Nuclear Science and Technology Organisation (ANSTO). There is no permanent repository currently approved for long-term radioactive waste disposal in Australia.

Table 5-1 below outlines some potential future scenarios for Australia's attitude towards nuclear waste management.

TABLE 5-1 EXAMPLE NUCLEAR SCENARIOS

Scenario	Underpinning attitudes and considerations
Avoidance of nuclear	Spent nuclear waste poses a long-term environmental as well as a security risk, and currently stored materials around the world are a significant hazard.
Costing into projects	Spent nuclear fuel needs to be costed for and adequately managed through temporary storage and reprocessing of medium - and high-level radioactive waste, as currently occurs at ANSTO.
Permanent repository waste management	Spent nuclear fuel is stored in a permanent repository in the Australian outback (a disused iron ore mine, for instance). Unique factors, including geological stability, political stability and very low population density, lend Australia to this purpose.

5.2.3 Review Findings

The Lazard report provides subsidised LCOE values for renewable energy sources (Table 5-2) based on provisions in the US Inflation Reduction Act (IRA): The Investment Tax Credit (ITC), the Production Tax Credit (PTC), and domestic content adder. The report did not present subsidised LCOE values for nuclear energy. As such, for the purposes of this review, un-subsidised values are more relevant and applicable. The report also outlines the marginal cost of existing generation, but in regards to nuclear this is irrelevant to the Australian context.

A summary of the unsubsidised and subsidised LCOE results is provided in Table 5-2 below.

TABLE 5-2 LCOE VALUES

Type	Technology	Un-subsidised LCOE US$/MWh	Subsidised LCOE US$/MWh
Renewable	Solar PV – utility-scale	24-96	16-80 (ITC); 0-77 (PTC)
	Solar PV + Storage – utility-scale	46-102	31-88 (ITC)
	Wind – onshore	24-75	0-66 (PTC)
	Wind + Storage – onshore	42-114	12-103 (PTC/ITC)
	Wind – offshore	72-140	56-114 (PTC)
Conventional Technologies	Gas peaking	115-221	*Not provided*
	Nuclear	141-221	*Not provided*
	Coal	68-166	*Not provided*
	Gas combined cycle	39-101	*Not provided*

Note: The report outlines LCOE figures for wind and solar generation in a standalone context and provides LCOE figures for these technologies, including storage capability.

5.2.3.1 Graphic Visualisation of the Energy Stack

Figure 5-4 and Figure 5-5 below graphically illustrate the lower and upper bounds of the un-subsidised LCOE figures resulting from Lazard's analysis. Based on this report's findings, nuclear is consistently more expensive, on an LCOE basis, than solar and wind. This includes the cases where renewables plus storage have been considered.

FIGURE 5-4 LOWER BOUND OF LAZARD'S UNSUBSIDISED LCOE FIGURES

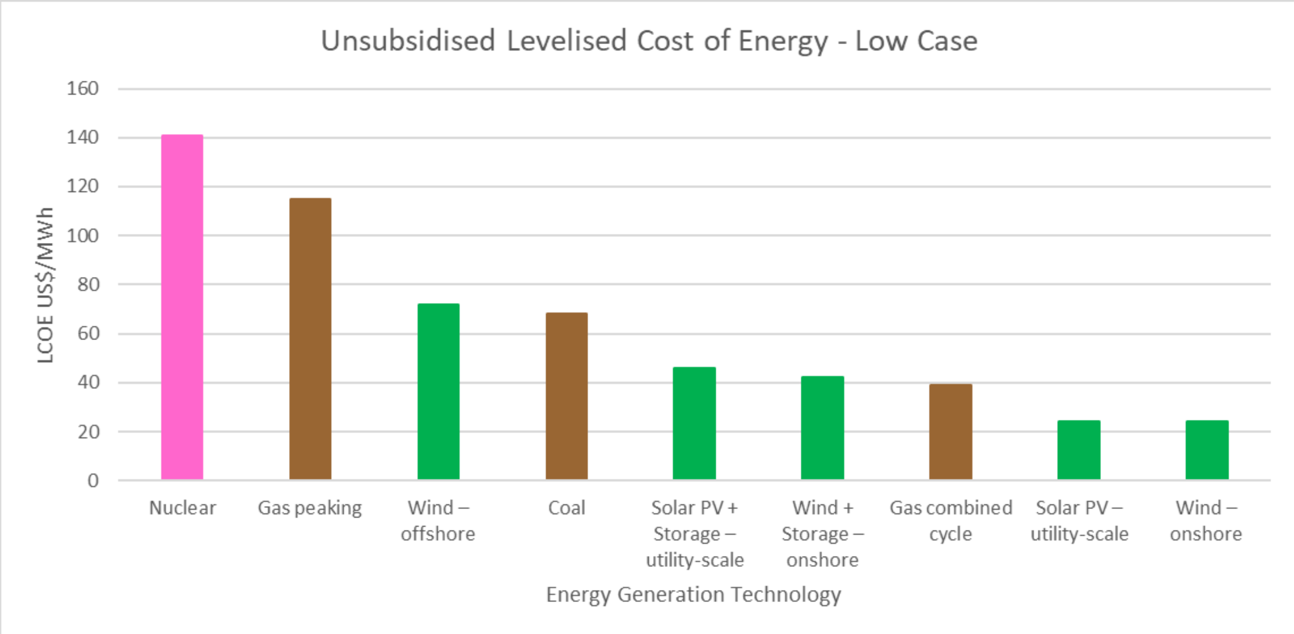
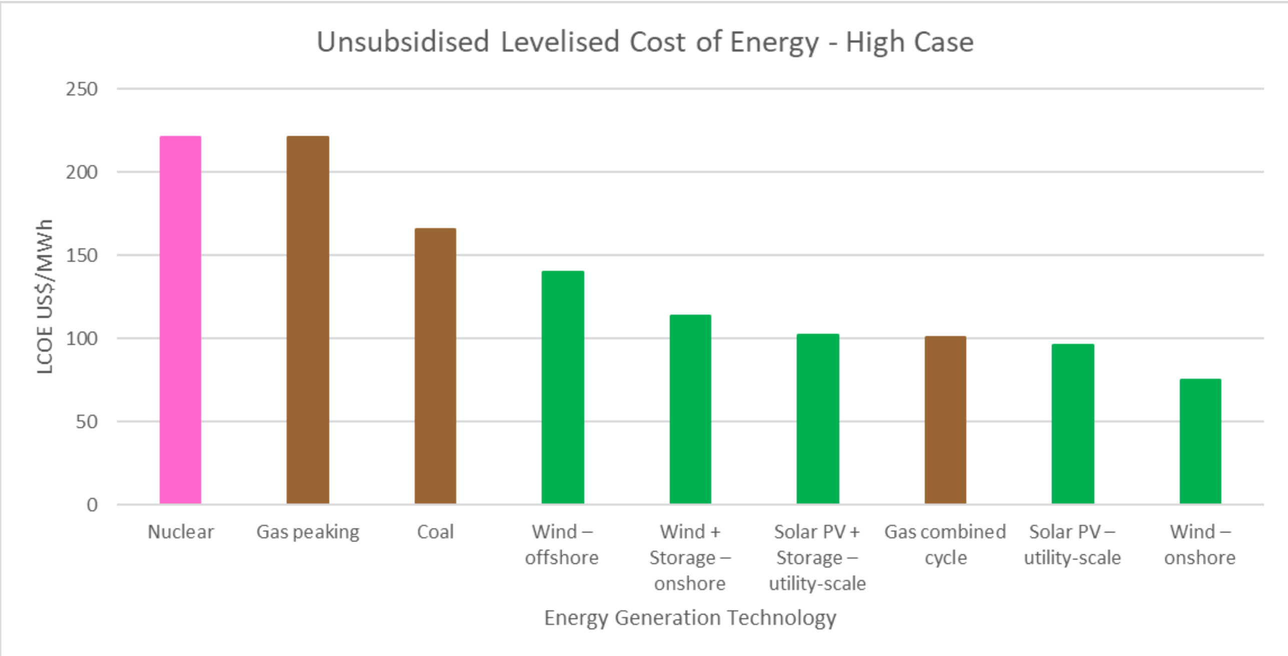


FIGURE 5-5 UPPER BOUND OF LAZARD'S UNSUBSIDISED LCOE FIGURES



5.2.4 Assumptions

As indicated in Section 4.3, the LCOE method is highly influenced by the assumed input variables. Table 5-3 below outlines some of the more impactful inputs that will be further examined in this review, as well as their assumed values. Lower and upper bounds are given to capital cost figures.

TABLE 5-3 KEY ASSUMPTIONS OF DISCUSSED INPUTS

	Solar PV – utility-scale	Solar PV + Storage – utility-scale	Wind – onshore	Wind + Storage – onshore	Wind – offshore	Nuclear (new build)
Facility life (years)	30	30	20	20	20	40
Total Capital costs (US$/kW)	700 - 1400	1075 - 1600	1025 - 1700	1375 - 2250	3000 - 5000	8475 - 13925
Investment period (years)	20	20	20	20	20	20
Discount rate	7.7%	7.7%	7.7%	7.7%	7.7%	7.7%

5.2.4.1 Discount Rate:

Lazard highlights that their study is a tool for educational purposes and not financial advice. The 7.7% discount rate used is, therefore, not tailored to a particular type of investor.

5.2.4.2 Investment Period:

The investment period significantly impacts Discounted Cash Flow (DCF) calculations. Although the nominated facility life values are different across the technologies, the report highlights that, for comparison purposes, all technologies calculate LCOE on a 20-year IRR basis.

A 20-year economic life more accurately reflects the actual facility life of wind turbines and solar panels – that are replaced approximately every 20 years – whereas this inaccurately reflects the actual facility life of a nuclear facility. The Lazard report assumes a 40-year timeframe, but it is accepted that nuclear power plants can operate beyond 40 years. As such, this assumption ignores the longer-term revenue stream that a nuclear plant could generate. Although a 20-year Internal Rate of Return basis assumption is made for comparison purposes, it will negatively impact the resulting LCOE for nuclear power plants.

- *Key note: Egis international analysis indicates that an economic life of 40-60 years is more commonly used to calculate LCOE for nuclear plants, with an economic life of 25-30 years common for renewables.*

5.2.4.3 Capital Costs:

The Lazard report cites their source throughout as "Lazard and Berger estimates, and publicly available information". Although this is non-specific, it could be assumed that information is gathered from a range of sources. For the costs for nuclear power plants, however, it is noted that these are based on the previous release Lazard LCOE v15.0 adjusted for inflation. In this report, costs for NPPs were based on the Vogtle Plant in the USA.

5.2.4.3.1 Plant Vogtle

The Vogtle nuclear power plant is a FOAK (first-of-a-kind) project consisting of four reactors, two of which have been operational since the late 1980s and early 1990s. The Vogtle expansion project, which commenced construction in 2009, consists of Vogtle Units 3 and 4. These were the first deployments of the AP1000 reactor design in the US. This was a period in the USA where there were no newly built nuclear capabilities and where safety regulations were increased as a result of the Fukushima nuclear accident. Challenges occurred for the nuclear industry in the decade post-2011, when the Fukushima disaster resulted in changes being made to safety and storage requirements for Nuclear Power Plants (NPPs). This caused delays and increased costs for Hinkley Point (UK), Vogtle (USA), and Flamanville (France). This situation no longer exists and has not impacted more recent projects in South Korea, UAE, Pakistan and China, with much lower LCOEs[xiii].

The cost of NPPs varies significantly between the USA, France, South Korea, Japan, Russia and China due to Nth-of-a-kind (NOAK) repetition, established supply chains, variations in labour costs, and government incentives[xiv]. None of these conditions exist in Australia as there is no nuclear energy industry.

The costs of FOAK projects are significantly higher than NOAK projects. FOAK incorporates extensive R&D costs, design, engineering, proof of concepts, materials and parts manufacture, testing, troubleshooting, redesign, simulated operation, testing and commissioning. As a result, the LCOE is potentially higher than could be expected from a NOAK nuclear power plant.

There are also NOAK costs unique to new markets based on site factors, transportation and training a local workforce that need to be factored into cost studies for the Australian context.

5.2.5 **Additional Considerations**

5.2.5.1 Sensitivity to Cost of Capital

The Lazard report analyses the sensitivity of the LCOE outcomes to the cost of capital, which influences the discount rate. As highlighted in this review, the discount rate used in the LCOE calculation has a significant impact on the results, especially for a nuclear power plant. The sensitivity analysis is conducted for a discount rate ranging between 4.2% and 10%.

5.2.5.1.1 Report Outcomes

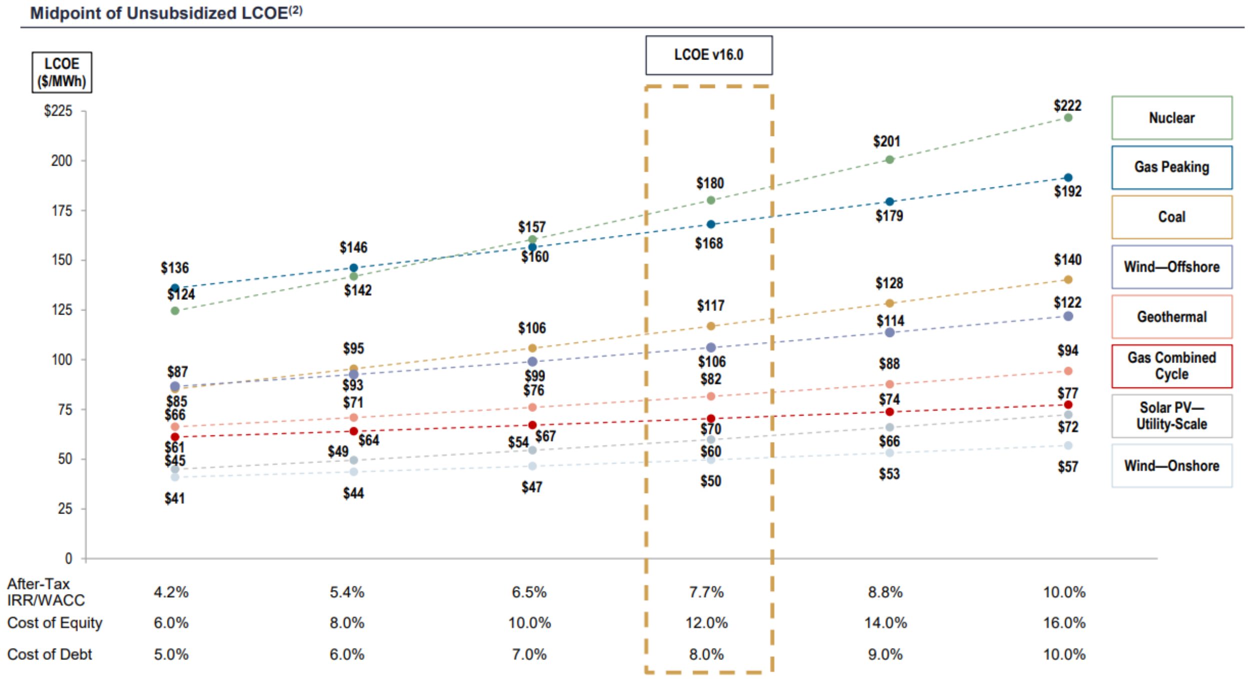
The findings of the Lazard report indicate that at a lower discount rate, nuclear is cheaper than gas-peaking technologies.

At a discount rate of 4.2%, the LCOE of nuclear is US$124/MWh and gas peaking is US$136/MWh. At a discount rate of approximately 6%, there is an intersection in cost, and above this rate, nuclear becomes more expensive than gas peaking. The highest discount rate investigated is 10%, at this rate the LCOE of nuclear becomes U$222/MWh, compared to US$192/MWh for gas peaking.

Onshore wind and utility-scale solar PV consistently sit at the bottom of the LCOE stack across discount rate values, meaning they have the lowest costs when evaluated at both lower and higher discount rates.

From inspection of Figure 5-6, the steepest gradient is that of the LCOE of nuclear generation – this is most impacted by the discount rate. This is largely due to the high upfront costs assumed for nuclear: capital cost estimates for the un-subsidised LCOE are between US$8,745 and US$13,925 (as per Table 5-3).

FIGURE 5-6 LAZARD SENSITIVITY TO COST OF CAPITAL ANALYSIS



5.2.5.1.2 Discount Rate Implications

A high discount rate coupled with a long construction period has a large impact on the upfront cost of a Nuclear Power Plant (NPP). LCOE is a discounted cash flow metric and is thus based on the time value of money. Higher upfront costs will be more impactful, and later revenues will be less so. Table 5-4 below outlines some discount rates, as well as the underlying assumptions and impacts of these on nuclear investment in particular.

TABLE 5-4 DISCOUNT RATE AND NUCLEAR INVESTMENT

Discount rate	Assumptions and impact
9-11%	Market-driven, typically based on high-risk options/proposals, such as SMRs and First-Of-A-Kind systems[xv].
5-8%	Some combination of public/private partnership or investment in different elements of projects. In France, a discount rate of 9% has created financial challenges for French projects over the past decade due to a lull in support for nuclear energy that has changed as a result of the war in Ukraine[xvi].
3-4%	Government sovereign wealth fund to support industry, for example, Sizewell, UK[xvii].

As per Section 4.3.1.1, the choice of an appropriate discount rate will be dependent on the type of investor. It is worth noting that the Lazard report only investigates up to a discount rate of 10%, although rates above this are possible, especially when considering private investment in projects with increased risk.

5.2.5.2 Cost of Firming Intermittency

Renewable energy sources like wind and solar are inherently intermittent and variable. Their integration into an energy system must be coupled with firming technologies – such as storage or backup plants – which have their own costs.

As outlined in Section 4.2.1, the LCOE methodology does not outline a consistent way to account for this. The Lazard analysis looks at four grid operators in different regions in the US, and the technology they use to firm their solar and wind resources. The assumed firming resources are natural gas combustion turbines for three scenarios, and a 4-hour lithium ion battery storage system for one. The report adds these costs on top of the

LCOE figures, as a snapshot of firming technologies rather than an exhaustive study into all possible firming costs.

5.2.5.2.1 Report Outcomes

According to the findings of the Lazard report, when comparing the cost of nuclear with that of renewables plus firming, all midpoint unsubsidised LCOE + firming values lie below (or at for one case) the unsubsidised LCOE of nuclear generation lower bound of US$141/MWh. According to this report, renewables are still competitive with nuclear when firming costs are considered.

- *Key note: This compares the midpoint LCOE value for renewables + firming with the low LCOE value for nuclear. The Midpoint LCOE value for nuclear is $182.5. When comparing midpoints, the gap is even greater.*

This analysis provides an example of how the cost of firming technologies can be considered alongside LCOE. It is based on specific US grid operators and their chosen firming technologies; it provides a good snapshot of these instances, but it is not an exhaustive study into potential firming costs. To comment fully on the cost of firming technologies and integrating renewables into the Australian system would require more specific investigation.

5.2.6 **Review Findings**

In summary, the key findings of this review are:

- The discount rate used in the Lazard report (7.7%) was higher than that used in the GenCost report (5.99%). The higher discount rate particularly impacts (increases) the LCOE of technologies with high upfront capital expenditure costs, including nuclear.
- Nuclear costs have been based on one FOAK project (Vogtle, US), which can be considered higher than many other demonstrated projects.
- LCOE was calculated over a 20-year period for all technologies. This does not accurately reflect the project lifetime and the total power generation of a nuclear plant (40 to 60 years).
- Cost of renewable firming is considered, but it is region-specific and not exhaustive of all technologies.

5.3 SMRs in the Australian Context 2nd Edition, 2022

SMRs - Small modular reactors in the Australian context 2nd Edition (2022 update) was commissioned by the Minerals Council of Australia (MCA). The Report highlights the potential benefits of SMRs as a low-cost, reliable, and emission-free source of power for Australia.

The Report states that an SMR can produce up to 300 – 800 MWe per module. Based on cost estimates collected and applying conservative assumptions, the future LCOE of the SMRs deployed in Australia would be between $64/MWh and $77/MWh. However, the capital costs included in the LCOE are considered "Nth of a kind" or "First of a kind" estimates based on the vendor's project budget rather than completed project costs. The Report noted that while there are cost estimates of SMRs, there is a lack of standardised methodology and no publicly available as-built cost data on which to base assessments.

The Report concludes that Australia should not wait until SMRs are globally available or play catch-up. Otherwise, Australia could lose its competitive advantage to other nations that are actively establishing the necessary conditions for SMR deployment.

5.3.1 **Small Modular Reactors**

The Report refers to three SMR designs that are undergoing development and regulatory approval in the USA and Canada. These are:

- NuScale's Power Module (USA)
- GE Hitachi's BWRX 300 (Canada)
- Terrestrial Energy's Integral Molten Salt Reactor (Canada).

5.3.1.1 NuScale's Power Module (USA)

NuScale is focused on the development and commercialisation of the NuScale Power Module, a 77 MWe factory-manufactured unit. Up to 12-unit power planet is planned, producing 924 MWe gross, and 884 MWe net.

The SMR design was approved by the U.S. Nuclear Regulatory Commission in September 2020, with anticipated opening in 2027. The US Department of Energy provided over $1.4 billion as a cost-share award.

Based on the NuScale example, the report estimates the deployment cost in Australia to be about $5,100/kW gross and $5,400/kW net ($2020).

5.3.1.1.1 Recent Update

NuScale was cancelled in 2023 due to a cost increase.[xviii] The projected build cost had increased to $9.3 billion for 462 MWe generation capacity from $3.6 billion for 720 MWe in 2020.

5.3.1.2 GE Hitachi's BWRX 300 (Canada)

In 2019, Ontario Power Generation selected BWRX-300, a 300 MWe (gross) power plant for the Darlington New Nuclear Project. Canada Infrastructure Bank committed a low-interest C$970 million loan for the Darlington New Nuclear Project.

Based on the SWRX 300 example, the report estimates the deployment cost in Australia to be about AUD $3,200/kW net ($2020).

5.3.1.2.1 Recent Update

Egis research suggests BWRX-300 is estimated to cost about $900 million[xix]. In 2023, three additional units of BWRX-300 were selected for the Darlington New Nuclear Project.

The Project is still under pre-construction assessment. An application for construction was submitted to the Canadian Nuclear Safety Commission in October 2022. The Commission is currently completing a technical assessment review and public hearings on the application. Construction is anticipated to begin in 2024.

5.3.1.3 Terrestrial Energy's Integral Molten Salt Reactor (IMSR)

IMSR is a 195MWe power plant, relatively smaller than NuScale and BWRX-300 power plants. The Government of Canada directly invested US$20 million towards the project. Based on the IMSR example, the Report estimates the deployment cost in Australia to be about AUD $4,100/kW net ($2020).

5.3.1.3.1 Recent Update

IMSR is still under the preconstruction assessment phase. In April 2023, the Canadian Nuclear Safety Commission concluded that there were no fundamental barriers to licensing the IMSR plant for commercial use based on Canadian regulatory requirements.

In December 2023, Terrestrial Energy signed a MOU with UAE to collaborate and cooperate on IMSR development and deployment.

5.3.2 Capital Cost Estimate

The Report refers to three independent studies published between 2015 and 2018 as a sample to demonstrate the estimated capital cost of SMR. These studies estimate the capital costs of SMR between $2886/kW and $11,317/kW. According to the Report, these estimates are below the $16,000/kW upper end of the cost range calculated by CSIRO in its GenCost 2019-20.

5.3.3 Key Assumptions

- There is no publicly available as-built cost data on which to base the cost of SMRs assessments. SMRs are under development phase.
- In SMRs, as in nuclear in general, overall costs are strongly driven by capital costs, but there is no complete project to confidently benchmark the cost.
- The LCOE metric does not take account of overall system value and system costs, and the outputs can change based on assumptions used.

The Australian Energy Market Operator cautions that it's published LCOE for new projects in Renewable Energy Zones do not accurately represent power system requirements and can be 'optimistic, or even misleading.

- For the Australian context, the Report applied a discount rate of 5.9 per cent, consistent with the rate applied to all technologies by the Australian Energy Market Operator and CSIRO.
- Costs in the Australian context will be heavily influenced by future regulatory settings, which are presently unknown and difficult to quantify.

5.3.4 Review Findings

Data that is available to date on SMRs is unreliable to use for energy planning purposes. The estimated costs used in the SMR report are subject to further changes due to research and development risks and delays from SMR development.

A more accurate assessment would be based on proven systems and technologies that have robust price and performance, for instance, based on recently completed LWRs from a range of vendors around the world.

If SMRs are to be considered, this would need to be based on completed projects using NOAK data since there is too much uncertainty regarding FOAK projects.

For developmental projects, NOAK costing projections is carried out by the SMR developers and assumes that the FOAK design will get developed and tested with limited changes. There is a risk that these assumptions cannot be achieved, as was shown by the NuScale SMR design where design changes increased projected price of SMRs. It is too early to say whether any similar cost increases will occur with other SMR developers. Getting actual NOAK costs from the very few operational SMRs from China and Russia is problematic from a geopolitical perspective and likely to be distorted by lower labour costs, and government subsidies.

6 INTERNATIONAL ASSESSMENT OF LCOE

6.1 Projected Costs of Generating Electricity 2020

Projected Costs of Generating Electricity – 2020 Edition is a report on the LCOE produced jointly every five years by the International Energy Agency (IEA) and the OECD Nuclear Energy Agency (NEA). An update is due in 2025.

The 2020 report collected data from 243 plants in 24 countries and presents the plant-level costs of generating electricity from fossil fuel, nuclear power, and a range of renewable sources such as wind and solar. It is a forward-looking study based on the expected cost provided by participating countries commissioning these plants in 2025.

The report highlights that the LCOE of low-carbon generation technologies are falling and are increasingly below the costs of conventional fossil fuel generation. However, this is not uniform across some participating countries. The report notes that the cost of renewable energy generation in Japan, Korea and Russia is higher than fossil fuel or nuclear-based generation. In Europe both onshore and offshore wind as well as utility-scale solar installations are competitive with gas and new nuclear energy.

Overall, the Report concludes, that renewable energy costs are decreasing and becoming more competitive to other energy sources. The cost of electricity from new nuclear power plants remains stable, yet electricity from the long-term operation of nuclear power plants constitutes the least cost option for low-carbon generation. However, this applies to existing nuclear projects overseas, and thus cannot be confirmed for new projects in the Australian context with no established nuclear plants in operation.

6.1.1 Key Insights

The LCOE calculation methodology continues to evolve. For the first time, the 2020 edition also includes cost data on storage, fuel cells, and the long-term operation of nuclear power plants but still excludes transmission and distribution costs.

A key determinant of LCOE competitiveness is the discount rate, which corresponds to the cost of capital in the LCOE methodology. In its central case, this report assumes a uniform discount rate of 7% for all technologies and countries.

7 AUSTRALIAN CONTEXT

7.1 Nuclear and Renewables in the Australian Grid

The extent to which a nuclear industry is already established in a region, as well as the existing and future proportion of VREs in the energy market will have a large impact on the potential for nuclear as a cost competitive energy source. Australia sits at one extreme end of the spectrum, with nuclear activity currently prohibited and no existing industry, and a significant existing share and target for VRE grid penetration. The combination of these facts limits the potential outlook for nuclear as a significant and economically viable contributor to Australia's future energy needs.

It is important to consider the Australian energy grid as different energy sources can either complement or impair each other. Australia's current trajectory towards 82% renewables by 2030 further impacts the potential benefits of nuclear energy development in Australia. The timing and cost limitations on the nuclear industry in Australia, outlined in Section 4.4, mean that by the time nuclear plants could be operational in Australia, the grid will be heavily driven by VREs. Nuclear is not suitable for a high VRE environment. Combining nuclear plants and VRE leads to a loss in efficiency and viability. At peak times, either cheap wind or solar is curtailed, or nuclear is. Nuclear plants are not operationally flexible but can be adjusted to some extent. However, curtailing their operation results in a decrease in their capacity factor. This loss of utilisation undermines the economic viability of such power plants, as their main benefit lies in providing a steady, consistent output of energy at a low cost after higher construction costs.

In regards to the reviewed reports, it should be noted that:

- The GenCost 2023-24 Draft Report and the Small Modular Reactors (SMRs) in the Australian Context report did not anticipate a long delay to SMR projects around the world, making them too slow to market. They would be too late to contribute to 2030 Australian emissions reduction targets, and difficult to factor into the NEM to meet the 2050 NZE target.
- The Small Modular Reactors (SMRs) in the Australian Context report did not explain this loss of efficiency and viability in combining SMRs with variable, renewable energy. SMRs run with a capacity factor of around 0.9, meaning they run at full capacity for 90% of the time to provide baseload electricity. If the capacity factor falls due to grid contributions from variable renewable energy sources, the financial viability of SMRs reduces significantly.

Nuclear can be used for steady, consistent output, subject to a change in the NEM trading mechanism. The NEM currently allows spot pricing and contracts typically lasting up to 1 year. This does not provide a secure return for investors in new generators that provide a steady and consistent output, where project viability relies on a high capacity factor. To address this issue, longer-term contracts would need to be introduced. For example, in the United Kingdom, 15-year contracts are provided on a "Contracts for Difference Basis" that provides a guaranteed return to a generator over a longer period of time. The NEM could still function as it currently does but would include both Contracts (current form) and Contracts for Difference Contracts. This is particularly important for nuclear and offshore wind, that require significantly higher capacity factors than onshore wind and solar to account for their higher initial construction costs.

Nuclear could also be suited for energy intensive industrial and mining applications that require 24/7 electricity and/or heat, particularly at remote locations, beyond existing grid connections.

- *Key note: The only option for nuclear energy is to guarantee baseload contracts, or for industrial and mining applications, as is planned for Dow in USA.*

7.2 Sovereign Wealth Funds v. Corporate Investors

Nuclear projects are being developed in other countries by utilising government support and Sovereign Wealth Funds (SWFs). These are used to fund nuclear power plants with long construction programs, high project risks, and reliance on long downstream earnings. Without government support, nuclear energy is unattractive to corporate investors. Governments are aware of this problem, and in the UK, for instance, a blended investment between the SWFs, national and international utilities, and corporate investors is being developed for the Sizewell C nuclear power station. If nuclear power is to be considered in Australia, it is likely that significant government and tax payer investment would be required.

7.3 Enabling Infrastructure

Enabling infrastructure is required for all energy generation technologies. For a nuclear power plant, the following are some of the enabling infrastructure that would be required:

- Regulatory Body: Collaboration with national and international regulatory bodies overseeing nuclear safety, security, and environmental protection.
- Emergency Response Facilities: Including onsite emergency response centres equipped to manage and mitigate potential accidents or incidents.
- Monitoring Stations: Instruments and sensors to continuously monitor radiation levels, air quality, and other environmental parameters both onsite and in surrounding areas.
- Access Roads: Roads providing access for construction, operation, and maintenance personnel, as well as for emergency response vehicles.
- Utilities: Infrastructure for water supply, electrical power distribution, and other utilities required for plant operation.
- Waste Management Facilities: Facilities for the storage, treatment, and disposal of radioactive waste generated by the plant.
- Security Systems: Fencing, access control measures, surveillance, and security personnel to protect the plant against unauthorised access and security threats.
- Communication Systems: Reliable communication infrastructure for internal plant operations and external communication with regulatory agencies and emergency responders.

7.3.1 Case Study: Australian Nuclear Waste Repository: Kimba proposal

The now-abandoned proposal to build a low-level waste storage facility in Kimba, South Australia shows the difficulties in obtaining social license and community acceptance for the development of nuclear waste management facilities.

In 2012, the Commonwealth government passed the National Radioactive Waste Management Act 2012[xx]. This Act set out a legislative framework for selecting and establishing a national radioactive waste management facility. The Australian Radioactive Waste Agency (AWRA) sought approval for a low-level waste nuclear repository. In November 2021 it was announced that a site near the town of Kimba, in South Australia, was the proposed site for the facility, after a seven-year consultation process[xxi]. In June 2023, Senate estimates heard the federal government had spent almost $14 million in legal costs against the BDAC (Barngarla Determination Aboriginal Corporation)[xxii], who opposed the site. In 2023, the court ruled that the facility cannot be built, and Australia continues to identify a site to permanently store low-and-intermediate-level nuclear waste. High-level waste is more complex to manage and poses further social, environmental, and safety issues.

7.4 Nuclear Insurance

The United States *Price-Anderson Act 1957* covers liability claims of members of the public for damage caused by a nuclear power plant accident. This legislation places a cap on the total amount of liability each nuclear power plant licensee faced in the event of an accident, which helps to encourage private investment in nuclear power[xxiii]. According to the United States Nuclear Regulatory Commission, currently owners of nuclear power plants pay an annual premium of US$500 million in private insurance for offsite liability coverage for each reactor site. Similar enabling legislation may be required in Australia to limit investors' exposure to risk and encourage market participation.

7.5 Long Term Considerations

Long term considerations for Australia have not been explored in these reports, such as how much energy is needed by 2050 for electricity, transport, industry and mining applications.

If clean energy is to be used in all markets and not just the NEM, then further consideration must be given to

- The energy mix including for baseload
- Whether nuclear could be introduced
- The relative impacts in terms of the cost of plants and grids
- Grid stability
- Carbon use, including embodied carbon
- Land use and amenity
- Waste and recycling costs

These questions are beyond the scope of this Peer Review but are important issues in developing as complete a picture as possible.

8 SUMMARY

This report reviewed the following three key documents:

- CSIRO GenCost 2023-24 Draft Report, 2023,
- Lazard Levelised Cost of Energy Version 16.0 2023, and
- Minerals Council of Australia SMRs in the Australian Context 2nd Edition

The three reports offer valuable insights into the LCOE across various energy sources. According to the GenCost 2023-24 Draft Report and the Lazard LCOE analysis, renewable energy sources exhibit a lower LCOE compared to fossil fuels and nuclear energy. This highlights the economic competitiveness and sustainability of renewables in the current energy landscape.

Contrastingly, the report on Small Modular Reactors (SMRs) in the Australian Context presents differing findings, suggesting that the LCOE for SMRs are relatively less than renewable energy. However, this report was based on the cost estimates of three projects in developmental stages. This discrepancy prompts for a deeper understanding of factors influencing energy cost dynamics.

LCOE serves as a widely used metric for evaluating the cost of electricity generation across different energy technologies. However, its usefulness belies a complexity that can be tailored to suit diverse strategic objectives.

The interpretation and application of LCOE can vary significantly based on the methodologies and assumptions employed, which can make comparing results across different studies or contexts challenging.

One primary challenge arises from the diversity of methodologies and assumptions used in LCOE calculations, which can yield disparate results. This variability makes it difficult to draw direct comparisons between studies, particularly when attempting to assess the relative competitiveness of various energy sources. Moreover, the availability and quality of data used in LCOE analysis can vary widely between regions and technologies. Inaccurate or incomplete data, as seen in the case of NuScale in the USA, can undermine the reliability of LCOE estimates and obscure the true economic viability of energy projects.

The choice of discount rate applied in LCOE calculations is another critical factor influencing the competitiveness of different energy sources. Differences in upfront costs, revenue streams, and project lifespans necessitate careful consideration when selecting an appropriate discount rate. Moreover, as LCOE continues to evolve, it must adapt to account for factors such as guaranteed capacity and the varying lifespans of projects. Failure to incorporate these nuances can result in skewed assessments of the economic viability of energy investments.

It is essential to recognise that LCOE, while informative, should not be used in isolation for investment planning. Instead, it should be integrated into a broader framework that considers additional financial, technical, and regulatory factors. By contextualising LCOE within a comprehensive analysis, decision-makers can make more informed investment decisions that align with their strategic objectives and risk tolerances. By adopting a holistic approach to energy investment evaluation, stakeholders can make more informed decisions that align with their strategic objectives and ensure the sustainability and resilience of energy systems.

APPENDIX A: REFERENCES

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