ASIA-PACIFIC
SOLAR RESEARCH CONFERENCE

2016

The Levelised Cost Of Energy Of Three Solar PV Technologies Installed At UQ Gatton Campus

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Abstract

Economic assessment of the viability of different types of solar PV tracking technologies suitable for installation in utility scale solar farms centers on assessment of whether annual production of the different tracking technologies is increased enough to compensate for the higher cost of installation and operation incurred by the tracking systems. To investigate this, the levelised cost of energy of three representative solar PV systems installed at the University of Queensland's Gatton Campus is calculated. These solar array technologies are Fixed Tilt, Single Axis Tracking and Dual Axis Tracking arrays. These calculations depend crucially on assumptions made about ($/kW) construction costs and annual capacity factors of the three solar technologies being considered. A key finding was that the Single Axis Tracking technology was the most competitive, followed by a Fixed Tilt system. The Dual Axis Tracking system was the least competitive technology of those considered. It is also demonstrated how LCOE can underpin a 'Contract-for-Difference' feed-in tariff scheme applicable to supporting investment in utility-scale solar PV.

1. Introduction

The economics of solar PV has changed significantly over the last decade with installation costs declining significantly following the marked take-up of solar PV systems. This has occurred on the back of generous government feed-in tariff support particularly in Europe. In Australia more recently, a marked increase in the up-take of roof-top solar PV occurred on the back of generous state-based feed-in tariffs and the Commonwealth Government's small scale renewable energy target (RMI, 2014).

To-date, investment in utility scale solar PV projects has proceeded largely on the basis of support from two particular programs: (1) Australian Capital Territory (ACT) reverse auction for solar PV projects (ACT, 2016); and (2) Commonwealth Government support from the Australian Renewable Energy Agency (ARENA, 2016a) and Clean Energy Finance Corporation (CEFC, 2016).

A measure commonly used to assess the feasibility of a renewable energy project is the Levelised Cost of Energy (LCOE) of the project. This variable is used to ascertain what return on average would be needed over the lifetime of the project to cover costs associated with its construction and operation while also securing an adequate return on invested capital.

Two factors conventionally produce higher LCOE estimates for wind and solar PV projects when compared with thermal generation technologies. The first is a relatively lower annual capacity factor (ACF) and the second is a significantly higher ($/kW) construction costs.

The production profile and ACF of a solar PV array will also be influenced by whether sun tracking technologies have been incorporated into the array's design. Wild (2016a, Section 3.2) demonstrated that the production of a Single Axis Tracking (SAT) array was between 23.9 and 24.3 per cent above the output of a Fixed Tilt (FT) array. Moreover, the output of a Dual Axis Tracking (DAT) array was between 38.0 and 39.1 per cent higher than the output from the FT array. However, account also needs to be taken of the capital and operational costs of the different solar array technologies. These costs are typically higher for DAT and SAT arrays than for FT arrays.

In this paper, we conduct a comparative assessment of the LCOE of three 630 kW FT, SAT and DAT arrays, calculated from simulated solar PV yields over the years 2007-2015, for representative FT, SAT and DAT arrays installed at the University of Queensland's (UQ) Gatton Solar Research Facility (GSRF) (UQ, 2015a). Note that choice of 2007-2015 period was based upon consideration of quality of solar irradiance data as well as a desire to capture the impact of different phases of the ENSO cycle on PV yield which is possible using data based on the 2007-2015 time period.

The GSRF was part of a large ARENA funded project involving investment by Australian Gas and Light Pty Ltd (AGL) in the Nyngan and Broken Hill Solar farms (AGL, 2015). The solar array installed at Gatton is a 3.275 megawatt pilot plant that comprises three different solar array technologies: (1) a FT array comprising three identical 630 kW sub-arrays (UQ, 2015b); (2) a 630 kW Horizontal SAT sub-array utilising First Solar's SAT system (UQ, 2015c); and (3) a 630 kW DAT sub-array utilising the Degertraker 5000 HD system (UQ, 2015d). A more detailed description of the GSRF including an overhead picture and identification of the representative FT, SAT and DAT sub-arrays can be found in (Wild, 2016b, Section 2).

The structure of this paper is as follows. The next section will provide a description of the assumptions used to calculate LCOE, including the ACF values used in the modelling. Section (3) documents the main findings. Section (4) discusses the link between LCOE and the determination of feed-in tariff support for renewable energy projects. Finally, Section (5) contains conclusions.

2. LCOE modelling

Economic assessment of the viability of different types of solar PV tracking technologies typically centres on assessment of whether the annual production of the different tracking technologies is lifted enough relative to the benchmark FT system to compensate for the higher cost of installation and operational expenditures incurred by tracking systems. The installation costs refer to the 'overnight' $/kW installation costs that would be incurred if the whole solar PV plant could be constructed overnight. This expenditure category would include costs associated with purchase of modules and inverters as well as various categories of balance of plant costs.

The second cost component is operational costs, in particular, operational and maintenance (O&M) expenditures associated with keeping modules and inverters operating efficiently. For tracking systems, additional O&M costs would have to be incurred against the need to also keep the tracking infrastructure working efficiently. In general, O&M expenses are likely to be directly proportional to the complexity of the tracking system employed. Therefore, O&M provisions associated with more complex two axis trackers such as the DAT system are likely to be higher because the tracking infrastructure is more complex, of larger scale and more prone to mechanical faults or break-downs.

In order to derive LCOE estimates, a number of key cost and technical assumptions need to be made for the three representative GSRF solar array technologies. These assumptions are illustrated in Table 1, Panels (A)-(C):

Table 1. Generation technology cost assumptions

Panel (A): Capital cost, unit size, useful life, and auxillary load assumptions

Generation Technology	Capital Cost ($/kW)	Unit Size (MW)	Useful Life (Years)	Auxillary Load (%)
Fixed Tilt	2,833	0.63	25	0.5
Single Axis Tracker	2,929	0.63	25	0.5
Dual Axis Tracker	4,534	0.63	25	0.5

Cost of capital: *11.0%* *Annual Inflation:* *2.5%*

Panel (B): O&M Rates ($/kW/Year)

Generation Technology	Fixed O&M $/kW/Year WP	Fixed O&M $/kW/Year PC	Fixed O&M $/kW/Year PC_low
Fixed Tilt	25.00	20.00	17.00
Single Axis Tracker	30.00	26.00	25.00
Dual Axis Tracker	39.00	33.00	32.00

Panel (C): O&M Cost ($m pa)

Generation Technology	Fixed O&M ($m pa) WP	Fixed O&M ($m pa) PC	Fixed O&M ($m pa) PC_low
Fixed Tilt	0.0158	0.0126	0.0107

Single Axis Tracker	0.0189	0.0164	0.0158
Dual Axis Tracker	0.0246	0.0208	0.0202

The parameters listed in Table 1, Panels (A)-(C) provide cost estimates of key components of the three representative solar PV technologies. The ($/kW) Overnight Capital Cost (OCC) estimates listed in column 2 of Panel (A) were partially determined from data cited in Table 3.5.2 of BREE (2012). Specifically, the following OCC estimates for the three solar PV technologies were listed as:

- FT: $3380/kW;
- SAT: $3860/kW; and
- DAT: $5410/kW.

These estimates were then rebased to an updated FT result linked to published information about the combined AGL Nyngan and Broken Hill solar farms that were commissioned in 2015. Specifically, the AGL FT OCC for the combined Nyngan and Broken Hill solar farms was calculated as ($439,082,000/155000) or $2832.79/kW. Similarly, basing the SAT OCC estimate on the Moree solar farm which was commissioned in early 2016 (ARENA, 2016b) produces a ($/kW) OCC cost of $2928.57/kW. Finally, rebasing the (BREE, 2012) OCC estimate for DAT OCC costs on the new AGL FT OCC gives:

- FT: $2832.79/kW;
- SAT: $2928.57/kW; and
- DAT: $4534.14/kW = (5410/3380)*2832.79,

which are listed in column 2 of Panel (A), of Table 1.

It should be noted that the ($/kW) OCC estimates for utility scale solar PV have been quite fluid over the last two years as more utility scale solar PV projects have secured government support. Updated FT and SAT ($/kW) results became available linked to published information from ARENA about successful projects listed in the most recent large-scale competitive Solar PV round (ARENA, 2016c). These estimates place average OCC costs for FT arrays at around $2151/kW and around $2204/kW for SAT systems. Therefore, when compared to these later cost estimates, the generic costs listed above will produce more conservative (e.g. higher) LCOE outcomes. However, the OCC cost estimates listed in Panel (A) of Table 1 will be sufficient enough to demonstrate they key themes the author wishes to convey to readers and are consistent with cost estimates of recently commissioned utility scale solar PV farms utilizing FT and SAT technologies. More uncertainty surrounds the true OCC estimate for DAT systems because of the relatively lower levels of uptake of this technology when compared to both FT and SAT technologies.

The unit sizes of each representative solar PV technology corresponds to an energy sent-out inverter capacity limit of 630 kW that is applicable for each sub-array at GSRF. We also assume auxiliary load factors of half a percent for each solar PV array, representing the amount of electricity consumed internally during the production of electricity. Finally, in Panel (A), we also assume a useful life for each technology of 25 years.

To gauge sensitivity of LCOE to variations in O&M costs, three O&M estimates are used. These estimates are compiled from Table 11 of BREE (2013). Note that we have adopted the same methodology outlined in BREE (2012, 2013) and assumed that all O&M expenditures applicable to solar PV arrays are classified as Fixed O&M (FOM) expenditure.

Panel (B) of Table 1 lists the ($/kW/year) FOM estimates used in the levelised cost modelling. The first set, denoted by 'WP', denotes the Worley Parsons 2013 updated values reported in Table 11 of BREE (2013). The second set of FOM cost estimates represent the average of the private O&M service provider estimates cited in Table 11 of BREE (2013). These estimates are denoted by 'PC'. The third set of estimates correspond to the lower range values of the private O&M service provider cost estimates reported in Table 11 of BREE (2013). These estimates are denoted by 'PC_low'.

In Panel (B), the FT array has the lowest FOM cost estimates, in the range $17/kW/Year to $25/kW/Year. The SAT array has the next lowest FOM estimates, in the range $25/kW/Year to $30/kW/Year. The DAT array has the highest FOM estimates, between $32/kW/Year and $39/kW/Year. It should be noted that the WP estimates were derived from a broad based assessment of the literature, including overseas studies, while the private O&M service provider estimates were sourced directly from private sector contractors.

The values reported in Panel (C) of Table 1 were derived by multiplying each ($/kW/year) estimate in Panel (B) of Table 1 by 630, representing the 630 kW energy sent-out capacity limit to give the annual dollar FOM cost and then dividing this by one million to convert to the equivalent ($m pa) estimate listed in Panel (C) of Table 1.

Other key assumptions required for LCOE estimation are the weighted average cost of capital (WACC), the cost and revenue inflation assumptions, annual capacity factors of the three representative technologies and deflation of array output over time. The cost of capital on a weighted basis is assumed to be 11.0% (nominal, pre-tax) and long run inflation is assumed to be 2.5%. The basis upon which inflation is applied is at full CPI against (non-finance) operating cost streams and only ¾CPI against revenue streams. This reflects real-world trends in power generation and the CPI disconnect is logical given that financing costs tend to be fixed up-front and form the dominant cost of power applications (Simshauser and Wild, 2009). Note that in deriving the WACC, the solar PV project is assumed to be financed with 70% debt and 30% equity.

An energy scale factor is used to model the loss in output over time. This output degradation rate is assumed to be an annual deflation rate equal to $(0.8)^{\frac{1}{n}} = 0.9911$, where 'n' denotes the number of years of useful life listed in Panel (A) of Table 1. This equation ensures that the year-on-year rate of output deflation is consistent with the guarantee of First Solar that 80% of the nameplate capacity of the modules installed at GSRF will be available after 25 years of operation.

In (Wild, 2016a), the NREL SAM model (Gilman, 2015) was used to simulate electricity production of the three representative solar PV systems at GSRF over 2007 to 2015. To run simulations in SAM, user supplied inputs relating to: (1) hourly solar and weather data; (2) technical information about modules, inverters, array sizing and design; (3) soiling effects; (4) shading effects; and (5) DC and AC electrical losses are required. In the modelling conducted in (Wild, 2016a), it was also assumed that all modules, inverters and tracking infrastructure were in good working order. This latter assumption was employed in the Yield modelling to ensure that the main differences between each array's PV yield could primarily be attributed to the nature of solar tracking employed in each array. Most other factors capable of influencing PV yield including solar irradiance, weather and potential outage differences were homogenized across the reference arrays. In contrast to this approach, Thevenard & Pelland (2013) propose a novel approach to estimating PV yield that is capable of accounting for variation in other modelling assumptions such as soiling, electrical losses (such as mismatch losses) and equipment availability across different arrays.

It should be realised that the simulations in (Wild, 2016a) underpinning the ACF's utilized in the LCOE modelling in this paper do not include any self-shading effects because such effects were not calculated for DAT systems in the most current version of SAM. However, SAM does calculate self-shading losses for both FT and SAT arrays thus enabling assessment of the impact of self-shading effects by comparing the annual PV yield between simulations with self-shading activated and 'turned-off'. Analysis of these simulation results indicates average self-shading losses of a tenth of one per cent for the representative FT array and one per cent for the representative SAT array. In the case of the SAT array, this equates to a reduction in the annual capacity factor of around 0.3 percentage points. For the FT sub-array, the rate of reduction was around 0.02 percentage points. Thus, PV yield will be over-stated because of the exclusion of self-shading effects. Moreover, there is also some evidence that the SAM model can be bullish in projecting PV Yield more generally (Suniva, 2012).

The outcomes cited in Section 3.3 of Wild (2016a) for years 2007-2015 and for three module soiling scenarios considered relating to 'low', 'medium' and 'high' soiling, are reported in Table 2. These ACF results will be used in the LCOE modelling reported in this paper. Thus, this analysis will produce sets of LCOE results according to module soiling scenarios and the 'WP' 'PC' and PC_low' FOM cost scenarios indicated in Panel (B) of Table 1. These results will permit sensitivity analysis of LCOE estimates associated with differences in module soiling and FOM costs.

Table2. Average energy sent-out ACF's by representative array type and soiling scenario: (Percentage)

Soiling	FT	SAT	DAT
Low	21.5	26.7	29.7
Medium	21.2	26.4	29.4
High	20.7	25.8	28.8

The 'levelised cost' involves calculating the present value of the time profile of annualised plant costs less potential revenue streams from the sale of large-scale renewable energy certificates (LGC) and sale of merchant electricity, deflated by the time profile of energy production of the solar array over its lifespan. Note that the LGC and sale of merchant electricity revenue streams are treated as negative cost entries in the LCOE calculation. See (Wild, 2016b, Section 3) for further details on the methodology used to calculate LCOE.

3. LCOE results

3.1. Conventional LCOE results

Conventional LCOE results are reported in Table 3. These LCOE estimates are calculated ignoring the cost-offsets associated with renewable energy certificate and merchant electricity sale revenue streams. Given our desire to link the discussion to that of feed-in tariff support which typically uses a 'c/kWh' denomination, we convert the ($/MWh) LCOE values into their equivalent (c/kWh) values using the conversion factor of 0.1, that is, $1/MWh = 0.1 c/kWh.

In Table 3, the LCOE estimates increase in magnitude as the rate of module soiling increases which produces reductions in the ACF estimates as indicated in row 6 of Table 3, thereby increasing the LCOE estimates. The lowest LCOE estimates are recorded for the low soiling scenario. These estimates are in the range 17.62 to 18.10 c/kWh for the representative FT array, 15.03 to 15.27 c/kWh for the representative SAT array and 20.62 to 20.93 c/kWh for the representative DAT array. In contrast, the highest LCOE estimates are associated with the high soiling scenario, in the range of 18.30 to 18.80 c/kWh for the FT array, 15.55 to 15.80 c/kWh for the SAT array and 21.27 to 21.58 c/kWh for the DAT array. These outcomes, more generally, point to average percentage increases in LCOE estimates associated with medium relative to low soiling of 1.4, 1.1 and 1.0 per cent for the FT, SAT and DAT arrays, respectively. Similarly, the average percentage increase in LCOE associated with high soiling relative to the low soiling is 3.9, 3.5 and 3.1 per cent, respectively. These results indicate that module soiling adversely affects the FT sub-array to a greater degree than is the case with the two solar tracking sub-arrays.

Table 3 also indicates that the SAT array is the most competitive technology with lowest LCOE in the range 15.03 to 15.80 c/kWh across module soiling scenarios. The next most competitive technology is the FT array with LCOE estimates in the range 17.62 to 18.80 c/kWh. This represents an increase in relative terms in LCOE of between 17.2 and 19.0 per cent relative to the lower SAT estimates. Finally, the least competitive technology is the DAT array, with LCOE estimates in the range 20.62 to 21.58 c/kWh. These latter LCOE estimates represents, in relative term and across module soiling scenarios, increases of between 36.6 and 37.2 per cent over the lower cost SAT estimates.

The role that different FOM costs could play can be discerned from the observed decline in LCOE estimates with lower FOM costs. For example, in average terms and across the different soiling scenarios, the reduction in LCOE for the 'PC' scenario relative to the higher cost 'WP' scenario are approximately 1.7, 1.2 and 1.2 per cent for the FT, SAT and DAT arrays. Moreover, the average reduction in LCOE for the lowest cost 'PC_low' FOM scenario relative to the highest 'WP' cost scenario is approximately 2.7, 1.6 and 1.5 per cent, respectively. Thus, the biggest reduction in LCOE flows to the FT array when compared with the other two solar PV tracking technologies considered.

Table 3 Conventional (c/kWh) LCOE estimates

	Low soiling			**Medium soiling**			**High soiling**		
FOM Cost Scenario	FT	SAT	DAT	FT	SAT	DAT	FT	SAT	DAT
WP	18.10	15.27	20.93	18.36	15.44	21.14	18.80	15.80	21.58
PC	17.80	15.08	20.67	18.05	15.25	20.88	18.49	15.60	21.31
PC_low	17.62	15.03	20.62	17.87	15.20	20.83	18.30	15.55	21.27
ACF(%)	21.5	26.7	29.7	21.2	26.4	29.4	20.7	25.8	28.8

3.2. *LCOE estimates with revenue from renewable energy certificates and merchant electricity sales included*

In this sub-section we investigate impacts on LCOE after including revenue streams relating to merchant sale of electricity to the wholesale electricity market and sale of renewable energy certificates. Merchant sale of electricity revenue is calculated by multiplying the MWh output of the GSRF by the Queensland (QLD) ($/MWh) average wholesale price in 2015, corrected for marginal loss and distribution loss factors to account for the location of GSRF within the electricity network. The volume weighted price for 2015 were compiled from half hourly demand and price data contained in AEMO (2016) for the Queensland 'QLD1' regional wholesale market. The 2015 wholesale price level used in simulations is $57.83/MWh.

The volume weighted average prices cited above incorporates adjustments for transmission and distribution loss using a marginal loss factor of 0.9723 and distribution loss factor of 1.0262. These values were determined as averages of the published values for these loss factors over the time period 2011/12 to 2015/16. Multiplying these two factors together produces a value of 0.9979 that was multiplied by the volume weighted average price level calculated from the source AEMO data. This produced a slight downward shift in the average wholesale price used in the analysis.

A representative and contemporaneous spot price value was adopted for the ($/MWh) LGC strike spot price used in the modelling. Specifically, a LGC spot price of $79.95/MWh was adopted, being sourced as the mid-point of the 'ask' and 'bid' range of the LGC spot price values listed on Mercari (2016) on 03/05/2016.[1]

In a manner similar to the presentation of the results in Table 3, the LCOE results reported below are expressed in terms of (c/kWh) values. These LCOE results associated with the wholesale market and LGC pricing assumptions mentioned above are reported in Table 4.

Table 4 indicates that the lowest required feed-in tariff rates are associated with the low soiling scenario. These estimates are in the range 3.73 to 4.21 c/kWh for the FT array, between 1.14 and 1.38 c/kWh in the case of the SAT array and between 6.74 and 7.04 c/kWh for the DAT array. In comparison, the highest contemporaneous feed-in tariff rates are associated with the high soiling scenario, and are in range 4.41 to 4.91 c/kWh, 1.66 to 1.92 c/kWh and 7.38 to 7.70 c/kWh, respectively.

It is apparent that of the three technologies considered, the SAT array continues to have the lowest required feed-in tariff support, in the range of 1.14 to 1.92 c/kWh, depending upon soiling and FOM cost scenarios. This is followed by the FT array with required feed-in tariff support levels of between 3.73 and 4.91 c/kWh. Finally, the required level of feed-in tariff support remains the highest for the DAT array, in the range of 6.74 to 7.70 c/kWh.

It should be noted that more detailed sensitivity analysis of LCOE to variations in both LGC and merchant electricity prices are documented in Wild (2016b).

[1] It should be noted that more recently, the spot LGC strike price has increased even further, rising to $89.15/MWh on the Mercari web-site on 10/10/2016.

Table 4 Required (c/kWh) feed-in tariff rates

	Low soiling			Medium soiling			High soiling		
FOM Cost Scenario	FT	SAT	DAT	FT	SAT	DAT	FT	SAT	DAT
WP	4.21	1.38	7.04	4.47	1.56	7.26	4.91	1.92	7.70
PC	3.91	1.19	6.78	4.16	1.36	6.99	4.60	1.72	7.43
PC_low	3.73	1.14	6.74	3.98	1.31	6.95	4.41	1.66	7.38

4. Linking LCOE to required feed-in tariff support rates

The LCOE results reported in Table 4 are significantly lower than the results associated with the conventional definition of LCOE reported in Table 3 and which underpin feed-in tariff support based upon a conventional fixed price feed-in tariff scheme (Cory et al., 2009) and (Couture et al., 2010). A key reason for this is that cost-offsets associated with revenue streams from the sale of renewable energy certificates and merchant electricity are ignored when calculating the LCOE estimates reported in Table 3 that underpin the fixed price feed-in tariff schemes.

These considerations raise a number of important policy implications. First, the magnitude of feed-in tariff levels and resulting size of government expenditure on the tariff scheme associated with the results in Table 4 will be significantly lower than support arrangements based on the conventional LCOE outcomes reported in Table 3.

Second, feed-in tariff support levels can be tailored to reflect changes in both the wholesale electricity and LGC markets over time.

Third, the role of learning and economies of scale and scope in PV component manufacturing and logistics over time would be expected to reduce both capital and operational costs. These trends would exert downward pressure on LCOE over time, thereby reducing the required level of feed-in tariff support required over time. This has been termed 'predetermined tariff degression' (Couture et al., 2010, pp. 36-42).

Fourth, the LCOE of a project still plays a key role in determining the required level of feed-in tariff support, thus ensuring renewable energy project viability. This goal would be central to any broader policy objectives related to promoting an innovative and viable renewable energy industry within the economy.

Fifth, least cost principles could be entrained in the design and implementation of the feed-in tariff scheme by: (1) choosing eligible projects on the basis of a competitive reverse auction process; and (2) allocating capacity segments of the scheme to be rolled out in parcels over time to ensure that competitive cost advantages associated with technological innovation and economies of scale and scope are built into the bids by participants over time.

Sixth, the feed-in tariff scheme generally envisaged by the above mechanisms most closely approximates the 'Contract for Difference (CfD)' feed-in tariff scheme adopted recently in Great Britain (UK Government, 2015). The 'strike' price would correspond to the conventional LCOE estimate identified in Table 3. The 'reference' price would correspond to an aggregate price calculated from both wholesale electricity price and LGC prices. Finally, the size and sign of the required return would indicate the nature of payments to and from the owners of the solar PV array to the government.

A key implication of the CfD feed-in tariff design is that it can be easily applied as a 'top-up' mechanism to other existing schemes such as a national carbon pricing mechanism or renewable energy certificate scheme based on some renewable energy obligation or target.

5. Conclusions

Studies of the economic viability of different types of solar PV tracking technologies centres on assessment of whether the annual production of the different tracking technologies is increased enough relative to the benchmark FT system to compensate for the higher cost of installation and operation incurred by the tracking systems. In this paper we have investigated this issue from the perspective of the LCOE of three individual FT, SAT and DAT sub-arrays located at UQ's GSRF.

Of crucial importance to the results in this paper are the assumptions made about the ($/kW) construction costs of the three different solar PV arrays technologies.

Another crucial parameter affecting LCOE is the ACF of each representative array. The NREL SAM model was used to simulate electricity production of the three representative solar PV systems installed at GSRF. Sensitivity of LCOE estimates to different module soiling and FOM cost scenarios was also investigated.

A number of broad conclusions follow from analysis of our results. First, of the three technologies considered, the SAT array is the most competitive. This is followed by the FT array and then the DAT array. LCOE estimates also increase with the level of module soiling reflecting the deterioration in the ACF associated with increased soiling. LCOE results were also shown to decline with reductions in FOM costs.

From the perspective of project feasibility, the appropriate level of feed-in tariff support was the rate needed to cover capital costs, operational costs and achieve a required return on invested capital over the lifespan of the project after accounting for renewable energy certificate and merchant electricity sales revenue streams. These latter revenue streams were treated as cost-offsets in the LCOE calculation.

A direct link was established between the LCOE value and the required feed-in tariff rate needed to ensure project feasibility. LCOE estimates were also shown to decline significantly when revenue from the sale of renewable energy certificates and merchant sale of electricity to the wholesale electricity market were incorporated in the LCOE modelling. Feed-in tariff support levels according to this methodology could also be tailored to reflect changes in conditions in the LGC and wholesale electricity market over time. The type of feed-in tariff scheme most closely aligned to the methodology developed in this paper would be a 'CfD' feed-in tariff scheme.

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