Innovative Optimally Combined Solar Forecasts

END OF PROJECT REPORT

Project Details

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EXECUTIVE SUMMARY

This is the End of Project Report from the ARENA funded Innovative Optimally Combined Solar Forecasts Project. As part of this project, Proa has demonstrated the ability of the Proa Forecasting System (PFS) to provide self-forecasts at three solar farms in the main climate zones of the NEM:

- Tropical: Kidston Solar Project (QLD) in partnership with Genex Power,
- Sub-tropical: Oakey 1 Solar Farm (QLD) in partnership with Oakey 1 Asset Company,
- Temperate: Bannerton Solar Project (VIC) in partnership with Foresight Australia.

The PFS combines four individual solar forecasting techniques — live data techniques, geostationary satellite cloud motion vectoring (CMV) algorithms, skycam CMV and Numerical Weather Prediction (NWP) models — to produce optimal forecasts at varying forecast horizons.

First, this Report shares relevant insights on the three main project outcomes:

- Outcome No. 1: A combination of forecasting technologies is required to provide the best forecasting performance by harnessing the advantages of each technology across a variety of weather patterns.
- Outcome No. 2: Skycams provide a significant benefit in reducing forecasting errors in high variability conditions, provided that the instruments are properly maintained and operated.
- Outcome No. 3: Self-forecasts present a solid Net Present Value (NPV), with benefits significantly outweighing their cost, which allows for their wide implementation across solar and wind farms in the NEM.

Second, the Report provides a cost-benefit analysis to determine the most affordable and fit-for-purpose combination of forecasting technologies for solar-PV farms. The best combination is a function of the solar farm size, climate zone and the market region in which it operates. For this analysis, Proa used forecast data from the project, capital and operational costs of the different technologies, and baseline Regulation FCAS costs. The Report concludes that the combination of live data + satellite + skycams provided the greatest forecasting accuracy improvements 5 minutes ahead. Despite the increased capex and opex costs required to integrate skycams into the forecasts, the combination which includes this hardware provides the highest return based on current FCAS prices.

Finally, the Report discusses the consequences for future projects and areas for future development based on the lessons learnt in the Project.

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1 PROJECT OUTCOMES

Outcome No. 1: A combination of forecasting technologies is required to provide the best forecasting performance by harnessing the advantages of each technology across a variety of weather patterns.

Category: Technical

Proa has compared the performance of three main forecasting approaches:

- Persistence
- SCADA live data + satellite data
- SCADA live data + satellite data + skycam data

The results are presented in Figure 1, for both temperate (representative of the weather patterns in SA, VIC and parts of NSW) and tropical & sub-tropical climates (QLD and parts of NSW). The results show that the absolute errors were significantly higher for solar farms in tropical/sub-tropical climates.

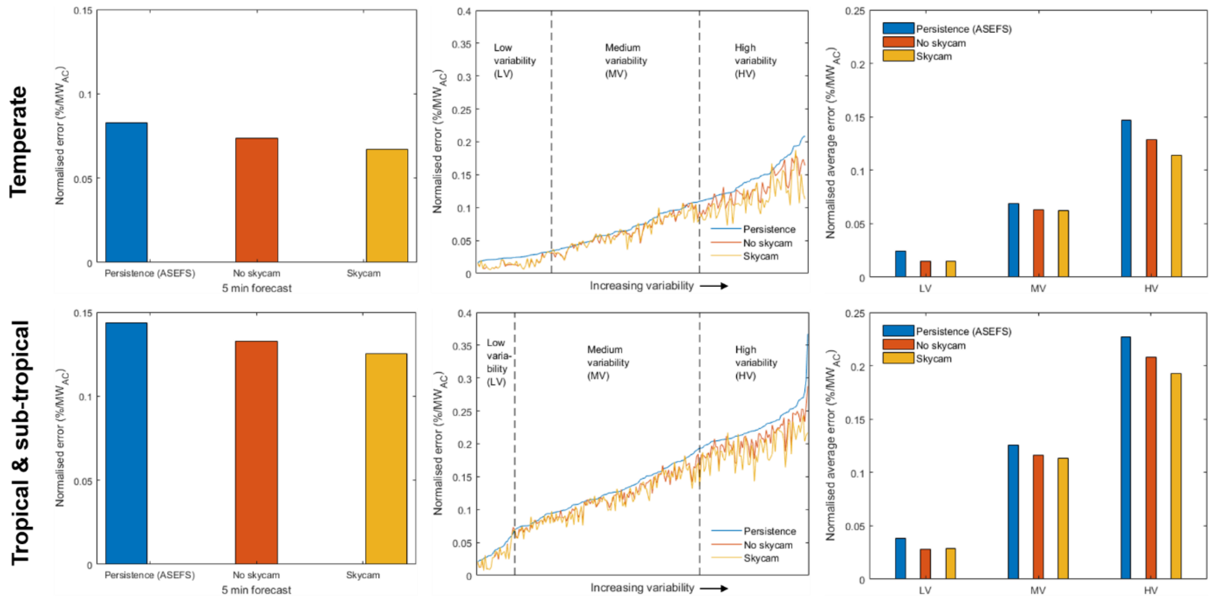


Figure 1. Forecast error comparison for different forecast technology combinations at solar farms in temperate (top row) and tropical & sub-tropical (bottom row) climates. (left column) 5 minutes ahead forecast error normalised to the capacity of the site. (middle column) Normalised error on each day in the period, with days ordered by increasing variability. The dashed lines indicate domains of days with low, medium, and high variability. (right column) Normalised error averaged over the days in each of the variability domains.

The left column shows the 5 minutes ahead forecast error over a half year period between July 2020 and Feb 2021. The satellite provides a moderate improvement over the SCADA based persistence methods, reducing errors by 7-11%. Including the skycam in the forecast results in a substantial 15-20% reduction in errors relative to the persistence forecast.

A more granular analysis shows the daily forecast errors (middle column), where days are ordered by increasing variability. These can then be divided into three broad domains, with errors shown in the right column:

- Low variability – small errors – typified by clear or overcast conditions.
- Medium variability – moderate errors – typified by uneven cloud cover with smooth edges.

- High variability – large errors – typified by small, dense, and rapidly evolving clouds.

For low variability conditions, forecasting errors could be reduced by 30-40% on clear days by correcting the forecasts for the morning and evening ramps. These are days with an absence of clouds, and therefore no benefit to using satellite or skycam imagery. On completely overcast days, these additional data sources only allowed for minor accuracy improvements over persistence models at short 5-minute time scales.

For medium variability days, the skycams and satellite provide a 10% and 8% improvement on the persistence forecasts, respectively. The cloud dynamics on medium variability days tend to cause relatively slower ramps in the generation which are well-handled by persistence models, and for which the resolution and update-time limitations of satellite imagery is less apparent.

For high variability days, when forecasting errors are largest, forecasts utilising skycams have substantial performance benefits, demonstrating a 20-25% improvement over the persistence forecasts, while the satellite shows an 8-12% improvement. On days of high variability, the increased resolution and reduced update time of skycam imagery improves the tracking of small, rapidly evolving clouds, thereby improving forecasting of the sharp ramps in generation caused by such clouds.

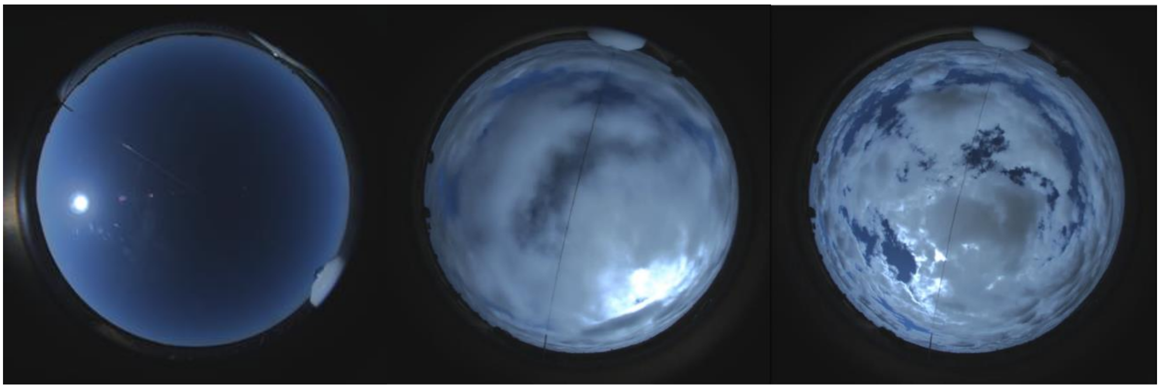


Figure 2. Images taken by Proa's skycams at NEM solar farms. Examples of a low variability clear day (left); a medium variability day (middle); and a high variability day (right).

Outcome No. 2: Skycam-based algorithms provide a significant benefit to reducing forecasting errors, provided a robust design and proper maintenance and operation of the instruments.

Category: Technical

The results presented in Outcome No. 1 of the report show that skycams can provide significant benefits to reducing forecasting errors 5 minutes ahead, particularly on days of high variability. These results were contingent on a robust design, and proper maintenance and operation of the skycam systems. Three learnings are detailed below.

First, skycams must withstand long-term exposure to inclement weather at solar farms located across the diverse and at times challenging climate zones of Australia. This requires the robust design of instruments and mountings to avoid any degradation in image quality or the sensitive alignment of the instrument. Proa's equipment has demonstrated its robustness in the full range of climates; from hot, wet, and humid north Queensland to the extreme temperature variability of north west Victoria.

Second, the proper operation and maintenance of the skycams is essential in extracting value from them. This project showed that remote monitoring of the operational status of the instruments is important when prompt, manual intervention from site staff was required (e.g. to clean the lenses after a soiling event or to ensure the supply of power). Soiling was identified as a major impediment to accurate skycam forecasts.

Third, ideally skycams would be cleaned on a daily or weekly basis, but due to personnel availability, cost, and sometimes difficult access to the instruments (e.g. installations at significant heights), this is not feasible. Proa has designed, installed, and tested an innovative automatic self-cleaning system able to periodically clean the lenses of skycams with pressurised water. These units were installed at two of the participating sites and have demonstrated success in removing atmospheric contaminants, such as dust, rain mud or others. Footprint traces or droppings from birds would however still require manual cleaning. The key lessons learnt for future projects have been:

- Automatic cleaning of instrumentation can significantly reduce O&M costs and increase the value of skycams.
- Cleaning of atmospheric contaminants using pressurised water is achievable, significantly reducing the impact of soiling on the instruments.
- Mechanisms to minimise the impact of footprint traces or droppings from birds are still required for the fully autonomous operation of the cleaning system.

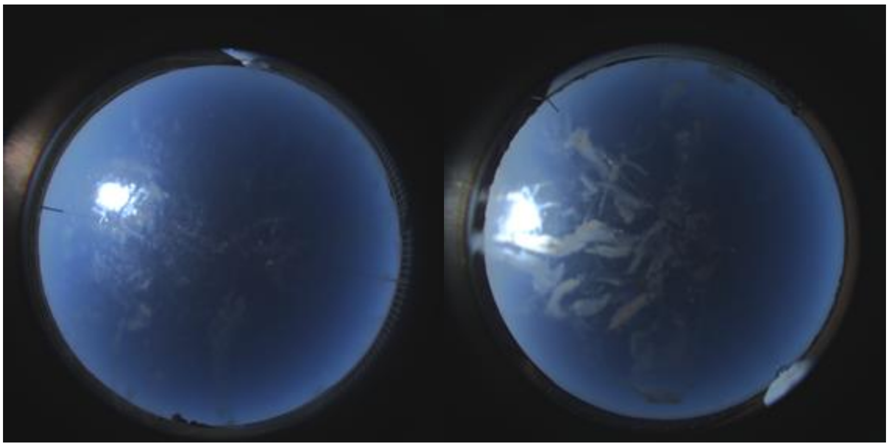


Figure 3. Example of cloud image from clean skycam lens (left) and dirty lens (right).

Outcome No. 3: Self-forecasts present a solid Net Present Value (NPV), with benefits significantly outweighing their cost, which allows for their wide implementation across solar and wind farms in the NEM.

Category: Commercial

The project has demonstrated that self-forecasts have significant financial benefits for the semi-scheduled generators in the NEM. These benefits can be derived from:

- Avoided 'causer pay' Regulation Frequency Control Ancillary Services (FCAS) charges.
- Incremental revenue from the energy market.

The latter has been found to be a marginal benefit compared to the avoided FCAS costs. FCAS costs for solar farms without self-forecasting in place were found to average around $1M/100 MW/year in 2019 and $650k/100 MW/year in 2020. Reducing these charges constitutes the cornerstone of the business case for self-forecasting in the NEM.

Proa has developed and validated a replicate of the Causer Pays Procedure, based on publicly available data. This model is used to calculate the MPF for a participant by optimising self-forecasts based on market factors. Under current market conditions, these corrections have a greater impact on MPF than forecasting accuracy and have allowed Proa to reduce the MPF of participants to as little as zero. Early adopters of self-forecasting are taking advantage of this opportunity, though the benefit is likely to diminish as the market matures.

Taking the 2020 FCAS charges as the baseline, an indication of the NPV of adopting Proa's self-forecasts under the current market conditions for solar farms ranging between 30 and 240 MW is provided in Figure 5. Further details about this analysis is provided in Section 4 of this report.

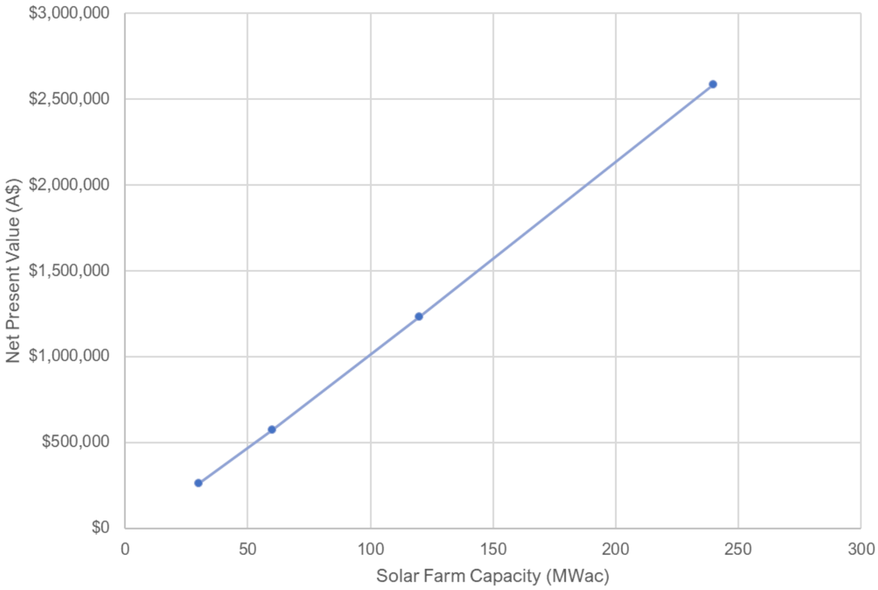


Figure 4. Net Present Value (NPV) of self-forecasts using skycams in the current market conditions.

2 CAPEX AND OPEX COSTS OF FORECASTING TECHNOLOGIES

Proa has built a mature commercial offering based on the technology and services developed during the life of the Project. This has provided a good understanding of the commercial costs of each forecast technology. It was found that the capex and opex costs of these services change as a function of the size of the site. These cost categories are described below in relation to self-forecasting.

- CAPEX. The capital expenditure covers the costs of the equipment, testing, freight, handling, installation, SCADA integration and forecast commissioning. The installation of skycams has a significant weight on the capex. Larger sites require a greater number of skycams to maintain the same level of forecast accuracy. The capex is significantly reduced if skycams are not used in the provision of forecasting services.
- OPEX. The operational expenditure covers the costs of labour required to monitor and maintain the forecasting service, data services, computing costs and license maintenance, among others. Ongoing costs are reduced by approximately 10-20% when skycams are not used.

Figure 5 and 6 provide a breakdown of the capex and opex costs of self-forecasts with and without skycams. The cost of the equipment, testing and installation of skycams represents around 40% of the total cost over a 3-year period and 20% over the design life of the instruments. When skycams are not included, the contribution of capex to the total cost is reduced to 3-5%. These proportions remain relatively constant across solar farm sizes, as more skycams are required for larger sites.

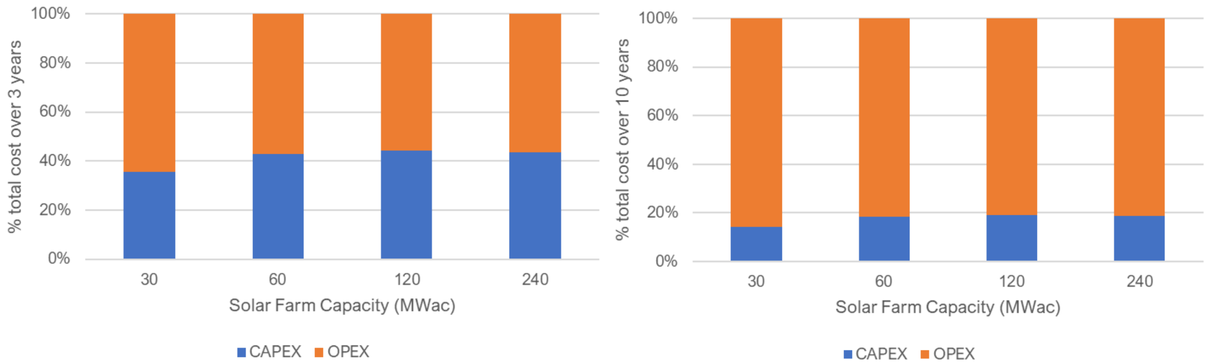


Figure 5. Capex and opex breakdown of self-forecasts using skycams for solar farms ranging between 30 and 240 MW.

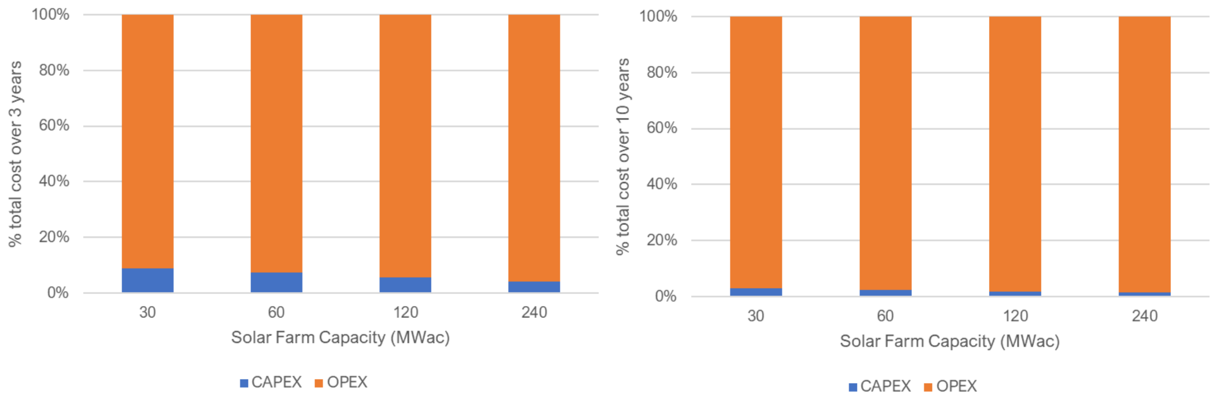


Figure 6. Capex and opex breakdown of self-forecasts not using skycams for solar farms ranging between 30 and 240 MW.

3 FINANCIAL BENEFITS OF SELF-FORECASTING

Self-forecasting has significant financial benefits for semi-scheduled generators. A more efficient dispatch trajectory enables generators to increase their dispatch revenue from the energy market and reduce their 'causer pays' charges for Regulation FCAS services. These two benefits are analysed below:

- Incremental revenue from the energy market. The electricity export of a semi-scheduled generator is limited to its dispatch target (usually set by the participant's self-forecast or ASEFS) when the semi-dispatch flag is raised. Persistence based models will cause generators to be constrained during ramp up events that coincide with the dispatch flag being raised. In the case of solar farms, this can occur during the morning ramp up or when clouds move away from the site.
  The incremental revenue from the energy market was analysed for the solar farms participating in the Project. The results showed only a marginal benefit for solar farms where the semi-dispatch is raised for extended periods of time, and no benefit for solar farms in more robust parts of the grid where the semi-dispatch cap is not frequently raised.
- Reduction in FCAS 'Causer Pays' Charges. The main financial benefit for semi-scheduled generators are the avoided costs from 'causer pay' FCAS. Figure 7 shows the overall cost of Regulation Raise and Lower services in the NEM for the period 2016-2020. The costs in 2019 were significantly higher than other years. Comparatively, 2020 saw a strong decline in FCAS

costs due to the adoption of self-forecasting by a majority of solar and wind farms in the NEM and the commissioning of several BESS and other projects providing regulation services.
In Figure 8 and 9 the Causer Pays FCAS costs for solar farms are analysed for the period 2019 and 2020. In 2019, most solar farms had not yet adopted self-forecasting, while in 2020 a significant share implemented self-forecasting in their operations. The annual costs were estimated at $1M / year / 100MW in 2019, coming down to $650k / year / 100MW in 2020, for solar farms without self-forecasting in place. The costs from 2020 were used as the reference in calculating the avoided costs that are achievable using self-forecasts.

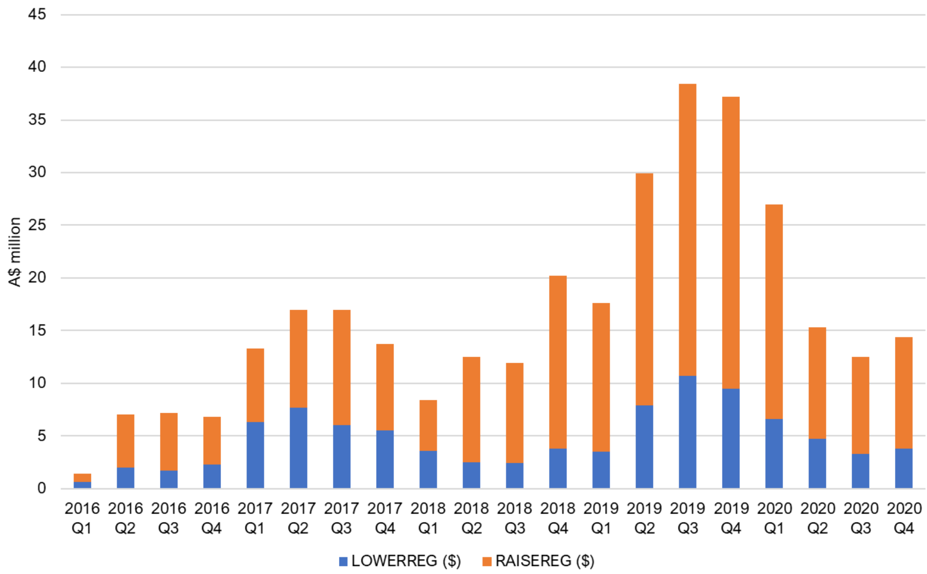


Figure 7. Overall Regulation FCAS costs for years 2016-2020. Source: Australian Energy Regulator.

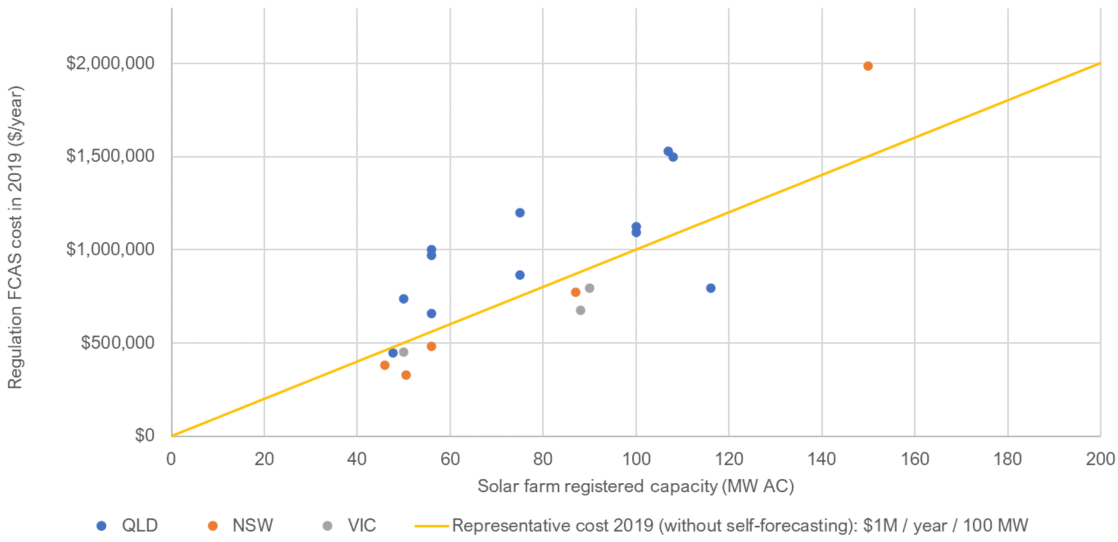


Figure 8. Regulation FCAS costs ($/year) for NEM Semi-Scheduled Solar Farms in 2019. Most solar farms had not adopted self-forecasts yet. Costs scale with solar farm capacity. Source: Proa analysis of AEMO data.

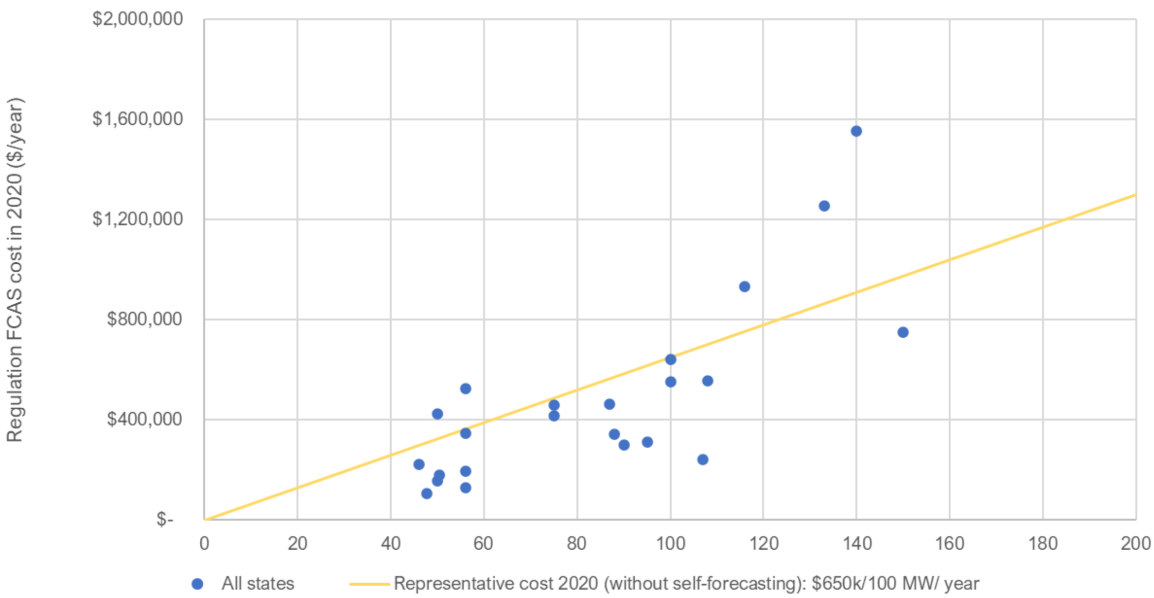


Figure 9. Causer Pays FCAS costs ($/year) for NEM Semi-Scheduled Solar Farms for period in 2020. Most solar farms have adopted self-forecasting. Source: Proa analysis of AEMO data.

Proa has been able to reduce the Market Participant Factor for participating solar farms to zero during some periods. In the current market conditions, artificial corrections to self-forecasts to designed to minimise MPF have a greater influence on the reduction of MPFs than forecasting accuracy. However, this situation is likely to reverse as more participants introduce such corrections, and MPF reductions will depend increasingly on forecast accuracy. Based on this, we define two scenarios:

- short-term FCAS cost reductions: 70-100% reduction.
- long-term FCAS cost reductions which rely mostly on forecasting accuracy: 20-30% reduction.

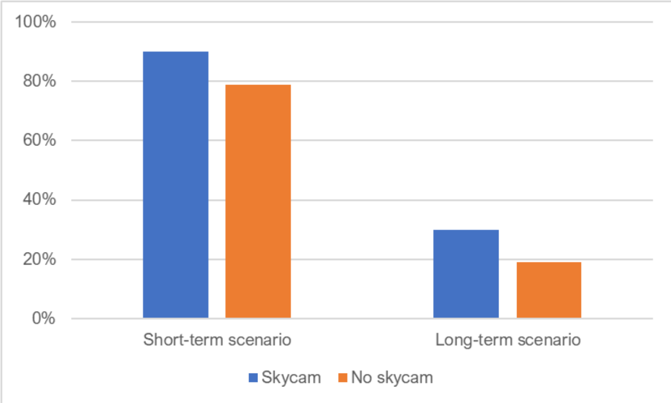


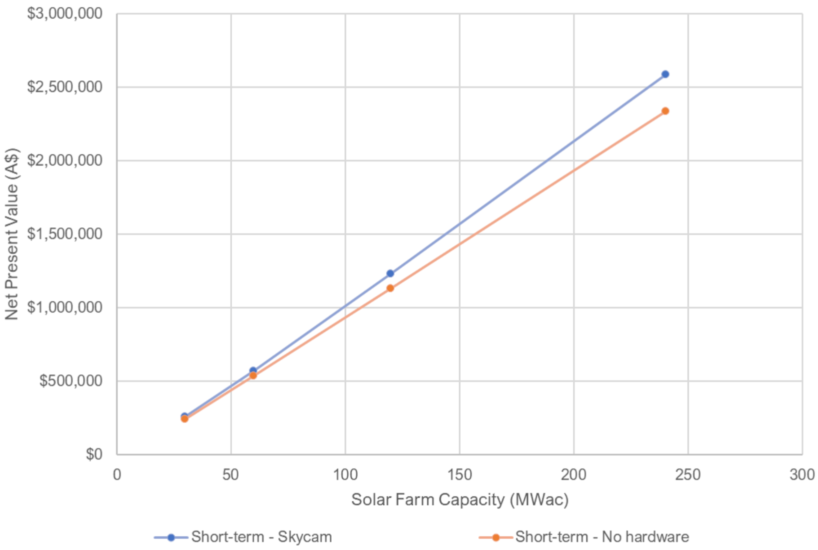
Figure 10. Short-term and long-term scenarios for FCAS charges reductions.

4 COST BENEFIT ANALYSIS OF SELF-FORECASTS

In this section, the Net Present Value (NPV) of the main forecasting combinations is calculated, considering the capex and opex, and the achievable avoided costs using each technology combination. The following assumptions were used in the NPV analysis:

- Project length: 3 years;
- Discount rate: 8%;
- Representative capacities for semi-scheduled solar farms ranging between 30 MW and 240 MW;
- Regulation FCAS annual costs for solar farms not using self-forecasts: $650k / year / 100 MW.
- Lead-time before use of self-forecast in dispatch;
- Varying capex and opex costs as a function of the solar farm size and the technology combinations:
  - No hardware: live data + satellite (marginal capex);
  - Hardware: live data + satellite + skycam (capex).
- Additional indirect integration costs for solar farms;
- Two scenarios for Regulation FCAS costs reductions:
  - Short-term scenario: reductions of 70% (without hardware) and 90% (with skycams)
  - Long-term scenario: reductions of 20% (without hardware) 30% (with skycams).

Figure 11 shows the resulting NPV for solar farms of 30, 70, 120 and 240 MW. While the business case improves significantly for larger solar farms, these results show that the live data + satellite + skycam forecasts combination provides the greatest returns at current FCAS costs. In the long-term scenario, the NPV of forecasts using skycams increases by as much as 40% compared to not using skycams. This is considering a project lifespan of only 3 years. As Proa provides industrial grade equipment with a design life over 10 years, the weight of the capex costs will be reduced and the business case for skycams will improve when considering longer project timelines.



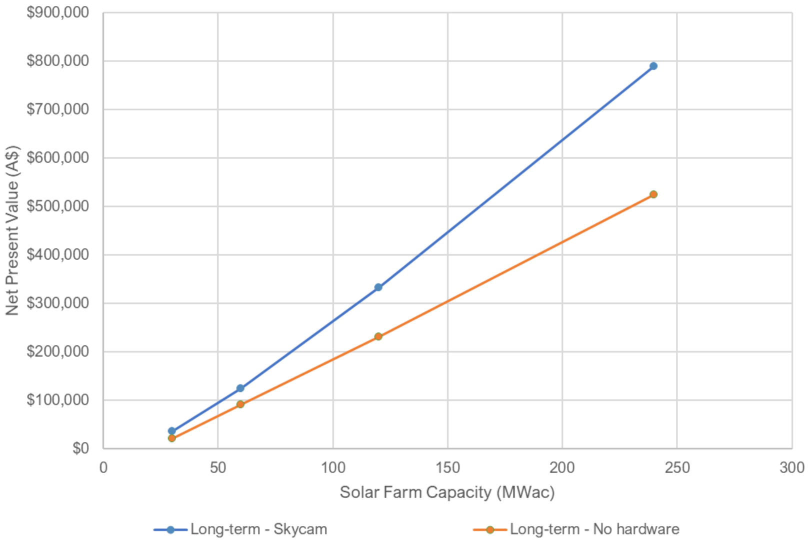


Figure 11. Net Present Value of integrating self-forecasting over a period of 3 years for solar farms ranging between 30 and 240 MW. The short-term scenario reflects the business case accounting for savings achievable in the current market conditions. The long-term scenario reflects a realistic business case in the long-term in mature and balanced market scenario.

Importantly, Figure 12 shows the necessary reduction of the baseline Regulation FCAS costs (relative to 2020 FCAS costs) that would make self-forecasting non-investable. For the short-term scenario, FCAS costs would need to reduce by as much 80-90% to make the NPV equal to 0 for all solar farm sizes. For the long-term scenario, there is a greater sensitivity to the solar farm size. In this case, the baseline costs would need to reduce by more than 30% for small solar farms, and around 80% for 240 MW solar farms.

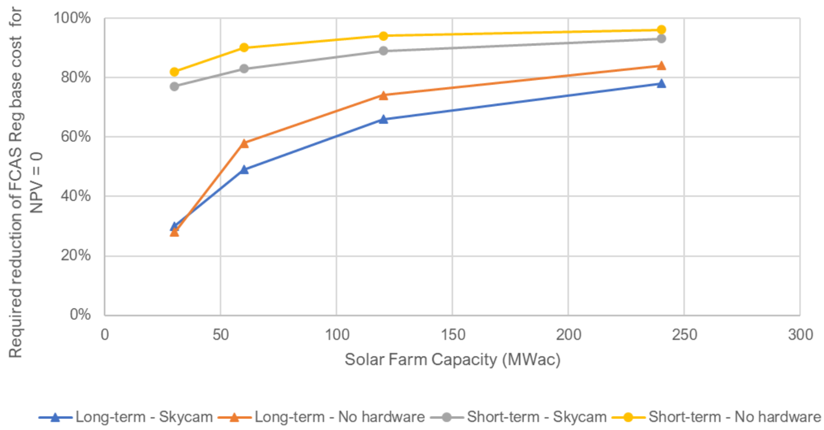


Figure 12. Required reduction of FCAS Regulation base costs (without self-forecasts) to make the NPV=0.

5 PROJECT CONSEQUENCES AND FUTURE DEVELOPMENTS

The project has enabled Proa to build a mature commercial offering for the market. The lessons, modelling techniques and processes developed under the ARENA funded project, could be applied commercially in providing self-forecasting services for solar farms in the NEM. Furthermore, the experience gained throughout the project has led to valuable developments in the mechanisms and processes required to operate skycams and integrate them with SCADA systems which can be directly transferred to solar forecasting projects outside the NEM and internationally. Additionally, the improved accuracy of short-term forecasts has implications for other applications like the dispatch of solar + battery energy storage systems.

The adoption of self-forecasts in the NEM provides direct benefits to the grid, market, and consumers. Improved solar forecasts reduce the need for regulation FCAS services in the NEM, thus removing pressure from the Regulation markets, which contributes to lowering the costs of Ancillary services that are passed onto the end consumer. Furthermore, lower uncertainty in the balancing of demand and generation makes the operation of the grid more robust. This enables more renewables to connect to the grid thereby further reducing emissions.

Proa has identified areas of our operations and systems for further improvement. Skycam CMV algorithms increase the complexity of the forecast model, making fast and robust algorithms essential to maintaining timely and well-synced processes, especially at the short 5 minutes ahead time frame. Additionally, machine learning techniques could be used to improve the optimum combination of forecast components. Furthermore, to get the best results from skycams it is integral that they are well maintained. Proa is currently working on further improving the effectiveness of its self-cleaning system.