COST EFFICIENT PROCUREMENT OF SOLAR PHOTOVOLTAIC PLANT FOR EMBEDDED GENERATION

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ABSTRACT

South Africa has one of the highest carbon emissions per capita in the world, and this has raised the need to reduce reliance on coal generated power which is carbon intensive. The South African government has focussed on introducing renewable energy technologies for power generation through the Renewable Energy Independent Power Producers Procurement Programme (REIPPPP) which is a renewable energy competitive bidding mechanism, which commenced in 2011.
The success of the REIPPP, has seen the average prices of utility scale solar PV dropping by 83 % from R3.65/kWh in 2011 to R0.62/kWh in 2016. South Africa's electricity tarrifs have increased by more than 300 % from 2008 to 2016, and this has caused various energy consumers to implement energy efficiency measures and reduce their electricity costs where possible. It has also raised the need for various energy consumers to look at alternative energy supply options, one of them being solar PV for own electricity use.

1. INTRODUCTION

1.1 Embedded solar PV generation in South Africa

With grid connected electricity prices rising and set to increase in the next coming years, embedded generation is becoming more attractive. This refers to a set up where small scale power production facility is connected within the electricity distribution network located close to the load. For an embedded solar PV system; the facility generates power to supplement daily use without feeding excess power back to the grid. As a result, embedded solar PV systems can reduce the electricity consumption of a consumer over a period of 20 to 30 years [2].

The procurement of PV assets generally involves a screening process where responses are evaluated based on scope, technical criteria, energy output and the financial offer. With this evaluation criteria, the bidders would only offer the lowest Engineering, Procurement and Construction (EPC) price and the performance of the solar PV plant is not guaranteed.

The tender for EPC contracts usually used to procure any asset for public entities is done through the following steps:

(i) Screening: to check the completeness of the submission;
(ii) Functionality: to evaluate the fulfilment of minimum technical requirements;
(iii) Price & Broad-Based Black Economic Empowerment (BBBEE).

For PV assets the cost of a PV system may be calculated in 2 different ways:

1) Total system cost (equipment + labour cost) in Rands
2) Total cost of a system in "Rands per watt" (the product of the system cost & size of the system

If you use option 1 for procuring PV assets the way you purchase other equipment it will be problematic. You might end up with less quality system which is cheaper in the beginning, however, you might lose on aggregate during the life time of the equipment. It is, therefore, necessary to use option 2. This option considers the Levelised Cost of Electricity (LCOE) which is a unit cost of generating electricity over the lifetime of the solar PV plant. The LCOE reflects all the costs required build and operate the solar PV plant over its economic life, normalised over the total net electricity generated.

1.2 LCOE for embedded generation

The CSIR has developed a PV procurement model that focuses at levelised cost of electricity (LCOE) from the PV plant. The LCOE approach considers a lifetime view of the solar PV asset and guarantees the performance and cost of the plant. This procurement model was successfully implemented in the procurement of the CSIR's PV assets (ground-mounted single-axis tracker, followed by a rooftop and a dual-axis tracker) at the Pretoria campus. A good quality system with very competitive LCOE was achieved for all 3 facilities onsite.
The LCOE, measured in R/kWh, of solar PV is expected to further decrease as the technology becomes more accessible. As a result, consumers are taking the next step after implementing energy efficiency measures, they are looking at solar PV as a means to supplement their energy consumption and reduce their electricity bill.

2. METHODOLOGY

The main objective of using the LCOE approach is to provide the best value on risk-adjusted, lowest lifetime cost basis [1]. The methodology developed by the CSIR for the procurement of solar PV assets allows for the evaluation of the proposals in an EPC contract based on the LCOE of the PV asset throughout its lifetime. This includes a control loop to ensure that the LCOE promised by the contractor is delivered.
The motivation behind this approach is that, where the procurement of a PV asset is based on the EPC price, it can lead in tenderers offering only the minimum required

installed capacity (kWp) with minimum quality (low energy output and poor equipment quality). This is because improving the quality and energy performance of the system is likely to lead to an increase in the EPC price and lower the chance of winning the tender.

The results presented in this paper were based on measurements which were taken from the single axis tracker solar power plant onsite. The energy and cost savings assessments were compiled using the data from the incomer at the CSIR which the City of Tshwane uses to bill the CSIR for their energy consumption. All the solar PV plants at the CSIR where procured using this cost efficient procurement approach.

3. RESULTS AND DISCUSSION

There are several acts, standards, grid codes and guidelines in place which apply when installing a solar PV facility for embedded generation. Small scale embedded generation in South Africa is limited to 1 MW [2] [3]. The CSIR has installed 3 solar PV plants onsite. The next table shows information for each of these.

Table 1: Solar PV plants installed at the CSIR Pretoria campus

Technology	Installed Capacity	Annual energy output[1]	Avoided CO_2 emissions
Single axis tracker	558 kWp	1 170 000 kWh	1 150 tons
Dual axis tracker	203 kWp	600 000 kWh	618 tons
Fixed rooftop	250 kWp	398 000 kWh	409 940 tons

All the plants provide energy needs for the Pretoria campus and there's no excess is sent back to the electricity grid. The avoided CO_2 emissions are based on Eskom's emission factor for 2015/2016 financial year on 1.03 ton CO_2 (eq)/MWh [4].

3.1 LCOE achieved for each of the solar PV plants

The next table and figure shows the LCOE achieved for all the solar PV facilities that are currently installed and the REIPPP prices achieved during each of the bidding windows respectively. The prices have all been adjusted to April 2017 to account for inflation throughout the years.

Table 2: LCOE achieved for each of the solar PV plants at the CSIR's Pretoria campus

Plant	LCOE achieved
558 kWp single axis tracker	0.88 R/kWh
203 kWp dual axis tracker	1.00 R/kWh
250 kWp Fixed rooftop	0.87 R/kWh

It should be noted that the LCOE achieved for each of the solar PV plants is lower than the electricity tarrifs during the CSIR's operating hours which fall within peak and standard rates (see City of Tshwane tarrifs in the next sections) during the week. During weekends, off peak tarrifs apply but energy consumption is lower compared to weekdays.

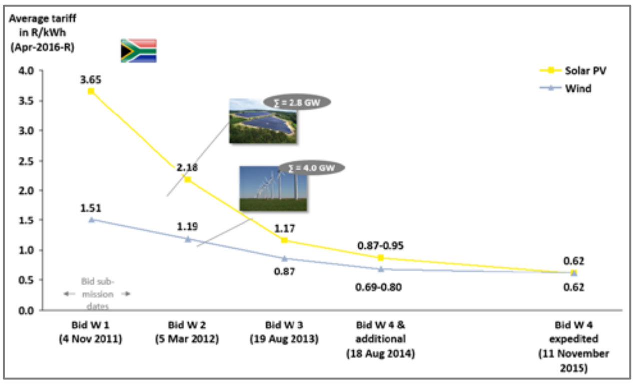

Figure 1: Bid windows for the Department of Energy's REIPPP [5]

This figure shows that the price of renewable energy technologies (solar and wind) have been dropping with each bidding window. The prices listed here are for utility scale plants and should not be compared with

3.2 Focus on the single axis tracker plant

The single axis tracker has been producing electricity since it was commissioned in October 2015, all the data related to the energy output and performance of this plant has been collected and forms part of the research that the CSIR is continuously conducting.

Quantified energy and cost savings

The figure below shows the energy and cost savings from the 558 kWp single axis plant for a period of 18 months during the operation and maintenance (O&M) period.

[1] This is the expected annual energy for a system calculated from the system size and the energy yield.

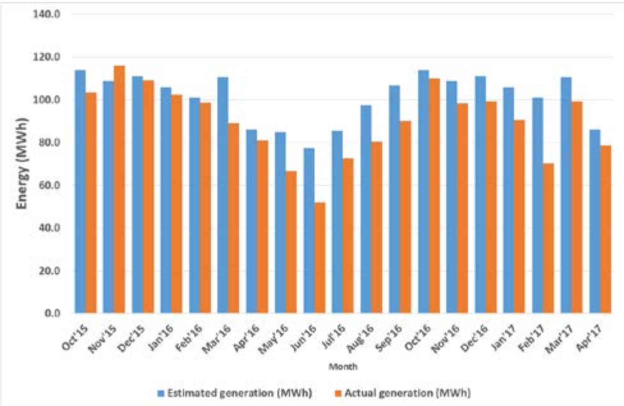

Figure 2: Energy output from the single axis tracker solar PV plant

The figure above shows the energy output from the solar PV and compares this output with the estimated energy output during the design stages. This figure shows that the estimated generation is relatively close to the actual generation. The slight differences could be due to factors such as soiling and unpredicted cloud cover.

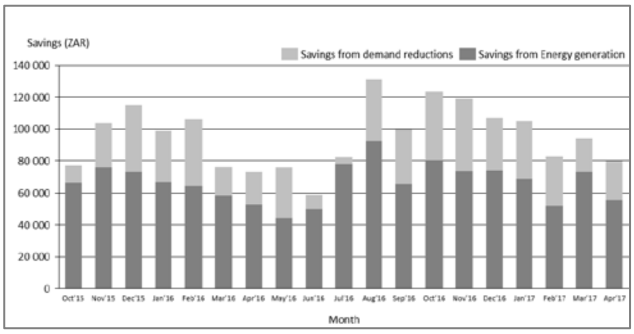

Figure 3: Cost savings for the single axis tracker plant

Prosumers (electricity users who generate electricity for own consumption without selling power back to the grid) tend to focus on how the PV assets will save them money on their electricity bill but these energy savings are usually calculated by the contractor when they are building a business case for the client there is no follow up on the actual energy savings when the plant starts operating. The general perception is that installing by solar PV asset onsite, they will be totally off the grid. Without proper planning and quantifying the performance of the solar PV plant this does not generally happen. The prosumer needs to monitor the energy savings in order to understand the full value of having the PV asset. This section shows the importance of quantifying the actual energy and cost savings in order to see the benefit of installing a solar PV facility onsite.

Ring fence financial savings

The energy savings which result from the solar PV facilities onsite have been ring-fenced to ensure that the cost savings are used to pay off the solar PV asset and refinance other electricity generating assets on the campus. These savings can also be used to finance energy efficiency initiatives.

The solar PV plants are owned by the CSIR and there is no power purchase agreement with an independent power producer in place. Within the CSIR, the solar PV plants are owned and managed by the Energy Centre which is one of the operating units at the research council. The next figure shows the electricity supply set up before the solar PV plants were installed.

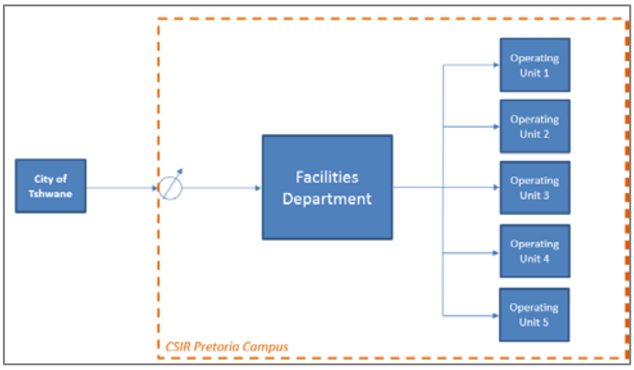

Figure 4: Electricity supply before solar PV installation

Before the solar PV plants were installed, the CSIR received a utility bill from the City of Tshwane which supplies electricity to the campus. The bill is managed and paid by the facilities department at the CSIR which is responsible for the upkeep and maintenance of the whole campus. Facilities department has installed electricity meters on each building for all the operating units at the campus. They use the monthly metered energy data for each of the operating units to bill them for their energy consumption. They compile this information to ensure that the money collected from each of the operating unit corresponds with the electricity bill that they received from the municipality.

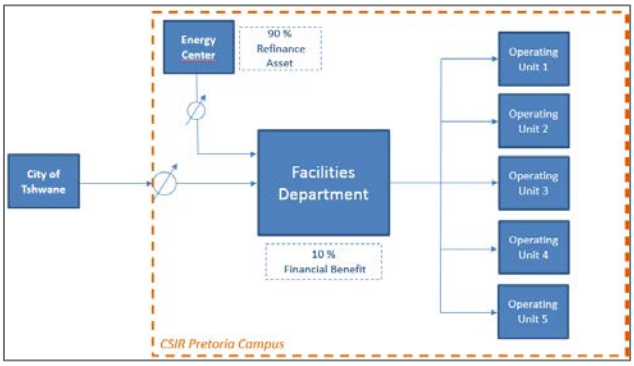

Figure 5: Electricity supply after solar PV installation

The figure above shows the electricity supply set up after the CSIR installed the solar PV plants. It shows that instead of relying on the municipality for their energy supply, the CSIR also generates their own electricity at the Energy Centre and the off taker of this electricity is facilities department. As an incentive, the Energy Centre only charges facilities department 90 % of what they were paying to City of Tshwane. The 10 % cost saving can be used to upgrade infrastructure on the campus and facilitate the implementation of energy efficiency measures, which will further reduce electricity costs for the CSIR. The Energy Centre which is the custodian of the solar PV plants ringfences the "revenue" generated from facilities to pay off the capital investment and refinance the solar PV asset.

The table below shows the tarrifs from City of Tshwane as show on their tariff book. The time of use tarrifs are shade in green (off-peak), red (peak) and yellow (standard). The peak period tariff is the most expensive, followed by the standard tariff and the off-peak tariff is the cheapest.

City of Tshwane's Energy Charge in R/kWh
Tariff week in high-demand season (July & August 2016, June 2017)

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Sunday	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58
Monday	0.58	0.58	0.58	0.58	0.58	0.58	3.11	3.11	3.11	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	3.11	3.11	1.07	1.07	1.07	0.58	0.58
Tuesday	0.58	0.58	0.58	0.58	0.58	0.58	3.11	3.11	3.11	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	3.11	3.11	1.07	1.07	1.07	0.58	0.58
Wednesday	0.58	0.58	0.58	0.58	0.58	0.58	3.11	3.11	3.11	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	3.11	3.11	1.07	1.07	1.07	0.58	0.58
Thursday	0.58	0.58	0.58	0.58	0.58	0.58	3.11	3.11	3.11	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	3.11	3.11	1.07	1.07	1.07	0.58	0.58
Friday	0.58	0.58	0.58	0.58	0.58	0.58	3.11	3.11	3.11	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	3.11	3.11	1.07	1.07	1.07	0.58	0.58
Saturday	0.58	0.58	0.58	0.58	0.58	0.58	0.58	1.07	1.07	1.07	1.07	1.07	0.58	0.58	0.58	0.58	0.58	0.58	1.07	1.07	0.58	0.58	0.58	0.58

City of Tshwane's Energy Charge in R/kWh
Tariff week in low-demand season (September 2016 --> May 2017)

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Sunday	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Monday	0.50	0.50	0.50	0.50	0.50	0.50	0.70	1.15	1.15	1.15	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	1.15	1.15	0.70	0.70	0.50	0.50
Tuesday	0.50	0.50	0.50	0.50	0.50	0.50	0.70	1.15	1.15	1.15	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	1.15	1.15	0.70	0.70	0.50	0.50
Wednesday	0.50	0.50	0.50	0.50	0.50	0.50	0.70	1.15	1.15	1.15	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	1.15	1.15	0.70	0.70	0.50	0.50
Thursday	0.50	0.50	0.50	0.50	0.50	0.50	0.70	1.15	1.15	1.15	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	1.15	1.15	0.70	0.70	0.50	0.50
Friday	0.50	0.50	0.50	0.50	0.50	0.50	0.70	1.15	1.15	1.15	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	1.15	1.15	0.70	0.70	0.50	0.50
Saturday	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.70	0.70	0.70	0.70	0.70	0.50	0.50	0.50	0.50	0.50	0.50	0.70	0.70	0.50	0.50	0.50	0.50

Figure 6: City of Tshwane tarrifs during high and low demand seasons

The solar PV plants generate electricity from sunrise to sunset, depending on the season in the year, this can range from 5am to 7pm in Pretoria. The City of Tshwane tarrifs show that during these periods, the peak and standard tarrifs are applicable during the week. The off-peak tariff is only applicable on Saturdays and Sundays.
The achieved LCOE for each of the 3 solar PV plants range from 0.87 to 1.00, these rates are lower than what is charged by the City of Tshwane during the high demand season. For the low demand season, the LCOE is only lower during the peak periods and electricity from the grid is cheaper during the standard period.

Plant performance during O&M period

The operation and maintenance (O&M) period for each of the plants is 3 years and during this period the contractor is responsible for ensuring that the Guaranteed Performance Ratio is met. The Guaranteed performance Ratio (GPR) given by the contractor was 102.4 %. The CSIR measures and calculates the performance ratio on a monthly basis, to monitor the performance of the plant. In an event where the PR is lower than the GPR during the O&M period, the contractor is made aware and given an opportunity to improve the performance ratio. During the first year of operation, the performance ratio achieved for this plant is 103 %, which is above the GPR. It should be noted that the contractor gets penalised for underperformance but there is no incentive for over-performance during the O&M period. This is because the contractor is the one who sets the GPR and they need to leave room for error which is not compensated.

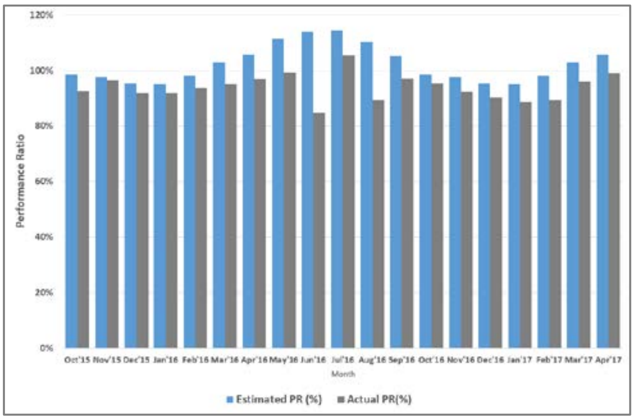

Figure 7: Comparison of estimated performance ratio with estimated performance ratio

Summarised results and highlights

Table 3: Actual benefits of the single axis tracker solar PV plant

Period	Energy (MWh)	Savings	Carbon emissions (ton)
Oct '15 - Sept '16	1 058	R 1 099 200	1 090
Oct '16 - April '17	646	R 712 302	665

The single axis tracker solar PV plant has reduced the total energy consumption from the electricity grid by 3.4 % and demand by 4.3 %. The total avoided carbon emissions since the plant started generating power is 1 755 tons.

The results presented in the paper show that the estimated and actual energy output, financial savings and the overall performance is slightly different from the projected values. This is because during the design states, historical data solar radiation was used to estimate the energy output. Other variables such as inflation and the municipality's tarrifs used to calculate the LCOE were also estimated.

4. CONCLUSION AND RECOMMENDATIONS

In conclusion please note the following summary:

- The CSIR successfully used the LCOE methodology to procure 3 of their solar PV facilities and obtained competitive LCOE for all 3 plants. The CSIR has published a guideline on *Cost-efficient procurement of photovoltaic assets* where this methodology is clearly outlined
- The Pretoria campus is billed by the City of Tshwane municipality on a time of use tariff, when comparing the cost of electricity from the grid with the achieved LCOE for each of the 3 solar PV plants, only the high season for peak and standard periods, as well as the low season during peak period are more expensive than the achieved LCOE.

- This methodology can be applied by consumers who are interested in procuring solar PV assets and owning their own asset instead of signing a power purchase agreement with an independent power producer.
- Embedded generators in the public sector can play an important role in climate change mitigation by successfully implementing/installing solar PV projects in a cost efficient. They can also increase the uptake of solar PV technologies and contribute towards localising the solar PV market and industrialisation.
- The capital cost for the solar PV plants per kW for each of the plants is R18 000 for the rooftop, R19 000 for the single axis tracker and R35 000 for the dual axis tracker plant. There plants have a minimum payback period of 11 years, after this period the electricity generated from the solar PV plants is free until the remaining lifetime of the installation of 25 years which was used as a basis for calculating the LCOE

Picture 1: CSIR's 558 kWp single axis tracker solar PV plant at noon

Picture 2: CSIR's of 203 kWp dual axis tracker plant

Picture 3: CSIR's of 250 kWp west facing rooftop plant

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