A Solar PV Procurement Method for Self-Consumption: Lessons Learned from a Commercial Installation at the CSIR…

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Abstract:

The Council for Scientific and Industrial Research (CSIR), an entity of the Department of Science and Innovation, is a national scientific council with headquarters in Pretoria, South Africa. The CSIR Pretoria campus owns and operates 2 MW of solar PV generators designed for self-consumption of the electricity, including fixed-tilt rooftop, single-axis tracking, and dual-axis tracking systems. A PV procurement method for the solar generators evolved with each new procurement project beginning in 2015, and the method has proven critical in ensuring long-term performance and risk-reduction for the investments. This article summarizes the key concepts embedded in the cost-efficient procurement method and shares lessons learned during the procurement and operation of a 558 kW PV system that began in 2015.

The PV procurement method developed by the CSIR includes three key concepts. First, the scope of work in the tender document includes the construction and the first three years of operations and maintenance. Second, the levelised cost of electricity (LCOE), not the construction price alone, determines the price ranking of bidders. Third, the winning bidder is contracted to deliver a guaranteed performance ratio (PR) at the end of the first three years of operations, otherwise face financial penalties. The net effect of these concepts provides incentives for the winning bidder to design and build a high-quality system that will deliver the predicted electricity generation at the lowest LCOE for the client. The CSIR developed and optimized this method over the course of several years and four projects. The details of the method will be published in an upcoming second edition for public and private entities to use a guideline.

This article presents lessons learned during the application of the PV procurement method during the procurement, construction, operation, and hand-over of the first PV plant installed at the CSIR. The first plant was a 558 kWp single-axis tracker PV system that cost R 10 750 000 in 2015 for the engineering, procurement, and construction. The plant has saved the CSIR over R 5.5 million in reduced electricity bills since commissioning. Despite the realized savings, actual electricity production fell short of the predicted production in the first five years by 12%. The decreased output led to an increase in the calculated LCOE. However, the CSIR was able to recover costs related to operations and maintenance (O&M) and restore the LCOE back to the contracted value by following the PV procurement method described in this article.

Keywords: Solar PV, PV procurement, LCOE, performance ratio, operations, maintenance

1. Introduction

Solar photovoltaic (PV) based electricity generation has increased rapidly across the world. By the end of 2020, global cumulative PV installations reached 707.5 gigawatts (GW) (IRENA, 2021). By 2022, experts predict annual installations between 100 GW and 232 GW globally, depending on the growth scenario (M. Schmela, 2018) with global installed capacity reaching 2 840 GW by 2030 (IRENA, 2019). The 2019 integrated resource plan (IRP) for South Africa plans for 8.3 gigawatts (GW) of utility-scale solar PV by 2030.

The rapid growth of grid-connected solar PV systems is largely attributable to the lower cost of electricity generated by new solar PV compared to new power plants based on other technologies. These lower costs have been driven by significant cost reductions in PV module prices, economies of scale, industrial production efficiencies and increased competition amongst project developers over the past ten (10) years. In the USA the National Renewable Energy Lab (NREL) tracks systems prices for residential, commercial, and utility scale systems. The inflation adjusted price per watt for commercial scale PV systems decreased from 5.43 USD/W in 2018 to 1.83 USD/W in 2018 marking a 66% reduction in price over 8 years (NREL, 2018). Overcoming the technical and legal challenges of connecting to electricity grids have also enabled low-cost electricity generation from variable renewable energy sources.

The Council for Scientific and Industrial Research (CSIR) became an early adopter of solar PV in 2015, investing in the first of four active PV plants. A method to guide the PV procurement process was designed along with the procurement projects to provide the best value for the CSIR on a risk-adjusted, least-lifetime cost basis. The CSIR implemented and improved the methods described in the guideline over the course of five years during the procurement of four separate PV projects at main campus in Pretoria. The PV procurement method provides a cost-efficient process for developing tender documents, evaluating bidders, monitoring the plant performance, and ensuring return on investment.

2. Background on the CSIR Energy Centre

The CSIR established an Energy Centre (EC) to focus research and innovation on challenges facing the national energy sector during the expansion of renewable energy-based power generation. The EC consists of several research groups focused on topics related to system modelling, energy supply and demand, energy efficiency, energy industry, energy storage, and developing a demonstration platform for energy related research. The research groups have implemented many energy related projects and capabilities on the CSIR campus, including a mini-IRP for the campus energy plan, electric vehicle demonstrations, energy efficiency studies, lighting retrofits, a thermal storage demonstration planned for the convention centre, a real-world outdoor testing facility for solar PV systems, an indoor performance and reliability lab for PV modules, battery materials research and development, and solar PV systems for self-consumption.

The EC established the Smart Utilities Program (SUP) in 2015 with the aim of creating the real-world research platform on campus by supplying energy from three primary energy sources: solar, wind, and biogas. The initial focus of the project was aimed at electricity supply for the campus, and the long-term goal is to demonstrate sector coupling of electricity with transport, hydrogen, and heating/cooling, as well as batteries and thermal storage. While wind and biogas have not progressed to the demonstration phase, solar PV has been deployed.

The SUP managed the procurement and commissioning of nearly 2 MW of solar PV under the program, as of January 2020. The solar PV generators include a 558 kW ground mounted system on single axis trackers, a 230 kW ground mounted system on dual axis trackers, and 1,164 kW of rooftop fixed-tilt systems installed on six (6) different rooftops. Total generation for 2019 from the existing PV plants was approximately 3,000,000 kilowatt-hours (kWh) of AC electricity, roughly 10 % of the CSIR Pretoria campus annual load in 2019 and 14 % of the annual load in 2020 which was reduced because of most staff working remotely during COVID-19 restrictions.

The SUP commissioned the first of four PV procurement projects in 2015. The PV system was installed on the north end of the Pretoria campus, just south of the N4 highway. The system was designed with single axis trackers that allow the PV modules to track the sun from sunrise to sunset which increases the output of the system compared to a fixed tilt system that does not track the sun. The PV system cost R 10 750 000 in 2015 for the engineering, procurement, and construction, and it has saved the CSIR over R 5.5 million in reduced electricity bills since commissioning.

3. The PV Procurement Method

Overview

Figure 1 summarizes the process followed during PV procurement. The PV procurement process was documented and revised over three PV procurement projects and now serves as a guideline to other public institutions, municipalities, and private companies interested in PV procurement for self-generation (Chiloane, 2017). The second edition of the PV procurement is due for publication in 2021.

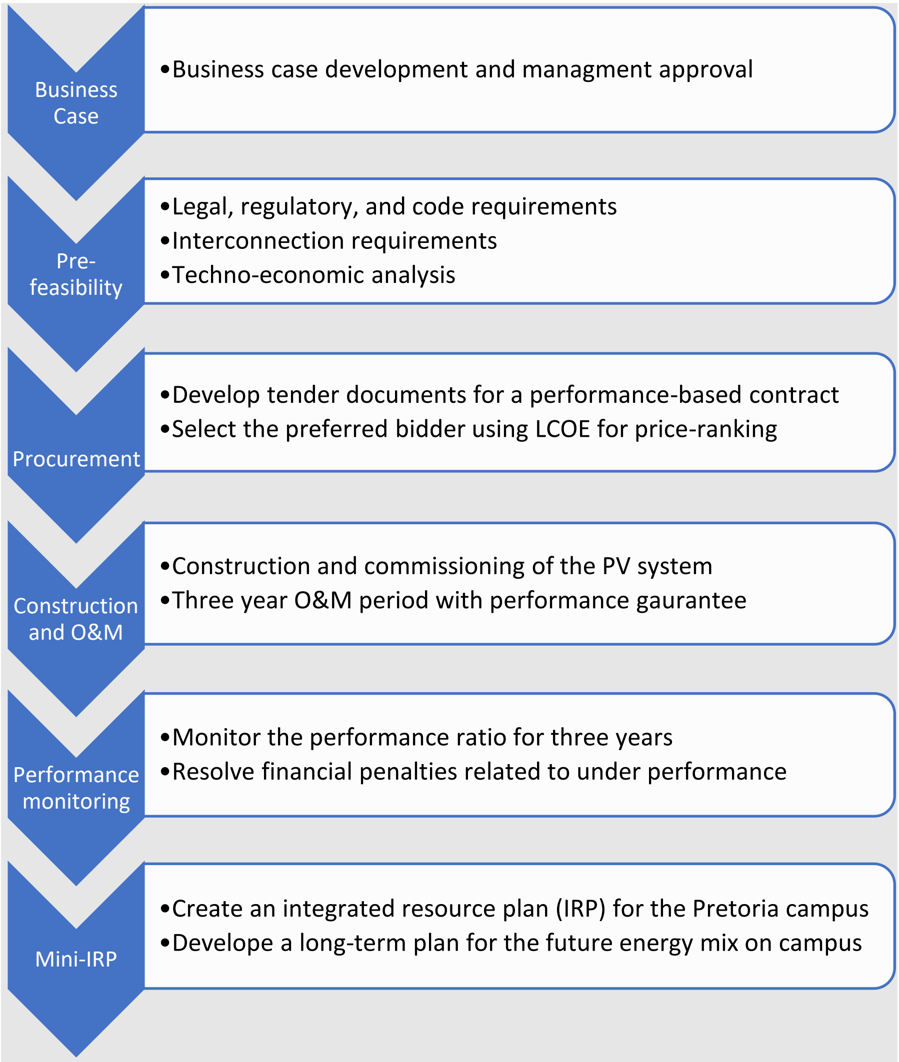

Figure 1 Process flow for PV procurement at the CSIR

Business Case Development

The business case proposal was an essential first step to secure management support and the finances needed to invest in the first PV system at the CSIR.

Pre-feasibility study

Following the business case approval, a pre-feasibility study was conducted to develop the high-level requirements for the PV procurement phase. The pre-feasibility focused on the following points:

1. Identify an installation location and system size given the specific location. The site may be rooftop or ground-mounted, depending on availability and suitability.
2. Determine the need for an environmental impact assessment (EIA) and generation permits. The requirements and permits depend on system size, location, and local authorities having jurisdiction.
3. Identify the interconnection points. The interconnection point between the new PV system and the existing electrical system must be assessed to identify necessary upgrades and associated costs.

4. Conduct a techno-economic analysis. A techno-economic analysis is needed to understand the impact of the new PV generation on the existing load, estimate the levelized cost of electricity, and determine the self-consumption rate during base and peak load periods.

Procurement

The PV procurement method followed the standard CSIR processes to ensure a fair and transparent process, as required by the Public Finance Management Act (PFMA). However, the PV procurement method included three additional clauses specific to PV systems:

1. Financial evaluation and price-ranking of tenders is based on a simplified estimate for the levelised cost of electricity (LCOE), not just the price for the capital expenditure (CAPEX). The simplified LCOE is the ratio of the net present value (NPV) of costs related to the EPC and O&M and the NPV of the value of the lifetime electricity production. In general, lower costs and higher production lead to lower LCOE, but a system with more expensive, high quality components can still be cost competitive if the system leads to higher lifetime electricity production.

$$LCOE = \frac{NPV(Life\ Cycle\ cost)}{NPV(Lifetime\ electricity\ production)}$$

2. The EPC company is held accountable for the first three years of (O&M). In response to the RfP, each bidder provides a guaranteed performance ratio (PR) that estimates the electricity production level during the first three relative to the measured solar resource. The annual PR is calculated as the ratio of the specific yield over the plane of array irradiance (POA), where the specific yield is the ratio of the AC electricity generation per kW of PV modules installed.

$$PR = \frac{\left(\frac{AC\ electricity\ produced\ over\ one\ year\ (kWh)}{DC\ capacity\ of\ the\ PV\ plant\ (kW)}\right)}{POA\ over\ one\ year\ (h)}$$

3. Financial penalties are imposed at the end of the O&M period if the EPC fails to deliver on the guaranteed PR. The financial penalties are included to motivate a good design, proper installation, and diligent O&M so that the PV plant will perform well over the 25-year lifetime. If the plant does not perform as expected, then the financial penalties effectively reduce the cost of the PV system so that the LCOE can be recovered.

The PV procurement method required a simple and transparent process to evaluate the LCOE submitted in the proposals. To facilitate the process, all the bidders were issued a Microsoft Excel-based ‘LCOE calculator’ with three main sections: inputs from the bidders and the client, pre-defined calculations based on the inputs, and outputs that include the estimated LCOE for price-ranking the bidders (Figure 2). The calculator does not provide a complete analysis for the business case, but rather provides a simplified means of comparing the LCOE estimates from multiple bidders under a consistent set of assumptions. This approach forces all the bidders to optimize their design towards lowest possible LCOE while ensuring highest quality to mee the guaranteed PR. The objective here is to provide the best value on risk-adjusted, least-lifetime-cost basis.

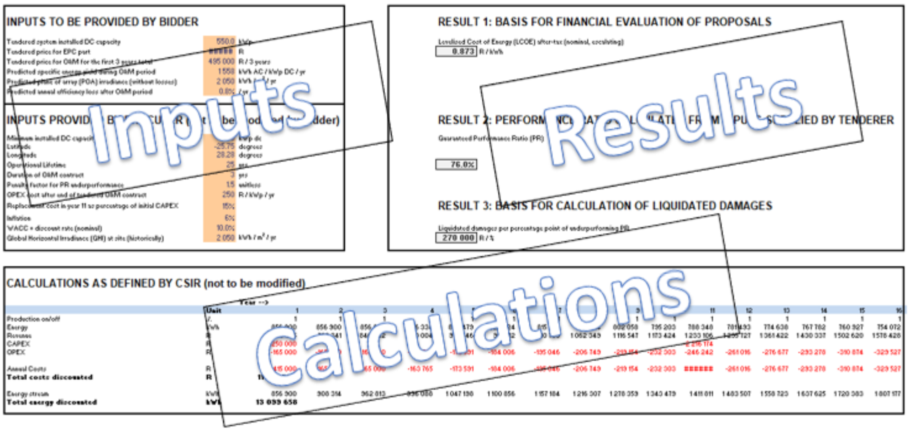

Figure 2: Microsoft Excel-based LCOE calculator user-interface in three sections

The LCOE calculator requires the following inputs from each bidder, unique to the proposed solution:

- Bid installed capacity (kW DC)
- Bid price (ZAR)
- Bid O&M price (ZAR / year)
- Predicted specific yield (kWh AC / kW DC / year)
- Predicted plane of array irradiance (kWh / m^2 / year)
- Predicted annual efficiency loss of the system

The LCOE calculator requires specific inputs from the client that are constant for all bidders. The inputs include the location of the PV plant, historical annual irradiance, expected operational lifetime, assumed inflation rate, and the nominal discount rate.

The bidder and client inputs are combined to compute the simplified LCOE, guaranteed performance ratio, and the financial penalty to be paid by the EPC for every percentage point shortfall in the guaranteed performance ratio. The winning bidder is then held accountable for the construction and performance of the system for the first three years, as documented in the LCOE calculator. The LCOE calculator and the detailed descriptions are included along with the upcoming PV Procurement Guideline.

Construction and O&M

The PV procurement process incentivises the EPC company to design and build a high-quality system that will deliver the predicted electricity generation at the lowest LCOE. The means and methods for the EPC and O&M are left to the EPC company, so even a system with higher CAPEX based on higher quality components can provide a lower LCOE compared with bidders using lower quality components.

Performance monitoring and liquidated damages

The EPC company was responsible for performance monitoring and meeting the guaranteed performance ratio during the first three years. The CSIR received regular reports regarding incidents, repairs, and overall performance to avoid surprises at the end of the O&M period.

When the PV system performs at the guaranteed performance levels during the first three years, the PV system is more likely to deliver the return on investment over 25 years.

The liquidated damages are an amount of money paid by the EPC to the client in case of under-performance during the first three years of operation. The total amount due is calculated based on the difference between the guaranteed performance ratio (GPR) as stipulated in the contract and the actual performance ratio (PR) over the first three years of operation. It is important to stress that the PR is used to assess the liquidated damages, while the LCOE is used for selecting the best price during procurement and assessing the return on investment. Thus, negotiated solutions over liquidated damages are challenging. The liquidated damages recover the LCOE, but they do not recover the PR which is solely based on the actual output, the nameplate rating of the plant, and the measured irradiance over the period.

Energy planning - CSIR IRP

Following the installation of the first PV plant, the CSIR developed a long-term energy plan for the campus. A systems-level approach utilizing long-term capacity expansion planning and optimisation incorporating all major cost drivers was pursued to validate the best energy mix for the CSIR Pretoria campus in the long-term. This is commonly referred to as an Integrated Resource Plan (IRP), and the CSIR Energy Centre completed a first iteration of this in 2018 and 2019 and more recently updated in 2020. The IRP was undertaken to determine the least-cost optimal energy mix of supply-side, demand-side and storage options within a set of boundary conditions and constraints whilst being augmented by other internal objectives (level of autonomy, decarbonisation, research mandate). A demand audit as well as resource assessment to determine the maximum amount of solar PV, wind, and biogas that could be installed on the CSIR Pretoria campus was also undertaken. The CSIR IRP was not a prerequisite for the first PV plant described in this case study because the peak output was less than 20% of the base load. However, the CSIR PV generation capacity is now 2 MW, so the IRP is key for integrating future energy efficiency programs, storage options, and other electricity generation plants.

4. Results

Business Case Development

The CSIR SUP developed the business case to secure management support and the finances needed for the first PV system at the CSIR. The business case was focused on the return on investment (ROI) considering the estimated costs for construction, O&M, and electricity production over 25 years.

Pre-feasibility study

Site selection

The CSIR identified a parcel of unused land at the north end of campus for the solar PV project. Some site preparation was required including tree removal, the removal of a small structure, and ground levelling. A topographical survey and geo-technical study for the land space was conducted and the results were provided to the bidders during the tender process.

Permits and licensing

The PV system was designed with environmental permit and licensing requirements in mind. According to the National Environmental Management Act No. 107 of 1998 (“NEMA”), major alterations to the natural environment should be subjected to (EIA) before a construction activity can commence. However, a land space of less than 1 hectare does not trigger an assessment. As per the Electricity Regulation Act (2006), Licensing Exemption and Registration Notice gazetted 26 March 2020, the following applies to PV systems connected to the grid irrespective of excess feed-in. PV systems with a capacity of no more than 100 kW are exempt from licensing and registration with NERSA. PV systems with a capacity of more than 100 kW but no more than 1000 kW are exempt from licensing but must be registered with the regulator. All PV systems with a capacity of more than 1000 kW (1 MW) need to obtain a generation license from NERSA before construction can start. Given these requirements, a 558 kW ground mounted tracking PV plant installed within one (1) hectare plot was planned.

Interconnection

The nearest electrical point of connection (PoC) for the 11 kV output was identified at a nearby building. The generator connection application requirements were discussed with Tshwane municipality, however, there were no guidelines to be followed by the municipality for connection to its network at the time. In addition, the CSIR main substation fell outside the City of Tshwane management since the campus is fed directly by a 132 kV line and manages its own low voltage (LV) reticulation network. Any issues arising within the reticulation network would be handled by the CSIR and pose not risk to the Tshwane municipality distribution network. Therefore, the CSIR went ahead with the decision to install the solar PV plant and inform the municipality.

Techno-economic analysis

The techno-economic analysis is key to developing the business case and setting expectations regarding the generation profiles and LCOE relative to the baseline case without the PV system. The Energy Centre now uses PVsyst (PVsyst, 2018) and the System Advisor Model (SAM) (NREL, 2020) software packages. However, this in-house capability did not exist in 2015, so the analysis was conducted by a third-party consultant. An Energy Centre analysis based on the original cost projections from the winning bidder was conducted in 2020 using SAM software. The model predicted an LCOE of R 0.92/kWh, lifetime AC electricity production of 25 582 938 kWh, and PR POA of 81% in the first year.

Procurement

The tender for EPC and O&M services was issued to the market in 2015. The scope of work included all the necessary design, procurement, construction, and interconnection phases to deliver a fully commissioned PV system to the CSIR at a fixed cost. The tender document included high-level requirements that specified a ground mounted single axis tracking PV solar system of at least 500 kW peak capacity. The PV facility was to occupy not more than 1 hectare of land and generate more than 1 GWh/year of electricity. The tender included a 36-month defect free period during which the EPC contractor would demonstrate PV plant performance at or above the guaranteed performance ratio specified in the contract, as calculated in the LCOE calculator. The means and methods for delivering the performance-based outcomes were left to the EPC.

The tender process was conducted per the CSIR procurement policies. All proposals were evaluated by a team for compliance, technical quality, price and B-BBEE. The first evaluation phase was based on a technical evaluation of each compliant bid according to a pre-defined scoring matrix that was included in the tender documents for fairness and transparency. The second evaluation phase was conducted on only those bids that met the minimum scoring criteria during the first phase. The second phase resulted in the price ranking of the LCOEs as calculated in the Excel spreadsheet for each bid. The LCOE for each bid was adjusted for B-BBEE status by a 90/10 weighing ratio to determine the least cost bid.

The winning bidder was selected based on a competitive LCOE of 0.84 ZAR-Cents for a 558 kWp single axis tracker PV system. An NEC3 contract was signed for the Engineering and Construction Contract (ECC) using option A (Priced Contract with Activity schedule). The CAPEX cost was R 10 750 000 and the OPEX cost was R 300 000 per year for the first three years. The predicted electricity generation was 1 159 900 kWh in year one and 26.2 million kWh over the 25-year lifetime. The guaranteed performance ratio based on the global horizontal irradiance (GHI) was 102.1%. The CSIR no longer uses the PR based on the GHI (PR GHI), but now follows the industry standard PR based on the plane of array irradiance (PR POA)

Construction, O&M, and monitoring

Figure 3 shows some examples of the PV systems on campus, including the single axis tracker plant taken in 2020. The single axis tracking PV plant has 1800 PV modules installed on an array of torque tubes that track with the sun over the course of each day. Twenty (20) PV modules are connected in series resulting in ninety (90) PV module strings that feed DC electricity to eight (8) inverters that feed AC electricity to the CSIR reticulation system through a 500 KVA transformer.

	
a) Ground mounted tracking systems	b) Rooftop fixed tilt system

Figure 3 a) Ground mounted tracking PV systems: the single axis tracker (foreground) and the dual axis tracker (background) and b) rooftop fixed tilt system on Building 22.

Jobs during and after construction

PV procurement creates economic benefits related to electricity cost savings and co-benefits such as job creation during the EPC and O&M phases of the projects. The job creation contributes towards a just energy transition as the country as a whole is moving away from non-renewable fossil fuel based technologies to renewable, low emission technologies.

The I-JEDI model jointly developed by the NREL and the CSIR provided an estimate for the number of jobs created during construction of the PV plant. The model estimated that 17 new jobs were needed during construction of the 558 kWp facility and 0.4 jobs will be needed over the lifetime of the plant. The actual number of jobs created was not validated during the design, procurement, and installation phases of the PV plant. The operations and maintenance require resources from the O&M contractor for regular monitoring, troubleshooting, fault-finding, cleaning, and vegetation control. The CSIR staff is also engaged with monthly billing, monitoring oversight, business case development for future projects, procurement support, and research on existing systems.

LCOE: Electricity generation trends

Figure 4 shows the cumulative electricity generation for the first five years of operation of the PV plant. The winning bidder predicted 5,735 MWh of electricity generation in the first five years, based on their performance model and the weather file provided by the CSIR. The actual generation only reached 5,069 MWh, or 88% of the predicted value. The third line shows the extrapolated production based on actual production during the first year and then degraded by the predicted 0.8% per year thereafter. The 0.8% annual degradation was also specified by winning bidder. The actual production and the extrapolated trends are nearly identical, suggesting the shortfall is related to production in the first few years. The actual electricity production failed to reach the predicted value in the first year alone based on several reasons. Faced with potential financial penalties for under-performance, the EPC engaged in a series of improvements to increase production in subsequent years, but still the overall production fell short of the original target after the first three years when the original O&M period ended. Accurate performance models for predicting electricity generation in the first year is critical to the project success, as the lifetime output of the PV plant and the LCOE are derived from the performance model.

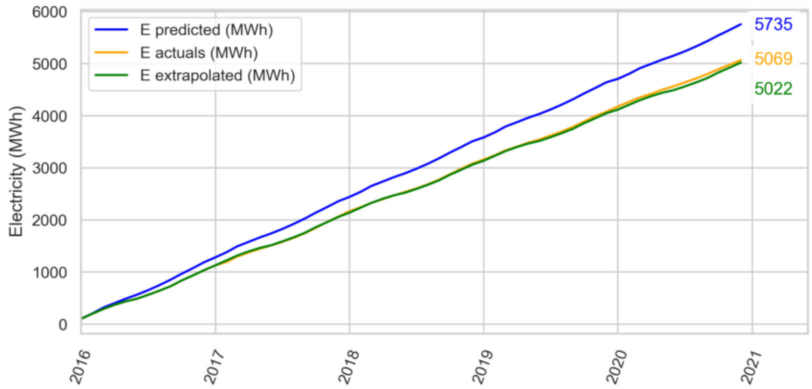

Figure 4 Cumulative electricity generation for actual, predicted, and extrapolated during the first five years where the extrapolated values were based on the actual production in the first year

Guaranteed performance ratio

Performance monitoring is critical over the lifetime of the PV plant as many faults can occur on PV plants (kWh analytics, 2019). The performance ratio (PR) is the preferred metric for monitoring PV plant performance because it normalizes the actual electricity generation by the amount of sunlight input to the PV generator as 'fuel'. Thus, small changes in available sunlight from one year to the next compared to the historical irradiance data assumed for the RfP do not impact the guaranteed PR. The PR based on the global horizontal irradiance (GHI) was used for contracting and monitoring in the beginning of the PV procurement program. However, the PR GHI has high seasonal variability, as shown in Figure 5. In 2017, CSIR began monitoring the PR based on the irradiance in the plane of array (POA) which shows less seasonal variability because the irradiance sensor is mounted in the same plane as the PV modules. When the irradiance sensor is mounted in the same plane as the PV modules, the geometric losses are the same for both the sensor and the modules which reduces the seasonal variability in the PR. Finally, the monthly PR POA with temperature correction is the most stable under normal operation because the electricity generation is normalized for both the irradiance and the temperature effects, the two biggest drivers of PV module performance under normal conditions (NREL, 2013).

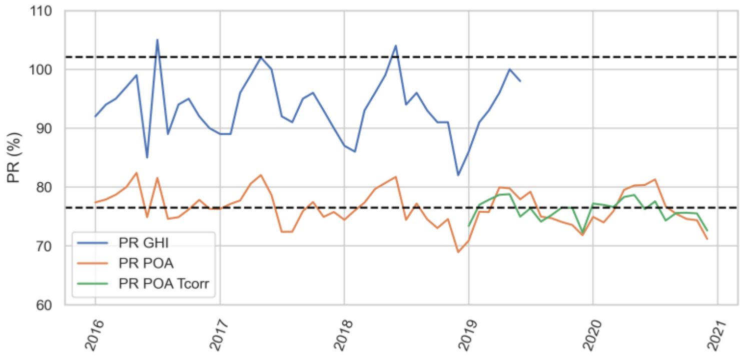

Figure 5 Performance monitoring based on monthly PR GHI (blue), PR POA (orange), and PR POA with temperature correction (green). The reference lines show the guaranteed PR GHI from the contract (102.1%) and the actual PR POA from 2020 (76.5%).

The guaranteed performance ratio (GPR) in the contract was based on the PR GHI, and the winning bidder guaranteed 102.1% during the first three years of O&M. Several factors impacted the plant performance during the O&M period, resulting in a PR GHI lower than guaranteed. The issues were related to various causes including sagging torque tubes, failures of the variable speed drive controlling one of the motors, vegetation control, soiling losses, relays in programmable logic controller (PLC) for the trackers, damaged drive beam rollers, lightning strikes, and the inverter manager system. The EPC contractor resolved the issues that arose during the initial O&M period at no additional cost to the CSIR in an effort to increase the PR to the level stipulated in the contract.

Liquidated damages

The liquidated damages for this project equated to approximately R 2 million at the end of the three-year O&M period. A straight cash payment would effectively reduce the CAPEX paid by the CSIR, reduce the overall cost of the project, and lower the LCOE while having no impact on the PR. However, both parties agreed to pursue a negotiated settlement based recovering the LCOE. Table 1 shows five scenarios with five different estimates for LCOE using two estimates for lifetime electricity generation, one based on the predictions in the original contract (scenario 1) and the other based on predictions given the first five years of actual production (scenario 2). Based on scenario 2, the extrapolated lifetime production estimates would lead to an LCOE significantly higher than contracted. In scenario 3, the R 2 million cash payment would have reduced the LCOE to R 0.733 R/kWh if the PV plant actual output matched the predicted output. Through negotiation, the EPC agreed to provide R 2 million in services (six years free OPEX) and spare parts totalling R 2 million at no cost to the CSIR, which reduced the NPV of the lifetime costs and resulted in an LCOE estimate of 0.76 R/kWh based on the predicted lifetime generation (scenario 4), well below the original contract value. In scenario 5, LCOE estimate is based on the negotiated costs and the predicted lifetime electricity production based on actual electricity production through 2020 and degraded by 0.8% year over year thereafter. This estimate provides a realistic estimate for the LCOE based on actual costs and actual electricity generation.

Table 1 LCOE estimates based on multiple scenarios including 1) as contracted, 2) as predicted at the end of the O&M period, 3) as contracted with penalty for liquidated damages, 4) as negotiated, and 5) 'actuals' based on reduced costs and revised estimates for lifetime electricity generation.

Scenario	Lifetime electricity generation (kWh)	O&M expenses (Rand)	Lifetime NPV(costs) (Rand)	Lifetime NPV(electricity) (Rand)	LCOE (R/kWh)
1. Contracted	26 241 578	900 k (3 yrs)	15 772 324	18 795 602	0.839
2. End of O&M	23 305 674	900 k (3 yrs)	15 772 324	16 671 647	0.946
3. With penalty	26 241 578	900 k (3 yrs)	13 772 324	18 795 602	0.733
4. Negotiated	26 241 578	0 (6 yrs)	14 330 729	18 795 602	0.762
5. Actual	23 305 674	0 (6 yrs)	14 330 729	16 671 647	0.860

Long-term O&M

Continuous monitoring and evaluation are critical for the long-term performance of the PV plant. Monitoring helps to identify under-performance due to soiling, vegetation control, lightning strikes, and other faults. Evaluation helps to understand the broader impacts of PV generators on the CSIR campus. Figure 6 shows the impact of the national lockdown on the load and generation profiles at the CSIR campus, for example. The generation profiles include the output from all the active PV plants and the City of Tshwane. The March 2020 weekly profile shows the typical baseload and peak loads when the campus is fully staffed, and the April 2020 weekly profile shows the baseload and peak loads under lockdown. The baseload decreased from 2500 kW to 1800 kW and the peak loads disappeared because staff was working from home. The global horizontal irradiance (GHI) profiles reflect normal weather patterns that are completely independent of the changes in load profiles due to the pandemic and resulting lockdown. The electricity generated by the solar PV was still completely self-consumed by the CSIR, even under a national lockdown scenario, however additional capacity may result in some back feed to the grid necessitating further planning.

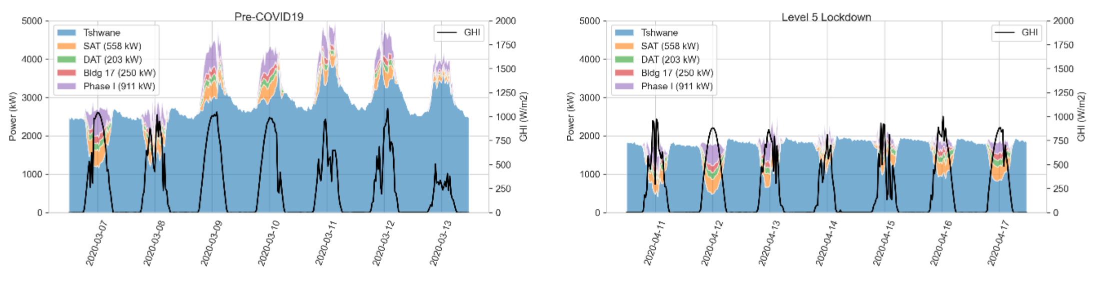

Figure 6 Weekly load and generation profiles for the CSIR Pretoria campus during normal operation and during the national lockdown resulting from the COVID19 pandemic

Energy planning

Energy planning is critical as the level of electricity from variable renewable sources increases. A range of modelling scenarios have repeatedly shown that investing in solar PV capacity is least-cost and least-regret for CSIR, i.e. all scenarios include solar PV regardless of sensitivities explored. This is in addition to energy-efficiency interventions. Up to 3 MW of solar PV for the CSIR campus was deemed least-cost optimal to invest in immediately and up to 4.6 MW by 2030. CSIR is already well on the way to this with 2 MW already installed by the end of 2020.

Various solar PV mounting configurations including fixed-tilt, single-axis tracking, dual-axis tracking were intentionally included as part of the planning and deployment of the existing 2 MW of PV installations. This was driven by the need for CSIR to further the research agenda that can be unlocked by having these installations on campus, though not always in line with the least-cost option. The CSIR energy planning also includes additional interventions like energy efficiency, battery storage, thermal storage, and the structured utilisation of backup diesel generators for avoidance of expensive time-of-use periods.

5. Lessons learned

The first PV procurement project for the CSIR began in 2015 and many lessons were learned along the way regarding, procurement, contracting, construction, operations, maintenance, and performance monitoring. Some of the key lessons learned include:

a) The LCOE calculator is effective for price-ranking tender proposals for PV systems by reducing the estimates for lifetime electricity cost to a single number.
b) The PV procurement method developed and followed by the CSIR is effective for de-risking investment in solar PV systems for self-consumption because the liquidated damages effectively reduce the up-front cost when under performance occurs.
c) PV plant performance is not assured, but the guaranteed performance clause in the contract put the burden on the contractor to ensure the financial investment is protected regardless of the issues that may arise in any given project.
d) Liquidated damages paid at the end of the O&M period restored the original LCOE on which the business proposal was based.
e) Continuous monitoring is critical to the success of a PV system, and the temperature corrected PR is effective at minimizing the seasonal variability due to changes in irradiance and temperature.
f) All energy modelling scenarios conducted for the CSIR include solar PV in the future energy mix, including the scenario for least cost.

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