INTRODUCTION

With all twelve of the ARENA-supported Large-Scale Solar (LSS) projects currently completed or under construction, this vignette presents a look at the information provided by the project proponents to ARENA, as part of their Knowledge Sharing obligations. The main source of information is the projects’ ARENA’s Levelised Cost of Energy (LCOE) spreadsheet and is verified and supplemented with information from proponent financial models and project websites.

Figure 1: Locations, AC power ratings and mounting technologies of LSS projects around Australia. All tracking projects use single-axis trackers.

The LCOE values reported here were obtained from ARENA’s LCOE spreadsheet calculator for all LSS projects, as determined at the LSS grant application phase. Per ARENA’s requirements, the LCOE inputs needed to be linked to the financial models employed by the proponents.

Analysis of both the LCOE spreadsheets and the financial models shows that proponents report and interpret costs differently across projects. These inconsistencies make it difficult at this stage to accurately compare which line-item costs contribute what amount to a project’s lifetime cost - for example, how and where piling costs are recorded, or whether PV module costs are recorded with, or without, transport to site. Given this context, this vignette looks to compare overall LCOE values and the proportion that capital expenditure (CAPEX) and operational expenditure (OPEX) have on lifetime costs.
OVERVIEW OF PROJECT LCOE VALUES

Figure 2 shows the project LCOE values as calculated using ARENA’s LCOE calculator, with each broken into OPEX and CAPEX components. The lowest LCOE achieved is 97.8 AU$/MWh, whereas the highest LCOE is 132.5 AU$/MWh. Across all twelve projects, the median LCOE is 108 AU$/MWh.

Figure 2: Overview of the CAPEX and OPEX components of the LCOE for the LSS projects.

Some projects defer capital costs over the lifetime (e.g. anticipating that modules or inverters need to be regularly replaced - in some cases assigning this to the CAPEX category, others to OPEX), whereas others have the capital costs upfront, and thus indicates some of the CAPEX/OPEX trade-offs applied by project proponents.

Looking at the variation in the project CAPEX and OPEX in Figure 2 and Figure 3, the LSS projects have a much larger spread in the OPEX than the CAPEX, which reflects the larger uncertainties and limited long-term market experience regarding operation and maintenance of utility-scale solar farms in Australia. The CAPEX as a percentage of the total LCOE varies from 79% to 91% and, conversely, the OPEX component of the LCOE varies from 21% to 9%.

Figure 3: Boxplots of the discounted (net present value) CAPEX and OPEX components of LCOE, and CAPEX as a percentage of the LCOE, and the total project LCOE values for the LSS projects. The line inside the box indicates the median value, with the box showing the values between 25% and 75% (the inter-quartile range IQR), and the whiskers extending to cover 1.5 times either beyond the IQR, with values that are outside of these bounds indicated as outliers.
**UNDERSTANDING LCOE**

While the LCOE is an imperfect metric and subject to much discussion, it does permit a comparison between projects with different technologies, such as wind versus solar, or between solar projects having different cost and generation profiles. In its simplest form, the LCOE is the ratio of the net present value (NPV) of the total lifecycle costs, divided by the NPV of the total lifetime energy production.

\[
LCOE = \frac{\text{NPV(Total lifecycle costs)}}{\text{NPV(Total lifetime energy production)}} \tag{1}
\]

The LCOE can be interpreted as the long-run marginal cost of electricity generation\(^1\). It is the price at which electricity generated must be sold to break even, given the costs incurred over the life of the plant.

The LCOE calculated for the LSS projects is as follows:

\[
LCOE = \frac{\sum_{t=1}^{n} (I_t + O_t + F_t)}{\sum_{t=1}^{n} E_t} \tag{2}
\]

Where:

- \(LCOE\) = Levelised Cost of Energy\(^1\), expressed as $/kWh or $/MWh
- \(I_t\) = (Capital) Investment expenditure (CAPEX) in the year \(t\)
- \(O_t\) = Operations and maintenance expenditure (OPEX) in the year \(t\)
- \(F_t\) = Fuel expenditure (part of OPEX) in the year \(t\); this is zero for solar PV.
- \(E_t\) = Electricity generation in the year \(t\)
- \(r\) = Discount rate (set by ARENA at 10% for all LSS projects)
- \(n\) = Amortisation period (typically the lifetime of the project: 25 years)

The LCOE using Eq (2) calculates the net present value of both costs and energy, and values investments and generation in later years less than the earlier years. The discount rate \(r\) is a key parameter for the LCOE, as high values of \(r\) (e.g. 10% or more) weigh costs and energy generation in early years much more highly than future costs and generation, whereas a low \(r\) value (e.g. 2.5%) gives a more similar weight to costs and energy generated today to those in the future. (Note that the PV industry has historically also reported LCOE without discounting future energy generation (\(r_{\text{energy}} = 0\%\) - essentially valuing future energy generation equal to today, which results in significantly lower LCOE values. The comparison and benchmarking of worldwide LCOE values needs to be done while keeping this in mind.) The discount rate is also known as the IRR\(^2\) hurdle rate, and reflects the risk perception for the project, its technology, the regulatory climate in which it operates, and the country risk itself.

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\(^1\) Note: Some sources use “electricity” instead of “energy”

\(^2\) IRR: Internal Rate of Return
Figure 4 demonstrates the sensitivity of the LCOE to the discount rate \( r \) for the LSS projects. The varying slope of these curves reflect the impact of timing of expenses and energy generation across the portfolio. Summary statistics of this figure are included in

![Graph of LCOE vs Discount Rate]

**Table 1.** Portfolio LCOE statistics at varying discount rates, in AU$/MWh.

<table>
<thead>
<tr>
<th></th>
<th>( r = 0% )</th>
<th>( r = 5% )</th>
<th>( r = 10% )</th>
<th>( r = 15% )</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Maximum</strong></td>
<td>$63</td>
<td>$94</td>
<td>$132</td>
<td>$175</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td>$55</td>
<td>$80</td>
<td>$112</td>
<td>$148</td>
</tr>
<tr>
<td><strong>Median</strong></td>
<td>$54</td>
<td>$79</td>
<td>$108</td>
<td>$144</td>
</tr>
<tr>
<td><strong>Minimum</strong></td>
<td>$48</td>
<td>$70</td>
<td>$98</td>
<td>$129</td>
</tr>
</tbody>
</table>

The LCOE for projects can be lowered by:
- decreasing costs (CAPEX or OPEX);
- spreading expenditure over the project lifetime;
- increasing energy generation; and,
- reducing financing costs (as reflected in the discount rate).

For PV projects, the increase in energy generation is easiest to achieve through site selection (higher solar resource) and technology choice (tracking the sun, over fixed orientation). These aspects then need to be balanced by the cost implications: for a same power rating, fixed orientation PV systems have a lower CAPEX and OPEX than tracking systems, and optimal solar resource sites may require additional investments in transmission infrastructure. While PV projects have intrinsically high overnight capital costs, some projects in the LSS portfolio have already explored spreading these expenditures over the project lifetime, to thus lower the LCOE. Financing costs can be lowered by reducing project uncertainties, for example by reducing solar resource forecast uncertainty, by using high-quality components, to exploring different capital structures.
PROJECT YIELDS AND TECHNICAL-FINANCIAL ASSUMPTIONS

The LSS projects exhibit a wide range of yield profiles, as can be seen in Figure 5. Among the main assumptions used by proponents that have an influence on the final energy yield that can be sold are the MLF (Marginal Loss Factor), system availability and PV module degradation. These are discussed further below.

![Graph showing normalised yields for LSS projects](image)

**Figure 5:** Annual values of the normalised yields for the twelve LSS projects. Here, the variation reflects different approaches to long-term yield and revenue forecasting inputs within financial models.

CONSIDERATION OF MODULE AND SYSTEM DEGRADATION IN FINANCIAL MODELS

All LSS projects consider the effect of degradation of PV modules on the solar farm’s yield, although there are relatively large variations between projects over the project duration: the degradation assumptions over the project life varies by proponent. Nevertheless, of interest is also the spread in average module degradation values which can be observed in Figure 6, which shows that the majority of projects assume either -0.40%/year or -0.50%/year average annual degradation rates for PV modules. All other things being equal, larger degradation rates (e.g., -0.80%/year) result in a higher LCOE as less energy will be generated by the project over its lifetime. However, the difference between -0.30%/year and -0.80%/year will not appear as pronounced for the LCOE for high discount rates $r$, see Eq (2), as future energy generation will be discounted.

![Boxplots showing capacity factors, annual degradation, and DC:AC ratios](image)

**Figure 6:** Boxplots of capacity factors for the first year and 25-year duration, average project module degradation assumptions and DC:AC ratios used by the LSS projects. The line inside the box indicates the median value, with the box showing the values between 25% and 75% (the inter-quartile range IQR), and the whiskers extending to cover 1.5 times either beyond the IQR, with values that are outside of these bounds indicated as outliers.
In theory, the DC:AC oversizing (having a larger DC power capacity than the AC inverter output capacity of the solar farm) should result in a lower observed AC or system degradation rate, as inverter saturation or clipping at high irradiance conditions will occur for the initial years of operation. This technical behaviour of modelling the energy yield for each year (and thus final AC degradation) would ideally be fed into the project financial models, per international best practices [2], whereas most of the LSS projects determine the yield for the first year, and subsequently apply the DC module degradation in the financial models. The combination of degradation, availability and MLF values then results in the 25-year Capacity Factor\(^3\) (CF) values being lower than those for the first year of operation, as shown in Figure 6.

**MARGINAL AND DISTRIBUTION LOSS FACTORS**

MLF values are determined by the Australian Energy Market Operator (AEMO) annually, and affect the revenue of the energy sold on the National Electricity Market (NEM):

\[
Revenue_{MLF \, gross-up} = E_{generated} \left( \frac{MWh}{\text{price}} \right) * MLF \% \tag{3}
\]

DLF values are calculated by the Network Service Provider (NSP), which varies by project, and affect the generated energy revenue similar to the MLF.

From a (solar) generator’s perspective, an MLF (or DLF) greater than 1 for a considered location is a price signal that increases the value of the energy generated (an MLF of 1.02 and 100 MWh generated is valued at 102 MWh), whereas an MLF less than 1 indicates that the revenue obtained from the generator will be reduced. Most of the MLF forecasts used by the proponents assume few if any changes to their MLF over the project lifespan, although 2 projects assume a drop in their MLF by year 20 of operation.

**AVAILABILITY**

Most of the LSS projects’ forecasts around the availability of the solar farm (and the grid) to generate electricity are generally consistent, with few changes from year to year. The availability reflects project-specific aspects, such as the probability of transmission lines being unavailable during the year due to weather-related and other types of events, as well as assumptions on the time required for a solar farm to return to operation after a fault. A few projects do assume larger year-to-year variations in their availability, which can give counterintuitive results when looking at the normalised annual yield. This is clear for projects that assume a lower value of availability in one year compared to the next, which results in a higher yield sold (and effectively generated) than the previous year, despite the presence of degradation.

**SUMMARY**

This vignette has provided a first look at some key values and assumptions that influence the LCOE of the LSS projects. Using ARENA’s discount rate \( r \) of 10% for all projects, the LCOE varies between 97.8 AU$/MWh and 132.5 AU$/MWh, and the median value 108 AU$/MWh, with the CAPEX portion ranging between 79% and 91%. When evaluating the same projects with varying discount rates, the median LCOE drops to 54 AU$/MWh at \( r = 0\% \) and increases to 144 AU$/MWh at \( r = 15\% \), highlighting the importance of stating, and understanding, the employed discount rates when comparing LCOE values for projects in different locations. The spread between project LCOEs increases with an increasing discount rate, and conversely decreases with lower discount rates. The discount rate used to determine the LCOE is particularly important when benchmarking Australian PV projects with projects in different countries. On a technical level, the LSS projects show a limited amount of spread on the average project degradation and DC:AC ratios, although degradation patterns over time are treated differently by project proponents.

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\(^3\) Capacity Factor: the equivalent percentage of hours in the year that the plant generates at full power.
REFERENCES
