Gridded Renewables Nowcasting Demonstration over South Australia

Public Report

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DOCUMENT CONTROL

Title:	Gridded Renewables Nowcasting Demonstration over South Australia – Public Knowledge Report		
Client:	Solcast https://solcast.com/	**Client Contact:**	Ben King

Revision	Date	Approved by	Comments
Final Draft	30/06/2022	Winnie Fu	
Complete	30/06/2022	Ben King	

Acknowledgement

The "Gridded Renewables Nowcasting Demonstration over South Australia" project ('the Project') is a collaboration between Solcast, Weatherzone, TESLA Forecast, AEMO, SA Power Networks, Snowy Hydro, Energy Australia, Acciona. The Australian Government, through the Australian Renewable Energy Agency (ARENA), is providing $994k towards to this $2.91m Project under its Advancing Renewables Program.

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Executive summary

The significant recent increase of variable renewable energy generation capacity in the National Electricity Market (NEM) has introduced challenges in predicting short-term aggregate supply and demand as the fuel mix has an increasing 'weather-as-fuel' highly variable component. This project developed and deployed novel weather forecasting technologies aimed at increasing the accuracy of short-term 5-360 minutes ahead solar and wind generation forecasts in the state of South Australia. The forecast technologies capitalise on high-resolution and rapidly updating satellite data and real-time ground observations. Generation forecasts were deployed for all 25 semi- and non-scheduled solar and wind farms, state total behind-the-meter rooftop PV, and state total demand.

The Project was technically successful, with forecast systems producing lower error than existing forecast methodologies for all data streams. Forecasts issued for 1 hour ahead improved nRMSE (normalised Root Mean Square Error) when compared with the benchmark NWP models (GFS & ACCESSG) by 66 % for utility scale solar, 40% for utility scale wind, 4% for rooftop PV, and 4.6% for demand. The improvement is also delivered on highly variable weather days, where the Project's forecast systems outperformed traditional methodologies on almost all occasions.

A selection of market participants were provided access to the forecast data to gain qualitative insights to the application of the forecast data; the energy market operator, AEMO, a distribution network service provider (DNSP), SAPN, gentailers Energy Australia and Snowy Hydro, and an asset owner, Acciona. All partners reported the Project forecast data was more accurate than existing technologies in most cases. The applicability of the forecast data to their specific use-cases was mixed. AEMO identified the forecast data was highly valuable for daily risk assessment procedures including near term variability, ramping, and situational awareness in the 5-360 minutes ahead horizon. SAPN utilised the data as an input to an upcoming network pilot and identified the data will be a required input as the pilot scales up. Snowy Hydro and Energy Australia did not find the data provided a material benefit to their trading teams, but comment that they expect the data will become more applicable as variable renewable energy generation capacity in the NEM increases. Acciona did not find the data useful to their maintenance operations or for self-forecasting.

The Project disseminated key project insights and lessons learned through a variety of knowledge sharing activities, including media reporting, regular ARENA public reporting, three energy industry conferences and one meteorological industry conference.

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List of Abbreviations

ACCESSC	The Australian Community Climate and Earth-System Simulator (City)
ACCESSG	The Australian Community Climate and Earth-System Simulator (Global)
AEMO	Australian Energy Market Operator
API	Application Programming Interface
ASEFS	Australian Solar Energy Forecasting System
AWEFS	Australian Wind Energy Forecasting System
AWS	Amazon Web Services
DER	Distributed Energy Resource
DNSP	Distribution Network Service Provider
FTE	Full Time Equivalent
GFS	Global Forecast System
IR	Infrared
MAE	Mean Absolute Error
MAPE	Mean Absolute Percentage Error
NEM	National Energy Market
nRMSE	normalized Root Mean Square Error
NWP	Numerical Weather Prediction
POE	Probability of Exceedance
RERT	Reliability and Emergency Reserve Trader
REST2	Replica Exchange with Solute Tempering
RMSE	Root Mean Square Error
SAPN	South Australian Power Networks
SCADA	Supervisory Control and Data Acquisition
+1hr	One hour ahead

Glossary

Term	Definition
ACCESSC	The Australian Bureau of Meteorology's high resolution NWP weather model proving data for Australian capital cities
ACCESSG	The Australian Bureau of Meteorology's global NWP weather model
Actuals, or measured actuals	Historic data measured with a local measurement device. (eg via a pyranometer or anemometer)
ASEFS1	The model used by AEMO to forecast Utility Scale solar energy generation in the NEM
ASEFS2	The model used by AEMO to forecast rooftop (<100kW) solar energy generation in the NEM
API	A type of software interface which enables connections and services between computers of computer programs
Aurora	A managed relational database service by Amazon Web Services
AWS	An on-demand cloud computing platform
AWEFS	The model used by AEMO to forecast wind energy generation in the NEM
Consensus forecasts	A combination of multiple forecast models
DER	Small, decentralised, grid-connected electrical generation and storage
DNSP	Organisations that own and control the hardware of the distribution energy network such as power poles, wires, transformers and substations
Estimated actuals	Estimated local conditions based on data measured with a remote sensor (eg via satellite)

GFS	A global numerical weather prediction (NWP) model generated by the American National Centres for Environmental Prediction (NCEP)
MAE	A measure of errors between paired observations expressing the same phenomenon, representing the average magnitude of errors
MAPE	A measure of errors between paired observations expressing the same phenomenon, representing the average magnitude of errors expressed as a percentage of the observation
Market Price Cap	The maximum wholesale price threshold in the NEM.
NEM	The Australian national grid, that stretches from far north Queensland down the east cost to south Australia, including Tasmania
NWP	Mathematical models of the atmosphere and oceans to predict the weather based on current weather conditions. The large and complex calculations required mean these models are run on supercomputers, typically by national meteorological agencies
Persistence forecast	A forecast that the future weather condition will be the same as the present condition.
RERT	A last resort mechanism that requires AEMO to pay a premium for additional generation capacity to be in reserve in case of supply and demand imbalance.
RESTful API	An API that conforms to the specific requirements of the REST architectural style
RMSE	A quadratic measure of errors between paired observations expressing the same phenomenon, which penalises large deviations
nRMSE	A quadratic measure of errors between paired observations expressing the same phenomenon, which penalises large deviations, normalised by the magnitude of the observations
S3	An AWS services, object storage with scalable storage infrastructure
Semi-dispatch caps	A dispatch instruction AEMO can issue to semi-scheduled generators that restricts their generation in that dispatch interval to no more than the dispatch target.
Gentailers	Entities that are both generators and retailers of energy.
REST2	A model which predict cloudless sky broadband irradiance, illuminance, and photosynthetically active radiation from atmospheric data.

1 Project overview

1.1 Today's electricity grid

In the past decade, Australia has seen a rapid increase in the use of renewable energy generation through the rise in capacity of utility and rooftop scale PV and utility scale wind technology. The consequence of which has been a dramatic shift in the operational characteristics of Australia's energy market and networks, namely short-term generation supply is increasingly difficult to forecast accurately as the fuel mix has an increasing 'weather-as-fuel' highly variable component. This is felt acutely in South Australia – in 2021 in South Australia 66.5% of total energy was produced by renewable assets (8,815 GWH of 13,525 GWH total generation), the highest proportion of any mainland NEM state (Clean Energy Council, 2022). The state is therefore most exposed to market and operational risks arising from variable renewable sources, which can lead to a reduction in security and reliability as well as the exacerbation of existing market inefficiencies if not managed appropriately.

Market impacts within South Australia may be quantified by the cost incurred by non-optimal dispatch, increased frequency keeping costs and increased reserve requirements. Inaccurate wind and solar forecasts leading to lack of short-term availability of renewables generation can lead to higher priced generation being dispatched to meet the shortfall. Inaccurate forecasting can also be a factor in Lack of Reserve (LOR) events, with potential to impact power system reliability and incurring costs associated with maintaining reliability. These costs may include high energy prices due to scarcity and emergency mechanisms like RERT. The increasing deployment of renewables in a power system may also increase the need for FCAS to manage short-term generation variability, which can impact electricity users though higher retail prices.

While adequate tools exist to support immediate situational awareness of the energy system at the market level (AEMO) and minimum operational demand events on the low voltage (LV) distribution network (SAPN), tools and forecast systems that can be implemented to minimise uncertainty improves electricity network security in South Australia.

Finally, electricity network security and reliability is negatively impacted whenever there is a mismatch of supply and demand experienced within the energy system. Reliability is primarily maintained through the confidence of AEMO's ability to correctly manage the energy markets, the bulk of which is achieved by AEMO sending accurate and timely market signals that anticipate the impacts of renewable energy intermittency on supply and demand. AEMO's Operational Forecasting team observes that this fundamental element of its role is becoming increasingly challenging as higher penetrations of renewable energy enter the South Australian system.

1.2 The role of nowcasting technology

The market operator, network service providers and market participants are increasingly relying on weather forecasts as a critical data input to the management of variable renewable energy (VRE) generation. These stakeholders have identified a need to improve the capabilities of 5-360 minutes ahead weather forecasts that are commercially available, particularly on a site-specific/localised level. Whilst substantial gains are being made in very short-range forecasting and day-to-week-ahead forecasting, there exists a significant technology gap across this short-term horizon. Yet this forecast horizon is where decision making for the orchestration of intermittency management techniques and demand-supply balancing occurs. Hence it is important for this information and technology gap to be filled in order to overcome the challenges that growing variable renewable energy generation presents.

There are four ways in which nowcasting technologies address the secure and reliable delivery of electricity. Firstly, the short-term accuracy improvements that nowcasting brings increases market efficiency by providing a more reliable short-term generation outlook, lowering reserve generation requirements and costs. Market operator and participants, namely AEMO, Energy Australia, and Snowy Hydro, report that improved forecasting capability on the nowcasting horizon can increase the reliability of the forecast reserve level and therefore reduce the frequency of events where renewable energy intermittency unexpectedly contributes to an LOR condition.

Secondly, improved nowcasts contribute to the increase of security of supply by improving the real-time and near-term visibility of supply & demand balance. In addition to reduced aggregate error, nowcasting technologies are better able to capture the impact of localised weather events: For solar energy, this most notably includes predicting the speed and size of significant cloud ramping events. For wind energy, this includes improved prediction of high-wind speed shutdown events. Combined, the nowcasting service can provide an improved forecast of reduction, ramping, or loss of renewable energy supply. Improved short-term forecasting also provides additional lead time for reserve generation, energy storage, demand response and load shedding, each of which require varying orders of lead time for deployment. With the high resolution and rapid updating that is provided by nowcasting, each of these mechanisms can be supplied with decision making data that is specific to the lead time requirements of the asset, increasing the effectiveness of these means for managing supply-demand balance.

Thirdly, improved nowcasts assist in the removal of barriers to renewables growth. Market inhibitors in the form of curtailments, deviation penalties and increasingly common smoothing requirements are used to control system stability and reliability concerns. Each of these plays a role in slowing or ceasing the development of further renewables projects. Specifically for residents in South Australia, the introduction of novel technologies like SAPN’s flexible exports trial with dynamic constraints on the LV network can increase the total capacity of rooftop PV able to be installed in the network by enabling additional control over the distributed assets. By improving demand forecasting in the 5 – 360 minute range, the perceived effects of the unpredictability of renewables can be reduced.

Finally, improved nowcasts enable technology for energy storage and demand response, primarily by enabling battery sizing with high resolution site-specific forecast data and improving state of charge management. While data from this Project was not used to better orchestrate energy storage and demand response, the nowcasting technologies have been deployed for this purpose in other commercial endeavours, both domestically and internationally.

Note that while there are many identified uses and benefits of nowcasting technology, this Project's primary focus is developing and validating accuracy improvements of the nowcasting technology and is informed via feedback from a selection of market participants. The specific use-cases of the nowcast data in this project are not exhaustive.

1.3 Project objectives

This Project sought to develop 'nowcasting' capabilities which fill this technology gap, that is, to better predict short-term weather conditions and VRE generation forecasting. Solcast improved its satellite-informed gridded nowcast generation software Cumulus, as well as its information distribution platform, the Solcast API, to meet this need. Generation forecasts were deployed for all 25 semi- and non-scheduled solar and wind farms, state total behind-the-meter rooftop PV, and state total demand in South Australia. Solcast's nowcast were evaluated by statistical methods, and through a selection of market participants providing feedback each with varying use-cases which is outlined below.

The market participants that evaluated the Project data were selected to inform a range of feedback from various market perspectives, including the energy market operator, AEMO, a distribution network service provider (DNSP), SAPN, gentailers Energy Australia and Snowy Hydro, and an asset owner, Acciona. Each of these partners utilised a variety of the forecast data streams, depending on their needs and use-cases. The evaluation partners provided feedback on nowcasting data performance, nowcast use-cases, and where applicable, estimates of economic values. Evaluation partners were also invited to provide feedback on recommendations and areas for improvement.

The Project was structured in two phases. In the first phase the nowcasting technologies were developed and delivered to Project partners. During the second phase the nowcast technologies were evaluated through quantitative analysis, through internal feedback and feedback by Project partners.

1.4 Project partners

1.4.1 Delivery partners (Weatherzone and TESLA Forecast)

Weatherzone and TESLA Forecast acted as delivery partners in this Project for some of the data feeds. Both parties ingested data from Solcast, applied some additional modelling steps to integrate the Solcast data into existing data products, before rendering the Solcast-enhanced data available to the below Project partners. Weatherzone is Australia's largest private weather company, and provides a suite of weather forecasting services to the energy industry. TESLA Forecast is an international energy industry forecasting solutions company, proving a suite of forecast tools to the energy industry.

1.4.2 Market Operator (AEMO)

AEMO (Australian Energy Market Operator) manages the electricity and gas systems and markets across Australia. Their primary role is to perform managerial functions and exercise the powers dictated to them by the national electricity and gas laws. For the market to operate, short-term and long-term predictions of supply and demand are provided by AEMO to market participants. The forecast and modelling of energy generation and changes in generation is critical to the work that AEMO does.

1.4.3 DNSP (SAPN)

South Australia Power Networks (SAPN) is the state's distribution network service provider. Their role is to build, maintain, and develop the LV network infrastructure and substations that deliver power to homes and businesses across South Australia. SAPN use supply and demand forecasting to inform their decision making surrounding the load management and operation of the distribution network.

1.4.4 Gentailers (Snowy Hydro & Energy Australia)

Snowy Hydro is a wholesale generator in the NEM with wind, solar, hydro, gas, and diesel generation assets. In South Australia they operate three diesel-fired power stations at Angaston, Lonsdale and Stanvac. The retail arm of Snowy Hydro is a combination of three sub-groups, Red Energy, Lumo Energy, and Direct Connect. Energy Australia is a wholesale generator in the NEM with gas, coal, wind, solar, and storage generation assets. In South Australia they operate the gas-powered Hallett Power Station. They also have a retailing arm under the same name.

1.4.5 Asset owner (Acciona)

Acciona is a global company that owns transport, real estate and wind energy generation assets across the globe. In South Australia they own and operate the Cathedral Rocks Wind Farm.

2 Development and delivery

2.1 Solar Nowcasts

Project work on the solar nowcast component involved developing extensions to the Cumulus system, including improvements to core functions cloud detection and cloud advection, and making iterative improvements to the forecast algorithm. The solar nowcasts are used to create utility scale solar, rooftop PV, and demand forecasts.

The Solcast method for generating solar irradiance nowcasts from geostationary weather satellites consists of four major steps:

1. Cloud detection: The detection of the presence of cloud cover and the characterisation of that cloud cover in terms of its impact on solar radiance to create a cloud index, which Solcast refers to as cloud opacity.
2. Cloud advection: Estimating the future position of cloud opacity grids using computer vision and cloud motion vectors.
3. Clear-sky model: Modelling the available solar irradiance under clear skies, including treatment of aerosols (dust, salt, etc.) and water content to create a clear-sky index.
4. Radiation modelling: Algorithmic estimates of the direct, diffuse, and global components of solar irradiance, including decomposition models which handle the separation of global surface irradiance into the irradiance components.

A number of cloud modelling improvements were achieved during this phase, the highlights of which are included here.

1. Developed cloud opacity estimates that more accurately represent the real-world physics of optical attenuation of irradiance Predicting ground level irradiance from satellite-based observations requires correcting for the observation and incident radiation
2. Increasing the resolution of ground surface albedo This creates cloud images with fewer false positives, reducing predicted cloud coverage as seen in the example in Figure 2-1.
3. Improved the cloud opacity advection pipeline to enable more accurate flow fields. This primarily has the effect of improving cloud front timing.

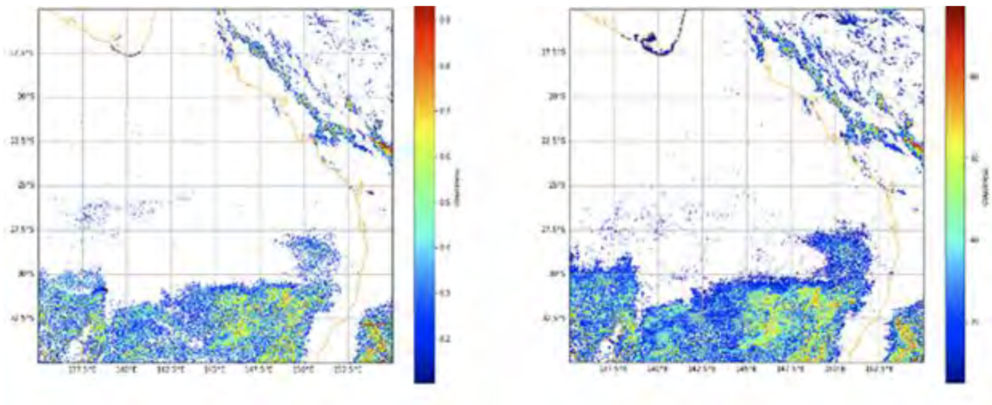

Figure 2-1 improved albedo thresholding in Cumulus (left) resulting in reduced occurrence of false cloud detection

2.2 Wind Nowcasts

Project work on the wind nowcast component involved building from scratch a wind forecast generator in the Cumulus system. The aim is to generate wind velocity data, which is used as an input to an existing Weatherzone forecast system. The wind nowcasts are used to generate the utility scale wind forecasts.

Solcast generates a wind velocity forecast time series extending out to 6 hours ahead (+6hr) by firstly ingesting NWP models hourly wind forecasts with low update frequency. The nowcast is based on machine learning methods applied to the NWP forecasts and wind farm production outputs from a range of wind farms across a spatial area. A statistically derived variable weighting is given to the nowcast and hourly forecast components.

2.3 Solcast API

Nowcast data is delivered to Project partners via Solcast’s data distribution layer, referred to as the Solcast API. The Solcast API determines the required input parameters needed for a data request, locates, and determines the best source data, and extracts the relevant data for the request. The API will apply any required post-processing on the data to generate the data output for the user, including resampling and calculation of derivable parameters. This is passed to a webhost and exposed by a RESTful API.

Data distribution design saw significant upgrades during the Project to accommodate the nearly 2TB of data processed each day. The new system design realises three key benefits:

1. The system allows for cloud opacity grids, the most cost and storage intensive data source and arguably to most critical to irradiance and PV power accuracy, to be stored and accessed at native resolution.

2. The system automates seamless gap-filling of missing data by making decisions on-the-fly about how and where to fill in gaps in the data stream, thus supplying a smooth and continuous output of data.
3. Both the data storage and distribution layers of Solcast's system treat each data source as a fully independent source. This means that it is easy to integrate new data sources into the system as well as mesh these sources even if they have different spatial or temporal resolutions.

The Solcast API delivers data to delivery and evaluation partners using a combination of API data feeds for raw data, and web portals through an online web portal for data exploration. Some selected examples of the dashboard and API data feeds are included below in Figure 2-2, Figure 2-3 and Figure 2-4, with examples of data extracts in Figure 2-5 and Figure 2-6.

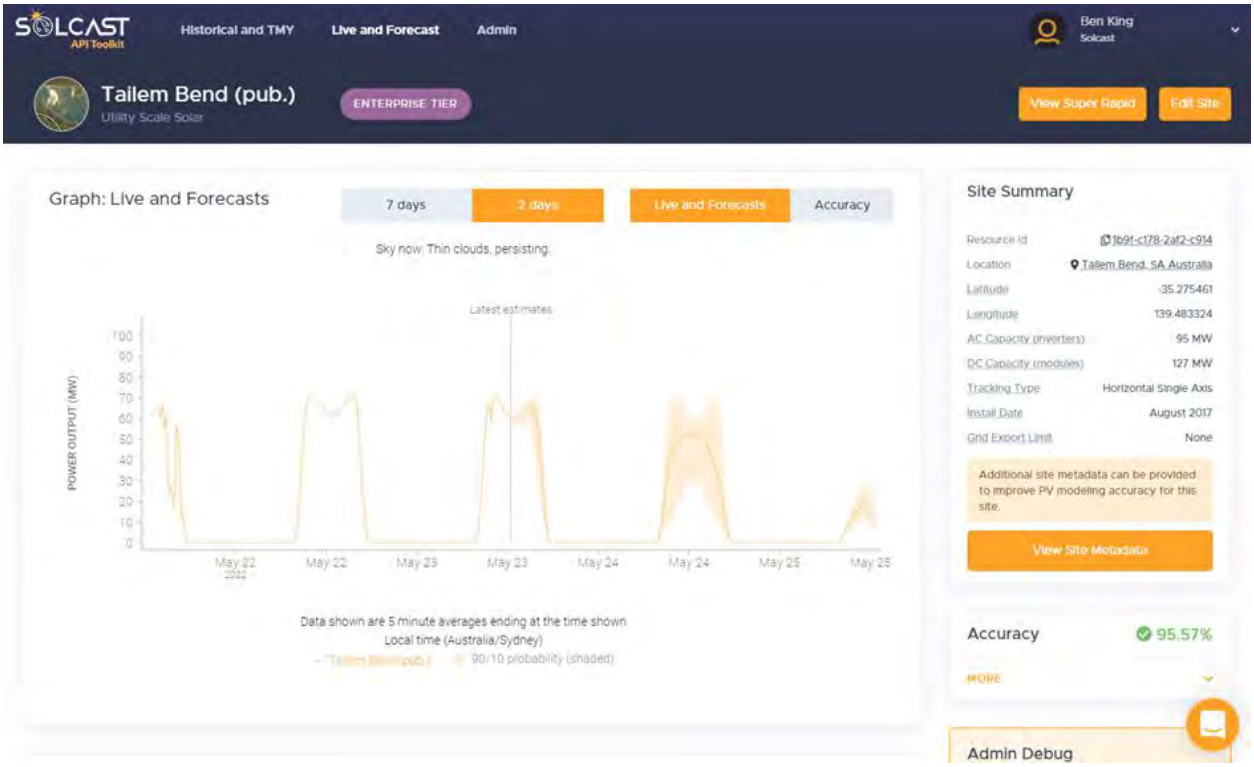

Figure 2-2 A selected example of a Utility Scale Solar forecast for Tailem Bend Solar Farm, shown through the Solcast API Web Toolkit. Data displayed includes estimated actuals for the last 48 hours, and forecasts for the next 48 hours. The P90/P10 ensemble data is shown in the shaded area. Also displayed is some basic metadata of the PV site, including location, capacity, and tracking type.

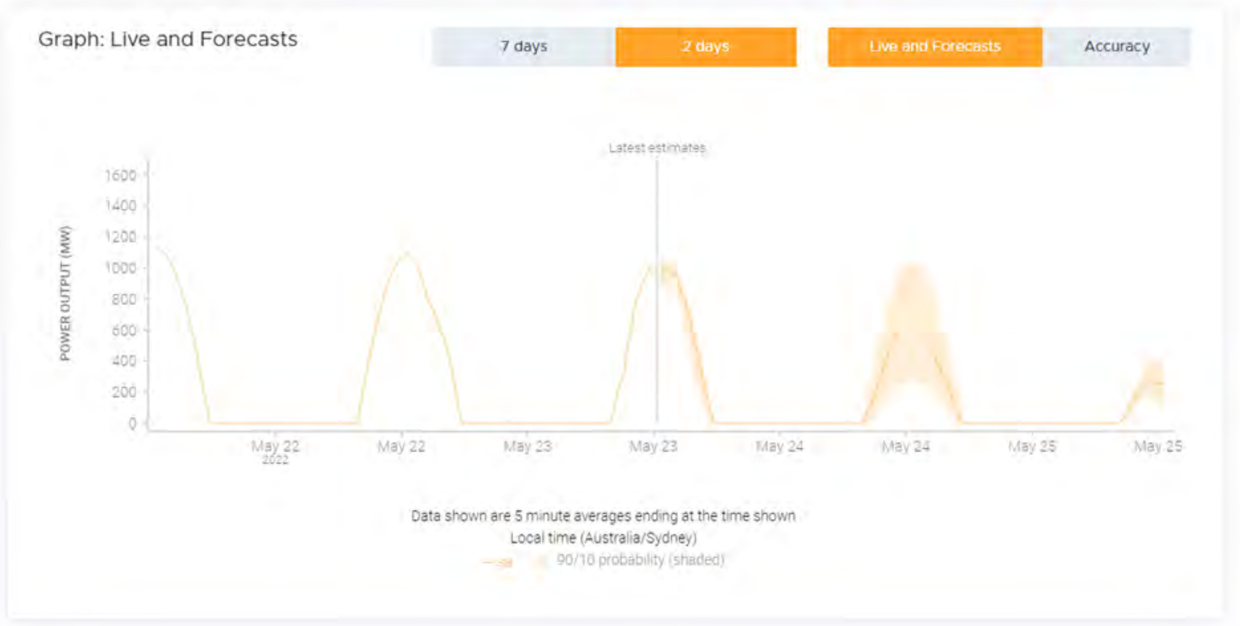

Figure 2-3 A selected excerpt from the Rooftop Solar PV page in the Solcast API Web Toolkit. Data displayed is BtM PV power data, including 48 hours of estimated actuals and 48 hours of forecasts. The P90/P10 ensemble data is shown in the shaded area

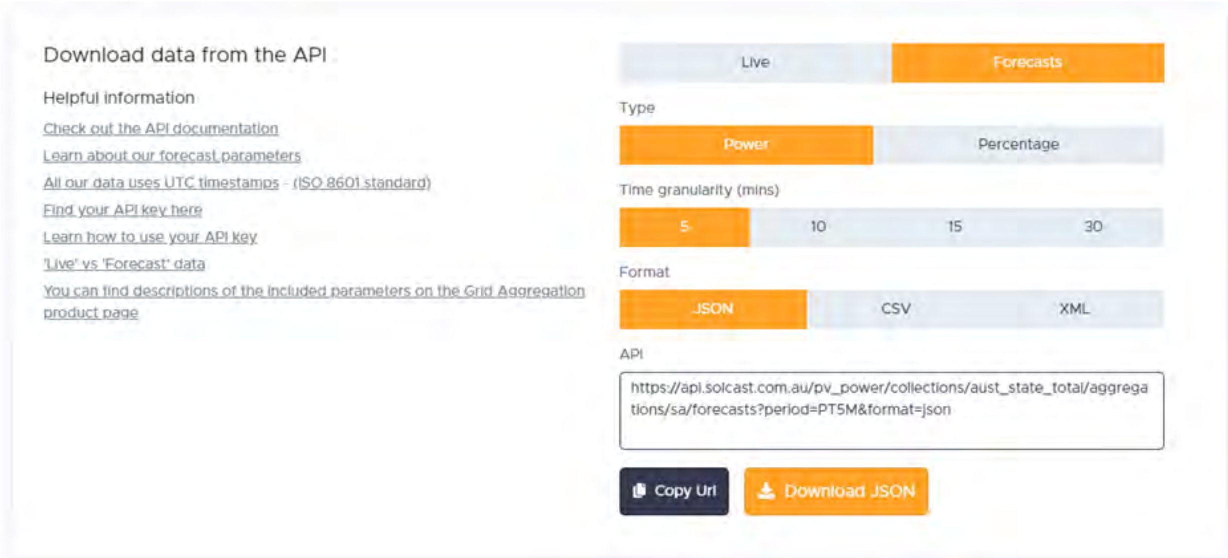

Figure 2-4 An excerpt from the Rooftop Solar PV page in the Solcast API Web Toolkit with data download selector. This card can assist users in constructing API calls.

Snapshot of GetAggregationPowerForecast generated by ServiceStack on 05/23/2022 02:38:38

view json datasource from original url: https://api.solcast.com.au/pv_power/collections/aust_state_total/aggregations/sa/forecasts?period=PT5M& in other formats: json xml csv jsv

Aggregation_name sa

Forecasts

Pv_estimate	Pv_estimate10	Pv_estimate90	Period_end	Period
979.5218	881.8682	1034.3318	2022-05-23T02:40:00.0000000Z	PT5M
979.3438	880.2717	1035.8655	2022-05-23T02:45:00.0000000Z	PT5M
979.9151	880.225	1036.9662	2022-05-23T02:50:00.0000000Z	PT5M
979.3104	878.6602	1035.8681	2022-05-23T02:55:00.0000000Z	PT5M
978.8278	876.2835	1034.4258	2022-05-23T03:00:00.0000000Z	PT5M
981.3817	875.1438	1035.8329	2022-05-23T03:05:00.0000000Z	PT5M
985.2373	874.3821	1038.3045	2022-05-23T03:10:00.0000000Z	PT5M
985.2721	870.4704	1036.3915	2022-05-23T03:15:00.0000000Z	PT5M
982.4906	864.5918	1031.1938	2022-05-23T03:20:00.0000000Z	PT5M
979.7739	859.7329	1025.522	2022-05-23T03:25:00.0000000Z	PT5M
977.4801	856.6287	1020.1135	2022-05-23T03:30:00.0000000Z	PT5M
976.6899	856.9506	1016.6642	2022-05-23T03:35:00.0000000Z	PT5M
976.5096	858.1056	1014.2923	2022-05-23T03:40:00.0000000Z	PT5M
972.6	854.7997	1008.1438	2022-05-23T03:45:00.0000000Z	PT5M
965.6857	848.3799	999.0918	2022-05-23T03:50:00.0000000Z	PT5M
959.0118	842.5798	990.9592	2022-05-23T03:55:00.0000000Z	PT5M
952.4607	836.8768	983.5086	2022-05-23T04:00:00.0000000Z	PT5M
942.0699	827.3527	972.4901	2022-05-23T04:05:00.0000000Z	PT5M
929.559	815.6186	959.1954	2022-05-23T04:10:00.0000000Z	PT5M
919.764	805.6129	948.4953	2022-05-23T04:15:00.0000000Z	PT5M
910.7048	793.6145	939.201	2022-05-23T04:20:00.0000000Z	PT5M
897.7983	772.8944	927.6344	2022-05-23T04:25:00.0000000Z	PT5M
882.8974	747.884	914.7189	2022-05-23T04:30:00.0000000Z	PT5M
867.1401	722.7472	900.9538	2022-05-23T04:35:00.0000000Z	PT5M
850.9183	697.7124	886.9726	2022-05-23T04:40:00.0000000Z	PT5M
833.8133	672.1071	872.2581	2022-05-23T04:45:00.0000000Z	PT5M
817.6548	647.415	858.6949	2022-05-23T04:50:00.0000000Z	PT5M
803.0263	624.6134	846.7363	2022-05-23T04:55:00.0000000Z	PT5M

Figure 2-5 A human readable data extract of the Rooftop Solar PV forecasts obtained via Solcast API

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Figure 2-6 json format data extract of Rooftop Solar PV forecasts obtained via Solcast API

2.4 Delivery partner APIs

Weatherzone and TESLA Forecast delivered data to evaluation partners using a combination of API data feeds and online web portal for data exploration. Some selected examples of the dashboard and API data feeds are included in Figure 2-7, Figure 2-8 and Figure 2-9.

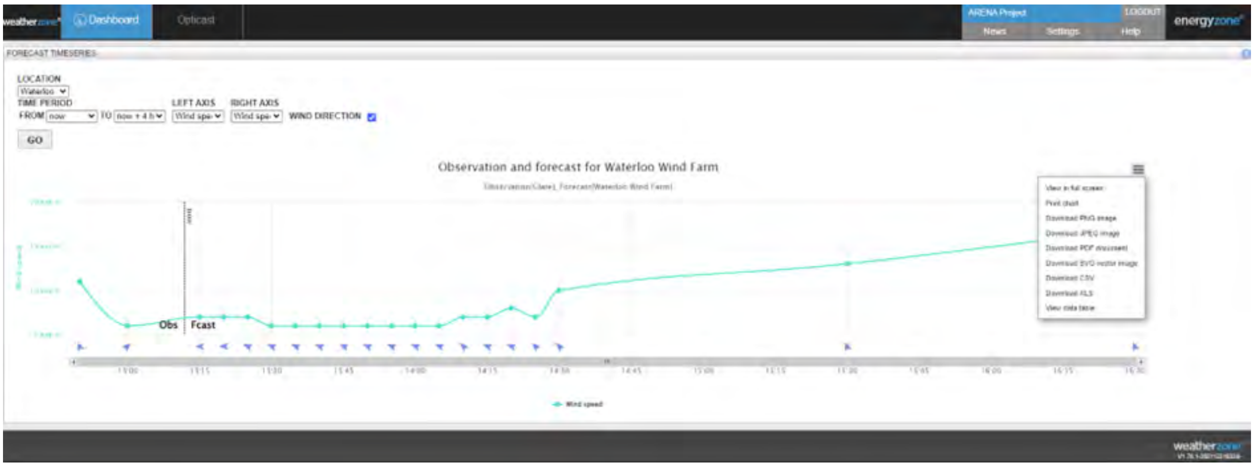

Figure 2-7 A Utility Scale Wind forecast through the Weatherzone Web Dashboard for Waterloo Wind Farm. Data displayed is the most recent wind observation, the first 60 minutes of nowcast data at 5 minute resolution, and continuing intra-day forecasts (Source: Weatherzone)

{"api_version":"1.0","metadata":{"sector":"weather","title":"Weatherzone","provider_name":"Weatherzone","provider_url":"http:\/\/
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Figure 2-8 A data extract of the Weatherzone API in json format (Source: Weatherzone)

Figure 2-9 The TESLA Forecast demand forecast shown through the TESLA Forecast Web Dashboard. Data displayed include both actuals and forecasts from various load models

3 Evaluation and feedback

This section of the report will summarise the quantitative performance of the forecasts systems, and qualitative feedback provided by Project partners.

3.1 Nowcast performance

The key quantitative evaluation metric selected as a benchmark in this Project is normalised root mean squared error (nRMSE) for values of hour-ahead forecasts. nRMSE was selected as it is sensitive to large deviations which allow major events to play a large role in the error performance analysed. In selecting nRMSE, the metric will capture the impact of extreme weather scenarios more effectively than an average error metric would. The hour-ahead time horizon is chosen since error growth of nowcasts is linear, such that one lead time is sufficient to capture overall improvement whilst maximising goal clarity. The improvement of the Project nowcast data compared with the benchmark NWP models (GFS & ACCESSG) is summarised in Table 3-1.

Table 3-1 Improvement of nowcast data compared with the benchmark NWP models

	Utility Solar	Rooftop PV	Utility Wind	Demand
% Improvement compared with NWP	66%	46%	40%	4.5%

The nowcast system for all data types demonstrated a clear accuracy gain over existing NWP weather models. Consistent with the Project's forecast system data generation approach, the use of rapidly updating surface and satellite observations (every 5 or 10 minutes) has clear accuracy benefits when compared with the slower four-per-day NWP update cycle.

3.2 Case Study

Over the course of this project's evaluation period, a series of case study days were observed and recorded to measure the performance of the project nowcasts from Solcast and Weatherzone in interesting weather scenarios. The nowcast data was compared to NWP models. The most noteworthy day is included here.

A weak trough clears to the east during the late morning of 13th January 2021. While the clearing during the day was forecast by the 24hr day-ahead model, both the timing and magnitude of this was significantly better represented by the more responsive Solcast +1hr and +2hr models. nRMSE was reduced by 52% and 15% for the nowcast models respectively. The forecasts from this day are shown in Figure 3-1.

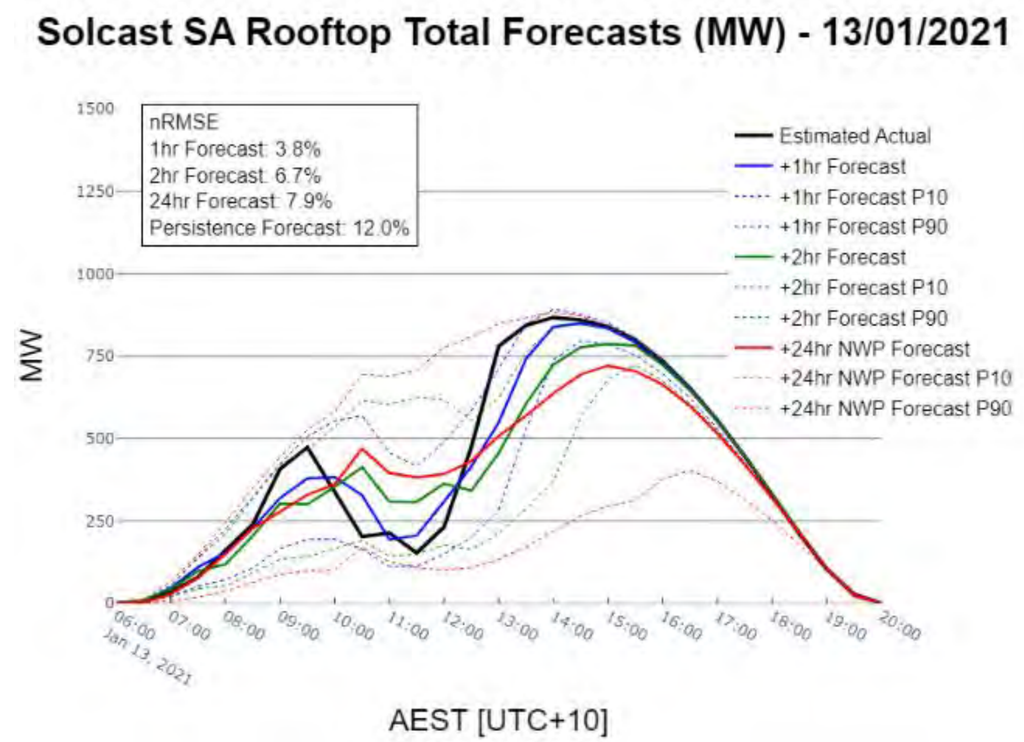

Figure 3-1 Solcast's estimated actual, +1hr, and +2hr forecasts against +24hr NWP forecasts for 2021-01-13. Note the irradiance to PV power model used in all data series is held constant, varying only the weather data input to facilitate comparison.

This event had a significant impact on many project partners. The morning cloud front saw a dramatic decrease in rooftop PV generation, causing an unforeseen ramp of ~325MW in grid demand over a one-hour period. The solar nowcasts did however predict the drop in generation.

Forecast differences of this magnitude are likely to result in significant price spikes. On this day there were two such intervals of spot pricing reaching $1,000/MWh at 10:00 and 10:05. The high prices are due to reserve thermal generation being offline when the supply side deviation occurred, meaning higher cost generation that can come online quickly to meet demand.

3.3 Review from partners

Market Operator (AEMO)

Uncertainty in the pre-dispatch outlook is a key issue for AEMO in determining whether the system will be secure and reliable. Un-forecast aggregate pre-dispatch errors may have a material impact on the grid if they are large enough, and an overestimation of available reserve generation can lead to reliability issues if the reserve generation is insufficient to meet demand.

Feedback from AEMO focused on the accuracy of Solcast's data relative to existing ASEFS1, ASEFS2, and AWEFS models. Solcast's forecasts exhibited higher accuracy over the 3-hour ahead nowcast horizon when compared to ASEFS and AWEFS in most scenarios, improving AEMO's ability to understand and quantify risk in the pre-dispatch forecast horizon.

Probabilistic forecast data outputting a range of possible outcomes assisted AEMO's Operational Forecasting team to identify uncertainty ahead of time by way of differences between forecasts, and action as appropriate. Potential uncertainty is indicated both by the range of the Solcast probabilistic forecast spread, and by comparing those Solcast forecasts to AEMO's equivalent forecasts.

Applications for the data in predicting high-wind events were expected, however during the evaluation period of the Project there were no circumstances where wind farms approached the cut-out wind thresholds. Primarily this is due to the positive Southern Annular Mode weather pattern that occurred over the 21/22 summer, which directed cold fronts south of the mainland through Tasmania. AEMO however commented the wind forecasts are expected to have value in predicting these high-wind events despite the lack of such events that occurred in the test period.

DNSP (SAPN)

The Solcast forecast data was used by South Australia Power Networks as an input into a pilot project. The goal was to estimate distributed energy resource (DER) exports on low voltage networks, with a reliance on temperature and irradiance data to predict load and rooftop generation of its customers.

SAPN report improvements in input data quality due to the higher granularity of solar insolation data from Solcast existing models, however no material benefit given the small pilot stage of the pilot project.

Gentailers (Energy Australia and Snowy Hydro)

The predominant use case of the forecast data for the participating gentailers was the efficient dispatch of generation, and anticipating 'ramping events' from wind and/or solar generation variation and modifying trading strategies accordingly. Both gentailers are sensitive to the ramping events' operational consequence on their fast response peaker plants.

Key feedback themes included an increased trading risk profile with the move to 5-minute settlements, increased revenue earning potential for the generators when large dispatch errors occur, and few occurrences of high temperature and demand events during the evaluation period which decreased the opportunity to evaluate the impact of the nowcasting.

Asset Owner (Acciona)

Acciona planned to use the wind nowcasting data for two purposes: firstly to review its possible application for self-forecasting, and secondly to assist in the scheduling of maintenance at Cathedral Rocks Wind Farm. Acciona ultimately found that the nowcasts were not suitable for self-forecasting owing to the market already offering forecast solutions designed for this specific purpose and likely offering a better feature set for this narrow use-case. On maintenance scheduling, Acciona noted that wind forecast data is critical to scheduling and performing maintenance at the site, as high winds limit the ability to perform any turbine or mast maintenance, but that traditional weather forecasts combined with real-time anemometer data was suitable to meet their needs.

4 Key Lessons Learned

Throughout this project there has been a series of lessons learnt. These lessons have primarily come in the form of improvements to the nowcasting system and the deployment to and use of data by the project partners. While the experience of the project partners and results from the findings have been discussed in previous sections, their implications to later iterations of the Project are discussed here.

4.1 Overcome deficiencies in ground observation stations

Knowledge Category:	Technical
Technology Type:	Renewable Energy Forecast
State / Territory	National

Algorithm development often relies on a source of truth to quantitatively assess the impact of potential changes. For satellite-based cloud detection, sourcing and utilising good quality truth data poses a number of issues which have to be overcome. One of the primary sources of truth for cloud optical density are point measurements of solar irradiance, observations taken from ground weather stations equipped with pyranometers. In Australia, the Bureau of Meteorology maintains a network of 24 weather stations which provide public access to ground measured irradiance data. While the measurement quality is generally good, the data have a number of major issues for use in an iterative development process.

Temporal availability

Equivalent networks in the United States make their data available either in near-real-time, or the following day. In Australia the data is available with a delay that is generally from 6 months to 2 years behind present time. This poses major limitations on the use of the data for operational, validation and model improvement purposes.

Spatial density of measurement sites

The cloud detection algorithm needs to function accurately over the highly varied conditions that can be found across Australia. As these 24 measurements sites (many of which are no longer operative and/or have a very short measurement history) are sparsely distributed and are point based, sourcing data that are representative of the full range of potential conditions is impossible. For an arbitrarily chosen 10km x 10km square land area, the likelihood of such a site being present is less than 0.03%. This compares to cloud variability, which exhibits relatively poor spatial autocorrelation compared to other weather elements, whereby local mean cloud optical depth can often vary substantially over much smaller scales, as small as 2-5km. To overcome the limited measurement locations, broad categories based on the primary cloud forcing mechanisms were identified and targeted with a generalised algorithm that performed well across all categories. This approach reduces the over-reliance on weather stations for calibration, and reduces the risk of over-fitting and worsening of out-of-sample performance of sites with no nearby weather station. Future projects developing a system for a large spatial area such as Australia should consider using a more generalised solution that captures a wide range of cloud behaviours, to help mitigate the inability to train on specific scenarios.

4.2 Software build or buy trade-off for smaller organisations

Knowledge Category:	Stakeholder engagement
Technology Type:	Renewable Energy Forecast
State / Territory	National

The software infrastructure for this project is expansive and complex, with requirements for processing up to 2TB of data every day, from multiple difference data feeds with different structures and behaviours. This Project went through a number of design cycles before ultimately selecting the final design. The first prototype was a fully custom database built from scratch, that while very complex would have fully met the requirements of the Project. However, the wider Project team had concerns that the prototype system would be difficult and time consuming to build, and increased the complexing of testing, maintaining, and building upon on the future. The Project evaluated a number of managed database solutions and structures including Cassandra, Mongo, Timescale, and Redshift, to help avoid the complexity of building a system fully inhouse. Several of these were prototyped with real data to stress test assumptions and exclude those that were not suitable. Ultimately the project selected Amazon Aurora. The effort required in design, prototyping, and testing was significant, roughly the same time investment as building the final solution.

As every Project has unique requirements what worked well for this Project may not work for others, even those working in a similar problem space. What is common to all software projects is that they need to be fully considered and planned for ahead of building a solution. Future projects could consider the following themes of the design and prototyping of this Project's infrastructure.

For small software engineering teams and organisations, buy before you build should be the preference for all outside of core business software. Business or Project outcomes are an asset, but custom code and systems creates liabilities that need to be maintained, tested, documented, build training for, etc. One should make sure there are no other options before building something custom and taking on that liability. Larger software teams can take on more of these risks, but smaller teams should elect to build customer solutions as a last resort.

Spending effort building prototypes with real data is time consuming and expensive, but critical to avoiding unknowns and headaches down the road. Think about the cost of managed solutions vs DIY, as well as flexibility, documentation, feature improvements you get vs build time and testing of custom builds. Stress testing with real data is the best way to answer these critical questions.

4.3 Serverless computing

Knowledge Category:	Technical
Technology Type:	Renewable Energy Forecast
State / Territory	National

The Project has identified a high order importance for 'on demand' power modelling solutions, so that forecasts can be updated using the latest observations datasets.

To deliver improved nowcasting for the Project solar farms, fast recalculation of the power simulation is critical, to keep up with rapidly changing weather and plant conditions. Also important is the ability to rapidly iterate on the cloud to irradiance and irradiance to power simulation algorithms. At the start of this milestone period, Project lead Solcast was using a mix of offline modelling (python and matlab code running on their own servers) and on-demand modelling (C# code running on our API servers). Running modelling logic on-demand allowed for fast updates and efficient computation at scale, but at the cost of having to maintain and update two separate code bases each with the same logic.

To solve this problem, Solcast chose an Amazon Web Services (AWS) Lambda functions approach. AWS Lambda provides a service to run code in containers that will scale with traffic loads, without having to manage hardware or servers. Coupled with AWS API Gateway, the functionality can be exposed to the Solcast API internally via HTTP requests via JSON request/response payloads. The end result is that algorithms can run with their own compute resources at larger scales and the Solcast API can treat the algorithms like any other external service exposed via an API.

There were a few challenges to getting the AWS Lambda setup to solve the problem, which the Project can share. The pricing model for AWS Lambda charges based on the number of requests and the duration of the requests, so it meant optimizing the amount of compute available to each AWS Lambda to ensure it was running as quick as it can, to avoid large costs based on long-running algorithms. Finally developmental testing environments were required for the engineering and modelling team, so that new algorithms behave as expected, and behaviour of existing algorithms are maintained. This is a key learning for future software focussed projects with operational delivery outcomes. The Project suggests GitLab's CI/CD platform, which can automatically run unit and integration tests for changes to the algorithms, as well as AWS CloudFormation, which automatically manages the complex AWS hosting arrangement.

4.4 Importance of data quality control procedures

Knowledge Category:	Technical
Technology Type:	Renewable Energy Forecast
State / Territory	National

The Project's forecast systems take inputs from multiple data sources, including satellite data, weather model data, ground observations, and renewable energy generators. Not all input datasets had fully cleaned data, with numerous examples of stuck, missing, or spurious data. Even datasets which typically have low instances of poor-quality data, the Project still found it necessary to build robust data quality control systems. Future projects should be aware that data quality issues are present in most data feeds, and should consider building some form of quality control into all input data feeds. In particular this Project found the following data sources to have the most challenging data quality issues, and consequentially has suggested some quality control procedures that have worked.

SCADA data from wind farms was found to contain the most occurrences of poor data quality. These typically were found in the form of 'stuck' measurements, where measurement values would remain exactly identical to previous measurement values for periods of hours and even days. This data was supplied with a data quality field, but it was found that this tag whilst useful, did not always correctly identify spurious measurement data. Measurement data from solar farms was less inconsistent, but data quality issues in irradiance measurements did occur. The Project encountered issues of incorrect averaging of multiple pyranometers, early morning shading of tilted irradiance sensors, and stuck measurements. The solution was twofold – first the development of a quality control algorithm that detects spurious measurement data, typically by comparing the measurement data to some physical truth. For example, irradiance cannot be greater than zero at night, or wind cannot remain at exactly constant velocity over a given interval of time. The second solution was to filter the spurious data feed and replace it with a background data feed from a different source to ensure continual operation of the system.

Weather station pyranometer data used in the cloud detection validation was found to be prone to fouling from things like dust or snow, and as a result additional quality control checks are required to remove inaccurate measurements. These checks can take significant time to perform which means useful measurement data is often not available for recent time periods without additional effort. As this data is used as truth data to validate algorithmic improvements, there is no fallback to background model data available. To minimise the impact, the Project prioritised the early sourcing of input data and focused quality control effort on scenarios where poorer performance from the cloud detection methodology was anticipated. By sourcing model data as early as possible, the overlap between the internal archive and the source of truth measurements was maximised. Similarly, focusing on applying quality control checks to high importance scenarios raised the value of the periods that were available.

Occasionally raw satellite image data is affected. Occurrence rate is low, but the data feed is considered critical so data quality control checks are required to prevent downstream derivations from ingesting the spurious data. The Project has had success in identifying these data quirks using a number of techniques for validity, unphysicality and other artefacts. An example of a partially-bad image is included below in Figure 4-1.

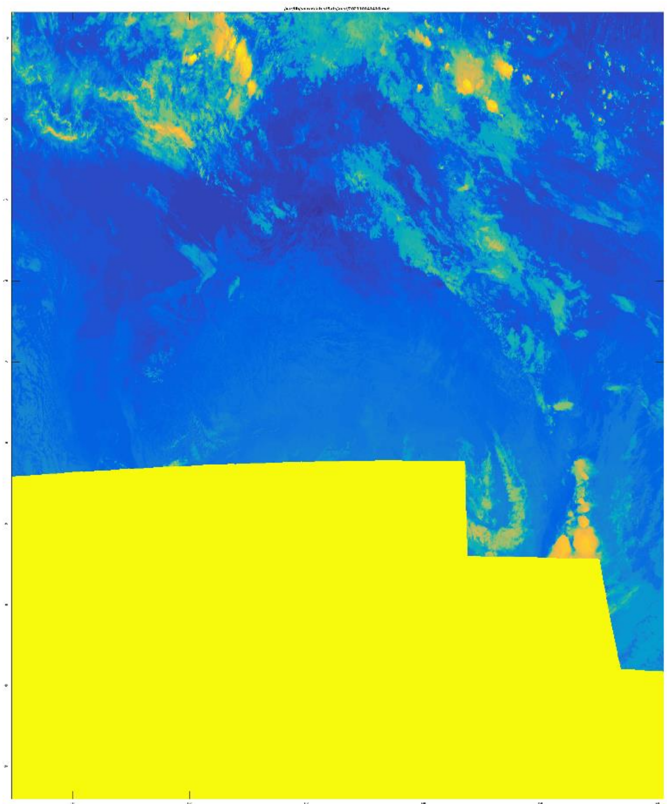

Figure 4-1 - A partial satellite image over the southern coast of Australia

4.5 Installed capacity of rooftop solar in South Australia

Knowledge Category:	Technical
Technology Type:	Renewable Energy Forecast
State / Territory	South Australia

The Project gathered installed capacity information for small solar PV installations from four sources: the South Australian low voltage network South Australia Power Network, the Clean Energy Regulator, Australian PV Institute, and AEMO. Capacity information was gathered for all generators <30MW (all generators >30MW, and AEMO listed generators <30MW, are treated separately).

Early analysis has demonstrated data variability between installed capacity sources for <100kW systems to be negligible. However, for the 100kW-30MW installations there was more variance in the data sets. This is fairly well understood by the industry, owing to a lack of centralised installed capacity data for these system sizes, with challenges including omission of this category by the CER, and the update intervals for installation data which result in differences in data update lag. This is consistent with Solcast's discussions with AEMO on the difficulty in visibility and forecasting for these assets.

The data was explored in bins of different system sizes. Ultimately the Project selected a single data source for each bin, with consideration paid to data age, difference from Solcast internal modelling, and accessibility. As with all Solcast modelling of distributed solar resources, the data is updated daily. These challenges have proven fairly easily to overcome through this strategy of employing multiple sources for PV installation data organised by PV system capacity size. A robust and functional, full representative PV installation dataset has now been assembled by the Project.

There is not a single source of truth in rooftop installed capacity for any energy market, but thankfully with the various source of information available, a statistically representative dataset can be assembled. This highlights the value of having multiple sources of DER registrations in order to build technologies which enhance their visibility. The arrival of the future DER registry NEM wide will be a welcome addition for future DER focussed projects in Australia.

4.6 Forecast evaluation metrics

Knowledge Category:	Technical
Technology Type:	Renewable Energy Forecast
State / Territory	National

It was known at the Project outset that forecast evaluation requires unique validation metrics and well considered approaches to forecast comparisons. This is driven by accuracy statistics that vary widely by geography, climate, season, the forecast horizon of interest, and the particular error measure chosen.

The Project found however that, despite attempts to have directly comparable results from the Project Partners, each still recorded differing results when comparing the new data feeds with existing operational data feeds. This was primarily driven by forecasts being evaluated over different time periods, and secondarily by partners selecting error measures most easily computed by their existing systems and team skill levels.

A primary example was conflicting results in value-add for demand forecasts. Whereas AEMO leveraged a MAE approach, TESLA Forecasting implemented an RMSE based evaluation. This made cross comparison difficult. When attempts to normalise these comparisons were undertaken, results were found to differ, owing to a small difference in the period used for evaluation.

Furthermore, the evaluation period was found to be highly important for like for like comparisons, as a single weather event (lasting 1-2 days) can impact the analysis, and if included in the evaluation period of one validation but not the other, can leave them at odds with one another. Such events are ideal options for completing case studies.

Recommendations for future projects include:

- Have project partners agree to use the same forecast evaluation metric, chosen to represent the key improvement the new data feed is attempting to develop, as the top-line evaluation metric
- Have project partners agree to use the same evaluation period for computation of forecast evaluation
- Employ qualitative feedback methods to explore how the forecasts perform outside of the top-line measure
- Use case studies where appropriate to explore forecast performance in specific circumstances where users have identified high-value weather events

5 Knowledge sharing

Solcast recognises the importance of sharing knowledge within the industry to benefit future renewable energy projects. Solcast has completed a series of knowledge sharing activities throughout the course of the Project, to promote the sharing of information and knowledge about renewable energy technologies. The objective of these exercises was to accelerate the development and growth of Australia's renewable energy sector. These include;

1. Short video presented by Dr. Engerer published on LinkedIn, announcing the start of the project.
2. Series of articles written in an informative and promotional capacity to announce the start of the project. Publications include Renew Economy, Solar Industry Magazine and the Daily Telegraph.
3. Presentations for knowledge sharing - Dr Nick Engerer, Solcast Chief Technical Officer, attended Energy Systems Integration Group (ESIG) and the Australian Meteorological and Oceanographic Society (AMOS) conferences to share results, findings and lessons learnt. Dr Engerer reached approximately 75-85 audience members at ESIG and 50 audience members at AMOS. These presentations were focused on the technical aspects of Solcast's nowcasting technology.
4. Presentations for project promotion - Dr Engerer attended the Smart Energy Virtual conference where 60 audience members were present for the Solcast workshop. Dr Engerer also attended the Solar Energy Future Australia conference to share Solcast nowcasting technology where there were 40 audience members in attendance. These presentations focused on explaining the capabilities and features of Solcast's nowcasting service to the renewable energy industry.

The main impact of these deliverables has been increasing visibility and awareness of the project. Technical content was mostly reserved for within the industry, whilst news articles and promotional material highlighting nowcast use-case scenarios was presented to the public.

6 Conclusions

The Gridded Renewables Nowcasting Demonstration over South Australia Project has demonstrated that a state-wide nowcasting system can deliver more accurate forecasts than traditional forecast systems. The Project delivered a live demonstration of forecasts including rooftop solar PV, utility scale solar, utility scale wind, and demand to a selection of energy market participants. All four forecast data types showed significant improvement over NWP forecast systems, ranging from 5 – 66 % improvement of normalised RMSE at the hour-ahead lead-time. The nowcast data demonstrates value to participants in both reducing average forecast error, and in specific high-impact weather events where it is capable of forecasting weather events that traditional models are incapable of predicting with fidelity.

The operational application of the nowcast data by Project participants was mixed. AEMO found the data highly valuable, improving renewable energy forecasting capability particularly through increased visibility of weather uncertainty. SAPN evaluated the nowcasting data as part of their network management pilot. SAPN was unable to gain material improvement from the nowcast data at this point in time due the scale of the pilot, but notes that the increased nowcasting granularity and accuracy may be beneficial to the next stages.

Gentailers Snowy Hydro and Energy Australia anticipated that the nowcast data would improve efficiency in responding to intermittent renewable energy generation through dispatch of reserve generation, but ultimately were unable to fully leverage the data due to a number of external factors unrelated to data accuracy. Asset owner Acciona was unable to extract value from the Project outcomes as it did not meet their needs for self-forecasting nor maintenance scheduling.

Outside of the specific use-cases of Project participants that have been reported on, possible applications of the nowcast data for market & network operators, gentailers, and asset owners include risk assessment, network planning, load forecasting, B2C products, Virtual Power Plants (VPP), AMDSs and Distributed Energy Resource Management Systems (DERMS). Solcast and Weatherzone will continue to explore the various use cases with users.

Solcast is continuing to develop the nowcast systems, with continuous improvements to data accuracy being the main focus of the work.

7 References and additional reading

References

Granwal, L. (2022, May 17). *Share of energy acquired from renewable sources in Australia in 2021, by state*. Retrieved from Statista: https://www.statista.com/statistics/1087804/australia-renewable-energy-penetration-by-state/

Additional reading

More information on SAPN's Flexible Exports for Solar PV Trial is available at: https://www.sapowernetworks.com.au/future-energy/projects-and-trials/flexible-exports-for-solar-pv-trial/