High level review of transmission connection point forecasts: Qld

A REPORT PREPARED FOR THE AUSTRALIAN ENERGY MARKET OPERATOR

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Executive summary

In 2012, the Council of Australian Governments (COAG) gave AEMO responsibility for developing independent maximum demand forecasts as an independent reference for the Australian Energy Regulator's (AER's) revenue reset determinations.

AEMO commissioned ACIL Allen (ACIL) to develop the original methodologies for forecasting maximum demand (MD) and energy consumption at the transmission connection point (CP) level.

AEMO engaged Frontier Economics (Frontier) to review AEMO's implementation of the methodology for NSW and Tasmanian (Tas) forecasts in 2014, and again in 2014/15 to review AEMO's implementation of the methodology to forecast maximum demand for QLD, VIC and SA. Frontier's role includes peer review and assistance to AEMO to further develop and improve the forecasting methodology, where possible. The methodology has been refined and improved during each round of CP forecasts. This report reflects Frontier's review of revisions to the original methodology and AEMO's application of the revised methodology to produce maximum demand forecasts for 103 Queensland (Qld) transmission CPs. The review and advice process included:

- a Red Flag review in which we identified key issues with proposed revisions to the methodology and its implementation for the Qld CPs
- ongoing advice and interaction with AEMO regarding the methodology and its implementation
- this report, which reflects a review of AEMO's Qld forecasts

Frontier was not required to produce an alternative set of forecasts. The review did not involve an audit-type exercise which would include a detailed review of computer code in the R statistical package and spreadsheet formulas.

Based on the scope of the review undertaken, in our opinion the maximum demand forecasting methodology that was applied for the QLD CP forecasts is robust and reflects appropriate improvements on the original ACIL methodology. On the basis of our understanding of the steps in AEMO's implementation of the methodology for the QLD CPs, AEMO has implemented the revised methodology correctly.

Frontier made a number of recommendations during prior rounds of CP forecasts (NSW and Tas, Vic and SA) and we have provided some additional recommendations for this round of Qld CP forecasts. Key developments in methodology identified and implemented during the Qld CP review include:

- Refining the statistical test for choosing between linear and cubic trends:

    - In previous forecast rounds, the choice between linear and cubic trends was based on two statistical tests: (a) a test for whether the addition of a quadratic term to the trend equation significantly improves the fit of the model, and (b) a test to check whether the most recent observation in historical data is an outlier with respect to the linear trend model. If either of these tests rejects the null hypothesis, the linear trend is replaced by the cubic trend.
    - For the Qld forecasts, Frontier recommended an alternative to the first of the tests which is more appropriate for the cubic trend alternative, which AEMO adopted and applied for these forecasts.
- Further development of the methodology for solar PV adjustments. AEMO improved the methodology to recognise more accurate solar PV output profiles for each CP. Previously, the solar PV output trace was based on a state average. In large states (such as Qld) solar output across the day will vary by CP location. AEMO has improved this methodology by developing/implementing custom solar PV output estimates by CP. Frontier reviewed and approved this methodology as part of this review.
- Recommendation of additional checks that should be applied in future forecasting rounds to ensure that POE10 is always suitably higher than POE50 forecasts, such as:
    - Check cubic horizons to ensure that POE10 horizons selected are always higher than POE50 horizons.
    - Check the gap between **reconciled** forecasts for POE10 and POE50 against the historical (normalised) gaps and manually intervene if required:
        - In Qld the historical gaps in POE10 and POE50 were typically at least 1% whereas the baseline forecasts for some CPs initially produced a distribution that was less than this. This meant that the reconciliation process resulted in forecasts for some CPs where the POE10 was below the POE50 (because the POE50 baseline forecast were scaled up by more than the POE10 baseline forecasts). This required manual intervention to adjust the baseline trends to ensure that the final reconciled forecasts for POE10 and POE50 were suitably distributed (at least 1% apart). This was achieved by applying the POE50 trend to the POE10 forecasts (though still using the POE10 starting point) for problem CPs to maintain the minimum gap.

On the basis of our review of AEMO's implementation of the maximum demand forecasting methodology for the Qld CPs, Frontier confirms that (a) the revised methodology adapted for the CP forecasts is reasonable and appropriate and (b) AEMO has correctly implemented this revised methodology to the best of our knowledge.

Our overall assessment of the methodology and implementation is that it meets the standard of good industry practice. The methodology has been implemented in a professional manner, and where issues of concern have arisen during the implementation of the methodology, all reasonable steps have been taken, within the time and resource constraints, to ensure the statistical integrity of the forecasts.

1 Introduction

1.1 Background

In 2012, the Council of Australian Governments (COAG) gave AEMO responsibility for developing independent maximum demand forecasts as an independent reference for the Australian Energy Regulator's (AER's) revenue reset determinations.

AEMO commissioned ACIL Allen (ACIL) to develop the original methodologies for forecasting maximum demand (MD) and energy consumption at the transmission connection point (CP) level.

AEMO engaged Frontier Economics (Frontier) to review AEMO's implementation of the methodology for NSW and Tasmanian (Tas) forecasts in 2014.

In 2014/15 AEMO is applying the methodology developed to date to forecast maximum demand for QLD, VIC and SA. AEMO has engaged Frontier to act as peer reviewer and advisor in this forecasting process, which includes:

- a peer review of the models, assumptions, methodology and forecasts developed by AEMO's Connection Point Forecasting team
- expert advice and guidance on the data, methodology, models and forecasts, as required; and
- identification of any issues and recommendations to address these.

Part of this role includes assistance to AEMO to further develop and improve the forecasting methodology, where possible. This report reflects Frontier's review of revisions to the original methodology and AEMO's application of the revised methodology to produce maximum demand forecasts for 103 Queensland (QLD) transmission CPs. The review and advice process included:

- a Red Flag review in which we identified key issues with proposed revisions to the methodology and its implementation for the Qld CPs
- ongoing advice and interaction with AEMO regarding the methodology and its implementation
- this report, which reflects a review of AEMO's Qld forecasts.

1.2 Scope of our review

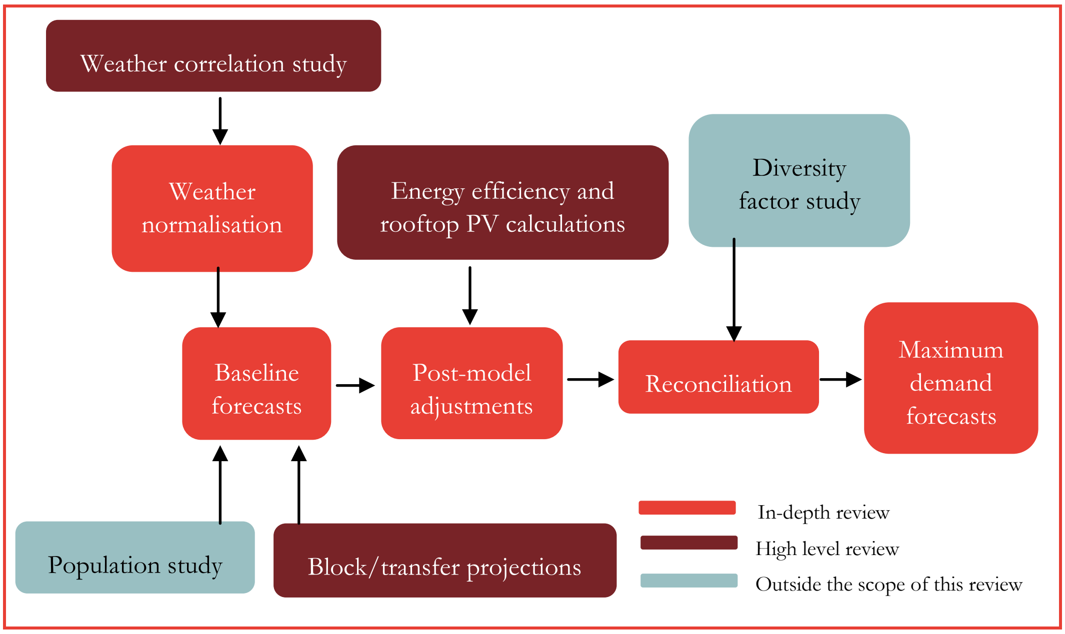
The scope of Frontier's role is to provide advice to AEMO on the maximum demand forecasting methodology (and potential improvements to the original methodology) and to review AEMO's implementation of the methodology and the resulting forecasts.

A simplified schematic representation of the steps involved in the forecasting methodology is presented in Figure 1. The scope of our engagement does not involve an in-depth review of all the steps involved in deriving the forecasts. Steps that have not been reviewed in any detail are shown as 'outside the scope of this review'.

Frontier was not required to produce an alternative set of forecasts. The review did not involve an audit-type exercise which would include a detailed review of computer code in the R statistical package and spreadsheet formulas.

In undertaking this review, we have assumed that appropriate investigations have been undertaken to select the required inputs, and that the preparation of the data used for the modelling has been performed to a professional standard. We have also assumed that the computer code has been checked carefully and does what it is intended to do (i.e. it is outside our scope to provide quality assurance or checks on the correctness of the computer code).

Figure 1: Scope of Frontier's maximum demand methodology review



Source: Frontier Economics

2 AEMO's maximum demand forecasting methodology

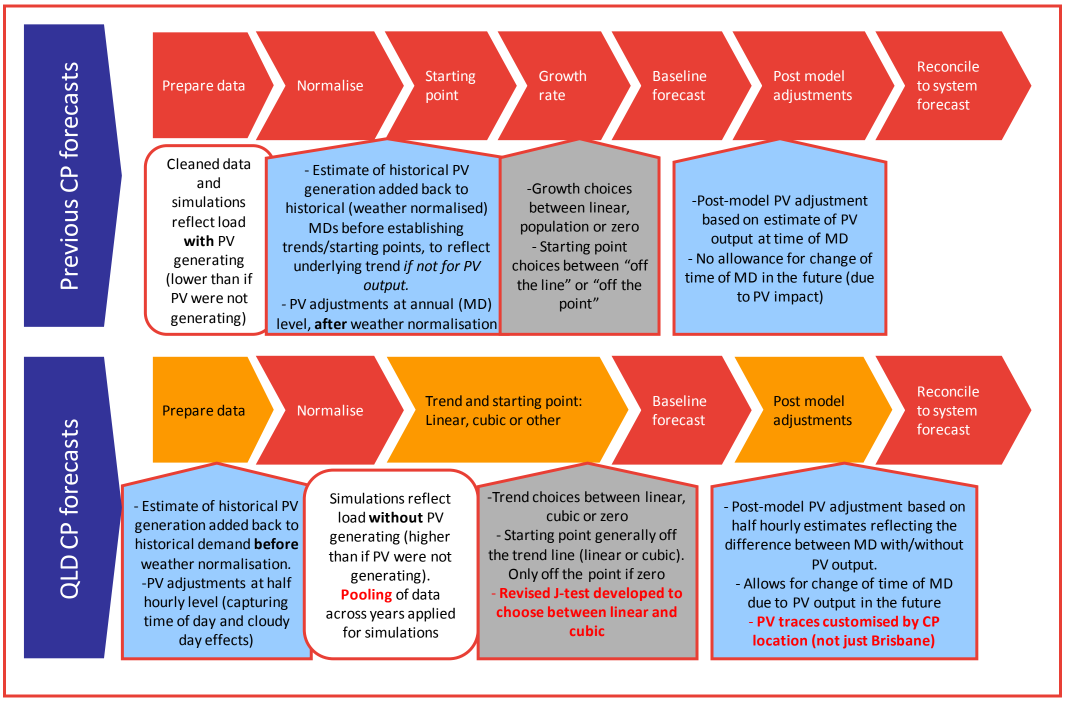
2.1 Overview

The methodology adopted by AEMO for the Qld CP forecasts is an improvement on the original methodology proposed by ACIL for forecasting maximum demand at the CP level and implemented in previous rounds of forecasts in other states.

A high level summary of the previous methodology for forecasting maximum demand at the CP level is shown in the upper half of Figure 2. The lower half of Figure 2 shows the revised methodology adopted for the Qld CP forecasts, highlighting the key changes from the previous methodology.

The steps involved in the previous approach are described in detail in the ACIL report. For the Qld forecasts some modifications were made to ACIL's proposed methodology in response to issues arising during its implementation in the previous rounds of forecasts (SA, NSW, Tas and Vic). These steps and changes are discussed in more detail in the following paragraphs. In all cases, any changes to the methodology and implementation were discussed in detail between AEMO and Frontier Economics.

Figure 2: Summary of original/revised methodology and key changes



Source: Frontier Economics

AEMO's current methodology consists of the following main steps:

1. **Data collection and manipulation**

- This step consists of the collection of load and temperature data, adjustments of load data for large industrial loads and embedded generation, and the treatment of influential and missing observations.
  - Under the original methodology, no adjustment was made for historical PV at this stage. A single PV adjustment was applied for each year/season <u>after</u> weather normalisation/simulation based on an estimate of PV output at the time of system MD.
  - Under the updated methodology, estimates of historical PV output are added back to the historical half hourly level demand, <u>prior</u> to weather normalisation. If the PV adjustments can be estimated accurately, this would better reflect the underlying trend in customer demand for each half hour (in the absence of PV).

2. **Weather normalisation**

- This step involves specification and estimation of temperature sensitivity models for daily maximum demand, followed by a simulation exercise to determine the P50 (POE50) and P90 (POE10)[1] levels of maximum demand for each historical year.
  - Under the original methodology, the weather normalised POE50 and POE 10 MD levels reflected estimates of MD when PV was generating. To estimate the underlying trend for MD at the consumer level, it was necessary to add back estimates of historical PV output to the annual historical non-coincident MDs;
  - Under the revised methodology the simulations reflect MD in the absence of solar PV generation (i.e. as if PV were not generating). Adjusting for estimates of historical PV for each half hour ideally should improve estimates of the underlying MD trends.
- On Frontier's recommendation, AEMO has also adopted and implemented "pooling" of data across years for the Qld forecasts, with year dummy variables included in the model to allow for different levels of MD in individual years.
  - AEMO previously tested the "pooling" approach during the SA CP forecasts, though this was not applied in the final SA forecasts.

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1 Throughout this report the 90th percentile (P90) corresponds to the 10% probability of exceedence (POE10).

3. Selection of a starting point for the demand forecasts &
4. Determination of a growth rate

- Under the original methodology, only linear trends were considered and decisions were made about the slope of the linear trend (growth rate) and the starting point.
  - the **starting point** was a choice between the last point on the linear trend line through the POE50 and POE10 historical demands ("off the line"), or the last actual observation for the POE historical demands ("off the point"). The choice depended on how well the trend line fit the data.
  - The **growth rate** was determined from either the linear trend line through the historical POE demands or anticipated population growth in the local area. In some cases a zero growth rate was assumed.
- The methodology was refined in previous forecast rounds because it became evident that for some CPs the time trend was non-linear or there was a structural break in the series. Hence the methodology was extended to allow for non-linear (cubic) trends. AEMO's default for extrapolating demand into the future is to use a linear trend. Alternatively, AEMO uses a cubic trend with a horizon value if the linear trend is not a satisfactory fit to the historical data. The choice between the linear and the cubic trends was originally based on two statistical tests, developed with Frontier's assistance:
  - a test for linearity and;
  - a test for whether or not the most recent observation in the historical data is an outlier.
  - If either of these tests rejects the null hypothesis, the linear trend is replaced by the cubic trend.
- For the Qld CP forecasts, Frontier recommended an improvement in the statistical test for linearity which is more appropriate for the cubic trend alternative. AEMO adopted and applied this test for the Qld forecasts.
- For Qld CPs characterised by rail, mining or industrial load, AEMO manually overrode these test results and applied a linear zero growth.
- During the Qld review, some problems also became evident in applying rules for selecting cubic horizons which resulted in POE10 and POE50 forecasts crossing in some cases. The decision rules for choosing cubic horizons were revised and this prevented forecast cross over in the final forecasts.

5. Calculation of baseline forecasts

- This is done by projecting the linear or cubic trend line to cover the years in the forecast period. In cases where a zero growth rate was selected, this growth rate was applied to the last weather normalised point. In all these cases, the weather normalised point was quite close to the fitted line.

6. **Post-modelling adjustments for photovoltaic solar generation (PV), energy efficiency improvements (EE) and block loads and transfers**

- Under the original methodology, AEMO determined the PV forecast at the CP level as a pro-rata allocation of the NEFR system level PV estimate based on the residential customers per CP. A limitation of this approach is that it implicitly assumes that all CPs have the same time of MD as the system (coincident) MD.
- Under the revised methodology, AEMO estimates the change in MD at the half hourly level with/without PV output for each CP. This requires pairing half hourly demand with half hourly PV traces. It is a more data intensive approach to accurately estimate PV output at the half hourly level, but the approach captures the effect of PV output on possibly changing the time of MD for each CP, and it also allows for different times of MD for each CP.
- For the Qld forecasts, AEMO has further improved the solar PV traces used for these adjustments. Previously, the same average solar trace was used for all CPs; but for the Qld CPs, customised PV traces were used for each CP which recognises differences in location and solar irradiation by time of day.

7. **Reconciliation of CP maximum demand forecasts to system maximum demand forecasts**

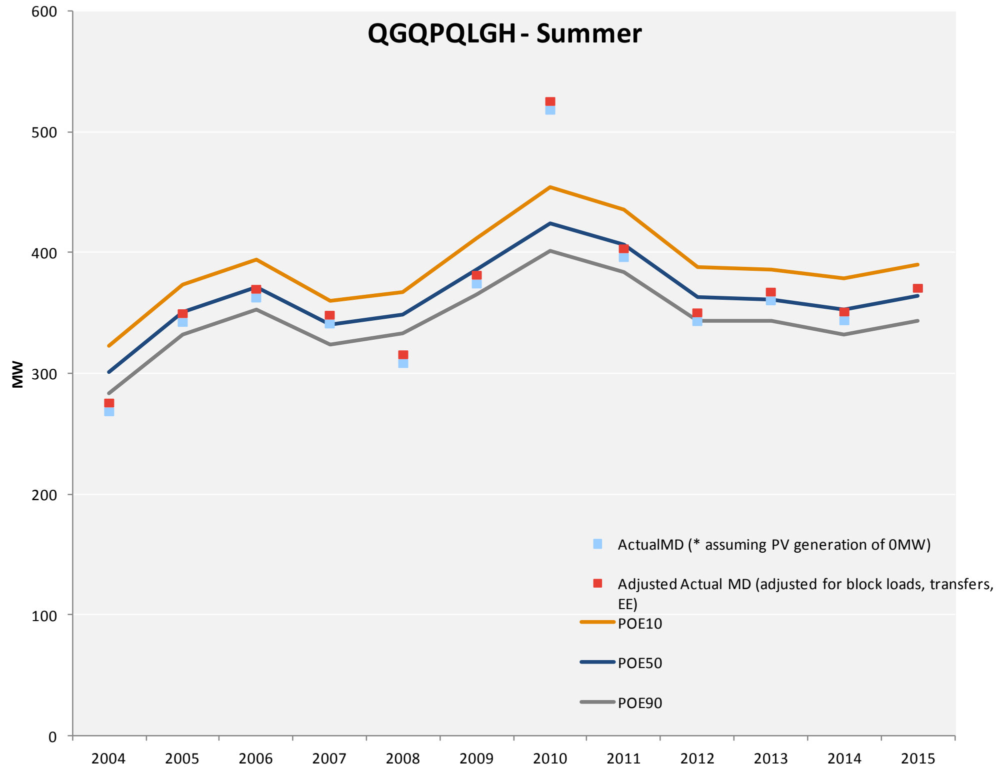
- This methodology is unchanged from before.
- Firstly, AEMO estimates a diversity factor for each CP, which reflects the ratio of the coincident demand (at the time of system level MD) to the non-coincident CP MD (at the time of the CP MD). This is based on an historical average over five years, so does not capture possible changes to the time of MD (coincident or non-coincident) or changes in the ratio. Despite this limitation, this is in line with the original methodology and is within the bounds of good industry practice. Since the non-coincident MD is always equal to or greater than the coincident MD, the diversity factors should never be greater than 100%. The review confirmed that this was the case for the Qld forecasts.
- Secondly, AEMO estimates a scaling factor to reconcile the sum of the CP coincident MDs to match the system level (regional) forecasts. Ideally these scaling factors should be close to 100% if the regional forecasts are consistent with the CP forecasts. For future rounds of forecasts, AEMO should investigate if scaling factors deviate materially from 100%, particularly in the early years of the forecasts.

2.2 Worked example of a connection point forecast

This section shows a worked example of the steps in the revised methodology, using the QGQPQLGH summer forecasts for illustration.

Steps 1 and 2: Data preparation, weather normalisation and simulation

Figure 3: Example: QGQPQLGH summer



Step 1. Data preparation. Light blue dots reflect historical actual MD with estimates of historical PV output added back (i.e. assuming PV generation of 0MW). Actual observed MDs from 2009 onwards would be lower than this since PV generation supplies some of the demand. This adjustment is made at the half hour level prior to determining MD, which is a revision to the original methodology.

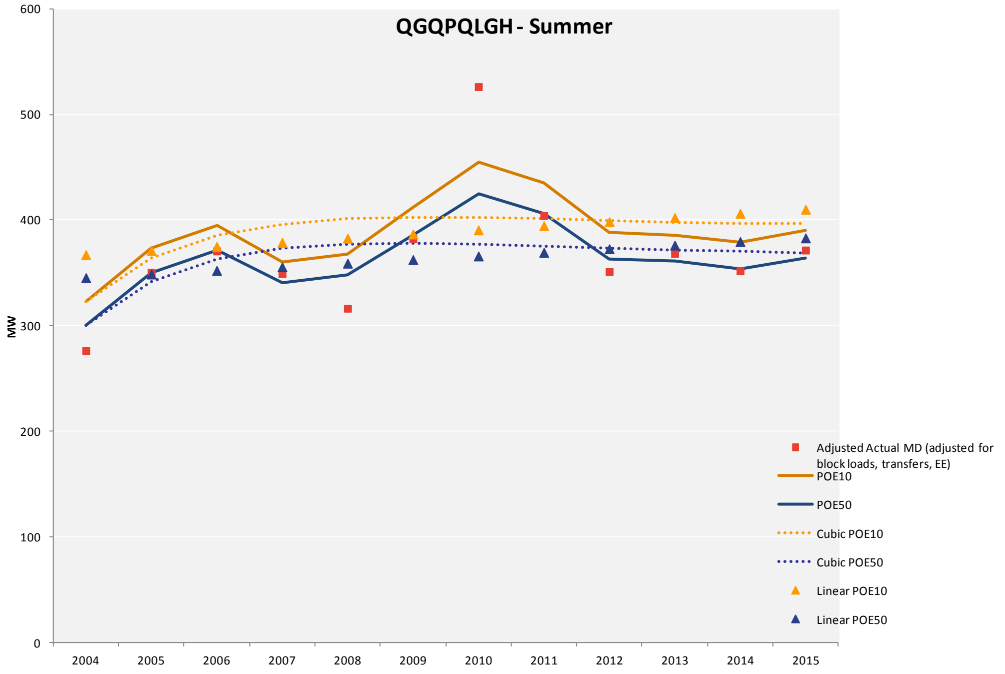
Red dots incorporate an additional adjustment to historical MDs to reflect differences between the historical years and the latest year (2014) with respect to block loads and load transfers. In this case, this results in an upward adjustment.

Step 2. Weather normalisation and simulations. The orange line reflects the POE10 MDs and the navy blue line reflects the POE50 MDs obtained from the simulation. Around half of the red dots should be above the navy blue line, and around 10% should be above the orange line (on average).

Source: Frontier Economics analysis of data provided by AEMO

Steps 3 & 4: Trend and starting point

Figure 4: Example: QGQPQLGH summer, Trend and starting point (trend selection)

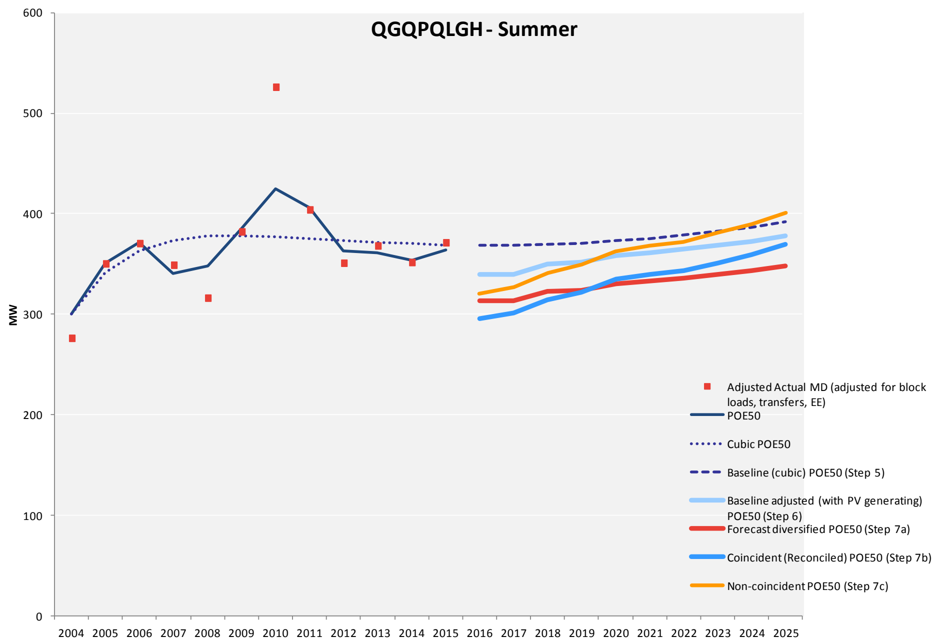


Steps 3 & 4. Cubic and linear trends estimated and statistical tests applied. For QGQPQLGH summer, the test found that the linear trend should be rejected and a non-linear trend should apply. Hence the cubic (dashed line) was chosen for the growth rate for each of the POE50 and POE10 demands. The starting point in this case is the last point on the cubic trend line.

Source: Frontier Economics analysis of data provided by AEMO

Steps 5, 6 & 7: Baseline forecasts, post-model adjustments, reconciliation

Figure 5: Example: QGQPQLGH summer, POE50: Baseline forecast, post-model adjustments and reconciliation (final forecasts)



Step 5. The **navy blue dashed line** shows the Baseline forecasts, which reflect the starting point and trend for the cubic trend line (selected in the previous step).

Step 6. The **light blue line** reflects the Baseline forecast adjusted for (1) block loads and transfers, (2) less post-model adjustments for future EE and (3) PV. This provides an unreconciled, non-coincident MD estimate. For this CP, the initial adjustment for block loads is a reduction in MD, though this is positive (an increase in MD) from 2018. The adjustment for EE only reflects a deviation from the historical trend: in this case the EE trend is toward *more* energy efficiency, which reduces the future MD forecasts downward. The adjustment for PV reflects an estimate of the total contribution of PV to reducing future MD. The adjusted forecast will start lower than the historical actual MDs (simulated MDs), as the historical actual MDs have PV output added back (i.e. the forecast is not directly comparable to the historical given that under this methodology, adjustments for PV are now made **before** the simulations). This is illustrated in the stylised example in Figure 7. In summer the PV contribution for this CP is around 20MW, which reduces the forecasts down.

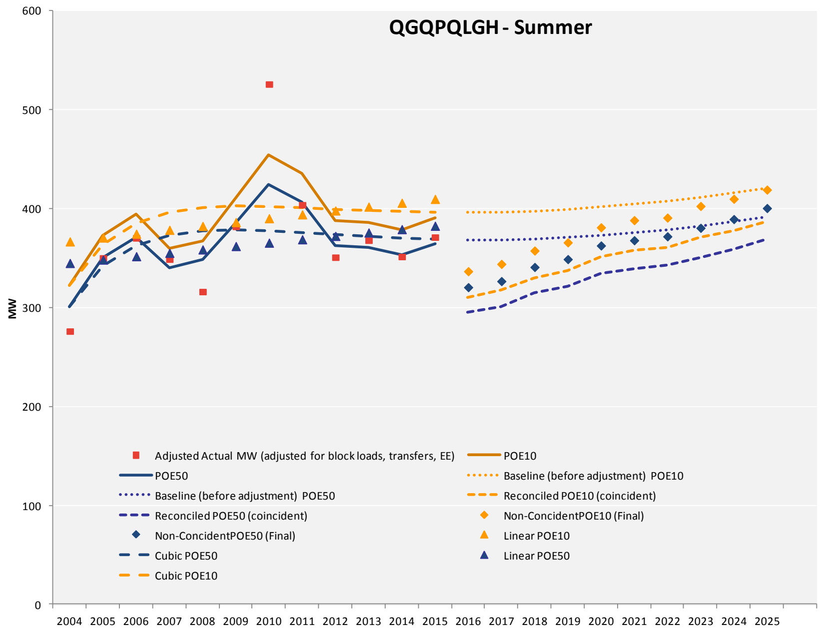
Step 7a. AEMO multiplies the Adjusted Baseline (light blue) by the diversity factor at that CP. The diversity factor is the historical ratio of the average CP demand at the time of the system MD to the CP demand at the time of the CP MD (**red**: this is the **unreconciled coincident MD**). Diversity factors will differ by CP, but under this methodology are constant over time for each CP. Diversity factors should always be less than 100% (this shift should always be down). For this CP the summer diversity factor is 92%.

Step 7b. AEMO scales the diversified MD of each CP so that the sum of the diversified MDs matches the regional (coincident) MD (**mid blue: reconciled coincident MD**). The same scaling factor is applied to all CPs, though a different scaling factor is applied by season and by POE. Scaling factors also differ over time, and can be greater or less than 100%, depending on whether the CP forecasts are higher/lower than the regional forecasts (ideally close to 100%). In the case of summer POE50, the scaling factors start at 92% and rise to 103%, so the mid blue line is below the red line initially (when scaling is <100%) and above the red line when scaling is >100%. This suggests that the regional forecasts increase more quickly than the sum of the CP forecasts (prior to reconciliation).

Step 7c. AEMO divided the reconciled coincident MD (mid-blue) by the diversity factor at each CP to obtain a reconciled **non-coincident final MD forecast** (**orange**). This shift should always be up (non-coincident MD should always be greater than coincident MD).

Source: Frontier Economics analysis of data provided by AEMO

Figure 6: Example: QGQPQLGH summer, POE50 and POE10: Final reconciled forecasts, coincident and non-coincident



Source: Frontier Economics analysis of data provided by AEMO

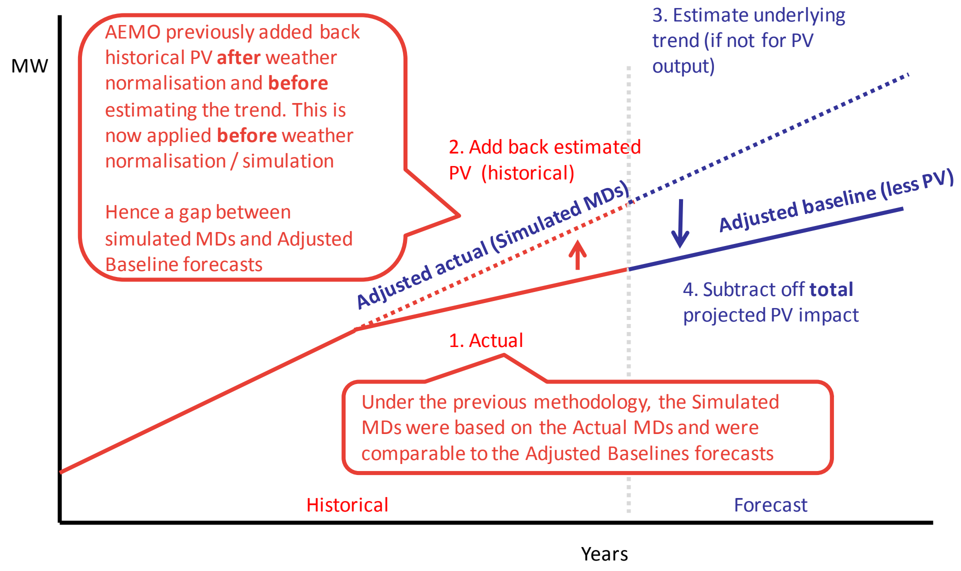
Stylised example of PV and EE adjustments

Figure 7 and Figure 8 show stylised examples of the difference in treatment of PV adjustments and energy efficiency (EE) adjustments. Figure 7 also illustrates the difference between the historical simulations (which reflect PV output of 0MW) and the baseline adjusted forecasts (which reflect a positive PV output and hence lower MD forecasts).

For PV, estimates of the total historical PV are added back to the historical MDs, the underlying trend is estimated and projected into the future (reflecting demand with PV not generating), and then estimates of the total PV impact in future are subtracted off the future forecasts. As discussed later, the PV "impact" on future MD is the estimated change in MD with/without PV in the future which, due to a possible change in the time of MD with/without PV, is not the same as estimated PV output at any given time.

EE is treated differently: historical EE is not added back to historical MD, hence the underlying trend that is estimated reflects the impact of EE. The methodology assumes that the impact of EE on MD is linear and continues to grow in the future at the same rate as in the past. Hence, the EE adjustment to future MD forecasts reflects only an estimate of the deviation from the historical, linear trend for EE impacts (which is less than the total EE impact).

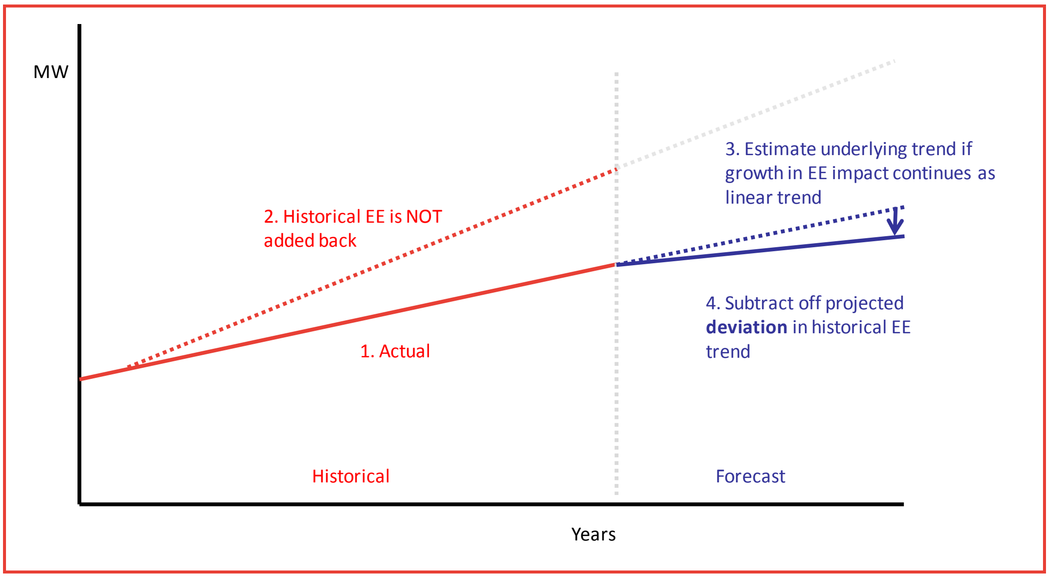
Figure 7: Methodology for PV adjustments



Note: Previously, future PV adjustment was based on pro-rata of NEFR, assuming same time of MD for all CPs. For the Qld forecasts, the PV estimates differ for each CP reflecting (a) a different time of MD for each CP (and allowing for changes over time) and (b) a customised PV output trace for each CP. Hence the sum of the CP PV adjustments can be larger than in the NEFR.

Source: Frontier Economics

Figure 8: Methodology for EE adjustments



Source: Frontier Economics

3 Review of AEMO's implementation of forecasting methodology

In this section we review AEMO's implementation of the revised forecasting methodology compared with that outlined in the ACIL Report and implemented in previous forecasts for other states.

Table 1: Summary of methodology, changes and recommendations

Step	Original methodology	Implementation (and modifications adopted) for Qld	Improvements to consider in future
Data preparation	Prior to undertaking regression modelling, daily maximum demand and weather data should be modified to: • remove known block load and transfers, as these are exogenous • remove weekends and public holidays • remove 'mild' days and potentially misclassified days (which appear as outliers). **No adjustments were made for historical PV at this stage in the original methodology.**	On Frontier's recommendations, for the QLD forecasts AEMO adjusted historical data for block loads and load transfers and added PV load ***before*** weather normalisation and simulations. AEMO changed the "base year" for block loads/ transfers to reflect the last year of the data (as opposed to the first). This is consistent with the approach previously adopted for the SA forecasts. This required AEMO to estimate historical PV output for each half hour, as opposed to a single estimate of historical PV output for each year/season. Frontier has not inspected the files or data where AEMO applied these historical PV adjustments, as this is highly data intensive. ***The methodology as described is reasonable and appropriate and in theory provides a more robust estimate of the underlying MD trend (without solar PV output) than the previous approach. This is subject to the calculation of estimated PV output at the half hour level given that this is not measured. From our review, the PV output estimates appear reasonable at the half hour level.*** Frontier has not inspected the data showing removal of major industrial load or the addition of embedded generation. We understand that in some cases (non-permanent events) data was not available and AEMO has made judgment calls on appropriate block load/transfer adjustments.	***The revised methodology applied for historical PV adjustments (and applying these prior to weather normalisation) reflects an improvement in methodology. Frontier recommends that this should continue to be applied/ considered in future implementations.***

Step	Original methodology	Implementation (and modifications adopted) for Qld	Improvements to consider in future
Weather normalis-ation	To weather normalise the maximum demand: • for each historical year, estimate a model of daily maximum demand as a function of temperatures • for each historical year, use this relationship to simulate a distribution of hypothetical historical annual peak demands under different weather scenarios and random influences • determine the POE50 and POE10 levels of peak demand for each year from these distributions	**No modifications to methodology were adopted for the final forecasts other than that adjustments to historical load were undertaken prior to weather normalisation.** **Weather normalisation:** Frontier has previously recommended pooling observations across years when estimating maximum demand-temperature models in order to more effectively use the available data. AEMO tested the pooling approach for the SA forecasts and, in line with Frontier recommendations, implemented the approach for the Qld forecasts. The approach pools 3 years of data when estimating temperature sensitivity models (1 year before/after the year of interest) and year dummy variables are included to allow for differences in the level of MD between years. **Weather simulations:** The distribution for maximum demand produced by AEMO's simulation procedure should be inspected to confirm that, on average, about 50% of the historical actual MDs do lie above the POE50 levels, and about 10% lie above the POE10 levels. ***Frontier recommended reviewing the weather simulation results against historical actual data and this review was undertaken for the QLD CPs. In most cases the simulation results appear within the bounds of reasonableness.***	***Frontier recommends that AEMO continue to apply data pooling for weather normalisation in future forecasts.***

Step	Original methodology	Implementation (and modifications adopted) for Qld	Improvements to consider in future
Estimate historical trends	Prior to estimating the trends, AEMO adjusted historical POE values for block loads and load transfers, and adds PV load to identify the underlying MD trend (if not for the impact of solar PV). Regression is used to fit linear trends through the historical POE50 and POE10 values.	PV adjustments In the modified methodology, adjustments for historical PV are made prior to weather normalisation/simulation rather than after, so no further PV adjustment is required at this stage. Cubic trends Some trends in the historical data are non-linear. When this is the case, it is inappropriate to use a linear trend line to determine the growth rate. AEMO fitted linear and cubic trends through the historical POE50 and POE10 values. Choice of horizon for cubic trends Fitting the cubic trend requires the choice of a horizon value, which is typically based on the historical maximum demand. Frontier previously recommended consideration of alternative horizon values, in particular the historical minimum demand where the demand trend is falling. AEMO adopted this approach for the Qld forecasts, though in the initial application of mechanical horizon rules this occasionally led to higher POE50 forecasts than POE10 forecasts (where the POE50 used the maximum and the POE10 used the minimum). These problem forecasts were identified and corrected during the review. ***The final approach appears reasonable and has been appropriately applied for the Qld forecasts.***	***POE10/50 crossover (horizon values)*** ***For future implementations, AEMO should review horizon choices to ensure that POE10/POE50 cubic forecasts do not cross over.***

Step	Original methodology	Implementation (and modifications adopted) for Qld	Improvements to consider in future
Select starting point for projecting forecasts	The starting point for forecasting is based in the last year for which actual data are available. ACIL recommends that, depending on how far the last observed point deviates from the trend line, the forecasts should start either: • "off the point": taking the most recent weather normalised observation, or • "off the line": taking the corresponding point on the fitted time trend line through the weather normalised data. During previous CP forecasts for other regions, Frontier recommended two statistical tests to determine whether the trend model is "well specified", in which case "off the line" should be used as the starting point.	When the linear trend was applied for a forecasts, the starting point applied was "off the line", consistent with the previous methodology. This is equivalent to projecting the estimated trend line to the years to be forecast. This methodology was revised to include an appropriate alternative when the cubic trend was applied. In this case, the estimated cubic trend line was projected to the years to be forecast. Where a zero trend was applied, the starting point was "off the point". During the Qld forecasts, Frontier recommended an improved statistical test to help determine whether to apply a linear or cubic trend (and hence starting point): discussed below. ***This approach appears reasonable and appropriate and was implemented by AEMO in the final forecasts.***	**Frontier recommends that AEMO continue to apply the revised statistical tests for linear/cubic trends.**

Step	Original methodology	Implementation (and modifications adopted) for Qld	Improvements to consider in future
Determine the trend	ACIL proposes that two approaches be investigated to determine the growth rate: (i) fitting a linear time trend regression model through the historical POE50 and POE10 series; and (ii) estimating a regression model with regional population as the driver. The approach with the better fit to the data is used to determine the future growth rate, provided that the estimated growth rate seems reasonable. If the growth rate does not seem reasonable, a zero growth rate is assumed. In previous CP forecasts for other regions, Frontier provided a statistical test to determine when use of the linear time trend model for producing forecasts was inappropriate due to nonlinearity. In cases where the statistical test rejected the use of the linear trend model for producing the forecasts, Frontier recommended using judgement to determine an appropriate alternative trend to use.	Linear and cubic trends were fitted to the historical data (above), and statistical tests were applied to determine the appropriate trend to apply for the forecasts. For the Qld forecasts, Frontier recommended an alternative test for linearity which is more appropriate for considering the cubic alternative. AEMO has adopted and applied this modified test for the Qld forecasts. The basis for choosing a linear or cubic trend was the result of the statistical tests, subject to possible override based on judgement. For example, If the tests accepted **<u>both</u>** linearity and found that the last point was not an outlier then the default position was to adopt a linear trend If **<u>either</u>** the hypothesis of linearity is rejected (accepting non-linearity) **<u>and/or</u>** the last point is deemed to be an outlier then the fallback position is to adopt a cubic trend AEMO correctly applied this revised test for the Qld forecasts, using a statistical threshold of 5%. A trend of zero was applied in cases where there was insufficient data to apply the tests or where the CP load was rail, industrial or mining. ***This approach is reasonable and appropriate and was implemented by AEMO in the final forecasts.***	Frontier recommends that AEMO continue to apply the revised statistical tests for linear/cubic trends. For the Qld forecasts, AEMO adopted a statistical threshold for these tests of 5%, which tends to favour a linear trend over cubic. For future forecasts, Frontier recommends that AEMO also consider and test a 10% threshold for the statistical threshold and visually review the results to observe whether more cubic trends appears more appropriate given the data.
Baseline forecasts	Apply the selected (linear) growth rate to the selected starting point to produce baseline forecasts	As above, the revised approach includes linear <u>or cubic</u> trends. ***The recommended approach was implemented by AEMO in the final forecasts. (This is an outcome of the starting point and trend determined above.)***	

<table>
<tr><th>Step</th><th>Original methodology</th><th>Implementation (and modifications adopted) for Qld</th><th>Improvements to consider in future</th></tr>
<tr><td>Post-model adjust-ments</td><td>Make post model adjustments to take into account factors that are known but not yet incorporated into the trend forecasts. Factors include:
• new large block loads, load transfers
• energy efficiency and the uptake of solar PV
Energy efficiency: AEMO adjusted CP forecasting for EE based on a pro-rata adjustment of the NEFR EE estimate for the state (based on customers per CP for building EE and residential customers per CP for appliance EE).
Solar PV: AEMO adjusted CP forecast for PV based on a pro-rata adjustment of the NEFR statewide PV estimate at time of MD. This was adapted to reflect the same time of (region) MD for POE50 and POE10.</td><td>Energy efficiency
This is unchanged from before, and the approach is reasonable and appropriate
Solar PV
The previous approach was consistent with the NEFR and relatively simple to apply given data availability and time constraints. However, one limitation of the previous PV approach is that it implied that all CPs have the same time of MD (which was the same as the statewide MD). This implied a “coincident PV” output.
For the Qld forecasts, AEMO adopted the approach adopted for the SA CP forecasts. This combined a half hourly trace of demand without PV with a half hourly trace of PV output (scaled to installed capacity) to estimate half hourly profiles with/without PV for each CP. This provided estimates of (a) the change in time of MD with/without PV for each CP for each year, (b) the level of MD for each CP with/without PV, and (c) the difference between the two, which reflects the contribution of PV to reducing the MD. This last term is not an estimate of the actual PV output at either time of MD (with/without PV), but it is a better estimate of the impact of PV on MD where PV is causing a change in the time of MD.
For example, if PV output was causing the MD to shift from midday to evening:
- PV output at midday would likely overestimate the impact of PV on MD;
- PV output at night would likely underestimate the impact of PV on MD;
- the net impact of PV on MD would lie between the two.
AEMO further improved the SA PV approach in the Qld forecasts by using a more accurate (customised) PV trace for each CP; previously AEMO used the same average PV trace for each CP, which did not entirely capture small differences in PV output by CP location/time of day
The revised approach adopted by AEMO is reasonable and appropriate and an improvement on the previous methodology.</td><td>The revised methodology applied for future (post model) PV adjustments is a further improvement in methodology. Frontier recommends that this should continue to be applied/considered in future implementations.</td></tr>
</table>

Step	Original methodology	Implementation (and modifications adopted) for Qld	Improvements to consider in future
Recon-ciliation with system forecasts	Scale the individual connection point forecasts so that the totals of the CP forecasts match the system level (regional) forecasts. AEMO estimates the diversity factor for each CP by averaging the annual diversity factors for the latest five years.	***No change in methodology was adopted for this implementation*** The switch from day peak to night peak due to increasing PV is likely to affect the relationship between maximum demand and coincident maximum demand, and hence the diversity factor. ***Frontier will work with AEMO to address this issue in future implementations*** The scaling factors for the Qld CPs appear to be reasonable. In summer, the scaling factor commences at around 92-94% and rises over time. It appears quite stable over time and close to 100%, suggesting consistency between the NEFR and the CP forecasts. In winter, the scaling starts near 100% but increases over time to around 120% by the end of the forecast period, suggesting that the regional forecasts grow more rapidly than the CP forecasts. The source of this discrepancy should be investigated in future implementations. ***Frontier will work with AEMO to address this issue in future implementations*** The scaling factor for POE10 is consistently larger than for POE50 for summer and winter. There is no theoretical reason why this should be the case. It suggests that the simulated spread of MDs due to weather conditions is larger in the system level forecasts than in the CP forecasts. The reason for this most likely lies in the different approaches used to develop the weather simulations. The reconciliation exercise overcomes the discrepancy between the approaches to some extent, but the source of the discrepancy should be investigated. ***Frontier will work with AEMO to address this issue in future implementations***	***Frontier will work with AEMO to*** ***(a) consider the potential for estimating changes to diversity factors over time (to reflect future changes to the time of MD) and*** ***(b) understand why scaling factors are increasing over time, and higher in POE10 cases than POE50***

3.1 Weather normalisation

3.1.1 Methodology

ACIL's approach to weather normalising maximum demand consists of two main steps:

- estimating a regression model to determine the temperature sensitivity of the daily maximum demands in a season
- using this model to simulate the annual maximum demands under many different weather scenarios. The simulations also incorporate a random term that varies from simulation to simulation. The random term encapsulates unobserved idiosyncratic factors that impact maximum demand.

The simulation step results in a distribution of hypothetical annual maximum demands for each historical year. The maximum demand for each year at any level of POE can be obtained from the corresponding percentile of this distribution.

3.1.2 Pooling

Frontier has previously recommended pooling the data across years when estimating the temperature sensitivity models.[2] Using a sample that covers several years has the following benefits:

- it increases the range of temperatures included in the estimation which leads to more precise estimates of the coefficients. The increased spread of temperatures also overcomes the problem that in mild years it is difficult to obtain statistically significant coefficients because the weather was too mild to evoke much demand response. Both of these factors will result in less instances of a CP being deemed to be not temperature sensitive.
- it increases the sample size, which further improves the precision of the estimates.
- it smoothes the estimated temperature sensitivity coefficients over time, which will result in less volatile weather normalised demands. This should also benefit the step where a trend line is fitted through the POE50 and POE10 historical maximum demands.

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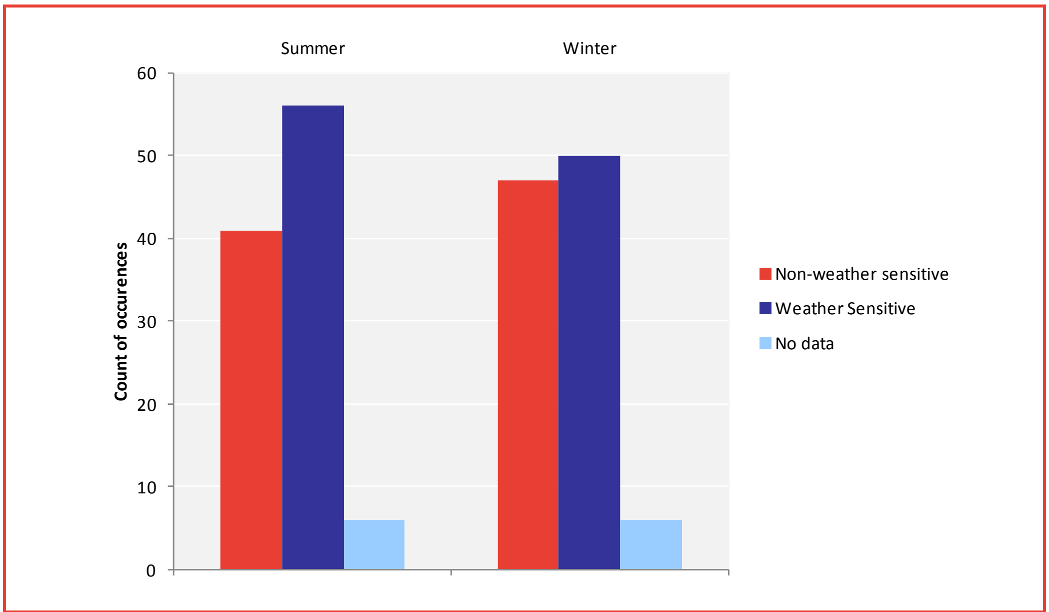
2 The pooled model recommended by Frontier includes yearly dummy variables to capture differences in the average level of demand from year to year. But determining the best approach to pooling the data across years requires further investigation.

AEMO investigated the pooling of data in a previous round of forecasts for NSW and Tas but did not implement it due to time constraints and to adhere to the original published methodology.

In the previous SA CP forecasts, AEMO tested the pooling approach (without year dummy variables) and judged that further investigation was required before implementing it. For the Qld forecasts AEMO has adopted the pooling approach (as recommended by Frontier). The pooling approach adopted is based on pooling data over 3 years, and the model includes year dummy variables to capture differences in the level of MD between years.

Figure 9 summarises the count of temperature sensitivity by CP in Qld.

Figure 9: Temperature sensitivity of Qld CPs



Source: Frontier Economics analysis of data provided by AEMO

3.1.3 Review of temperature model / simulation results

The distribution for maximum demand produced by AEMO's simulation procedure should result in, on average, about 50% of the historical actual adjusted MDs below the POE50 levels, and about 90% below the POE10 levels.

As an example, the results for QGQPQLGH summer are shown in Figure 10. Comparing the "adjusted actuals" (navy blue dots) against the simulations, 58% (7 out of 12) are below the MW POE50 simulations (navy dotted line) and 92% (11 out of 12) are below the MW POE10 simulations (red dotted line).

In general, the simulations appeared reasonable when compared with historical adjusted actual MDs across the CPs. Where the results did not seem reasonable, AEMO refined the temperature model and/or the mild-days definition to improve the alignment of POE values with actual MDs.

Across all CPs and historical years (with available data) 89% of adjusted actual MDs are below the summer POE10 simulations and 64% are below the POE50 simulations (weighted by the number of occurrences by CP and years, not load). This suggests that the simulations may be marginally on the high side, as this last figure should be closer to 50%.

Similarly, if we divide the POE50 simulations by the adjusted actual MDs, then we would expect these to average around to 100% across all years/CPs (reflecting a close fit). The average of the POE50 divided by the adjusted actual MD across all Qld CPs/historical years (weighted by count of occurrences as opposed to load) is 105% in summer, which is marginally higher than expected. However, when we estimate the weighted average of these (by load) then the average of the POE50 divided by the actual adjusted MDs is 101.7%, which is a closer fit.

For winter, 79% of adjusted actual MDs are below the winter POE10 simulations and 56% are below the POE50 simulations (weighted by count of occurrences by CP and years, not load). This suggests that the simulations are a reasonable fit.

The average of the POE50 divided by the adjusted actual MDs across all Qld CPs/historical years (weighted by count of occurrences as opposed to load) is 101% for the Qld CPs in winter, which appears reasonable. When we estimate the weighted average of these historical simulations (weighted by load) the ratio of the POE50 simulations to actual adjusted MDs is 99.2%, which is a reasonable fit.

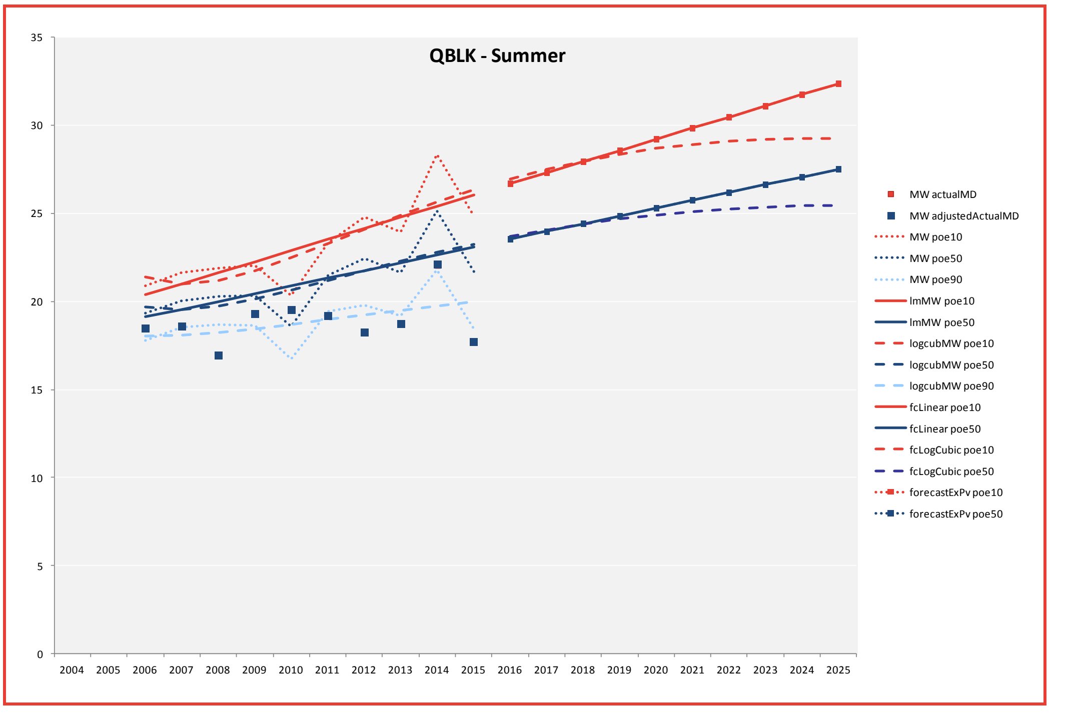
Figure 10: Example: QGQPQLGH summer

Source: Frontier Economics analysis of data provided by AEMO

Future recommendations

We recommend that in future AEMO undertake similar statistical analysis of simulation results to complement the visual reviews. For example, counts of simulations>adjusted actuals can identify potentially problematic CP simulations. Figure 11 shows that for QBLK summer, 9 out of 10 simulated POE50 points (MW POE50: navy dotted line) are above the adjusted actual MD (navy blue dots), suggesting that the simulations are on the high side. In aggregate, there are few CPs with such problems in the final forecasts, however, where possible, AEMO should review the exclusion rules and adjustments for CPs where simulated results appear too high or low.

Figure 11: Example: QBLK summer



Source: Frontier Economics analysis of data provided by AEMO

3.2 Historical trends in MDs and starting points for the forecasts

3.2.1 Previous methodology

ACIL's original methodology to determine growth rates includes fitting a linear trend line through the historical weather normalised MD data. However, for a number of CPs it appears that the time trend is non-linear or that there is a structural break in the series.

The methodology was extended in previous forecasts rounds (SA) to account for non-linear trends. AEMO's default for extrapolating demand into the future is to use a linear trend. Alternatively, AEMO uses a cubic trend with a horizon value if the linear trend is not a satisfactory fit to the historical data. In previous forecast rounds, the choice between the linear and the cubic trends was based on two statistical tests, developed with Frontier's assistance:

(a) a test for non-linearity which tests whether the addition of a quadratic term to the trend equation significantly improves the fit of the model, and

(b) a test to check whether or not the most recent observation in historical data is an outlier with respect to the linear trend model.

If either of these tests rejects the null hypothesis, the linear trend is replaced by the cubic trend.

For the Qld CP forecasts, Frontier recommended an improvement to the test for the non-linear trend which takes account of the cubic trend alternative to the linear trend. This test is discussed below.

3.2.2 New development in the methodology (Qld forecasts): J-test

The two statistical tests were developed at a time when the cubic trend model had not yet been adopted. At that time the alternative to the linear model was a subjective trend extrapolation from the last actual data point ("off the point"). For the Qld forecasts, Frontier recommended an alternative to the first of the tests which is more appropriate for the cubic trend alternative that was adopted by AEMO and applied for these forecasts. We recommend that this test continue to be used instead of the previous quadratic trend test to test for non-linearity. The outlier test should still be used as it is presently.

3.2.3 Application of the test

Table 2 summarises the number of instances when the tests determined that a linear or non-linear trend should be applied in Qld, including where manual adjustments were applied to the trend implied by the statistical tests. Where there was insufficient historical data (NA), a zero trend was applied. In some other cases, a zero trend was imposed where the CP reflected rail, industrial or mining load (which is assumed to remain relatively constant), despite the result of the statistical tests. This applied to 20 CPs. Table 2 summarises the test results (and final trends applied) in summer and Table 3 provides the same summary for winter.

Table 2: Trends applied to Qld CPs: Summer

Trend	Trend based on tests	Modified trend		
		Linear	Cubic	Zero
Linear	61	51	0	10
NA (insufficient data)	17	0	0	17
Cubic	25	0	18	7
Total number of CPs	**103**	**51**	**18**	**34**

Source: Frontier Economics analysis of data provided by AEMO

Table 3: Trends applied to Qld CPs: Winter

Trend	Trend based on tests	Modified trend		
		Linear	Cubic	Zero
Linear	53	47	0	6
NA (insufficient data)	22	0	0	22
Cubic	28	0	18	10
Total number of CPs	**103**	**47**	**18**	**38**

Source: Frontier Economics analysis of data provided by AEMO

3.2.4 Future recommendations

We agree with the enhancement to the methodology and with AEMO's application of these modifications in the Qld CP forecasts.

The results in the Qld forecasts are based on an assumed threshold of 5% for the statistical tests, which will tend to favour the null hypothesis that a linear trend is preferred over a cubic trend. Having inspected graphs of the outcomes of this threshold, we recommend that in future forecast rounds, AEMO should also consider a higher threshold (10%) for the test and compare the results to determine if this provides better fits to the data.

3.3 Solar PV adjustments

The original methodology applied for PV adjustment was a reasonable approach given time constraints and data availability, but some limitations were identified in both the pre-model adjustments and post-model adjustments for PV.

The methodology was revised for the SA forecasts to attempt to improve the forecasts and address these limitations. The improved approach has been applied again for the Qld forecasts, with further improvements included to reflect customised PV output/adjustments applicable to each CP (as opposed to the same PV output trace for all CPs) to reflect differences in CP location.

3.3.1 Pre-model adjustments for PV

Original methodology

Under the original methodology, a single PV adjustment was applied for each year/season *after* weather normalisation/simulation based on an estimate of PV output at the time of MD. This is a manageable and implementable approach (as estimated PV output can be derived from the NEFR) but it implicitly assumes that either the MD for each CP is at the same time as the MD for the region or that the PV contribution is the same (if the time of MD is different). Although PV only begins to affect MD after around 2010 (when installed capacity increases) this may have an effect on estimates of the underlying trends if the time of CP MD differs from the statewide MD (and PV output would be different for each).

Revised methodology

Under the updated methodology, estimates of historical PV output are added back to historical half-hourly demands *prior to* weather normalisation. If the PV adjustments can be estimated accurately then this should better reflect the underlying demand trend (in the absence of PV) for each half hour, capturing differences in time of day and the "cloudy day" effects (when solar radiation was lower on some days).

This revised approach was first implemented in the SA forecasts using the same solar PV output trace for all CPs. Although this approach was an improvement, one limitation of using a single PV trace is that it doesn't fully reflect location differences by CP. In general, the PV output trace should be marginally earlier in the day for eastern CPs and slightly later in the day for western CPs. For the Qld forecasts, AEMO has applied customised PV traces developed by the University of Melbourne University for each CP. This should address the minor issue of differences in CP location (and PV output) and reflects an improvement on the SA PV methodology.

Frontier did not review the actual calculations (as this was beyond the scope of the review) but the methodology appears sound and reasonable and worth implementing in future forecasts.

One implication of these revisions to the methodology is that the "Actual MDs" (historically) that form the basis of the simulations are after PV adjustment (i.e. reflect underlying demand, assuming 0MW PV output). This is not comparable to the actual MDs used for the simulations in prior forecasts (which reflect underlying demand less PV output). This also means that the historical actual MDs (which are now based on 0MW PV) should be compared with the final unreconciled forecasts *prior* to the post-model PV adjustments; previously, these would be compared against the final unreconciled forecasts *after* the post-model PV adjustments.

3.3.2 Post-model solar PV adjustments

Original methodology

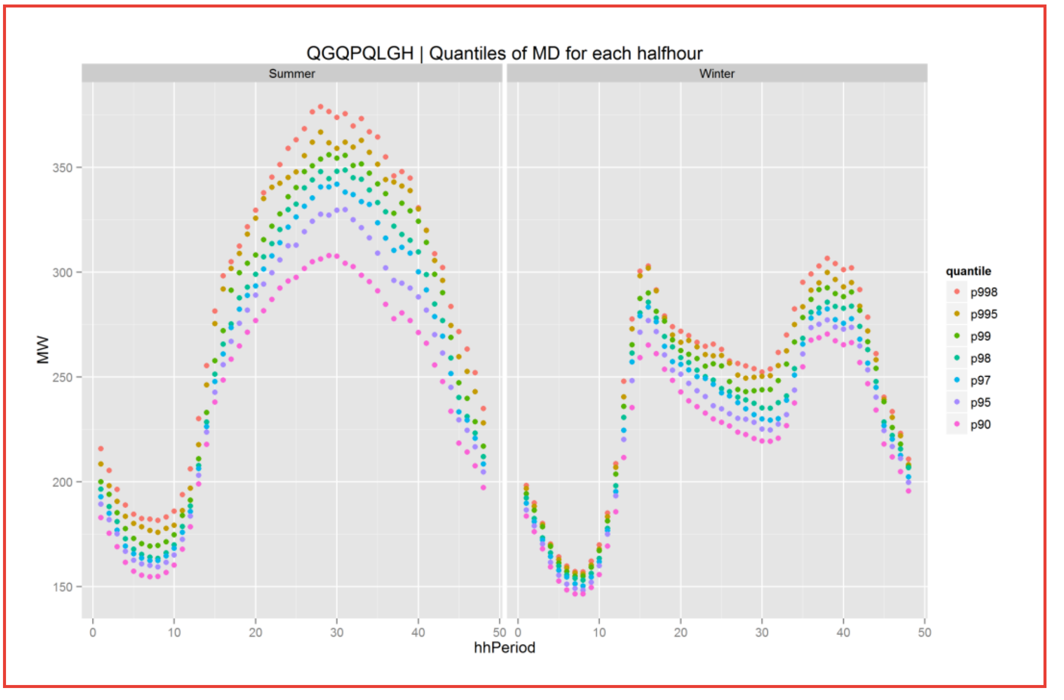
Under the previous methodology, AEMO determined the PV forecast at the CP level as a pro-rata allocation of the NEFR system level PV estimate based on the residential customers per CP. This is a reasonable approach given time and data constraints, but a limitation is that it implies that all CPs have the same time of MD as the system (coincident) MD, or otherwise that PV output is the same at both times. This is potentially a problem where there is a shift in the time of the regional MD from the middle of the day (high PV output) to the evening (low PV output).

Revised methodology

Under the revised methodology, AEMO estimates the change in MD at half hourly level with/without PV output for each CP. This requires pairing of half hourly demand with half hourly PV traces. This is a more data intensive approach to accurately estimate PV output at the half hourly level, but if this can be reasonably estimated given the available data, then the approach should better capture the effect of PV output on changing the time of MD for each CP, and allow for different times of MD for each CP.

As an example, **Error! Reference source not found.** shows a typical trace for demand across a day at QGQPQLGH if PV output were zero.

Figure 12: Hourly demand trace example, QGQPQLGH (PV output of zero)



Source: AEMO

The 98th percentile of this demand trace (with zero PV) is then combined with an estimate of PV output across the day <u>for that CP</u> (i.e. the estimated PV output is subtracted from the demand trace). The estimated PV output at each CP is based on:

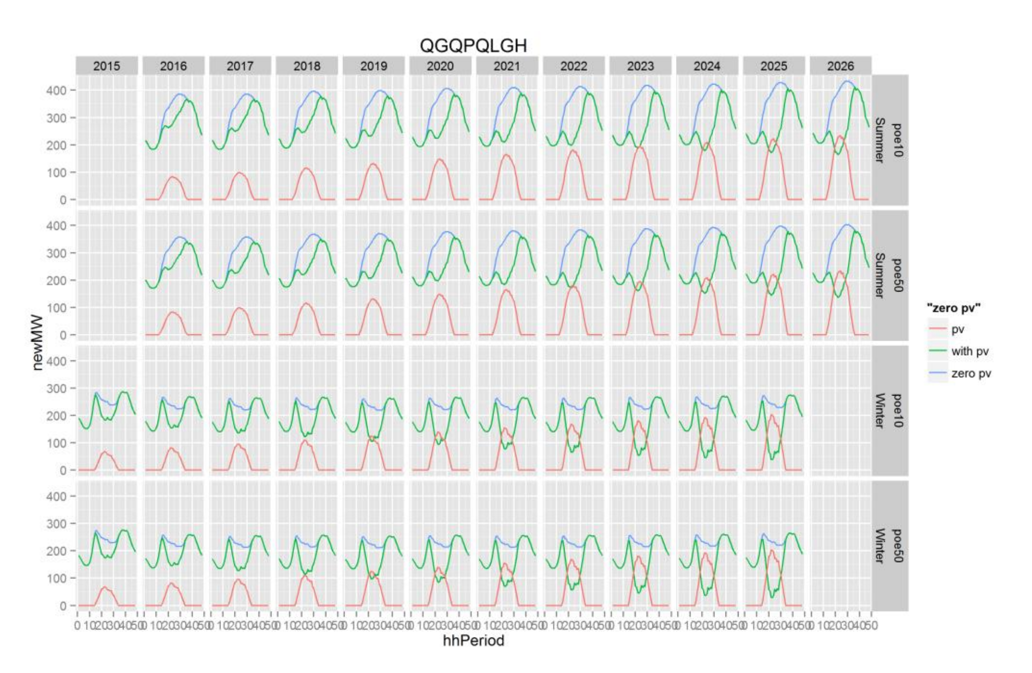
(a) a typical PV trace for that CP and season, using the median PV output from the top five demand days for that season; and

(b) estimated PV capacity by CP.

For the Qld forecasts, a marginally different PV trace is applied to each CP to reflect differences in location and resulting PV output.

The estimated demand trace with/without solar output is shown in Figure 13. This is used to identify the changing time of MD with/without PV, and the difference caused by solar output. There is no difference in the estimated PV output for the POE10 and POE50 demand level.

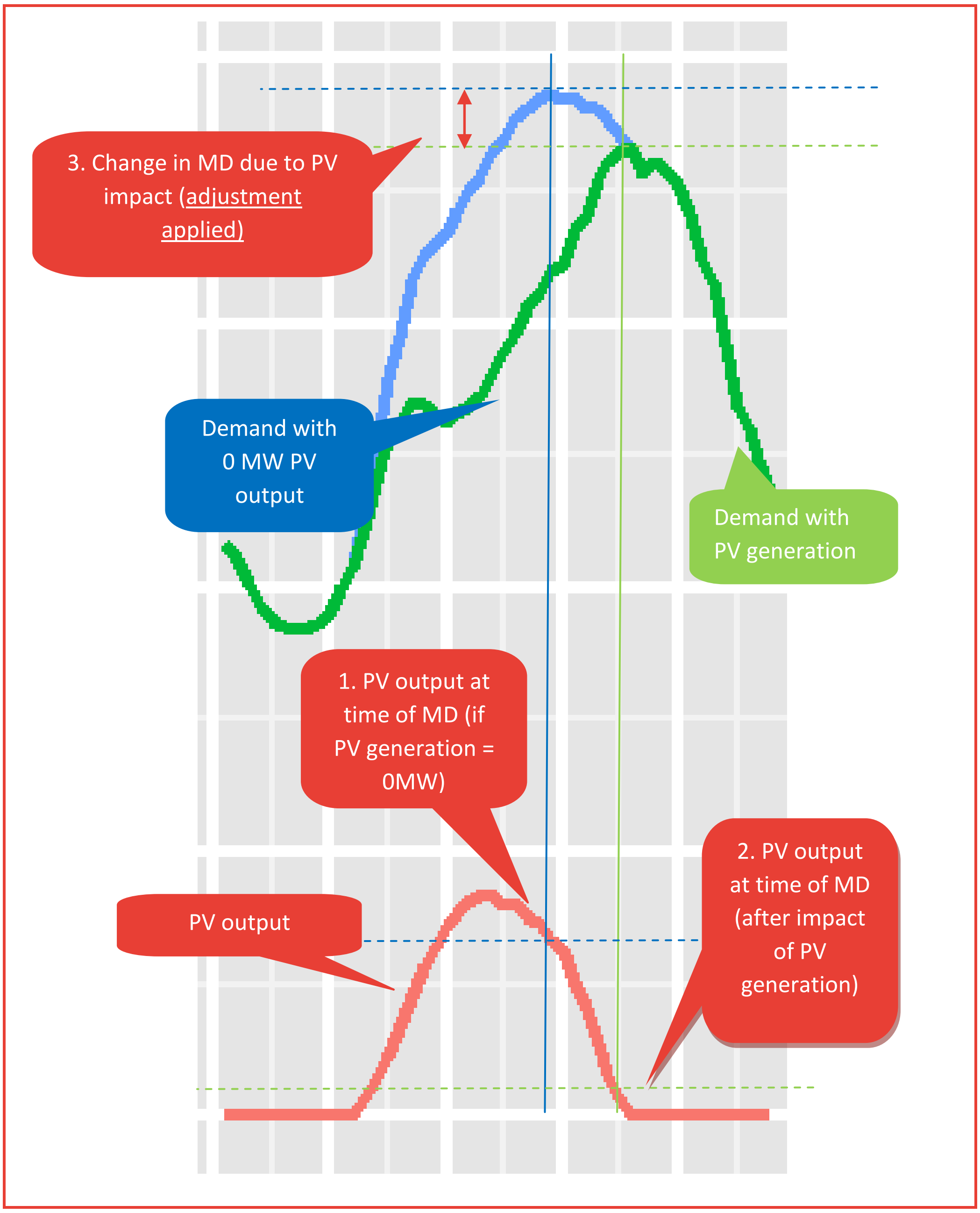
Figure 13: Hourly demand with/without PV example: QGQPQLGH



Source: AEMO

Figure 14 shows in detail the difference in demand with/without PV, the different time of MD with/without PV and the difference in PV output at those times. An estimate of PV output at the time of MD without PV (#1: midday) would likely result in too large an adjustment as PV output is higher in the afternoon. Similarly, an estimate of PV output at the time of MD with PV (#2: evening) would likely result in too small an adjustment as PV output is lower in the evening. Neither approach would accurately capture the effect of pushing MD to later in the day (the changing time of MD). However, the blended approach applied by AEMO (looking at MD with/without PV: #3) appears to reasonably reflect this.

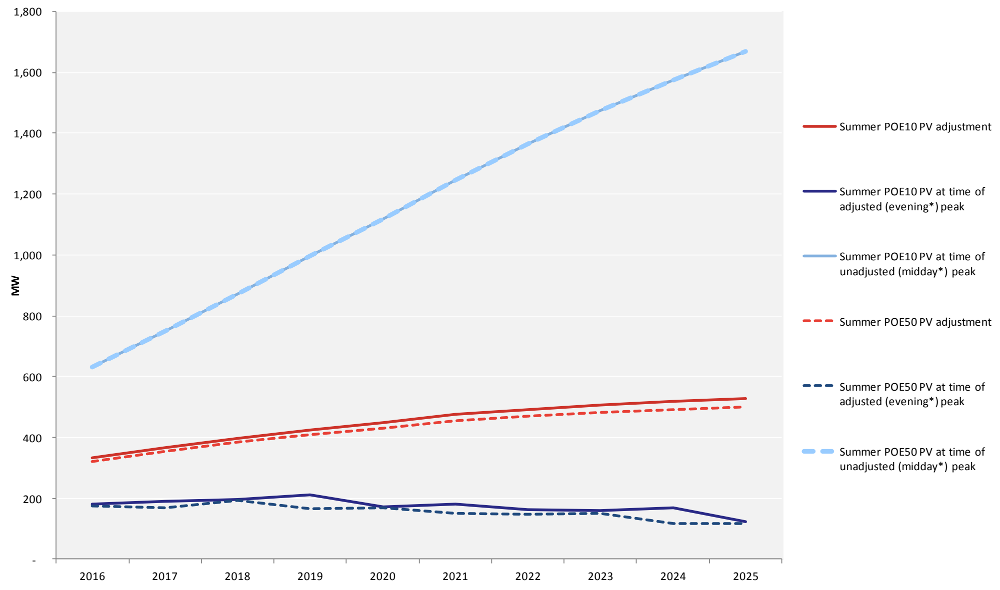
Figure 14: Hourly demand with/without PV example: QGQPQLGH, 2016



Source: AEMO

The difference between these approaches for the Qld CPs is illustrated in Figure 15 where we compare the sum of the CP PV adjustments under each approach. If the adjustment was based on estimated PV output at the time of the unadjusted peak demand (e.g. midday) this would reflect a large PV adjustment (light blue). If the adjustment was based on the peak demand after accounting for PV output then the PV adjustment would be very small (navy blue). The actual adjustment applied corresponds to the red line.

Figure 15: PV output comparisons, QLD totals



Non-coincident PV contribution = the sum of each CP for the difference between MD without solar and MD with solar. In most cases the time of MD is closer to the middle of the day if PV output is zero and later in the day with PV output is positive, so this approach does not reflect solar PV output at any given time of day. This estimate will be less than the total solar output at the time of MD (without solar generating) but more than the solar output at time of MD (with solar generating).

Source: Frontier Economics (analysis of AEMO data)

Frontier has reviewed this revised methodology for PV and it reflects a reasonable improvement to the forecasting approach. Frontier has not reviewed all calculations and code used in applying these PV adjustments in the final implementation, as this was beyond the scope of the review. However, the direction and magnitude of the adjustments applied is reasonable.

3.4 Final check: scaling factors

As a sense check of the final forecasts, Frontier reviewed the scaling factors applied to the Qld forecasts during reconciliation. These should generally be expected to be close to 100% if the CP forecasts are consistent with the region forecasts. In particular, these should be close to 100% in the initial years of the forecast as there should be consistency between the regional and CP totals (as the diversity factors are based on recent data and should result in similar totals).

As a general principle we recommend investigating the source of discrepancy between the region forecasts and the CP totals to understand the possible cause of difference where:

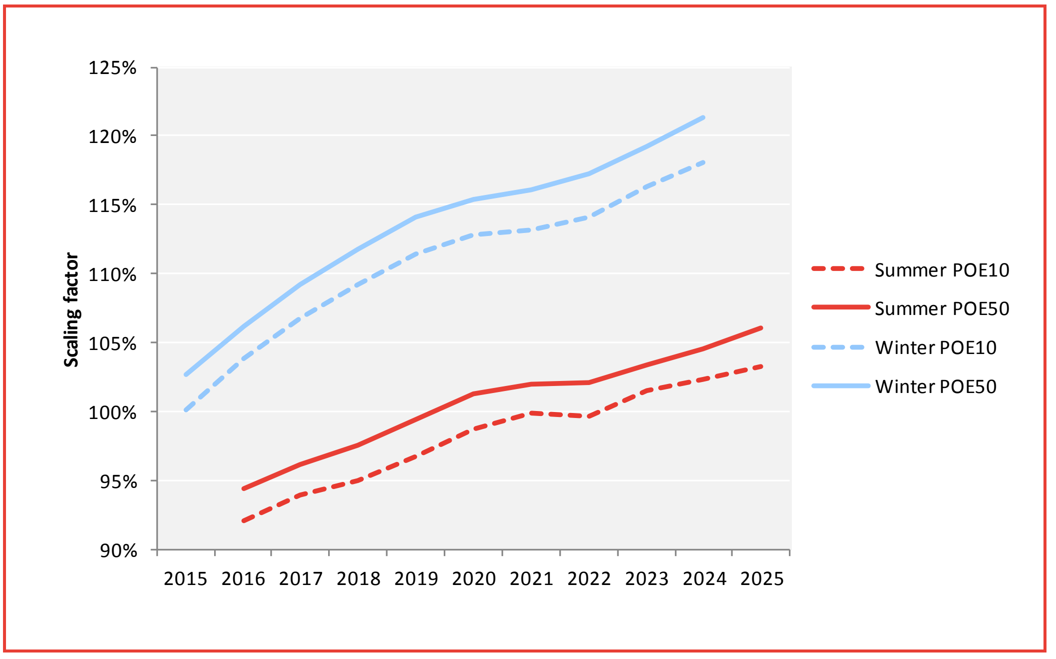
- The scaling factors are more than 110% or less than 90%
- There is a material difference in the initial years of the forecast (as the diversity factors should ensure that the region/CP totals are close initially)
- There is a material difference between the POE10 and POE50 scaling, in particular where the POE10 scaling is less than the POE50 scaling, as this will bring the distribution together and there is a risk of POE10/POE50 crossover.

This would require some reconciliation of the CP forecasts and the NEFR approaches to understand the potential source of difference.

Figure 16 shows the factors applied for each season and POE level. The scaling rate for the summer forecasts begin at around 92-94% (depending on the POE) and rises over time to 103-106%. This suggests that the sum of the baseline CP forecasts are initially around 6-8% higher than the NEFR/regional forecasts. If similar results eventuate in future forecasting rounds then it would be worth investigating to understand the source of difference between the NEFR (region forecasts) and the CP forecasts: we would expect that the diversity factors (if derived and applied correctly) would result in a sum of baseline CP forecasts that is close to the NEFR/regional forecasts, at least initially. This is the case in winter, where the scaling rates commence at around 100%. However, the winter scaling factors rise over time to around 120%, suggesting that the baseline (unreconciled) CP forecasts are growing more slowly than the NEFR/regional forecasts.

Similarly, there is no reason why the POE10 scaling should be consistently lower than the POE50 scaling, as is the case here, and the reasons for this should be investigated. It is particularly important to review future forecasting results where the POE10 scaling is lower than the POE50 scaling, as is the case in the Qld forecasts. This results in a narrowing of the POE10 and POE50 distribution for each CP and, in extreme cases, can lead to higher reconciled POE50 forecasts than the POE10 forecasts. This problem was observed for several CPs in Qld, particularly in winter. It was solved through manual intervention to ensure that the distribution of reconciled forecasts (POE10 and POE50) were reasonably consistent with the historical distributions: for CPs where the POE10 was less than 1% higher than POE50, the forecast POE50 trend was applied to the POE10 forecasts (though starting off the POE10 line). This was to ensure that a reasonable distribution between POE10 and POE50 was maintained, to prevent the gap reducing to less than 1%.

Figure 16: Scaling factors: Qld



Source: Frontier Economics (analysis of AEMO data)

4 Assessment of AEMO's forecasting procedure

On the basis of our review of AEMO's implementation of the maximum demand forecasting methodology for the Qld CPs, Frontier confirms that (a) the revised methodology adopted for the CP forecasts is reasonable and appropriate, and (b) it appears that AEMO has correctly implemented the revised methodology.

Our overall assessment of the methodology and implementation is that it meets the standard of good industry practice. The methodology has been implemented in a professional manner, and where issues of concern have arisen during the implementation of the methodology, all reasonable steps have been taken, within the time and resource constraints, to ensure the statistical integrity of the forecasts. Frontier also commends AEMO's commitment to the continuous improvement of the methodology.

FRONTIER ECONOMICS | MELBOURNE | SYDNEY
Frontier Economics Pty Ltd 395 Collins Street Melbourne Victoria 3000
Tel: +61 (0)3 9620 4488 Fax: +61 (0)3 9620 4499 www.frontier-economics.com
ACN: 087 553 124 ABN: 13 087 553 124