TransGrid

TransGrid Revenue Proposal
2018/19 – 2022/23

Appendix B

Powering Sydney's Future

RIT-T: Project Specification Consultation Report

Powering Sydney's Future

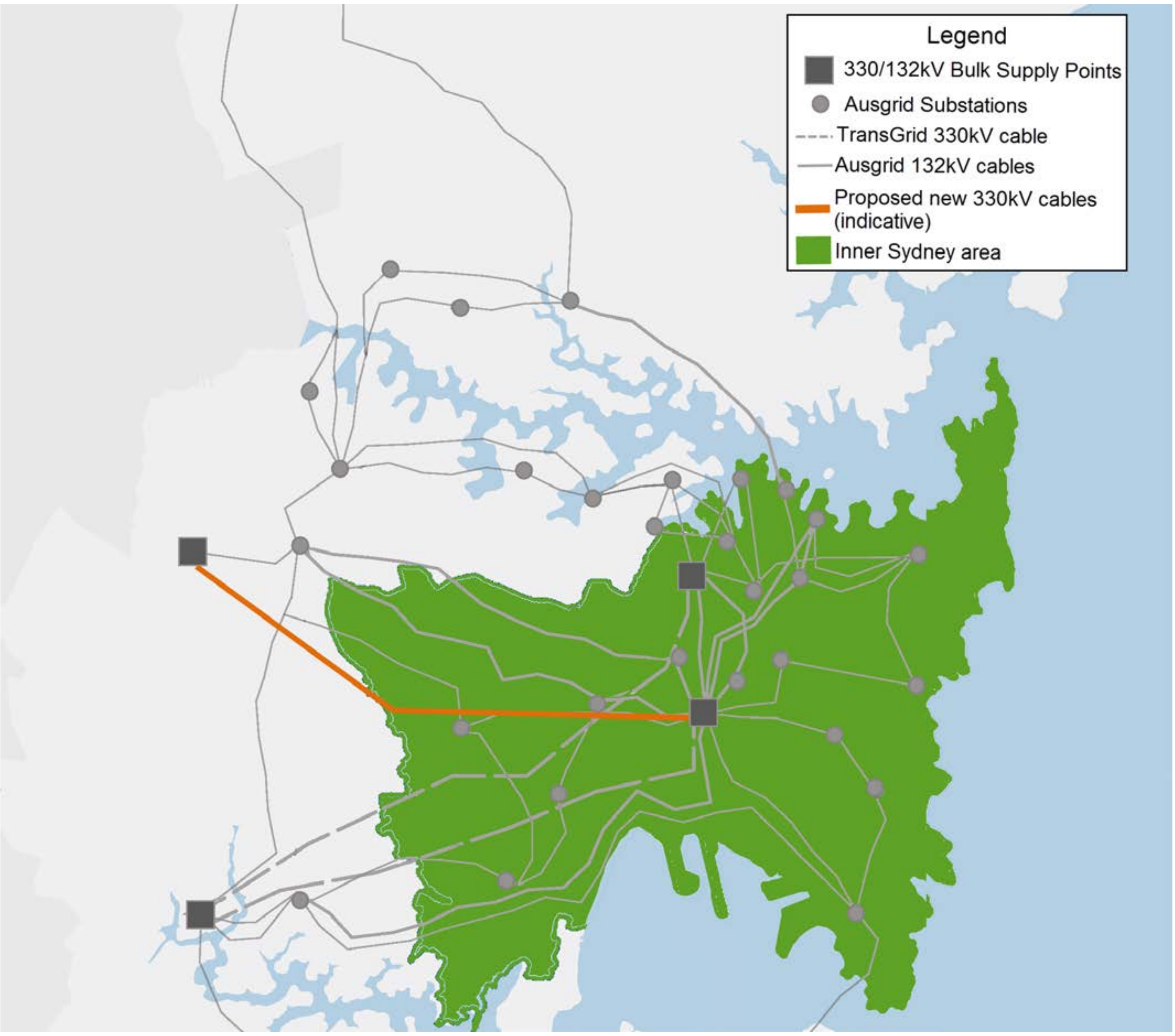
11 October 2016

1. Executive Summary

Powering Sydney - now and into the future

A reliable, affordable and sustainable electricity supply is essential for our way of life. If you live, work or operate a business in the Inner Sydney area, you are connected to one of the most critical parts of the NSW electricity network.

The Inner Sydney area, shown in the figure below, includes the CBD, which is a hub for economic activity, major transport infrastructure, industry and tourism. Increasingly it is also home to a growing number of people attracted to shorter commutes, harbour views and the many benefits that city living has to offer. The Inner Sydney area provides a base for a number of significant entities such as the Australian Securities Exchange, Reserve Bank of Australia, NSW Parliament, Port Botany and Sydney Airport. A number of public transport agencies, large datacentres and financial institutions are also located in this area and require a high level of both reliability and security when it comes to their electricity supply. Inner Sydney is the lifeblood of the Australian economy and an uninterrupted supply of electricity is vital for our continued participation in global markets.



TransGrid and Ausgrid have worked together to power this vital part of the electricity network for many years. Through ongoing monitoring and analysis, we ensure our assets such as poles, wires and cables, are in appropriate working order to keep the network functioning. Parts of the transmission and distribution networks which supply electricity to the Inner Sydney area were built in the 1960s and 70s. Some of those assets are approaching the end of their serviceable lives. TransGrid and Ausgrid have been jointly working to identify the most economically viable solutions that deliver environmental responsible and socially acceptable outcomes. We invite you to be part of the process and encourage you to lodge a submission outlining any opportunities you believe we should consider as we move through the Regulatory Investment Test for Transmission (RIT-T) process for the Powering Sydney's Future project.

Learnings from early engagement

Powering Sydney's Future, which originally launched in 2014, was a key milestone in TransGrid's stakeholder engagement journey. Through this initiative, TransGrid and Ausgrid investigated a number of solutions to maintain reliability and security of electricity supply to Inner Sydney. Between January and October 2014, TransGrid and Ausgrid implemented a range of engagement activities including workshops, information sessions, surveys and briefings and sought feedback from stakeholders, businesses and communities on a range of initiatives that could deliver a coordinated and cost effective solution for the future energy needs of inner Sydney. Through this engagement TransGrid and Ausgrid received feedback from more than 350 stakeholders.

In 2015, the demand forecasts published in TransGrid's Annual Planning Report indicated a lower peak demand and a slower rate of growth for Inner Sydney over the coming decade. This change enabled TransGrid to defer capital expenditure. In its early Engagement and Feedback Report published in December 2014, TransGrid committed to:

- Continue working closely with Ausgrid on a joint planning approach
- Work with industry on demand management research
- Communicate any significant project updates to stakeholders

A solution is needed by 2021/22

Based on the results of testing and analysis of the condition of the affected assets and updated demand forecasts we estimate that we will need to have a solution in place to meet the Inner Sydney network constraint by 2021/22. Throughout the RIT-T process, TransGrid and Ausgrid will consider a range of solutions. These could be network, non-network, or a combination of network and non-network solutions.

If it is decided that a network solution is the most feasible and cost-effective option it could take up to five years to implement due to the work involved in approvals, environmental assessments, planning and project delivery. While it may be possible to implement non-network solutions earlier, we need to start the process now and invite expressions of interest (EOI) from solution providers for alternative solutions. We can then evaluate such EOI opportunities and procure as appropriate.

A collaborative approach

TransGrid and Ausgrid are working together to find the most efficient, environmentally responsible and economically feasible response to constraint on a critical part of the NSW electricity network. The need for a solution is being driven by several factors which are outlined in detail in this report.

- The deteriorating condition and reduced capability of assets (330 kV Cable 41 by TransGrid and a number of 132 kV cables by Ausgrid)
- Implication of compliance with the proposed IPART reliability standard for planning
- The deteriorating condition of aging oil-filled cables in the existing network and the derating of the 330 kV Cable 41 by TransGrid (in 2011 and 2016) and the derating of a number of 132 kV cables by Ausgrid (beginning in 2012).

- Ausgrid’s planned retirement of three oil-filled cables in Inner Sydney in the next two years.
- The age-related deteriorating condition of a further eight oil-filled Ausgrid cables in the Inner Sydney area.
- An increase in forecast peak demand due to renewed economic activity within Inner Sydney.

Proposed Reliability standard

The level of reliability set by the NSW Government is an important input into TransGrid's and Ausgrid’s capital program. Any change to the transmission reliability standard for NSW will need to be reflected in TransGrid's and Ausgrid’s network planning and operational decisions, including our upcoming revenue proposal. The NSW Government asked the Independent Pricing and Regulatory Tribunal (IPART) to review and recommend revised NSW transmission reliability standards, which would apply to TransGrid from 1 July 2018.

On 29 September 2016, IPART published a Supplementary Draft Report detailing recommendations on the new reliability standards for the Inner Sydney area.

The recommended standards include a level of redundancy and an annual undelivered, or unserved energy allowance at each bulk supply point across TransGrid’s and Ausgrid’s network. They do not prescribe how TransGrid must invest but instead, explicitly provide for TransGrid and Ausgrid’s to determine the combination of network and non-network solutions required to provide reliability.

For the Inner Sydney area, IPART’s draft recommendation is that the amount of the unserved energy allowance should be 0.6 minutes per year, at average demand. This would apply across the five Inner Sydney bulk supply points (Beaconsfield West, Haymarket, Rookwood Rd, Sydney North and Sydney South). IPART expects that its recommendations would allow a small increase in the expected unserved energy in the Inner Sydney area but given the total unserved energy allowance is small, at around half a minute a year, it considers that its recommendations would not result in a significant change to the level of reliability experienced by customers.

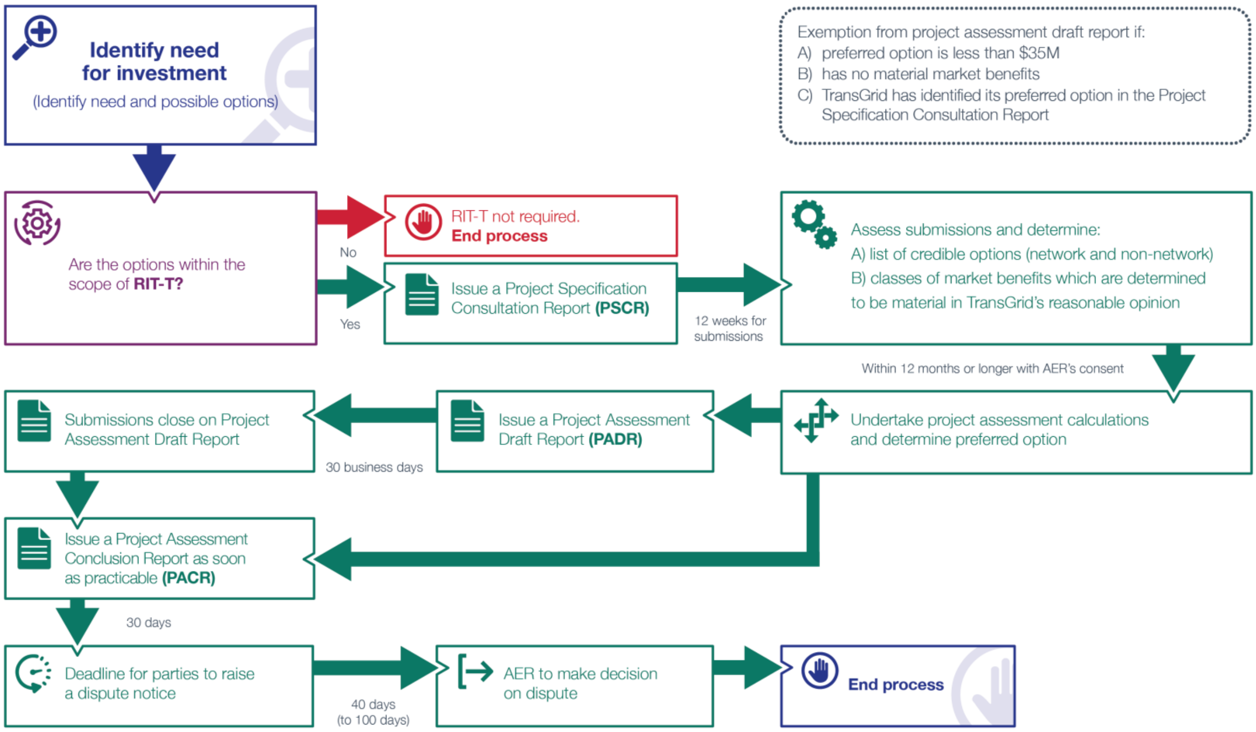
The supplementary draft report is available on the IPART website. IPART seeks submissions by 28 October 2016 before a supplementary final report is provided to the NSW Government in December 2016[1]. This process coincides with the joint RIT-T process being conducted by TransGrid and Ausgrid for the Powering Sydney’s Future project. We do not anticipate a change that would affect the project significantly; however we will continue to communicate with IPART throughout the process and consider any impact from the outcome of the review and incorporate it into the Project Assessment Draft Report (PADR).

RIT-T assessment has begun

Publication of this Project Specification Consultation Report (PSCR) marks the first stage of the Regulatory Investment Test for Transmission (RIT-T) consultation process. The process is designed to inform stakeholders of the investment need and proposed options (both network and non-network) to address it, test the market for more efficient solutions, and advise stakeholders of the outcome of the selected solution.

[1] https://www.ipart.nsw.gov.au/Home/Industries/Energy/Reviews/Electricity/Review-of-Electricity-Transmission-Reliability-Standards/29-Sep-2016-Media-Release/Media-Release-Supplementary-draft-report-on-electricity-transmission-reliability-standards-Sept-2016

RIT-T Consultation Process



Potential options to address the need

TransGrid and Ausgrid have identified six credible network options as part of the PSCR, all of which involve building new 330 kV cables between TransGrid's Rookwood Road and Beaconsfield substations.

Summary of potential credible network options

Option	Indicative capital cost ($2016 real)	Indicative O&M cost ($2016 real)
Option 1: install two 330 kV cables in stages, retire Cable 41 and decommission Ausgrid cables in two stages	$435 million	2 per cent of new capex + $15 million in decommissioning costs
Option 2: operate Cable 41 at 132 kV, install two 330 kV cables in stages and decommission Ausgrid cables in two stages	$443 million	2 per cent of new capex + $15 million in decommissioning costs
Option 3: install two 330 kV cables at once, retire Cable 41 and decommission Ausgrid cables in one stage	$417 million	2 per cent of new capex + $15 million in decommissioning costs
Option 4: remediate Cable 41, install two 330 kV cables in stages and decommission Ausgrid cables in one stage	$560 million	2 per cent of new capex + $12 million in decommissioning costs
Option 5: remediate Cable 41, install two 330 kV cables at once (initially operating at 132 kV) and decommission Ausgrid cables in two stages	$555 million	2 per cent of new capex + $12 million in decommissioning costs

Option 6: remediate Cable 41, install two 330 kV cables at once and decommission Ausgrid cables in one stage	$542 million	2 per cent of new capex + $12 million in decommissioning costs

TransGrid and Ausgrid consider that there is potential for non-network options (such as embedded generation and demand response) to defer the time at which network investment would be required.
These options within Inner Sydney include:

- Embedded generation;
- Energy power storage, which inject power into the grid when required; and
- Voluntary curtailment of load.

TransGrid and Ausgrid have estimated the approximate level of network support required to provide the minimum amount of reduced estimated unserved energy to defer the network investment. These requirements, detailed in the Table below, are based upon availability of network support for an entire year. Further information on the specific requirements for network support is in Section 4.

Year	Minimum network support required
2022/23	60 MW
2023/24	90 MW
2024/25	150 MW

TransGrid and Ausgrid welcome submissions to this PSCR from potential providers of non-network solutions. Any non-network option raised through the Expression of Interest process and considered to be technically and commercially feasible will be assessed as part of the PADR assessment.

How to get involved

TransGrid and Ausgrid welcome written submissions on this PSCR.

Submissions are due on or before 13 January 2017, which exceeds the 12 weeks prescribed in the National Electricity Rules (NER) and accommodates for the end of year holiday period. In particular submissions are sought on the credible options presented and from potential proponents of non-network options that could meet the technical requirements set out in this PSCR.

If you would like to discuss the material presented in this document or require further information to assist with a submission, please contact us.

Submissions can be made via the following email address: PSFConsultations@transgrid.com.au.

Contents

Appendix A.1 – Checklist of compliance clauses

Appendix A.2 – TransGrid and Ausgrid Inner Sydney oil-filled cables

Appendix A.3 – Approach to the calculation of unserved energy

Appendix A.4 – Reliability model of aging oil-filled cables

Appendix B – Cable 41 Investigation Summary Report

Appendix C – HoustonKemp VCR Report

Appendix D – BIS Shrapnel Demand Forecast Report

2. Introduction

2.1 Aging electricity infrastructure presents real and increasing risk to consumers

A reliable electricity supply to the Inner Sydney area (which includes the Sydney CBD and a number of inner suburbs) is of crucial importance, both to customers and businesses located in these areas, as well as more broadly to New South Wales, due to the importance of this area in contributing to the wider economy.

Key elements of the current electricity transmission networks supplying the Inner Sydney area are aging. In particular, there are a number of oil-filled cables that have been in operation since the 1960s and 1970s and have recently identified issues with their backfill and bedding material, which is compromising their operating performance. As a consequence, TransGrid and Ausgrid have both had to downgrade the capacity that these cables can provide.

These aging oil-filled cables are at a stage in their technical life where they are associated with an increasing likelihood of failure. When a failure occurs the cable is required to be out of service for lengthy periods to enable repairs, generally up to 3 months but can be longer for difficult locations. This increases the chances that these network elements are out of service when failure of another network element occurs, which may result in undelivered, or 'unserved', energy. Electricity consumers in Inner Sydney are therefore becoming increasingly vulnerable in terms of the expected level of disruption to their electricity supply.

In addition, peak demand in the Inner Sydney area is forecast to rebound on the back of renewed economic activity, as confirmed by committed new customer connections, as well as a large increase in future demand from anticipated customer connections. This increases the amount of energy that may be disrupted as a consequence of increasing capacity constraints.

TransGrid and Ausgrid have undertaken analysis as part of this Project Specification Consultation Report (PSCR) that shows a significant forecast increase in unserved energy to the Inner Sydney area. In particular, if a forced outage of two or more significant transmission elements occurred, the impact of load curtailment, particularly for Inner Sydney would be significant.

This PSCR arises from the joint planning efforts of TransGrid and Ausgrid to identify the most efficient solution across their respective networks as a whole.

2.2 Drivers of this Regulatory Investment Test for Transmission

The identified need for this Regulatory Investment Test for Transmission (RIT-T) is TransGrid and Ausgrid's assessment that the future value of unserved energy, environmental and financial impacts associated with oil-filled cables that are avoided by undertaking investment exceeds the investment cost of doing so.

In the absence of undertaking such investment, the following are expected to increase the amount of unserved energy in the future, environmental and financial risk:

1. The deteriorating condition of aging oil-filled cables in the existing network and the derating of the 330 kV Cable 41 by TransGrid (in 2011 and 2016) and the derating of a number of 132 kV cables by Ausgrid (beginning in 2012).
2. Ausgrid's planned retirement of three oil-filled cables in Inner Sydney in the next two years.
3. The age-related deteriorating condition of a further eight oil-filled Ausgrid cables in the Inner Sydney area.
4. Forecast increases in peak demand due to renewed economic activity within Inner Sydney.

TransGrid and Ausgrid intend to value the reductions in the expected unserved energy, environmental and financial impacts associated with oil-filled cables associated with each credible option, compared to the option of doing nothing.

TransGrid and Ausgrid note that the reliability standards applying to transmission in New South Wales from 1 July 2018 were recently reviewed by the Independent Pricing and Regulatory Tribunal. While the final standards are not yet known, a move to a standard that explicitly acknowledges the value of unserved energy to customers is expected.[2] TransGrid and Ausgrid therefore consider the approach to valuing reductions in the expected unserved energy associated with each credible option to be consistent with the approach used to derive the new standard.

TransGrid and Ausgrid also note that the approach taken to modelling the costs and benefits in this RIT-T will be adapted (if necessary) to be consistent with the final reliability standard decided by the Minister of Industry, Resources and Energy. TransGrid and Ausgrid note that they have also assessed the identified need against the existing modified N-2 reliability standard (as if it continued to apply from 1 July 2018) and consider that investment is required in order to be compliant.

2.3 This RIT-T represents a re-commencing of the Powering Sydney's Future project

This RIT-T represents a formal recommencing of the Powering Sydney's Future project that TransGrid and Ausgrid consulted on extensively during 2014 and, ultimately, decided to defer in light of decreasing maximum demand forecasts at the time. A number of factors have contributed to this project being re-evaluated and this RIT-T commencing, which are summarised in the box below along with the 2014 consultation process.

Box 2: Previous consultation on the Powering Sydney's Future Project

During 2014, TransGrid and Ausgrid consulted widely on the Powering Sydney's Future project. Between April and October 2014, TransGrid and Ausgrid conducted a range of stakeholder engagement activities including workshops, surveys and community information sessions. TransGrid and Ausgrid conducted a public forum on 19 June 2014 ('Planning Inner Sydney's Electricity Future Forum') and published a subsequent Interim Engagement and Feedback Report in August 2014, as well as an Early Engagement and Feedback Report in December 2014.[3] Through this engagement, feedback was received from over 350 stakeholders.

At the time, there were five key drivers behind the Powering Sydney's Future project – namely:

1. the 'modified N-2' NSW transmission reliability standard in place at the time;
2. the age and reliability of TransGrid's Cable 41;
3. the rating of Cable 41, which had been derated from 663 MVA to 575 MVA in 2011;
4. the rating and retirement of Ausgrid oil-filled cables; and
5. peak demand was forecast to increase.

In late 2014, following these engagement activities, TransGrid and Ausgrid updated the maximum demand forecast information for the Inner Sydney area, which suggested a lower peak demand in the near term and a slower rate of growth. These revised forecasts meant that there were no longer forecast supply constraints in the near term and TransGrid and Ausgrid elected to defer the project at that time.

Since 2014, there have been a number of developments that have contributed to the Powering Sydney's Future project being re-evaluated and the commencement of this formal RIT-T process. In particular:

- all oil-filled cables in Inner Sydney are now two years older and consequently less reliable;
- a further derating of Cable 41 from 575 MVA to 426 MVA in August 2016 as a result of testing the thermal resistivity of backfill and bedding materials;
- an increase in summer peak demand in Inner Sydney in 2016 and a forecast increase in demand from heightened economic activity expected within Inner Sydney;

[2] The final IPART recommendation on the appropriate reliability standard to apply from 1 July 2018 was provided to the Minister for Industry, Resources and Energy on 31 August 2016 which involved explicit consideration of the value of unserved energy compared to the cost of providing higher reliability. IPART published a Draft Supplementary Report on 29 September 2016 seeking submissions on the recommendations, with a final report to the Minister due by the end of 2016 for a decision on what standards should apply.

[3] These reports are available on TransGrid's website, available at: http://www.transgrid.com.au

- an expected move, from 1 July 2018, away from the modified N-2 deterministic reliability standard towards a cost benefit assessment of network investments. This approach will assess the cost of the investment against the benefit to the community of risk reductions of different solutions. This benefit includes the value of expected unserved energy, environmental and other benefits.

2.4 Requirement to apply the RIT-T

TransGrid and Ausgrid are required to apply the RIT-T to this investment, as none of the exemptions listed in NER clause 5.16.3(a) apply. TransGrid and Ausgrid have classified this project as a reliability corrective action because the existing network will not be able to provide the required level of reliability under the NER under the expected transmission reliability standards that will apply in New South Wales from 1 July 2018.

TransGrid and Ausgrid note that, while the consideration of investment in this RIT-T is driven partly by replacement of aging infrastructure, the credible options outlined in this Project Specification Consultation Report (PSCR) will also augment supply to the Inner Sydney area. TransGrid and Ausgrid consider that the application of the RIT-T is relevant in this context since none of the exemption clauses listed in 5.16.3 and 5.16.4 of the NER apply. TransGrid and Ausgrid note that the Replacement Expenditure Planning Arrangements rule change is currently being considered by the Australian Energy Market Commission and may result in the RIT-T process also being explicitly applied to replacement expenditure in the future.[4]

The reliability limitation of electricity supply to Inner Sydney and the need for a non-network solution or/and a new 330 kV cable development has been identified in AEMO's 2015 National Transmission Network Development Plan (NTNDP).[5]

2.5 Structure of this document

This PSCR has been jointly prepared by TransGrid and Ausgrid in accordance with the requirements of the National Electricity Rules (NER) clause 5.16.4. It represents the first stage of the formal consultation process set out in the NER in relation to the application of the RIT-T.

In particular, this PSCR:

- describes the identified need which TransGrid and Ausgrid are seeking to address, together with the assumptions used in identifying this need;
- sets out the technical characteristics that a non-network option would be required to deliver in order to address this identified need, and calls for Expressions of Interest from non-network proponents (particularly aggregated solutions);
- describes the credible options considered which may address the identified need; and
- discusses specific categories of market benefit that, in the case of this specific RIT-T assessment, are unlikely to be material and so which TransGrid and Ausgrid do not currently anticipate including in the PADR modelling.

Appendices to this PSCR provide further information in relation to the assumptions adopted for the RIT-T assessment.

2.6 Submissions and next steps

TransGrid and Ausgrid welcome written submissions on this PSCR.

Submissions are due on or before 13 January 2017, which exceeds the 12 weeks prescribed in the NER and accommodates for the end of year holiday period. Submissions are particularly sought on the credible options presented and from potential proponents of non-network options that could meet the technical requirements set out in this PSCR.

---

4 Australian Energy Market Commission website, see: http://www.aemc.gov.au/Rule-Changes/Replacement-Expenditure-Planning-Arrangements

5 AEMO National Transmission Network Development Plan 2015, p. 20.

Submissions can only be made via the following email address: PSFConsultations@transgrid.com.au.

TransGrid is bound by the Privacy Act 1988 (Cth). In making a submission in response to our consultation process in relation to the Powering Sydney's future RIT-T submission, TransGrid will collect and hold your personal information (that is, information about you such as your name, email address, employer and phone number). TransGrid will collect this information for the purpose of receiving your submission and may use your contact details to follow up on your submission. A copy of your submission, as well as your personal information, will also be provided to Ausgrid. In making a submission, you consent to TransGrid collecting and holding your personal information for this purpose, and providing this information to Ausgrid. Under the National Electricity Law there are circumstances where TransGrid may be compelled to provide information to the AER. We will advise you should this occur.

At the conclusion of the submissions process, all submissions received will be published on the TransGrid and Ausgrid websites. If you do not wish for your submission to be made publicly available, then please clearly specify this at the time of lodging your submission.

Our Privacy Policy sets out our approach to managing your personal information. In particular, it explains how you may seek to access and/or correct the personal information that we hold about you, as well as how to make a complaint about a breach of our obligations under the Privacy Act, and how we will deal with complaints. You can access our Privacy Policy here.

A Project Assessment Draft Report (PADR), including full option analysis, is expected to be published by the end of March 2017.

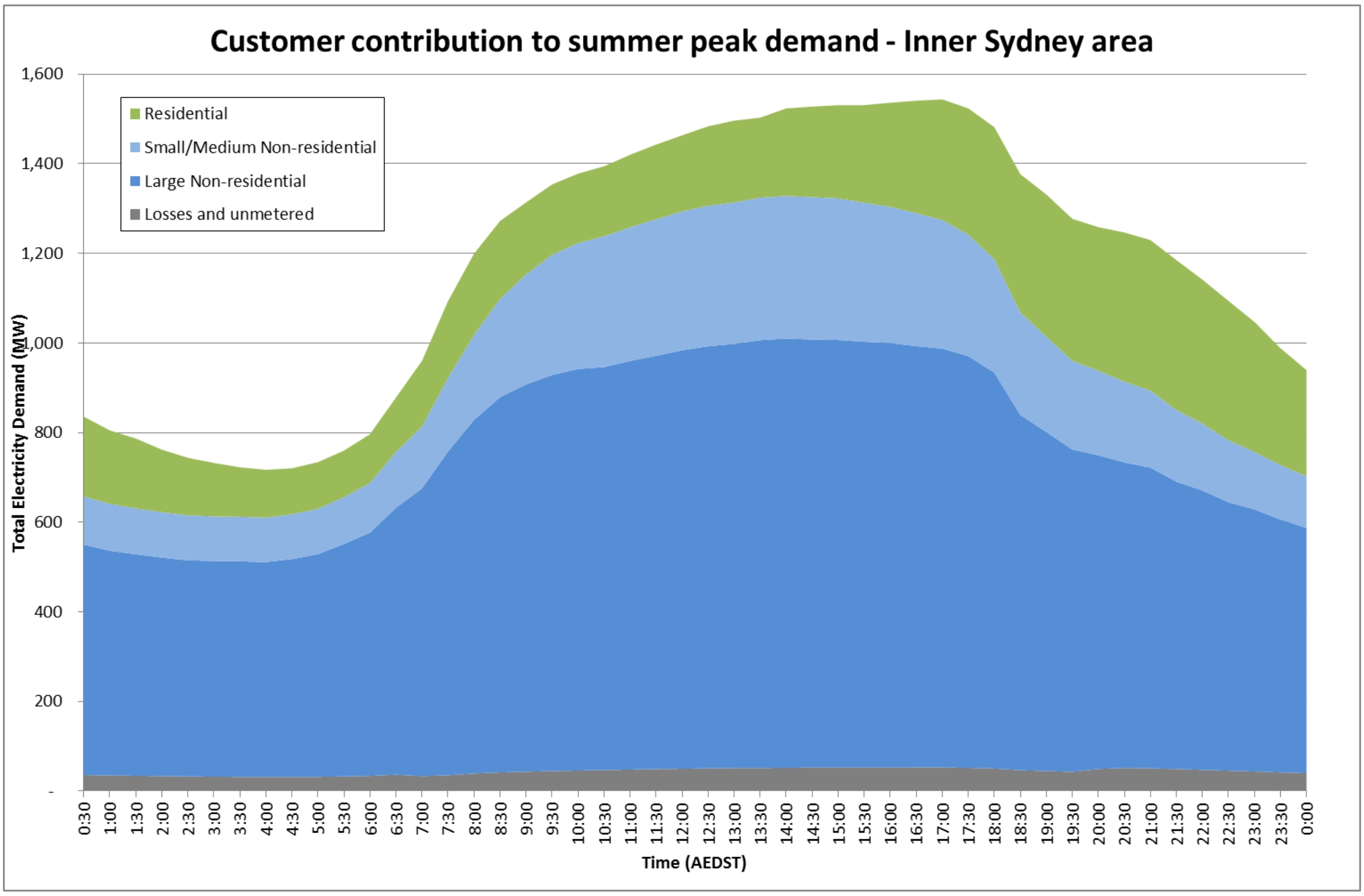
3. Identified need

This section discusses the identified need for this RIT-T. It first sets out relevant background material regarding the existing electrical supply to Inner Sydney before outlining the specific identified need for this RIT-T and the key assumptions underlying the identification of this need.

3.1 Existing supply to Inner Sydney

There are around 440,000 electricity customers in the Inner Sydney area who consume about 11 per cent of New South Wales' annual electricity use. On the most recent summer peak demand day of 25 February 2016, the maximum electricity demand from the electricity grid for the Inner Sydney area was 1,559 MW, or around 11 per cent of New South Wales' total peak demand (13,527 MW) on the same day.

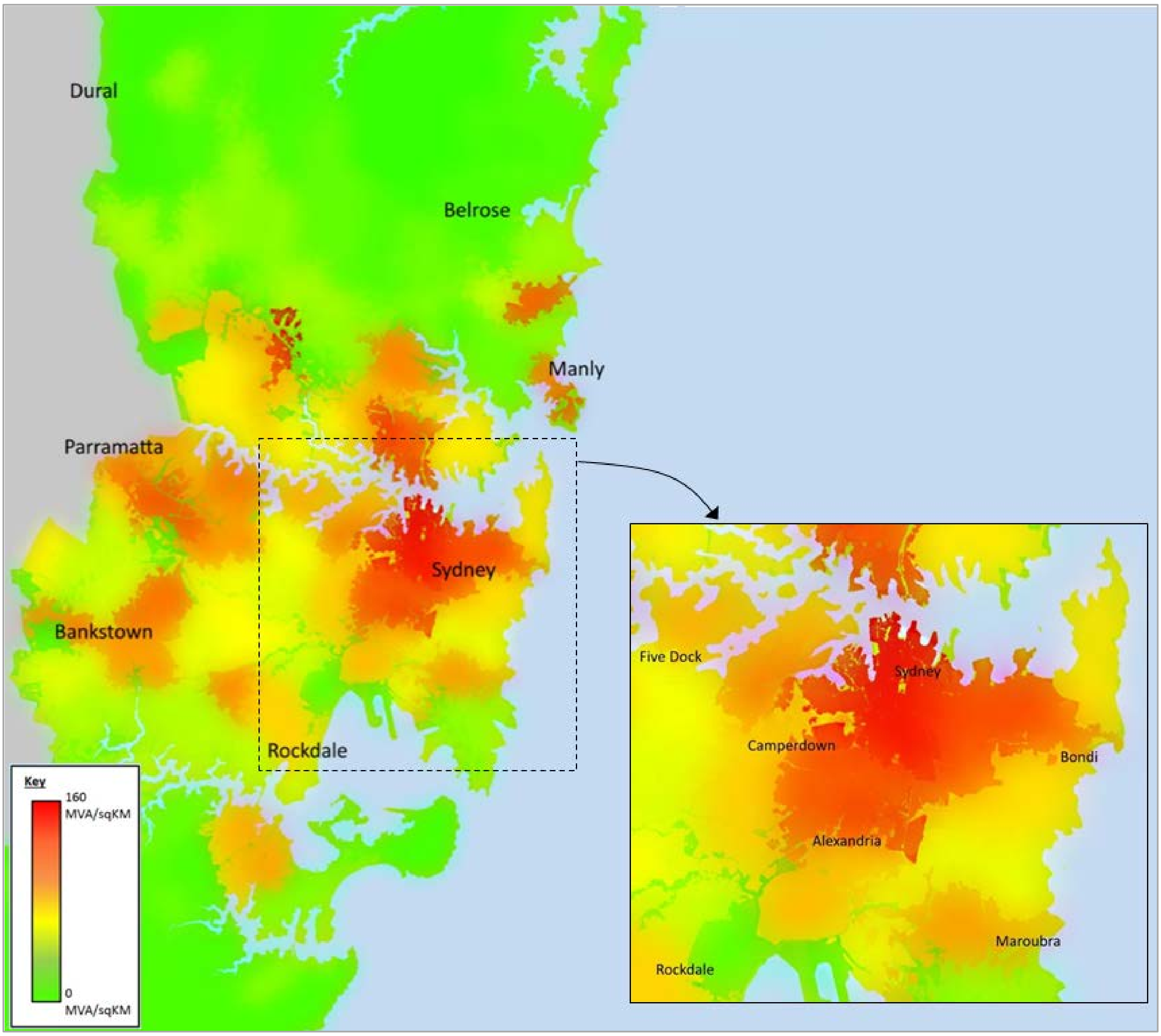
Demand for electricity in the Inner Sydney area is dominated by non-residential customers, which includes not only business and industry but also transport infrastructure such as roads, rail, air and sea ports and health and education facilities. During the peak demand period from noon to about 6pm, on a summer peak day in the Inner Sydney area, 62,000 non-residential customers are responsible for about 85% of the summer peak demand or about 1,300 MW. The remaining 380,000 residential customers are responsible for about 150-250 MW of electricity demand. See figure below.



Inner Sydney is an area of critical economic importance and the provision of a reliable supply to Inner Sydney is among TransGrid and Ausgrid's most important responsibilities. Any interruption will affect essential services such as gas, water, telecommunications, hospitals, and transportation by impacting road and traffic control, major road tunnels, Sydney railways, Sydney Airport, Port Botany and institutions of economic importance such as the ASX.

The figure below illustrates the magnitude of the load served in Inner Sydney compared to the wider area, with the largest load per square meter occurring in predominantly commercial and industrial areas.

Figure 3.1 Maximum demand in Inner Sydney compared to surrounding areas, summer 2015/16



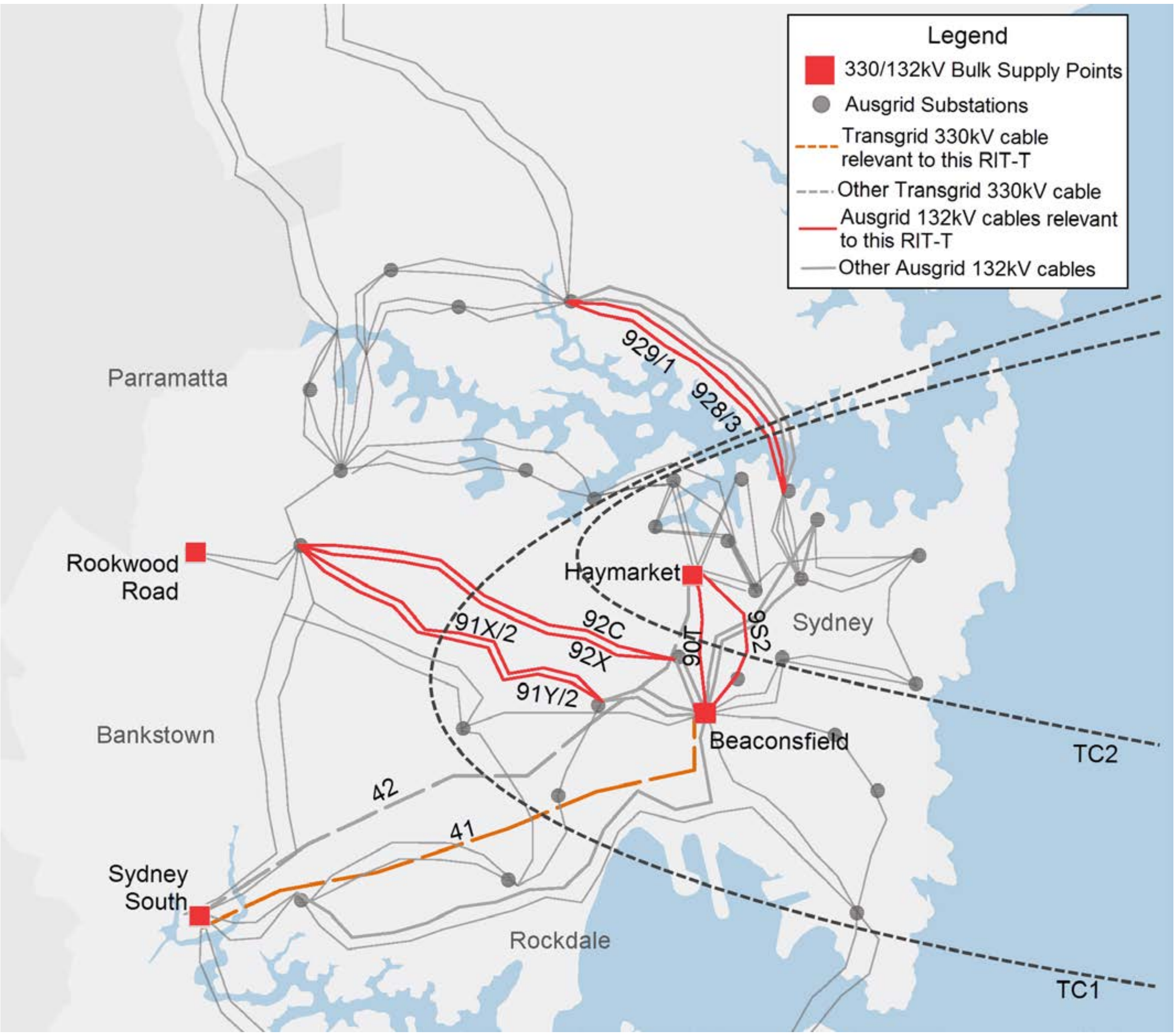
The Inner Sydney network is operationally centred on two transmission supply corridors operating as a meshed system of 330 kV (TransGrid owned) and 132 kV (Ausgrid owned) circuits, as shown in the figure below – namely:

- Transmission Corridor 1 ('TC1') defines the network capability to deliver supply from 330/132 kV bulk supply points on the outer ring of Sydney into the Inner Sydney area. The network includes TransGrid's 330 kV cables 41 and 42, as well as a number of Ausgrid 132 kV circuits. All these circuits operate in parallel such that retirement or de-rating of any one circuit may affect the supply capability into the area.
- Transmission Corridor 2 ('TC2') defines the network capability to deliver supply into the Sydney CBD and surrounding areas. This corridor provides supply into the Haymarket and Ausgrid supply points from Beaconsfield and Sydney South. The network includes TransGrid's 330 kV Cable 42, as well as a number of Ausgrid 132 kV circuits.

There are significant interdependencies between both Transmission Corridors. These two corridors supply the two primary sets of load in Inner Sydney area as follows:

- the Inner Sydney loads referred to are supplied by TC1; and
- Sydney CBD loads are supplied predominantly by TC2, inclusive of some loads supplied by Beaconsfield Bulk Supply Point.

Figure 3.2 Network diagram of the Inner Sydney Transmission System



The integrated supply arrangement has been in place since the 1960s and 1970s and has been progressively developed through TransGrid and Ausgrid joint planning. Joint planning looks for solutions with the least economic cost to all those who produce, consume and transmit electricity in the National Electricity Market. The solutions take into account community expectations including environmental impact and inconvenience during both construction and operation of any new assets constructed. Decisions are not influenced by which organisation will do the work, but once an option is chosen then each organisation implements their part of the work. From a community perspective, the overall most efficient solution is undertaken. At the time that the integrated supply arrangement was put in place, Ausgrid's 132 kV meshed cable system had adequate residual asset life. The majority of 330 kV and 132 kV cables which make up the Inner Sydney Transmission System are oil-filled cables.[6]

[6] Appendix A.2 provides details on the TransGrid and Ausgrid oil-filled cables within Transmission Corridor 1 and Transmission Corridor 2.

3.2 Description of identified need

The identified need for this RIT-T is TransGrid and Ausgrid's assessment that the future value of unserved energy[7] and environmental and operating and maintenance costs that can be avoided by undertaking the investment exceeds the investment cost. This RIT-T is being jointly undertaken by TransGrid and Ausgrid to ensure the most efficient and cost-effective solution is developed across their respective networks.

In the absence of undertaking such investment, the following are expected to increase the amount of unserved energy, environmental and financial risk in the future:

1. The deteriorating condition of aging oil-filled cables in the existing network and the derating of the 330 kV Cable 41 by TransGrid (in 2011 and 2016) and the derating of a number of 132 kV cables by Ausgrid (beginning in 2012).
2. Ausgrid's planned retirement of three oil-filled cables in Inner Sydney in the next two years.
3. The age-related deteriorating condition of a further eight oil-filled Ausgrid cables in the Inner Sydney area.
4. Forecast increases in peak demand due to renewed economic activity within Inner Sydney.

TransGrid and Ausgrid intend to value the reductions in the expected unserved energy, environmental risk and increased costs to maintain the deteriorating cable systems associated with each credible option, compared to the option of doing nothing.

The reliability standards applying to transmission in New South Wales from 1 July 2018 were recently reviewed by the Independent Pricing and Regulatory Tribunal (IPART). While the reliability standards to apply from 1 July 2018 are not yet known, a move to a standard that explicitly acknowledges the value of unserved energy to customers is expected.[8] TransGrid and Ausgrid therefore consider the approach to valuing reductions in the expected unserved energy associated with each credible option to be consistent with the approach used to derive the new standard.

The approach taken to modelling the costs and benefits in this RIT-T will be adapted (if necessary) to be consistent with the final reliability standard decided by the Minister of Industry, Resources and Energy. TransGrid and Ausgrid have also assessed the identified need against the existing modified N-2 reliability standard (as if it continued to apply from 1 July 2018) and consider that investment is required in order to be compliant.

The figure below illustrates the magnitude of potential unserved energy out to 2026/27 estimated by TransGrid and Ausgrid with no remediation or augmentation works to Cable 41.[9] Specifically, it illustrates the range of potential unserved energy, in MWh, in Inner Sydney going forward assuming one contingency event as the lower bound (e.g., 'N-1') and five contingency events as the upper bound (e.g., 'N-5').

Examples of contingency events assumed include:

- Cable 42 failing at a time when Cable 41 is unavailable due to repairs or vice versa; and
- Cable 41 and/or Cable 42 failing when portions of the 132 kV network are out of service for maintenance.

While instances of coincident failures are considered rare in transmission networks generally, the age and condition of the oil-filled cables that make up the majority of the Inner Sydney transmission network means that these cables fail more frequently than cables employing modern cable technology and take longer to repair. As a consequence, these cables are currently often out of service for both planned maintenance and due to unplanned events, which is expected to worsen as these cables age further. This means that at any

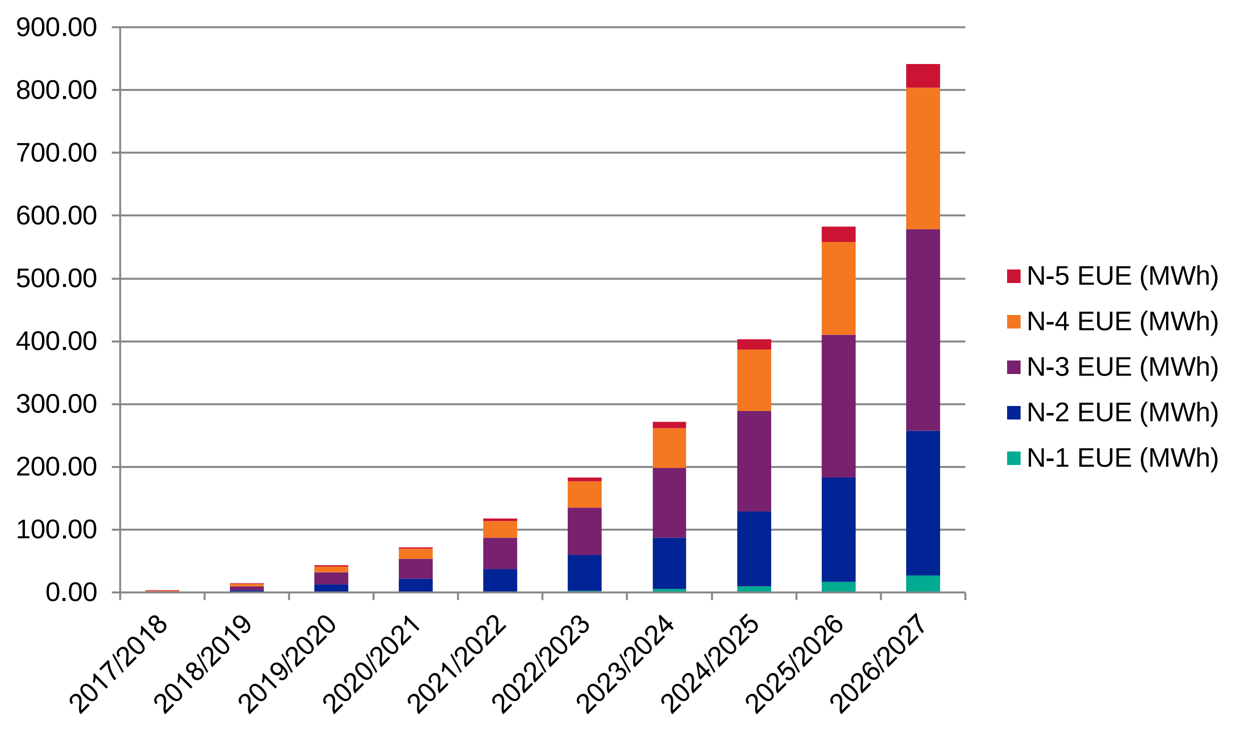
[7] Note that this refers to undelivered energy.

[8] IPART published a Draft Supplementary Report on 29 September 2016 seeking submissions on the draft recommendations, with the Final Supplementary Report due to the Minister for Industry, Resources and Energy by the end of 2016 for a decision on what standards will apply. The next stage of the IT-T process will further address these pending changes.

[9] These unserved energy forecasts are based on information and forecasts available to TransGrid and Ausgrid at the time of publishing this PSCR but may be subject to change.

time the likelihood of one or more elements already being out of service increases, there is the result that multiple contingency events can eventuate.

Figure 3.3 Forecasts of unserved energy in Inner Sydney, 2017/18 to 2026/27



There are a number of notable loads/customers in Inner Sydney that can be expected to place a very high value on the security and consistency of their electrical supply, e.g., NSW Parliament, the Australian Securities Exchange, the Australian Navy, large financial institutions, major rail and road links, major data centres, Sydney Airport and Port Botany. An interruption to the electrical supply of these customers would therefore come at a significant cost.

The forecast unserved energy represents the averaged unserved energy in megawatt hours for a year, assuming the outage impacts were averaged over a prolonged period. Notwithstanding this, if a forced outage of two or more significant transmission elements occurred, the impact of load curtailment, particularly for Inner Sydney would be significant. During this period, it is reasonably foreseeable that supply disruptions would be 'cycled' across different areas in Inner Sydney.

Should contingency events occur, as outlined above, there are likely to be significant consequences above and beyond simply unserved energy for substantial disruptions to supply. The box below outlines a number of such consequences that occurred in 2009 when there were three supply interruptions on the Ausgrid Inner Sydney network.

Box 3: Previous supply disruptions in Inner Sydney

In 2009, there were three supply interruptions to the Inner Sydney area and surrounding areas due to faults on the Ausgrid (then Energy Australia) 132 kV network. These interruptions lasted between 36 minutes and two hours and had major negative impacts, including:[10]

[10] For a detailed discussion of these supply interruptions, see: Energy Australia, *Sydney CBD supply interruptions – 30 March, 4 April and 28 April 2009*, Final Report, May 2009.

- major traffic disruption as a result of traffic signal outages and the closure of the Sydney Harbour Tunnel;
- Police having to respond to a large number of calls to 000 to report traffic signals out of order;
- Police and the Fire Service having to respond to a large number of calls for people trapped in elevators;
- NSW Fire Brigade responding to numerous automatic fire alarms across Sydney as well as possible building fires due to fumes from diesel generators, motor vehicle accidents and a shop fire in Surry Hills; and
- as a result of one fault, insulating fluid leaked from the cable and the NSW Department of Environment and Climate Change had to despatch environmental officers to assess the impact of the fluid leak and to continually monitor Sydney Harbour in the event that any fluid migrated to the harbour.

3.3 Key assumptions made in relation to forecast escalating unserved energy

This section describes the key assumptions underpinning TransGrid and Ausgrid's assessment of the identified need.[11] In particular, it outlines the four key drivers of forecast unserved energy in the future, i.e.:

1. The deteriorating condition of aging oil-filled cables in the existing network and the derating of the 330 kV Cable 41 by TransGrid and the derating of a number of 132 kV cables by Ausgrid.
2. Ausgrid's planned retirement of three oil-filled cables in Inner Sydney in the next two years[12].
3. The age-related deteriorating condition of a further eight oil-filled Ausgrid cables in the Inner Sydney area.
4. Forecast increases in peak demand due to renewed economic activity within the Inner Sydney area.

Each of these drivers is discussed in the sections below.

3.3.1 The derating of a number of oil-filled cables due to their condition

Both TransGrid and Ausgrid have a stock of oil-filled cables in Inner Sydney that were installed by their common predecessor, the Electricity Commission of New South Wales, in the 1960s and 1970s. These cables are now very old and their oil-filled technology is largely obsolete. Close monitoring of these cables (and their thermal backfill and bedding materials) by TransGrid and Ausgrid over the last few years has resulted in a number of these cables having their operating capacity derated, as outlined in the sections below.

TransGrid derating the 330 kV Cable 41 in 2011 and 2016

Cable 41 is an approximately 20km long, oil-filled paper insulated 330 kV cable that was commissioned in 1979 by the Electricity Commission of New South Wales. The cable system was designed around the assumption of a 25°C summer ground temperature, low thermal resistivity backfill, and a specific native ground thermal resistivity.

While the original rating of Cable 41 was 663 MVA it has been derated twice due to testing of the thermal resistivity of backfill and bedding materials, which found that the fully dried out thermal resistivity of backfill and bedding at various locations along the cable route were higher than the design assumptions.

- In December 2011, Cable 41 was derated to 575 MVA, following investigations undertaken by TransGrid into cable backfill and bedding materials that identified that thermal resistivity was higher than originally believed.
- Cable 41 was subsequently derated in August 2016 to a summer cyclic rating of 426 MVA, as detailed in the Cable 41 Investigation Summary Report attached in Appendix B.

[11] In accordance with NER clause 5.16.4(b)(2).

[12] These three oil-filled cables are being retired due to age-related deteriorating condition issues.

Thermal performance of the cable installation is currently considered to be adequate, provided there is sufficient moisture content in the surrounding soil. However, there is potential for overheating of the cable to occur if the cable is subject to high loading following an extended period of low rainfall. Operationally under emergency conditions, the cable may be operated at a higher rating for very short periods of time[13]; however this requires sustained favourable moist soil conditions.

An unplanned loss of Cable 41 would present a risk to the reliability of the Inner Sydney supply. A subsequent failure of Cable 42 would lead to significant demand curtailment during high load periods. TransGrid's Cable 42, which has a cable monitoring system, appears to be in good condition and is not associated with poor backfill and bedding material issues.

TransGrid has four options regarding the future state of Cable 41 – namely:

- continue to operate Cable 41 at 330 kV with its reduced rating of 426 MVA;
- remediate Cable 41 back to 575 MVA and continue to operate at 330 kV;
- reconfigure Cable 41 to operate at 132 kV with a reduced capacity of 170 MVA[14]; or
- decommission Cable 41 entirely.

The decision regarding these four options form are a key component of the credible options expected to be assessed as part of this RIT-T (and those outlined in section 5 below).

Ausgrid derating a number of 132 kV cables beginning in 2012

The soil thermal resistivity of bedding and backfill is the most critical aspect of calculating the rating and operating temperature of cables. If the soil thermal resistivity used is incorrect, the calculated rating of the cable is also incorrect which increases the risk of cable failure as the cable may not be operating within its thermal rating.

In 2011 there was a thermal failure of two of the three gas filled 33 kV cables supplying Enfield zone which had been installed in 1962. An investigation was carried out on the failures by Ausgrid in June 2011, which revealed that the failures were due to a combination of:

- abnormally high loading (due to hot weather and previous outage of the 3rd gas filled feeder); and
- the presence of a localised area of backfill with unexpectedly high thermal resistivity (also noted in reports from other parts of the industry).

On this basis, a number of recommendations were made including that a program of backfill sampling at identified hotspots of critical 132 kV oil-filled cables are completed. The results of this sampling were to be used to review the rating of individual feeders and to further inform the need to change general rating assumptions.

As the soil thermal resistivity of bedding is most critical to the rating and operating temperature of the cables, Ausgrid performed bedding, backfill and native undisturbed soil testing on the most heavily loaded oil-filled cables individually and these cables were re-rated based on the test results along with any mutual heating from other circuits within 4 metres. For previous oil-filled cables there is a lack of confidence that the "as built" backfill thermal resistivity was the same as the design backfill thermal resistivity. This was confirmed by sample testing of selected heavily loaded and strategically important oil-filled cables which had the backfill and native undisturbed soil tested and the results extrapolated for other "like" installations.

Each of the identified feeders had an individual Rating Assessment report giving revised ratings with supporting data from the thermal resistivity test reports, trench cross sections, mutual heating sources, etc. The table below shows the most recent (2015) ratings of Ausgrid cables.

[13] In accordance with the TransGrid Operating Manual

[14] In accordance with Appendix B, taking into account the dielectric losses, the normal cyclic rating would be 273 MVA.

Table 3.1 Summary of cable de-ratings[15]

Circuit	From	To	kV	2008 rating	2015 rating	Difference	
				Amps	Amps	Amps	MVA
91M/1	Beaconsfield BSP	Peakhurst STS	132	980	800	-180	-41
91M/3	Beaconsfield BSP	Bunnerong STSS	132	980	800	-180	-41
91A/1	Beaconsfield BSP	St Peters	132	595	440	-155	-35
92C	St Peters	Chullora STSS	132	595	455	-140	-32
91B/1	Beaconsfield BSP	St Peters	132	595	440	-155	-35
92X	St Peters	Chullora STSS	132	595	455	-140	-32
91X/1	Beaconsfield BSP	Marrickville	132	595	435	-160	-37
91X/2	Marrickville	Chullora STSS	132	595	440	-155	-35
91Y/1	Beaconsfield BSP	Marrickville	132	595	435	-160	-37
91Y/2	Marrickville	Chullora STSS	132	595	440	-155	-35
928/3	Lane Cove STSS	Dalley St	132	650	530	-120	-27
929/1	Lane Cove STSS	Dalley St	132	585	530	-55	-13
9SA	Beaconsfield BSP	Campbell St	132	1105	565	-540	-123
9SB/1	Beaconsfield BSP	Surry Hills Annex	132	1105	565	-540	-123
90T/1	Green Square	Haymarket BSP	132	1190	970	-220	-50
9S2	Beaconsfield BSP	Haymarket BSP	132	1230	985	-245	-56
9SE	Beaconsfield BSP	Green Square	132	1190	995	-195	-45

3.3.2 The deteriorating condition of a number of Ausgrid's 132 kV oil-filled cables

A key issue to be addressed in the Inner Sydney area is the continuing deterioration of some of Ausgrid's existing oil-filled cables that were originally installed in the 1960s and 1970s.

The continued operation of these cables raises a number of issues:

- Oil-filled cables pose a significant environmental risk when oil leakage occurs. This is particularly the case when feeders are near, or cross, waterways. This environmental risk increases as the cables age due to further deterioration of the cable servings and joints. Oil leakage can also be caused by third party damage to the cable. While Ausgrid has processes in place to minimise this risk, damage to oil-filled cables resulting in environmental incidents cannot be completely prevented.

[15] Ausgrid and TransGrid, Joint Planning Report - Inner Metropolitan Area Strategy D15/707274, October 2015, pp 5-6.

- As the cables age and continue to deteriorate repair costs are forecast to increase. An increasing number of repairs results in the cables being taken out of service more often which in turn leads to increased unavailability of the feeders.
- The probability of oil-filled cable failure increases as the cables age and deteriorate and is worsened during periods of hot dry weather with subsequent high electricity demand.
- An increased number of failures further increases feeder unavailability as fault repairs typically require the cable to be out of service for significant periods (2 to 3 months) due to the complexity of oil-filled cable fault repairs. Some of the complexity is associated with the location of some of these cables in major roadways. Repair has the potential to cause significant disruption to the community. The ongoing need to support and maintain these assets further increases the cable unavailability risk.
- The continued operation of these cables involves significant costs due to the complexity of the oil-filled cable system and the frequency of planned maintenance that is required. Costs will continue to increase as the cables and other components in this 'system' grow older and repairs / fault requirements increase.

The failure of multiple oil-filled cables is a 'high impact low probability event' that can cause major supply risks to large areas. This was evidenced in Auckland in 1998 when multiple oil-filled and gas pressured 110 kV cable failures caused a three-week blackout to the central business district.[16] And as mentioned above, Ausgrid experienced a number of major supply interruptions to the Inner Sydney area in 2009 due to third party damage to oil-filled cables.

Ausgrid has already committed to the retirement of three oil-filled cables which form part of the Inner Sydney Transmission System over the next two years and the potential construction of new 330 kV cables by TransGrid allows the opportunity to retire an additional eight cables. Each of these two sets of cables are outlined in the sections below.

Appendix A.4 provides more details on the increasing unavailability and escalating costs associated with continued operation of oil-filled cables. Appendix A.2 provides more detail on the current stock of Ausgrid and TransGrid oil-filled cables in Inner Sydney.

Ausgrid's scheduled decommissioning of three 132 kV oil-filled cables in the Inner Sydney area

Ausgrid has committed to decommissioning three 132 kV oil-filled cables in the next two years due to their current poor condition – namely:[17]

1. the 43-year-old 91M/1 cable running 19.5 km from Peakhurst to Beaconsfield is scheduled to be retired in 2016/17;
2. the 46-year-old 92L/3 cable running 10.8 km from Lane Cove to Dalley Street is scheduled to be retired in 2017/18; and
3. the 46-year-old 92M/1 cable running 10.8 km from Lane Cove to Dalley Street is scheduled to be retired in 2017/18.

Retirement of 91M/1 was initially planned for 2012, but was delayed as a short term capacity risk mitigation strategy following the reduction in rating of Cable 41 to 575 MVA in 2012. Preparation for its retirement is well underway and scheduled to occur in late 2016.

Retirement of 92L/3 and 92M/1 are scheduled for June 2018, following the commissioning of 90Y. Commissioning of 132 kV feeder 90Y between Beaconsfield and Belmore Park is scheduled to be completed by December 2017.

The retirement of 132 kV oil-filled cables has been discussed at length in previous Ausgrid Distribution and Transmission Annual Planning Reports.[18]

[16] IEEE Power Engineering Journal – June 1998 (p. 109 – 114)

[17] The expected retirement dates are based on information and forecasts currently available to Ausgrid but may be subject to change going forward.

The deteriorating condition of eight additional oil-filled Ausgrid cables relevant to this RIT-T

There are a number of Ausgrid's oil-filed cables in the Inner Sydney area that are in poor condition. Eight of these cables could be retired if additional 330 kV cables are built, in addition to the three cables scheduled to be decommissioned over the next two years. These cables are the following:

1. the 48-year-old 92C cable running 14.5 km from Chullora to St Peters;
2. the 48-year-old 92X cable running 14.5 km from Chullora to St Peters;
3. the 44-year-old 91X/2 cable running 13 km from Chullora to Marrickville;
4. the 44-year-old 91Y/2 cable running 13 km from Chullora to Marrickville;
5. the 28-year-old 9S2 cable running 5.2 km from Beaconsfield to Haymarket;
6. the 35-year-old 90T/1 cable running 3.8 km from Green Square to Haymarket;
7. the 50-year-old 928/3 cable running 11.9 km from Lane Cove to Dalley Street; and
8. the 50-year-old 929/1 cable running 12 km from Lane Cove to Dalley Street

TransGrid and Ausgrid have included the retirement of these eight cables in the credible network options to be assessed as part of this RIT-T (outlined in section 5 below).

3.3.3 Future peak demand

Following a period of declining maximum demand in Inner Sydney between 2010/11 to 2013/14, maximum demand is expected to increase with the most recent forecast showing maximum electricity demand expected to return to approximately 2010/11 levels by 2018/19. The primary reason for the increased forecast is due to planned network architecture changes and a number of significant new customer loads which will increase summer peak demand in the Inner Sydney area by about 200 MW by 2023.

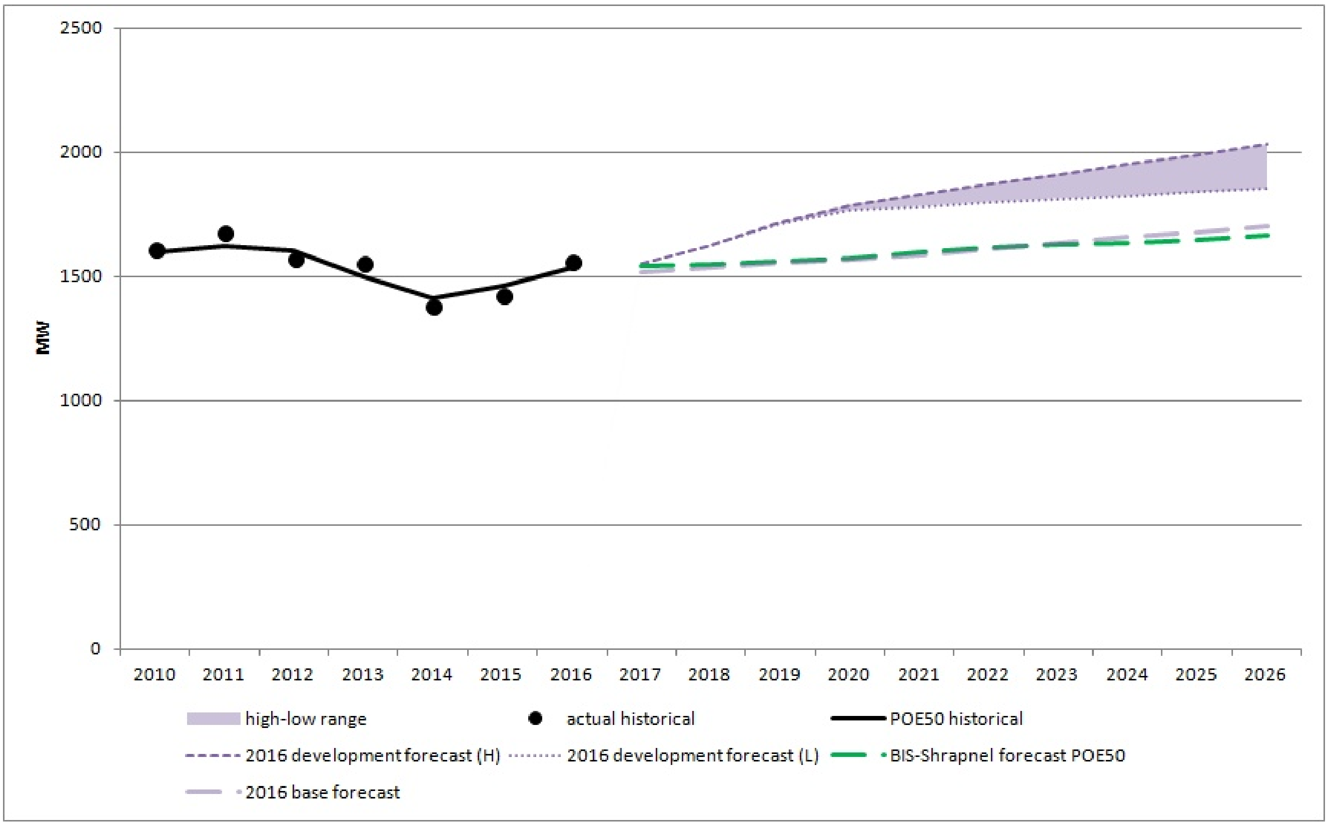
TransGrid and Ausgrid use the Ausgrid 2016 development forecast in assessing the identified need illustrated in Figure 3.4 below. The figure, also shows actual and weather corrected historical maximum demand in the Inner Sydney area and the Ausgrid 2016 base and development forecasts. Weather corrections to historical demand are based upon a POE50 standard, or 50% probability of exceedance in any year. Forecasts displayed are the POE50 forecasts, which form the basis for planning decisions, with upper and lower bounds to the forecast range used for sensitivity testing. The development forecast is derived from the base forecast, but includes future planned changes to network architecture and known planned customer connections.

BIS Shrapnel has independently developed demand forecasts for Inner Sydney for this project (discussed further below) as part of the network need assessment.[19] The BIS Shrapnel forecast is also shown in Figure 3.4 below.

[18] For example, see: Ausgrid Distribution and Transmission Annual Planning Report 2015, p. 97; and Ausgrid Distribution and Transmission Annual Planning Report December 2014, p. 230.

[19] Their report is provided as an Appendix D to this PSCR.

Figure 3.4 Transmission Corridor 1 historical demand and POE50 development forecasts



Base forecast background

During the 2010/11 to 2013/14 period, while growth in customer numbers and economic activity were muted, customer response to increases in electricity prices, improvements in the energy efficiency of appliances and buildings and growth in rooftop solar power systems contributed to a period of decline in electricity demand. During this period, weather corrected demand in the Inner Sydney area declined by 13% or about 200 MW. Analysis by Ausgrid attributes much of this decline to customer response to higher prices and improvements in the energy efficiency of appliances and buildings, supported by the conclusions reached by BIS Shrapnel.

The actual peak demand for the Inner Sydney area recorded during the 2015/16 summer exceeded the 2015 demand forecast by about 5% or 70 MW. Subsequent analysis of historical trends by customer sectors over the entire Ausgrid network indicated a strong rebound in residential customer demand in summer 2015/16 with a relatively flat trend for non-residential customers.

Following a number of years of price increases, electricity prices have remained relatively flat since 2012/13 with Retail electricity price growth expected to remain muted in future. Projections commissioned by AEMO and used in the Ausgrid base forecast show price increases to 2025 of about 0.6% pa for residential customers and about 0.9% pa for non-residential. These price increases are projected to be below CPI and this forecast absence of future price growth removes a significant suppression of future demand.

Forecast impacts from energy efficiency remain a material impact on final forecast demand and are included as adjustments that suppress demand. These impacts are largely driven by government policy decisions on energy efficiency standards for appliances and buildings. A recent update to the expert advice Ausgrid receives on these energy efficiency impacts shows a modest decline in the impact from future standards and programs. Due to the scale of the impact from energy efficiency, updates are obtained annually to ensure that latest available information is included in the forecast.

Forecast impacts from embedded generation such as rooftop solar are not significant for the Inner Sydney area with modest levels of connected systems. While the Inner Sydney area represents about 30% of Ausgrid's total demand, the total connected capacity of solar power systems in the area is only about 30 MW, or 10% of the Ausgrid total. A major contributor to the lower take-up is both the larger share of non-residential customers in the area and the high rate of residents living in apartments with over 60% of residential customers living in apartments. The capacity for solar power systems in the Inner Sydney area is forecast to increase to 70-100 MW by 2025, with impacts included in the base forecast.

The impacts from residential battery storage are also included in the base forecast, but with a modest impact projected to 2025. Detailed analysis using a representative sample of actual customer interval data indicates relatively poor financial returns for customers for some time. Based upon projected battery storage pricing from Bloomberg New Energy Finance and current tariff structures, customer payback remains in excess of 20 years until 2025. The 2016 forecast includes an estimated 7 MW of peak demand reduction in 2025 and 174 MW reduction in 2035 at system total level. As take-up of battery storage systems are forecast to reflect solar power system take-up, the impacts in the Inner Sydney level area are projected to be a modest share of this. The 2016 forecast does not as yet include impacts from non-residential battery storage systems or electric vehicles.

The base forecast uses population projections from the 2014 version of the NSW Department of Planning's "A Plan for Growing Sydney" master planning document. Recently, an update was issued by the Department of Planning which has revised upwards the population forecasts for the Inner Sydney area. According to the 2016 update, the NSW Department of Planning forecasts population growth in the Inner Sydney area of about 180,000 to 2026, up from 171,000 in the 2014 projections.

The base forecast also includes the scheduled retirement of Ausgrid's Rockdale 33/11 kV zone substation in the St George area which will transfer about 20 MW of load by 2023 to the Inner Sydney area. This zone substation is currently supplied from Peakhurst 132/33 kV sub-transmission substation which is outside the Inner Sydney area and will be transferred to Rockdale 132/11 kV zone substation served from the Inner Sydney transmission network.

Development forecast impacts

Adjustments to the base forecast are necessary to correct for planned changes to the network architecture such as load transfers and any planned new customer connections which have not been included in the base forecast. In the 2016 forecast, adjustments to the development forecast for the Inner Sydney area amounted to 229 MW by 2023 driven by significant network load transfers and major new customer load.

The scheduled retirements of Ausgrid's Arncliffe 33/11 kV and Blakehurst 33/11 kV zone substations in the St George area, will transfer about 40 MW of demand by 2023 to the Inner Sydney area. These zone substations are currently supplied from Peakhurst 132/33 kV sub-transmission substation which is outside the Inner Sydney area and will be transferred to Kogarah, Hurstville North and Rockdale 132/11 kV zone substations served from the Inner Sydney transmission network.

The largest impact to the near term development forecast is due to a number of significant planned customer connections which total about 190 MW by 2023. This includes about 80 MW in new load to service major road, rail and air transport infrastructure and about 80 MW in new load from major commercial redevelopments and large customers. The remaining 30 MW of additional load is from miscellaneous planned customer connections to the 11 kV network.

Combined with forecast customer connections in the near future that are included in the base forecast, the impact on the forecast from requests by customers for new connections has increased from about 225 MW in 2015 to 320 MW in 2016.

Future demand not included in the development forecast

The development forecast does not include for demand from a number of significant infrastructure and redevelopment projects that may potentially add a significant volume of additional load to the Inner Sydney area over the next 5-10 years. These projects are:

- Westconnex Stage 3
- Sydney Metro and associated station and commercial development at the proposed Barangaroo, Martin Place, Pitt St, Central and Waterloo stations.
- Central to Eveleigh redevelopment
- White Bay precinct redevelopment

BIS Shrapnel comparison forecast

BIS Shrapnel have independently developed demand forecasts for Inner Sydney for this project.[20] Consistent with the maximum demand forecasts outlined above, BIS Shrapnel concluded that peak demand is expected to grow over the forecast period roughly tracking energy consumption, which they forecast to have bottomed out in 2014 with steady growth expected in future. As shown in Figure 2.4, the forecast developed by BIS Shrapnel show peak demand for Inner Sydney growing in line with Ausgrid's base forecast.

While the Ausgrid forecast directly projects forecast peak demand, the approach taken by BIS Shrapnel has been to forecast energy and model the link between maximum demand and energy. BIS Shrapnel has forecast strong underlying growth in the number of customers (residential and commercial) and a key driver of rising demand. BIS Shrapnel also note that there is limited potential for the uptake of solar PV in the high density Inner Sydney area and that they forecast rising investment will drive increases in commercial peak demand.[21]

But while the BIS Shrapnel forecast is a valuable assessment of forecast drivers of electricity demand and an important comparison with the forecast methodology used for planning by TransGrid and Ausgrid, the forecast offers a comparison with the base forecast rather than the development forecast. In particular, adjustments for planned modifications to the network architecture and an assessment of planned high voltage customer load is not included in the BIS Shrapnel forecast. As noted in the BIS Shrapnel report, industrial load is assumed to remain unchanged whereas about two thirds of new customer load included in the development forecast in the Inner Sydney area will be supplied to high voltage customers.

3.3.4 Changing reliability standard

TransGrid and Ausgrid note that there is currently a 'deterministic' transmission reliability standard applying, under which TransGrid and Ausgrid are required to plan its network to meet certain redundancy criteria. Specifically, a modified 'N-2' level of reliability currently applies to the Inner Sydney area and also applied at the time of the 2014 Power Sydney's Future public consultation.

The reliability standards are currently being reviewed by IPART, and a move to a standard that explicitly acknowledges the trade-off between the value of unserved energy and the cost of avoiding it is anticipated to apply from 1 July 2018.

On 29 September 2016, IPART published a Supplementary Draft Report detailing recommendations on the new reliability standards for the Inner Sydney area.

The recommended standards include a level of redundancy and an annual unserved energy allowance at each bulk supply point across TransGrid's network. They do not prescribe how TransGrid must invest but instead, explicitly provide for TransGrid to determine the combination of network and non-network solutions required to provide reliability.

For the Inner Sydney area, IPART's draft recommendation is that the amount of the unserved energy allowance should be 0.6 minutes per year, at average demand. This would apply across the five Inner Sydney bulk supply points (Beaconsfield West, Haymarket, Rookwood Rd, Sydney North and Sydney South).

The draft supplementary report indicates that IPART expects its recommendations would allow a small increase in the expected value of unserved energy in the Inner Sydney area but given the total unserved energy allowance is small, at around half a minute a year, it considers that its recommendations would not result in a significant change to the level of reliability experienced by customers.

The supplementary draft report is available on the IPART website. IPART seeks submissions by 28 October 2016 before a supplementary final report is provided to the NSW Government in December 2016[22]. This process coincides with the joint RIT-T process being conducted by TransGrid and Ausgrid for the Powering

[20] Their report is provided as an Appendix D to this PSCR.

[21] Refer BIS Shrapnel report page 14 in Appendix D

[22] https://www.ipart.nsw.gov.au/Home/Industries/Energy/Reviews/Electricity/Review-of-Electricity-Transmission-Reliability-Standards/29-Sep-2016-Media-Release/Media-Release-Supplementary-draft-report-on-electricity-transmission-reliability-standards-Sept-2016

Sydney's Future project. We do not anticipate a change that would affect the project significantly; however we will continue to communicate with IPART throughout the process and consider any impact from the outcome of the review and incorporate it into the Project Assessment Draft Report (PADR).

TransGrid and Ausgrid also note that the approach taken to modelling the costs and benefits in this RIT-T will be adapted (if necessary) to be consistent with the final reliability standard decided by the Minister. TransGrid and Ausgrid note also that they have also assessed the identified need against the existing modified N-2 reliability standard (as if it continued to apply from 1 July 2018) and consider that investment is required in order to be compliant.

3.4 Assessment of unserved energy going forward

This section describes the key assumptions underpinning TransGrid and Ausgrid's assessment of the value of unserved energy going forward.[23] In particular, it sets out the technical details behind the unserved energy forecasts (MWh) as well as what value would be appropriate to apply to this unserved energy for Inner Sydney (in $/MWh). Additional detail on the unserved energy calculations is provided in Appendix A.3.

3.4.1 Calculation of unserved energy

The forecast unserved energy shown in Figure 3.3 above has been calculated by tallying selected critical system states that result in the inability of the network to service the required load.

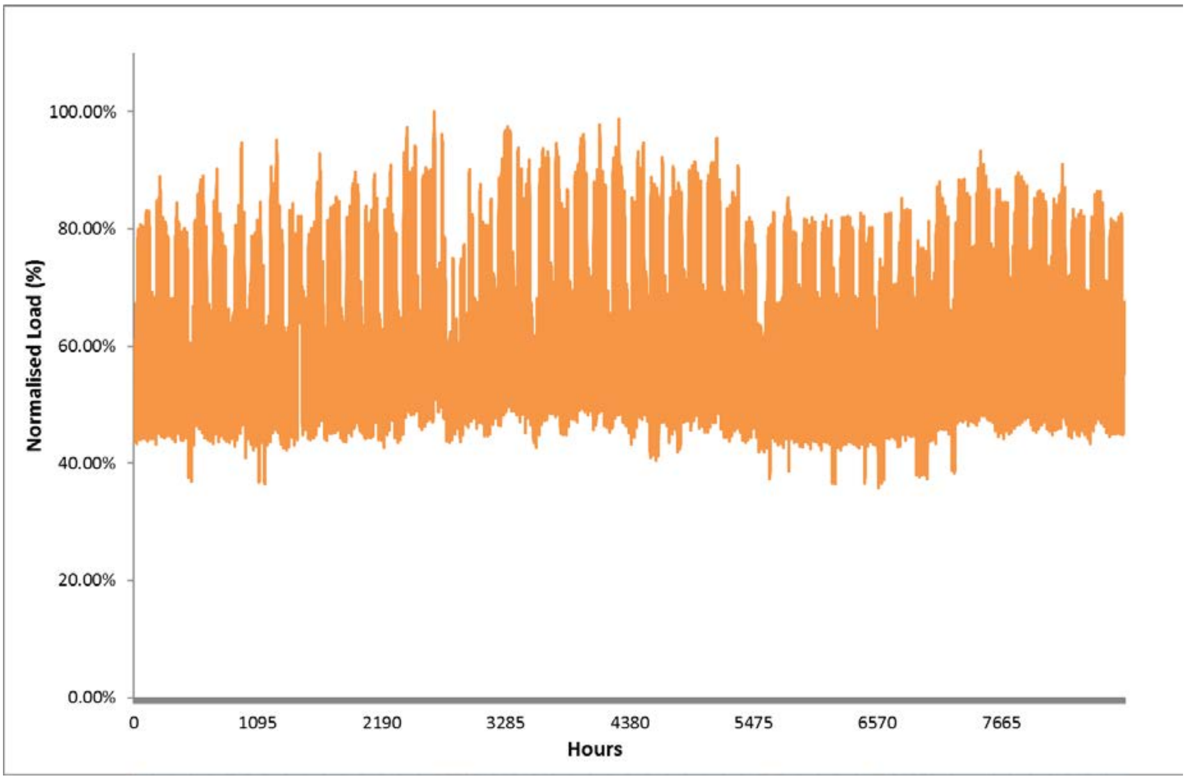
This calculation has been done for half hourly load intervals during a financial year, then scaled by the medium POE 50 maximum demand forecast to evaluate future load. For each critical system state, the unserved energy has been determined based on the network topology, equipment availability, load level and system capacity.

The expected unserved energy has been calculated using approximately 1600 contingency states, which were selected on the basis of network impact and likelihood of occurring.

TransGrid and Ausgrid have used a historical yearly load profile (2013/14) to calculate the unserved energy, which is illustrated in the figure below.

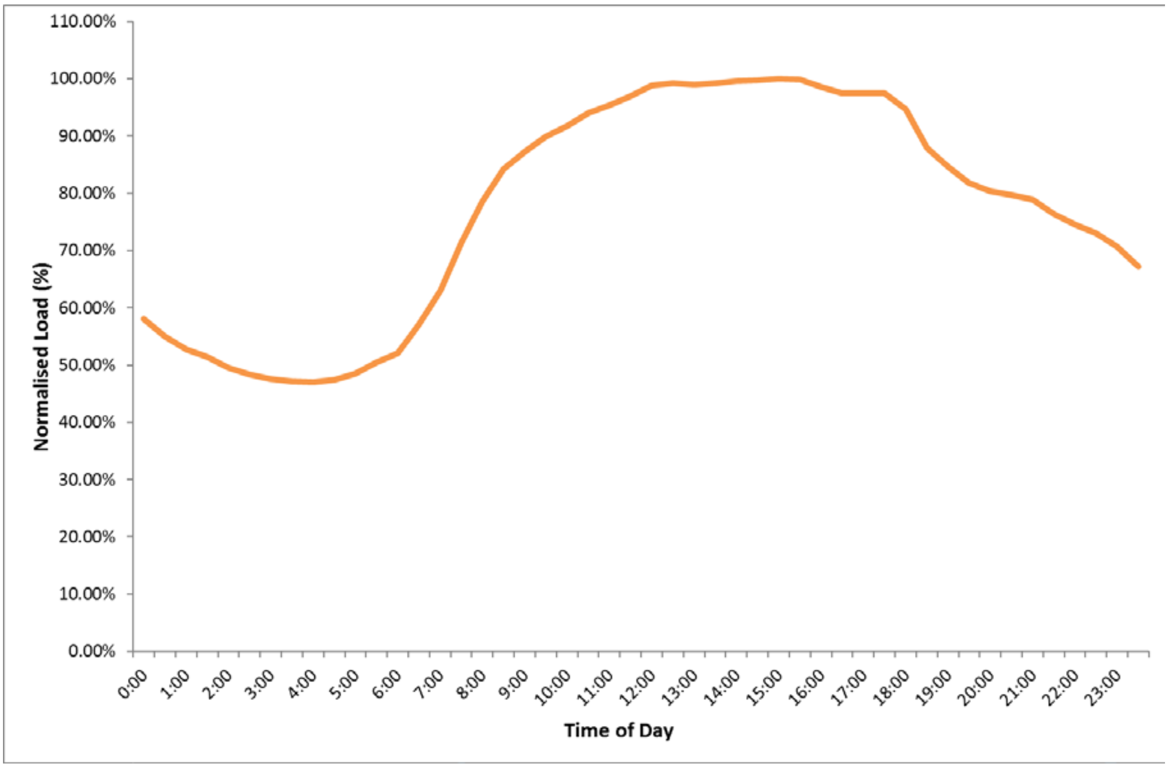
[23] In accordance with NER clause 5.16.4(b)(2).

Figure 3.5 Inner Sydney load profile, 2013/14



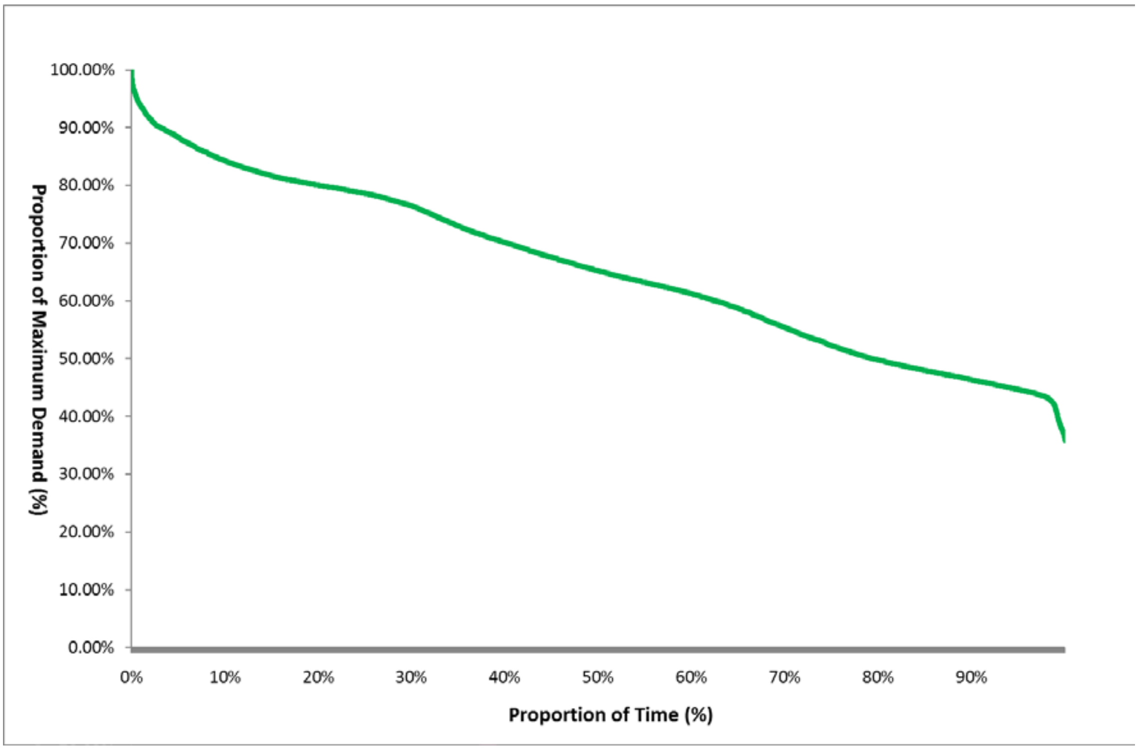
The figure below illustrates the load profile for a typical summer (peak) day in 2013/14, i.e., the year used to calculate the unserved energy.

Figure 3.6 Inner Sydney typical summer day of maximum demand, 2013/14



The figure below illustrates the load duration curve for 2013/14, i.e., the year used to calculate the unserved energy.

Figure 3.7 Inner Sydney load duration curve, 2013/14



3.4.2 Value of customer reliability

As outlined above, a key benefit for this RIT-T will be a reduction in the amount of expected unserved energy in Inner Sydney going forward under each of the credible options.

Under the RIT-T assessment, the benefit associated with the reduction in unserved energy is valued at the Value of Customer Reliability (VCR), expressed in $/kWh.

It is important that the VCR estimates used are fit for purpose and accurately reflect the costs that electricity supply interruptions impose on the end-use customers in question.

In the case of this RIT-T, TransGrid and Ausgrid do not consider that the application of AEMO's standard VCR estimates,[24] without modification, would be appropriate, for two reasons:

1. the AEMO estimates are not broken down into different geographic areas beyond state-level values and therefore do not provide any insight into differences in VCR between customers in regions like Inner Sydney, and the rest of New South Wales; and
2. the methodology used to calculate the AEMO estimates does not cater for prolonged outages (the longest outage considered was 12 hours) and so the 'low probability but high impact' supply interruptions contemplated in this RIT-T are not accurately captured.

In addition, the AEMO estimates do not include customers in Inner Sydney that could be reasonably expected to place a high value on the reliable supply of electricity, such as the Australian Securities Exchange, NSW Parliament, large financial institutions, public transport agencies, large datacentres, Port Botany and Sydney airport.

The inappropriateness of applying the standard AEMO VCR estimates to assessing the cost to customers of events that cause wide-spread, severe or prolonged supply shortages is noted by AEMO itself in its VCR Application Guide.[25] Specifically, the AEMO Guide notes that, because the VCR may not accurately estimate the impacts of widespread and/or prolonged outages, additional offsets to the VCR might be appropriate to

[24] AEMO produces VCR estimates for each jurisdiction in the National Electricity Market, across four customer classifications, as well as a state-wide average. The customer classifications include residential and different sizes of commercial customer.

[25] AEMO, Value of Customer Reliability – Application Guide, Final Report, December 2014, p. 20.

estimate effects not captured through customer surveys. The guide notes that VCR survey respondents are not expected to have a good understanding of the social and safety impacts related to widespread and/or prolonged outages and so extrapolating survey results to cater for this kind of event might necessitate additional offsets due to the non-linear nature of a VCR over time and space. A recent consumer forum held by AEMO also suggested the possible use of multipliers to cater for outages of these types.[26]

Overall, TransGrid and Ausgrid consider that the use of the standard AEMO estimates without modification would under-represent the costs that electricity supply interruptions impose on end-use customers in Inner Sydney.

The consulting firm Houston Kemp was engaged by TransGrid to independently determine an appropriate value for the VCR applied to unserved energy estimates in both the Sydney CBD and the Sydney Inner Metropolitan Area. Houston Kemp was asked to take the AEMO VCR estimates as a starting point and applied insights garnered from other published studies to develop alternate VCR estimates.

The final Houston Kemp VCR report recommended a value in the range of $150-192kWh be used for the Sydney CBD area and $90/kWh for the Sydney Inner Metropolitan area.[27] The Houston Kemp report is provided as Appendix C to this PSCR.

TransGrid and Ausgrid therefore intend to adopt a VCR estimate of $170/kWh for the Sydney CBD and $90/kWh for Inner Sydney area for the purpose of valuing unserved energy as part of this RIT-T.

In applying these VCR values TransGrid and Ausgrid have applied a methodology whereby, where the contingency states result in load curtailment, the first 300 MW (approximately) of load shedding would be applied to the Inner Sydney area (lower VCR customers), then afterwards the Sydney CBD area (higher VCR customers).

3.5 Previous consultation on Powering Sydney's Future project

During 2014, TransGrid and Ausgrid consulted widely on the Powering Sydney's Future project. Between April and October 2014, TransGrid and Ausgrid held a range of stakeholder engagement activities including workshops, surveys and community information sessions. TransGrid and Ausgrid conducted a public forum on 19 June 2014 ('Planning Inner Sydney's Electricity Future Forum') and published a subsequent Interim Engagement and Feedback Report in August 2014, as well as an Early Engagement and Feedback Report in December 2014.[28] Through this engagement, feedback was received from over 350 stakeholders.[29]

At the time of this earlier consultation, there were five key drivers behind the Powering Sydney's Future project:

1. the 'modified N-2' NSW transmission reliability standard in place;
2. the age and reliability of TransGrid's Cable 41;
3. the rating of Cable 41, which had been derated from 663 MVA to 575 MVA in 2011;
4. the rating of Ausgrid oil-filled 132 kV cables; and
5. forecast increase in peak demand.

In late 2014, following these engagement activities, updated maximum demand forecast information was received for the Inner Sydney area, which suggested a lower peak demand and a slower rate of growth over the following decade than had been earlier assumed. These forecasts meant that there were no longer forecast supply constraints. This was the primary driver behind the Powering Sydney's Future project being deferred.

[26] AEMO, Consumer Forum Meeting Pack 5 August 2016, Handout 4: Regulatory Investment Test for Transmission (RIT-T) Improvements, p. 3.
[27] Houston Kemp Economists, CBD and Inner Metro VCR estimates, July 2016
[28] These reports are available on TransGrid's website, available at: http://www.transgrid.com.au
[29] These reports are available on TransGrid's website, available at: http://www.transgrid.com.au

The drivers of the identified need have been discussed substantively in previous TransGrid Transmission Annual Planning Reports under 'Supply to the Sydney Inner Metropolitan Area' and 'Powering Sydney's Future'.[30]

Since 2014, there have been a number of developments that have contributed to the Powering Sydney's Future project being re-evaluated and the commencement of this formal RIT-T process. In particular:

- all oil-filled cables in Inner Sydney are now two years older and consequently less reliable;
- a further derating of Cable 41 from 575 MVA to 426 MVA in August 2016 as a result of testing of the thermal resistivity of backfill and bedding materials;
- an anticipated rebound in peak demand in Inner Sydney due to heightened economic activity expected within Inner Sydney, as confirmed by committed new connections including many large residential developments, significant infrastructure projects; and
- a move away from the modified N-2 reliability standard towards an approach that explicitly acknowledges the value of unserved energy to end-use customers versus the cost of investment.

This RIT-T reflects the commitment to stakeholder engagement emphasised by TransGrid and Ausgrid in the Power Sydney's Future Project, and are committed to proactive and transparent processes. It is consistent with the desire to inform, consult and collaborate with interested parties, and believe that two-way communication is key to building long-term relationships with communities affected by our future and current operations.

3.6 How to meet the need date

Using the cost benefit analysis process, the identified project need date is 2021/22.

The impact of the IPART draft reliability standard and the project delivery timing are further addressed in Sections 4 and 5.

[30] See for example: TransGrid, Transmission Annual Planning Report 2016, p. 53; TransGrid, Transmission Annual Planning Report 2015, p. 92; TransGrid, Transmission Annual Planning Report 2014, p. 72. TransGrid, Transmission Annual Planning Report 2013, p. 49. TransGrid, Transmission Annual Planning Report 2012, p. 55.

4. Required technical characteristics of non-network options

TransGrid and Ausgrid note that a number of non-network solutions could effectively defer the network investment and address the risk of unserved energy. Here, we define the minimum amount of network support required to defer the network investment, and separately call for non-network proponents to submit an Expression of Interest to help address the risk, i.e., the remaining expected unserved energy. Network support up to 300 MW will be considered on a cost benefit basis against the reduction in unserved customer energy. Non-network options within Inner Sydney might include:

- embedded generation;
- energy storage (including battery systems), which injects power into the grid when required; and
- voluntary curtailment of customer load.

This section outlines the required technical characteristics that non-network options would need to provide in order to assist with meeting the identified need. TransGrid and Ausgrid are keen to consider non-network alternatives are part of this RIT-T and call for Expressions of Interest from non-network proponents (particularly aggregated solutions).

4.1 Nature of any load reduction or additional supply required

Unlike typical capacity driven projects, the risk which needs to be addressed in this instance is the failure of network elements and the consequent need to maintain supply to customers using alternate means. So unlike a typical capacity driven need where non-network solutions are called upon to provide network support for short periods on a handful of peak days (often 40-60 hours per year), this project will require the capability to provide network support across a substantially larger number of days and hours.

In the event of the failure of a network element, the non-network solution would need to provide network support for up to 8 weeks while repairs are completed. And in future years, there is a strong likelihood of multiple contingency events in a single year and so a viable non-network solution will need to provide the capacity to provide effective network support for multiple events in a single year.

As shown in Figure 3.6, the demand profile for the Inner Sydney area exhibits a lengthy peak period due to the largely commercial load in the area. And due to the influence of load from businesses, demand is much lower on weekends and holidays. For this reason, network support is required for the period from 8am to 8pm on working weekdays. We note that a combination of non-network proponents may be able to meet this operation profile over a sustained period.

To address the risk of lack of supply to customers, a preferred non-network solution would offer network support on all working weekdays in the year. But while the failure of a network element can occur at any time of the year, the variation in demand over the year results in a limited volume of estimated unserved energy in the late autumn, winter and early spring period. To optimise a potential non-network alternative, TransGrid and Ausgrid would consider any solution which offers at a minimum network support during the extended summer period from November to March.

4.2 Indicative size and duration of non-network solutions for deferral

To estimate the size of any load reduction or additional supply required to defer the need for investment, the volume of estimated unserved energy has been re-calculated by TransGrid and Ausgrid for a range of the peak reductions that would result from the deployment of non-network solutions. The range of peak reductions considered started at 25 MW and then in increments of 25 MW to 200 MW.

In the assessment, the load profile for the entire year has been reduced by the appropriate peak reduction due to the non-network solution, and then the expected unserved energy was re-calculated. The revised value of net benefits from estimated unserved energy and other impacts such as environmental benefits was then compared with the annual deferral value for the project is estimated to be about $12.4M[31].

Note that the deferral benefit is based on the expenditure for Stage 1 only as the non-network options considered are relevant to the first stage only.

TransGrid and Ausgrid have estimated the approximate level of network support required to provide the minimum amount of reduced estimated unserved energy to defer the network investment. These requirements, detailed in Table 4.1 below, are based upon availability of network support for an entire year.

Table 4.1 Minimum level of required network support for deferral

Year	Minimum network support required
2022/23	60 MW
2023/24	90 MW
2024/25	150 MW

Where a non-network solution offers network support for a reduced number of days in the year, the minimum level of network support required to allow deferral of the network option would need to be higher. For example it is estimated that a non-network solution offering support for a six month period over an extended summer would need to be about 5-10% higher than the figures in Table 4.1.

4.3 Indicative size and duration of non-network solutions to address risk

The estimated values in Table 4.1 are the demand reductions required to defer the investment only and do not remove all load at risk. TransGrid procured 40 MW of demand management in 2012/13 for risk mitigation purposes in the Sydney metropolitan area. We expect the demand management market will have developed more since that time, and non-network solutions available prior to 2022/23 will be assessed for the capability to manage the risk of residual unserved energy[32] prior to the scheduled project delivery during 2022/23. If available non-network solutions are not adequate, then the project delivery schedule will be accelerated.

To meet the new reliability standard described above, TransGrid will be required to invest in network or non-network solutions to reduce the EUE to or below the threshold prescribed by IPART. Between 2017-2022, 0.6 minutes per year equates to approximately 8-9 megawatt-hours of energy across TC1, which slightly increases over time.

TransGrid and Ausgrid are interested in proposals from non-network providers which further reduce the load at risk. Demand reductions beyond the minimum required to defer the investment will be assessed on a cost benefit basis against the reduction in unserved customer energy. Network support up to 300 MW will be considered.

[31] TransGrid has used the current regulated Weighted Average Cost of Capital as the discount rate to estimate the deferral value on the basis that the identified need is reliability driven and that wholesale market benefits are not expected to be material. This is subject to change once the preferred solution has been identified later in the RIT-T process.

[32] less any allowance prescribed by IPART's reliability standard.

4.4 Location and operating profile

Due to the network configuration in the Inner Sydney area, the effectiveness of non-network solutions varies by location. The most effective locations are within the Sydney inner metropolitan area including the CBD, the Eastern suburbs, and parts of the Inner East and Inner West.

Table 4.1 details the minimum level of required network support and

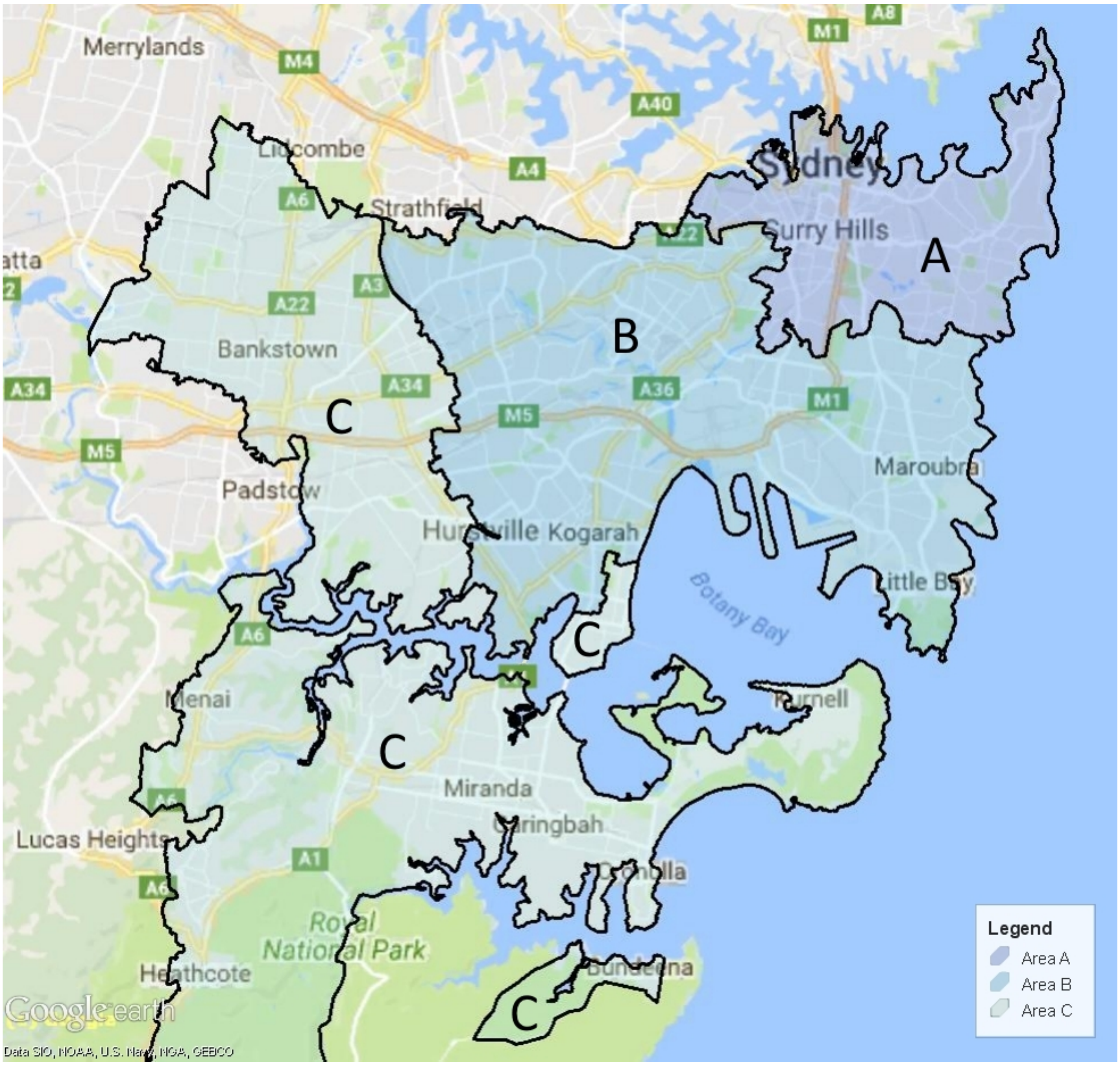
The map below in Figure 4.1describes the approximate effectiveness of non-network solutions for three broad areas.

Area A represents the area supplied by TransGrid's Beaconsfield bulk supply point. Non-network solutions in this area are considered highly effective for all contingency events.

Area B represents the remaining area within Transmission Corridor 1 (TC1). Non-network solutions in this area are considered moderately effective for most contingency events and moderate to highly effective for some contingency events.

Area C represents areas that can influence the load on some supply cables in the TC1 area for some contingency events. Non-network solutions in this area have low effectiveness for most contingency events.

Figure 4.1 Assessment of effectiveness of non-network solutions



TransGrid and Ausgrid invite proponents of non-network options within these areas to make submissions as part of this consultation process. Any non-network option considered to be technically and commercially feasible will be assessed as part of the PADR assessment, most likely in combination with a deferred network option.

4.5 Call for Expressions of Interest regarding non-network options

TransGrid and Ausgrid encourage parties to submit an Expression of Interest (EOI) regarding the potential of non-network options to satisfy, or contribute to satisfying, the identified need outlined above.

TransGrid and Ausgrid note that it is likely that the scale of non-network support that would need to be provided is such that a non-network option would need to encompass a range of different facilities and/or service providers. TransGrid and Ausgrid therefore encourage aggregated solutions to submit an EOI, and will give priority in identifying credible non-network options that are of sufficient scale.

The proposed solution must be large enough collectively, to reduce the loading on the transmission network during multiple outages. To manage a complex portfolio of demand management of sufficient scale, we require the proposed solutions to provide a minimum aggregated capacity of 1 MW. TransGrid may choose to select a subset of non-network solutions it determines that is most economical and reliable.

The proposed solutions must be reliably dispatched, immediately in a post-contingent scenario, using proven technology. Over a sustained period, a longer day ahead notification period is likely. TransGrid is conducting a pilot using the OpenADR 2.0a+b protocol, and invites proponents of non-network options that can either communicate using this protocol, or uses technology that provides a similar level of reliability.

The table below sets out the parameters that TransGrid and Ausgrid request parties nominate in any EOI.

Table 4.3 Parameters Description

Parameter	Description
Block ID	Block Identifier (e.g. Block 1) of non-network solution
Block Capacity	Discrete amount of the non-network option (reduced load or additional supply) capacity in kW. Sum of block capacities must meet a minimum requirement of 1 MW. TransGrid may choose to select a subset of blocks it determines that is most economical and reliable to dispatch.
Location	Refer to map in Figure 4.1. For new generation solutions, details of the proposed sites for the new generators
Availability Period	Period for that block is available within the operating profile (months/days/hours)
Call Notice Period	Minimum period of time before the block can be dispatched
Establishment Fee	Setup payment that applies to a block
Availability Fee	A fee per month for a block to be made available to be dispatched
Indicative Dispatch Fee	Fee for a block to be dispatched per MWh
Timeframe for project delivery	When the block of DR will be available for dispatch
Communications	Proposed dispatch communications protocol with TransGrid's control room
Metering	Metering equipment installed or to be installed to measure and record the data to be verified

Queries relating to non-network options should be emailed to demandmanagement@transgrid.com.au or by telephone to 02 9284 3354.

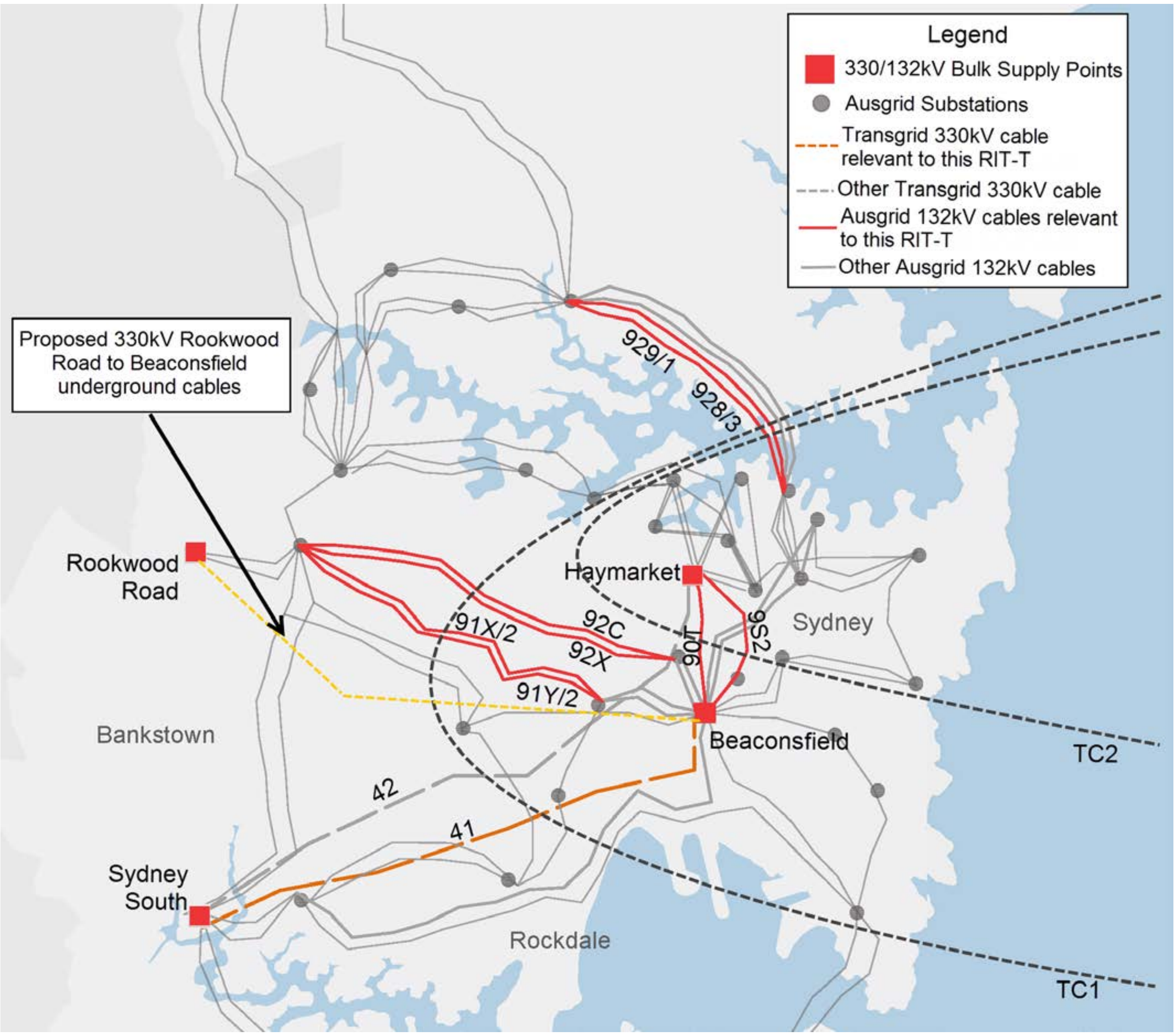
EOI can only be made via the following email address: PSFConsultations@transgrid.com.au.

5. Potential credible options to address the identified need

This section provides a description of the six credible network options TransGrid and Ausgrid have identified as part of the PSCR.[33] All credible options assessed as part of this RIT-T will be compared against a base case 'do nothing' option. In addition, TransGrid and Ausgrid intend to evaluate a combined network and non-network option as part of the RIT-T assessment.

Any new cables built under the credible network options would follow the same general route (Rookwood Road to Beaconsfield). TransGrid and Ausgrid have investigated the costs and risks of alternate routes and consider that there is no one preferable route. A network diagram illustrating this route selection (light orange dashed line) is provided in the figure below.

Figure 5.1 Network diagram illustrating route selection for new cables



The credible network options considered differ principally based on:

- whether Cable 41 is remediated, operated without remediation (including at a lower voltage), or retired;
- whether two new 330 kV cables are built together, or in stages;

[33] As required by NER clause 5.16.4(b)(5).

- whether eight of Ausgrid's aging oil-filled cables considered as part of this RIT-T in the Inner Sydney area are retired at once, or in stages.

A summary of these six network options is provided in the table below. Figure 5.2 on the next page illustrates the construction timetable and commissioning date of the various components for each option.

Table 5.1 Summary of potential credible options

Option	Indicative capital cost ($2016 real)	Indicative O&M cost ($2016 real)
Option 1: install two 330 kV cables in stages, retire Cable 41 and decommission Ausgrid cables in two stages	$435 million	2 per cent of new capex + $15 million in decommissioning costs
Option 2: operate Cable 41 at 132 kV, install two 330 kV cables in stages and decommission Ausgrid cables in two stages	$443 million	2 per cent of new capex + $15 million in decommissioning costs
Option 3: install two 330 kV cables at once, retire Cable 41 and decommission Ausgrid cables in one stage	$417 million	2 per cent of new capex + $15 million in decommissioning costs
Option 4: remediate Cable 41, install two 330 kV cables in stages and decommission Ausgrid cables in one stage	$560 million	2 per cent of new capex + $12 million in decommissioning costs
Option 5: remediate Cable 41, install two 330 kV cables at once (initially operating at 132 kV) and decommission Ausgrid cables in two stages	$555 million	2 per cent of new capex + $12 million in decommissioning costs
Option 6: remediate Cable 41, install two 330 kV cables at once and decommission Ausgrid cables in one stage	$542 million	2 per cent of new capex + $12 million in decommissioning costs

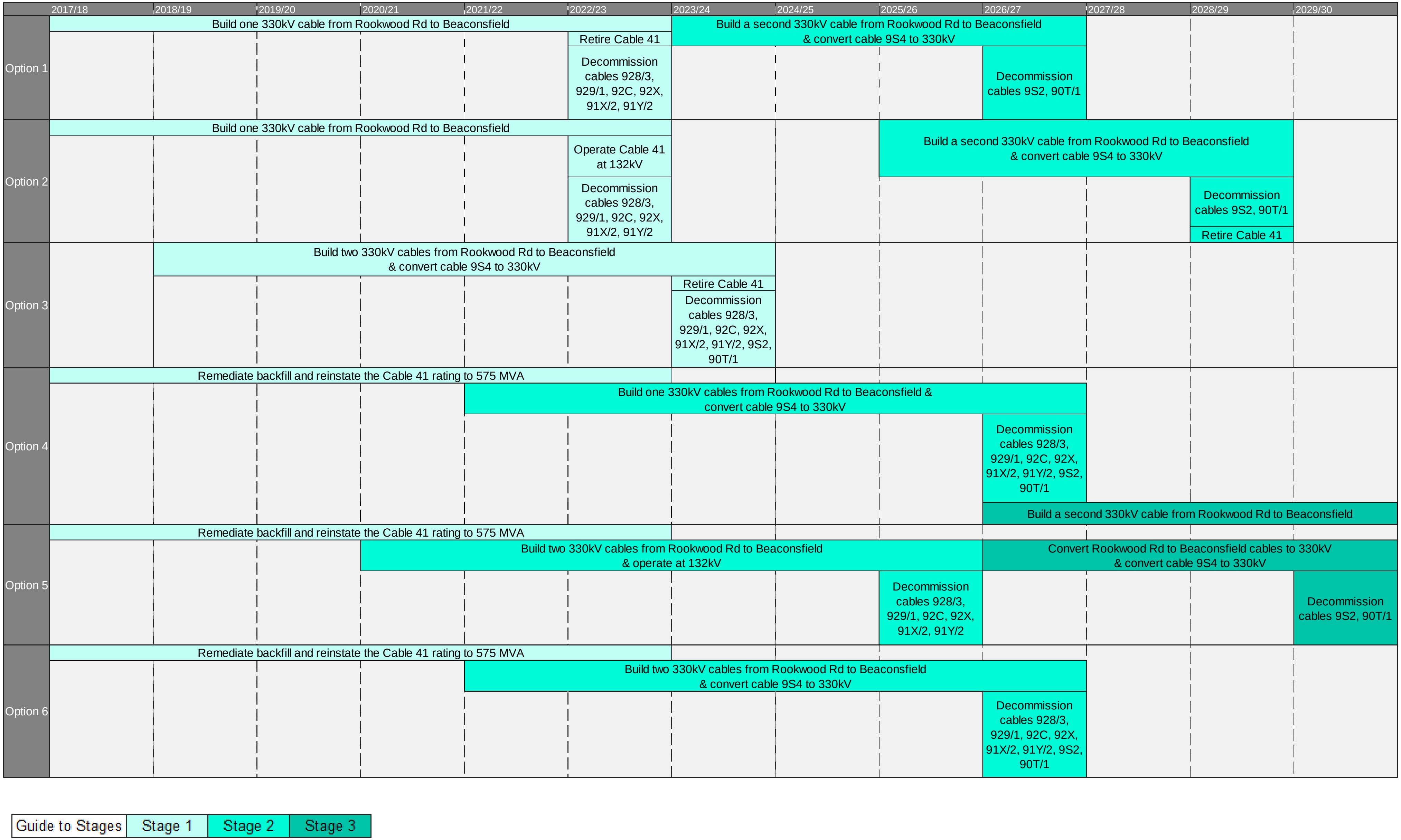
Each of these six credible network options are expected to be both technically and commercially feasible and able to be implemented in sufficient time to meet the identified need. We will review the new reliability standard requirements, once approved by the Minister, and address any impact on expected unserved energy in the PADR.

TransGrid considers that its estimates of the various cost components of each option are within +/-25 per cent, while Ausgrid considers its estimates are within +/-40 per cent. Both TransGrid and Ausgrid are working to refine these estimates for the assessment in the PADR. In addition, the assessment in the PADR will also test the sensitivity of the results to the underlying costs used.

TransGrid and Ausgrid consider that there is potential for non-network options (such as generation and demand management) to defer the time at which network investment is required. As noted in section 4.1 above, any non-network option raised through the EOI process and considered to be technically and commercially feasible will be assessed as part of the PADR assessment, most likely in combination with a deferred network option.

This section also discusses a number of other options considered by TransGrid and Ausgrid, and the reasons why these are not considered to be credible options for the purpose of this RIT-T assessment.

Figure 5.2 Construction timetable and anticipated commissioning date of each credible network option



TransGrid Ausgrid

5.1 Option 1: install two 330 kV cables in stages and retire Cable 41

Option 1 involves ultimately installing two 330 kV 750 MVA cable circuits between Rookwood Road and Beaconsfield substations, retiring Cable 41 and retiring the eight Ausgrid oil-filled cables in two stages.

The two cables would be installed and commissioned in two stages – namely:

- Stage 1: build one 330 kV 750 MVA cable between Rookwood Rd and Beaconsfield substations, terminate new cable onto existing transformers at Beaconsfield, extend 330 kV GIS at Rookwood Rd, and then retire Cable 41 along with six Ausgrid oil-filled cables (cables 928/3, 929/1, 92C, 92X, 91X/2, 91Y/2); and
- Stage 2: install a second 330 kV 750 MVA cable from Rookwood Rd to Beaconsfield, extend 330 kV GIS at Beaconsfield and connect the two 330 kV cables from Rockwood Rd. Stage 2 would also involves extending the 330 kV GIS at Haymarket and converting cable 9S4 from Beaconsfield to Haymarket to 330 kV 750 MVA operation. This allows two additional Ausgrid oil-filled cables to be retired (cables 9S2, 90T/1).

Capital costs for this option are estimated to be approximately $435 million, with major cost components shown in the table below. The scope and estimate are currently being refined and will be updated in the PADR. Operating costs include decommissioning costs of cables, as well as annual operating costs associated with new capital costs, which are estimated to be about two per cent of the capital cost.

TransGrid and Ausgrid estimate that the environmental approval and construction timeline for Stage 1 of Option 1 is five years, with commissioning possible during 2022/23. TransGrid and Ausgrid further estimate that the construction timeline for Stage 2 of Option 1 is three years, with commissioning proposed during 2026/27. The complete construction timeline is shown in Figure 5.2 above.

Table 5.2 Option 1 - install two 330 kV cables in stages and retire Cable 41

Project description	Cost ($2016 real)	Construction timetable; commissioning date
Stage 1		
Install one 330 kV cable circuit from Rookwood Road to Beaconsfield and provision for a second 330 kV circuit that is to be installed at a later date	$260 million (capex)	5 years, with commissioning possible during 2022/23
TransGrid decommissioning costs (Cable 41)	$3 million (opex)	
Ausgrid decommissioning costs (cables 928/3, 929/1, 92C, 92X, 91X/2, 91Y/2)	$11 million (opex)	
Stage 2		
Install second 330 kV cable circuit from Rookwood Road to Beaconsfield	$150 million (capex)	3 years, with commissioning proposed during 2026/27
Convert cable 9S4 to 330 kV	$25 million (capex)	
Ausgrid decommissioning costs (cables 9S2, 90T/1)	$1 million (opex)	

5.2 Option 2: operate Cable 41 at 132 kV and install two 330 kV cables in stages

Option 2 involves ultimately installing two 330 kV 750 MVA cable circuits between Rookwood Road and Beaconsfield substations, reconfiguring Cable 41 to operate at 132 kV with rating of 170 MVA and retiring the eight Ausgrid oil-filled cables in two stages.

The two cables would be installed and commissioned at in two stages – namely:

- Stage 1: build one 330 kV cable between Rookwood Rd and Beaconsfield, terminate new cable onto existing transformers at Beaconsfield, extend 330 kV GIS at Rookwood Rd, reconfigure Cable 41 to operate at 132 kV with a rating of 170 MVA and retire six Ausgrid oil-filled cables (cables 928/3, 929/1, 92C, 92X, 91X/2, 91Y/2); and

- Stage 2: install a second 330 kV 750 MVA cable from Rookwood Rd to Beaconsfield, extend 330 kV GIS at Beaconsfield and connect the two 330 kV cables from Rockwood Rd. Stage 2 would also involve retiring Cable 41 and extending the 330 kV GIS at Haymarket and converting cable 9S4 from Beaconsfield to Haymarket to 330 kV 750 MVA operation and connecting to the 330 kV GIS at Beaconsfield and Haymarket, This allows two additional Ausgrid oil-filled cables to be retired (cables 9S2, 90T/1).

Capital costs for this option are estimated to be approximately $443 million, with major cost components shown in the table below. The scope and estimate are currently being refined and will be updated in the PADR. Operating costs include decommissioning costs of cables, ongoing opex associated with the continued operation of Cable 41 as well as annual operating costs associated with new capital costs, which are estimated to be about two per cent of the capital cost.

TransGrid and Ausgrid estimate that the environmental approval and construction timeline for Stage 1 of Option 2 is five years, with commissioning possible during 2022/23. TransGrid and Ausgrid further estimate that the construction timeline for Stage 2 of Option 2 is three years, with commissioning proposed during 2028/29. The complete construction timeline is shown in Figure 5.2 above.

Table 5.3 Option 2 – operate Cable 41 at 132 kV and install two 330 kV cables in stages

Project description	Cost ($2016 real)	Construction timetable; commissioning date
Stage 1		
Install one 330 kV cable circuit from Rookwood Road to Beaconsfield and provision for a second 330 kV circuit that is to be installed at a later date.	$260 million (capex)	5 years, with commissioning possible during 2022/23
Operate Cable 41 at 132 kV	$8 million (capex)	
Ausgrid decommissioning costs (cables 928/3, 929/1, 92C, 92X, 91X/2, 91Y/2)	$11 million (opex)	
Stage 2		
Install second 330 kV cable circuit from Rookwood Road to Beaconsfield	$150 million (capex)	3 years, with commissioning proposed during 2028/29
Convert cable 9S4 to 330 kV	$25 million (capex)	
TransGrid decommissioning costs (Cable 41)	$3 million (opex)	
Ausgrid decommissioning costs (cables 9S2, 90T/1)	$1 million (opex)	

5.3 Option 3: install two 330 kV cables at once and retire Cable 41

Option 3 involves installing two 330 kV 750 MVA cable circuits between Rookwood Road and Beaconsfield substations at once, retiring Cable 41 and retiring the eight Ausgrid oil-filled cables at once.

Two 330 kV 750 MVA cables would be built between Rookwood Rd and Beaconsfield substations and connected to the extended 330 kV GIS at Rookwood Rd and Beaconsfield substations. Then cable 41 would be retired. Option 3 also involves extending the 330 kV GIS at Haymarket substation and converting cable 9S4 from Beaconsfield to Haymarket substations to 330 kV 750 MVA operation. This allows eight Ausgrid oil-filled cables to be retired at the same time.

Capital costs for this option are estimated to be approximately $417 million, with major cost components shown in the table below. The scope and estimate are currently being refined and will be updated in the PADR. Operating costs include decommissioning costs of cables, as well as annual operating costs associated with new capital costs, which are estimated to be about two per cent of the capital cost.

TransGrid and Ausgrid estimate that the construction timeline for Option 3 is five years, with commissioning proposed during 2022/23.

Table 5.4 Option 3 – install two 330 kV cables at once and retire Cable 41

Project description	Cost ($2016 real)	Construction timetable; commissioning date
Install two 330 kV cable circuits from Rookwood Road to Beaconsfield	$392 million (capex)	5 years, with commissioning proposed during 2022/23
Convert cable 9S4 to 330 kV	$25 million (capex)	
TransGrid decommissioning costs (Cable 41)	$3 million (opex)	
Ausgrid decommissioning costs (cables 928/3, 929/1, 92C, 92X, 91X/2, 91Y/2, 9S2, 90T/1)	$12 million (opex)	

5.4 Option 4: remediate Cable 41 and install two 330 kV cables in stages

Option 4 is to remediate Cable 41 thermal backfill to increase the cyclic rating to approximately 575 MVA as detailed in the Cable 41 Investigation Summary Report provided in Appendix B, ultimately install two 330 kV 750 MVA cables between Rookwood Rd to Beaconsfield and retire eight Ausgrid oil-filled cables in one stage.

The option would be conducted in three stages – namely:

- Stage 1: remediate Cable 41 and continue to operate at 330 kV with a rating of 575 MVA;
- Stage 2: build one 330 kV 750 MVA cable between Rookwood Rd and Beaconsfield and extend the 330 kV GIS at Rookwood Rd and Beaconsfield. Stage 2 would also involve extending the 330 kV GIS at Haymarket and converting cable 9S4 from Beaconsfield to Haymarket to operate at 330 kV with 750 MVA rating. This allows eight Ausgrid oil-filled cables to be retired at once; and
- Stage 3: install a second 330 kV 750 MVA cable from Rookwood Rd to Beaconsfield.

Capital costs for this option are estimated to be approximately $560 million, with major cost components shown in the table below. The scope and estimate are currently being refined and will be updated in the PADR. Operating costs include decommissioning costs of cables, ongoing opex associated with the continued operation of Cable 41 as well as annual operating costs associated with new capital costs, which are estimated to be about two per cent of the capital cost.

TransGrid and Ausgrid estimate that the construction timeline for Stage 1 of Option 4 is five years, with commissioning possible during 2022/23. TransGrid and Ausgrid estimate that the construction timeline for Stage 2 of Option 4 is five years, with commissioning proposed during 2026/27. TransGrid and Ausgrid further estimate that the construction timeline for Stage 3 of Option 4 is three years, with commissioning proposed during 2029/30.

Table 5.5 Option 4 – remediate Cable 41 and install two 330 kV cables in stages

Project description	Cost ($2016 real)	Construction timetable; commissioning date
Stage 1		
Remediate backfill and reinstate the Cable 41 rating to 575 MVA	$125 million (capex)	5 years, with commissioning possible during 2022/23
Stage 2		
Install one 330 kV cable circuit from Rookwood Road to Beaconsfield and provision for a second 330 kV circuit that is to be installed at a later date	$340 million (capex)	5 years, with commissioning proposed during 2026/27
Convert cable 9S4 to 330 kV	$25 million (capex)	
Ausgrid decommissioning costs (cables 928/3, 929/1, 92C, 92X, 91X/2, 91Y/2, 9S2, and 90T/1)	$12 million (opex)	
Stage 3		
Install second 330 kV cable circuit from Rookwood Road to Beaconsfield	$70 million (capex)	3 years, with commissioning proposed during 2029/30

5.5 Option 5: remediate Cable 41 and install two 330 kV cables at once, initially operating at 132 kV

Option 5 is to remediate Cable 41 thermal backfill to increase the cyclic rating to approximately 575 MVA as detailed in the Cable 41 Investigation Summary Report provided in Appendix B, and install two new 330 kV cables between Rookwood Rd and Beaconsfield that would initially operate at 132 kV.

The option would be conducted in three stages – namely:

- Stage 1: remediate Cable 41 and continue to operate at 330 kV with a rating of 575 MVA;
- Stage 2: build two 330 kV cables between Rookwood Rd and Beaconsfield and operate at 132 kV with 290 MVA ratings[34], as well as retiring six Ausgrid oil-filled cables (cables 928/3, 929/1, 92C, 92X, 91X/2, 91Y/2); and
- Stage 3: extend the 330 kV GIS at Rookwood Rd and Beaconsfield and convert the cables from Rookwood Rd to Beaconsfield to 330 kV 750 MVA operation. Stage 3 would also involves extending the 330 kV GIS at Haymarket and converting cable 9S4 from Beaconsfield to Haymarket to 330 kV 750 MVA operation. This allows two additional Ausgrid oil-filled cables to be retired (cables 9S2, 90T/1).

Capital costs for this option are estimated to be approximately $555 million, with major cost components shown in the table below. The scope and estimate are currently being refined and will be updated in the PADR. Operating costs include decommissioning costs of cables, ongoing opex associated with the continued operation of Cable 41 as well as annual operating costs associated with new capital costs, which are estimated to be about two per cent of the capital cost.

TransGrid and Ausgrid estimate that the construction timeline for Stage 1 of Option 5 is five years, with commissioning possible during 2022/23. TransGrid and Ausgrid estimate that the construction timeline for Stage 2 of Option 5 is five years, with commissioning proposed during 2025/26. TransGrid and Ausgrid further estimate that the construction timeline for Stage 3 of Option 5 is three years, with commissioning proposed during 2029/30.

---

[34] Taking into account the dielectric losses, the normal cyclic rating for a single circuit in service the rating may be 330 MVA.

Table 5.6 Option 5 – remediate Cable 41 and install two 330 kV cables at once, initially operating at 132 kV

Project description	Cost ($2016 real)	Construction timetable; commissioning date
Stage 1		
Remediate backfill and reinstate the Cable 41 rating to 575 MVA	$125 million (capex)	5 years, with commissioning possible during 2022/23
Stage 2		
Install two 330 kV cable circuits from Rookwood Road to Beaconsfield operating at 132 kV initially	$270 million (capex)	5 years, with commissioning proposed during 2025/26
Ausgrid decommissioning costs (cables 928/3, 929/1, 92C, 92X, 91X/2, 91Y/2)	$11 million (opex)	
Stage 3		
Convert the Rookwood Road to Beaconsfield cables from 132 kV to 330 kV	$135 million (capex)	3 years, with commissioning proposed during 2029/30
Convert cable 9S4 to 330 kV	$25 million (capex)	
Ausgrid decommissioning costs (cables 9S2 and 90T/1)	$1 million (opex)	

5.6 Option 6: remediate Cable 41 and install two 330 kV cables at once

Option 6 is to remediate Cable 41 thermal backfill to increase the cyclic rating to approximately 575 MVA as detailed in the Cable 41 Investigation Summary Report provided in Appendix B, and install two new 330 kV cables between Rookwood Rd and Beaconsfield.

The option would be conducted in two stages – namely:

- Stage 1: remediate Cable 41 and continue to operate at 330 kV with a rating of 575 MVA;
- Stage 2: extend the 330 kV GIS at Rockwood Rd and Beaconsfield and build two 330 kV cables between Rookwood Rd and Beaconsfield. Stage 2 would also involve extending the 330 kV GIS at Haymarket and the conversion of cable 9S4 from Beaconsfield to Haymarket to 330 kV 750 MVA operation. This allows eight Ausgrid oil-filled cables to be retired at once.

Capital costs for this option are estimated to be approximately $544 million, with major cost components shown in the table below. The scope and estimate are currently being refined and will be updated in the PADR. Operating costs include decommissioning costs of cables, ongoing opex associated with the continued operation of Cable 41 as well as annual operating costs associated with new capital costs, which are estimated to be about two per cent of the capital cost.

TransGrid and Ausgrid estimate that the construction timeline for Stage 1 of Option 6 is five years, with commissioning possible during 2022/23. TransGrid and Ausgrid further estimate that the construction timeline for Stage 2 of Option 6 is five years, with commissioning proposed during 2026/27.

Table 5.7 Option 6 – remediate Cable 41 and install two 330 kV cables at once

Project description	Cost ($2016 real)	Construction timetable; commissioning date
Stage 1		
Remediate backfill and reinstate the Cable 41 rating to 575 MVA	$125 million (capex)	5 years, with commissioning possible during 2022/23
Stage 2		
Install two 330 kV cable circuits from Rookwood Road to Beaconsfield	$392 million (capex)	5 years, with commissioning proposed during 2026/27
Convert cable 9S4 to 330 kV	$25 million (capex)	
Ausgrid decommissioning costs (cables 928/3, 929/1, 92C, 92X, 91X/2, 91Y/2, 9S2, 90T/1)	$12 million (opex)	

5.7 Non-network options

TransGrid and Ausgrid note that a number of non-network solutions could effectively reduce the amount of unserved energy that would occur in the event of an unplanned loss of Cable 41, and potentially postpone the timing of network investments. The technical requirements for non-network options are detailed in section 3.

5.8 Options considered but not progressed

This section discusses additional options that TransGrid and Ausgrid have considered but do not consider technically and/or economically feasible, and therefore which are not being progressed as credible options.

Two cables from Lane Cove to CBD and two cables from Rookwood Rd to Beaconsfield

This option involves building two new 132 kV cable circuits from Lane Cove to Pyrmont and two 330 kV cable circuits from Rookwood Rd to Beaconsfield, operating at 132 kV initially.

Stage 1 of this option would involve installing two 132 kV cable circuits from Lane Cove to Pyrmont. Stage 2 involves installing two 330 kV cable circuits from Rookwood Rd to Beaconsfield, and subsequently operating the cable circuits at 132 kV.

TransGrid and Ausgrid do not consider that these measures are sufficient to address the identified need and consequently, together, do not constitute a technically feasible option.[35] Specifically, the following render these schemes as technically infeasible options:

- High project risks costs related to the submarine sections and landing connections; and
- Uncertainty around timing since it is closely tied with multiple cable retirements in the Lane Cove, Dalley St and Pyrmont area.

In addition, TransGrid and Ausgrid consider that these options will not provide sufficient capacity under high demand growth scenarios and will result in an unacceptably high level of unserved energy.

Four cables from Chullora to Beaconsfield, in stages, and two cables from Lane Cove to Pyrmont

This option is to ultimately build four new 132 kV cable circuits from Chullora to Beaconsfield and two 132 kV cable circuits from Lane Cove to Pyrmont.

[35] The AER RIT-T Guidelines state that an option is technically feasible if the TNSP reasonably considers that there is a high likelihood, that the option (if developed) will provide the services that it is assumed it will provide, while also complying with all mandatory requirements in relevant laws, regulations and administrative requirements. See: AER, Final Regulatory Investment Test for Transmission Application Guidelines, June 2010, version 1, page 10.

Stage 1 of this option would involve installing two 132 kV cable circuits from Chullora to Beaconsfield (to replace 91X and 91Y). Stage 2 would involve installation an additional two 132 kV cable circuits from Chullora to Beaconsfield (to replace 92C and 92X) and two cable circuits from Lane Cove to Pyrmont.

TransGrid and Ausgrid consider that these options will not provide sufficient capacity under high demand growth scenarios and will result in an unacceptably high level of unserved energy.

Remediation of Cable 41 to 663 MVA

TransGrid and Ausgrid have considered options involving remediating Cable 41 to 663 MVA (i.e. this requires excavation of the thermal bedding material around the cables which must be out of service) and the installation of a fully integrated dynamic rating system (i.e. attaching a Distributed Temperature Sensing fibre optic cable to the centre phase cable which requires Cable 41 to be out of service). While these options are technically feasible, the additional benefits over other options do not compensate for the two-year cable outage requirements for implementation and are therefore deemed not credible options.

Replacing existing 132 kV oil-filled cables on a 'like-for-like' basis

TransGrid and Ausgrid have considered replacing existing oil-filled 132 kV cables with new technology cables. However, it is considered that the cost of doing so is prohibitive and renders this option commercially infeasible. In particular, the costs of replacing these cables is expected to be up to 50 per cent greater than the credible options outlined in this PSCR due to the civil works associated with replacing these cables (given the much greater number of kilometres of construction required through Inner Sydney) and is not anticipated to deliver commensurately greater benefits. In addition, the construction timeline is estimated to be around ten years during which time there would disruption to many streets all around Sydney near all of the existing cable routes.

5.9 Material inter-regional impact

In accordance with NER clause 5.16.4(b)(6)(ii), TransGrid and Ausgrid have considered whether the credible options considered above are expected to have a material inter-regional impact.

A 'material inter-network impact' is defined in the NER as:

> *A material impact on another Transmission Network Service Provider's network, which impact may include (without limitation): (a) the imposition of power transfer constraints within another Transmission Network Service Provider's network; or (b) an adverse impact on the quality of supply in another Transmission Network Service Provider's network.*

AEMO currently defines the criteria for material inter-network impact. AEMO's suggested screening test to indicate that a transmission augmentation has no material inter-network impact is that it satisfies the following:[36]

- a decrease in power transfer capability between the transmission networks or in another TNSP's network of no more than the minimum of three per cent of the maximum transfer capability and 50 MW;
- an increase in power transfer capability between transmission networks of no more than the minimum of three per cent of the maximum transfer capability and 50 MW;
- an increase in fault level by less than 10 MVA at any substation in another TNSP's network; and
- the investment does not involve either a series capacitor or modification in the vicinity of an existing series capacitor.

The credible network options set out in this PSCR involve neither a series capacitor nor modification in the vicinity of an existing series capacitor. None of the options discussed above are expected to result in a material change in power transfer capability between New South Wales and neighbouring transmission

[36] The screening test is set out in Appendix 3 of the Inter-Regional Planning Committee's Final Determination: Criteria for Assessing Material InterNetwork Impact of Transmission Augmentations, Version 1.3, October 2004.

networks. In addition, fault levels are not expected to increase by more than 10 MVA at any substation in another TNSP's network.

As a consequence, by reference to AEMO's screening criteria, there are no material inter-network impacts associated with the credible options included in this PSCR.

6. Materiality of market benefits for this RIT-T assessment

TransGrid and Ausgrid consider that for this particular RIT-T, the following categories of market benefit are likely to be material:

- changes in involuntary load shedding through reduced unserved energy; and
- changes in network losses.

TransGrid and Ausgrid consider that all other categories of market benefit under the RIT-T are unlikely to be material in relation to the RIT-T assessment for all options.[37] [38] The sections below outline why this is considered to be the case for each category of market benefit.

TransGrid and Ausgrid note that one of the benefits of addressing the identified need will be the avoided operating and maintenance costs as well as the lower cost of complying with environmental obligations associated with continued use of oil-filled cables. Reductions in these costs are not captured under the prescribed RIT-T 'market benefit' categories but, instead, will be included in the RIT-T assessment as reduced costs relative to the base case.

6.1 Market benefits relating to the wholesale market

The AER has recognised that if the proposed investment will not have an impact on the wholesale market, then a number of classes of market benefits will not be material in the RIT-T assessment and so do not need to be estimated.[39]

The credible network options described in section 5 do not address network constraints between competing generating centres and are therefore not considered to result in any change in dispatch outcomes and wholesale market prices.

TransGrid and Ausgrid therefore consider that the following classes of market benefits are not material for this RIT-T assessment for any of the credible network options:

- changes in fuel consumption arising through different patterns of generation dispatch;
- changes in voluntary load curtailment (since there is no impact on pool price);
- changes in costs for parties, other than for TransGrid and Ausgrid (since there will be no deferral of generation investment);
- changes in ancillary services costs; and
- competition benefits.

TransGrid and Ausgrid note that credible non-network solutions proposed to meet the identified need may potentially impact the wholesale market. If TransGrid and Ausgrid consider that a proposed non-network solution identified during the consultation period will impact the wholesale market, the materiality of all of the above classes of market benefits associated with that option will be assessed. As a result of that assessment, where any of these classes of market benefit are considered to be material, they will be quantified as part of the RIT-T assessment.

---

[37] Under NER clause 5.16.4(b)(6)(iii), the PSCR should set out the classes of market benefit that the NSP considers are not likely to be material for a particular RIT-T assessment.

[38] The NER requires that all categories of market benefit identified in relation to the RIT-T are included in the RIT-T assessment, unless the NSP can demonstrate that a specific category (or categories) is unlikely to be material in relation to the RIT-T assessment for a specific option. (NER clause 5.16.1(c)(6).)

[39] AER, Final Regulatory Investment Test for Transmission Application Guidelines, June 2010, version 1, p 15.

6.2 Differences in the timing of unrelated expenditure

TransGrid and Ausgrid do not at this stage consider that any of the credible options for this RIT-T will affect the timing of other transmission or distribution investments (to meet unrelated needs). However, this matter will be reviewed as part of the detailed development of the PADR.

6.3 Option value

TransGrid and Ausgrid note the AER's view that option value is likely to arise where there is uncertainty regarding future outcomes, the information that is available in the future is likely to change and the credible options considered by the TNSP are sufficiently flexible to respond to that change.[40]

TransGrid and Ausgrid note that there is uncertainty regarding future demand in Inner Sydney since a large component of it is driven by significant new customer connections. In future, new information may result in changes to the volume and impact of new customer connections which would lead to changes in the demand forecast. As revised forecasts or other material changes become available, the cost benefit analysis will be reassessed.

However, TransGrid and Ausgrid note that the primary driver of the identified need in this RIT-T is the fact that certain oil-filled cables owned by TransGrid and Ausgrid are aging and consequently deteriorating in condition, which is known with a high degree of certainty and is unlikely to change going forward.

TransGrid and Ausgrid also note the AER's view that appropriate identification of credible options and reasonable scenarios captures any option value, thereby meeting the NER requirement to consider option value as a class of market benefit under the RIT-T. TransGrid and Ausgrid will incorporate several reasonable scenarios in conducting the RIT-T analysis, which reflect differences in the future level of expected spot load development, amongst other factors.

For this RIT-T assessment, the estimation of any option value benefit over and above that already captured via the scenario analysis in the RIT-T would require a significant modelling assessment. At this stage of the assessment, TransGrid and Ausgrid consider that the additional modelling would be unlikely to affect the outcome of the analysis, and so would be disproportionate. TransGrid and Ausgrid therefore have not estimated any additional option value market benefit as part of the quantification of market benefits presented for the RIT-T assessment at this stage.

TransGrid and Ausgrid will continue to monitor and assess the materiality of modelling option value as part of this RIT-T going forward, particularly in the light of any changes made to the reasonable scenarios included in the analysis following the firm commitment of additional spot load.

[40] AER, Final Regulatory Investment Test for Transmission Application Guidelines, June 2010, version 1, p. 39 & 75.

A.1 Checklist of compliance clauses

This section sets out a compliance checklist which demonstrates the compliance of this PSCR with the requirements of clause 5.16.4(b) of the National Electricity Rules version 83.

Rules clause	Summary of requirements	Relevant section(s) in the PSCR
5.16.4(b)	A RIT-T proponent must prepare a report (the project specification consultation report), which must include:	-
	(1) a description of the identified need;	2
	(2) the assumptions used in identifying the identified need (including, in the case of proposed reliability corrective action, why the RIT-T proponent considers reliability corrective action is necessary);	2
	(3) the technical characteristics of the identified need that a non-network option would be required to deliver, such as: (i) the size of load reduction or additional supply; (ii) location; and (iii) operating profile;	3
	(4) if applicable, reference to any discussion on the description of the identified need or the credible options in respect of that identified need in the most recent NTNDP;	1
	(5) a description of all credible options of which the RIT-T proponent is aware that address the identified need, which may include, without limitation, alternative transmission options, interconnectors, generation, demand side management, market network services or other network options;	4
	(6) for each credible option identified in accordance with subparagraph (5), information about: (i) the technical characteristics of the credible option; (ii) whether the credible option is reasonably likely to have a material inter-network impact; (iii) the classes of market benefits that the RIT-T proponent considers are likely not to be material in accordance with clause 5.16.1(c)(6), together with reasons of why the RIT-T proponent considers that these classes of market benefits are not likely to be material; (iv) the estimated construction timetable and commissioning date; and (v) to the extent practicable, the total indicative capital and operating and maintenance costs.	4 & 5

A.2 TransGrid and Ausgrid Inner Sydney oil-filled cables

Table A.6.1 shows the cables within Transmission Corridor 1 and Transmission Corridor 2, the age and length.

Table A.6.1 Summary of Inner Sydney cables

Feeder	Owner	Year Commissioned (oldest cable section)	Age in 2016 (years)	Feeder Route Length (km)
41	TransGrid	1979	37	19.7
42	TransGrid	2004	12	27.5
92L/3	Ausgrid	1970	46	10.8
92M/1	Ausgrid	1970	46	10.8
91M/1	Ausgrid	1973	43	19.5
928/3	Ausgrid	1966	50	11.9
929/1	Ausgrid	1966	50	12
92X	Ausgrid	1968	48	14.5
92C	Ausgrid	1968	48	14.5
91X/2	Ausgrid	1972	44	13
91Y/2	Ausgrid	1972	44	13
90T/1	Ausgrid	1981	35	3.8
9S2	Ausgrid	1988	28	5.2
9SA	Ausgrid	1973	43	5.7
92P	Ausgrid	1973	43	5.5

A.3 Calculation of unserved energy

This appendix provides more detail on how unserved energy has been estimated as part of this RIT-T.

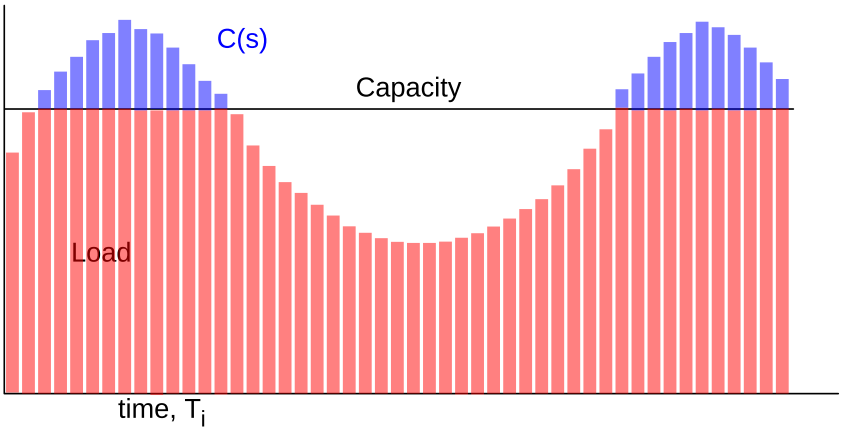
Unserved energy calculation

Unserved energy has been calculated by tallying selected critical system states that resulted in the inability of the network to service the load. This calculation has been done for half hourly load intervals during a financial year, then scaled by the medium POE 50 maximum demand forecast to evaluate future load.

For each system state, the unserved energy has been determined based on the network topology, equipment availability, load level and system capacity.

The figure below shows a simplified illustration of how unserved energy has been calculated.

Figure A.1 Illustrative figure of how unserved energy is calculated



The probability of residing in each state is calculated from the unavailability of each component. Therefore, the probability of residing in each state is given by the equation below.

$$P(s) = \prod_{i=1}^{N_d} PF_i \prod_{i=1}^{N-N_d} (1 - PF_i)$$

Where:

N	is the total number of components
N_d	is the number of failed components
PF_i	is the unavailability of the ith component

The total annual expected unserved energy for each year is calculated by weighting each system state load curtailment by the probability of residing in that state and the duration of the load level. The expected unserved energy is given by equation below.

$$EUE = \sum_{i=1}^{NL} \left(\sum_{s \in F_i} P(s) \cdot C(s) \right) \cdot T_i$$

Where:

NL	is the number of load levels
F_i	is the set of all system states with load curtailment
T_i	is the time length of the ith load level

Transmission Corridor Capacity

The transmission corridor capacity is intended to be calculated such that, in the event of coincident outages beyond (n-1), pre-contingent load shedding would not be employed to satisfy NER requirements of operating in a secure operating state[41]. Instead a secure state would be achieved by developing contingency plans that required manual interventions to manage overloads, and return the system to a secure operating state (for the next most critical contingency). This is similar to the current practice which allows cyclic load shedding (outside Sydney CBD) for short periods of time following a simultaneous outage of a single 330 kV cable and any 132 kV transmission feeder or 330/132 kV transformer, in Inner Sydney, until corrective switching is carried out.

This assumption is to maximise the utilisation of the existing network and reduce the likelihood of investing prematurely. It should be noted that advice from Ausgrid's operations staff is that this situation has not occurred in practice and is therefore untested. It has always been possible to maintain a secure operating state without pre-contingent load shedding or the need to rely on contingency plans with manual interventions.

Asset Unavailability

A specific unavailability (expressed as percentage time per year) has been applied for each cable considered in the capacity analysis. This has been based on the outage duration multiplied by frequency, observed from historical cable failures. The contingency states applied will be tested across a range of coincident conditions, ranging from (n-1) to (n-4). The compounded probabilities of most multiple element outages (n-4) and greater have been found to produce negligibly small expected unserved energy, and hence will be excluded. The equations used were:

$$f = L\lambda(t_2^{\eta} - t_1^{\eta})$$

where:

f	is the frequency of failures (i.e. also commonly known as the outage rate)
L	is the length of the cable segment
t_1	is the age of the cable segment at the start of the year (years)
t_2	is the age of the cable segment at the end of the year (years)
η	is a scale parameter
λ	is a scale parameter

$$U = \frac{f * MTTR}{365}$$

where:

U	is the cable unavailability
$MTTR$	is the mean time to repair (days/repair)

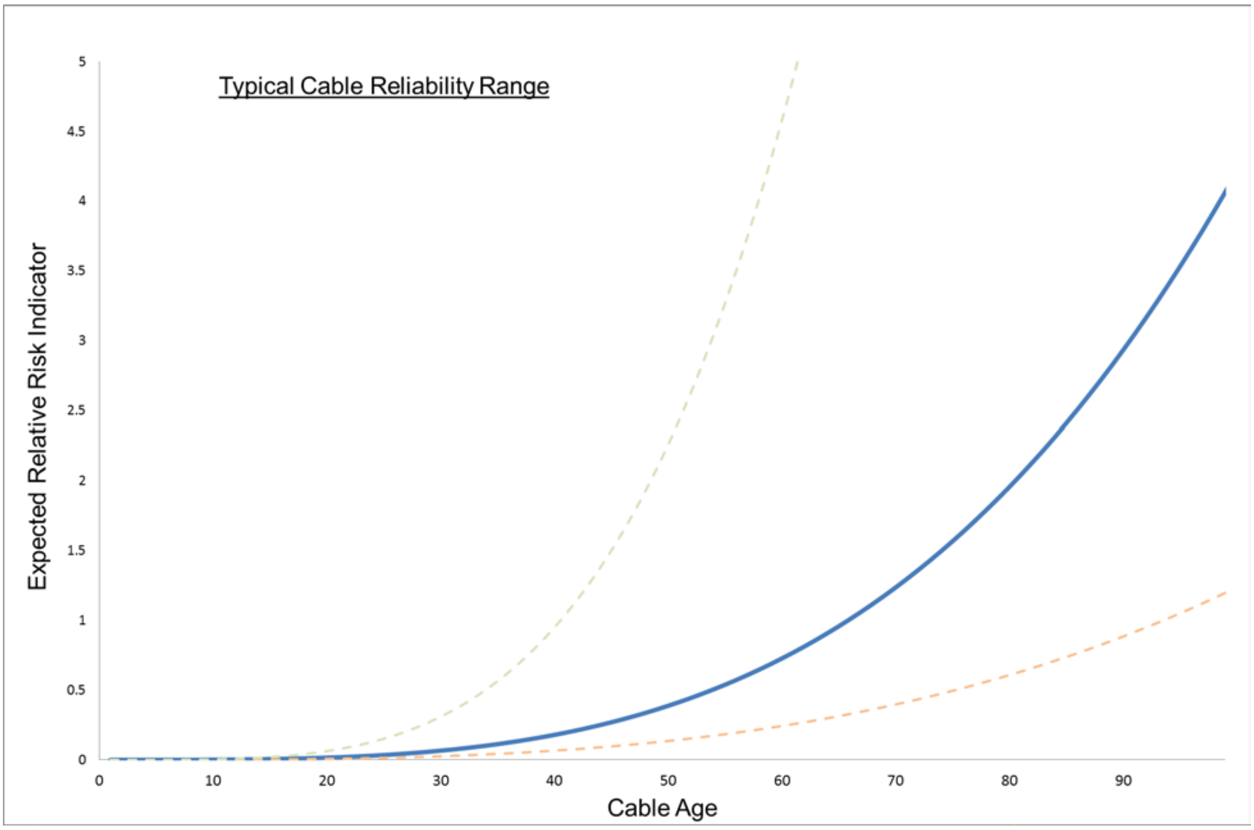
A.4 Reliability and increasing cost of aging oil-filled cables

This appendix has been included to provide additional detail on the reliability of oil-filled cables as they age, as well as why the cost involved with servicing these cables is considered to be significantly greater than modern cables.

Deteriorating oil-filled cables are less reliable over time

It is understood that oil-filled cables buried in the ground exhibit age related degradation leading to an increase in the probability of failure over their lifetime. The expected failure rate (per km) of a typically oil-filled cable over its lifetime, based on an assessment of Ausgrid's oil-filled cable population is illustrated in the figure below.

Figure A.2 Typical projected failure rate of an oil-filled cable over its useful life



The figure above shows a sharp increase in the projected failure rate of oil-filled cables. Given Ausgrid and TransGrid have a large proportion of cables over 40 years of age, without intervention the projected failure rates across the population of all oil cables is considered to be sharply increasing. The cables planned for replacement by Ausgrid represent some of the worst performing on the network and therefore have a worse failure rate than the typical projected model shown above.

With large recovery times and lack of ongoing support (i.e. parts and skills) coupled with the increased failure rate, the unavailability of these cables into the future poses a significant risk.

Increased cost associated with continuing to use oil-filled cables

The cost of continuing to use oil-filled cables are expected to be greater than alternatives for three main reasons, which are outlined in the subsections below. Avoiding all of these costs contribute to the benefits of retiring deteriorating oil-filled cables.

Oil-filled cables have significantly longer repair times than for modern cables

The average repair time for oil-filled cables is significantly longer than for cross-linked polyethylene (XLPE) or paper insulated lead covered cables.

When a repair commences on an oil-filled cable, the cable cannot be returned to service until it has been fully completed, oil has been pumped back into the cable and the cable has been electrically tested. This ‘unavailability’ of the cable means that the electricity supply has to be diverted to an alternative route which can place additional electrical stress on adjoining cable(s) due to increased loading, particularly where these cables are of a similar vintage and pose a similar risk.

The additional stress may cause long term damage to the adjoining cable which reduces its remaining service life or may cause it to fail as well (a ‘coincident event’). The unavailability of a failed cable may also be exacerbated because other planned outages required for maintenance, repair or replacement work must be cancelled until repairs are completed on the failed cable.

Oil-filled cables pose a greater environmental risk

Oil-filled cables that leak pose a risk to the environment and in particular in relation to pollution of water and land. The Environmental Protection Agency (EPA) of NSW has expressed concern about Ausgrid’s oil-filled cables and the long period of which they will remain in service before they are retired.

Oil-filled cables are difficult to physically access (and are expected to be more difficult going forward)

The physical location of these cables and their associated access pits can lead to restricted access to undertake work. A number of these feeders are located under major roadways in the Sydney area where access is extremely restricted. As a result of road access restrictions, sections of some of these feeders have become unmaintainable resulting in large maintenance backlogs.

Any major repair work would have major impacts on these traffic routes for several weeks, particularly for joints failures or cable damage by external parties which required construction of a new joint bay. Given Sydney’s increasing population and associated increasing traffic levels, road access restrictions for cable works is expected to worsen over time.

Oil-filled cable spare parts and relevant expertise are scarce

Generally, the electricity industry worldwide has moved away from the installation of oil-filled cable technology with the preferred option now being XLPE cable for the last 10-20 years or more. This is partly due to the lower manufacturing costs, reduced environmental risks and lower levels of auxiliary systems required for XLPE cable systems.[42] Manufacturers have moved away from making or supporting the oil-filled cable technology, including jointing kits and this has also been a driver for the electricity industry to move towards XLPE cable technology.

Ausgrid holds some spare 132 kV oil-filled cables to match existing cable types if they fail or are damaged by external parties, as this cable will not be available from manufacturers in the short time frames that are needed to repair a cable and return it to service. If Ausgrid was to replenish the emergency spare cable following its use, the availability of the exact replacement cable is becoming more difficult and / or expensive to source as manufacturers no longer make the cable, or are unwilling to make the cable. TransGrid also holds strategic spares for each of its 330 kV cables.

Jointing kits are also held as emergency spares but not for every cable type. Jointing kits are made to exacting requirements, to ensure the integrity of electrical insulation coverage within the joint and also to ensure oil containment. When a jointing kit is required that is not held as an emergency spare, it is manufactured by a cable supplier or other specialist provider as a ‘one off’ and usually at a premium cost. Some jointing kits can cost over $250,000 per joint to manufacture this way.

The ability to support this cable technology into the future is also becoming more challenging in terms of maintaining engineering expertise and trade skills. As cable manufacturers are already no longer supporting oil-filled cable technology, their ability and willingness to provide engineering expertise has decreased. Experienced transmission cable jointers and oil technicians are also difficult to locate and attract.

[42] For example, they do not require pressure alarms systems or oil / gas reservoirs.

Appendix B – Cable 41 Investigation Summary Report

TransGrid

Cable 41 Investigation Summary Report

1. Executive Summary

Cable 41 was commissioned in 1979. At the time it was the longest 330 kV underground cable in the Southern Hemisphere at just under 20 km.

This report summarises the historical condition assessments and remedial actions taken on the cable system. The condition assessments considered the power cable, joints, accessories, bridges, thermal backfill and bedding materials, installation and operating conditions that may impact on the future reliability, capability and operation of the cable system.

The actual installation and operating conditions now identified on Cable 41 are far different to the conditions on which the cable was designed.

The signs of a shorter than expected service life of Cable 41 is the direct result of the deterioration of the thermal backfill and bedding material (sand/cement) due to the leaching of cement from the bedding mixture. It is now apparent that the trench materials in their current state have a shorter lifespan than anticipated at the design stage.

In addition to the backfill issues, temperature data from the Cable 42 Condition Monitoring System (CMS), which follows a similar route, indicates that ambient ground temperatures are higher than the design assumptions.

Given these installation conditions, in December 2011 it was decided to reduce the summer cyclic rating to 575 MVA (down from 663 MVA). There were uncertainties with the 575 MVA value, subjected to annual review based on rainfall patterns. Further derating could have been required if there were long periods without rain. This uncertainty is unacceptable from a planning perspective.

The need for transmission augmentation is highly dependent on the long term rating and condition (proposed retirement date) of Cable 41. Following a comprehensive sampling regime of the material above the cable protective slabs and native soil at 29 sites in 2016, the cable was derated to a summer cyclic rating of 426 MVA in August 2016. This rating assumed a minimal level of moisture that could reasonably be expected (not fully dried out), so no further derating would be required during long dry periods. A further study in September 2016 determined the 6-hour emergency rating to be 564 MVA.

The cable system was designed around the assumption of a 25°C summer ground temperature, low thermal resistivity (TR) sand/cement backfill, and a specific native ground thermal resistivity (TR). Ground temperatures measured by the more recently installed Cable 42 Condition Monitoring System (CMS), which follows a similar route to Cable 41, were found to be much higher the 25°C assumption. Some areas of Cable 42 have 36°C peak ground temperatures. Previous opportune sampling found that the fully dried out thermal resistivity of backfill and bedding at various locations along the cable route were found to be significantly higher than the design assumptions.

A Cable 41 condition assessment project, to determine the condition of the cable insulation, is currently in progress and the findings will determine the residual service life of the cable and may influence the credible options currently under consideration for cable 41.

This report includes credible options for cable 41, which include remediation of backfill to recover some rating, continue 330kV operation at reduced rating, conversion to 132kV operation or retirement. Other factors impacting cable life are also noted in this report.

2. Background

Cable 41 was delivered under contract 2609, awarded to Mitsui Australia in February 1977 by The Electricity Commission of NSW (EC NSW). The cable was commissioned in 1979. The contracted cable ratings were as follows:

- Continuous
  - Summer 600 MVA
  - Winter 700 MVA
- Cyclic
  - Summer 663 MVA
  - Winter 718 MVA

The design assumptions are shown in Table 1

Original design parameters	Original Design Values
Maximum ground temperature - summer	25°C
Maximum ground temperature - winter	10°C
Mean soil temperature@ standard burial depth (900mm)	18°C
Maximum air temperature	40°C
Minimum air temperature	-5°C
Maximum air temperature over 24 hours	35°C
Thermal Resistivity - native soil	1.2 Km/W
Thermal Resistivity – trench bedding	1.2 Km/W
Thermal Resistivity – trench backfill	1.2 Km/W

Table 1: Cable 41 design assumptions

The maximum allowable operating conductor temperature of paper insulated self-contained fluid filled (SCFF) paper cables is 85°C. The conductor size of Cable 41 is a uniform 1200mm² copper conductor.

The conductor operational temperature for any given rating is governed by several factors:

- Ground temperature
- Thermal Resistivity (TR) of materials
- Cable spacing
- Burial depth
- Cable losses (including losses introduced by circulating sheath currents)

The ground temperature and Thermal Resistivity (TR) of material were provided by the EC NSW, see Table 1. The cable conductor size, spacing and losses were calculated by the manufacturer based on the environmental data supplied by the EC of NSW.

A native soil TR survey was not completed as part of the design process.

2.1 Design Departures - Temperature

The design of Cable 41 allowed for a maximum summer ground temperature of 25°C. Cable 42, commissioned in 2004, used the same assumption. However Cable 42 has a Condition Monitoring System (CMS) which includes an optical fibre[1] Distributed Temperature System. After an extended December outage, the CMS identified ground temperatures as high as 36°C. The highest temperatures recorded were in sections where the cable was laid under asphalt in the centre of the road. The December temperature range over the entire route is shown in Figure 1.

[1] Optical fibre cable is attached to the centre phase cable

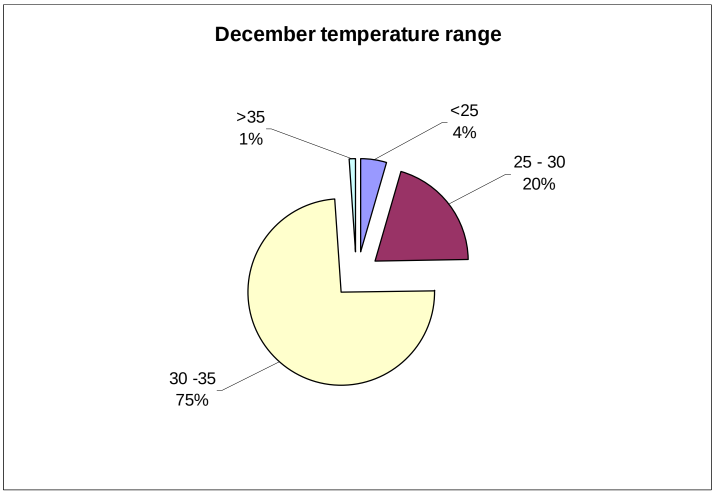


Figure 1: Cable 42 Ground Temperature Range (December 2006)

2.2 Design Departures - Backfill

2.2.1 30 Year Condition Report

A 30 Year Condition report was written by the Asset Manager in 2010. It was reviewed by cable experts Dr George Anders and Mr Harry Orton in 2011.

Before the comprehensive sampling in 2016, several samples of cable backfill have been taken along the cable route over the past 15 years for Thermal Resistivity (TR) tests. Generally samples were taken on an opportune basis (such as the installation of a service crossing or defect investigations). These samples showed that the fully-dried out TR was considerably higher than design on most samples. In many cases the sand/cement material had deteriorated to such an extent that there was little or no cement left in the backfill mixture. Whilst the in-situ TR results varied from 0.58 to 1.1 Km/W, when fully dried the range became 1.92 to 3.73 Km/W.

Due to the safety and operational requirement to take the cable circuit out-of-service when working below the cable protective slabs, most data available was for the backfill (above the cable protective slabs). Two results of the bedding mix (below the cable protective slabs) were available from works at Arncliffe Street (refer section 2.4). The TR of the bedding material was tested at 2.88Km/W. Material from the incident in 2005 was also tested and showed a fully dried out TR of 3.3 Km/W. In one sample the sand / cement ratio was 65:1.

Clearly the cable system would be unable to support rated load during times of low moisture. Calculations at the time revealed that if the backfill and surrounding bedding mix were fully dried out the resultant rating would be 223 MVA, approximately equivalent to the charging current. However, this is an unlikely situation. There will generally be varying degrees of moisture, at least in the native soil. This was confirmed by Canadian cable expert Dr George Anders, commissioned to review TransGrid's Cable 41 30 year condition report (2009). Dr George Anders conducted a finite element method (FEM) study using a more realistic situation which assumed a fully dried out backfill and bedding mix within the 50°C isotherm and material with moisture outside. FEM is more accurate than IEC rating calculations, which uses an analytical method involving several approximations resulting in conservative (lower) ratings. This is how the new 575 MVA summer normal cyclic rating was determined. It assumed a 3 Km/W within the isotherm and 1 Km/W outside, aligning with previous results.

The new rating was implemented following the above investigations and conclusions with an Internal Memorandum from the Manager/ Asset Performance signed by EGM/NP&P on 13th December 2011. This document noted that the Cable 41 (C41) rating was to be reviewed on an ongoing basis due to the ground moisture assumption. Reviews since this direction have kept the rating as unchanged.

Sudden changes in rating are unacceptable for adequately managing the supply risks. In order to provide rating certainty that could be used on an ongoing basis, TransGrid initiated a project entitled 'Need 1096' was raised for "Cable 41 Thermal Model". This project had several iterations, the final of which involved a comprehensive (29 locations) backfill and native soil testing regime, conducted in early 2016.

2.2.2 Determining backfill replacement option suitability

In order to determine if replacement of backfill above the cable protective slabs was an option worth considering, TransGrid commissioned JPower, now Sumitomo, to conduct FEM analysis for the cable with good backfill. The results determined that assuming a 36°C ambient soil temperature; TR between 2 to 3 Km/W; bedding between 2.88 to 3.3 Km/W and the original rating of 600 MVA continuous would correspond to 88 and 96.4°C conductor temperature. This would be utilising the emergency capacity of the insulation, with the 96.4°C being outside emergency capacity.

The System Planning group advised that having a near original nominal rating as a long time contingency rating would be worth considering.

The latest desktop assessment determined that replacement of the backfill above the cable protective slabs only would cost $127M (unescalated 2016/17 dollars).. This cost is considerable. As the cable is approaching its nominated 40 year economic life, the condition of the cable insulation must be confirmed as acceptable if it is to provide value for money. Sumitomo were engaged to provide a "Testing Proposal". The proposal outlines tests that would be conducted on a length of cable and a cable joint for the purposes of evaluating deterioration and determining remaining life. They were directed to provide a scope for sampling at three shortlisted locations, chosen on the basis for ease of sampling. Sumitomo concluded:

> *The inspection, testing and analysis of samples of cable and a joint, actually taken from C41 after decades of service, is definitely one of the most valid ways to make a true assessment of the cable's present condition and, hence, to estimate its remaining life. However, if the sample location is not representative of the worst conditions along the route, wrong conclusions may be easily drawn.*
>
> *If the proposed sampling and testing of C41 proceeds, the findings would still only valid (sic) for the sampled location. Subjective judgement must still be made as to how the findings are likely to compare with the still-unknown "actual" worst case. Despite this, any findings of serious deterioration would provide a valid conclusion that the cable's life is limited. However, if no serious deterioration is found, the cable's remaining life will remain uncertain because it will still be possible that worst deterioration exists elsewhere along the route.*

2.2.3 2016 Backfill and Soil Investigations

A comprehensive regime of taking backfill samples for TR commenced and was completed in early 2016. Cable expert Dr George Anders was engaged to use these results to provide a reasonably worst case rating. The sampling regime covered backfill and native soil sampling at 29 location along the route. At each location samples were taken in the following positions:

- Above the cable protective slabs
- Native soil next to the trench
- Native soil in the verge

There were no samples taken of the bedding mix around the cables as this would require working below the cable protective slabs. Outages would be required on Cable 41 to provide a safe work environment and significantly larger excavations in order to remove the 1000 mm long cable protective slabs to obtain access to the cable bedding mix).Typical cable arrangement is shown in Figure 2.

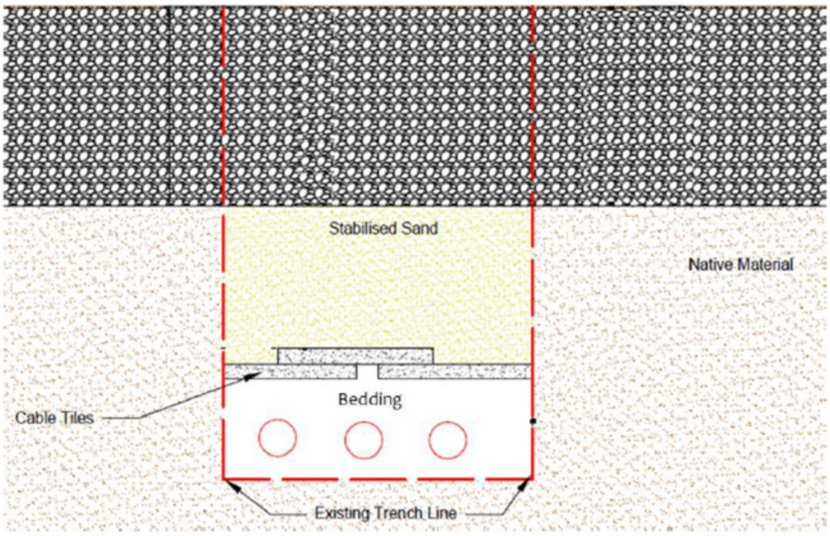


Figure 2: Typical Cable Arrangement

Dr George Anders was then engaged to provide a revised rating that could be used regardless of rainfall and weather patterns using the 2016 test results and other relevant information such as:

- Summer and winter load cycles
- Ground and air temperature readings from the Cable 42 Distributed System
- CSIRO Moisture data
- Previous condition reports on Cable 41.

Backfill Sampling Summary:

The TR ranges of existing samples are as follows:

	In Situ TR (Km/W)	TR at assumed minimum moisture[2] (Km/W)	Fully Dried (Km/W)	Dry Density	Fully Dried TR Design Assumption (Km/W)
Cable Bedding	Not Sampled	Not Sampled, 2.88 assumed	Not Sampled, 2.88 assumed	Not Sampled	1.05
Cable Backfill	0.35 – 1.90	0.75 – 3.00	1.08 – 3.78	1.38 – 1.98	1.2
Native beside trench	0.30 – 1.04	0.30 – 2.00	0.64 – 2.68	1.33 – 1.92	1.2
Native in verge	0.30 – 0.90	0.45 – 1.80	0.50 – 2.11	1.55 – 1.98	1.2

Table 2: 2016 Backfill and soil analysis summary

It can be seen in Table 2 that the TR is significantly higher than the assumptions made in the Cable 41 design. These issues are widespread. Only three of the 29 sites sampled had backfill TR at assumed moisture less than the fully dried out design assumptions. The low dry density values indicate that the compaction of the backfill is poor and highly porous. As the backfill dries and moisture leaves these pores, the remaining air (TR ~35 Km/W) causes that material to have a very high TR. This is displayed in the TR moisture relationship example shown in Figure 3.

It should be noted that the samples were conducted after a relatively wet period, which would result in lower in-situ readings.

[2] For sandy backfill 2% moisture was assumed, for clay soil 5% and 3-4% for sand/clay or stone/clay. Sandy material has a higher porosity.

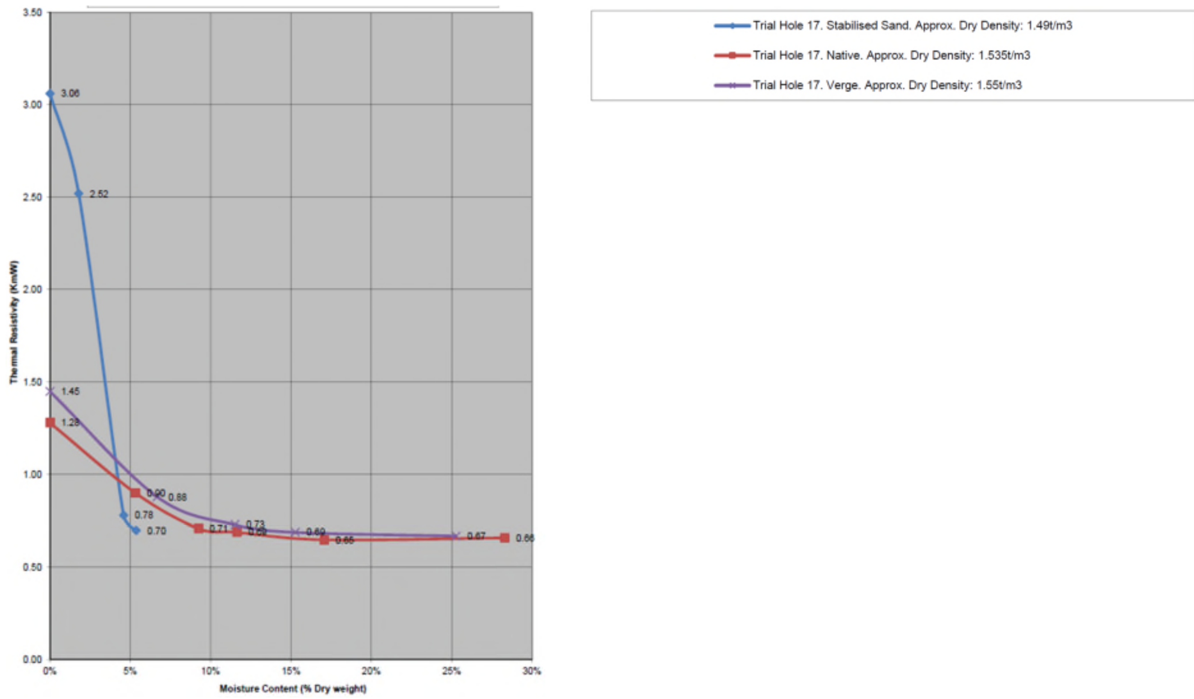


Figure 3: TR – Moisture Curve

Rating Determination:

As mentioned previously, using fully dried out values in rating calculations would result in a very low rating that would render the circuit unusable. A minimal moisture content, dependant on the type of material was chosen. Using the curves TR at the chosen moisture was interpolated. The chosen minimal moisture values were as follows:

- 2% - Sandy backfills and sandy soils
- 5% - Clay soils
- 3-4% - for mixtures if sand and clay or stone and clay
- 1% at one location where material was poorly compacted.

This is similar to Ausgrid's assumptions:

- 3% Native soil
- 3% Sand backfill

For the material below the slabs TR of 2.88 Km/W was assumed. This corresponds to a fully dried out value sampled on a previous occasion. Higher readings have been recorded previously for material (up to 3.3 K.m/W), so cannot be considered overly conservative. TR curves are not available to allow a minimal moisture assumption (only fully dried value available). It is also consistent with several fully dried sand/cement samples above the cable protective slabs, however, the material below the slabs has a different original design to the backfill above the slabs (14:1 sand cement as opposed to 20:1), so a direct comparison cannot be made.

The worst location was found to be "Site 16", which is on Forest Rd, close to the Bonds Rd intersection. These vales at this location are shown in Table 3.

	In Situ TR (Km/W)	Fully Dried (Km/W)	Assumed moisture content	TR at assumed minimum moisture (Km/W)
Cable Bedding	Not Sampled	Not Sampled, 2.88 assumed	0%	Not Sampled, 2.88 assumed
Cable Backfill	0.85	3.5	2%	2.2
Native Soil	0.68	2.5	5%	1.8

Table 3: 2016 Backfill and soil analysis summary at "Site 16"

The final report and design advice note that the cable requires derating to **426 MVA** summer normal cyclic. The winter normal cyclic rating is **492 MVA.** These are peak values of "normal" cyclic ratings where the cable's conductor does not exceed its rated operating temperature (85°C). The load cycle is as per TransGrid's operating manual, which generally follow the actual load duration curve. Further rating information is discussed in section 3.4.

Sensitivity Analysis:

The sensitivity analysis performed by Dr George Anders showed that small changes in ground conditions can have significant impact in cable ratings. Dr Ander's report notes that for every 0.1 K.m/W change in TR of the cable bedding, which was not measured during the 2016 sampling, makes a difference of 4 MVA to 6 MVA (TR values between 2 and 4). This places significant impact on the 2.88 K.m/W bedding assumption. With regard to ambient ground temperature, a 1°C change in temperature rise has an impact of approximately 8 MVA.

Emergency Ratings Analysis:

Emergency ratings were not determined in the main Dr George Anders report of May 2016. When specifying the future ratings Management advised that no over temperature capacity would be considered. In September 2016 Dr George Anders was re-engaged to define emergency ratings.

From the Dr George Anders September 2016 report calculations, TransGrid has implemented allowable emergency ratings in Operating Manual *OM 304*.

The long-time contingency ratings (95°C Conductor Temperature) were determined are as follows:

- Summer Emergency cyclic: 499 MVA
- Winter Emergency cyclic: 551 MVA

Short term ratings are to be used with caution. The rating calculations assume the steady state load cycle for the prior loading.Running the cable at conductor temperatures between 85°C and 95°C will cause accelerated aging of the paper insulation.

2.2.4 2016 Cable and Joint Sampling

Works are currently underway to take a Cable 41 and joint sample near the identified most constrained location. A suite of inspections and tests will be conducted with the intention of identifying the extent of insulation deterioration and hence give an indication of the Cable 41 remaining life.

Initial works at this location have shown that the bedding material around the slabs to be quite varied. In some locations it was quite soft, indicating loss of cement, yet a few metres further on the bedding was so hard high pressure water blasting failed to break up the bedding, requiring the use of electrical hammer drills significantly increasing the risk of damage to the Cable 41 outer sheath, jeopardising the integrity of the cable. The fully dried laboratory TR results are not yet available but the non-porous nature of such a material would indicate favourable results.

Site 16 is at the top of the oil profile, so on average would be expected to have lower levels of moisture, hence higher TR, than locations closer to sea level.

2.3 Thermal Runaway and Backfill Dry-out

Thermal runaway in cables is a situation where an increase in temperature causes a change in the insulation; this degradation causes greater insulation losses which in turn cause an increase in temperature. This positive feedback of accelerated increase in temperature leads to insulation failure.

The Auckland power crisis in 1998 is an example of how thermal runaway can impact on a cable network. Auckland suffered a 5-week long outage to the CBD. At the time, almost all of downtown Auckland was supplied via four 110 kV power cables. Two cables were 40-year-old gas-insulated cables that were past their replacement date. One of these cables failed in January, possibly due to the unusually hot and dry conditions. The second gas cable failed 20 days later, leaving only the two remaining cables supplying the city. Due to the increased load from the failure of the first cables, these remaining two cables failed after 10 days.

In the five weeks it took to restore the power supply, about 60,000 of the 74,000 people who worked in the area worked from home or from relocated offices in the suburbs. Some businesses relocated staff to other New Zealand cities, or even to Australia. The majority of the 6,000 apartment dwellers in the area had to find alternative accommodation.

The old gas cables were found to be repairable and were put back into service, but were restricted to 30 MVA capacity. The newer oil cables were irreparable, so to restore full supply to the city, a temporary 110 kV overhead line was constructed along a rail corridor until a new power cable circuit could be built.

The equivalent scenario in Sydney would be catastrophic. Any interruption will affect essential services such as gas, water, telecommunications, hospitals, and transportation by impacting road and traffic control, major road tunnels, Sydney railways, Sydney Airport, Port Botany and institutions of economic importance such as the ASX. There are around 440,000 electricity customers in the Inner Sydney area who consume about 11 per cent of New South Wales' annual electricity use. TransGrid would be unable to use a temporary overhead option as per Auckland.

The future widespread damage of Cable 41 due to thermal runaway is not considered credible due to the derating measures. The new ratings are chosen on the basis of backfill with a minimal amount of moisture.

TransGrid does however store spares to cater for a thermal runaway event over a hotspot. There are usually inadequately deigned (or improperly installed) service crossings. This is a credible situation and has occurred on the Ausgrid network.

Thermal runaway is the major cause of cable failure worldwide, after third party damage and accessory failure.

2.4 Major Incidents

There have been 3 locations where major incidents have occurred involving Cable 41, since commissioning in 1979.

Burrows Road Beaconsfield

- 1992 – Blue phase of joint-bay 40/41 failed due to core movement. Joint replaced and movement sensors installed on all 3 phases.
- 1993-1995 - Joint movement detected by sensors in each of the joints. Special joints, with allowance for core movement, designed and manufactured by Sumitomo Electric Industries
- 1996 - Additional joint-bays 40/41A and 40/40C added, special joints installed and new sections of cable installed with snaking to prevent core movement. Hall Effect sensors were installed to monitor core movement.
- 2010-2012 – Core movement detected in red and white phase joint in JB39/40 (via Hall Effect sensors). This joint had a 50mm movement allowance which had been exhausted. The joint was X-rayed to confirm core movement. The joint was replaced in 2012 with a "conductor clamping" joint. The detection of movement initiated oil sampling in JB38/39 one joint up in Canal Rd, where concerning results were found. This is described below.

Canal Road Beaconsfield

- 2011-2012 – Joint bay 38/39 in Canal Road was x-rayed in conjunction with the 1990's Burrows Rd works. No movement was detected. Oil lines were retrofitted for monitoring. Sampling was eventually abandoned when no changes were noted in the oil samples. When core movement was detected in Burrows Rd a sample was taken which showed detectable acetylene in white phase. The joint X-rayed and movement confirmed. This joint has zero core movement allowance. The joint was replaced in 2012 with a "conductor clamping joint" during the same outage as the Burrows Rd joint.

Tempe Bridge Arncliffe

- 1998 – Tempe cable bridge subsided during construction of the East Hills to Sydney Airport rail tunnel. This led to severe concerns at the time that the bridge would fail. Extensive remedial works were carried out to support and protect the cables. Approximately 50-100m of cable trench was excavated and existing thermal bedding material replaced with new material

Arncliffe Street - Arncliffe

- 2003 – Road subsidence due to water-main leak. Cable supported and trench reinstated with new bedding material.
- 2005 - Road subsidence, between Guess Ave and Lusty Street, due to undermining of road during the installation of a sewer main. The red and blue phase joints at joint-bay 31/32 were replaced with special joints. Movement sensors were installed on all three phases.

2.5 Loading History and Possible Thermal Stresses

Cable 41 has been operated since commissioning within the design limits and load curves advised by the cable manufacturer.

The loading on Cable 41 reached a peak in 2000. Consequently data later than 2005 has been disregarded. The load distribution curves in Figure 4 show that the time duration of loading above 600 MVA increased from 0.09% in 1993 to 10% in 2000.

As most of the severe loading occurred in peak summer this would have corresponded with the maximum soil temperature and maximum ground TR conditions. These combined events would have contributed to the gradual breakdown of the sand to cement bonds and the resulting increase in TR values. Under these conditions the cable conductor temperature would exceed the design temperatures leading to a gradual reduction in the electrical strength of the paper insulation.

The logarithmic scale shows that a 50 MVA change in ampacity makes a significant difference in terms of expected cable overload. Dr George Anders advised that an additional 50 MVA could be achieved simply by 3°C temperature and 0.5 K.m/W change. The result would be a ten-fold reduction of time the cable is exceeding this rating greatly impacting the expected aging of the insulation. This highlights the uncertainties and issues in determining whether the cable has been operated above its rated temperature.

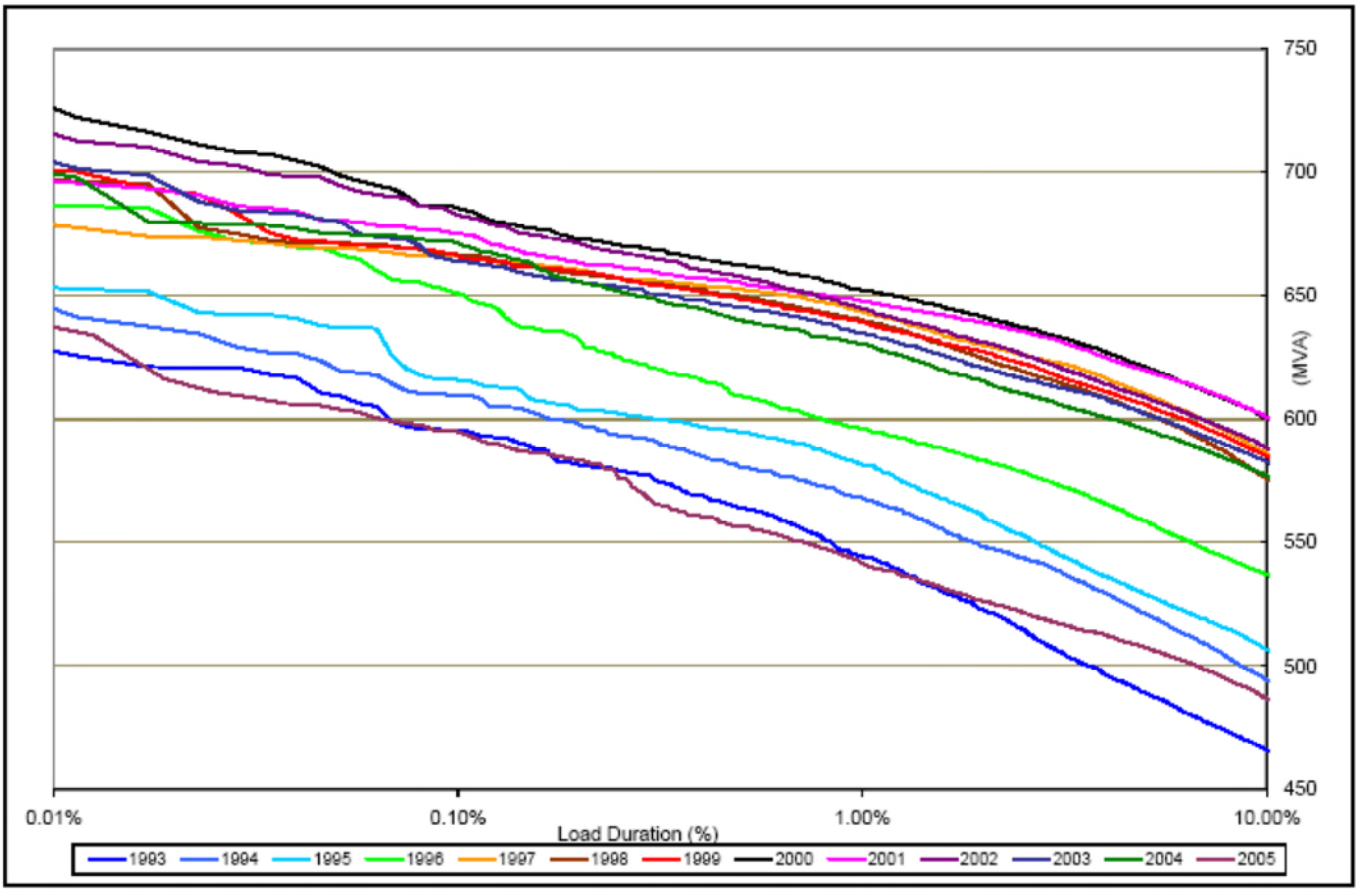


Figure 4 Cable 41 Load Distribution prior to Cable 42

3. Maintenance and Operations

3.1 Oil Cable Maintenance Requirements

In addition to the standard sheath insulation resistance and route/security patrols, which would be present on all cables, the oil system on Cable 41 requires the following maintenance tasks.

C41 Alarm and accuracy tests

Gauges drift over time and this task checks that the gauges are indicating correctly and the alarms are operating at the required set-points.

C41 Gauge reading

Before the online oil system was installed, gauges were read on a monthly basis. The purpose of this is for early notification of an oil leak. If the cable was to drop to the L1 alarm (first level) before action was taken a significant amount of oil could have already escaped. With the online monitoring now in place this is now completed on a six-monthly basis at the same time as the alarm and accuracy checks.

C41 Fluid Samples

Oil samples are taken on an annual basis for dissolved gas analysis. Oil sampling locations are at stop and feed joints, terminations (sealing ends) and joint bays 38/39 and 39/40 which had oil sample lines installed after core movement issues. In total there are 12 sets of 3 samples; Associated with the oil sampling is oil pumping to replace removed oil.

Oil sampling provides a form of condition monitoring of accessories and surrounding cable. Oil sampling successfully picked up the core movement issue in Canal Road in 2011. This joint would have failed under the same failure mode as the 1992 failure.

Oil Leak Maintenance (Non routine)

The Cable 41 oil system has only experienced a handful of minor oil leaks over the cable lifetime. This is due to the superior joint design of Cable 41 compared to the Ausgrid 132kV oil cable design.

Currently there are no detectable oil leaks. In the last 7 years we had one oil leak on Hydraulic section 1 of Cable 41. It was leaking at a rate of 1 litre per week. This was repaired in October 2011. As part of sheath fault investigations an oil leak was found on stop joint 10/11. This leak was so small it was not detected. This was repaired in Oct 2010. There is a currently a sheath fault in joint bay 5/6. There has been no detectable loss of oil. It is possible it is a small leak from the “impregnation nipple” into the surrounding coffin (which is filled with a bituminous compound). This fault investigation/repair has been deferred due to the sampling works on Forest Road.

Outer Sheath Test

The outer sheath test or “Sheath IR” is not unique to oil cables, however on Cable 41 this is completed on an annual basis. On TransGrid’s newer 330kV XLPE Cables 43/44 the Sheath IR tests are carried out once every three years. The reason for the increased frequency is due to the criticality of the Cable 41 and reduced protection (direct buried rather than ductbank). This Sheath IR test is required to identify damage due to external interference that may not be prevented by route patrols and works standby. Damage to the cable may not immediately cause a trip or oil leak, however the uneven electric field distribution within the damaged cable can eventually cause insulation failure, resulting in a forced (unplanned) outage of Cable 41 putting the Inner Sydney electricity supply at risk. In March 2009 an Ausgrid cable failed due to previous damage that deformed, but did not puncture the metallic sheath. Whist the protection correctly tripped this cable, mal-operation of other protections at the same time caused a widespread CBD outage[3].

[3] Sydney CBD Supply Interruptions – 30 March, 4 April and 28 April 2009 – Energy Australia Final report - May 2009.

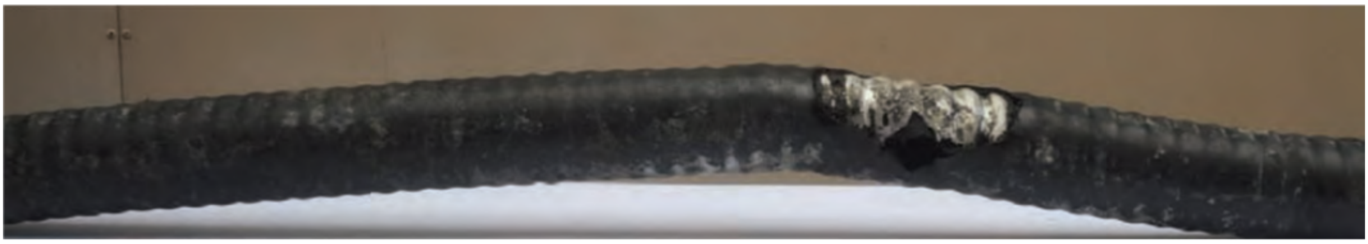


Figure 5: Ausgrid Cable 919 – Failed March 2009

3.2 Cable 41 Other Condition Issues

3.2.1 Core Movement

As described in section 2.4, there have been two incidents of core movement, the first one causing a forced outage the second picked up via monitoring allowing intervening action. Only the joints in Arncliffe St and Canal / Burrows Rd have Hall Effect sensors. Joint bay 38/39 and 39/40 at Canal and Burrows Rd are the only non-stop/feed joint with oil monitoring. There is oil monitoring at stop/feed joints, but these would not be subject to core movement.

The amount of core movement that may have taken place at the other 31 joint locations is unknown and poses a risk of forced outage. Installing Hall Effect sensors and/or retrofitting oil sample lines at these locations would take many years. Outages of Cable 41 are only available in spring and autumn, so only a couple of locations can be actioned at a time. It would also be very disruptive to the community given the majority of the line is in major roads. Significant increases to the OPEX budget would also be required to perform the additional sensor readings or oil sampling.

3.2.2 Dissolved Gas Analysis

Oil can only be removed for sampling at the stop and feed joints and terminations as this is where the sampling points are located. This limits its use for condition of the accessory and the surrounding cable rather than the whole cable length. Two normal joints bays have oil sample lines retrofitted; sampling from one of these locations highlighted the need for TransGrid to take preventative action against core movement failure.

The production of Carbon Monoxide (CO) is a direct result of degradation of cellulose based material (i.e. Kraft paper within Cable 41). Its rate of increase is temperature dependant. Therefore, increases in CO and the corresponding reduction in the CO2/CO ratio are considered good indicators of higher temperature of insulation paper.

The chemical bonds of cellulose start to break down at temperatures above 100°C, this leads to paper decay and results in reduced paper strength. Accordingly, the cable design allows for a maximum conductor temperature of 85°C. Tests on HV cables have found that in stable conditions cables can operate satisfactorily with reductions in paper strength of up to 40%.

Various international cable standards[4] suggest that low CO2/CO ratios, lower than 3, as being of some concern. New cables typically have a ratio of greater than 8. Whilst sections of Cable 41 have CO2/CO ratios as low as 0.5, this should not be of a concern as the absolute values for each gas is low. The highest CO level detected in 2015 was 57ppm. The Anders/Orton commentary on the TransGrid 30 year condition review indicated that TransGrid should not be considering applying the CO/CO2 ratio until CO reached a minimum of 200ppm.

Combustible gases are used for indication of heating or electrical discharge. Oil Sections 3 and 4 have high hydrogen indicating overheating of oil. The levels of hydrogen are steadily increasing over time on all phases of the Section 4 side of JB21/22.

There is some detectable, but stable, acetylene at JB13/14 red phase. High levels of hydrogen are also present. Whilst not overly concerning this joint will be examined as part of the Forest Road sampling works. Anders/Orton commentary noted that a high resistance connector will result in high temperatures

[4] CIGRE WG 21.05 "Diagnostic methods for HV Paper Cables and Accessories"

of the surrounding papers and fluid and if DGA is carried out in the adjacent port, gases such as methane, ethane, ethylene and carbon monoxide should be detected.

3.2.3 Polychlorinated Biphenyls (PCB)

Polychlorinated biphenyls (PCB) are organic chlorine compounds and were once widely deployed as dielectric and coolant fluids in electrical apparatus. The International Research Agency on Cancer (IRAC), rendered PCBs as definite carcinogens in humans. PCBs do not easily break down or degrade, PCB's biomagnify up the food chain. Whilst not initially supplied with PCB, some parts of Cable 41 have been cross-contaminated by oil handing plant with traces of PCB. Thirty of the 45 oil sampling points have recent oil samples containing non-scheduled PCB (classified as between 2 to 50 ppm PCB). The highest reading is 25 ppm PCB.

PCB's must be considered with any retirement plans. At present the contaminated oil is contained within the cable which is monitored for pressure. Any leaks present themselves as a loss of pressure requiring preventative action. Cable retirement would involve purging and disposal of contaminated oil and applying solder capping. Due to the nature of oil impregnated paper it will not be possible to remove all the oil. Some oil will seep out of the paper over time and be released into the environment in the event of third party damage or solder capping failure. TransGrid would not have any visibility of this event as protection and monitoring systems would not be functional.

3.2.4 Dieldrin Termite Protection

Dieldrin is an organochloride, used as an insecticide against termites. However, it is an extremely, persistent organic pollutant; it does not easily break down. Furthermore, it tends to biomagnify as it is passed along the food chain. According to the Cable 41 contract documentation Dieldrin was specified to be mixed in with the PVC outer sheath. Also Mixed into the 14:1 bedding mix is Aldrin, which oxidises to dieldrin in soil, on plant surfaces, or in the digestive tracts of insects. Aldrin is not toxic to insects; it is oxidized in the insect to form Dieldrin which is the active compound. Low levels (below reporting thresholds) of Dieldrin were detected during the current cable and joint works described in 2.2.4. The impacts and required controls when working with Dieldrin must be considered when evaluating backfill and bedding replacement options.

3.3 Cable 41 Sampling for Condition Assessment

3.3.1 Previous Cable Insulation Samples

As cable insulation samples are a destructive process, very few results are available. Samples were taken from the following locations:

- 1996 – Burrows Rd during joint works – No deterioration detected.
- 2005 – Arncliffe St incident – worst case 10% loss of age.
- 2012 – Canal Rd – No deterioration detected

These results are not considered reliable in determining the general condition of the cable insulation as the hottest spots on the cable will not occur in joint bay areas.

3.3.2 Sampling Works in Progress

In 2014 feasibility studies on three locations to conduct cable sampling were undertaken. The locations were chosen for ease of sampling. Sumitomo noted at the time that sampling is only worthwhile if the cable environment at the sample location is in a poor thermal environment. At the time it was decided to defer any testing until a complete survey could be completed. The backfill survey was completed early-2016.

There are multiple factors to be considered before the viability of Cable 41 backfill replacement can be considered credible. Determining the condition of Cable 41 insulation system is fundamental to determining the future of Cable 41. Apart from the high loads prior to MetroGrid (Cable 42 and Haymarket substation), where the load was above 600 MVA for 10% of the time, there is currently no evidence to suggest that there is widespread deterioration of Cable 41. A small number of paper tests (Degree of Polymerisation (DP)) that have been conducted on Cable 41 show the insulation in very good condition. However these tests were opportune, taken during joint repairs. As cable joint bays are cooler sections of a Cable 41 system these tests could not rule out insulation stress elsewhere.

To determine insulation condition, destructive sampling and laboratory tests are required.

Cable insulation analysis is a destructive test, involving the replacement of a cable joint and a short section of cable with two new joints and cable. Due to the cable location predominately in busy roads, taking a sample is an expensive and disruptive process. In the Dr George Anders report, of all the locations studied, “Site 16” (Forest Rd and Bonds Rd) is noted the highest thermally constrained location. This site is very close to the existing online temperature monitoring location. Data from this location shows that since commissioning of the online system the cable has been operating well within the design temperature. This might indicate that even in the most constrained location the cable has not been overly stressed, at least since Cable 42 commissioning. Sampling in this location is made difficult due to traffic constraints and the fact that the nearest joint bay is an oil feed location. Other locations were investigated but it was determined that sampling would provide an answer that was less definitive.

It was considered prudent that a length of cable and cable joint will be cut out and a suite of tests undertaken. These works are currently underway with Cable 41 expected to be returned to service on 6th October 2016. A report in the condition is expected by December 2016. These works have been estimated to cost $4.26M. This excludes a HVAC test, unable to be completed in Japan due to PCB contamination. Quotes for testing locally were excessive and required the use then replacement of the spare sealing ends. Tests in Japan would have used a deionised water connection, significantly reducing costs.

This assumed preferred location is based on the cable bedding being similar condition to the backfill. As noted in the sampling summary section, 0.1 K.m/W change corresponds to approximately 5 MVA. If the bedding mix was in good condition compared to the rest of the cable the results will not be indicative. The change in backfill moisture over time may also not be consistent.

If the proposed sampling and testing of Cable 41 proceeds, the findings would still only be valid for the sampled location. Subjective judgement must still be made as to how the findings are likely to compare with the worst case. Sample results showing good condition may not be representative of other parts of the cable.

Despite this, any findings of serious deterioration would provide a valid conclusion that the cable’s life is limited.

Estimating the thermal stresses that the cable has been subject to in the past could be determined by the creation of a thermal model. Cable temperatures could be estimated based on the TR results over various moisture content, rainfall and temperature response of existing thermal monitoring. Creation of a thermal model was originally part of the sampling project, which had the scope reduced to provide a rating only.

3.4 Operation of Cable 41

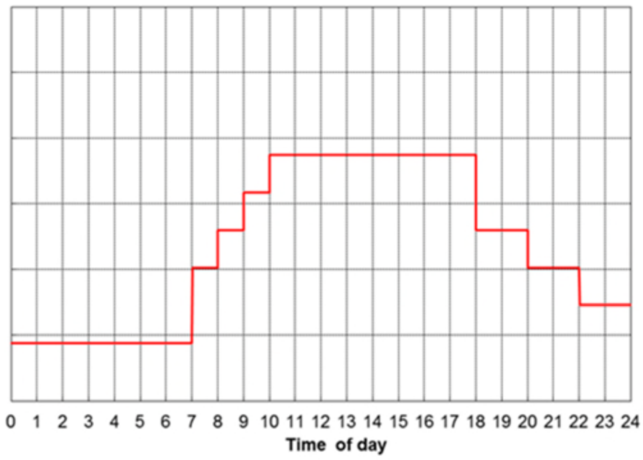
3.4.1 Normal Cyclic Ratings

As noted in Section 2.2.3, the new ratings for Cable 41 are as follows:

- “Summer” (December to May): 426 MVA (745 A)
- “Winter” (June to November): 492 MVA (860 A)

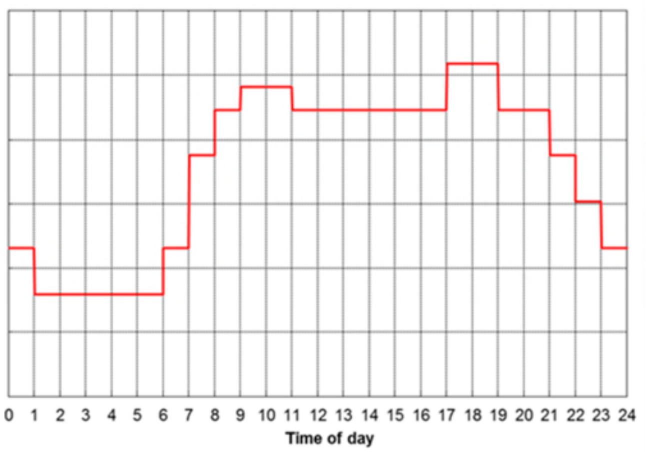
Seasons are offset due to the thermal time constant of ambient soil. These are **normal cyclic** ratings. The rating shown is the peak of the cycle and is calculated to keep the conductor temperature at or below the rated 85°C. This long thermal time constant is also the reason cyclic ratings are provided for underground cables. If a continuous rating was specified the rating would be much less.

The load cycles are as per the TransGrid Operational Manual *OM304 Ratings of Main Grid Circuits* and are unchanged from previous rating and shown in Figure 6 and Figure 7. The Loading approximately follows the loading expected.



Load Duration Hours	% of load Cycle Peak
7	50
1	70
1	80
1	90
8	100
2	80
2	70
2	60

Figure 6: Summer Load Cycle



Load Duration Hours	% of load Cycle Peak
1	60
5	50
1	60
1	80
1	90
2	95
6	90
2	100
2	90
1	80
1	70
1	60

Figure 7: Winter Load Cycle

3.4.2 Emergency Rating

As per the Dr George Anders emergency rating study dated 15th September 2016, a 564 MVA short-time emergency is able to be maintained. This is 6-hour cyclic rating enabling the cable to ride out the afternoon / evening peak in the event of contingency. This short-time rating will apply all year round. The following day the rating shall revert to the normal cyclic rating (426 MVA summer / 492 MVA winter). If a further contingent event was to occur (including the day immediately after the first) the emergency rating again is acceptable. The emergency rating shall only be used to manage the next contingent event and not be used repeatedly.

4. Options for Cable 41

Reducing the rating of Cable 41 effectively derates the other circuits due to circuit impedances and network configuration. Cable 42 and the other 132 kV supplies out of Sydney South have to have power flows reduced by sectionalising to force power flows from alternative substations.

Options to alleviate this situation fall into the following categories:

- Remediation of Cable 41
  - Replace backfill above the cable protective slabs
  - Replace backfill above and below the cable protective slabs
- Continue to operate Cable 41 with new reduced ratings.
- Augmentation – New Cables from Rookwood Road to Beaconsfield, then retire Cable 41.
- Operation of Cable 41 at reduced voltage of 132kV. In conjunction with a new cable.

4.1 Future Options

4.1.1 Backfill Replacement above the cable protective slabs

The option of a backfill replacement (above the cable protective slabs only) was considered under TransGrid project *Need 42 - Capability of Cable 41 Sydney South to Beaconsfield* (option 2001B). J-Power Systems (now Sumitomo) were commissioned to provide a FEM analysis of Cable 41 with poor 3 Km/W backfill below the slabs and new 1.2 Km/W backfill installed above.

The study confirmed that a backfill replacement would enable Cable 41 to have a long term emergency rating of approximately the original rating (original rating resulted in 96°C conductor temperature). Assuming approximately 8 MVA per 1°C temperature rise quoted by Dr George Anders, a 575 MVA summer normal cyclic rating would be possible.

Excluded from this option:

- Replacement of the sand backfill in joint bays and joint bay taper areas.
- Replacement of bedding mix in cable bridges.
- Replacement of bedding mix in the Boomerang Reserve tunnels.
- Replacing any bedding mix below cable protective slabs.
- Replacement of backfill above ductbanks.
- Replacement of any bedding mix or backfill in and around troughs.
- Replacement of any backfill in the following low lying area:
  - From The River Road to Little Salt Pan Cable Bridge.
- Replacement of backfill in area identified with low thermal resistivity backfill:
  - From Bexley cable bridge to Chamberlain Rd.

The detailed scoping determined that the costs of a complete backfill replacement would be in the order of $127M (unescalated 2016/17 dollars).

Constructability

This option involves excavating the backfill from ground level to the concrete cable protective slabs along the entire length of Cable 41 and replacing the backfill with a Thermal Stabilised Backfill. Excavation above the cable protective slabs does not require an access authority under Power System Safety Rules Revision 5.2. However, TransGrid's tier one contractors and consultants have exercised their duty of care by raising their concerns of performing such works with Cable 41 in service.

The 20:1 backfill will be replaced with Thermal Stabilised Backfill (TSB) as shown in Figure 8, below. Road surface reinstatement is to be as per Roads and Maritime Services authority (RMS) or council requirements. A 300mm layer of base course consisting of 75mm crushed sandstone shall be installed under turf in open/grassed areas. New warning tapes shall be installed.

Due to Cable 41 being predominantly in main roads, a significant portion of these costs are in traffic control and loadings associated with night works. These works would be significantly disruptive to the community. These costs would still be considered applicable, the 2016 sampling showed approximately 90% of the route had TR above specified levels.

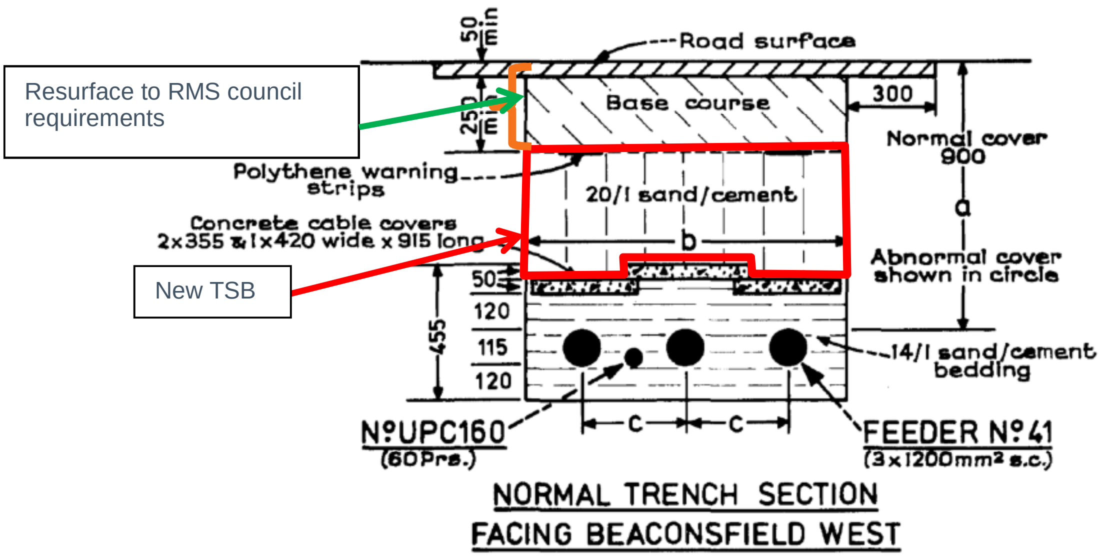


Figure 8: Backfill Replacement in road

The RMS is responsible for the high volume roads such as Henry Lawson Drive, Stoney Creek Road and the Princess Highway and Rockdale Council is responsible for the low volume roads. Based on consultation with RMS and Rockdale Council, working requirements will be very strict and the following restrictions likely imposed.

- RMS
  - Work to occur between 10pm and 5am and to be trafficable outside these hours.
  - Maximum length of excavated road opening of 20m – 30m.
- Rockdale Council
  - Work to occur between 10am and 3pm and to be trafficable outside these hours.
  - Maximum length of excavated road opening of 50m.

Telecommunications, electrical, gas, water, sewer and drainage services near Cable 41 have been identified which have a high risk of damage as a result of the construction works. Restrictions of the time permitted for the removal of the backfill may lead to difficulty in excavating around existing service crossings and increase the risk of damage to these services. The following identified underground services is provided as an indication only of the number of services that could potentially be affected by the works, however, it should not be used as a guide for construction and all appropriate measures should be undertaken by the contractor to identify all underground services.

Electrical supply cables are located along the route of Cable 41, many running parallel to Cable 41. Similar to the communications cables, excavations parallel to these services can be undertaken without affecting them. However, there are several crossings of banks of cables at many of the road intersections. There are up to 60 such crossings on the 19 kilometre route to be rehabilitated.

4.1.2 Backfill Replacement above and below the cable protective slabs

The option of a backfill replacement (above and below the cable protective slabs) was considered under TransGrid project '*Need 42 - Capability of Cable 41 Sydney South to Beaconsfield'* (option DCN42AB).

This would provide a normal cyclic rating of between 575 MVA and 663 MVA. Due to the higher than designed ground temperatures; the original 663 MVA cannot be achieved.

Excluded from this option:

- Replacement of the bedding mix or binding layer below the cable level.
- Replacement of the sand backfill in joint bays and joint bay taper areas.
- Replacement of bedding in cable bridges.
- Replacement of bedding in the Boomerang Reserve tunnels.
- Replacement of backfill above ductbanks.
- Replacement of any bedding or backfill in and around troughs.
- Replacement of any backfill in the following low lying area:
    - o From The River Road to Little Salt Pan Cable Bridge.
- Replacement of backfill in area identified with low thermal resistivity backfill:
    - o From Bexley cable bridge to Chamberlain Rd.

Constructability

This option involves the removal and disposal of the existing backfill, bedding mix and base course above the cable protective slabs and the TSB below the cable slabs. The 20:1 backfill will be replaced with Thermal Stabilised Backfill (TSB) as shown in Figure 9. Road surface reinstatement is to be as per RMS or council requirements. A 300mm layer of base course consisting of 75mm crushed sandstone shall be installed under turf in open/grassed areas. New warning tapes shall be installed.

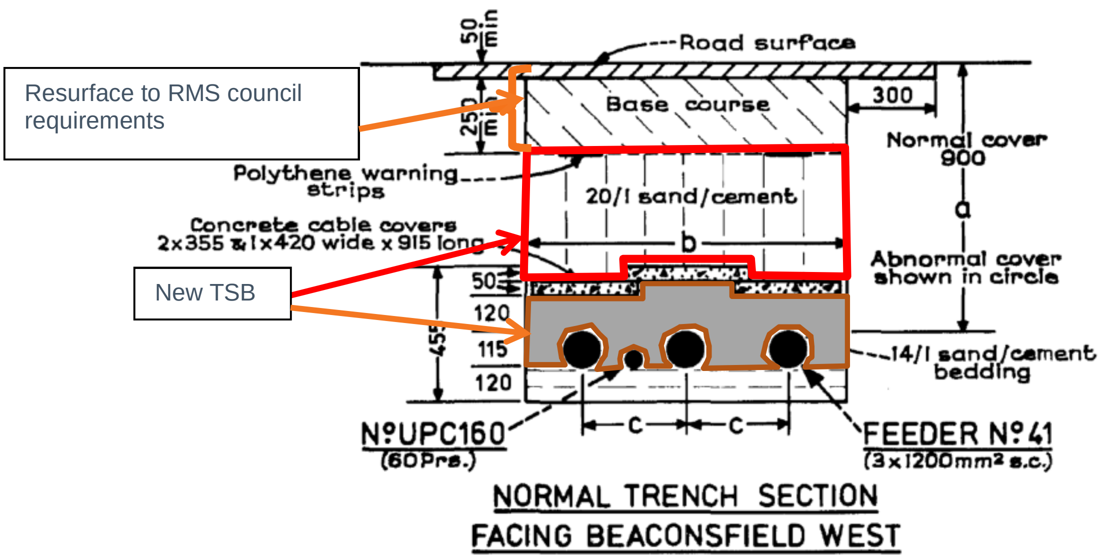


Figure 9: Backfill and bedding replacement in road

In addition to the RMS, council and utility constructability factors noted in 4.1.1, an outage is required when working below the cable cover slabs. Outages are only available in spring and autumn, so the time taken to complete the replacement would take years (the OFS assumed 62 months from project approval). These outages must be coordinated with Ausgrid. Such an extensive outage requirement could impact on performance of Ausgrid routine maintenance and delivery of their capital program, ironically having a negative impact on reliability.

Compared to modern cables, the PVC outer sheath on Cable 41 is relatively thin, as low as 3 mm. This requires careful selection of TSB material when placing around the cable. Aggregate within the TSB must be "smooth river stones", other stone types can cause damage to the outer jacket causing the metallic aluminium sheath to be faulted to earth. There is limited availability of smooth river stones in the Sydney area reducing the likelihood of getting competitive quotes.

Experience from the cable sample project is that the material below the slabs is very variable. In a short section of less than 20 metres the material changed from quite soft to so hard high pressure water blasting was unable to cut the sand/cement mix. In this case manual methods of wooden wedges were used to break away the material. This is a very slow process. Replacement of material this hard would have to be abandoned. Bedding samples would be taken in this instance for TR testing to enable the condition of the remaining sections to be known. Whilst it is likely that backfill this hard will have a good TR, there is a possibility the interned ratings may not be able to be achieved.

4.1.3 Continue to Operate Cable 41 at 330kV with 426 MVA rating

Essentially this is the "do nothing" option, by continuing to operate Cable 41 at 330kV with the 426 MVA summer normal cyclic rating, which does not address the future demand forecast needs.

4.1.4 Operation of Cable 41 at 132kV in conjunction with a new cable

Operation of Cable 41 at a reduced voltage of 132 kV and associated reduced capacity rating would utilise any residual life in cable 41. However, this option can only be exercised in conjunction with the installation of a new 330 kV 750 MVA XLPE cable between Rookwood Rd and Beaconsfield substations.

Operation of Cable 41 at a reduced voltage of 132kV with a normal summer cyclic rating of 170 MVA would allow operation of Cable 41 with the equivalent conductor losses. However, there are more losses than simple conductor losses. When considering the reduced dielectric losses additional capacity is available. The May 2016 Dr George Anders report determined the total loss per metre, *W* for the 330kV for the 426 MVA normal rating is 21 W/m. The total losses are given by the following equation:

$$W = (W_c + W_s)X\ Lf + W_d$$

Where

- W_c – conductor losses – proportional to square of the current
- W_s – Metallic sheath 0.08 times conductor loss W_c
- Lf – Load loss factor – 0.64 as per the load curves in the OM.
- W_d – Dielectric losses – proportional to the square of the voltage

The dielectric loss (W_d), which is proportional to the square of the voltage, would reduce from 9 W/m to 1.44 W/M. The allowable conductor loss and hence load current is therefore:

$$W_c = 28.3\ W/m = Ri^2$$
$$i = 1196A$$

Where

- R: AC resistance at 85°C with spacing at "site 16" 0.01979 mΩ/m

Therefore the actual new summer normal cyclic rating of Cable 41 running at 132kV would be 273 MVA

For planning purposes reactive properties of the cable should also be considered. According to the Cable 41 contract schedule, the maximum charging current per kilometre at rated voltage is 22.1 A, so 144 MVAr for the entire length. Therefore, at 132kV the charging power provided would be 57 MVAr.

4.1.5 Online Condition Monitoring on Cable 41

Cable 41 has a temperature monitoring system which monitors the cable, backfill and ambient temperatures of 8 points along the cable route. This is used for operational purposes. In a contingency situation the system operator is able to monitor the temperatures via SCADA (Figure 10).

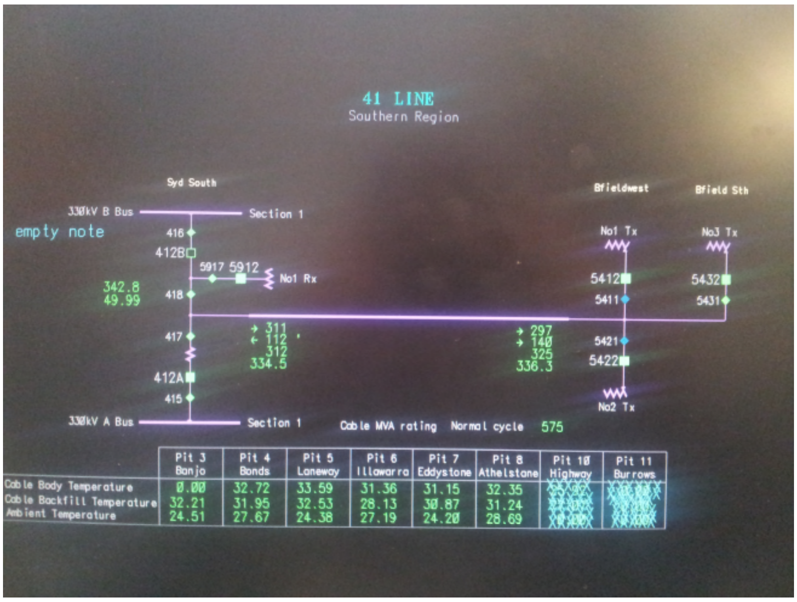


Figure 10: Cable 41 SCADA page with cable monitoring temperatures

A similar system could be implemented which provides a "real time rating". The benefit associated with the implementation of a real time rating is the ability to predict the operating environment (e.g. soil temperature, moisture content and thermal resistivity) and operate the cable within the ratings corresponding to the prevailing operating conditions (rather than expected worse case).

The lack of comprehensive cable bedding samples introduces unknowns. The cable bedding will have the most significant impact on the cable thermal behaviour and the resulting cable rating. However, as outlined earlier in the report, due to outage restrictions the scope was revised to not include sampling below cable covers. The installation of cable environmental monitoring will provide additional certainty that the correct rating has been chosen.

Dr Lyall, a recognised cable expert, has developed a system of measuring thermal resistance of soil. These devices have been installed with some success on some Ausgrid cable systems. The system also monitors soil moisture and temperature. Applying the lessons learnt from the Cable 41 temperature monitoring system and the Ausgrid online TR would be expected to provide a reliable system for operational purposes.

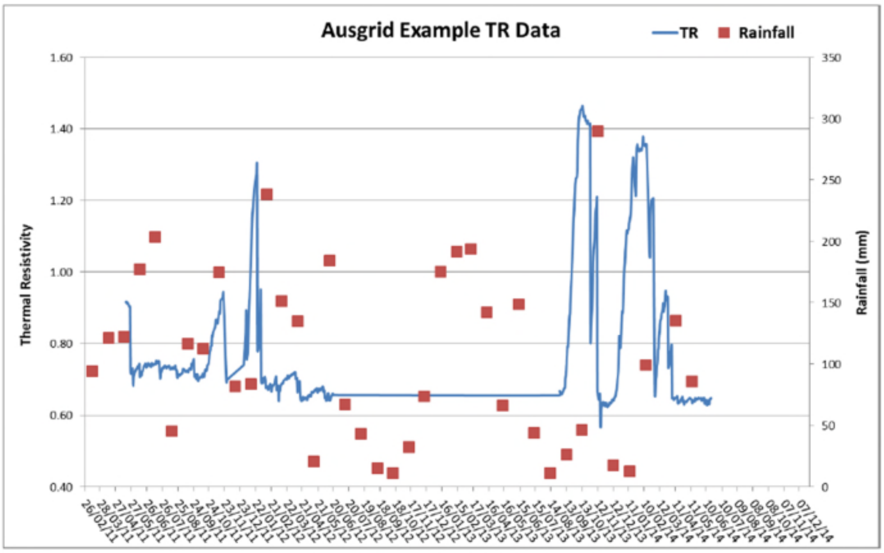


Figure 11: Ausgrid Online TR data

Online monitoring of the cable environment was originally part of the scope for the "Cable 41 Thermal Model" project. During the scoping stage this requirement was removed due to the large cost and feasibility of commissioning multiple sites, required delivery timeframe and outage requirements.

It should be noted that that despite the large number of backfill sample locations selected as the most likely constrained studied in 2016, there is no guarantee that other constrained locations exist on the cable route. In the short length of cable excavated for the cable sampling works the condition of the backfill was quite variable. In addition the material found below the slabs was considerably different to the material above the slabs that was sampled. As the material below the slabs makes the greatest influence on the ampacity if this material is good it would not be the most constraining location.

Ausgrid advised informally that indicative costs for design, supply and installation of a spot-monitoring solution would be in the order of $100,000 per location. This cost does not include development costs, however, Ausgrid have indicated that arrangements could be made to share suitable information with TransGrid. This cost also excludes incidental costs such and server maintenance and licensing fees.

A monitoring system to provide a “short term rating” is being proposed on Cable 41 as a NCIPAP project for the 2018-2023 regulatory period. Using the 2016 sample results to select constrained locations, targeted locations were chosen, reducing the number of sites to 5.

4.1.6 New Cables from Rookwood Rd to Beaconsfield

This option to install 2 new 330 kV 750 MVA cables between Rookwood Rd and Beaconsfield substations can either be delivered as a single project or in stages to meet the Inner Sydney demand forecast requirements.

The new 330 kV cable duct bank installation will reduce the risk of the cables being damaged by third parties coupled with the cable supply source and route diversity will significantly increase supply reliability to Inner Sydney.

The installation of a new 330 kV 750 MVA cable will enable the retirement of Cable 41.

5. Future Works

This report will be updated once the current project, to assess the condition of the cable insulation system has been completed.

Endorsed:

Steve Stavropoulos
M/Transmission Lines and Cables Assets

Approved:

Mark Jones
A/M/Asset Strategy

Appendix C – HoustonKemp VCR Report

CBD and Inner Metro VCR estimates

A final report for TransGrid on research, methodology and results

28 July 2016

HoustonKemp.com

Report Author/s

Virginia Wheway

Ann Whitfield

Adrian Kemp

Contact Us

Sydney
Level 40
161 Castlereagh Street
Sydney NSW 2000

Phone: +61 2 8880 4800

Singapore
12 Marina View
#21-08 Asia Square Tower 2
Singapore 018961

Phone: +65 6653 3420

Disclaimer

Contents

Tables

Executive Summary

HoustonKemp has been engaged by TransGrid to determine defensible values of the Value of Customer Reliability (VCR) that can be applied to unserved energy estimates in both Sydney's CBD and Sydney's Inner Metropolitan (Inner Metro) areas, drawing on existing, publicly available VCR estimates. The resultant VCR estimates are to be suitable for use in the 'Powering Sydney's Future' (PSF) study of electricity supply to the CBD and Inner Metro sub-regions of Sydney, being jointly undertaken by TransGrid and Ausgrid.

TransGrid requested that the starting point for developing our VCR estimates be AEMO's 2014 VCR study.[1]

A key component of the PSF study is focused on options that would address low probability, but high impact supply outages in the CBD and Inner Metro sub-regions. AEMO's 2014 VCR study did not stratify VCR results into the CBD and Inner Metro sub-regions of NSW of interest in the PSF study. Nor did it include an assessment of the VCR associated with long duration outages. We therefore consider that AEMO's 2014 VCR estimates will *understate* the VCR values associated with the locations and types of outages that are the focus of the PSF study, particularly for commercial customers. In addition, AEMO's 2014 VCR study does not specifically consider significant customers in the Sydney CBD and Inner Metro area that can be expected to place a high value on having a continuous and reliable electricity supply, such as the Australian Securities Exchange (ASX), large financial institutions, the NSW Parliament and Sydney Airport.

Ausgrid has calculated separate VCR values for Sydney's CBD and Inner Metro sub-regions for the purposes of the PSF study by:

- **CBD:** Applying various uplift factors to a demand weighted average of AEMO's customer VCR estimates for NSW, to reflect expected drivers of key differences between the CBD area and NSW as a whole;
- **Inner Metro:** Weighting AEMO's customer VCR estimates for NSW together on the basis of the contribution to demand from each customer group to total urban load in the Inner Metro area.

We have reviewed Ausgrid's VCR estimates and the methodology underpinning them. Our conclusions are:

- **CBD:** We consider that Ausgrid's VCR estimate for the CBD of $191/kWh derived on the basis of adjusting the weighted average of AEMO's NSW customer VCR estimates to account for the higher economic contribution of Sydney's CBD is valid methodologically.
  - However, we note that the lack of consideration of the impact of long-duration outages in the AEMO study means that the value derived by Ausgrid using this approach can be expected to *under-estimate* the actual VCR associated with the types of outages being considered in the PSF study.
  - We do not consider that there is a robust justification for the other two uplift factors used by Ausgrid (ie, differences in floor space rental and differences in relative reliability performance targets). Neither of these factors appear to clearly drive differences in VCR between the Sydney CBD area and NSW as a whole, or are necessarily correlated with factors that may be expected to drive these differences. We therefore do not consider that the $245/kWh and $363/kWh VCR estimates derived by Ausgrid have a robust methodological basis.
- **Inner Metro:** Ausgrid's demand-weighting of AEMO's VCR estimates across different customer groups is methodologically sound, and reflects the approach suggested by AEMO to deriving VCR estimates for specific network studies. However, due to the shortcomings of the AEMO VCR estimates in terms of both lack of stratification of customers in urban areas and no consideration of long duration outages, we consider that the $40/kWh value derived by Ausgrid on this basis will *under-estimate* the VCR of customers in the Inner Metro region.

We considered several options in order to calculate specific VCR values for both Sydney CBD and Inner Metro customers, suitable for use in the PSF. Conducting a new, targeted survey of VCR was not possible in

[1] AEMO, *Final Report – Value of Customer Reliability*, September 2014

the time available, and we were unable to gain access to AEMO's raw data or sampling plan from its 2014 study.

A further option we considered was scaling up AEMO's average NSW VCR estimates by factors that capture differences in the expected VCR for CBD and Inner Metro customers compared to that for average NSW customers. However, given that this is that approach taken by Ausgrid in deriving its VCR estimate for Sydney CBD customers, we instead concentrated on an approach that augments the results of AEMO's 2014 VCR study with information derived from other published VCR studies. In particular, we have drawn from the more stratified results available from a 2012 VCR study by Oakley Greenwood (OGW).[2]

The VCR estimates for Sydney CBD and the Inner Metro area resulting from our analysis, and a comparison of those derived by Ausgrid, are set out in Table E-1, which also shows the different methodologies used.

Table E-1: Summary VCR estimates and methodology for Sydney's CBD and Inner Metro regions ($2015/16)

Sydney Sub-region	Ausgrid methodology for customer sector VCRs	VCR range Ausgrid ($/kWh)	HoustonKemp methodology for customer sector VCRs	VCR range HoustonKemp ($/kWh)
CBD	Obtain preliminary CBD VCR by demand weighting AEMO customer VCRs by customer demand breakdown in the CBD. Apply various uplift multipliers to preliminary VCR to account for differences in (i) economic contribution, (ii) STPIS targets and (iii) value of floor rental	$191- $363 (mid-point $250) (Results from uplift multipliers: (i)STPIS:$363 (ii) Economic contribution: $191 (iii) Floor space rental:$245)	**Residential** – use AEMO VCR **Commercial small & medium** – lower bound calculated by using OGW NSW state-wide VCR , upper bound calculated by escalating OGW NSW state-wide VCR by 50% to reflect a consistent ratio between CBD feeder results and all NSW feeder results **Commercial large** – use OGW CBD VCR	$150 - $192
Inner Metro	Obtain Inner Metro VCR by demand weighting AEMO VCRs by customer sector.	$15-$65 (average $40)	**Residential** – use AEMO VCR **Commercial small & medium** – use OGW Urban VCR **Commercial large** – use OGW Urban VCR	$90

The key results of our analysis are:

1. Our CBD VCR estimate is $150-$192/kWh.
   > This shows good alignment with Ausgrid's CBD VCR estimate of $191/kWh that was based on an economic contribution multiplier. Ausgrid's higher VCR estimates are based on multipliers we consider to be less appropriate; and
2. Our Inner Metro VCR estimate is $90/kWh.
   > This is approximately double Ausgrid's Inner Metro VCR estimate. Our higher value arises from our adoption of OGW's VCR estimate for small & medium commercial customers in an urban area. OGW's VCR estimate for these customers is significantly higher than AEMO's state-wide VCR estimates for the same customer groups. However, we consider that the OGW estimates are likely to

[2] Oakley Greenwood, *Final Report - NSW Value of Customer Reliability,* May 2012

be more robust, as they are specifically focused on commercial customers in urban areas, whose VCR value can be expected to differ materially from commercial customers in non-urban areas.

In both cases the VCR studies we have drawn on to derive our estimates do not consider long duration outages. We therefore consider that in the case of the PSF study, where the reduction in long duration outages is a key focus, our VCR estimates above will *under-estimate* the true VCR value, for both the CBD and Inner Metro sub-regions.

The Independent Pricing and Regulatory Tribunal (IPART) has recently commented on the shortcomings of the AEMO 2014 VCR study as the basis for determining reliability standards in particular areas of NSW. We agree with IPART that the only robust way to derive appropriate VCR estimates would be to conduct a new VCR study, focused on highlighting differences in VCR between different geographic areas in NSW and different customer groups. The study would also need to explicitly consider the VCR associated with low probability but high impact, long duration outages, such as those being addressed by the PSF study.

1. Background

1.1 HoustonKemp's task

We have been engaged by TransGrid to determine a defensible value of the Value of Customer Reliability (VCR) that can be applied to unserved energy estimates in both Sydney's CBD and Sydney's Inner Metropolitan (Inner Metro) areas. The resultant VCR estimates are to be suitable for use in the 'Powering Sydney's Future' (PSF) study of supply to the CBD and Inner Metro sub-regions of Sydney, which is being jointly undertaken by TransGrid and Ausgrid. In addition, we understand that both TransGrid and Ausgrid are seeking VCR estimates that would be suitable for use in other network planning assessments (including the RIT-T and RIT-D) relating to augmentation of supply to the Sydney CBD.

TransGrid requested that we use AEMO's 2014 VCR estimates as the starting point in developing our estimates.[3]

We understand that the PSF study is considering a number of different outage scenarios. Some outage scenarios, although low probability, would have a high impact and are of particular relevance for the PSF study. Such outage scenarios are characterised by:

- prolonged supply disruptions over a period of weeks, with repeated rolling outages for customers over this time; and
- widespread supply disruption within an area, restricting the ability of customers to mitigate the impact of a disruption (eg, by eating out in their neighbourhood rather than cooking at home).

The VCR approach seeks to determine the costs that electricity supply interruptions impose on end-use customers. It is assumed that a customer would be willing to pay a price for increased reliability that is no more (and presumable somewhat less than) the cost they would incur in the event of an interruption to their electricity supply.

As part of our task, we were also asked to review VCR estimates developed by Ausgrid for Sydney's CBD and Inner Metro sub-regions.

1.2 AEMO's 2014 VCR study is the most recent.

The AEMO 2014 VCR study estimated the VCR for each jurisdiction in the National Electricity Market (NEM), across four (4) customer classifications, as well as a state-wide average. The customer classifications include residential and different sizes of commercial customer.

Table 1-1 below presents AEMO's VCR 2014 summary results for NSW for each customer sector and across the state as a whole.

[3] AEMO, *Final Report – Value of Customer Reliability*, September 2014

Table 1-1 : Summary of AEMO NSW VCR estimates from 2014 study[4] ($2014)

Customer Sector	AEMO VCR NSW (S/kWh)
Residential	$26.53
Small commercial (<40 MWh pa)	$57.13
Medium commercial (40-100 MWH pa)	$57.28
Large commercial (>100 MWh pa)	$42.13
NSW average	**$34.15***

** Includes direct connect customers*
Note: AEMO provides a margin of error for its VCR estimates as +- 30%

Because the transmission and distribution networks supply many different classes of customer from the same connection point, AEMO's VCR Application Guide points out that it is necessary to weight VCRs so as to arrive at a single usable value for modelling purposes for specific network planning studies.[5] AEMO's VCR Application Guide suggests weighting VCRs by the sectoral split in energy consumption for a particular location in applying its VCR estimates to specific investment decisions.[6]

1.3 Shortcomings with adopting the AEMO VCR estimates for the PSF study

Before applying existing published VCR values from AEMO (or any other sources), we need to ensure that the VCR values are 'fit for purpose' for the current PSF study. This involves critical examination of whether or not the sample from the AEMO study (and other studies) is representative of the types of customers being considered in the PSF study, and whether the outage scenarios considered are also representative of the outage scenarios under consideration in the PSF study.

We see two major shortcomings in using AEMO's 2014 VCR values for the PSF study:

1. AEMO's VCR estimates are not stratified into different geographic areas beyond state-level values and therefore do not provide any insight into differences in VCR between customers in CBD and Inner Metro sub-regions, and the rest of the state. Section 2 discusses the unique features of CBD and Inner Metro customers and reasons for which it is reasonable to expect that VCR values for customers in these sub-regions to be significantly higher than state averages; and
2. The methodology used to calculate AEMO's VCR estimates did not consider prolonged outages (the longest outage considered was 12 hours).[7] Therefore the low probability but high impact supply interruptions of interest in the PSF study are not captured in AEMO's study and resulting VCR estimates. It is reasonable to expect that the impact on customers of a prolonged and widespread outage will be greater than the impact of shorter duration outages, leading to a higher VCR in relation to avoiding these outages. Again, Section 2 provides some insight into why we would expect this to be the case.

[4] AEMO, *Final Report – Value of Customer Reliability*, September 2014, pp.23-24.

[5] AEMO, *Value of Customer Reliability - Application Guide*, December 2014, pp. 6-9.

[6] AEMO, *Value of Customer Reliability - Application Guide*, December 2014, p. 7.

[7] AEMO, *Final Report – Value of Customer Reliability*, September 2014, p. 11.

In addition to the above shortcomings, we also note that:

- AEMO's study does not include important customers in the Sydney CBD and Inner Metro area, such as the Australian Securities Exchange (ASX), NSW Parliament, large financial institutions, public transport agencies and Sydney airport;
- AEMO's study does not provide any information or data on CBD-specific sampling;
- AEMO's VCR estimates rely on a very specific methodology (choice modelling) which is different to that adopted in previous studies (where the estimates were derived from surveys). Whilst the different methods used to estimate VCR are both valid, the difference in methodology limits the ability to perform detailed statistical analysis and comparisons between VCR values derived from the different studies. This is because they rely on different assumptions in relation to the underlying data as well as differences in the structure of the model used; and
- AEMO's VCR methodology does not make the distinction that the losses incurred by residential customers as the result of a supply disruption will be significantly different in nature to those incurred by commercial businesses who rely on electricity to generate and collect revenue.

The Independent Pricing and Regulatory Tribunal (IPART) recently released a Draft Report prepared in the context of setting NSW Electricity Transmission Reliability Standards, which discusses the appropriateness of using AEMO's VCR estimates in the context of setting reliability standards in NSW.[8] Concerns raised about use of AEMO's VCR estimates include the small sample size,[9] the strong dependence on the specific methodology used,[10], and customers such as the Australian Stock Exchange, NSW Parliament and large financial institutions not being included in the sample.[11]. In addition, concerns are raised that AMEO's VCR study does not adequately capture low probability but high impact supply interruptions.[12] Submissions to IPART generally acknowledged that these issues will take time to address.[13]

A separate report by Parsons Brinckerhoff (PB)[14] commissioned by IPART also considered and rejected alternatives to using AEMO's average VCR estimate in the aggregated weighted VCR values being derived by IPART in the context of the reliability review. It did not recommend using upper quartile or maximum values derived from AEMO's study as it considered that these approaches will overstate the VCR[15]. In addition, the PB report tested the sensitivity of the VCR values calculated for each connection point and found them insensitive to changes in assumed customer splits.[16]

The above issues raise questions about the representativeness of the customer sample used in the AEMO study, and its consequent ability to produce robust VCR estimates for sub-regions, let alone for particular customer segments within sub-regions.

Based on the above observations regarding AEMO's 2014 VCR study, it is our opinion that AEMO's VCR estimates will be *under-estimating* VCR values for commercial customers in the CBD and Inner Metro sub-regions. We also consider that the AEMO VCR estimates are not suitable for valuing customer reliability for prolonged outages in the CBD, or in the Inner Metro area.

[8] IPART, *Electricity Transmission Reliability Standards, An economic assessment – Energy - Draft Report*, May 2016, p. 28. This draft report discusses responses to issues raised in IPART's earlier Issues Paper: IPART, *Electricity Transmission Reliability Standards, An economic assessment – Energy - Issues Paper*, December 2016

[9] Essential Energy submission to IPART Issues Paper, 28 January 2016, p 5.

[10] ETSE Consulting submission to Issues Paper, 27 January 2016, p 7.

[11] Ausgrid submission to IPART Issues Paper, 22 January 2016, pp 7-8.

[12] Ausgrid submission to IPART Issues Paper, 22 January 2016, p 9.

[13] IPART, *Electricity Transmission Reliability Standards, An economic assessment – Energy - Draft Report*, May 2016, p. 28

[14] Parsons Brinckerhoff, *NSW Transmission Reliability Standards Review, Value of Customer Reliability*, May 2016

[15] Parsons Brinckerhoff, *NSW Transmission Reliability Standards Review, Value of Customer Reliability*, May 2016, p. 3.

[16] In our opinion this outcome is more a reflection of the sample limitations in the AEMO study, rather than a true artefact of VCR insensitivity to customer splits.

1.4 Structure of this report

The remainder of this report is structured as follows:

- Section 2 discusses differences between CBD and Inner Metro electricity customers, and those across NSW as a whole, that can reasonably be expected to lead to different VCR values, as well as the higher VCR that is likely to be associated with prolonged disruptions;
- Section 3 provides commentary on Ausgrid's estimates of the VCR for CBD and Inner Metro customers;
- Section 4 outlines the options considered by HoustonKemp for developing VCR estimates for the Sydney CBD and Inner Metro sub-regions, suitable for adoption in the PSF study;
- Section 5 introduces Oakley Greenwood's (OGW) 2012 VCR study and provides our observations on this study and its applicability to the VCR estimation task at hand;
- Section 6 provides the detail and results of our calculations of a Sydney CBD VCR estimate;
- Section 7 provides the equivalent detail and results of our calculations of a Sydney Inner Metro VCR estimate; and
- Section 8 summarises our conclusions.

2. What differentiates the VCR for CBD and Inner Metro customers versus average NSW customers?

Customers' expectations for reliable electricity supply are significantly different in the Sydney CBD and Inner Metro sub-regions compared with other areas of NSW. This is evidenced by higher reliability standards applied in the CBD and to feeders in urban areas compared to rural feeders. It is also reasonable to expect that the value that customers place on having a reliable electricity supply is different in both the CBD and Inner Metro sub-regions than in more rural areas of NSW, due to differences in both:

- the nature of commercial businesses in the CBD and Inner Metro sub-regions, and therefore the impact on them of a disruption in their electricity supply; and
- the higher residential incomes in these areas, which can be expected to lead to a greater ability and therefore willingness to pay for a more reliable electricity supply.

These drivers for a higher VCR value for customers in the areas affected by the PSF study are discussed further below.

We also discuss the reasons why prolonged and widespread supply disruptions, which are a particular focus of the PSF study, may be expected to lead to a greater impact on customers, and therefore why it is reasonable to expect that a higher VCR estimate would be appropriate for these types of outages.

2.1 Commercial customers

Sydney's CBD is characterised by a high density of high value businesses that generate a substantial proportion of the state of NSW's GDP. Such businesses include banks and financial institutions, head offices of large corporations, and local offices of large multinationals. It is reasonable to expect that these businesses would place a substantially different value on the reliability of their electricity supply than businesses located elsewhere in the state, as a result of the impact on them of a supply disruption.

Sydney's CBD accounts for 5% of NSW's electricity consumption yet contributes 21.4% of the state's GDP/Gross State Product.[17] Based on this, we can conclude that higher 'worth' or value is created from each kWh consumed in the CBD, and that interruptions to electricity supply in the CBD would have a higher impact on the revenue generated by CBD businesses than would an interruption to commercial businesses located in rural NSW.

Many large commercial customers in the Sydney CBD have made significant investment in order to manage outages, in the form of back-up generators, or through choosing to locate in buildings that provide back-up power supply. This indicates that such customers place a different value on the reliability of electricity than say smaller commercial operations or residential customers.

Vital public services such as NSW Parliament and several State Government departments have their primary operations in Sydney's CBD. Such organisations have not been surveyed as part of the VCR estimation studies to date and no doubt a prolonged electricity outage would have wide-spread, significant impact on the services they provide. In addition, Sydney's heavy and light rail networks require electricity to operate - an electricity outage would require passengers to move to buses or private vehicles or at worst, not travel to and within the CBD and around Sydney at all, resulting in wide-spread economic impacts. Sydney Airport is

[17] Data provided by Ausgrid , sourced from: http://economy.id.com.au/ and http://www.economicprofile.com.au/

also located in the Inner Metro region of Sydney and it appears reasonable to expect that it too would place a high value on electricity reliability.[18]

2.2 Residential

Residents living in Sydney's CBD are likely to have greater ability and more willingness to pay for reliability in their electricity supply, resulting in a higher CBD residential VCR.

We obtained ABS data on the average incomes of residents across statistical divisions within NSW and Sydney. After analysing the data, we observed that the average total income for residents in Sydney's CBD was about 10-20% higher than those of residents in the remainder of NSW.[19] This supports the above view.

In Section 5, we introduce and discuss a 2012 VCR study undertaken by Oakley Greenwood (OGW)[20] OGW's VCR estimates for residential CBD customers are higher than its average state-wide VCR for residential customers, which also aligns with our observations above.

Similarly, OGW's VCR estimate for residential customers on Urban feeders is above its estimate of residential VCR across NSW as a whole, although the difference is less pronounced than for the CBD.

We also analysed the ABS income data for Inner Metro residents and observed that the average total income for residents in Sydney's Inner Metro sub-regions was about 5% higher than those of residents in the remainder of NSW.[21]

2.3 Impact of prolonged outages

It is generally understood that the impact of an electricity outage depends on its duration. However, the cost and effects of prolonged outages (ie of more than 24 hours) have not been widely published or analysed in the literature on VCRs.

In Appendix A.2 we summarise the effects and impacts of a prominent prolonged outage; that experienced by Auckland in 1998. Not all impacts and costs can be quantified, but the summary describes the wide-ranging impacts on citizens, businesses and public services. It is clear from the descriptions available of the Auckland experience that a prolonged outage in a CBD area would have a major impact on both commercial and residential customers.

We discussed above that many businesses in the CBD choose to adopt back-up generation, or to locate in buildings that provide a back-up electricity supply service. However, these strategies would not be sufficient to address prolonged outages, such as those being considered as part of the PSF study. It is not typical practice to run back-up generators for extended periods of time, and we understand that back-up generators are typically sourced to run emergency lighting and elevators for a short period of time, rather than to replicate full operations.[22] This is discussed further in Appendix A.1.

Given the above, it is therefore reasonable to consider that the VCR associated with a prolonged outage in the Sydney CBD and Inner Metro area would be substantially higher than that associated with short duration outages. None of the existing VCR studies to date have considered long duration outages, and so information is not currently available to underpin an estimate of the VCR for longer outages. As a consequence, both the existing AEMO VCR estimates, and our estimates derived in this report can be expected to under-estimate the VCR associated with the types of outages being considered in the PSF study.

[18] We understand from discussions with TransGrid and Ausgrid that Sydney Airport does not have a separate back-up generation and relies primarily on grid-connected electricity supply.

[19] The figures we obtained were averages across suburbs and do not reflect variation in incomes. We were also unable to draw out differences in wages versus investment and other income.

[20] Oakley Greenwood, *Final Report - NSW Value of Customer Reliability,* May 2012

[21] The figures we obtained were averages across suburbs and do not reflect variation in incomes. We were also unable to draw out differences in wages versus investment and other income.

[22] SKM Consulting, *Standby generation for demand management,* April 2008.

3. Ausgrid's VCR calculations

Ausgrid has estimated separate VCR values for Sydney's CBD and Inner Metro sub-regions, drawing on AEMO's 2014 VCR estimates. [23] We have reviewed Ausgrid's VCR estimates, and this section summarises our conclusions.

3.1 Ausgrid's CBD VCR

Table 3.1 summarises Ausgrid's VCR estimates for customers in the Sydney CBD.

Table 3-1: Ausgrid's VCR estimates and methodology ($2015/16)

Base CBD VCR ($/kWh) ($2014)	Uplift metric	Adjustment factor	Resulting proxy VCR ($/kWh)
$44	Relative targets under Service Target Performance Incentive Scheme	8.1	$363
	Contribution to NSW Economic GDP	4.3	$191
	Relative floor space rentals	5.5	$245
Final adjusted CBD VCR (midpoint of above proxies)			**$250**

*Note : base CBD VCR value of $44 ($2014) is first escalated to $2015/16, adjusted for losses and then the multiplier applied

Ausgrid has used a preliminary aggregate VCR for the CBD across all customer groups of $44/kWh ($2014), based on demand weightings for the different customer groups in the CBD,[24] indexation of the AEMO 2014 VCR estimates to 2015/16 dollars and adjusting by 3.9% to account for network losses.[25]

Three different methods have then been applied to calculate an 'uplift factor' which is then applied to this preliminary CBD aggregate VCR, to reflect the unique factors that mean that customers in the CBD can reasonably be expected to have a higher VCR value than those across the state as a whole.

3.1.1 Difference in targets under the Service Target Performance Incentive Scheme (STPIS)

Ausgrid's CBD reliability targets are 3.8 and 12.5 times more stringent than for urban areas for SAIDI and SAIFI[26] respectively. Ausgrid argues that it is unreasonable to expect that such different levels of service reliability do not reflect similarly different values for customer reliability. Since SAIDI and SAIFI performance are equally weighted in calculating STPIS outcomes, Ausgrid has used an implied multiple of 8.1.

Applying an adjustment/uplift factor of 8.1 to the $44/kWh ($2014) aggregated CBD value results in an adjusted VCR of $363/kWh ($2015/16).

[23] TransGrid / Ausgrid : *Powering Sydney's Future Value of Customer Reliability in the Inner Metropolitan Area Selection Methodology Report, 26 May 2016,* pp. 10-11.

[24] See Table 6-1 in this report for the demand weightings used.

[25] TransGrid / Ausgrid : *Powering Sydney's Future Joint Planning Report V1.2*, p. 10.

[26] TransGrid / Ausgrid : *Powering Sydney's Future Joint Planning Report V1.2*, p. 10.

In our opinion, the differences in the STPIS targets between CBD and urban areas are not necessarily indicative of differences in the value of electricity reliability; as the targets are set on the basis of actual performance, rather than by reference to VCR. We therefore don't think that this particular uplift factor is appropriate.

We also note that the uplift factor is calculated on the basis of differences between CBD STPIS targets and urban targets, rather than by reference to the difference with average NSW-wide STPIS targets.

3.1.2 Contribution to economic productivity

As discussed in Section 2.1, businesses in the CBD contribute a higher proportion of NSW's GDP per kWh of electricity used than do businesses across the state as a whole. The Sydney CBD accounts for 5% of energy consumption in NSW, but 21.4% of Gross State Product.[27] The value generated by each kWh of electricity consumed in the CBD is therefore a little over four times higher than the state average.

Ausgrid has applied an uplift factor of 4.3 to the \$44/kWh (\$2014) aggregate CBD value, to result in an adjusted VCR of \$191/kWh (\$2015/16).

We support the general methodological approach taken by Ausgrid in applying a GDP-related uplift factor to the aggregate VCR value for the CBD. As discussed earlier, data shows that the types of businesses in the CBD contribute more to the state's GDP (or Gross State Product) per kWh of electricity consumed than do businesses across the state as a whole. The value of a kWh of electricity to these businesses can therefore be expected to be higher, as the output that it leads to is 'worth' more than for businesses in other areas. There is therefore a link between the uplift factor applied by Ausgrid and factors that can be expected to drive a higher VCR value in the CBD area.

In terms of the specific approach adopted by Ausgrid, we recommend that the adjustment factor be applied to the VCR associated with commercial customers only and not to the 3% of demand that is consumed by residential customers. However we recognise that the very low contribution that residential customers make to the aggregate CBD VCR estimated by Ausgrid makes this change immaterial.

3.1.3 Difference in floor space rentals

Ausgrid makes the assertion that real estate costs represent another relatively elastic cost input to businesses that choose to locate in the Sydney CBD, with higher rents reflecting the value they are able to generate from being located in this area compared to other urban or state-wide locations. Ausgrid quotes retail rents in the Sydney CBD as averaging from \$6,000-\$7,000 per square metre. For urban and neighbourhood shops this drops to \$300 per square metre – a ratio of twenty to one. Office space shows a little less divergence. Ausgrid compares the costs of Sydney CBD office space to office space in North Ryde and states that the CBD cost is 2-3.5 times higher. Ausgrid also notes that office space rental cost in North Ryde would itself be higher than the NSW state average.

Ausgrid averages the retail and office space rent multipliers to give an average multiplier of 5.5.

Applying an uplift factor of 5.5 to the \$44/kWh (\$2014) aggregated CBD value results in an adjusted VCR value of \$245/kWh (\$2015/16).

In assessing this uplift factor, we note that a business locates itself in the CBD for many reasons; including access to skilled labour, being in the proximity of clients and peers and, in some cases, for the prestige. Reliability of electricity supply will not necessarily be valued in the same way a business values and decides on which floor space they will rent. Nor will it necessarily be correlated with factors that do drive differences in VCR value. We therefore don't consider that this adjustment factor represents a good proxy for elevating the VCR estimate for the CBD.

[27] Data provided by Ausgrid , sourced from: http://economy.id.com.au/ and http://www.economicprofile.com.au/

3.1.4 Ausgrid's adjusted CBD VCR

Ausgrid calculates a final adjusted CBD VCR by taking the midpoint of its three proxy VCRs, calculated in accordance with the three uplift factors discussed above. This gives a final adjusted CBD VCR of $250/kWh ($2015/16).

Given that we consider only one of the above uplift factors to reflect drivers of differences in the VCR value for the Sydney CBD, we don't consider this adjusted VCR value to be applicable.

3.1.5 Summary

We consider that Ausgrid's methodology in adjusting its aggregate VCR value for the CBD for differences in the economic contribution of the CBD relative to NSW as a whole to be sound, and therefore support the value of $191/kWh ($2015/16) obtained by Ausgrid as a more appropriate estimate of the CBD VCR than use of the unadjusted AEMO VCR estimates alone.

We do not believe the two higher adjustment factors using floor space rental and STPIS reliability standards to be well-justified.

In addition, we consider that the $191/kWh ($2015/16) value is likely to be an *under-estimate* for the purposes of the PSF study, as it is based on the AEMO VCR estimates which do not include prolonged outages, which can be expected to lead to higher VCR values.

3.2 Ausgrid's Inner Metro VCR

Ausgrid's VCR estimation methodology for Inner Metro load is based on AEMO's VCR Application Guide[28] [29].

Ausgrid's Inner Metro VCR value reflects the composition of customers within the Inner Metro sub-region of Sydney.

The distribution of demand across customer groups was determined and then applied to AEMO's 2014 VCR values, indexation of the AEMO 2014 VCR estimates to 2015/16 dollars and adjusting by 3.9% to account for network losses.[30]

We agree with the methodology that Ausgrid has adopted of demand-weighting the AEMO VCR estimates, and note that it is consistent with AEMO's recommended methodology.

However we believe that AEMO's VCR estimates are *too low* for customers in the Inner Metro area, particularly commercial customers, as they reflect the average VCR for customers across NSW as a whole. We also consider that the AEMO VCR values will *under-estimate* the VCR associated with long duration outages, which are important in the context of the PSF study.

[28] TransGrid / Ausgrid : *Powering Sydney's Future Value of Customer Reliability in the Inner Metropolitan Area Selection Methodology Report, 26 May 2016,* p. 9.

[29] AEMO, *Value of Customer Reliability - Application Guide*, December 2014, p. 7.

[30] TransGrid / Ausgrid : *Powering Sydney's Future Joint Planning Report V1.2*, p. 10.

4. Options considered by HoustonKemp for developing CBD and Inner Metro specific VCR estimates

We considered several options for calculating specific VCR values for both Sydney CBD and Inner Metro customers, suitable for use in the PSF study. Table 4-1 below describes the four key options considered and the reasons for their feasibility or otherwise.

Table 4-1 : Summary of options considered by HoustonKemp

Option	Notes	Feasible?
Conduct a new, targeted VCR survey	Not feasible on the time available	☒
Form aggregated VCR by stratifying AEMO's VCR estimates	No access to AEMO raw data or sampling plan	☒
Scale up AEMO NSW average VCRs by factors relevant to CBD/Inner Metro (such as GDP & income)	Need to ensure scaling factors are unique to CBD/Inner Metro	☑
Augment AEMO VCR estimates with other VCR studies	Apply observed trends in Oakley Greenwood 2012 study to AEMO VCR	☑

AEMO's 2014 VCR study does not consider prolonged outages, nor provide stratified VCR results across specific Sydney sub-regions.[31]

In order to develop suitable VCR estimates that reflect the particular characteristics of different types of CBD and Inner Metro customers, and to adequately assess the impact of long duration outages, it would be necessary to undertake a new VCR study specifically focused on deriving these values.

Other recent commentary has also highlighted the need for more focused studies in order to derive VCR estimates suitable for application in targeted areas. IPART in its recent draft report on NSW electricity transmission standards states that accurate VCRs will need to be based on high quality survey work and recommend a new, comprehensive VCR study.[32] A report by Parsons Brinckerhoff (PB)[33] commissioned as part of IPART's review, recommends that a framework be put in place to outline future reliance on VCR and to develop a roadmap to overcome current uncertainties[34]. We agree with both IPART's and PB's recommendations.

A bespoke VCR study could target:

- specific customer types in Sydney's CBD and Inner Metro sub-regions;

[31] AEMO, *Final Report – Value of Customer Reliability*, September 2014, p.11.

[32] IPART, *Electricity Transmission Reliability Standards, An economic assessment – Energy - Draft Report*, May 2016, p. 28.

[33] Parsons Brinckerhoff, *Final Report - NSW Transmission Reliability Standards Review, Value of Customer Reliability*, May 2016

[34] Parsons Brinckerhoff, *Final Report - NSW Transmission Reliability Standards Review, Value of Customer Reliability*, May 2016, p. iii.

- specific losses that would be incurred by CBD and Inner Metro businesses; and
- the impact on VCR of widespread, long duration outages.

However, the short length of time available for the current study makes the option of conducting a new, bespoke VCR study infeasible.

A second option we considered was to build up alternative VCR estimates by stratifying AEMO's 2014 VCR estimates according to the sampling plan[35] that was used to derive those estimates. However, TransGrid has been unable to gain access to AEMO's raw data, nor its sampling plan and therefore this is also an unfeasible option in practice.

This leaves us with two further, but less data intensive, options:

- Scale up AEMO's average NSW VCR estimates by factors that capture differences in the likely VCR between CBD and Inner Metro customers compared to average NSW customers:
  - We need to ensure scaling factors are unique to the CBD and Inner Metro sub-regions and reflect (or are correlated with) drivers of differences in VCR values; and
- Augment results of AEMO's 2014 VCR study with information derived from other published VCR studies:
  - In particular, by drawing on the more stratified results available from OGW's 2012 VCR study[36].

The first of these two approaches is the one taken by Ausgrid and summarised in Section 3.1. We have provided comments on Ausgrid's methodology and results in Section 3.1.

To provide an alternative estimation approach, we have therefore concentrated on the second of the above approaches, augmenting the AEMO VCR study with information derived from other public studies. We discuss our approach in the remaining sections of this report.

[35] A sampling plan is a detailed outline of which surveys will be undertaken across which customers. The sampling plan should ensure appropriate coverage of all variables of interest; in this case customer type, location and size as measured by annual electricity consumption.

[36] Oakley Greenwood, *Final Report - NSW Value of Customer Reliability,* May 2012

5. Oakley Greenwood's (OGW) 2012 study of VCR Values

The OGW 2012 study of VCR values in NSW[37] was commissioned by the AEMC and was widely applied prior to AEMO's 2014 VCR study.

One purpose of OGW's study was to assess the value of electricity supply reliability to customers, and in particular to provide specific values of customer reliability for:

- Three (3) customer sectors (residential, small business and medium to large businesses, as defined by their annual electricity consumption);
- Each of the three feeder types maintained by the state's electricity distribution companies (ie, CBD, urban and rural;
- The three DNSPs – Ausgrid, Endeavour Energy and Essential Energy; and
- NSW as a whole.

As with AEMO's 2014 VCR study, prolonged outage durations were not put to survey participants - the maximum outage considered was 24 hours.[38] Therefore, the OGW VCR estimates still have material shortcomings in being applied to long duration outages such as those being considered in the PSF study.

However, an advantage of the OGW VCR study compared to AEMO's 2014 VCR study is that it provides results for different customer types in sub-regions such as Sydney's CBD and on Urban feeders, rather than only the state average.

The approach to OGW's VCR study differs from AEMO's 2014 VCR study and follows the methodology used by Monash University in 1997, 2002 and 2007[39] in applying interview techniques rather than choice modelling. OGW undertook different surveys for residential and business customers and differentiates between the types of costs incurred by these distinct customer types following an electricity supply disruption. Electricity supply disruptions are more likely to see residential customers' costs dominated by inconvenience rather than direct costs (eg a longer interruption will result in spoiled food but a short outage can cause material inconvenience such as preventing food preparation or using appliances). On the other hand, businesses incur direct costs through the impact of the disruption on their ability to operate and earn revenue, and intangible costs via damage to reputation or inability to deliver products in line with customer's expectations. Such intangible costs are certainly more difficult to estimate but should be included to the extent possible in the estimation of damages resulting from electricity outages.[40]

The OGW study sampled 41 customers in the CBD, which we understand is significantly more than those sampled in AEMO's 2014 study. However, only 11 commercial customers were sampled in the CBD, which raises concern as to the robustness of the OGW VCR estimates for this particular sector.

Table 5-1 below shows the NSW VCR values calculated by OGW, split by customer and feeder type. As can be seen, the VCR values for small to medium businesses are significantly higher than the corresponding values for residential and larger business customers.

[37] Oakley Greenwood, *Final Report - NSW Value of Customer Reliability,* May 2012

[38] Oakley Greenwood, *Final Report - NSW Value of Customer Reliability,* May 2012, p. 17.

[39] www.aemo.com.au/~/media/Files/Other/planning/0409-0002%20pdf.pdf

[40] Oakley Greenwood, *Final Report - NSW Value of Customer Reliability,* May 2012, p. 12.

Table 5-1 : OGWs state-wide VCRs by sector and feeder type ($/kWh) ($2012)[41]

Customer Sector	All feeders ($/kWh)	CBD feeders ($/kWh)	Urban feeders ($/kWh)	Rural feeders ($/kWh)
Residential	$20.71	$32.27	$23.05	$15.11
Business <160 MWh pa	$413.12	$295.87*	$452.12	$302.49
Business >160 MWh pa	$53.30	$80.54*	$29.96	$128.50*
Total	**$94.99**	**$120.52**	**$93.88**	**$93.86**

*Values marked with a * refer to low sample size*

OGW list the following caveats for wider application of their VCR estimates:

- The VCR estimates likely overstate the damages of inconvenience associated with most power failures because respondents were asked to consider an outage at a time that is the worst for them.
  - Given that the current PSF exercise seeks to estimate VCR values for prolonged and multi-day outages with wide-spread inconvenience and impact, we consider this issue to have no material implications for the adoption of the OGW VCR estimates for the PSF study;
- It is likely that the customer is going to be using a higher than average amount of electricity at the time he or she defines as being the 'worst' time for a power failure. OGW did not inflate electricity use in its report because it was unknown how much electricity was being used at the 'worst' time.
  - Again, given that the current PSF exercise seeks to estimate VCR values for prolonged and multi-day outages with wide-spread inconvenience and impact, we consider this issue to have no material implications for the adoption of the OGW VCR estimates for the PSF study;
- The VCR values based on CBD feeders for commercial customers are based on a small sample size.
  - We agree with concerns relating to the small sample size used to calculate OGW's commercial VCR values for CBD customers. However, in the absence of access to AEMO's raw data or the sampling plan from its 2014 VCR study, and given the lack of other published studies, we consider that the OGW CBD VCR estimates do provide relevant information; and
- The VCR values presented in the OGW study are not point estimates. There is a material error band around several of the VCR estimates that needs to be kept in mind when reporting VCR estimates across sectors and feeders.
  - We report on sensitivity of our VCR estimates in Sections 6.3 and 7.3.

5.1 HoustonKemp's observations from OGW's 2012 VCR study

OGW's commercial VCR estimates are higher than those estimated by AEMO, and this trend also holds for OGW's CBD commercial VCR values, despite the small sample size.

Table 5-2 below provides a summary comparison between AEMO's VCR estimates and OGW's VCR estimates by sub-region and customer type. We note that:

- AEMO does not split its VCR estimates into sub-regions, so all AEMO VCR values given are NSW state-wide values.

[41] Oakley Greenwood, *Final Report - NSW Value of Customer Reliability,* May 2012, p.42.

- AEMO and OGW define the threshold of energy consumption for medium and large businesses differently, with AEMO having a 100 MW pa threshold and OGW having 160 MWh pa threshold. We have elected to show the OGW threshold value of 160 MWh in Table 5-2 as this matches the customer demand profile provided in the PSF Joint Planning Report[42].
- The OGW 2012 VCR estimates in Table 5-1 have been escalated to 2014 dollars for comparison with the AEMO 2014 VCR estimates.
- OGW's standard error of the mean (SEM) for CBD medium commercial customers is high for CBD feeders but lower for Urban feeders. We believe OGW's high SEMs are due to low sample size and high variation within the small sample.

Table 5-2 : Summary comparison between AEMO and OGW VCR estimates ($2014)

Region	Customer segment	AEMO vs OGW VCR ($/kWh) (all figures in $2014)	Comments
NSW state-wide	Residential	OGW $21.75 AEMO $26.53	OGW 18% lower than AEMO but still within +/- 30% margin of error given by AEMO. Not statistically significant
NSW state-wide	Small & Medium Commercial (<160 MWh pa)	OGW = $433.78 AEMO = $57.13-$57.28	OGW significantly higher than AEMO
NSW state-wide	Large Commercial (>160 MWh pa)	OGW = $55.97 AEMO = $42.13	OGW 32% higher than AEMO which is very close to the +/- 30% margin of error given by AEMO.
Inner Metro	Residential	OGW = $24.20 AEMO state-wide $26.53 No Inner Metro VCR values available from AEMO study	OGW 9% lower than AEMO state-wide but still within +/- 30% margin of error given by AEMO. Not statistically significant
Inner Metro	Small & Medium Commercial (<160 MWh pa)	OGW = $474.73 AEMO state-wide $57.13-$57.28 No Inner Metro VCR values available from AEMO study	OGW significantly higher than AEMO state-wide
Inner Metro	Large Commercial (>160 MWh pa)	OGW = $31.46 AEMO state-wide = $42.13 No Inner Metro VCR values available from AEMO study	OGW 25% lower than AEMO state-wide but still within +/- 30% margin of error given by AEMO. Not statistically significant
CBD	Residential	OGW = $33.88 AEMO state-wide = $26.53 No CBD VCR values available from AEMO study	OGW 28% higher than AEMO state-wide but still within +/- 30% margin of error given by AEMO. Not statistically significant
CBD	Small & Medium Commercial (<160 MWh pa)	OGW = $310.66* AEMO state-wide = $57.13-	OGW significantly higher than AEMO state-wide, caution must be observed with low sample size

[42] TransGrid / Ausgrid : *Powering Sydney's Future Value of Customer Reliability in the Inner Metropolitan Area Selection Methodology Report, 26 May 2016,* p. 3.

		$57.28. No CBD VCR values available from AEMO study	
CBD	Large Commercial (>160 MWh pa)	OGW = $84.57* AEMO state-wide = $42.13 No CBD VCR values available from AEMO study	OGW significantly higher than AEMO state-wide, caution must be observed with low sample size

** small sample sizes and therefore results should be treated with caution*

The values given in Table 5-2 have been adjusted to 2014 dollars and therefore the OGW figures provided in Table 5-2 do not exactly match those given in the table on page 42 of OGW's report[43] because they have been inflated to adjust from 2012 dollars to 2014 dollars.

The key observations from Table 5-2 are:

- All OGW residential VCR values are within the +/- 30% margin of error given for AEMO VCR estimates;
- For large commercial state-wide and Inner Metro customers, OGW VCR values are within the +/- 30% margin of error given for AEMO VCR estimates;
- OGW's VCR estimates for large commercial customers in the CBD are significantly higher than AEMO's state-wide value for large commercial customers. (However we note that OGW CBD VCRs are based on a small sample);
- For all small & medium commercial (<160 MWh pa) customers, OGW VCR values are significantly higher than AEMO VCR values (However we note that OGW CBD VCRs are based on a small sample);
- There is trend of large commercial businesses having lower VCR values than small & medium businesses across both studies, and in all sub-regions. We note that this is a common finding across a number of VCR studies.
  - Potential reasons for this trend are discussed in Appendix A.1, but are likely to in part reflect greater incidence of back-up generation, which can address short duration interruptions in power supply; and
- A ratio of 50% is observed between OGW's VCR estimates for residential and large commercial customers in the CBD and OGW's state-wide VCRs for those same customer groups. However we note that OGW highlights its CBD commercial values as being less robust.

We expand on this last point in the following section.

5.2 Observed ratio of VCR for CBD customers versus NSW state average

Table 5-3 below shows the ratios observed between OGW's VCR estimates for each customer group for CBD feeders compared with its All Feeder estimates.

Table 5-3 : Ratio of OGW CBD VCR to State-wide OGW VCR by customer type

Customer type	CBD feeders : All feeders
Residential	1.56
Business <160 MWh pa	0.72*
Business >160 MWh pa	1.51*

**blue highlighted cells refer to VCR estimates with low sample size*

[43] Oakley Greenwood, *Final Report - NSW Value of Customer Reliability,* May 2012, p.42.

The same ratio of 50% is observed for CBD residential customers to state-wide residential customers and for CBD large commercial customers and all large commercial customers.

We believe that this 50% ratio of the VCR for residential and large commercial CBD customers to state-wide VCRs for these customer groups provides a helpful proxy for considering the relative differences between VCRs for customers in the CBD compared with customers across the state as a whole.

In the absence of other more robust information, it appears appropriate to assume that the same ratio may apply for small commercial customers, albeit that the OGW estimates show a lower ratio for this customer group (based on a low sample size). The ratio between CBD VCR and state VCR may not necessarily be the same for all customer groups, but adopting this same ratio for small commercial customers likely reflects a conservative lower bound in estimating the higher VCR that may be expected for small commercial customers in the CBD. Moreover we would not expect this ratio to change substantially over time because the underlying drivers of VCR are unlikely to have changed since the OGW work.

We acknowledge that the ratio of 1.51 calculated for large commercial customers (>160MWh pa) is based on a small sample. To test our belief that this higher ratio is appropriate, we have reviewed global studies that estimate the costs of electricity outages, and customers' willingness to pay for a more reliable electricity supply. Whilst the results of these studies are not directly comparable to the NSW VCR estimates, they do show a trend of the costs of outages and customers' willingness to pay being significantly higher in cities as opposed to regional and rural areas.[44] [45] [46]

In Section 6.2 and 7.2, we discuss how we incorporate the observed ratio between CBD customer VCR values and NSW state-wide values arising from the OGW VCR study into the calculation of VCR estimates for CBD and Inner Metro commercial customers.

[44] Larwence Berkeley Laboratory : *Estimated value of Service Reliability for Electric Utility Customers in the United States, June 2009,* pp. xxi-xxvi.

[45] London Economics, 2013 : *The Value of Lost Load (VoLL) for Electricity in Great Britain*, July 2013, pp.108-111.

[46] Göteborg University :*The effect of power outages and cheap talk on willingness to pay to reduce outages (Sweden), 2009*, p.10.

6. Our approach: CBD VCR value

Based on our analysis to this point, and the information available to us, we have adopted different methodologies for estimating VCRs for residential and commercial customers.

We have estimated a CBD VCR of $150-192/kWh (in 2015/16$), with a relative standard error (RSE) of 32%.

6.1 CBD Residential VCR

We have used the AEMO 2014 state-wide residential VCR of $26.53/kWh ($2014) as an appropriate basis for deriving the VCR value for residential customers in the Sydney CBD.

Our rationale for using this value is:

- OGW provides a stratified VCR value for CBD residential customers of $33.88/kWh (in 2014 dollars), which is well within the +/- 30% margin of error given in AEMO's 2014 VCR study. Therefore, no additional information would be gained by using OGW's residential CBD VCR value over AEMO's state-wide residential VCR;
- OGW calculates the relative standard error (RSE, as a percentage of VCR) of its CBD residential VCR value as 18.2%, which is lower than AEMO's margin of error, and also leads us to conclude that the AEMO and OGW residential VCR values are within each other's margin of error;
- The demand weighting applied to residential customers in the CBD is only 3% (refer to Table 6-1), and interchanging the AEMO state-wide residential VCR and the OGW CBD residential VCR values makes no material difference to the aggregated CBD VCR value.

As a sensitivity, we applied CBD income uplift factors of between 10% and 50% to account for CBD residents' higher incomes and greater ability and willingness to pay to avoid electricity outages. The reasonableness of applying an income uplift factor is reinforced by the fact that OGW's CBD residential VCR values are higher than its state-wide VCR values by approximately 50%. However, a sensitivity analysis showed that applying this income uplift factor is immaterial to the aggregated CBD VCR value. Given that residential customers' electricity demand in the CBD accounts for only 3% of total CBD demand (see Table 6-1), it is not surprising that inclusion of these income uplift factors made no material difference to the aggregated CBD VCR estimate.

Given the immateriality of applying an income uplift factor, we have elected to use AEMO's 2014 state-wide residential VCR of $26.53/kWh ($2014) with no uplift applied.

6.2 CBD Commercial VCR

6.2.1 Small & Medium commercial customers (<160 MWh pa electricity consumption)

We have calculated lower and upper bounds for the CBD small & medium commercial VCR as follows:

- **Lower bound:** we used OGW's state-wide VCR value for small & medium commercial customers of $413.12/kWh ($2012);
- **Upper bound:** we escalated OGW's state-wide VCR for small & medium commercial customers of $413.12/kWh ($2012) by 50% to reflect a consistent ratio between OGW's VCR estimates for different customer groups between CBD feeders and across all feeders, as discussed in Section 5.2 and shown in Table 5-3.

We believe this approach is preferable to using AEMO's state-wide commercial VCR estimate because:

- The lower bound is based on surveys that targeted the specific losses suffered by commercial businesses; and
- The upper bound is based on a consistent ratio observed from the OGW study between the VCR estimated across feeders state-wide, and that estimated across CBD feeders only.
  - The point estimate of $295.87/kWh[47] ($2012) for small and medium commercial customers estimated in the OGW study is based on a small sample size and OGW notes that caution must be taken not to apply this value directly. We therefore consider that this value can be ignored, in favour of instead adopting a value for these customers based on the above adjustment to the state-wide VCR estimate.

6.2.2 Large commercial customers (>160 MWh pa electricity consumption)

We calculate a point estimate of the VCR for large commercial customers in the CBD based on OGW's estimate of VCR for large commercial customers in the CBD of $80.54/kWh ($2012). Despite this value being based on a small sample size, we have chosen to adopt OGW's VCR estimate rather than AEMO's in this case for consistency with the adoption of the OGW estimate for small & medium commercial customers, since the cut-off thresholds between medium and large commercial businesses differ between the AEMO and OGW studies. However, the AEMO and OGW VCR estimates for large commercial businesses are within the +/- 30% error bounds for AEMO's estimate.

6.3 Results

We have weighted the customer specific VCR derived above for the CBD according to the energy consumption demand profile of each customer type within Sydney's CBD, which is given in Table 6-1. For example, residential customers make up 3% of the electricity consumption within Sydney's CBD and in an aggregated total their VCR value is given a 3% weighting.

Table 6-1 : CBD electricity consumption – demand weighting by customer type

Customer category	Energy consumption (GWh)	Demand weighting
Residential	287	3%
Small commercial(< 40 MWh pa)	1,033	10%
Medium commercial (40-160 MWh pa)	980	10%
Large commercial (>100 MWh pa)	7,798	77%

Source: TransGrid / Ausgrid : Powering Sydney's Future Value of Customer Reliability in the Inner Metropolitan Area Selection Methodology Report, 26 May 2016, *p. 9.*

The final step in calculating a final aggregate VCR estimate for the CBD is to index the base VCRs to 2015/16 dollars and then apply a loss factor of 3.9% as per Ausgrid's calculation.[48] An aggregate VCR is then formed by applying the demand weighting profile given in Table 6-1.

Applying the approaches described in Sections 6.1 and 6.2 and calculating an aggregated CBD VCR as described above results in a range for the **CBD VCR of $150-192/kWh (in 2015/16$),** with a relative standard error (RSE) of 32%.

We note this range of values shows good alignment with Ausgrid's CBD VCR estimate of $191/kWh, which has been derived on the basis of an Economic Contribution multiplier (see discussion in Section 3.1).

[47] Oakley Greenwood, *Final Report - NSW Value of Customer Reliability,* May 2012, p.4.

[48] TransGrid / Ausgrid : *Powering Sydney's Future Value of Customer Reliability in the Inner Metropolitan Area Selection Methodology Report, 26 May 2016,* p. 10.

Although we consider our estimated range for the VCR value for the CBD to be reasonable, based on the available information, we also note that it is likely to *under-estimate* the true VCR of CBD customers, particularly for the types of long-duration outages that are being considered in the PSF study.

7. Our approach: Inner Metro VCR value

As with our estimates of the VCR for CBD customers, we have adopted different methodologies for estimating VCRs for residential and commercial customers in the Inner Metro area.

We have estimated an Inner Metro VCR of $90/kWh (in 2015/16$), with a relative standard error (RSE) of 7.5%.

7.1 Inner Metro Residential VCR

We have adopted the AEMO 2014 state-wide residential VCR estimate of $26.53/kWh ($2014) as the basis for our estimate of the VCR for residential customers in the Inner Metro area.

Our rationale for using the AEMO VCR value for residential customers is:

- OGW provides a stratified VCR value for residential customers on Urban feeders of $24.20/kWh ($2014), which is well within the +/- 30% margin of error given in AEMO's 2014 VCR study. Therefore, no additional information would be gained by using OGW's residential Inner Metro VCR value over AEMO's state-wide residential VCR;
- OGW calculates the relative standard error (RSE as a percentage of VCR) of its Urban residential VCR value as 6.4%, which is lower than AEMO's margin of error of +/- 30%, and also leads us to conclude that the AEMO and OGW residential VCR values are within each other's margin of error;

As a sensitivity we applied CBD income uplift factors of between 10% and 30% to account for Inner Metro residents' higher incomes and greater ability and willingness to pay to avoid electricity outages. The reasonableness of adopting an income uplift factor is reinforced by the fact that OGW's Urban residential VCR value is higher than its state-wide VCR estimate by approximately 10%. However, a sensitivity analysis showed applying this income uplift factor to be immaterial to the aggregated Inner Metro VCR value.

As a consequence, we have elected to use AEMO's state-wide residential VCR of $26.53/kWh ($2014) with no uplift applied.

7.2 Inner Metro Commercial VCR

7.2.1 Small & Medium commercial (<160 MWh pa electricity consumption)

We have elected to use OGW's small and medium commercial VCR estimate for customers connected to an Urban feeder ($452.12/kWh - $2012, Table 5-1) as the basis of our VCR estimate for small and medium commercial customers in the Inner Metro area.

Our rationale for using the OGW value is:

- The sample size is sufficiently large and no caution is given by OGW as to the robustness of this VCR estimate;
- The RSE for OGW's Urban feeders small & medium commercial VCR is 7.7%, which is significantly lower than AEMO's +/- 30% margin of error for all of its commercial VCR estimates;
- OGW's study stratifies its VCR values into Urban areas, which can be taken as representative of the Inner Metro area and provide more granularity in the small & medium commercial VCR estimate than does the AEMO study; and
- OGW's study uses a more targeted survey for commercial customers than AEMO's study does. This recognises that commercial customers incur substantially different types of loss than residential customers - in particular they suffer loss in their ability to generate and collect revenue if there were to be an electricity outage.

7.2.2 Large commercial (>160 MWh pa electricity consumption)

We have elected to use OGW's VCR estimate for large commercial customers on Urban feeders ($29.96/kWh - $2012 Table 5-1) as the basis of our VCR estimate for large commercial customers in the Inner Metro area, for the following reasons;

- OGW's study stratifies its VCR estimate into results for large customers on urban feeders, which corresponds to the Inner Metro area and provides more granularity than AEMO's VCR estimates;
- The sample size used by OGW is sufficiently large and no caution is given by OGW as to the robustness of the VCR estimate;
- The RSE for OGW's VCR estimate for large commercial customers on urban feeders is 24.6%, which has OGW's value falling within AEMO's +/- 30% margin of error for all its large commercial VCR estimates;
- OGW's study uses a more targeted survey for commercial customers than does AEMO's study. As noted earlier, this recognises that commercial customers incur different types of loss than residential customers.

The observed trend in both the AEMO VCR study and the OGW VCR study of large commercial businesses (ie those consuming over 160MWh per annum) having lower VCR values than small and medium sized commercial businesses is not surprising. Appendix A.1 discusses the findings of our research into this trend.

7.3 Results

We have weighted the customer specific VCR derived above for the Inner Metro area according to the energy consumption demand profile of each customer type within the Inner Metro area, which is given in Table 7-1 below. For example, residential customers make up 37% of the electricity consumption within Sydney's Inner Metro and the Inner Metro residential VCR estimate is given a 37% weighting in the aggregate Inner Metro VCR estimate).

Table 7-1 : Inner Metro electricity consumption – demand weighting by customer type

Customer category	Energy consumption (GWh)	Demand weighting
Residential	29,611	37%
Small commercial(< 40 MWh pa)	5,694	7%
Medium commercial (40-160 MWh pa)	5,194	7%
Large commercial (>160 MWh pa)*	38,514	49%

The final step in calculating a final aggregate VCR estimate for the CBD is to index the base VCRs to 2015/16 dollars and then apply a loss factor of 3.9% as per Ausgrid's calculation.[49] An aggregate VCR is then formed by applying the demand weighting profile given inTable 7-1.

Applying the approach described in Sections 7.1 and 7.2 to derive the residential and commercial VCR estimates, and then bringing them together into an aggregate VCR number as described above results in an **Inner Metro VCR of $90/kWh (in 2015/16$),** with an RSE of 7.5%.

We note this value is approximately double Ausgrid's estimate of $40 for the average VCR for the Inner Metro area. Our higher estimate arises from our adoption of OGW's VCR estimate for small & medium commercial customers in urban areas; which is significantly higher than AEMO's commercial VCR estimate

[49] TransGrid / Ausgrid : *Powering Sydney's Future Value of Customer Reliability in the Inner Metropolitan Area Selection Methodology Report, 26 May 2016,* p. 10.

for NSW as a whole. We believe the value of $90/kWh to be more representative of the likely commercial VCR in the Inner Metro area, because of the stratification made by OGW into the specific Urban sub-region.

As with our estimate of the VCR for the CBD areas, we consider that our estimate is likely to *under-estimate* the true VCR of Inner Metro customers for the types of long-duration outages that are being considered for the PSF study, as neither the AEMO nor the OGW VCR studies considered long duration outages.

8. Conclusion

We have thoroughly reviewed both AEMO's 2014 VCR study and OGW's 2012 VCR study, as well as relevant industry reports on calculating aggregate VCRs for Australian jurisdictions.

Our conclusions from this review are:

- A key component of the PSF study is focused on options that would address low probability, but high impact supply outages in the CBD and Inner Metro sub-regions. AEMO's VCR values are not stratified beyond a NSW state-wide level and do not differentiate between the expected higher value of electricity reliability in Sydney's CBD & Inner Metro sub-regions, as opposed to the rest of the state;
- AEMO's 2014 VCR study also did not include an assessment of the VCR associated with long duration outages. We therefore consider that AEMO's 2014 VCR estimates will *understate* the VCR values associated with the locations and types of outages that are the focus of the PSF study, particularly for commercial customers; and
- Whilst OGW's study stratifies its VCR values into CBD and Inner Metro sub-regions, the sample size for commercial customers in the CBD is small (11 in total) and these VCR values should be used with caution. In contrast, OGW's VCR estimates for both large and small & medium commercial customers on Urban feeders have a sufficiently large sample size and are considered robust.

As a consequence of these observations, we have applied different methods to estimating VCR in each sub-region (ie, CBD vs Inner Metro).

For the Sydney CBD we have estimated a range for the VCR of $150-$192/kWh ($2015/16). This range shows good alignment with Ausgrid's CBD VCR estimate based on its economic contribution uplift factor, which resulted in an estimate for the CBD VCR of $191/kWh ($2015/16).

For the Inner Metro VCR, we have used OGW's estimates of the VCR for commercial customers attached to Urban feeders, as representative of the VCR for customers in the Inner Metro area. These VCR estimates are more stratified than AEMO's NSW-wide estimates of commercial VCR. They also have low relative standard errors and are based on targeted surveys for commercial customers.

Our approach results in an estimate of the Inner Metro VCR of $90/kWh ($2015/16) with a relative standard error of 7.5%. This value is significantly higher than that obtained by Ausgrid by averaging AEMO's commercial VCR estimates. However, we believe the higher Inner Metro VCR of $90/kWh to be more representative of the particular customer composition that makes up the Inner Metro sub-region of Sydney.

In both cases the VCR studies we have drawn on to derive our estimates do not consider long duration outages. We therefore consider that in the case of the PSF study, where the reduction in long duration outages is a key focus, our VCR estimates above will *under-estimate* the true VCR value, for both the CBD and Inner Metro sub-regions.

We agree with recent observations by IPART that the only robust way to derive appropriate VCR estimates would be to conduct a new VCR study, focused on highlighting differences in VCR between different geographic areas in NSW and different customer groups. The study would also need to explicitly consider the VCR associated with low probability but high impact, long duration outages, such as those being addressed by the PSF study.

A1. Research into the observation that large commercial customers have a lower VCR than small and medium commercial customers

Studies consistently estimate smaller VCRs for large commercial businesses, compared to small and medium commercial businesses. For example, as discussed in the body of this report:

- Oakley Greenwood's 2012 VCR estimates (in $2012) are for:[50]
  - Businesses <160 MWh pa: $413.12/kWh
  - Businesses ≥ 160 MWh pa: $53.30/kWh
- AEMO's 2014 VCR estimates for commercial businesses (in $2014) are:[51]
  - Small size (generally <40 MWh pa): $57.13/kWh
  - Medium size (generally 40-100 MWh pa): $57.28/kWh
  - Large size (generally >100 MWh pa): $42.13/kWh

AEMO noted that its estimation of a lower VCR for larger businesses is consistent with previous studies conducted domestically and internationally, and suggested this may be due to larger businesses establishing back-up systems to mitigate the effect of outages.[52]

There is evidence for this in Sydney. A study conducted by SKM in 2008 identified 194 standby generators (predominantly diesel) in the Sydney CBD intended to supply electricity to a building in the event of an outage.[53] It is probable that the number of emergency generators in the CBD has increased since SKM's study was undertaken – newly constructed buildings commonly feature emergency generators, for example:

- Commonwealth Bank Place at Darling Quarter was built with two 1650kVA back-up emergency generators[54];
- Liberty Place was constructed with stand-by power generators that power base essential services[55];
- 420 George St was built with two 2200 kVA emergency diesel generators[56]; and
- 200 George St has a standby generator to accommodate 'realistic load backup'.[57]

However, we note that these back-up generation arrangements would likely have limited effectiveness for prolonged outages, such as are being considered as part of the PSF study. The majority of diesel generators are rated for standby or emergency use, which applies to generators that will be used to short periods of time when the main supply fails and are typically used for less than 16 hours a year.[58] Generally, emergency generators are used to ensure that essential services in a facility (ie, lifts, fire services, medical and electronic equipment) receive a continuous supply of electricity. Emergency generators have been designed with this type of usage in mind. Diesel generators typically draw fuel from a day tank, which has capacity to

[50] Oakley Greenwood, *Final Report - NSW Value of Customer Reliability,* May 2012, p.42.

[51] AEMO, *Final Report – Value of Customer Reliability*, September 2014, pp.23-24.

[52] AEMO, *Final Report – Value of Customer Reliability*, September 2014, p. 1.

[53] SKM Consulting, *Standby generation for demand management,* April 2008.

[54] Mpower website: https://www.mpower.com.au/solutions/cogeneration/commonwealth-bank-place-case-study/

[55] Liberty Place website: http://libertyplace.com.au/wp-content/uploads/2014/01/LP1735-Liberty-Place-Tech-Specs-ANZ-Tower_V4.pdf

[56] 420 George St website: http://www.420georgestreet.com.au/Core/Pages/GetFile.aspx?id=1b052892efb747f48eb4

[57] Mirvac website: http://www.mirvac.com/uploadedFiles/Main/Content/200%20George%20leasing%20brochure%20226%20x%20320_v18_flipbook%20version.pdf

[58] Econnect, *Demand management and planning project – preliminary feasibility study, December 2006,* p. 24.

operate the generator for a few hours, after which fuel is drawn in from a main store tank (which typically has a capacity 10 times that of the day tank). [59] For example:

- 20 Bond St: maximum duration of day tank is 4 hours;[60]
- 55 Market St: maximum duration of day tank is 4 hours;[61]
- 153 Clarence St: maximum duration for day tank is 6.5 hours; [62] and
- 453-461 Kent St: maximum duration for day tank is 11 hours.[63]

Furthermore, running emergency generators for extended periods can be unsafe. During the 1998 Auckland power outage, emergency generators led to fires due to running beyond their intended utilisation time and the refilling of generators while they were running.[64] Therefore, the ability of emergency generators to mitigate the effects of a prolonged outage appears likely to be limited.

The studies that find VCR estimates for large businesses are lower than those of small and medium sized businesses due to investments in standby generators have relatively short durations:

- the Oakley Greenwood 2012 study uses outage durations of 20 minutes; 1 hour; 2 hours; 4 hours; 8 hours; or 24 hours; [65] and
- the AEMO 2014 study has scenarios with outage durations of 1 hour, 3 hours, 6 hours or 12 hours[66].

Therefore, the VCR estimates for large businesses faced with an outage of prolonged duration is likely to be under estimated by both the Oakley Greenwood and AEMO VCR studies.

[59] Econnect, *Demand management and planning project – preliminary feasibility study, December 2006,* p. 23.

[60] Econnect, *Demand management and planning project – preliminary feasibility study, December 2006,* p. 35.

[61] Econnect, *Demand management and planning project – preliminary feasibility study, December 2006,* p. 40.

[62] Econnect, *Demand management and planning project – preliminary feasibility study, December 2006,* p. 45.

[63] Econnect, *Demand management and planning project – preliminary feasibility study, December 2006,* p. 49.

[64] Davis, G., 1999, *The Auckland electricity supply disruption 1998: emergency management aspects*, Australian Journal of Emergency Management, p. 45.

[65] Oakley Greenwood, *Final Report - NSW Value of Customer Reliability*, May 2012, p.14.

[66] AEMO, *Final Report – Value of Customer Reliability*, September 2014, p.11.

A2. Research into the impact on customers of prolonged outages

It is widely understood that the impact of an electricity outage depends on its duration. However, the cost and effects of prolonged outages (ie of more than 24 hours) have not been widely published or analysed in the literature on VCRs.

Below we summarise the effects and impacts of a prominent prolonged outage; that experienced by Auckland in 1998. Not all impacts and costs can be quantified, but the following summary describes the wide-ranging impacts on citizens, businesses and public services.

Auckland 1998 outage

On 20 February 1998, downtown Auckland lost power when the four cables that supplied the area's electricity all failed. The outage lasted for five weeks.[67] At the time 8,000 businesses, employing 70,000 people were located in Auckland's central business district and 6,000 people resided there, largely in high-rise apartments. [68]

In response to the outage, Mercury Energy – the power company responsible – brought in generators from other areas of New Zealand and Australia. The largest generators were used to reinforce Mercury's substations, while smaller generators were given to Mercury's major customers.[69] A large proportion of generators in New Zealand were moved to Auckland.[70]

There was a significant impact on corporate businesses located in the CBD. The emergency power supplies of office buildings were insufficient to power air-conditioning, lifts and computers, which meant employees could not work in their offices. [71] Many large organisations mitigated the effects by moving operations outside the CBD, and in some cases, outside New Zealand. Many companies distributed staff between regional offices, or asked employees to work from home. [72] For example;

- The Bank of New Zealand closed its nine CBD branches, and its transferred employees to other branches;[73]
- A leading law firm (Buddle Findlay) moved the location of its computer network and installed ISDN in four partner's homes and a motel; and
- Qantas moved its entire Auckland office to Sydney.[74]

Despite these workarounds, overall productivity was reduced as access to information and communication were impeded. For example, retrieval of paper documents required a trip to the CBD and many companies had inflexible computer systems that needed the network wiring in their particular building.[75] Re-establishing communication with employees and clients required changes to computer systems, and telephone and fax lines.

---

[67] Wired Magazine's website: http://www.wired.com/1999/04/life/

[68] Wired Magazine's website: http://www.wired.com/1999/04/life/

[69] Wired Magazine's website: http://www.wired.com/1999/04/life/

[70] Ackermann, T. and Muller, Dorte, 1998, *Auckland unplugged*, Electric Light and Power, vol. 76, no. 11, pp. 20-22.

[71] Ackermann, T. and Muller, Dorte, 1998, *Auckland unplugged*, Electric Light and Power, vol. 76, no. 11, pp. 20-22.

[72] Ackermann, T. and Muller, Dorte, 1998, *Auckland unplugged*, Electric Light and Power, vol. 76, no. 11, pp. 20-22.

[73] Wired Magazine's website: http://www.wired.com/1999/04/life/

[74] Ackermann, T. and Muller, Dorte, 1998, *Auckland unplugged*, Electric Light and Power, vol. 76, no. 11, pp. 20-22.

[75] Davis, G., 1999, *The Auckland electricity supply disruption 1998: emergency management aspects*, Australian Journal of Emergency Management, p. 45; Wired Magazine's website: http://www.wired.com/1999/04/life/

An additional cost to businesses was security, with some companies engaging security staff to protect their premises.[76]

Businesses located in the CBD that relied on commuters as their customer base were also impacted, as foot traffic in the city fell. Of the approximately 1,000 retailers operating in Auckland's CBD, about 200 remained open through the outage. [77] Businesses operating in hospitality and entertainment industries saw similar reductions in customer numbers.[78] There is evidence that the power outage led to small businesses going out of business, due to lack of patronage.[79] The outage also led to losses, for example, restaurants without access to generators had to dispose of the contents of their freezer. [80]

The tourism industry in Auckland was significantly affected, as the city's tourist facilities lost power. [81] Reports of the outage had a negative effect on tourism, 30 to 40 percent of hotel reservations were cancelled, although 25 hotels in the CBD continued to run on generators.[82] A large tourist vessel cancelled a three day visit and moved on to the next port.[83]

Many governmental organisations operating in Auckland were also disrupted during the power outage. For example:

- the Fire Department received an unusually high number of emergency calls, mostly related to generators – fumes from operating generators without sufficient ventilation, fires due to refuelling generators while they were running and fires due to generators running for extended periods;[84]
- traffic control was also made difficult, as traffic lights were only intermittently supplied with electricity; [85]
- government departments based in Auckland's CBD were unable to carry out regular businesses, for example, the Land Title Office could not process thousands of transactions; and [86]
- the Health Department was concerned that food outlets were retaining food that had insufficient refrigeration. [87]

[76] Ackermann, T. and Muller, Dorte, 1998, *Auckland unplugged*, Electric Light and Power, vol. 76, no. 11, pp. 20-22.

[77] Wired Magazine's website: http://www.wired.com/1999/04/life/

[78] Davis, G., 1999, *The Auckland electricity supply disruption 1998: emergency management aspects*, Australian Journal of Emergency Management, p. 45.

[79] Wired Magazine's website: http://www.wired.com/1999/04/life/

[80] Ackermann, T. and Muller, Dorte, 1998, *Auckland unplugged*, Electric Light and Power, vol. 76, no. 11, pp. 20-22.

[81] Davis, G., 1999, *The Auckland electricity supply disruption 1998: emergency management aspects*, Australian Journal of Emergency Management, p. 45.

[82] Wired Magazine's website: http://www.wired.com/1999/04/life/

[83] Davis, G., 1999, *The Auckland electricity supply disruption 1998: emergency management aspects*, Australian Journal of Emergency Management, p. 45.

[84] Davis, G., 1999, *The Auckland electricity supply disruption 1998: emergency management aspects*, Australian Journal of Emergency Management, p. 45.

[85] Davis, G., 1999, *The Auckland electricity supply disruption 1998: emergency management aspects*, Australian Journal of Emergency Management, p. 45.

[86] Davis, G., 1999, *The Auckland electricity supply disruption 1998: emergency management aspects*, Australian Journal of Emergency Management, p. 45.

[87] Davis, G., 1999, *The Auckland electricity supply disruption 1998: emergency management aspects*, Australian Journal of Emergency Management, p. 45.

HOUSTONKEMP
Economists

Sydney
Level 40
161 Castlereagh Street
Sydney NSW 2000

Phone: +61 2 8880 4800

Singapore
12 Marina View
#21-08 Asia Square Tower 2
Singapore 018961

Phone: +65 6653 3420

Appendix D – BIS Shrapnel Demand Forecast Report

BIS Shrapnel

ENERGY AND DEMAND ASSESSMENT

FOR TRANSGRID'S "*POWERING SYDNEY'S FUTURE*" PROJECT

26 SEPTEMBER 2016

Disclaimer & Attribution

Although great care has been taken to ensure accuracy and completeness in this project, BIS Shrapnel Pty Ltd has not independently verified, and does not accept responsibility for, the completeness and accuracy of the factual information on which its opinions and assumptions are based, which information has been derived from public authorities or government bodies.

This report is the product of extensive analysis, projections and modelling undertaken by BIS Shrapnel. This study was led by Darren Anderson with support from Husam El-Tarifi.

Darren Anderson
BIS Shrapnel Pty Limited
Level 8, 99 Walker Street
North Sydney NSW 2060, Australia
T: +61 (02) 8458 4200
F: +61 (02) 9959 5795

Transgrid Job Reference Number: T65635/40
BIS Shrapnel Job Number: A6462

Contents

01

OVERVIEW

Background

Deliverables and Context

Transgrid commissioned BIS Shrapnel to undertake an assessment of energy and demand in the Sydney metropolitan area, in relation to the “Powering Sydney's Future” project.

This area is defined in the figure to the right as covering the substations marked in red.

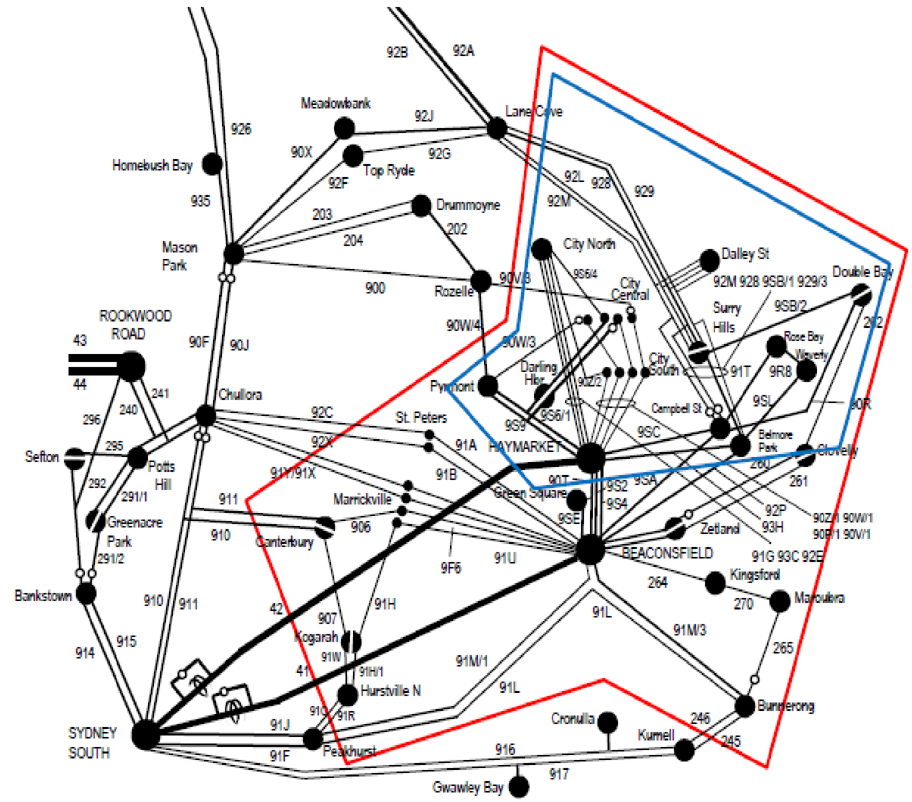
BIS Shrapnel have previously undertaken energy and demand forecasts for the NSW electricity network leasing transactions, which involved:

- An assessment of the historical underlying drivers of energy for TransGrid, Ausgrid, and Endeavour Energy’s businesses.
- The production of a 30 year forecast, including 10 per cent and 90 per cent probability of exceedance margins.

Through these economic, energy and demand forecasts, we have had an opportunity to learn which approaches work well, and which do not. Furthermore, we regularly analyse how our previous forecasts have performed against actuals. We are using these results (and conversations with other stakeholders with an interest in long-term forecasts) to challenge our prior conceptions of appropriate methodologies.

The approach we develop in this report reflects BIS Shrapnel’s current and best assessment of how we can best use our resources to identify the magnitude and directionality of key shifts in energy and demand for the Sydney Metropolitan area over the coming years.

Defining the Sydney Metro area: Zone Substations Within the Red Border



Approach

We use underlying energy to forecast peak demand.

Energy

We have utilised an end-use analysis to forecast energy consumption in the Sydney Metro area. This approach draws upon our in-house strength in understanding individual industries and forecasting their outlook. We have great confidence in this approach as it allows us to isolate the key drivers of change in electricity consumption.

In this analysis we found:

- Recent declines in energy consumption were broad based – occurring in both residential and commercial areas.
- Falls were mainly driven by a response to higher prices and technology driven improvements in energy efficiency.

Peak Demand

In contrast with energy, peak demand requires econometric modelling given the substantial day to day variation that is caused by temperature and seasonality. We use an econometric model to analyse and forecast peak demand, with seasonal variables capturing the variation.

The approach we have taken is to model the link between demand and energy.

This allows us to rely on energy forecasts for broad based, long term shifts in consumption patterns while using the statistical modelling to identify the effects of shorter term movements in temperature and seasonality.

Source: Ausgrid Data, BIS Shrapnel

Key Findings

Energy and peak demand are expected to trend up over the next 30 years.

Forecasts

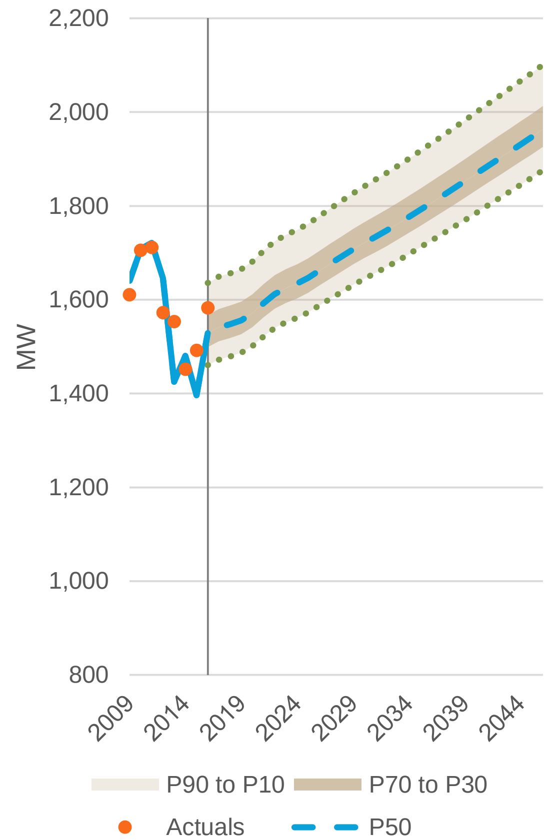
We anticipate energy consumption in the Sydney Metro area to have bottomed out in 2014, with steady growth expected over the forecast horizon.

Underlying growth in the number of customers (residential and commercial) will be the key factor shaping the profile of energy in the coming years.

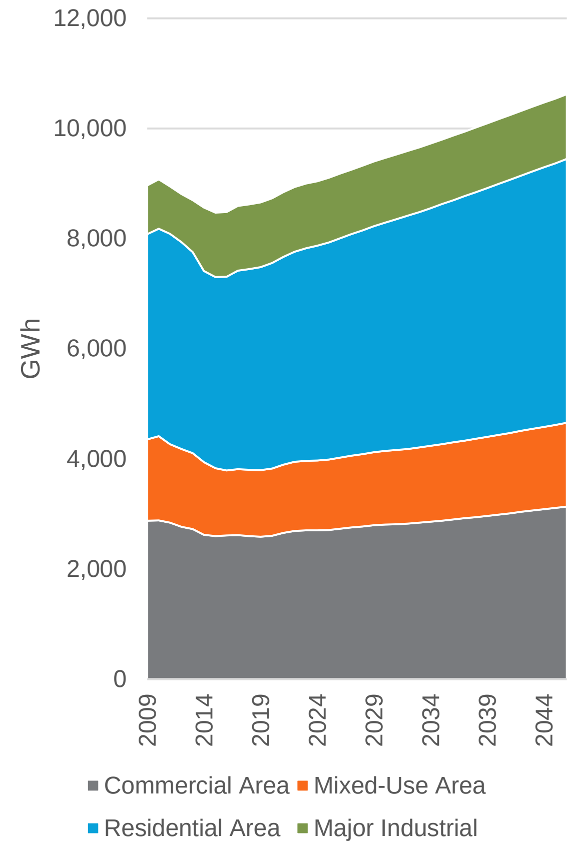
We forecast energy consumption to grow by a cumulative 25 per cent from 2016 to 2046. This represents a compound annual growth rate of 0.8 per cent per annum.

Peak demand is also expected to grow over the forecast period roughly tracking energy consumption. We forecast summer peaks (and therefore overall peak demand) to grow by 29 per cent from 2016 to 2046. This represents a compound annual growth rate of 0.9 per cent.

Historical and Forecast Peak Demand



Historical and Forecast Energy



Source: Ausgrid Data, BIS Shrapnel

02

ENERGY

Understanding History – Ausgrid Catchment

Households and key segments of the manufacturing sector have driven falls in electricity consumption in recent years.

Energy Consumption has Declined Significantly Since 2009

The Sydney Metropolitan area is a subset of Ausgrid's catchment, which covers the eastern half of the Greater Sydney area, as well as the Central Coast and Hunter regions.

Sales of electricity in Ausgrid's entire catchment have fallen significantly, down 17% in 2014 from its peak in 2009.

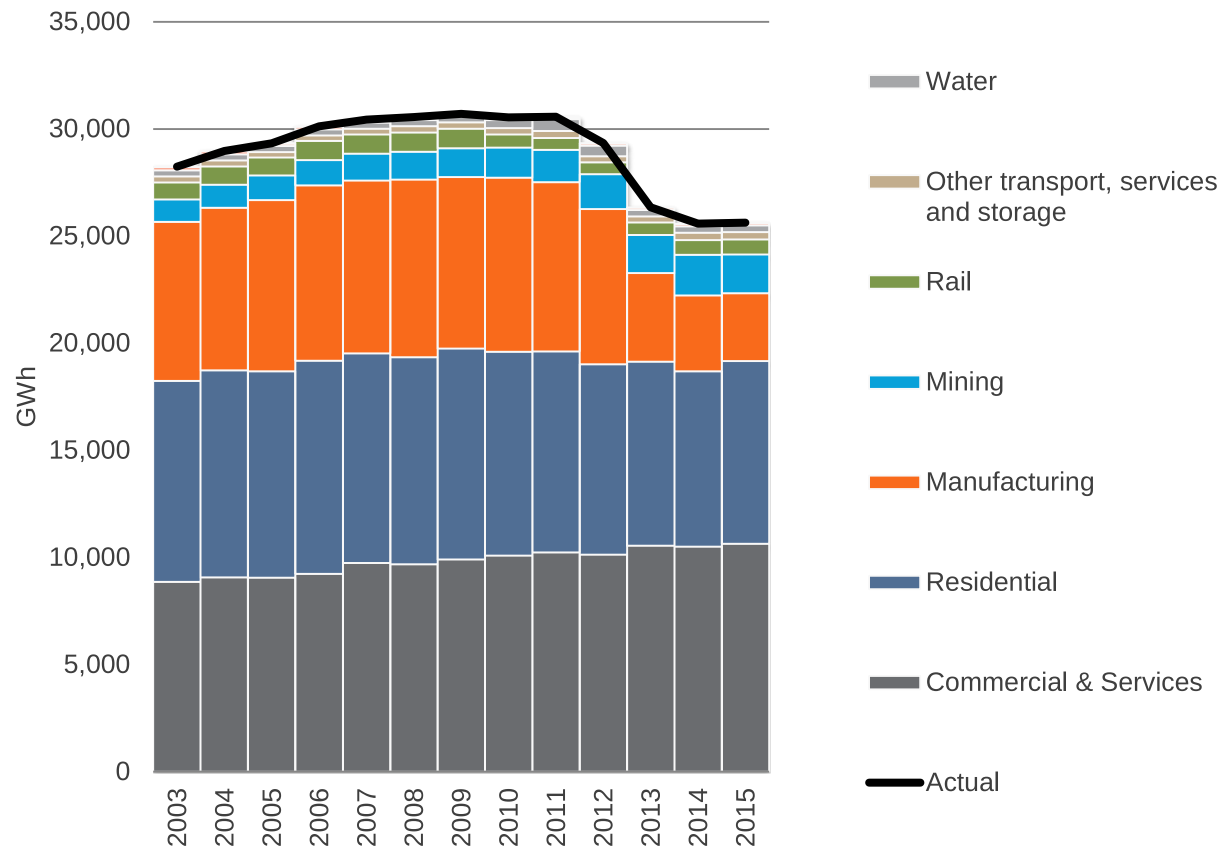
This fall was driven by:

- Declines in consumption amongst households.
- The decline of key subsectors of the manufacturing industry, especially high energy users such as the Kurri Kurri aluminium smelter in 2012/13.

In this context, BIS Shrapnel has chosen to undertake a bottom-up analysis by end-use sector for modelling energy consumption to explain historical dynamics.

Historical Electricity Consumption by End-use Sector

Whole of Ausgrid Catchment, Financial Years



Source: Ausgrid and Department of Industry Data, BIS Shrapnel. We acknowledge there are some issues with the historical data. We know railroads didn't drop by half and we've noticed a similar issue for water consumption. We use it for compositional purposes and as a sense check against our historical backcasts by end-use sector.

Understanding History – Ausgrid Catchment

The declines in household energy have mainly stemmed from an increase in prices.

Drivers of Change

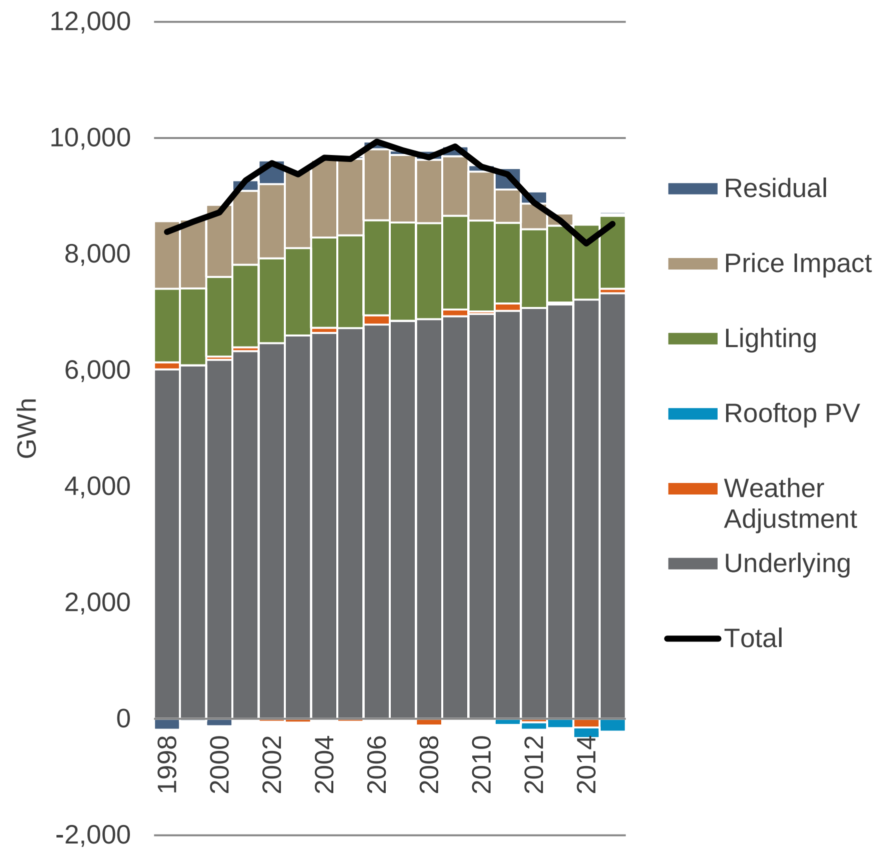
Although the number of residential customers in Ausgrid's catchment has continued to trend up, total electricity consumption has declined. We believe this was driven in-part by a sensitivity to rising prices.

Recent years have seen significant increases in electricity prices, in part due to the introduction of the carbon price and a need to finance investment into the electricity networks. These rising prices resulted in residential users scaling back their use of electricity.

A technology-driven increase in the use of energy efficient lighting (LEDs and CFLs) and the rising use of photovoltaic solar panels have further reduced the energy transmitted through Ausgrid's distribution network.

Historical Ausgrid Residential Electricity Consumption

Financial Years



Understanding History – Sydney Metro Catchment

The Sydney Metro area has seen broadly similar trends in electricity consumption as the Ausgrid catchment as a whole.

Similarities and Differences to Total Ausgrid

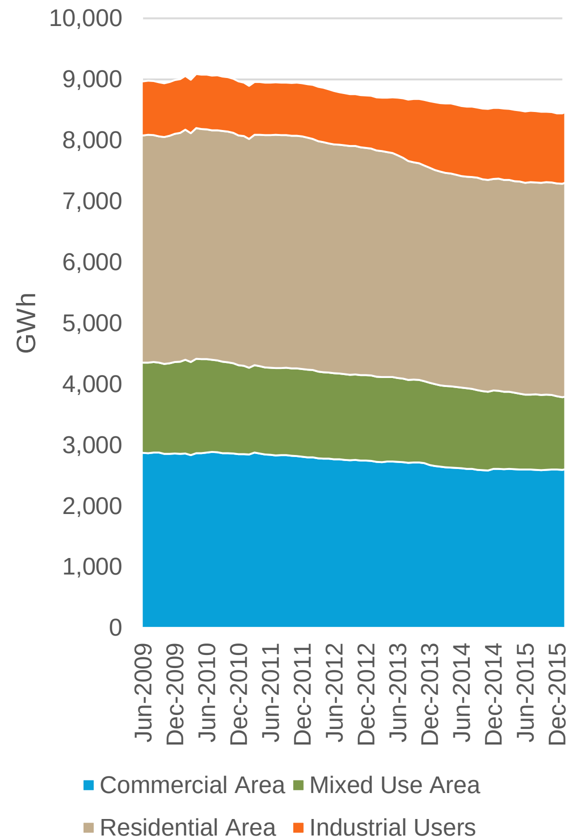
Broadly, electricity consumption in the Sydney Metro area has tended to track Ausgrid's overall energy use.

Areas of difference include:

- Commercial energy use has seen lower growth in the Sydney Metro region in part due to a slower growth in commercial activity.
- Residential energy use has tracked Ausgrid totals when prices increased but has seen a divergence in the last two years when prices fell. Our hypothesis is that this is related to household wealth effects.
- Industrial consumption appears to have undergone a 'one off' increase in consumption in the Metro area. We don't expect this to repeat.

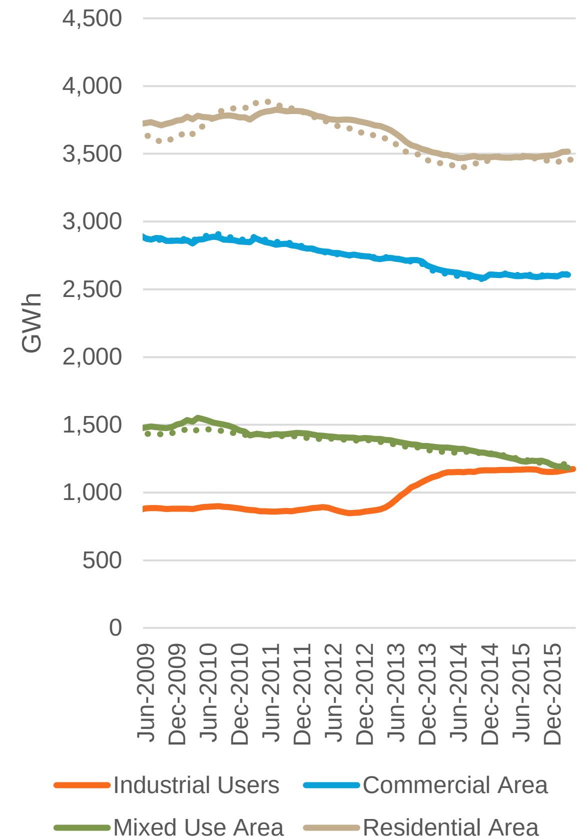
Weather Adjusted Energy Consumption

Moving Annual Totals (MATs)



Weather Adjusted Energy Consumption

MATs, Dotted Lines are Actuals



Data note: Ausgrid supplied BIS Shrapnel with 15 minute interval demand data which we converted into estimates of energy consumption. We used this derived series instead of the annual energy figures provided for Local Government Areas because we can more precisely exclude zone substations outside of the Sydney Metro area and we can use a longer time-series that is available at monthly (or finer) timescales. Commercial and Residential splits are obtained by classifying zone substations into each category.

Residential and Commercial Consumption by Region

Commercial consumption is highly concentrated in the Sydney Metro area.

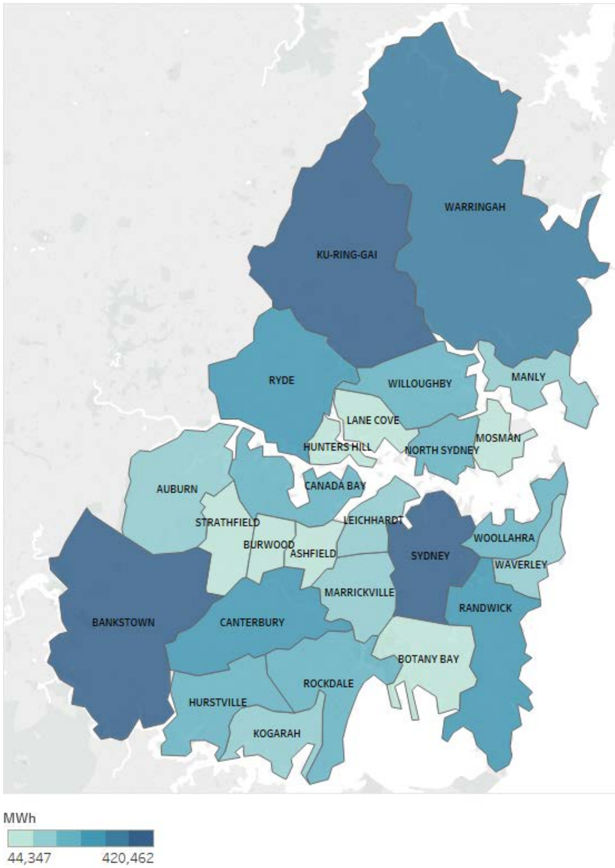
Sydney Metro Area

The Sydney Metro area mainly consists of the "Sydney" Local Government Area (LGA) and surrounding LGAs – such as Marrickville, Botany Bay and Randwick.

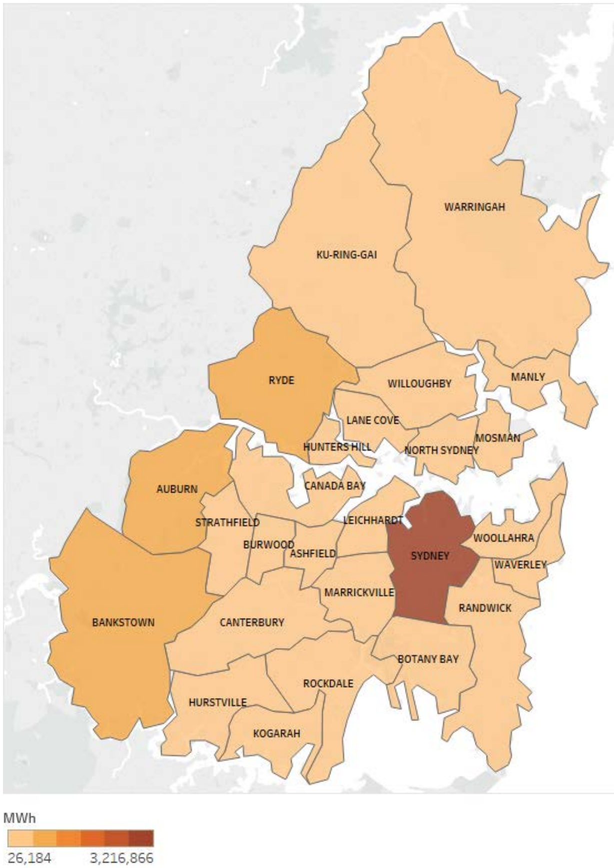
This area features a significant portion of Ausgrid's commercial consumption as well as a sizable share of residential due to the region's relatively high housing density.

Areas outside of defined Metro region include some commercial areas such as Ryde and North Sydney as well as large pockets of population towards the north and west.

Residential Energy Consumption by Local Government Area – 2014/15



Commercial Energy Consumption by Local Government Area – 2014/15



Residential Customers

Comparatively low growth in the number of households in the Sydney Metro area will place a ceiling on potential growth in electricity consumption.

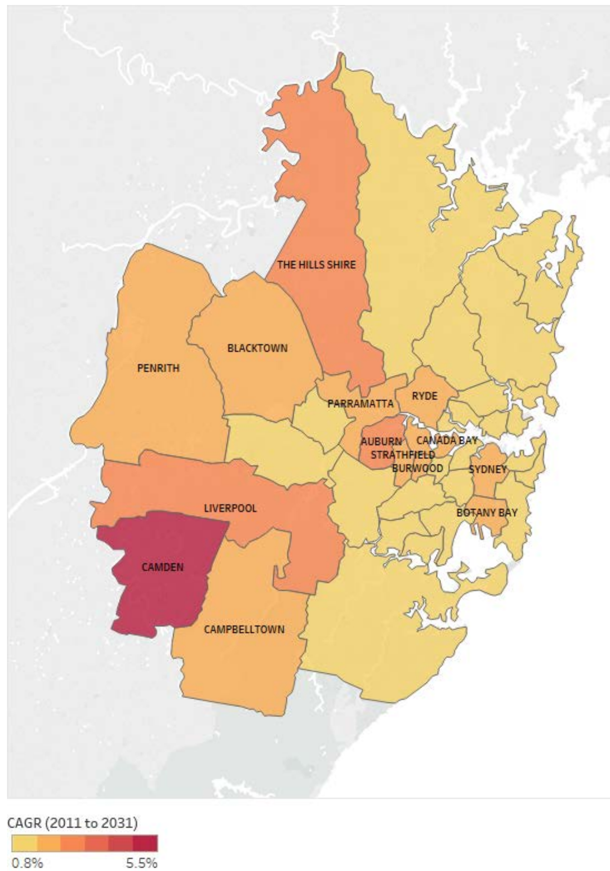
NSW Government Forecasts: The Fastest Growing Regions are Further West

Based on NSW Department of Planning and Environment Forecasts for each Local Government Area (LGA), the fastest growing regions over the next 3 decades are expected to be in the western suburbs of the Greater Sydney area.

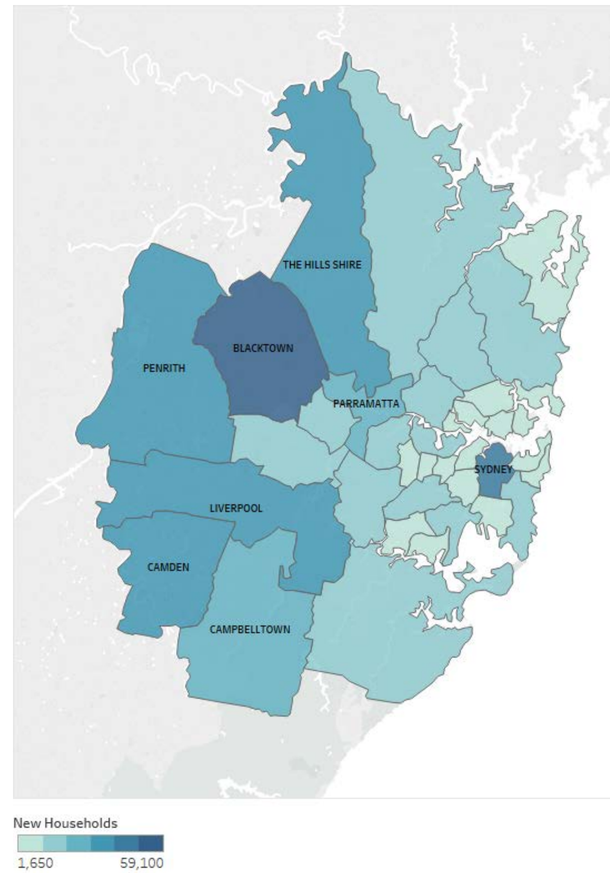
The "Sydney" LGA – encompassing the central business district and immediately adjacent suburbs – is generally expected to be fast growing, but it is surrounded by slow growing areas.

Since our definition of the Sydney Metro area includes these low growth LGAs, the growth in the number of households in our area of interest should be approximately 1.4 per cent per annum between 2011 and 2031 (+140,000 new households). This is in comparison to a forecast average growth rate of 2.0 per cent per annum for the outer western suburbs of Greater Sydney (+330,000 new households).

Sydney – Forecast Growth in the No. of Households by LGA – 2011 to 2031



Sydney – Forecast Increase in the No. of Households by LGA – 2011 to 2031



Residential Area Consumption per Customer

Rising prices from the early 2000s have resulted in falls in consumption in residential areas. Falls in prices over the past two years are not having the reverse effect.

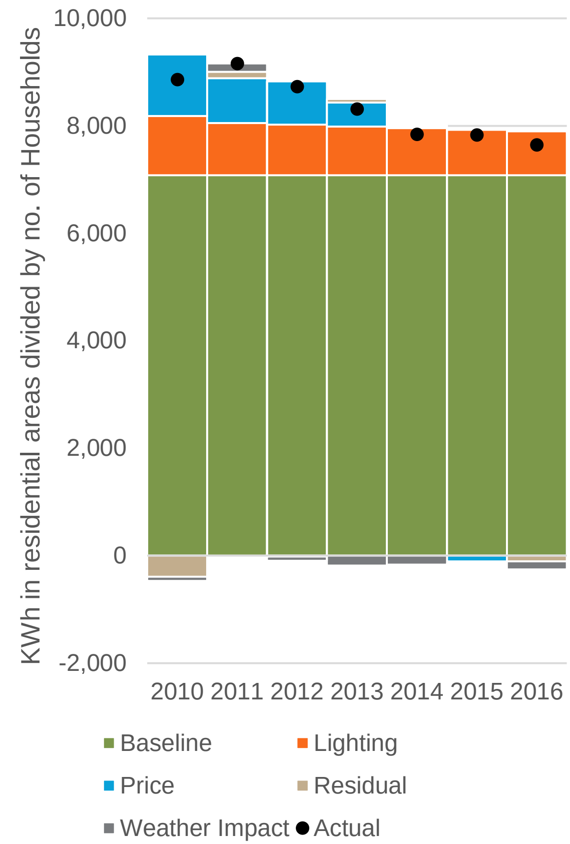
Price Elasticity

Strong growth in electricity prices from the early 2000s to 2014 saw a significant response from residential users. Our analysis suggests that this explains the vast majority of recent declines in residential electricity consumption.

An earlier unpublished analysis of residential electricity consumption by BIS Shrapnel found slight differences in behaviour in the 21 months since prices began to fall after 30 June 2014 between the NSW regions of Ausgrid (covering the eastern half of the Greater Sydney area) and Endeavour Energy (covering the western half). Specifically the analysis found there was a greater response to falling prices in Endeavour than in Ausgrid.

A deeper analysis of Sydney Metro residential customers suggests a similar difference within Ausgrid, where the price reaction has been less pronounced in this region. BIS Shrapnel's working assumption is that while all regions responded to the price increases in a similar manner, they did this using a mix of different strategies. Eastern (and generally wealthier) suburbs favoured permanent changes through purchases of energy efficient appliances more than western (and generally less wealthy) suburbs, whose responses to increasing prices were more behavioural, and could be reversed once prices fell.

Composition of Sydney Metro Residential Substations – Financial Years, Normalised*



Residential Area Consumption per Customer

Limited potential for the uptake of solar PV in the high density Sydney Metro area should see energy consumption from the grid rise significantly faster than in other regions.

Rising energy efficiency

Technology driven rises in energy efficiency have helped moderate electricity consumption over much of the past two decades. Lighting especially has resulted in significant declines as the uptake of CFLs and LEDs has ramped up as the technologies became cheaper and more accessible.

We expect rising energy efficiency to continue to have a significant impact in the future, however, the introduction of new technologies can often have the reverse effect over long time scales (for example, the uptake of air conditioners). In our analysis we have therefore opted to isolate what we believe to be the largest contributor to declines in recent years – lighting – but have avoided making explicit assumptions on the raft of other technologies being developed.

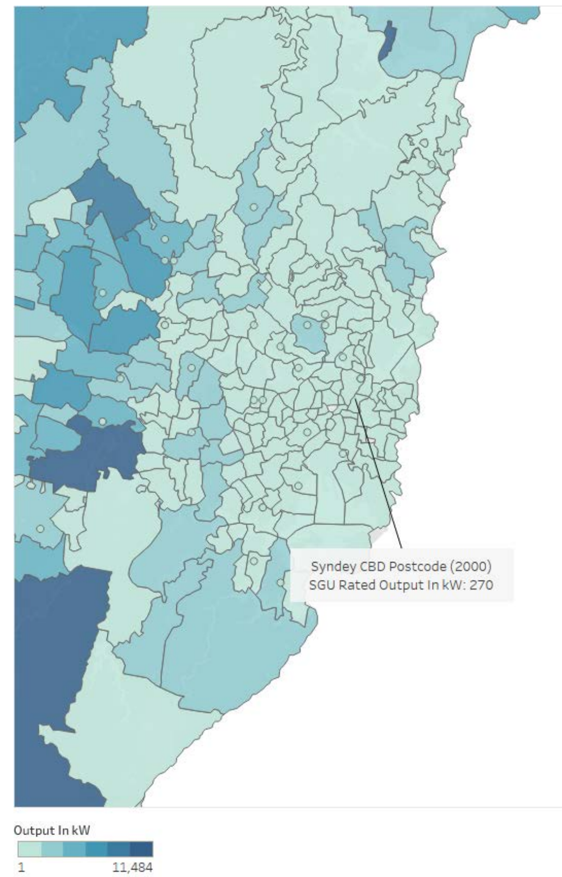
Solar PV

We believe rooftop PV will have a significant dampening effect on residential energy consumption in the NSW region as a whole as it significantly reduces consumption from the grid – especially when battery technologies improve over the coming years.

However, we estimate only 2 per cent of all small scale solar panels in NSW/ACT are in the Sydney Metro area. High density commercial and residential space means relatively little room for growth. We therefore expect minimal impact from this factor.

Since the Sydney Metro area is unlikely to experience any significant reduction in demand from this source, consumption per customer is likely to rise comparatively faster than other regions.

Postcode Data for Small-Scale Solar PV Installations - Sydney



Source: Clean Energy Regulator

Total Residential Zone Consumption

We forecast overall residential consumption to trend up over the next 30 years.

Forecasting Approach and Comments

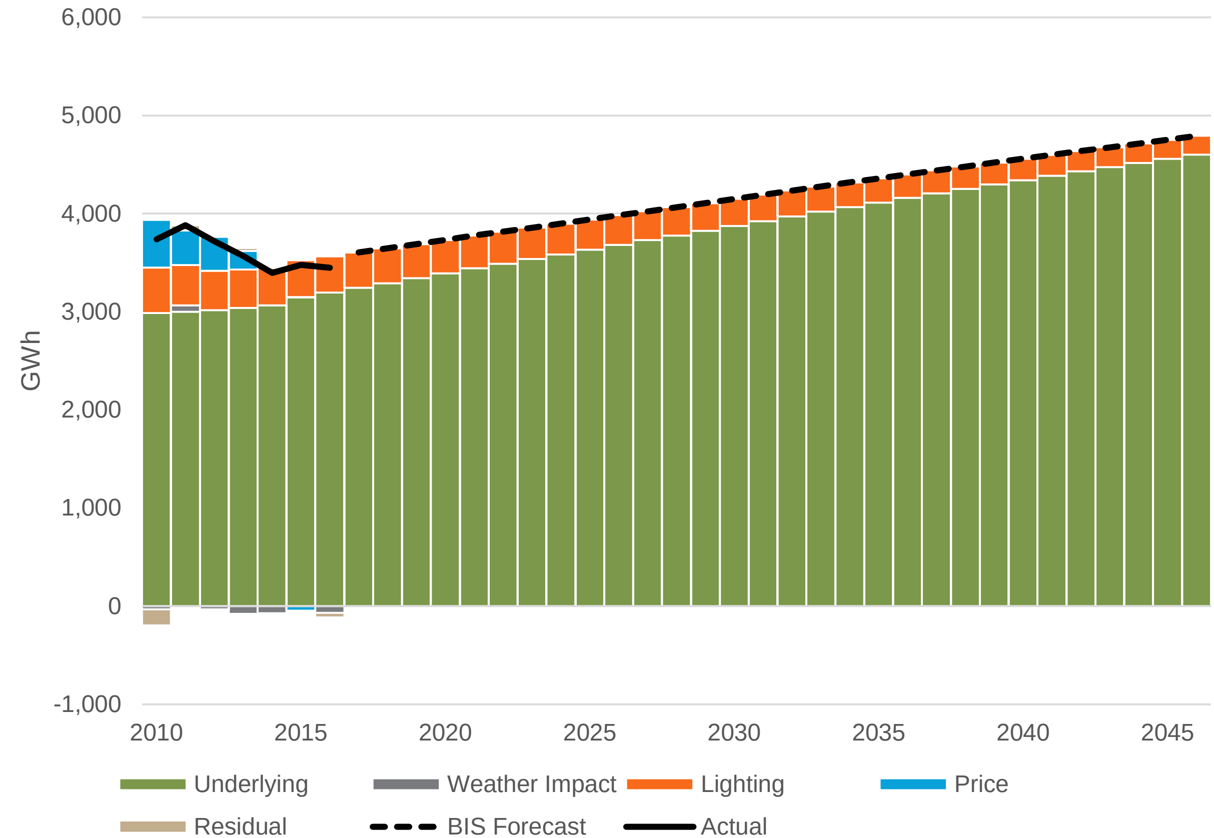
To forecast overall residential area consumption we:

1. Forecast consumption normalised by the number of customers using Energy Information Administration (EIA) assumptions on lighting efficiency and our own judgment on solar PV and prices.
2. We married up the per customer figures with forecasts of household population growth, publicly available from the NSW Department of Planning and Environment.

We forecast a stronger growth profile for the Sydney Metro area than for surrounding regions, largely due to our expectation on the lack of a moderating impact from solar PV in high density areas.

In the Sydney metro region we forecast residential energy consumption to grow by a cumulative 36 per cent from 2016 to 2046. This represents a compound annual growth rate of 1.0 per cent per annum.

Historical and Forecast Residential Zone Electricity Consumption
Sydney Metro, Financial Years



Commercial Zone Consumption

Strong gains in energy efficiency and limited growth in office floor space in recent years have resulted in declining commercial energy consumption.

Drivers of Change

Usable office floor space in the CBD has grown at a slower pace than Non-CBD areas such as Parramatta and Chatswood. An improvement in energy efficiency over the past few years – which we largely attribute to price responsiveness – has then more than offset the slow pace of growth in office space to result in declining energy consumption.

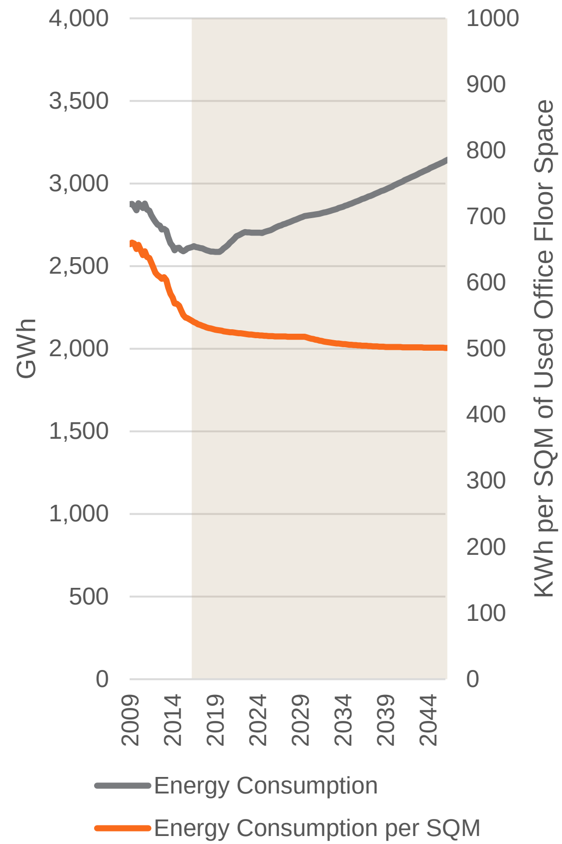
We use office floor space in our modelling because it directly captures the size of the office market and employment and indirectly captures shifts in retail activity. These are all key drivers of commercial energy consumption.

We forecast commercial energy consumption using EIA assumptions on commercial lighting efficiency and BIS Shrapnel's own forecasts of occupied floor space.

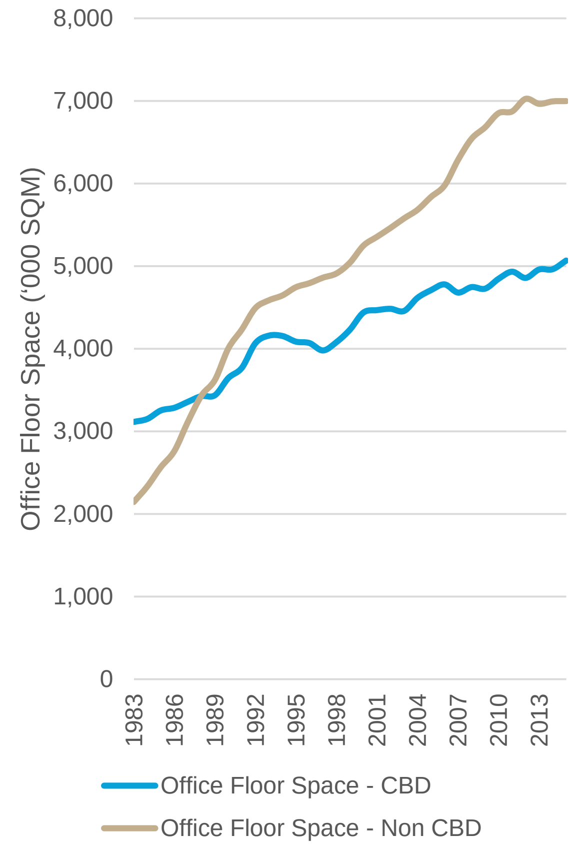
Overall, we expect rising investment in the CBD area will drive increases in commercial energy consumption at an average rate of 0.6 percent per annum.

Assuming prices track inflation over the forecast period, further significant reductions in energy use per square meter of floor space should be more subdued.

Commercial Energy Consumption
Financial Years



Sydney Office Usable Floor Space
Calendar Years



Source: Property Council of Australia, BIS Shrapnel

Industrial Consumption

Industrial consumption is assumed flat over the forecast period.

Forecast Assumption

Industrial consumers in our sample are defined as the users of Ausgrid's high voltage lines.

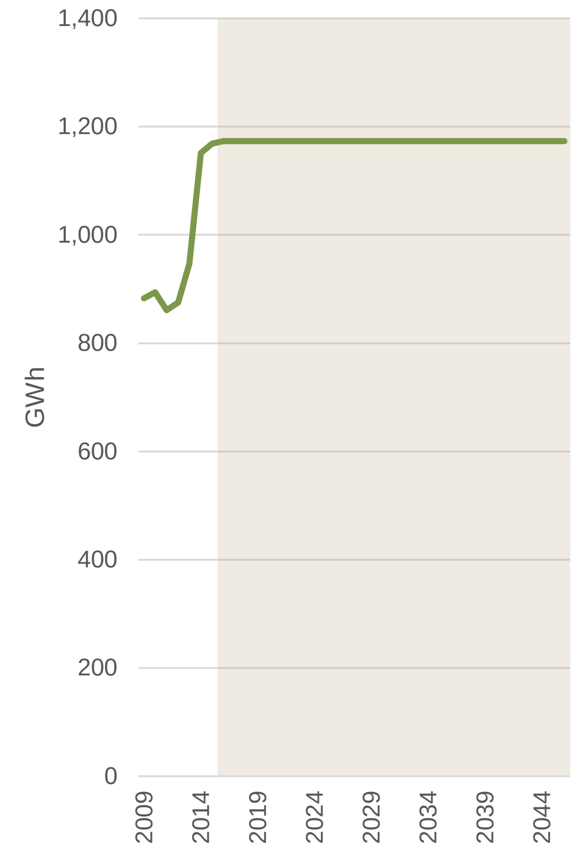
Data for these users is not publicly available and was provided via special request to Ausgrid. The dataset we received included anonymised historical consumption data by customer.

Based on this data we believe the recent uptick in industrial energy consumption is a 'one off'.

We have assumed a flat profile for industrial consumption moving forward because:

- We do not have visibility on who the major industrial users are and we cannot make explicit assumptions on the lifespan and closure of major plants.
- Major industrial consumption is unlikely to be a significant driver of growth in the Sydney Metropolitan area as the high cost of land near the inner city makes it more likely that new industrial users will choose to locate in cheaper locations.
- Our NSW outlook for energy intensive manufacturing – which we assume is represented in this industrial user category – is generally quite weak.

Industrial Energy Consumption
Financial Years



Source: Ausgrid Data

BIS Shrapnel

Total Electricity Consumption in the Sydney Metro Area

We forecast overall electricity consumption in the Sydney Metro area to trend up over the next 30 years.

Drivers of Change

If our assumption on limited real price increases holds, we expect increases in energy efficiency to slow over the near to medium term as the incentives to invest in efficient appliances will not be as large. This is true for commercial and residential areas ('mixed use' regions such as Zetland and Darlinghurst are driven by a combination of these factors).

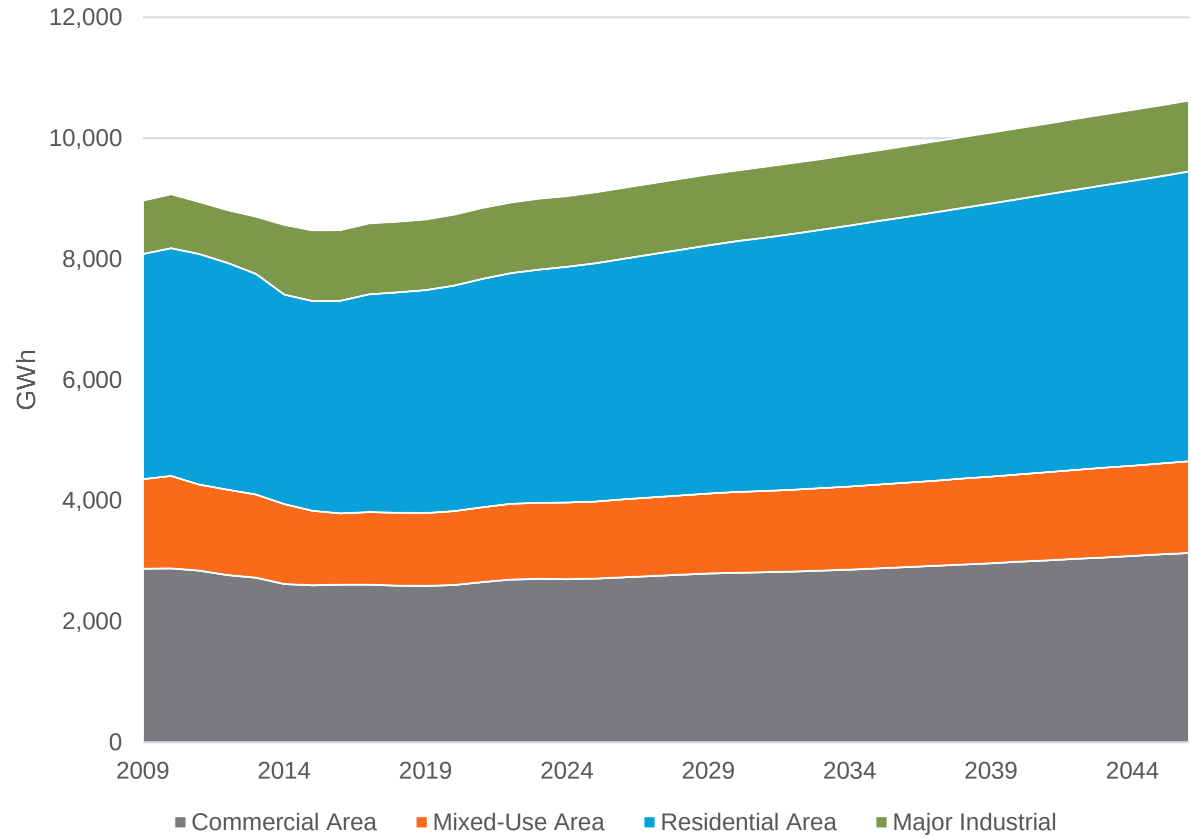
Underlying growth in the number of customers is therefore expected be more important in shaping the profile of energy use in the coming years.

Continued growth in the number of households and in commercial activity in the Sydney Metro area should exceed the reductions associated with energy efficiency, resulting in rising electricity consumption over the next 30 years.

We forecast energy consumption to grow by a cumulative 25 per cent from 2016 to 2046. This represents a compound annual growth rate of 0.8 per cent per annum.

Historical and Forecast Electricity Consumption by End-use Sector

Sydney Metro Area, Financial Years



Source: Ausgrid Data, BIS Shrapnel

03

PEAK DEMAND

Understanding History - Seasonal Profile

Winter features the lowest levels of peak demand in the Sydney Metro area as this is when commercial demand is at its lowest.

Explaining the Seasonal Profile

Electricity demand in commercial areas feature peaks during business hours – where temperatures are generally at their warmest.

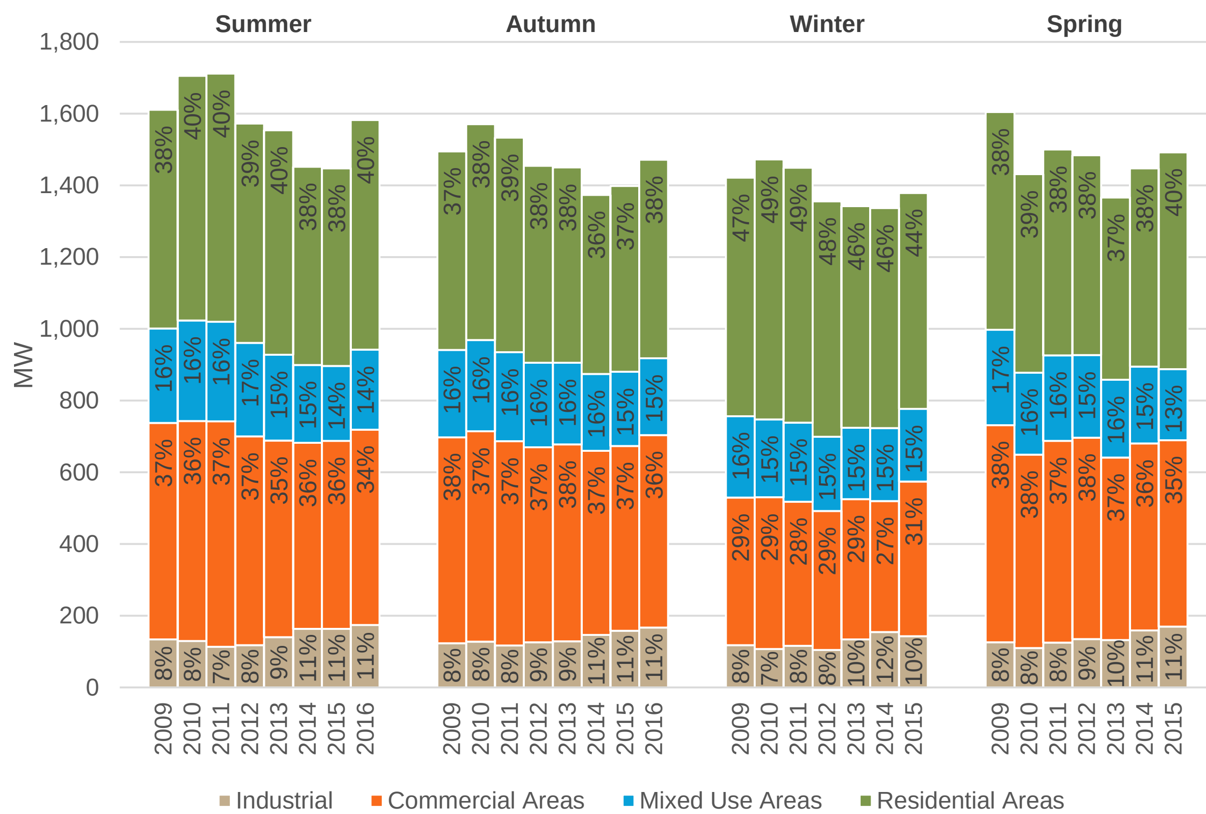
In winter, this means temperatures are not high enough to necessitate as much demand for air conditioning and not cold enough to necessitate demand for heating.

In comparison, residential area peaks are more likely to occur after business hours, when the temperature is colder. This is why residential demand is comparatively strongest in the winter months.

However, the Sydney metro area features a comparatively less prominent residential base – many workers in the CBD will commute from outside of the Metro area. As a result, the stronger showing by residential in winter is overwhelmed by the reduced electricity needs in the commercial sector.

Peak Demand by Season – Sydney Metro Area, Split by End User Category

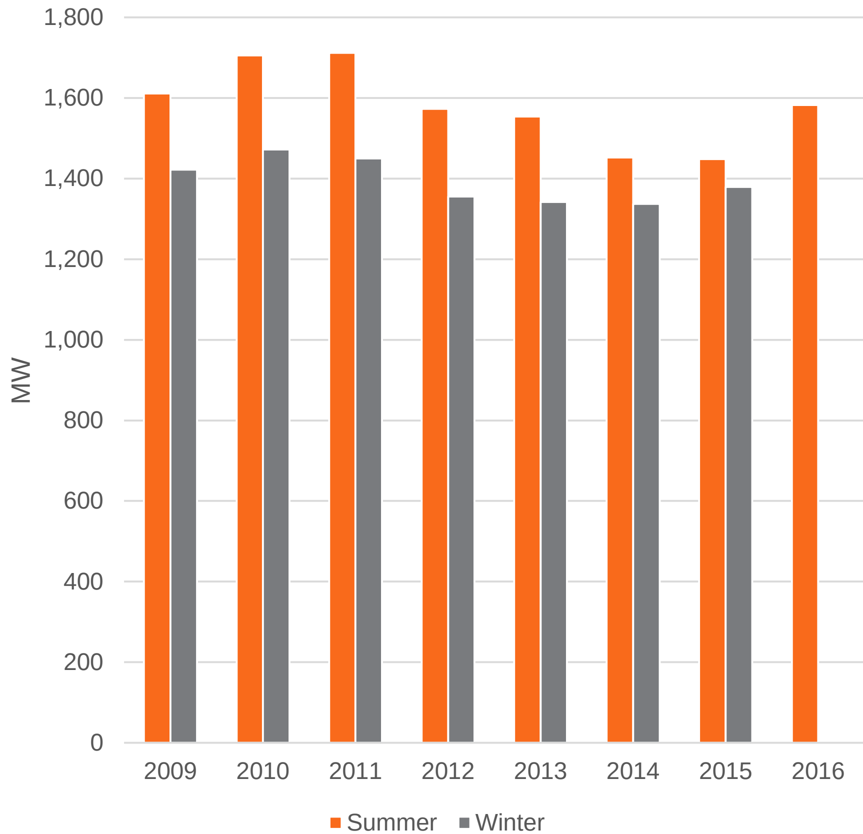
Financial years for summer and calendar years for other seasons



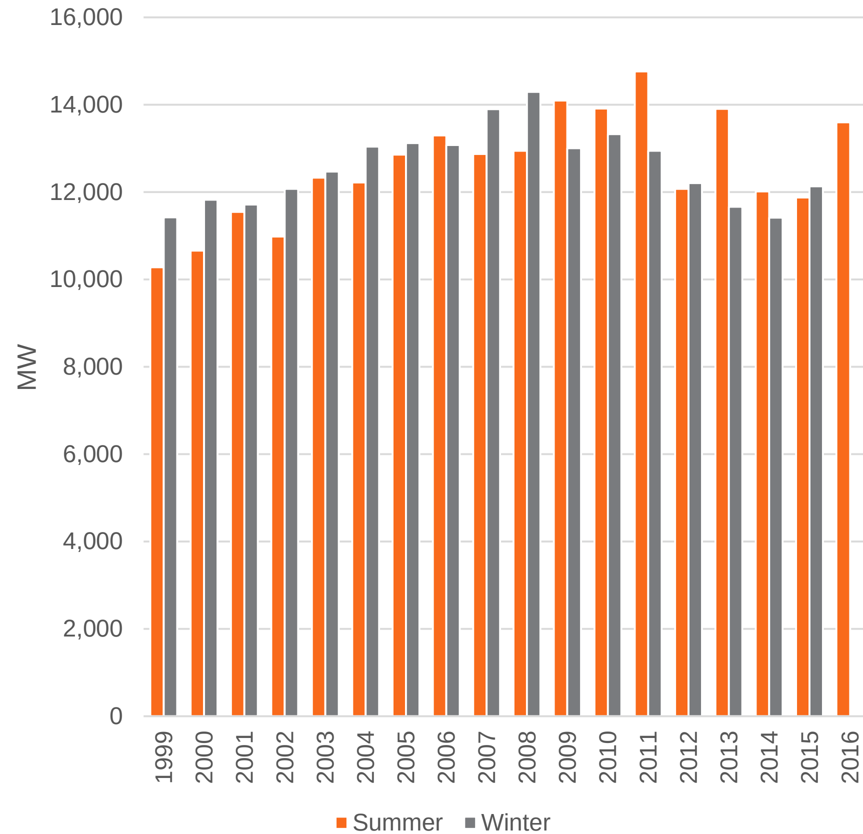
Understanding History - Seasonal Profile

Peak demand in the Sydney Metro area features comparatively higher summer peaks than other areas, mainly due to the region's heavy commercial presence.

Peak Demand by Season – Sydney Metro Area
Financial years for summer and calendar years for winter



Peak Demand by Season – NSW and ACT
Financial years for summer and calendar years for winter



Source: Ausgrid and AER Data

Understanding History - Seasonal Profile

In the Sydney Metro area, winter generally features the lowest levels of peak demand – this is in stark contrast to the Ausgrid catchment as a whole, where winter peaks can exceed summer peaks.

Peak Demand is Driven by High Temperatures

Peak demand in the Sydney Metro region is closely associated with high temperatures.

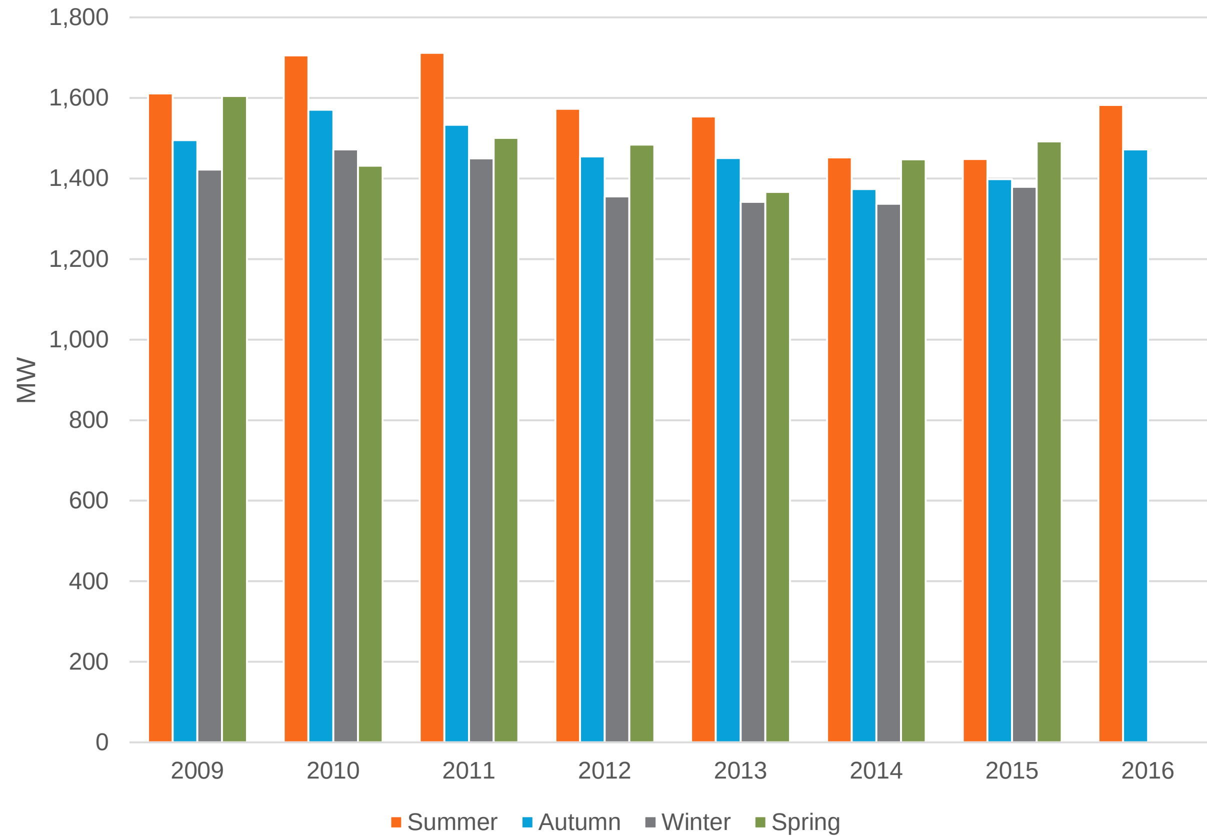
The highest peaks generally occur in the summer months, while winter is typically associated with low levels of demand.

The in-between seasons – autumn and spring – generally fall in the middle. High temperatures during these periods – most likely to occur in November and March (the shoulder periods around summer) are also a significant driver of peak demand.

This seasonal profile is notably different to other areas where peak demand in a year can occur in winter.

Peak Demand by Season – Sydney Metro Area

Financial years for summer and calendar years for other seasons



Source: Ausgrid Data

BIS Shrapnel

Understanding History - Key Drivers of Demand

Recent declines in peak demand have stemmed from declines in both the residential and commercial segments.

Energy

The biggest driver of underlying demand over the medium to longer term is underlying energy.

Simply put, if electricity consumption in a region is high, that region should also see comparatively high levels of peak demand.

Further breaking energy down into end use sectors (namely residential and commercial users for the Sydney Metro area) provides for a more robust relationship as separate components of energy drive demand in different and distinct ways.

For example, if a commercial region starts to see declines in office space while its residential base increases, it is possible that peak demand could moderate even if total energy consumption rises. This would result from a 'spreading out' of the load profile – reducing work-hour summer peaks while boosting evening (residential) winter peaks.

We therefore believe it is important to link the demand story to these components, otherwise it is possible to miss large structural shifts.

The Link Between Energy and Demand

While the link between energy and demand is relatively stable, the increased use of certain appliances can impact this relationship.

For example, a higher prevalence of air conditioners can result in stronger spikes in demand when temperatures are high.

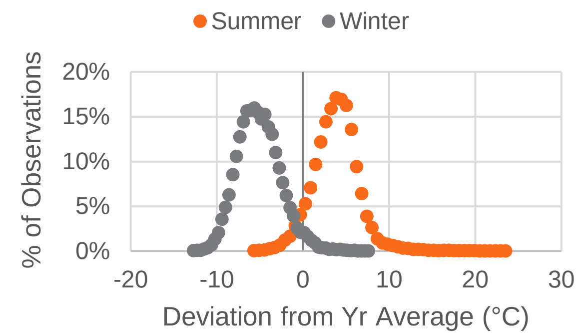
These must be examined in detail as they can affect the accuracy of longer term forecasts.

Seasonal Factors

Seasonal factors such as temperature and calendar related effects are the most important drivers of demand over the short to medium term.

Temperature is not easily predictable unless the task is to forecast only a few days into the future. However, temperature does follow a very stable distribution in the medium term. This allows us to present confidence intervals around our forecasts where the difference between a high (P10) and a medium (P50) scenario is an unusually hot or cold period.

Distribution of Temperature observations
Sample: 2005 to 2015 – 15 min intervals



Energy as a Key Driver of Demand - Residential Loads

Residential loads feature significant winter evening peaks.

Observations

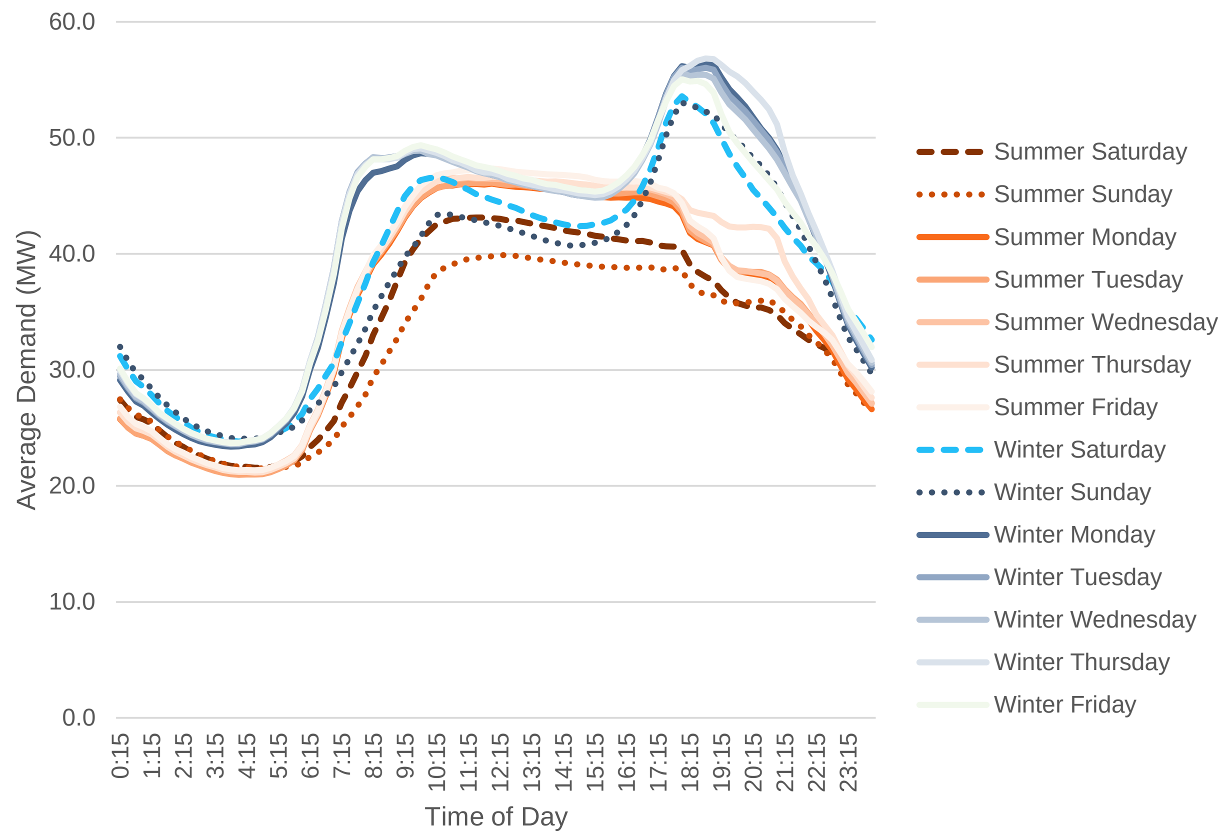
In residential areas, summer peaks tend to be relatively less prominent than in commercial areas because business hours tend to coincide with the high temperatures in the middle of the day rather than low temperatures in the evening.

This means residential loads feature significant peaks in winter after business hours – at approximately 7pm.

It is important to note the potential variance from these average levels is greater than the variance for commercial customers – for example, residential customers can make up a more significant share of winter peak demand than implied by average energy levels as few households use 'always on systems'. This results in a stronger responsiveness to lower temperatures.

Double Bay – Zone Substation Demand Profile

Average profile from 2005 to 2015



Energy as a Key Driver of Demand - Commercial Loads

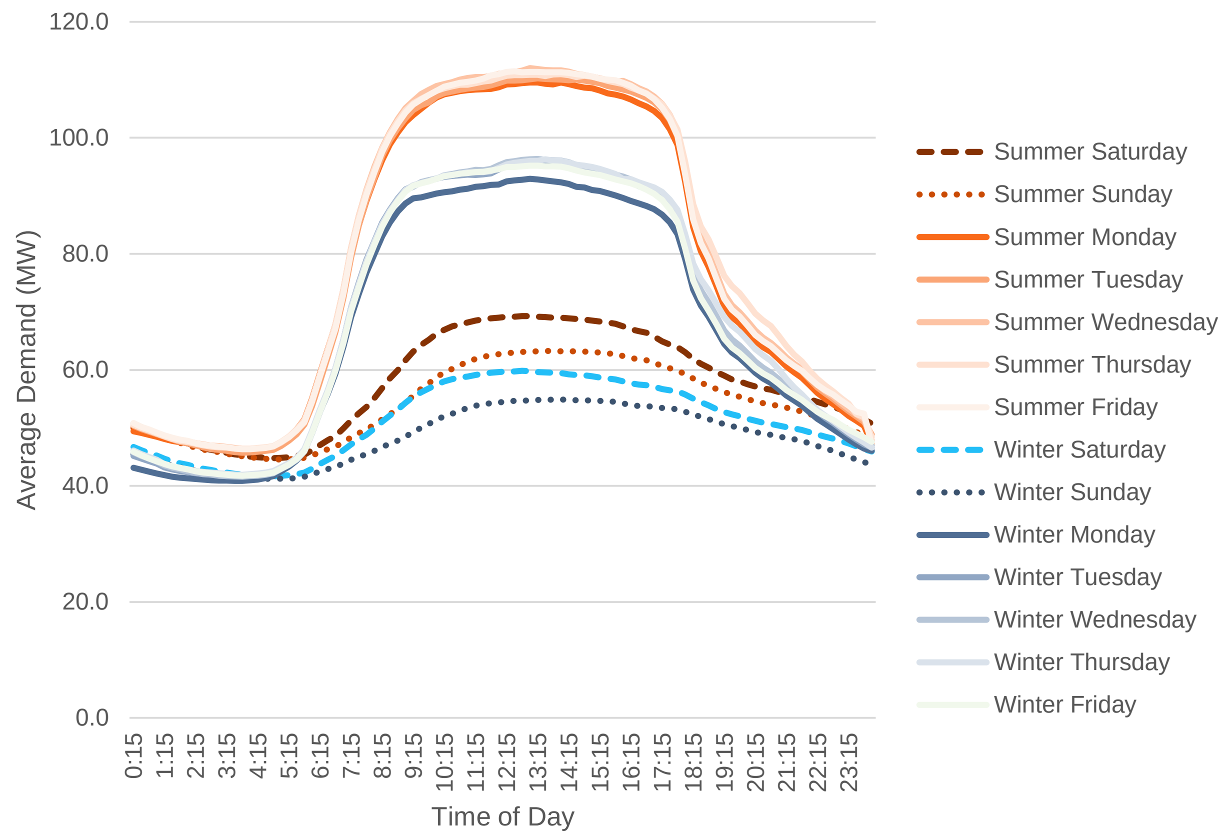
Commercial loads feature significant noon summer peaks.

Observations

Commercial loads tend to follow business hours. Peaks tend to be around mid day where the temperature is highest.

Winter peaks are significantly less prominent in commercial areas as mid-day temperatures are not high enough to necessitate as much demand for air conditioning and not cold enough to necessitate demand for heating.

City Central – Zone Substation Demand Profile
Average profile from 2005 to 2015



Source: Ausgrid Data

BIS Shrapnel

Mixed Use Areas

Mixed commercial/residential areas need to be examined carefully.

Observations

Mixed use areas such as Darlinghurst, Surry Hills, and Zetland feature a mixture of the demand profiles associated with residential and commercial loads:

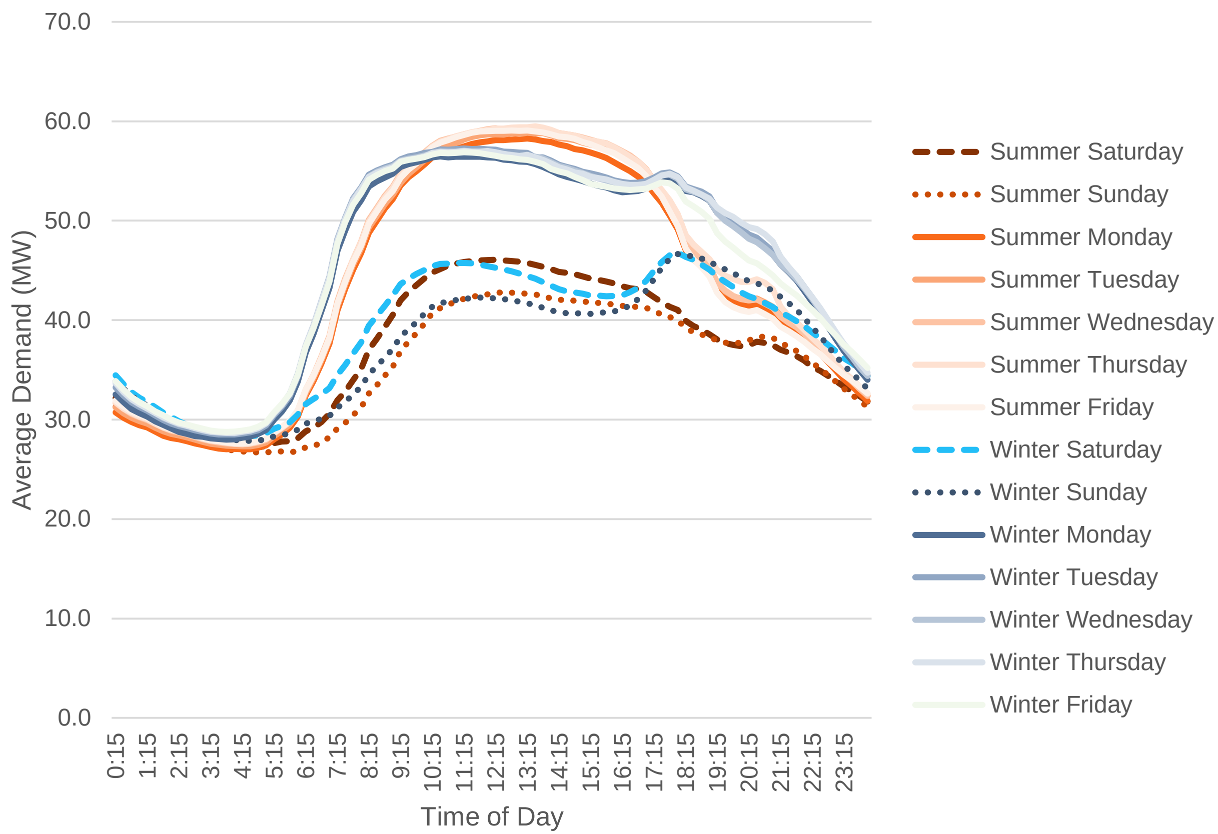
The evening-based winter peaks associated with residential loads are seen in conjunction with the mid-day peaks of commercial loads.

Shifts in the residential/commercial composition of these areas will result in a shift in the demand profile.

For example, a faster rate of increase in residential consumption compared with commercial should shift the substation demand profile. In this scenario winter peaks in the evening should appear more prominent than before as the substation moves away from the typical commercial profile towards a more typical residential profile.

Zetland – Zone Substation Demand Profile

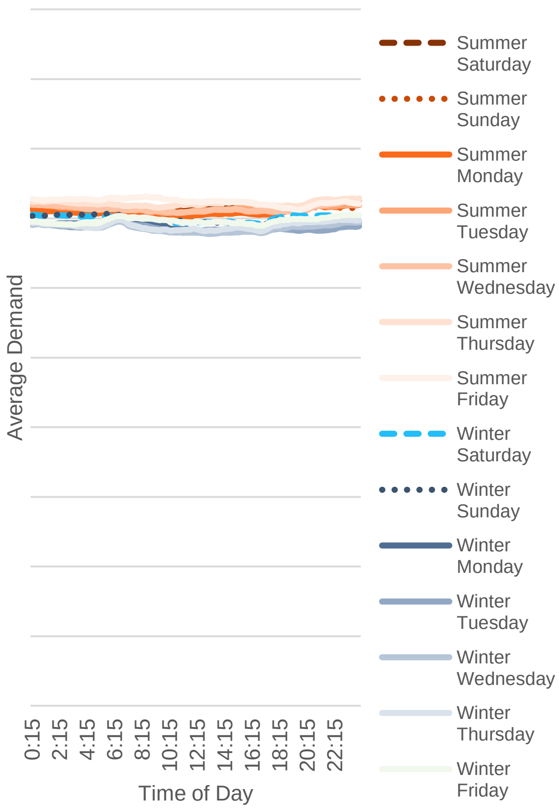
Average profile from 2005 to 2015



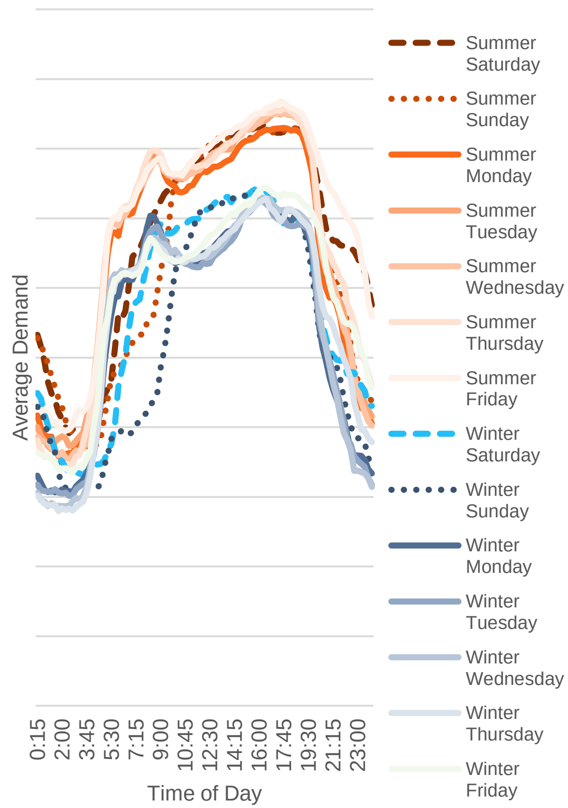
Energy as a Key Driver of Demand – Industrial Loads

There are three broad types of load profile for industrial customers.

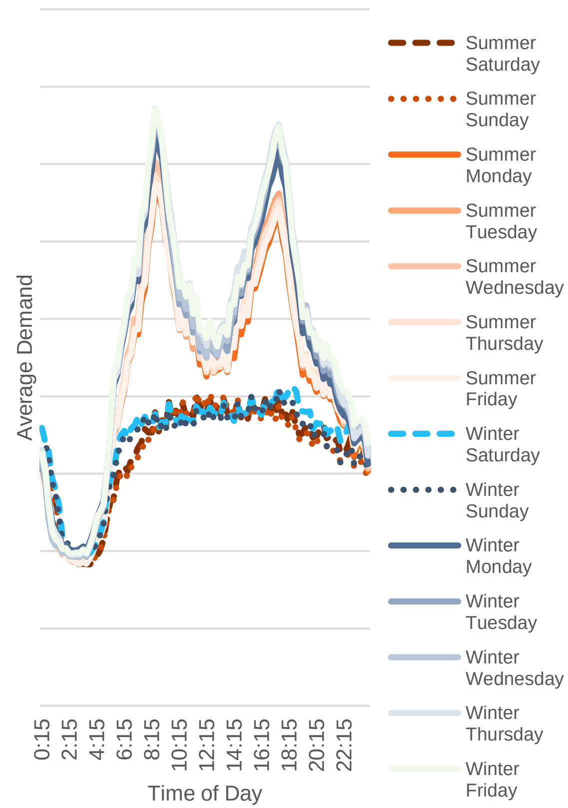
‘Flat’ Profile – Energy Intensive
Average profile from 2009 to 2016



‘Work day’ Profile – Labour Intensive
Average profile from 2009 to 2016



‘Peaky’ Profile – Commute Driven
Average profile from 2009 to 2016



Source: Ausgrid Data
Each Profile references one customer. Y-axis has been removed to maintain privacy.

Modelling Approach – Choosing the Right Variable

For the residential segment, the multiplier between peak demand and average energy has been relatively stable over time, even before accounting for temperature and seasonality.

Choosing the Right Variable

We opted not to model electricity demand directly because this would not appropriately capture shifts in energy over a longer time frame.

Instead we modelled the deviation of demand from its average level – where average demand is a simple fixed multiple of underling energy.

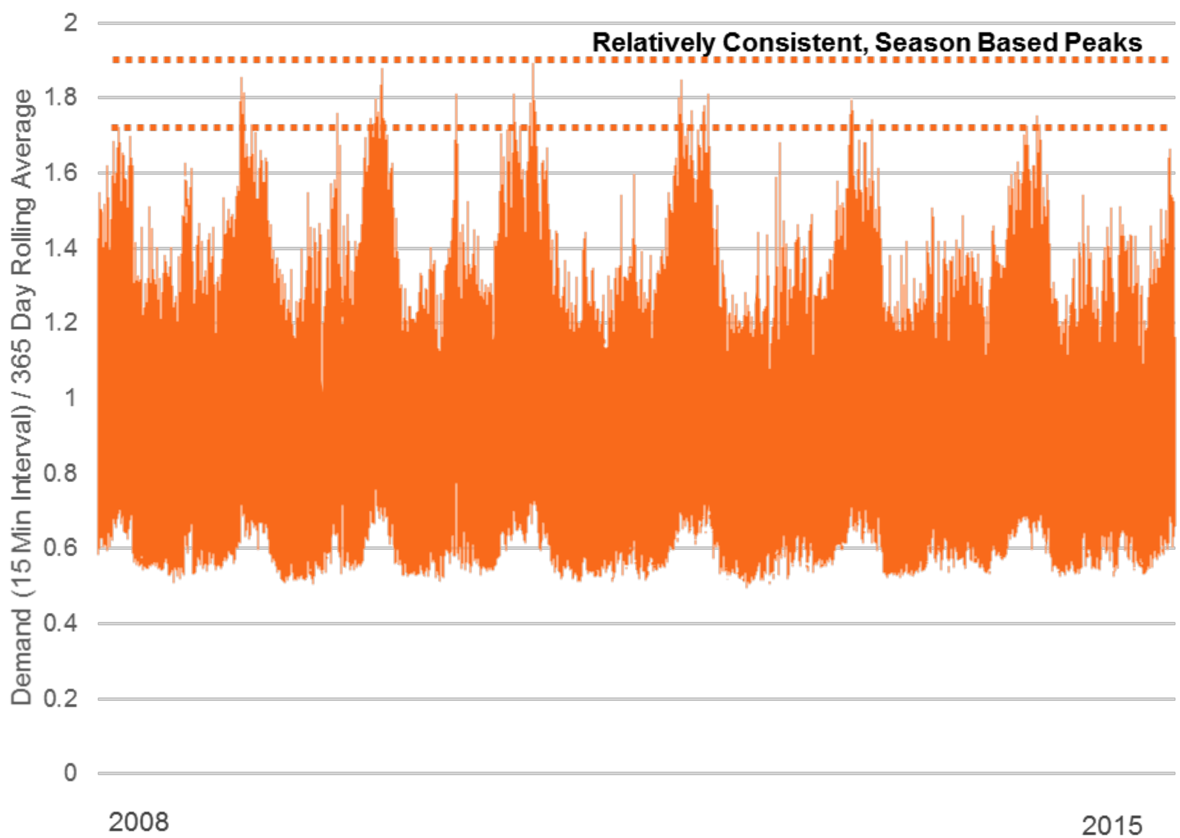
The relationship between demand and energy has been remarkably stable over time, supporting our belief that shifts in underling energy consumption have been the primary drivers of declines in peak demand in recent years.

This relationship is similar to the inverse of the load factor. Where the load factor is typically defined as:

$$Load\ Factor = \frac{Underlying\ energy\ (365\ days)}{Underlying\ peak\ demand}$$

This choice of variable allows us to separate the time and temperature driven volatility associated with demand from the long term structural drivers associated with energy while maintaining the link between the two factors.

Point Demand/Rolling Average Demand – Double Bay Zone Substation



Modelling Approach – Adjusting for Temperature

It is important to consider temperature in conjunction with other seasonal factors.

Temperature Effects

Temperature is the primary driver of short term volatility in electricity demand.

It generally affects demand in two distinct ways. High temperatures result in a surge in air conditioner use, which drives up peak demand. Similarly, when temperatures are low, the use of heaters increases, driving up consumption.

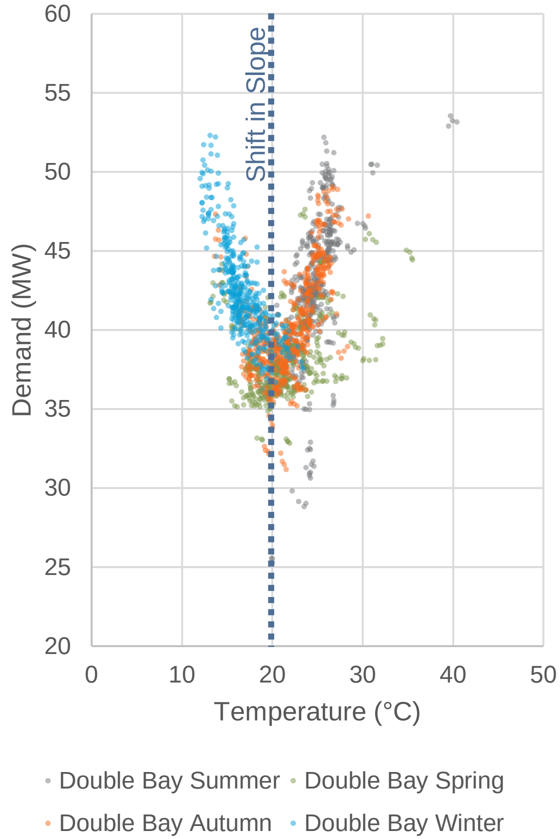
The natural breakpoint between these two distinct demand response events is the 20 °C mark.

Temperature effects are generally difficult to control for because the time of day and the day of the week both impact the magnitude of the demand response (ie, the slope of the line).

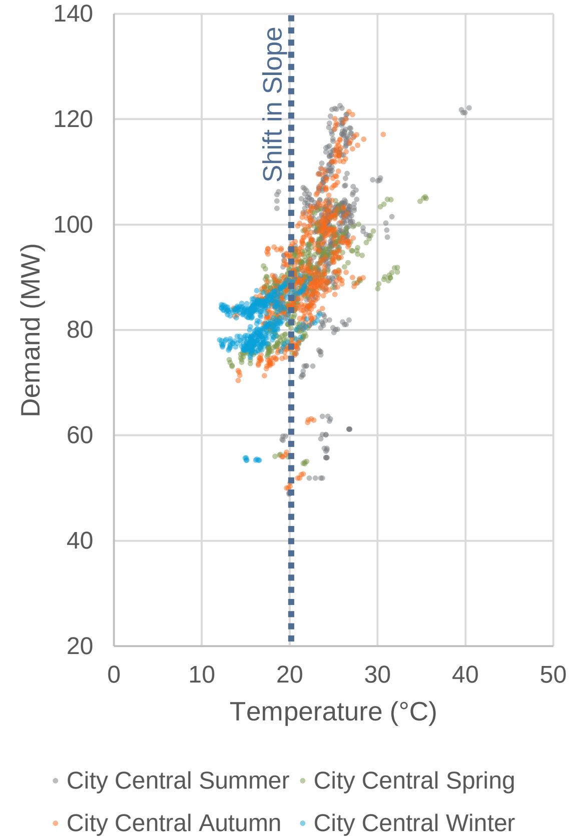
Few households turn on their heaters at midnight, even if temperatures are very low. However, at 7pm, after work hours, residential users are much more sensitive to a decline in temperature.

The impact of holidays is most significant for commercial districts. The low outliers in the rightmost chart represent Holiday periods.

Residential Temperature Response
4pm to 5pm, Weekdays, Double Bay



Commercial Temperature Response
4pm to 5pm, Weekdays, City Central



Source: Bureau of Meteorology (Observatory Hill 15 minute interval observations), Ausgrid Data

BIS Shrapnel

Modelling Approach

We used a consistent modelling methodology for all zone substations.

Comments

In our modelling process, we developed one model specification that we then applied to each of the zone substations. This model included variables that accounted for temperature, time of day, day of week, and holiday periods.

We opted to use a single, relatively simple model to avoid problems of over fitting to the historical data – namely selecting variables that may appear to explain current history well but don't generalise very well to other time periods.

This has meant ignoring variables which (appear to) improve the performance of the model in the short term – such as including leads and lags of temperature – but which don't make a material difference over a longer term horizon.

Fitting this model separately for each zone substation still allows for socio-economic variation between regions which we generally assume to remain constant over time. Double Bay, for example features larger, older houses than inner city suburbs which could be cooled more efficiently in summer.

Modelling Process

1 . Generate Baseline:

A. Generate annual rolling average demand and then seasonally adjust series.

B. Generate a series for '*demand deviation from the mean'* by dividing demand at each 15 minute interval by the seasonally adjusted rolling annual average.

C. Fit the model to the historical data to obtain temperature, time and day based coefficients.

D. Examine the residuals to identify any consistent patterns that may imply rising air conditioner efficiency or other bias.

2. Generate Peaks for the Modelled 'Demand Deviation from the Mean' Variable:

A. Fit historical temperature observations for each time of day to a statistical distribution (we found a normal distribution was generally reasonable).

B. Simulate temperature events by drawing from these statistical distributions.

C. Identify the simulated maximums and their distribution.

3. Convert 'Demand Deviation from the Mean' into an Estimate of Demand:

A. Convert forecasts of energy into rolling average demand by applying a fixed multiplier based on the number of hours in each period.

B. Multiply the modelled deviation with the rolling average to obtain an estimate of demand.

Modelling Approach – Adjusting for Shifts in the Relationship between Peak Demand and Energy

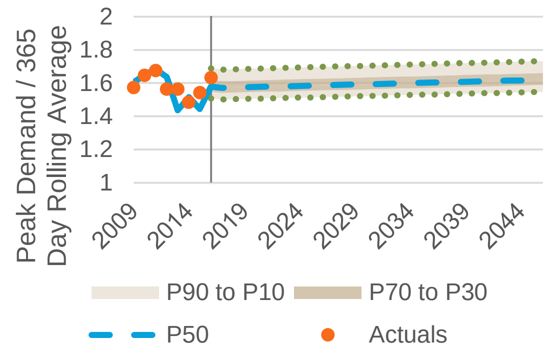
The Sydney Metro area is likely to be insulated from many factors that can shift the relationship between peak demand and underlying energy.

Solar PV and Battery Storage

We expect rooftop PV will have a dampening effect on mid-day peaks in the NSW region as a whole. This may also impact other time periods when battery technologies improve over the coming years.

However, we estimate only 2 per cent of all small scale solar panels in NSW/ACT are in the Sydney Metro area. High density commercial and residential space means relatively little room for growth. We therefore expect minimal impacts from this factor for our area of interest.

Historical and Forecast Peak Demand vs Rolling Average Demand – Financial Years



Electric Cars

Electric cars can act as large moving battery packs.

They have the potential to smooth out peaks slightly for commercial loads but their charging needs could also act in the opposite direction. The overall impact on the CBD area is likely to be minimal as most commuters in the region use public transport.

Residential loads, on the other hand, will need careful examination by network planners. If all cars start charging at 7pm, when workers get home, we would expect to see significant spikes in demand. If instead electric cars are metered separately in a controlled load system that pushes out charging needs to off-peak hours, residential peaks wouldn't be affected significantly.

In our modelling we have assumed the latter scenario because the former could entail significant new investment costs to the transmission and distribution networks and is relatively easily adjusted for by modifying the incentives for consumers.

Air Conditioner Efficiency

Air conditioner penetration has likely stabilised in the region.

Both the ABS and our in-house survey data indicate that air conditioning penetration has been flat since 2012, at around 65%.

Rising air conditioner efficiency however could have a dampening effect on the relationship between peak demand and underlying energy.

A review of the residuals in our model, however, suggests this effect isn't clear in the data.

Climate Change

In our modelling we assumed an average increase in temperature of 0.1 degrees every 5 years. This assumption was informed by standard demand modelling practices and 'medium scenario' CSIRO models.

This results in a slight upward increase in the peak demand to average demand ratio.

Sydney Metro Peak Demand Forecast

We forecast peak demand to grow by 29 per cent over the next 30 years.

Comments

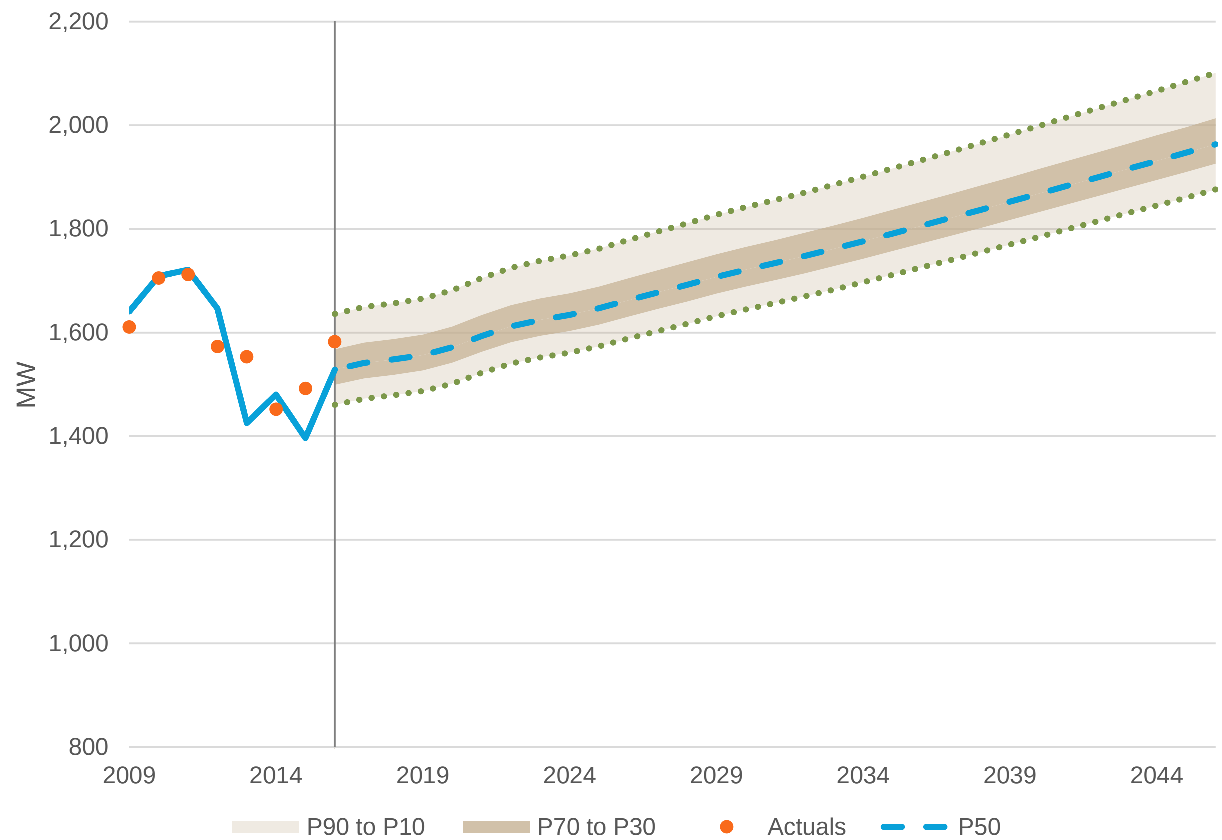
The summer months are expected to remain the key drivers of peak demand over the foreseeable future in the Metro area.

Forecast residential consumption did not outpace commercial consumption enough to result in a significant enough increase in winter peak demand.

We forecast summer peaks (and therefore overall peak demand) to grow by 29 per cent from 2016 to 2046. This represents a compound annual growth rate of 0.9 per cent.

Historical and Forecast Peak Demand

Financial Years, Forecast Margins Reflect Variation Resulting from Weather



Acronyms

ABS: The Australian Bureau of Statistics

CBD: Central Business District

CFL: Compact fluorescent lamp

CSIRO: Commonwealth Scientific and Industrial Research Organisation

EIA: U.S. Energy Information Administration

GWh: Gigawatt Hours

LED: Light Emitting Diode

LGA: Local Government Area

MAT: Moving Annual Total

MW: Megawatts

MWh: Megawatt Hours

PV: Photovoltaic Solar Panels

SQM: Square Meter