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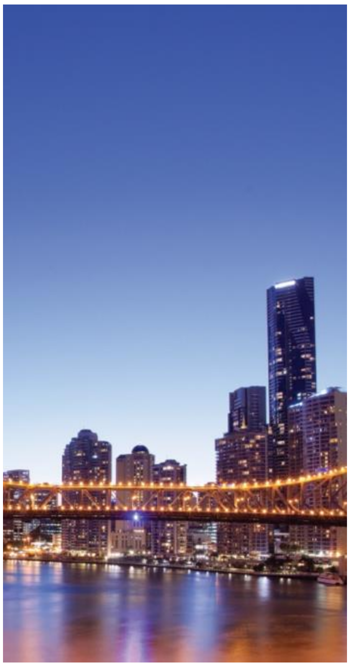
GHD review of demand and customer forecasts

Ausgrid

GHD Advisory



Review of 2017 demand and customer connection forecasts

Ausgrid

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1. Executive summary

The authors of this report have reviewed Ausgrid's electricity demand and customer connection forecasts, including methods, processes and assumptions used to prepare those forecasts. We have made all the inquiries that we believe are desirable and appropriate and no matters of significance that we regard as relevant have, to our knowledge, been withheld.

The spatial electricity demand forecasts, including forecasts of new customer connections, are a key input into Ausgrid capital expenditure forecasts. The spatial demand and customer forecasts directly influence the need for future augmentation and connection capital expenditure, and also are a key input into developing major replacement projects.

GHD has examined the methods, processes and assumptions that underlie Ausgrid's electricity demand forecast preparation and found that reasonable steps have been taken to ensure that the forecasts are as accurate as they can be, robust and fit for purpose.

Ausgrid's overall approach to preparing its demand forecasts is based on three main building blocks, which include:

1. identification of representative underlying trends in recent historical demands (in the absence of 'lumpy' loads designated as 'block loads'
2. response of underlying long term demand (not including block loads) to recognised demographic and economic drivers of demand
3. application of post model adjustments (including above trend energy efficiency, take-up of battery storage, roof top solar generation, future electric vehicle charging and the addition of block loads)

The overall approach is determined by Ausgrid's main requirement, of identifying changes in locational demands on the network that may need to be addressed by network planning, by Ausgrid's well informed understanding of planned new connections to its network through the connection applications process, and by the detailed corporate understanding of the nature of what drives electricity demand built up by the experience of current and previous forecasters.

Ausgrid's approach to demand forecasting and its detailed implementation have evolved over time in response to evidence based trials of alternative models and assumptions. The methods used by Ausgrid are at least as sophisticated as the methods used by similar utilities around Australia and overseas in the United Kingdom and the Middle East. Ausgrid model inputs and assumptions are also reasonable. We have made a number of observations on matters of detail linked to a series of recommendations for potential further refinement of the forecast preparation process. By and large these observations are unlikely to have a major impact on the reliability of the demand forecasts. However we do believe two particular issues are noteworthy from a comparison of results with AEMO forecasts. These are:

- the size of the increase forecast by Ausgrid in block loads in the near term appears to be unprecedented, and does not appear to be included in AEMO's (almost equivalent) forecast
- the small impact that post model adjustments have on dampening underlying long term growth in Ausgrid's forecast, relatively to AEMO's (almost equivalent) forecast

We were furnished with sufficient information from Ausgrid to form the view that the short and long term underlying trends, and the assumptions made by Ausgrid leading to the block load and other post model adjustments were a reasonable view of the future. However a lack of information about the basis of AEMO's forecasts prevents us from independently quantifying the reasons for the divergence of their forecasts from

Ausgrid's system forecast. Further investigation may be informative, but would require cooperation from AEMO and an extension of the scope of our current assignment.

The overall approach to preparation of Ausgrid's 2017 electricity demand and customer forecasts, the methods used and the data inputs were appropriate – and in some cases innovative - and conducive to the production of reasonably accurate forecasts. Notwithstanding, we made some suggestions for maintaining a constantly adaptive and improving forecasting process which may be found in section 5.9.2 below and which are repeated below. The existence of suggestions for improvement do not reflect on any perceived unreliability of the 2017 forecasts. Rather these suggestions are aimed at ensuring that the testing of alternative methods, and checking the evolving accuracy of forecast outcomes, continue at Ausgrid and are enshrined as an ongoing practice.

1.1 Recommendations

Regarding the ongoing improvement of the forecasting process:

1. All assessments of alternative implementation practices, including the historical period used to determine short term trends and data pooling during weather correction, be formally documented in brief, to provide formal reasons for choosing between alternative practices.
2. External consultants' reports (e.g. on energy efficiency impacts) should generally be refreshed on an annual basis or when circumstances have materially changed.
3. The current practice of discounting identified block loads using learning about completion rates from previous years should be continued and refined each year on the basis of new information.

Regarding the short term forecasts:

4. When simulating Equation 4-2 for locational weather correction, (a) use diagnostic checks to test the assumption of normality of the equation errors and (b) if normality is found to be a reasonable assumption, use two standard errors rather than one standard error in the derivation of the simulated maximum demands.
5. Eliminate the impact of climate trends from weather correction, for example by following steps 1 to 4 in section 5.2.1 below.

Regarding the long run forecasts:

6. Implement out-of-sample back-casting on a regular basis to test the accuracy and bias of the estimated system level long run equations.
7. Trial pooling of years for the system wide weather correction process.
8. Eliminate climate trends from weather correction as in recommendation 5 above.

Regarding testing and presentation of the forecasts:

9. Conduct empirical tests of overall forecast accuracy on a regular basis, similar to the manner in which the 2014 enhancements to the forecasting process were tested to determine MAPE over several forecast years.
10. In order to show relative significance of various assumptions, make available high level information for presentation showing the contributions made by each of the main components of the demand forecasts, including growth modelled by macroeconomic variables, embedded PV generation take-up, increased air conditioner penetration, battery storage, above trend energy efficiency and electric vehicle charging.

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2. Introduction

The authors of this report acknowledge that we have read, understood and complied with the Federal Court of Australia's Practice Note CM 7, Expert Witnesses in Proceedings in the Federal Court of Australia.

2.1 Background

Ausgrid is a regulated NSW electricity distribution business. The Australian Energy Regulator (AER) is responsible for Ausgrid's economic regulation in the National Electricity Market and is required to set a ceiling on the revenues or prices that Ausgrid can earn or charge during a regulatory period[1].

Ausgrid's next five-year regulatory control period runs from 1 July 2019 to 30 June 2024. The determination to be made by the AER will be based on an efficient level of spending (including operating and maintenance, capital expenditure, asset depreciation costs and taxation liabilities) and a commercial return on capital. As part of the defined two-year process by which the final determination is made, Ausgrid will be required to submit a regulatory proposal to the AER. The regulatory proposal will include forecasts of Ausgrid's proposed spending over the forthcoming regulatory period.

A key input to Ausgrid's capital expenditure forecasts are the spatial electricity demand forecasts including forecasts of new customer connections. The spatial demand and customer forecasts directly influence the need for future augmentation and connection capital expenditure, and also are a key input into developing major replacement projects.

The AER has issued Ausgrid a draft regulatory information notice (RIN) under which Ausgrid is required to "*provide evidence that any independent verifier engaged by Ausgrid has examined the reasonableness of the method, processes and assumptions used in determining the forecasts of demand and connection forecasts and has sufficiently capable expertise in undertaking a verification of forecasts, and all documentation, analysis and models evidencing the results of the independent verification*."

2.2 Purpose

GHD was engaged by Ausgrid to review the forecasting methods, processes and assumptions applied by Ausgrid in preparing their 2017 electricity demand and customer connection forecasts. This report is explicitly directed towards the AER's requirement set out above. It examines the reasonableness of Ausgrid's method, processes and assumptions underlying the 2017 demand and connection forecasts. The authors have been provided with a copy of the Federal Court of Australia's "*Guidelines for Expert Witnesses in Proceeding in the Federal Court of Australia*". The report has been prepared in accordance with those Guidelines.

2.3 Approach

The objectives of our review of Ausgrid's 2017 electricity demand and customer forecasts were as follows.

- to gain a critical technical understanding of the processes and assumptions used by Ausgrid and to identify any reasonable alternative processes and assumptions;
- to identify the materiality of, and quantify where possible, each process or assumption, compared with the reasonable alternatives; and
- to clearly and comprehensively explain our review process, findings, and their significance, in the regulatory context.

[1] The National Electricity Law and Rules set out the regulatory framework for electricity networks.

To achieve these objectives, we conducted an investigation of the methods, processes and assumptions used to develop the forecasts, and we undertook limited analysis of the forecast outcomes. Our investigation consisted of the following activities.

- **A review of the methods used by the forecasters**
  This review was focussed on the typical, generalised approach taken by Ausgrid to forecasting electricity demand at each substation location. We have not encountered the use of methodological factors applied specifically to some individual locations and not others. This does not include assumptions made by Ausgrid about block loads, which may be applied at specific locations.
- **Focus on potentially contentious matters**
  We focussed on areas of known previous contention, including the future impact of changes in end-use energy efficiency and block loads. These issues have been central to differences of opinion about demand forecasts in previous NEM regulatory determination processes.
- **Checks for consistency**
  We compared forecast outcomes for consistency with previous Ausgrid forecasts at individual locations in areas of significant network development, and also at an aggregate network level. Significant areas of network development generally coincide with high forecast demand growth and high potential consequences of unreliability, such as the inner Sydney area.
- **Comparisons with other forecasts**
  We attempted to find reasons for differences with alternative comparable forecasts. The only forecasts that might be comparable for this purpose are at system level and for this the only ones available to us were AEMO's transmission connection point forecasts for Sydney and the Hunter region. These forecasts in aggregate represent demand on the Ausgrid network, but differ materially from Ausgrid's summation of its substation demands in that:
  - AEMO's measurement of Sydney demand is at TransGrid's 132 kV supply points including Beaconsfield West, Rookwood Road, Haymarket, Sydney East, Sydney North and Sydney South; whereas Ausgrid's measure of the same demand is based on power supplied at its sub-transmission and zone substations, generally at lower voltages
  - demand measured at transmission connection points, as used by AEMO, includes losses in the 132 kV system, whereas Ausgrid's measurement of system demand does not include these losses; and
  - AEMO excludes demand in the Ausgrid supply area supplied directly from a distribution level connection to neighbouring Endeavour Energy sub-transmission substations.
- **Empirical testing of forecast performance**
  We reviewed the results of tests undertaken by Ausgrid to validate the performance of the forecasting models. Testing the performance of forecast models through techniques such as out of sample forecasting can be an effective means of understanding the quality of the forecast and the effectiveness of any proposed improvements to the forecasting process.

2.4 Scope and limitations

We performed our review by examining relevant Ausgrid documentation provided to us during the course of the review and by consideration of additional evidence provided by Ausgrid through interviews and workshops. Our purpose was to identify and rate the importance of identified issues in terms of their likely impact on forecast reliability. Our review assumed that Ausgrid followed their documented processes and that those processes (as clarified through the interview process) were free of error. We did not undertake a rigorous audit of the forecasting process.

3. Assessment framework

This section compares the general nature of electricity demand forecasting with the forecasting quality requirements under the National Electricity Rules to establish our framework for assessment of Ausgrid's forecasting processes.

3.1 General accuracy of electricity demand forecasts

Distribution Network Service Provider (DNSP) electricity demand forecasts are generally developed as the constituent sum of various elements that are more amenable to individual analysis. Some of the elements of analysis may take advantage of observed historical data relationships while others are effectively fixed by assumption. However, no matter the level of sophistication and care taken to develop the forecasts, the outcomes are by nature always uncertain and imprecise. Ex ante forecast accuracy may to some degree be quantitatively assessed on the basis of the underlying statistical relationships. However, these relationships may be subject to change in unprecedented ways, or additional causal relationships that previously had no significant impact on demand may become significant in the future. A principle source of forecast uncertainty, however, is that the reasonableness of many of the forecast inputs and assumptions can only be thoroughly known ex post.

3.2 Requirements under the Rules

Under the National Electricity Rules (NER), the Australian Energy Regulator (AER) must accept the capital and operating expenditure forecasts of a Distribution Network Service Provider (DNSP) if the AER is satisfied that the proposed expenditure reasonably reflects, amongst other things, *a realistic expectation of the demand forecast*[2].

The AER has expressed a view that in order to achieve a realistic expectation of the demand forecast, desirable forecasting techniques should include the following:

- "*Accuracy and unbiasedness of data – an unbiased forecast of demand should include careful management of data (removal of outliers, data normalisation), data quality and forecasting model construction (choosing a model based on sound theoretical grounds that closely fits the sample data).*
- *Transparency and repeatability – as evidenced by good documentation, including documentation of the use of judgment, which ensures consistency and minimises subjectivity in forecasts.*
- *Appropriate incorporation of key drivers (inputs) of demand and exclusion of spurious drivers.*
- *Model validation and testing – including, where appropriate, assessment of statistical significance of explanatory variables, goodness of fit, in-sample forecasting performance of the model against actual data, diagnostic checking of the old models, out of sample forecast performance.*
- *Accuracy and consistency of forecasts at different levels of aggregation – affects the overall reasonableness of the forecasts, as accuracy at the total level may mask errors at lower levels that cancel each other out.*
- *Use of the most recent input information.*"[3]

[2] NER Version 94, clauses 6.5.6(c)(3) and 6.5.7(c)(3).

[3] AER (2011) Aurora 2012–17 draft distribution determination, Section 3.2, p76: https://www.aer.gov.au/networks-pipelines/determinations-access-arrangements/tasnetworks-aurora-energy-determination-2012-17/draft-decision.

From the above discussion we can only conclude that DNSPs should prepare their forecasts in accordance with whichever methods and processes are most likely to produce the most accurate outcomes, the standards for which should be set by reference to the best industry practices.

3.3 Assessment framework

The assessment framework we have adopted, as set out in Table 3-1, is firmly rooted in the above criteria. For evidence of the degree to which any of the AER criteria may be met by Ausgrid, we will primarily look to Ausgrid's documented processes and available evidence of their manner of implementation. The table includes some important examples of the types of revealed behaviours and activities that could provide evidence of adherence to the AER criteria. Some examination of forecast results is also implicit in this framework, for example to test out of sample forecast performance and consistency between forecasts at different levels of aggregation.

Table 3-1 Assessment framework

AER criteria	Incorporated in processes	Included in implementation
Accuracy and unbiasedness of data	Demonstrated understanding of data sources, alternative methods and reasons for choice	Criteria used to identify outliers for removal, consistency of data preparation with subsequent data adjustment processes
Transparency and repeatability	Established process documentation procedure, willingness to provide explanation to encourage feedback	Level of detail of original documentation and updated versions
Appropriate incorporation of key drivers	Detailed understanding shown of alternative similar models	Estimation and testing of the significance of alternative variables
Model validation and testing	Understanding of appropriate statistical tests and interpretation of results to select best model	Out of sample forecast performance
Accuracy and consistency of forecasts at different levels of aggregation	Consistent framework for assembling forecasts of inter-related elements, especially the way in which the disaggregated spatial forecast related to the forecast of the system as a whole	Consistent approach to information inputs and forecast results at both the spatial and whole of network levels
Use of the most recent input information	Forecast reflect latest available information that can be processed	For forecasts produced in mid-year, for a generally summer peaking system, the most recent relevant demand data is from the last southern hemisphere summer

4. Ausgrid demand forecast preparation

This section summaries the key elements of Ausgrid's electricity demand forecast preparation process.

4.1 Overview

Ausgrid prepares forecasts for both summer and winter[4] maximum demand for each zone and sub-transmission substation in the network. There are currently 181 zone substations (generally supplying power at 11 kV) and 32 sub-transmission substations (generally supplying power at 33 kV) in service in the network. The spatial forecast preparation begins immediately following the end of the summer season each year. Each forecast is composed of:

- a short term (years one and two) projection of the established historical trend;
- a long term forecast (year five onward) derived from estimated price and income elasticities and projected price and income scenarios; and
- a weighted sum (years three and four) of the short and long term forecasts to achieve a smooth transition between the two forecasts.

4.2 Outline of demand forecast preparation

The processes underlying the short term and long term forecasts both include a breakdown of the demand into:

- 'block loads', that consist of specific customer connections that are significantly large enough to affect the underlying trend; and
- 'general load', which is the remainder.

Forecasts for block loads are derived from Ausgrid's knowledge of customer intentions, including connection enquiries and applications, as well as past activity by representative customers. Past activity informs Ausgrid forecasters of the likelihood of customer power requirements being planned for during the connection process being achieved during the forecast period.

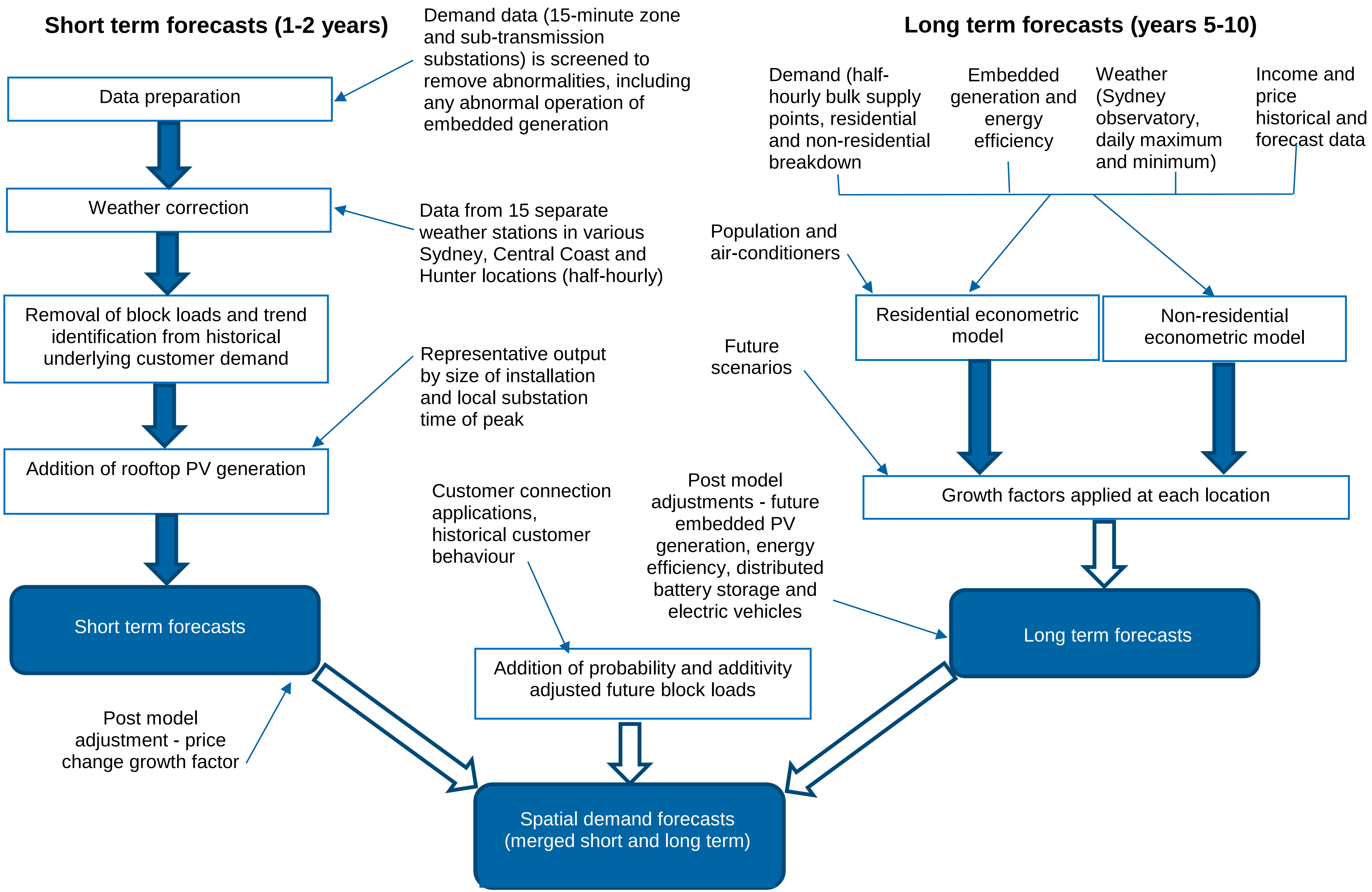
Forecasts for general load are 'weather corrected' to provide a consistent reference based on 'probability of exceedance' (POE) levels of demand for a particular season. This generally includes POE 10 and a POE 50 forecast, which refer to the levels of demand that are expected to be exceeded in 10 out every 100 and 50 out of every 100 years, respectively.

Ausgrid prepares whole-of-system level summer and winter maximum demand forecasts using the individual forecasts for each zone and sub-transmission location, a network model that accounts for the complex interaction of multiple locational demands in a meshed system and assumptions about local diversity factors.

Each type of demand to be forecast may consist of several components, each of which is considered separately prior to assembly of the final forecast. Below we describe the steps involved, and the assumptions and data inputs required, in preparing each forecast component. Figure 4-1 shows the major steps followed by Ausgrid to prepare the spatial demand forecasts.

[4] Ausgrid defines summer as 1 November to mid-March and winter as 1 May to 31 August. A relatively early end to summer allows for the collection of historical data so that preparation of the new yearly forecasts can begin promptly.

Figure 4-1 Overview of demand forecast preparation processes



Source: GHD as informed by Ausgrid.

4.3 Short term demand forecast preparation

Refer to Figure 4-1 (left hand side) for an overview of the sequential steps followed by Ausgrid to prepare the short term forecasts for each network location, and the main additional data inputs required in each step.

4.3.1 Data inputs

The first step is to collect and prepare the historical raw demand data for each location. The data generally consist of 15 minute observations for each of the most recent seven summers and winters[5]. This raw demand data is cleansed to remove outliers, which are identified from data visualisation methods such as scatter plots of demand and temperature and 3D plots of demand over a season. Outliers generally occur where load has been temporarily switched between substations, resulting in an abnormal network configuration. The process of cleansing also identifies and removes any abnormal operation of embedded generation. The end point of demand data preparation is a store of observed daily maximum demands for each summer and winter day for each location.

Ausgrid also prepares weather data sourced from a number of Bureau of Meteorology weather stations and consisting of half hourly temperature observations for the most recent 10 years, covering the same summer and winter periods as the demand data. These observations are used to prepare a store of daily average temperatures.

4.3.2 Weather correction

The cleaned up historical daily maximum demand data, inclusive of embedded PV generation, are used to estimate seasonal maximum demands that would have occurred under standard conditions. Specifically, the weather corrected 50 per cent probability of exceedance (50 POE) summer demand is the level of demand that could be expected to be exceeded in one out of every two summers (winters). Similarly the 10 per cent probability of exceedance (10 POE) demand could be expected to be exceeded in one out of every ten seasons. The process of calculation of 10 POE and 50 POE demands is called weather correction.

Ausgrid's weather correction is a two stage process, in which temperature sensitivities are estimated for each network location, for working and non-working days, and for each summer and winter.

Temperature sensitivity is estimated by regressing daily maximum demand on daily average temperature as shown in Equation 4-1.

Equation 4-1 Estimation of locational temperature sensitivity

$$D_t = C + SENS \cdot T_t + ERR_t$$

Where D_t is maximum demand on day t, $SENS$ is the estimated temperature sensitivity based on daily average temperature T and ERR is a random error representing changes in demand that are not explained by temperature change.

Weather stations are matched to Ausgrid substations according to their geographical proximity, subject to reliable availability of the temperature data. Only days with temperatures greater than or equal to the 'knee-point'[6] summer temperature (generally 22 degrees subject to assessment of the data for each location representing a positive relationship between demand and temperature), and days with temperatures less than or equal to the winter knee-point temperature (generally 15 degrees and representing a negative

[5] For this purpose, summer is 1 November to mid-March and winter is 1 May to 31 August. The relatively early cut off for summer each year allows for a prompt start to development of the new forecast for the year.

[6] Below the knee point temperature there exists a negative relationship between electricity demand and temperature and above the knee point there exists a positive relationship between demand and temperature there is generally assumed to be a small range of temperatures which have no relationship with demand for electricity. The term 'knee point' refers to the inflection points in this overall relationship, which may be represented in two dimensions by a bucket shaped line. Ausgrid may depart from the generally adopted knee-points of 22 and 15 degree average temperatures where justified by the data for particular locations.

relationship between demand and temperature) are included in the estimation of Equation 4-1. Between the two knee-point temperatures there is no observable relationship between demand and temperature, for average daily temperatures calculated in the applicable fashion.

Ausgrid then uses the estimated respective temperature sensitivities to simulate demand under a variety of possible conditions as shown in Equation 4-2.

Equation 4-2 Weather correction simulation for locations

$$D_t = C + SENS \cdot T_t + N_t(0, SE)$$

Where D_t is maximum demand on day t, $SENS$ is the previously estimated temperature sensitivity, a simulated daily average temperature T is drawn randomly from 10 years' of historical observations and $N_t(0, SE)$ is drawn at random from a normal distribution with mean 0 and standard deviation SE, equal to the estimated regression standard error.

Equation 4-2 is used to create 2,000 demand series at each location, separately for working weekdays and non-working days, and for each year and each season separately. Seasonal maximum demands from each set of demand series then form the basis for selecting percentiles of maximum demand used as POE levels of demand (refer to Section 4 above).

4.3.3 Trend growth rate

Following the weather correction process, weather corrected demands (e.g. POE 50 demands for summer at a particular location) are adjusted for historical block loads, load transfers and embedded PV generation.

Estimates of historical non-dispatchable embedded PV generation, at half-hour intervals, at each zone substation are prepared using a representative sample of actual half hourly PV generation data from gross meters to create standard daily profiles. These profiles are then applied to the known actual number, size and location of solar installations in each respective season and year. These estimates are used to derive the quantities of embedded PV generation at each location at the times of seasonal peaks, which are then added to the respective daily maximum demands. The cleaned-up metered demand data plus embedded PV generation are equal to the total customer demand for electricity at each zone substation.

Ausgrid planners then interrogate historical project records for details of block loads and load transfers to be removed from the historical record. This step, which takes a considerable amount of time and planning resources, is undertaken to remove the impact of step changes that may otherwise distort the underlying trend at each location. Using actual demand data, the impact in each year from block loads totalling greater than 1 MW at a location are removed from the historical record to derive the underlying demand. A linear trend is then estimated using the adjusted underlying demand data.

The slope of a linear trend line through the last five years of each seven year sample of weather corrected and adjusted seasonal maximum underlying demands is the trend short term growth rate for each respective location (inclusive of customer demand met by embedded solar generation). Ausgrid judges that five years is a period that generally picks up a consistent recent trend, given that demand generally fell for the first three years of the last seven and has recently risen.

Following the publication of the 2016 demand forecast, retail prices rose unexpectedly by 10 per cent and further price rises have occurred during 2017, and further price increases are now expected in the next two years. Ausgrid has factored in the ongoing impact of these price increases into the 2017 short term forecasts by supplementing the trend growth rates by a (negative) 'price shock' adjustment factorusing the price elasticities estimated in the preparation of the long term forecasts. This reflects Ausgrid's judgement that projected (and actually realised) nominal price increases of over 20 per cent from July 2017 will have a significant impact on maximum demand for the following two summers[7].

4.3.4 Starting point demand level for forecast

Cumulative historical block loads are added back to the estimated trend point line and the most recent point establishes a base level of demand from which to project forward the forecast underlying growth rate. The short term forecast at each location, for each of summer and winter, is then calculated by applying the respective forecast growth to the base level of demand, after which the short term price shock is applied and forecast embedded PV generation is removed to arrive at the forecast grid supplied customer demand.

4.4 Long term demand forecast preparation

Refer to Figure 4-1 (right hand side) for an overview of the sequential steps followed by Ausgrid to prepare the long term forecasts for residential and non-residential whole of network demand, and the main additional data inputs required in each step. The modelling at this stage serves to estimate price and income elasticities at a whole of network level, which are then used to allocate growth due to changes in price and income to all Ausgrid locations.

4.4.1 Data inputs

The demand data available for developing the long run forecasts spans a total period from 2003 onwards. Historical demand data are sourced from bulk supply points at 30 minute resolution for the purpose of initial weather correction. Ausgrid allocates system demand between separate residential and non-residential proportions, in part by attributing observed patterns of demand from a large sample of customers with interval metering to the remaining customers with accumulation meters.

The sum of all observations in a single time period is equal to demand on the entire Ausgrid network. This sum is divided into residential and non-residential components by estimating the shares of each component at the time of maximum summer demand from interval meter data covering approximately one third of all customers using regression analysis.

System-wide historical embedded generation, allocated to each of the residential and non-residential sectors, at the times of maximum demand, is added into the daily maximum demand data at this stage.

An energy efficiency impact on historical demand is determined from the consequences of the E3 program which implements Minimum Energy Performance Standard (MEPS) and efficiency labelling for appliances, the NSW Energy Savings Scheme (ESS) and building energy performance standards encompassed in the Building Code of Australia (BCA). Ausgrid sought expert advice on empirical estimates of energy efficiency impacts as follows.

- George Wilkenfeld & Associates provided data on the impact of MEPS and appliance labelling in 2016 and these results were rolled forward for 2017;
- Energy Efficient Strategies reported on ESS and BCA in "Review of Post Modelling Adjustments to the NSW DNSPs long term energy forecast" in August 2013;
- The NSW Office of Environment & Heritage provided updated advice about the status of ESS programs in 2016 and this was rolled forward for 2017.

Daily minimum and maximum temperatures at Sydney Observatory weather station are used to calculate average daily temperatures in correspondence with the daily maximum demands. Average temperatures below 21 degrees for the residential sector and below 18 degrees for the small and medium business sector

[7] Refer to Jacobs (2017), "Retail Price History and Projected Trends", report for AEMO, https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Electricity-Forecasting-Insights.

are excluded. The knee point does not apply to the large business sector, since these customers do not exhibit a weather dependency and so are not weather corrected.

The residential model price and income input variables are real retail residential electricity price and real average household disposable income NSW. The non-residential model inputs are real retail non-residential electricity price and Gross State Product NSW. These inputs are drawn from the NSW data base also used by AEMO in the preparation of its own demand forecasts.

4.4.2 Weather correction

The weather correction at the whole of network level is similar to the process used for substation demands. Residential and non-residential demand data are corrected separately, for each year using summer maximum demands. Non-residential is further broken down into small, medium and large. Large non-residential demand is not weather dependent and is not weather corrected. Non-working days are not included. Equation 4-3 shows the estimation of temperature sensitivities and Equation 4-4 shows the general method of simulating alternative demand outcomes.

Equation 4-3 Estimation of residential and non-residential temperature sensitivity

$$D_t = C + SENS \cdot T_t + ERR_t$$

Where D_t is maximum residential or non-residential demand in year t, $SENS$ is the estimated temperature sensitivity based on temperature T and ERR is a random error representing changes in demand that are not explained by temperature change.

Equation 4-4 Weather residential and non-residential correction simulation

$$D_t = C + SENS \cdot T_t + N_t(0, SE)$$

Where D_t is maximum residential or non-residential demand in year t, $SENS$ is the previously estimated temperature sensitivity, a simulated temperature T is drawn randomly from 10 years' of historical observations and $N_t(0, SE)$ is drawn at random from a normal distribution with mean 0 and standard deviation SE, equal to the estimated regression standard error.

Equation 4-4 is used to create 2,000 demand series for each of residential and non-residential demand services, for each year separately. Seasonal maximum demands from each set of demand series are the basis for selecting percentiles of maximum demand used as POE levels of demand services (refer to Section 4 above).

4.4.3 Long run elasticities

Long run elasticities are estimated using a data construct termed "electricity services" which attempts to measure the consumer activities that use electrical power, rather than the consumption of electricity itself. Energy services is calculated as electricity demand plus the impact on demand due to the increasing energy efficiency of appliances used (including building thermal efficiency) plus customer demand supplied by their own PV generation.

The demand data are thus adjusted to remove the effect of historical energy efficiency and reflect true underlying demand for the services that are powered by electricity. Elasticities are estimated using the general form shown in Equation 4-5.

Equation 4-5 Typical medium long term estimation of elasticities

$$ln(DS_t) = C + EP \cdot ln(P_t) + EI \cdot ln(I_t) + ERR_t$$

Where DS_t (energy services) is weather corrected maximum demand in year t, adjusted for energy efficiency, EP and EI are the estimated elasticities of price and income, based on price P and income I, respectively, and ERR is a random error representing changes in demand that are not explained by the right hand side variables. The equation is estimated using natural logarithms of the variables, so that the coefficient estimates represent elasticities that are fixed over the sample period.

For the estimation of residential demand elasticities, the left-hand side variable is weather corrected residential energy services per residential customer, the real price variable is for residential customers and the income variable is real household disposable income per capita.

For the estimation of non-residential demand elasticities, the left-hand side variable is weather corrected (small-medium) non-residential energy services, the real price variable is for non-residential customers and the income variable is real gross state product.

4.4.4 Spatial allocation of long term growth rates

The long term demand forecasts are conditional on forecasts of scenarios for income and price, air conditioner penetration, residential customer numbers, embedded generation, (above trend) energy efficiency, electric vehicle use and distributed battery storage.

Long term growth rates are applied to weather corrected historical demands, split into residential and non-residential proportions, supplied at individual substation locations. The growth rates are combinations, weighted where relevant by the proportions of residential and non-residential demand, of:

- population projections from the NSW Department of Planning (for residential demand)
- change in residential demand due to the change in the proportion of residential customers using air conditioning (air conditioner penetration)
- residential and non-residential income and price elasticities applied to projected changes in income and price respectively
- projected post modelling adjustments, including growth in embedded generation, above trend energy efficiency, electric vehicle charging and distributed battery storage discharging[8]

Air conditioner penetration is estimated to have grown linearly between 2006 and 2014. This growth is projected forward to reach a saturation level of 65 per cent from 2020/21 onwards. Ausgrid used data from a 2011 survey of residential customers to estimate maximum demand per customer with (2.0 kW) and without (0.6 kW) air conditioning. These estimates are used to determine the impact of growth in residential customer numbers, independent of any change in average customer demand for each air conditioned or non-air conditioned residence.

4.5 Blended forecast preparation

4.5.1 Merging short term and long term forecast

The short and long term forecasts, after preparation as described above are combined as follows:

- the short term forecasts are adopted for years one and two
- the long term forecast is used for year five onwards
- forecasts for years three and four are derived as the weighted average of the short and long term forecasts

Post model adjustments are then applied as described below.

[8] There is no consideration of BES charging because it is assumed that BES will typically be discharging at times of maximum demand.

4.5.2 Post model adjustments

The following adjustments are applied as the final stage of development of the demand forecasts.

4.5.2.1 New block loads forecast preparation

There is a need to identify a threshold level of individual customer demand to qualify as a block load. Ausgrid's trend analysis is intended to identify an underlying, or 'organic', rate of growth where new connections are individually insignificant. In this context, block loads may be defined as incremental changes in demand that would, if included, significantly alter the trend in the data that Ausgrid identifies on the basis of a seven year sample.

The primary sources of information about future block loads are the planned electrical capacities of new customer applications to connect to Ausgrid's network. Preliminary analysis of the coincidence of the time of planned maximum demand at each new connection with system demand is used to discount the planned maximum demand for each block load to represent its expected impact on system maximum demand. Ausgrid then identifies and applies further scaling factors to each block load in its forecasts as set out below.

1. For 11 kV substations, new connections are included where they collectively add up to 50 A or more (almost 1 MVA); and
2. For connections at 33 kV and above, all new customer connections are classified as block loads.

All future block loads are scaled down and further categorised in terms of their progression through Ausgrid's connection process. General 11 kV customer connection applications are further classified as either 'late' or 'early' stage as follows.

- An application is deemed a late stage block load when a connection agreement has been signed and associated connection fees have been paid. A scaling factor of 0.78 (derived from historical conversion rates) is applied to the planned capacity allowed for these block loads.
- An application is otherwise deemed an early stage block load when negotiations over the method and timing of the connection continue. A scaling factor of 0.34 (derived from historical conversion rates) is applied to the planned capacity allowed for these block loads.

The distinction between late and early stage block loads and the application of different scaling factors is based on a clear identified variation between customer connections at an early stage and a later stage of the connection process. This categorisation is a refinement to the traditional blunt application of a single estimated scaling factor.

Meanwhile, for 33 kV connection applications, scaling factors are assigned on an industry basis rather than by the 'firmness' of their proposed connection process. Various types of connection applications, including rail, airport, data centre, road tunnel, commercial/residential building developments, mining, air force, navy and industrial customers, and large embedded generation projects are categorised as either a large commercial connection, in which case scaling probability factor of 80 per cent is applied, or a large infrastructure connection, in which case the probability factor is 90 per cent. Scaling factors are then derived for each proposed connection using the probability factor multiplied by the applicable estimated diversity factor, between the expected maximum demand of each connection application and the actual maximum demand of previous connections falling within the same industry classification. The assumed staging and scale of load at each new large connection is based upon detailed discussions with the customer requesting the load.

All the above scaling factors are intended to take account of the extent of the degree of additionality of the block load (i.e. whether it is partially replacing load elsewhere in the system) and the likelihood of planned investment being undertaken in full and in the expected timeframe.

4.5.2.2 Roof top PV forecast

Ausgrid forecasts the number of rooftop PV systems without a battery separately from combined PV and battery storage systems. Impacts on maximum demand are assumed to occur in summer only. Typical output curves are derived from existing gross metered solar customers. Solar peak output per kW of installed PV capacity is around 0.67 kW at close to 1 p.m. daylight saving time, which is much greater than the impact at the time of system (or substation) maximum demand, which generally occurs close to sunset. From this analysis, knowledge of total installed PV systems capacity can be turned into a system-wide maximum demand impact.

Based on recent history, Ausgrid projects total future PV installation to increase by 48 MW a year. Future installations are expected to begin at 90 per cent of systems without a battery and 10 per cent paired with a battery storage system. The proportion of systems with a battery is projected to increase to 30 per cent in time, resulting in uptake of 33 MW a year for systems without a battery and 15 MW a year for systems paired with battery storage by 2025. Total PV capacity is projected to reach 835 MW by 2027.

Future rooftop PV is projected to be allocated amongst substations in the same proportions as it is at present. Since the pre-adjusted demand forecast has the impact of distributed PV removed, the forecast is reduced by the full amount of forecast PV generation at the time of maximum demand.

4.5.2.3 Distributed battery energy storage forecast

Future distributed battery energy storage installations are assumed to be paired with PV systems. From an existing base of 1,000 residential battery installations, the medium POE 50 scenario projects an escalating growth to an average of 2,000 installations a year between 2020 and 2024, and 3,000 installations a year thereafter. This equates to around 20-25 per cent of new PV installations also including a battery system. During the 2019-24 regulatory period, with this percentage increasing to 30-40 per cent from 2025 onwards. Ausgrid assumes that the average storage capacity of new residential batteries is 10 kWh. At the system level, battery storage systems are projected to reduce maximum demand by 34 MW in 2025 and by 95 MW in 2035.

No adjustment has been made to historical demand for the impact of battery storage as existing capacity is insignificant.

4.5.2.4 Above trend energy efficiency forecast

As reported above in Section 6.1, Ausgrid sought external advice on the energy efficiency impact of the MEPS, ESS and BCA. The projected future consequences of these programs over and above the identified historical trend leads Ausgrid to believe that above-trend energy efficiency will reduce network demand by around 290 MW by 2027 and by 560 MW by 2037. The energy efficiency impact for each year is separated into residential and non-residential impacts, which are allocated to each zone substation in proportion to each substation's respective share of annual metered residential and non-residential electricity volume.

4.5.2.5 Electric vehicle charging forecast

Ausgrid's electric vehicle charging forecast seeks to assess the likely impact on future maximum demand of battery electric vehicles and plug-in hybrid vehicles, should charging occur at times of high network demand. Assumptions behind the forecast include electric vehicle sales and the maximum demand for charging electric vehicles on an average per vehicle basis. The forecasts for electric vehicle sales have been derived from the AEMO Insights 2016 report[9]. NSW electric vehicle registration data have been used to adjust the total NSW region (including the Australian Capital territory) electric vehicle forecasts from the AEMO insights to account for a slower than predicted take up of electric vehicles and to allocate the NSW region forecast to the Ausgrid network area. The assumptions made for the maximum demand impact of electric vehicle charging per vehicle are admittedly based on relatively small data samples and trial programs in Australia

[9] Refer to AEMO (2016) in section 7 below.

(the Smart Grid Smart City trial) and the United States (US Department of Energy), reflecting the uncertainty of this unprecedented source of electricity demand.

Specific assumptions underlying the forecast contribution to Ausgrid maximum demand from electric vehicle charging include:

- The majority of existing electric vehicles in NSW are garaged in Ausgrid network area, based on NSW electric vehicle registration data
- Electric vehicle sales assumed to rise from 800 (an insignificant number) to 14 per cent of new vehicle sales by 2028 (leading to a stock of around 157,000 EVs), with further increases thereafter
- Average contribution of electric vehicles to system peak of 0.3 kW per vehicle based on trial results based on 20 vehicles in Australia and 8,300 vehicles in the United States
- Total Ausgrid maximum demand impact estimated at 47 MW by 2028 (157,000 x 0.3 kW)
- Electric vehicle charging load allocated to substations on a glide path from existing allocation to long run allocation based on gross income on a Local Government Area (LGA) basis.

The future growth path of electric vehicle uptake predicted in AEMO Insights has been scaled back by Ausgrid to align with recent actual EV registration data.

4.6 Accounting for customer connection numbers and air conditioner penetration

Ausgrid forecasts residential customer numbers to make a compensating adjustment to the demand forecasts. The forecast of new residential customer connections has no direct impact on Ausgrid's capital expenditure programme. The approach to forecasting residential customer numbers is as follows:

- for forecast years one to three, the predicted number of housing starts from the Housing Industry Association are used to determine new NSW dwellings, after which a fixed proportion of forecast total NSW growth is applied to historical Ausgrid customer numbers
- for forecast years beyond the first three years, Ausgrid uses household growth projections from the NSW Department of Planning (DOP) for LGAs within Ausgrid's network area to derive residential customer numbers

Forecast growth in residential customer numbers is used as a direct input to forecast long term residential demand growth, since the long term income and price adjustment factors apply on a per customer basis.

Ausgrid also make another, separate, adjustment for the impact of changing air conditioner penetration, by estimating the independent impact of the penetration rate on maximum demand and projecting this into the future assuming a path for future penetration rates. Since air conditioner penetration is assumed to have all but saturated at 65 per cent by 2021, from the current rate of 61 per cent, this is an insignificant issue.

5. GHD assessment

Ausgrid's methodology is built on the foundations of long organisational experience of preparing electricity demand forecasts and is informed by practices commonly used by other DNSPs. It is implemented by relatively automated processes and adequately documented. The models used are in some aspects innovative, but in most cases practical, well tested and developed on the basis of available data.

5.1 Demand forecast preparation overview

There is no single recognised best approach to demand forecasting, with the techniques used and the level of sophistication adopted largely dependent on the time horizon required of the forecasts and the relevant data that is available. However, it is common practice for electricity utilities in Australia and overseas to separate 'bulk' demand, or 'block' loads, from 'general' demand, where block loads are generally large, non-divisible, residential and non-residential, connected at high voltage, not weather sensitive and unresponsive (in the short-medium term) to general economic conditions. Block loads are generally identified as a result of customer connection enquiries. Ausgrid follows a careful practice of identifying historical block loads and establishing probabilistic analysis of future block loads.

It is also common for utilities to develop spatial forecasts (for general electricity demand) as projections of historical trends and relationships. In some cases, the spatial forecasts are aggregated to determine system peak demand, after the application of appropriate loss and diversity factors. In this bottom up approach, local factors are used to derive overall system demand. In other cases, the bottom up forecasts are reconciled to a top down econometric forecast prepared at the system level. In this top down approach, high level factors such as average price, state-wide income and growth in overall customer numbers drive proportional impacts on the individual substation forecasts. Ausgrid's approach treads carefully between the bottom up and the top down approach, using the available local and system wide information to best advantage.

5.2 Short term demand forecast preparation

The historical trend analysis is designed to accurately allocate network demand to individual localities, determine growth due to unspecified factors related to each location and build in inertia in growth rates. The underlying trend in demand can be affected by changing energy efficiency (i.e. increasing recent energy efficiency would depress trend demand growth), which may not be a true reflection of long term growth if the increase in efficiency is not sustained at the same rate.

Ausgrid employed back-testing to test the accuracy of forecasting trend growth rates, which showed no consistent improvement between alternative methods of trend determination, which included ordinary least squares (OLS) and weighted least squares (WLS). This represents good practice in testing the relative accuracy of alternative approaches.

Ausgrid does not remove the impact of changing energy efficiency from the historical data when preparing the short term forecasts. The underlying trends used to derive the short term forecasts therefore implicitly include historical trends in energy efficiency. However, an estimate of historical embedded PV generation is added to the demand series used to derive historical demand trends. To correctly align the forecasts with the historical trend, projected energy efficiency must include only out-of-trend changes, whereas projected embedded PV generation must include the full impact of future installations. Ausgrid has correctly implemented these alignments.

During the estimation of weather sensitivities in Equation 4-1, for each single summer, approximately 70 observations are available for weekdays and about 50 for weekends. This is likely to be sufficient to provide suitably unbiased estimates of temperature sensitivity, provided that the relationship between demand and temperature remains linear at extremely high temperatures. However, these relatively small sample sizes likely result in high standard errors for the regressions, leaving a relatively high proportion of the simulated maximum demands (using Equation 4-2) to be determined by the random element, rather than via the temperature sensitivity element. This does not necessarily introduce any bias into the calculation of particular POE levels, provided the simulated demands fall within the range covered by relevant observed demands for a particular temperature.

In Equation 4-2, the random element is based on variations of up to one standard error, which (for a normal distribution) means that around 16 per cent of actual demand observations could be expected to fall above the simulated range of forecast demands[10]. This procedure therefore makes for a conservative estimate of POE 10 demands, although no bias is introduced for POE 50 demands.

We recommend, firstly, testing regression errors for normality before continuing to make that assumption, and secondly, trialling the use of two standard errors in the simulation equation.

5.2.1 Potential extensions to weather correction procedures

Pooling of multiple years' data

The samples for weather correction would be improved by pooling of data over several years (using dummy variables to adjust demand from various years to a common base). This would improve the standard errors associated with each temperature sensitivity estimation. However, there are a number of drawbacks to Ausgrid adopting this procedure. Firstly, pooling data in the weather correction procedure would smooth out and possibly delay identification of turning points if the underlying behaviour is changing. Such changes in behaviour could be significant, for example, as a result of increasing air conditioner efficiency. Secondly, pooling would require adjustment of all years to the same network configuration and identification and standardisation of all block loads across years to be meaningful.

Ausgrid chooses not to so adjust the raw data in the pre-weather correction stage, as it is a lengthy process that would create a dependency within the forecasting process and significantly delay the publication of forecasts until later in the year. Nonetheless Ausgrid have experimented with pooling data in the preparation of weather corrected maximum demands, with results that demonstrate insignificant variation in the pattern of historical weather corrected data. This is an example of Ausgrid's exploration of alternative methods and approaches and evidence-based assessment that constitutes good industry practice

Alternative weather specifications

Ausgrid uses daily average temperatures derived from half hourly observations. This procedure provides sufficient resolution to account for all possible intra-day temperature variation. This provides a more sensitive measure of daily temperature variation, compared to using only daily maximum and minimum temperatures.

It is possible that humidity and wind speed, in addition to ambient temperature, also have a significant impact on human comfort and the use of electrical appliances, although any statistical representation may present significant collinearity. An alternative approach would be to use a single weather measure that includes various temperature and non-temperature dimensions such Apparent Temperature[11]. This approach requires access to additional data and introduces additional complexity into the interpretation of demand outcomes. Ausgrid has tested the relative accuracy of using apparent temperature, rather than ambient temperature, to prepare weather corrected demand and found it to produce inferior results for a majority of the zone substations tested for summer demands. This is another example of Ausgrid's exploration of alternative methods and approaches and evidence-based assessment that constitutes good industry practice.

[10] Two standard errors would cover about 95 per cent of actual demands.

[11] See Bureau of Meteorology at: http://www.bom.gov.au/info/thermal_stress/.

Lagged temperature

Lagged thermal inertia provided by building insulation may be represented by introducing lagged temperature variables into the weather correction equation. As with the incorporation of additional weather variables above, this procedure may increase the realism of the demand-temperature model, but any increase in accuracy is untested. Only experimentation with alternative weather correction models can determine whether any improvement in accuracy outweighs the additional complexity.

Incorporate warming climate trend

Randomly drawn temperatures only reflect true percentiles if there is no underlying trend. If there is a significant warming trend in the last 10 years, the POE levels calculated by Ausgrid may not reflect the true POE levels. The bias resulting from ignoring climate warming would be likely to increase proportionally with the length of the temperature series used to determine POE levels of maximum electricity demand. For example, using a sample of temperatures collected over 20 years might double the error from this source, compared with the use of a sample of temperatures collected from the most recent 10 years. However, restricting the length of the temperature series also has the disadvantage of limiting the observed variation in temperature around the mean.

To eliminate the impact of climate trends, we recommend trialling a refinement to the weather correction forecast processes along the following lines.

1. Assign a yearly trend climate change rate to the sample of weather data (e.g. 0.0095 degrees Celsius a year, based on CSIRO/BOM assessment of one degree warming in Australia since 1910)
2. Remove the trend from the weather data by adding differing multiples of the yearly trend climate change rate to data collected from each year (e.g. starting from 2017, data from 10 years ago (in 2007) would all have a factor of 10 x 0.0095 = 0.095 added, 2008 would have a factor of 9 x 0.0095 = 0.086 added, etc.)
3. Prior to simulation for weather correction of each year, adjust the entire sample of weather data to the appropriate level for that year (e.g. all 10 years data for 2007 would have a factor of 0.095 subtracted)
4. Introduce an additional short and long term growth factor for forecasting, based on the current temperature sensitivities and the projected trend climate change rate over the forecast horizon (e.g. for a climate change rate of 0.0095 degrees a year and a temperature sensitivity of 100 A per degree, a cumulative 0.95 A should be added to the forecast each year)

5.3 Long term demand forecast preparation

Ausgrid is unique in accounting for increasing energy efficiency in its estimation of price and income elasticities. This is achieved by using electricity services, calculated as weather corrected maximum demand plus energy efficiency. This measure accounts for the quantum of appliance outputs, or the services actually consumed, rather than simply the power flowing into those appliances. This is of prime importance to accurate estimation of price elasticity (and to some extent income elasticity), because in recent times energy prices increased significantly at the same time as appliance efficiency. In the absence of any measure of efficiency in the estimated demand-price-income relationship, reductions in demand due to efficiency would be falsely attributed to price rises, thereby resulting in elasticity estimates that were too high (in absolute terms). Alternatively, if efficiency were included as an explanatory variable on the right hand side of the equation, collinearity between efficiency and price may make it difficult to establish accurate estimates of either coefficient.

The same price and income elasticities estimated using historical data for summer are subsequently applied to forecasts of both summer and winter demands. This appears to be a reasonably parsimonious approach, as the majority of the network is summer peaking and the impact of changes in income and price are likely to be felt largely on underlying, non-weather sensitive demand, rather than on behaviour occurring on peak days. The differential impact of price and income elasticity on summer and winter peak demand is something that Ausgrid may wish to test empirically. This could only be done by repeating the elasticity estimation (refer to Equation 4-5) using data relating to winter.

GHD has not examined the detailed statistical results of Ausgrid's elasticity estimation. However, numerous studies of electricity data from around the world show it to be non-stationary yet cointegrated with income and price data. Empirical testing of this conclusion for Ausgrid's dataset would be necessary to prove the statistical significance of the estimated income and price elasticities conclusively. Furthermore, the estimated equation used to determine the elasticities uses logarithms of the original data on both sides of the equation, meaning that the estimated elasticities are constant over time. Alternative functional forms of the estimated equations – such as the linear form – would almost certainly produce slightly different elasticity estimates (and these estimates would vary from year to year). However, notwithstanding that the true values of Ausgrid's price and income elasticities may vary slightly from the estimated values, Ausgrid's practices are reasonable in comparison with practices undertaken by similar utilities and the estimated values are statistically significant, of correct sign and within the expected inelastic absolute value range of less than one.

The process of estimating elasticities and the results are documented by Ausgrid[12]. The estimations are based on relatively small samples of 10 years for residential and 11 years for non-residential, selected from a maximum available time series of 13 years. The time periods selected for the estimations are reduced, partly due to the use of lagged price data, and partly due to instability of the results obtained when varying the estimation period. Statistically, this instability does not inspire confidence that the historically estimated relationships will hold up in any future period, even though the results obtained align with all reasonable expectations. The chosen models for the elasticity estimations use a lag of two years for the price variable, in both the residential and non-residential models, while the income variables are concurrent. This specification was chosen as having the best overall statistical fit and it represents a reasonable representation of long run adjustment to a change in electricity prices.

A relatively straightforward back-casting procedure – which we recommend - for Ausgrid to test the accuracy of the elasticity relationships would be to estimate those relationships using data for years up to and including 2015, and then forecast the known results for 2016 using actual income and price data.

Energy efficiency trends are part of the observed historical trend, so that the forecast trends must be estimated as the total future improvement in energy efficiency minus the projection of the historical trend over the forecast period. Energy efficiency impacts resulting from new buildings or building renovations in the 2017 demand forecasts are sourced a BCA review dated 2014. Other sources of energy efficiency data used are the MEPS program (up to 2016) and the NSW ESS (up to 2016). Ausgrid intends to refresh the three energy efficiency consultancies for the 2018 forecast. It is possible that more up to date historical data would result in a different historical energy efficiency trend to date and therefore a different above trend forecast.

Similar to our observations on the short term modelling in Section 5.2 above, the number of observations available for performing the weather correction for each season is relatively small. There should be less of an impediment to pooling data across years at the system level, compared to for each individual substation, since it would not be necessary to account for transfers between substations. There is however a possibility that pooling data for weather correction would reduce the impact of a rapid increase in weather sensitivity. Using the weather corrected data to then estimate elasticities would then falsely attribute an upturn in demand to reduced price or increased income growth. On balance we would recommend experimenting by

[12] Refer to References, Ausgrid (2017a), Section 3.

pooling data for system-wide weather correction from the current and up to two previous seasons, using dummy variables to represent average demand growth between years, to compare with existing results.

5.4 Block loads forecast preparation

Ausgrid meticulously records various snapshots of block loads records used in past forecasts, separates those that have reached detailed design stage from each snapshot, and compares total planned against total actual to arrive at the scaling factors. This ensures to a reasonable extent an equal treatment of historical and forecast block loads.

For lower voltage (11 kV) planned new connections, different scaling factors are applied depending on the stage to which the project has developed. The threshold for qualification as a block load of 50 A is low relative to the size of Ausgrid's network but significant at individual substations.

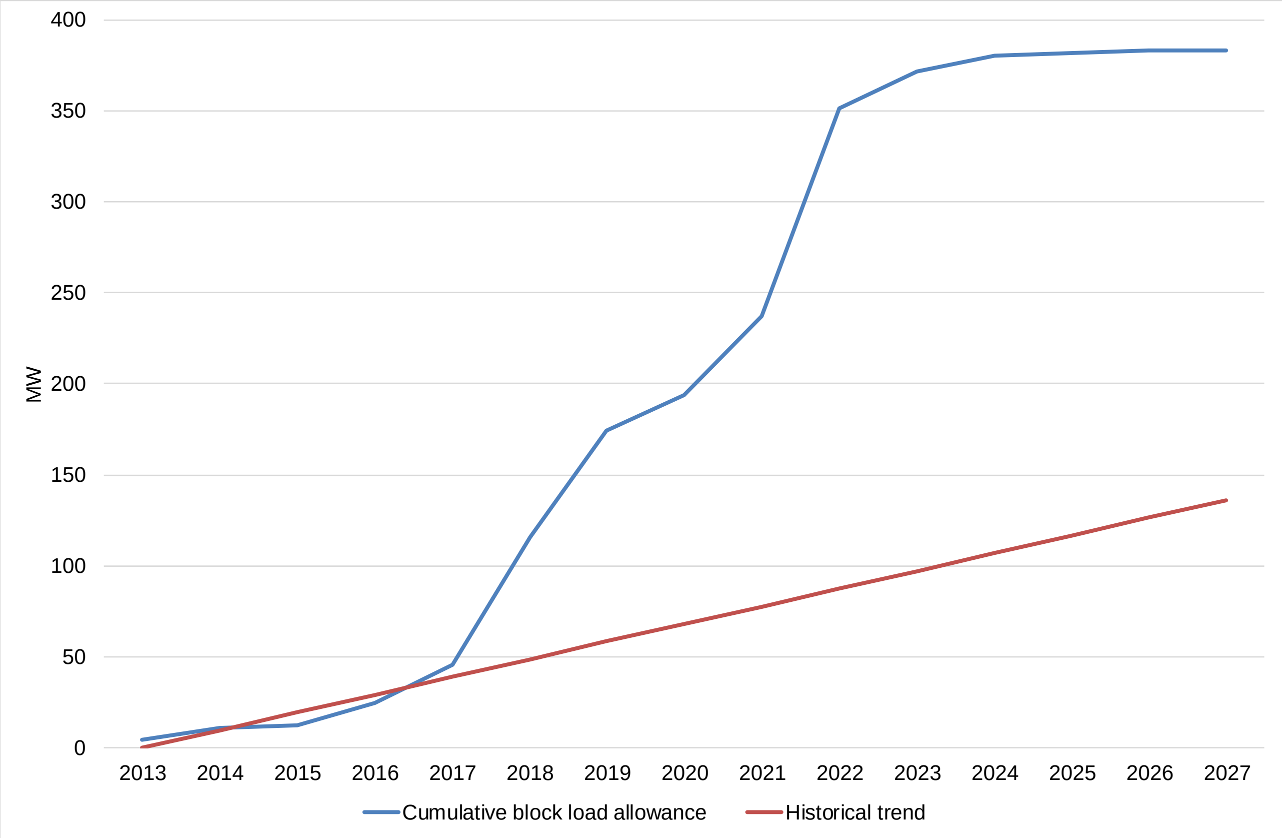
In contrast, the scaling factors for higher voltage (33 kV and above) planned new connections are applied according to the type of development. All planned new connections at high voltage are taken to be block loads.

The above assumptions taken together appear to be reasonable in terms of predicting future demands on the Ausgrid system from the identified block loads.

Figure 5-1 presents a historical trend derived from three major categories of 11 kV block loads (data centres, road tunnels and railways) and suggests that the historical data if projected forward from 2017-18 would support a growth of around 10 MW per year for these categories. Figure 5-1 also shows the current Ausgrid forecast for growth in demand across these three block load categories. It is clear that the current forecast projects a significant departure from the recent historical trend. This analysis demonstrates that significantly different demand forecasts will result if a historical trend is assumed to explain future growth in block loads.

Ausgrid removes historical block load data from weather corrected substation demands to determine the short-term trend (thereby removing the historical trend influence of these loads). The historical trends developed include no allowance for block loads it is therefore appropriate that an explicit forecast of the contribution of block loads to peak demand is added to the forecast derived from the historical trend to derive the demand forecast for the Ausgrid supply area. GHD is satisfied that reasonable steps are incorporated in the Ausgrid process to avoid any double counting of block loads.

Figure 5-1 Future estimates of datacentres, road tunnels and railways block loads



Source: Ausgrid data and GHD analysis

5.5 Blended forecast preparation and post model adjustments

5.5.1 Blended forecast preparation

Ausgrid's blending of short term and long term forecasts produces a response that is consistent with recognised behavioural responses to long term drivers of electricity demand, which include the persistence of short term trends as the impact of driver variables take some time to reach their full impact.

5.5.2 Post model adjustments

Average battery storage capacity assumed by Ausgrid is lower than the assumptions adopted by AEMO in their 2017 Electricity Forecasting Insights publication[13]. Ausgrid assessed available connection application data, the assumptions used by AEMO, payback for Ausgrid customers and surveys of customers to reach the conclusion that take-up of battery storage by commercial and industrial customers is unlikely to be material for more than five years. Accordingly, Ausgrid do not allow for any uptake of non-residential battery energy storage in their forecast. AEMO[14], on the other hand, locates a proportion of forecast battery storage capacity in the commercial sector. In the longer term, when storage capacity becomes significant, this may produce relatively higher maximum demand forecasts from Ausgrid in localities dominated by commercial customers such as the Sydney CBD, although in practice there is no directly equivalent AEMO forecast to compare with Ausgrid's CBD forecasts.

[13] Refer to AEMO (2017) in section 7 below.

[14] The Jacobs report included in AEMO (2017) projects uptake of commercial small scale PV systems contributing 10 per cent of total small scale systems energy for NSW.

Also in contrast to Ausgrid, AEMO forecasts assume no EV charging at the time of maximum system demand and therefore no increase in maximum demand from this source. This may eventually produce higher maximum demands from Ausgrid, but given the relatively small number of EVs assumed for the next few years, this is unlikely to be a significant source of difference between the two sets of forecasts in the medium term. On balance Ausgrid's assumption appears more reasonable in the absence of any regulatory move to curtail the times of day when EV charging may take place.

5.6 Forecast comparison

AEMO connection point forecasts include a forecast for the greater Sydney and Hunter region but not specifically for individual Ausgrid transmission connection points. AEMO's forecast for the Sydney area includes much of metropolitan Sydney as well as the Central Coast, between Sydney and the Hunter region. AEMO's forecast for the Hunter region includes a consolidation of transmission supply to Newcastle and other areas served by Ausgrid north of the Central Coast. AEMO's forecasts for the two regions is derived from analysis of each whole region as a consolidated entity, each of which is adjusted (along with all other AEMO connection point forecasts for NSW) so that the sum of NSW connection point forecasts matches AEMO's most recent top-down forecast for New South Wales. To the extent this procedure reduces growth equally across the entire NSW region, it may disproportionately reduce high growth localities such as Sydney.

In contrast, Ausgrid's forecast for its network area is derived from a build-up of forecasts for each individual zone substation within the area, using a network model of the meshed system and allowing for individual diversity. Much of the short term forecast demand growth is derived from specific block loads representing known projects. It is possible that the absence of an overall system constraint on forecast growth could result in Ausgrid's system level forecast including multiplicative upward or downward bias. However we found no obvious source for such bias.

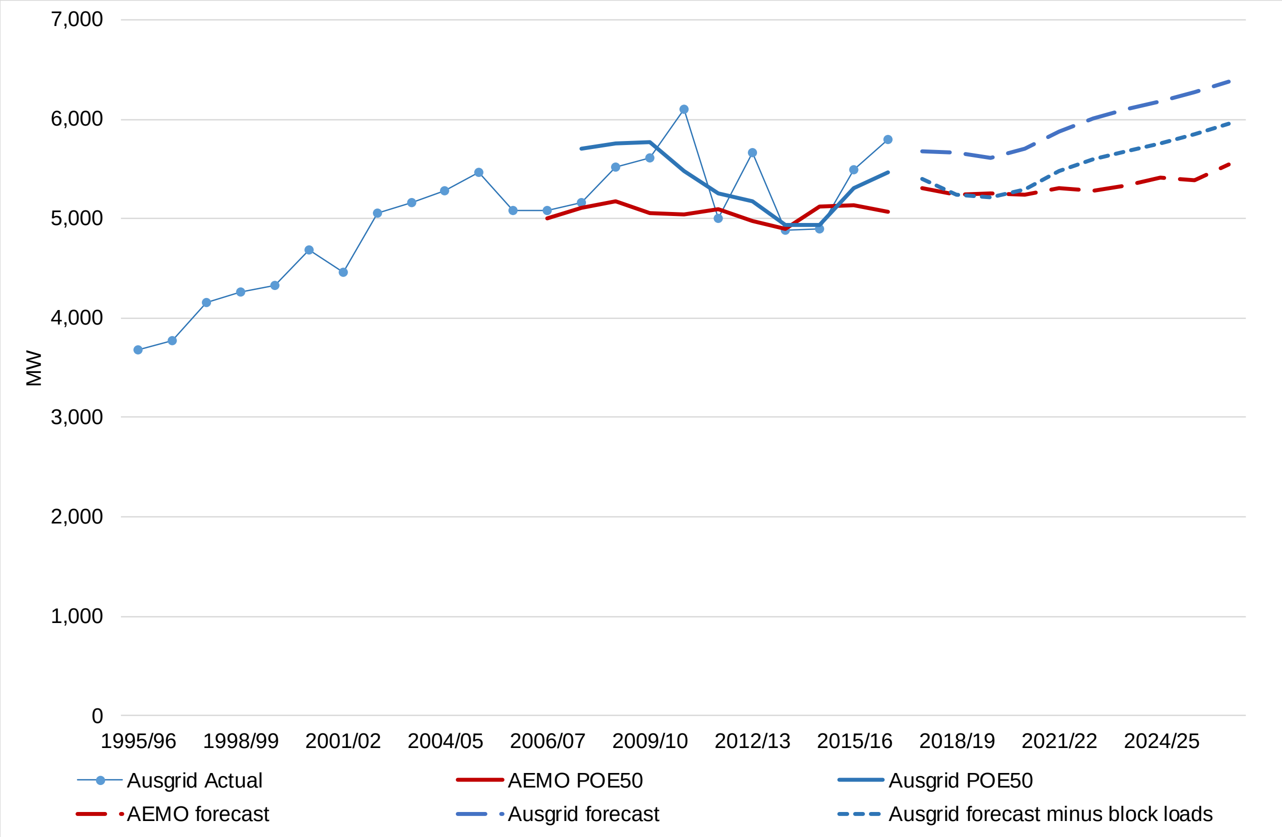
AEMO data is compiled from its combined Sydney Area and Hunter Region connection point demands. Ausgrid data is compiled from all its coincident zone and sub-transmission substation demands. The basis of the raw demand data used by AEMO to develop its historical POE 50 demands and forecasts includes losses in the 132 kV system and excludes Ausgrid demand supplied via the neighbouring Endeavour Energy network. In these respects the basis of the AEMO demand data is lower in the order of 70 MW compared to the basis used by Ausgrid.

A number of interesting features are highlighted by comparing the total system forecast for summer maximum demand prepared by Ausgrid with the AEMO equivalent. A comparison is presented in Figure 5-2 below and includes actual (i.e. not weather corrected) as well as POE 50 maximum demands, and forecasts starting in summer 2017/18.

Figure 5-2 illustrates the following:

- actual demand displays a trend increase until 2010/11, after which it generally fell until apparently resuming growth in the most recent two years
- Ausgrid's estimate of historical POE 50 maximum demand follows the observed falling then rising trend in actual demand, whereas AEMO's estimate does not
- when block loads are excluded, the initial four years' POE 50 maximum demand level is similar for the AEMO forecast and the Ausgrid forecast
- including block loads, Ausgrid's forecast for the initial four years is almost 400 MW above the AEMO forecast
- the growth rate over the ten-year Ausgrid forecast of 1.2 per cent is more than double the AEMO forecast growth rate of 0.5 per cent

Figure 5-2 Summer maximum demand on Ausgrid's system and medium POE 50 forecasts



Source: AEMO and Ausgrid data and GHD analysis.

In order to delve deeper into the relative reliability of the Ausgrid and AEMO forecasts we believe three important questions should be pursued:

- Firstly, to what extent (if any) should Ausgrid's block loads be included in AEMO's forecast, or else removed from Ausgrid's forecast, to produce a comparable starting level for the forecasts?
- Secondly, given the use of identical macroeconomic forecast variables and similar orders of magnitudes of estimated elasticities, why is there little or no growth in the AEMO forecasts, or else why do post model adjustments not offset more growth in the Ausgrid forecast?
- Thirdly, given the broadly similar processes of weather normalisation used by AEMO and Ausgrid, how is it that the respective weather corrected historical series end up on two very different trend trajectories?

With regards to the first question, the sources of information about block loads are almost exclusive to Ausgrid's connection application process, and therefore, provided the methods described above for consistent identification, classification and scaling of block loads are applied, we would expect Ausgrid's forecasts of block loads to be authoritative.

With regards to the second question, both the Ausgrid and AEMO forecasts are driven by short and long term responses to changes in macroeconomic variables (albeit by different mechanisms) and both use an identical set of macroeconomic forecasts. These forecasts include minimal electricity price growth and close to historically average growth in income, and so any reasonable estimation of income elasticity should provide a steady increase in electricity demand. A significant offset to this increase is the assumed impact of above-trend energy efficiency, charging and discharging of battery storage, and the increasing take-up of distributed solar generation. In Ausgrid's forecast, post model adjustments including increases in distributed generation, battery storage and discharge, above-trend energy efficiency impacts and electric vehicle charging incrementally reduce maximum summer demand on the network, reaching a total impact of around 300 MW by 2027. AEMO's 2017 assumptions around these impacts are not quantifiable from published information.

The third question, we suspect, goes back to the issues of detail that are discussed above in section 5.2.1 and in particular the degree to which consecutive years of demand data were pooled to establish the statistical temperature-demand relationship[15]. To the extent this relationship is changing significantly from one summer to the next, pooling would suppress the statistical expression of such a change. Although to the non-forecaster such issues may appear to be arcane and highly technical, the depiction of historical demand is critical to the projection of future trend growth.

5.7 The evolution of forecasting methodology

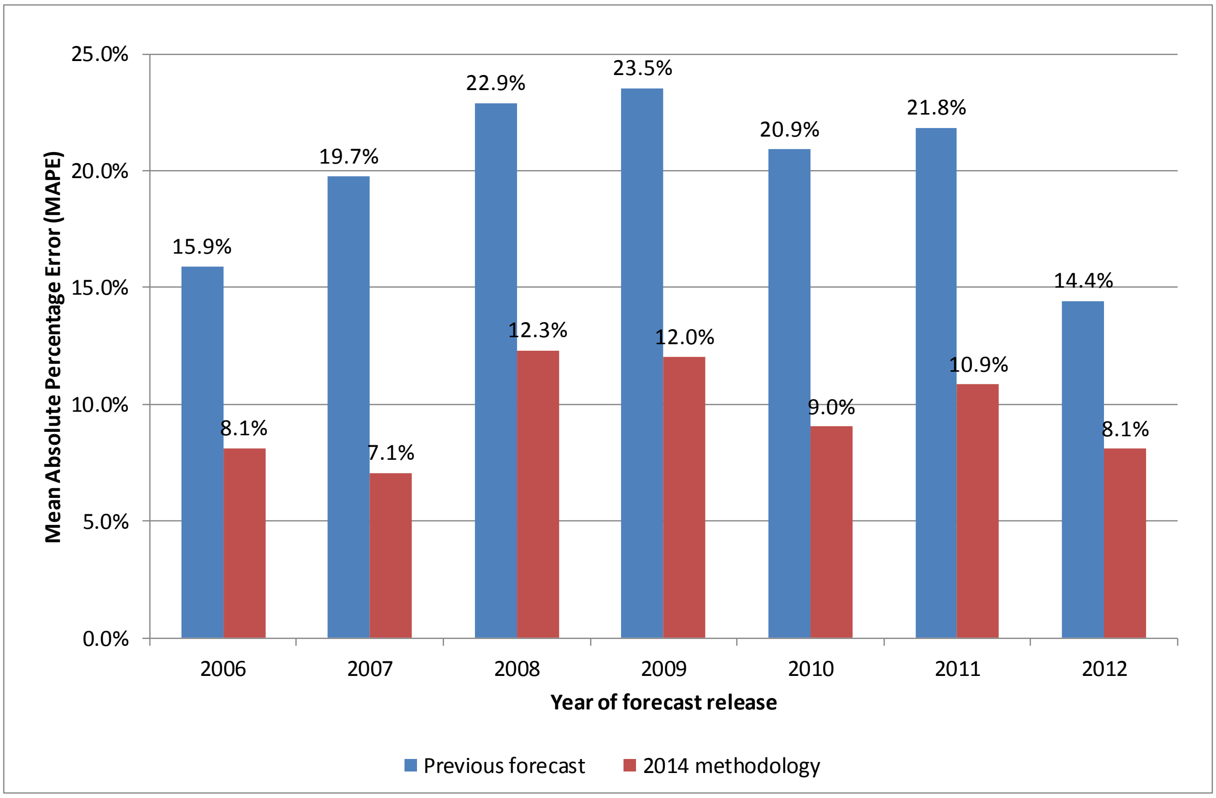
Ausgrid made significant enhancements to the method used to forecast zone substation demand in 2014, over and above regular enhancements and minor adjustments that are typically made each year. The change in Ausgrid's forecast since 2012 is typical of the scale of change in demand forecasts produced by AEMO and other parties since that time, following a downturn in electricity demand that was not foreseen by the industry and generally not encompassed by industry forecasting methodology at that time.

The improvement delivered by Ausgrid's new approach of incorporating energy services was tested in 2014 using back-casting analysis to examine the improvement in forecast accuracy that would have occurred if the new technique had been used to produce previous forecasts. This analysis indicates that on average the current approach produces more accurate results. Representative of the improved forecasting accuracy of these changes is a significant decrease in mean absolute percentage forecasting error (MAPE) as shown in Figure 5-3.

It is the nature of forecasts to always be in error to some degree, and what is a reasonable degree of error varies according to the forecasting problem at hand. In Figure 5-3, the percentages shown refer to differences between actual and forecast demand growth. For example, a 10 per cent error would be equivalent to forecasting 1.0 per cent growth when actual growth was 0.9 per cent.

[15] It is difficult to identify the 'correct' level of weather corrected maximum demand. However, over a period of time we should expect the true POE 50 demand to exceed actual demand about half the time. With respect to Ausgrid's series of 10 years, Figure 5-2 shows that the historical POE 50 demand exceeds the actual series in six out of 10 years, whereas AEMO's historical POE 50 series exceeds the same actual demand in only three of 11 years.

Figure 5-3 Results of multi-year back-casting using current and previous methodologies



Source: Ausgrid.

Although MAPE provides no information about the direction of any systematic bias in the forecast, it is informative of the difference between forecast and actual outcomes regardless of the direction of the difference. Figure 5-3 shows multiple year MAPEs calculated for succeeding forecast years, where each year's forecast is prepared using only the information available in year. The resulting out-of-sample forecasts thus represent forecasts that would have been made in that year and are compared against actual outcomes that have subsequently become available.

The blue bars in Figure 5-3 show calculated MAPEs using the previous methodology. The red bars show calculated MAPEs using the 2014 methodology (i.e. the new methodology). Actuals used in the MAPE calculations are weather corrected. The analysis presented in Figure 5-3 considers the performance in forecasting the demand for the entire Ausgrid supply area. The current 2017 methodology has retained the enhancements made to the 2014 methodology, with adaptation to new historical data and improved PV data.

It would be worthwhile to repeat this analysis using 2015 and 2016 forecast results, to verify that the average MAPE reductions since 2012 (to generally well below than 15 per cent) have continued. We recommend a similar analysis of forecast accuracy be conducted on an annual basis as a routine part of forecast preparation.

5.8 Accounting for customer connection numbers and air conditioner penetration

Ausgrid forecasts of residential customer numbers make good use of available specialist forecast data. The customer numbers forecasts are used to make minor adjustments to the demand forecasts, since the demand model initially determines growth on a per dwelling basis. An issue that may arise in connection with forecast comparisons is whether NSW Department of Planning population projections, relied upon by Ausgrid, are consistent with population projections used by comparable forecasters such as AEMO.

Ausgrid projections of air conditioner penetration follow the pattern of similar markets elsewhere, such as Queensland, where affordability sustained an initial rapid rate of growth but where penetration eventually approached a ceiling as the market became saturated. The projected penetration rate is used in a reasonable fashion to make a further adjustment to the demand forecasts. This is justified as the demand model implicitly determines growth on the basis of the average historical penetration rate. Air conditioner penetration is assumed to have currently all but saturated at 65 per cent by 2021, from the current rate of 61 per cent, so this is not a material adjustment.

5.9 Key findings and recommendations

This section sets out our key findings on Ausgrid's electricity demand forecast methods and our recommendations. As is the case for all utility demand forecasting processes, alternative methods and approaches always exist and the gathering of evidence for adopting enhancements may only be limited by resource constraints. As such our recommendations highlight the issues and potential investigations that we found likely to be most material at the time of investigation.

5.9.1 Key findings

Table 5-1 presents our key findings in order of increasing materiality.

Table 5-1 Key findings (in order of materiality, beginning with the most material findings)

Forecasting stage	Existing process description	Potential issues identified	Improvements to consider
Short term forecasts	A warming climate trend is not incorporated into the forecasting process at any stage	It is to be expected that, if the climate is warming, a fixed POE level of summer demand would increase, and that a fixed POE level of winter demand would decrease over time	One method of incorporating a warming climate trend is described in Section 5.2.1 above
Analysis of forecast accuracy	Ausgrid have undertaken a one-off out-of-sample forecasting exercise to test major enhancements to the forecasting methods that were first implemented in 2014.	This was a worthwhile exercise as the demonstrable improvements in accuracy were able to be quantified. However the exercise has not been repeated since.	Ausgrid should implement annual forecasting accuracy tests annually as a routine part of the forecast preparation process
Long term forecasts	The preferred regression models are selected on the basis of high R^2, low t-statistic probabilities, a positive sign for income elasticity and a negative sign for price elasticity	Greater confidence in the preferred models as forecasting models could be achieved by the use of back-casting	As described in Section 5.3 above, back-casting may be performed by re-estimating the model withholding the most recent data, then forecasting the most recent, out of sample, period, and using actual historical data as inputs. The actual and forecast demand may then be compared and tested for accuracy (where the two series have similar mean values) and bias (where differences between the two series persist in one direction only)
Short term forecasts	Temperature sensitivity is estimated one season at a time using a limited data sample	The limited amount of data available likely results in a high dependence on the random element, relative to the temperature sensitive element, in determining simulated demands from which the temperature corrected seasonal maxima are selected	Ausgrid should a) test for normality of the errors from existing temperature sensitivity equations b) experiment (as described in Section 5.2.1 above) with pooling of multiple years to expend the amount of data available
Short term forecasts	After temperature correcting the substation seasonal maximum demands, a straight line trend is fitted to the data	The identified demand trend is dependent on the historical period over which it is estimated (especially if this period includes a turning point from growth to decline or vice versa)	The historical period used for trend estimation has been chosen as the last five years. It would be worthwhile to test the impact on forecast outcomes of varying this period to six and four years in turn
Short term forecasts	Temperature sensitivity estimation uses a single temperature variable	Other possible specifications could include lagged temperature and the inclusion of dimensions such as humidity and wind speed	Only by experimenting with alternative specifications can the potential benefits and costs be determined. Ausgrid should continue to assess alternative specifications

Forecasting stage	Existing process description	Potential issues identified	Improvements to consider
Long term forecasts	Weather correction of whole of network demand is performed one season at a time	There is a limit of the number of observations available with which to draw statistical inferences	Pooling of years for weather correction should be trialled, as described in Section 5.3 above
Block loads	A considerable amount of infrastructure and commercial development is taking place in Sydney which is reflected in the high block load component of the electricity demand forecasts	There is a potential to over-estimate this element of the forecasts, either by under-estimation of the number of projects that are scaled back or delayed, or else by double-counting general demand by drilling down to too small a scale for block load connections	Ausgrid should continue the current practice of discounting identified block loads using learning about completion rates from previous years
Post model adjustments	Ausgrid assumes that any distributed battery energy storage systems will only be taken up by the residential sector in conjunction with a rooftop PV system and that no commercial business case will exist to install batteries. Ausgrid also assumes that a significant electric vehicle charging load will occur at the time of maximum demand	While defensible, these assumptions may be at odds with other similar forecasts or forecasting practice	It may be of value to Ausgrid to present the reasoning behind these assumptions and their quantitative significance
Long term forecasts	Price and income elasticities are estimated using summer maximum demand data only	The instantaneous demand response to long term changes in price and income may be different in winter, compared to summer	This proposition could be tested by repeating the process of estimating price and income elasticities using winter data. Alternatively the sample length could be doubled (with consequent advantages) if both summer and winter maximum demand were included in each single equation
Long term forecasts	The results of the two long term elasticity equations (residential and non-residential) show high R^2 (indicating the data is a good fit to the model) and low t-statistic probabilities (indicating the coefficient estimates are significantly different from zero)	No other statistical testing of the long term elasticity equations is presented and these results are not compared to alternative possible specifications (although Ausgrid reports experimentation with alternative lag specifications and data sample selection)	Cointegration testing would consist of two components – testing of the individual data series for stationarity and testing the residuals from the elasticity equations for cointegrating relationships between the variables. Unfortunately the total amount of data available is limited to 14 years of a single summer or winter season at most. However this could be doubled as explained immediately above.

Forecasting stage	Existing process description	Potential issues identified	Improvements to consider
			Alternative specifications could include equations in linear, log-linear and linear-log forms
Long term forecasts	Energy efficiency estimates used to determine forecast above trend maximum demand impacts are based on three key programs	Energy efficiency historical trends and projections are both uncertain and the combination of both is required to calculate the above trend impact. Also required are assumptions about seasonal load factors on the days of maximum demand and a method of allocating energy efficiency impacts between the residential and non-residential sectors	The energy efficiency estimates may not be based on the most recent data. It may be of value to Ausgrid to present high level information about the demand forecasts showing the contributions made by various elements, including energy efficiency
Post model adjustments	External energy efficiency advice reviewing post model adjustments to the forecasts was updated in 2013	This was four years ago and estimates of actual energy efficiency, forward projections and the incorporation of information into the Ausgrid electricity demand forecasts may all have changed significantly	External consultants reports should be refreshed on an annual basis or when circumstances have materially changed
Short term forecasts	Historical energy efficiency impacts are not removed from demands prior to determining underlying weather corrected trend	Significantly abrupt changes in historical energy efficiency could influence the identified trend (as could any abrupt change during the historical period). This is one of a number of reasons to expect that the short term trends in historical demand will not necessarily continue into the future. It serves to highlight that one of the fundamental assumptions of Ausgrid's forecast approach is that established demand trends are relatively persistent	This potential issue could only be eliminated by removing the impact of changing energy efficiency on the historical demands prior to trend analysis. However, there are no directly measurable energy efficiency data at the level of granularity required to adjust historical demands at each location in the Ausgrid system. As such this is a level of refinement that is better not attempted

5.9.2 Recommendations for Ausgrid

The overall approach to preparation of the 2017 electricity demand and customer forecasts, the methods used and the data inputs were appropriate – and in some cases innovative - and conducive to the production of reasonably accurate forecasts. Notwithstanding, we made some suggestions for maintaining a constantly adaptive and improving forecasting process which may be found in section 5.9.2 above and which are repeated below. The existence of suggestions for improvement do not reflect on any perceived unreliability of the 2017 forecasts. Rather these suggestions are aimed at ensuring that the testing alternatives methods and checking the evolving accuracy of forecast outcomes continues at Ausgrid and is enshrined as an ongoing practice.

Regarding the ongoing improvement of the forecasting process:

1. All assessments of alternative implementation practices, including the historical period used to determine short term trends and data pooling during weather correction, be formally documented in brief, to provide formal reasons for choosing between alternative practices.
2. External consultants' reports (e.g. on energy efficiency impacts) should generally be refreshed on an annual basis or when circumstances have materially changed.
3. The current practice of discounting identified block loads using learning about completion rates from previous years should be continued and refined each year on the basis of new information.

Regarding the short term forecasts:

4. When simulating Equation 4-2 for locational weather correction, (a) use diagnostic checks to test the assumption of normality of the equation errors and (b) if normality is found to be a reasonable assumption, use two standard errors rather than one standard error in the derivation of the simulated maximum demands.
5. Eliminate the impact of climate trends from weather correction, for example by following steps 1 to 4 in section 5.2.1 above.

Regarding the long run forecasts:

6. Implement out-of-sample back-casting on a regular basis to test the accuracy and bias of the estimated system level long run equations..
7. Trial pooling of years for the system wide weather correction process.
8. Eliminate climate trends from weather correction as in recommendation 5 above.

Regarding testing and presentation of the forecasts:

9. Conduct empirical tests of overall forecast accuracy on a regular basis, similar to the manner in which the 2014 enhancements to the forecasting process were tested to determine MAPE over several forecast years.
10. In order to show relative significance of various assumptions, make available high level information for presentation showing the contributions made by each of the main components of the demand forecasts, including growth modelled by macroeconomic variables, embedded PV generation take-up, increased air conditioner penetration, battery storage, above trend energy efficiency and electric vehicle charging.

6. Conclusions

The authors of this report have reviewed Ausgrid's electricity demand and customer connection forecasts, including methods, processes and assumptions used to prepare those forecasts. We have made all the inquiries that we believe are desirable and appropriate and no matters of significance that we regard as relevant have, to our knowledge, been withheld.

Ausgrid's overall approach to preparing its demand forecasts is based on three main building blocks, which include:

1. identification of representative underlying trends in recent historical demands (in the absence of 'lumpy' loads designated as 'block loads'
2. response of underlying long term demand (not including block loads) to recognised demographic and economic drivers of demand
3. application of post model adjustments (including above trend energy efficiency, take-up of battery storage, roof top solar generation, future electric vehicle charging and the addition of block loads)

The overall approach is determined by Ausgrid's main requirement, of identifying changes in locational demands on the network that may need to be addressed by network planning, by Ausgrid's well informed understanding of planned new connections to its network through the connection applications process, and by the detailed corporate understanding of the nature of what drives electricity demand built up by the experience of current and previous forecasters.

Ausgrid forecasts residential customer numbers, which are then used to make minor adjustments to the demand forecasts, since the demand model initially determines growth on a per dwelling basis. Forecast customer numbers rely in part on NSW Department of Planning population projections on an LGA basis. We believe Ausgrid's approach to determining customer numbers is reasonable.

Ausgrid's approach to demand forecasting and its detailed implementation have evolved over time in response to evidence based trials of alternative models and assumptions. The methods used by Ausgrid are at least as sophisticated as the methods used by similar utilities around Australia and overseas in the United Kingdom and the Middle East. Ausgrid model inputs and assumptions are also reasonable. We have made a number of observations on matters of detail linked to a series of recommendations for potential further refinement of the forecast preparation process. By and large these observations are unlikely to have a major impact on the reliability of the demand forecasts. However we do believe two particular issues are noteworthy from a comparison of results with AEMO forecasts. These are:

- the size of the increase forecast by Ausgrid in block loads in the near term appears to be unprecedented, and does not appear to be included in AEMO's (almost equivalent) forecast
- the small impact that post model adjustments have on dampening underlying long term growth in Ausgrid's forecast, relatively to AEMO's (almost equivalent) forecast

We were furnished with sufficient information from Ausgrid to form the view that the short and long term underlying trends, and the assumptions made by Ausgrid leading to the block load and other post model adjustments were a reasonable view of the future. However a lack of information about the basis of AEMO's forecasts prevents us from quantifying the reasons for the divergence of their forecasts from Ausgrid's system forecast.

7. References

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Appendix

Appendix A GHD's relevant experience

GHD Advisory is an integrated part of GHD's connected network which has a track record of delivering robust outcomes for our clients for more than 85 years.

GHD is one of the world's leading professional services companies operating in the global markets of water, energy and resources, environment, property and buildings, and transportation. Privately owned by our people, GHD provides engineering, architecture, environmental and construction services to private and public sector clients across five continents and the Pacific region.

Focused on creating lasting community benefit, our connected global network of 8500 people delivers projects with high standards of safety, quality and ethics. Committed to sustainable development, GHD improves the physical, natural and social environments of the many communities in which we operate.

[www.ghd.com/ advisory](www.ghd.com/advisory)

GHD has substantial experience in assisting with regulatory reviews of electricity network businesses, both in Australia and overseas. We have undertaken demand forecast reviews of Australian electricity network businesses in the eastern states and in Western Australia, both on behalf of the businesses and on behalf of the regulator. We have also reviewed utility forecasts in the United Kingdom and in several Middle Eastern and African countries.

The lead author of this report, Richard Hickling, had substantial experience prior to working with GHD in developing demand forecasts and demand forecast capability for AEMO and TransGrid.

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