CASE STUDY FACT SHEET

ELECTRICITY SECTOR CLIMATE INFORMATION PROJECT

The impact of climate change on transmission line ratings

Introduction

TransGrid,[1] the Commonwealth Scientific & Industrial Research Organisation (CSIRO) and the Bureau of Meteorology (BOM) have collaborated on this Electricity Sector Climate Information (ESCI) case study to analyse potential implications of increasing temperature on the ratings of high voltage transmission lines.

The case studies are designed to demonstrate the choice and application of appropriate climate information for long-term decision-making for the sector, and the use of the ESCI Climate Risk Assessment Framework (Refer to User Guidance Module 1.1). This case study is also presented as a Summary Case Study Fact Sheet, along with other ESCI Case Study Fact Sheets, on the ESCI website.

This case study and other case studies from the project can be found at: www.climatechangeinaustralia.gov.au/en/projects/esci/esci-case-studies

1 TransGrid operates and manages the high voltage electricity transmission network in New South Wales (NSW) and the Australian Capital Territory (ACT), connecting generators, distributors and major end users.

Overview

Climate change projections are indicating that temperatures are likely to increase, with transmission line ratings potentially affected impacting the reliability of the network. This case study demonstrates how to apply the ESCI Climate Risk Framework (Figure 1) in an analysis of just how projected temperature changes may affect line ratings.

Figure 1 ESCI Climate Risk Assessment Framework, based on International Standard ISO 31000 'Risk Management' and Australian Standard AS 5334 'Climate change adaptation for settlements and infrastructure'.

The Electricity Sector Climate Information (ESCI) project was funded by the Department of Industry, Science, Energy and Resources (DISER) and was a collaboration between the Bureau of Meteorology (BOM), the Commonwealth Scientific & Industrial Research Organisation (CSIRO) and the Australian Energy Market Operator (AEMO). The ESCI website is at: www.climatechangeinaustralia.gov.au/esci

Case study context

High voltage electricity transmission networks connect generators, distributors and major end users. Transmission line ratings define the maximum power that can be safely carried by a line, essential to avoid damage from overheating and to limit sagging beyond minimum clearance levels. For NSW and ACT, line ratings assume maximum power transfer and co-incident high temperature and low wind speed, derived from historical weather data.

Rising temperatures associated with climate change may have implications for the safe and efficient operation of Australia's electricity system. An exploration of the potential effects on electricity transmission from higher temperatures is presented here. Also, strategies for mitigation of, and adaptation to, the risks from these projected temperature increases are offered, for integration within ongoing planning and operational decision-making frameworks for electricity transmission.

Stakeholders

Australian and international transmission network service providers (TNSPs), distribution network service providers (DNSPs), market operators, rule-making bodies and regulators can benefit from this assessment.

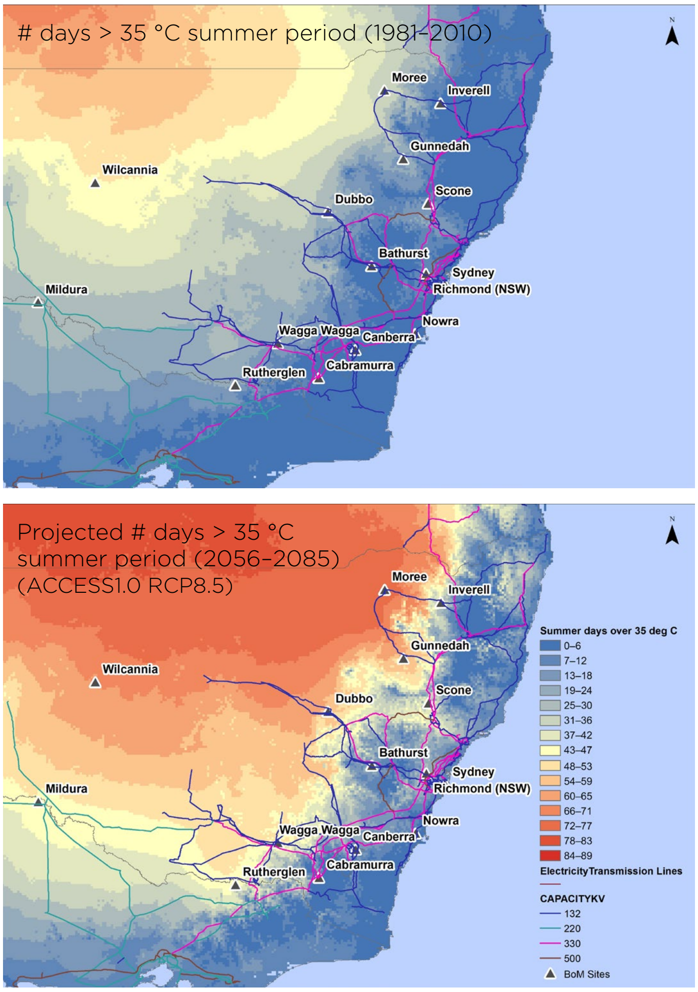

Figure 2 Average number of summer days above 35 °C during the period 1981–2010 (left) and during 2056–2085 (ACCESS1.0 climate model, RCP8.5 greenhouse gas concentration pathway) (right). Sites selected for the study (BOM ACORN_SAT) and corresponding transmission lines with varying voltage capacity (kV) (see legend).

Identify historical climate risk

Australia is already experiencing the effects of climate change due to increases in greenhouse gases. Ongoing increases in greenhouse gases over the coming decades will lead to further climate change, with impacts that will affect our economy, communities and ecosystems. Of relevance to this case study is that climate change will increase the magnitude and frequency of hot weather, with risks to electricity transmission. For example, Mildura averaged 27 summer days above 35 °C from 1981 to 2010, and by 2056 to 2085 this could increase to 38–51 days above 35 °C (Figure 2).

Transmission line ratings define the maximum amount of power that can be safely carried by a line (measured in MVA). The rating is limited to prevent the line from overheating and from sagging below the minimum clearance between the conductor and the ground (or other conductors) and to prevent damage caused by excessive heat. Transmission line ratings are one of several mechanisms that determine actual network capability.

The key design parameters which influence the temperature of a transmission line conductor (and therefore its rating) are the nominal voltage, design temperature and type of phase conductor. Operational and environmental factors influencing a conductor's temperature are the power transfer across the line, incident solar radiation, ambient temperature and wind speed. Solar radiation and higher ambient temperature increase the temperature of the conductor, lowering the power that it can safely carry, and lowering the line rating. On the other hand, wind cools the conductor, and increases the theoretical line rating. As such, the maximum power that a transmission line can safely carry over summer (termed as 'maximum summer day normal' line ratings) is assessed at maximum power transfer and coincident high temperature and low wind speed.

TransGrid's methodology to calculate the rating of transmission lines follows the approach recommended by the international power system body, CIGRE. This approach uses historical weather data to calculate the line rating. TransGrid calculates the 15th highest temperature over the previous 15 years, corresponding to a 'temperature that is met or exceeded at least once a year'. Yet as temperatures rise in future, an approach that considers only historical weather data is likely to result in a diminished safety margin over time.

Analyse future climate risk

An initial scoping study was undertaken by TransGrid to assess potential implications of climate change on transmission line ratings in order to determine whether a more detailed analysis was necessary. Results suggested that by 2070 some lines could be theoretically de-rated by up to 7 per cent, an amount warranting further investigation. This de-rating was of a similar magnitude to a study by Bartos and colleagues (2016) who found that in the United States by mid-century (2040–2060), increases in temperature may reduce average summer transmission capacity by 1.9 per cent to 5.8 per cent relative to the 1990–2010 reference period.

Assessment locations

Fifteen BOM ACORN-SAT weather stations (Trewin 2013) from around NSW were selected to capture varying climate regions situated along TransGrid's transmission system, as well as locations of possible future transmission projects (Figure 2).

Analysis period

Daily time-series of maximum temperature data were sourced for a historical 30-year period centred on 1995 (1981–2010) and for forecast 30-year periods centred on 2030 (2016–2045), 2050 (2036–2065), and 2070 (2056–2085) under a range of climate models and future greenhouse gas concentration pathways. The data were sourced from the Climate Change in Australia (CCiA) website to procure time periods that match TransGrid's historical modelling. Projections out to 2085 were used as the life of a transmission line exceeds 50 years.

Future climate scenarios

Future climate scenarios are influenced by three main sources of uncertainty:

1. Future greenhouse gas emission pathways
2. Regional climate model responses to a given emission pathway
3. Natural variability at timescales ranging from hours to decades

When conducting a risk assessment, it is important to consider a range of greenhouse gas emission pathways and also a range of plausible regional responses simulated by different modelling groups from around the world.

Greenhouse gas concentration pathways

Given the recommendation that a range of emission pathways are used to assess potential best and worst cases,[2] the TransGrid assessment employed a low (RCP2.6), a mid-case (RCP4.5), and a high (RCP8.5) pathway in the risk modelling presented here.

Climate models

Of the 40 global climate models (GCMs) available for assessing projected climate changes, each provides a different simulation of future weather and climate at a given location. For this assessment, a set of 'maximum consensus' models were selected (Table 1). 'Maximum consensus' describes the category where a high percentage of models agree on the magnitude of change (Clarke et al. 2011). Using the Climate Futures tool,[3] models from the 'maximum consensus' warming category (for summer maximum temperature for the east coast of Australia for the 2070 period) for each of the three emissions pathways were selected (Table 1).

2 See ESCI Key Concept—Choosing representative emissions pathways (RCPs).

3 https://www.climatechangeinaustralia.gov.au/en/projections-tools/climate-futures-tool/introduction-climate-futures/ See also ESCI Key Concept—Using CCiA to choose alternative climate information.

Table 1 Models and greenhouse gas concentration pathway combinations used in the TransGrid study. *Fewer models were available for use under the RCP2.6 emissions pathway.

RCP 2.6*	RCP 4.5	RCP 8.5
	GFDL-ESM2M	GFDL-ESM2M
	ACCESS1.0	ACCESS1.0
	HadGEM2-CC	HadGEM2-CC
MIROC5	MIROC5	MIROC5
CNRM-CM5		

Historical and projected temperature time-series

Historical and future temperature time-series span 30-year periods centred on 1995 (1981–2010), 2030 (2016–2045), 2050 (2036–2065) and 2070 (2056–2085). Data for the future periods are derived by modifying the historical data. BOM ACORN-SAT station data (Trewin 2013) was scaled by projected monthly temperature changes from each climate model/RCP (Table 1), using the delta-scaling method.[4] These pre-calculated future daily time-series data sets can be accessed from the Climate Change in Australia website. In order to align with the 'maximum summer day normal' line ratings methodology, only the central 15 years was selected from the 30-year time-series (e.g. the 1988–2003 period was selected from the 1981–2010 time series). The '15th hottest day' from the historical and future 15-year time-series was then determined for all sites, models and RCPs.

Average projected maximum temperatures for the analysed climate models across all sites are shown for the three RCPs: two models for RCP2.6 and four for each of RCP4.5 and RCP8.5 (Figure 3). The range of uncertainty produced when combining multiple models is shown as a shaded envelope around the average, representing the maximum and minimum projected temperatures at each time period. Note the range is reduced where only two models have been used in the analysis. On average, the higher the concentration pathway, the higher the projected temperatures.

Figure 3 Projected range of future '15th highest temperature over previous 15 years' temperature for RCP2.6 (two models; left), and four models for RCP4.5 (middle) and RCP8.5 (right) (see Table 1) across all sites for 1988–2003, 2023–2048, 2043–2058 and 2063–2078. Average projected temperature is indicated by the darker line. The range of uncertainty due to different sites and different climate models is shown by the shaded envelope.

Analysis of the data suggests that locations far from the coast show a greater increase in temperature over the projected period, with Dubbo, Narrabri and Wagga Wagga experiencing the largest increase in temperature. On average across the models, Dubbo experiences up to a 3.5 °C (RCP8.5), 2.2 °C (RCP4.5) and 1.4 °C (RCP2.6) increase in 15th highest temperature by 2063–2078 relative to the 1988–2003 baseline. In comparison, the average across models indicates Newcastle as a coastal location experiences a 2.8 °C (RCP8.5), 1.8 °C (RCP4.5) and 1.4 °C (RCP2.6) increase.

Another way of considering the projections is to look at individual model results for the selected sites. Table 2 shows the current and projected 15th highest summer temperature for two climate models and two RCPs. For example, at a relatively cool site such as Cabramurra, the 15th highest temperature increases from 28 °C in 1988–2003 to between 29.6 °C (MIROC5, RCP4.5) and 30.5 °C (GFDL-ESM2M, RCP8.5) by 2063–2078. At a relatively hot site such as Wilcannia, the 15th highest temperature increases from 43.9 °C in 1988–2003 to between 47.5 °C (MIROC5, RCP4.5) and 42.9 °C (GFDL-ESM2M, RCP8.5) by 2063–2078.

4 See ESCI Key Concept—Climate models and downscaling.

Table 2 Current (1988–2003) and future (2063–2078) 15th highest summer temperature for two climate models and RCPs

		2063–2078			
Site	1988–2003	MIROC5 RCP4.5	GFDL-ESM2M RCP4.5	MIROC5 RCP8.5	GFDL-ESM2M RCP8.5
Cabramurra	28.0	29.6	30.4	30.3	30.5
Canberra	37.6	38.8	40.4	39.7	40.1
Dubbo	40.4	41.5	43.6	42.8	44.1
Gunnedah	39.7	40.7	42.6	41.6	43.0
Inverell	36.7	39.0	39.5	39.0	40.0
Mildura	42.4	44.5	44.5	44.5	45.3
Moree	40.5	42.2	44.0	42.8	44.1
Nowra	38.8	40.2	41.5	41.3	41.2
Richmond	40.8	42.9	43.5	43.6	43.7
Rutherglen	40.3	42.6	42.5	42.7	42.6
Scone	39.1	43.1	42.0	41.3	42.3
Sydney	36.5	39.9	38.8	39.0	39.2
Wagga	41.1	45.2	44.4	43.7	44.2
Wilcannia	43.9	47.5	46.7	46.1	47.0
Williamtown	39.2	42.5	41.3	41.5	41.9

Transmission line designs

To analyse as much of TransGrid's transmission network as possible while ensuring the analysis itself was efficient, the range of design configurations across TransGrid's existing network was assessed. It was identified that 47 combinations of the most common design parameters, namely nominal voltage, design temperature, conductor type and location, were able to capture 84 per cent of TransGrid's existing network. This includes lines with voltages at 500kV, 330kV, 220kV and 132kV and design temperatures with the most common being 120 °C and 85 °C.

Evaluate climate risk

The assessment of the theoretical de-ratings of TransGrid's transmission network due to increasing temperatures shows a clear relationship: the higher the projected warming the higher the theoretical de-rating.

From an analysis representing 84 per cent of TransGrid's transmission assets, projected warming could reduce the theoretical 'maximum summer day normal' rating of TransGrid's network by 2.3 per cent (RCP2.6), 3.5 per cent (RCP4.5) and 5.1 per cent (RCP8.5) by 2078, against the 2003 baseline rating (Figure 4). These results have been weighted by line length, so the de-rating of longer lines have a proportionally larger impact on the results.

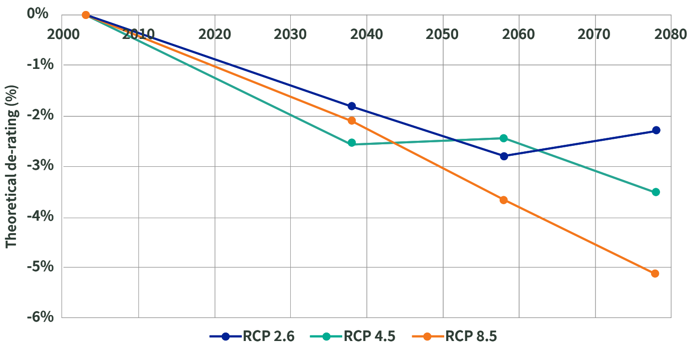

Figure 4 Reduction in theoretical rating of TransGrid's network based on an 84% coverage of the network, weighted by line length. De-rating calculated using average value from respective maximum consensus model output.

The results in Figure 4 show unexpected cross-over in the de-ratings associated with RCP4.5 and RCP8.5 in 2038 and between RCP2.6 and RCP4.5 in 2058. This is driven by the variance in temperature projections for specific NSW locations from individual climate models (two models used for RCP2.6 and four models used for RCP4.5 and RCP8.5). The uncertainty in temperature projections is described in more detail in the historical and projected temperature time-series section above.

The higher the nominal voltage, the higher the power that can be carried. This analysis indicates that design temperature has the largest bearing on the percentage reduction in line ratings due to rising temperatures. For example, a line designed to 85 °C will see a reduction in line ratings by 1.75 per cent (+/−0.17 per cent) for every 1 °C increase in temperature, whereas a line designed to 120 °C will only be de-rated by 1.17 per cent (+/−0.04 per cent) for the same 1 °C increase. This trend is continued for lower design temperature lines, as seen in Figure 5 for RCP8.5.

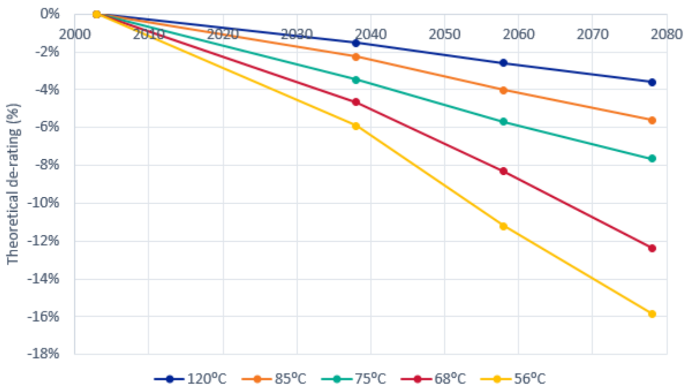

Figure 5 Projected theoretical de-ratings out to 2078 based on design temperature under scenario RCP8.5 (Note: average of all models for RCP8.5 (Table 1) calculated to inform the theoretical de-rating assessment).

Figure 6 shows the theoretical de-ratings for a 330kV and 500kV line located at specific sites in NSW. The 330kV line could experience a theoretical 33MVA (4.0 per cent) drop in line rating by 2063–2078 for RCP4.5, compared to an 85MVA (2.5 per cent) drop for a 500kV line. Climate projections differ based on location, influencing the shape of the de-rating profile below.

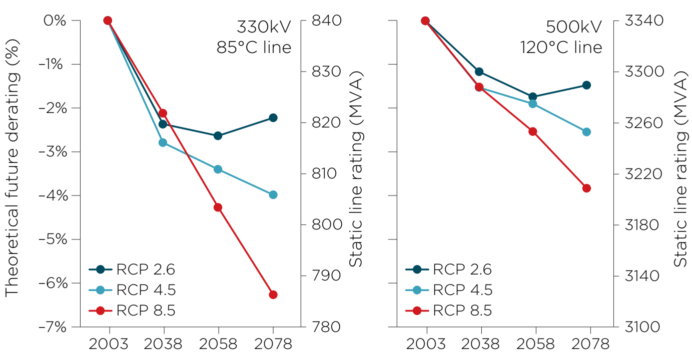

Figure 6 Projected de-ratings out to 2078 for a 330kV, 85 °C line (left), and a 500kV, 120 °C line (right) in NSW. (Note: average of all models (Table 1) for the respective RCP calculated to inform the theoretical de-rating assessment). Note: timescale is non-linear.

Risk treatment

In order to maintain the existing risk profile for the ratings of transmission lines, the impact of rising temperatures should be considered for the operation of existing lines and during the design of new transmission lines.

Existing transmission lines

Existing lines could be re-rated every 5–10 years using the same current rating methodology, reflecting the increasing ambient temperatures. Alternatively, a modification of the line rating methodology could be considered to include projected temperature increases.

Future transmission lines

Implications of climate change should be considered when planning new transmission lines, as the safe carrying capacity will drop over time as temperatures rise. As such, a cost–benefit analysis should be undertaken during the planning phase to assess whether it is economic to enhance the line design in response to future temperature rise. Since new interconnectors and transmission lines forming backbones of renewable energy zones are likely to be highly loaded, particularly during the day when high solar generation will coincide with maximum temperatures, small increases in ambient temperature and the associated de-ratings could have more frequent operational implications.

Future projections uncertainties

It is important to note the spread of theoretical de-ratings that result from the variability in each climate models' response. The range of minimum and maximum de-ratings are indicated by shaded envelope around the average de-rating in Figure 7. Assessing multiple 'maximum consensus' models (two models, RCP2.6; four models, RCP4.5 and RCP8.5; Table 1) highlights the potential uncertainty of projected temperatures, translating into uncertainty around the theoretical line de-ratings.

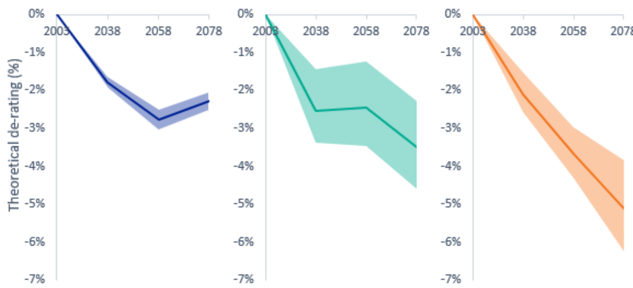

Figure 7 Projected range of system de-rating for RCP2.6 (two models; left), and four models for RCP4.5 (middle) and RCP8.5 (right) (see Table 1) from 1988–2003, 2023–2048, 2043–2058 and 2063–2078. Average value is indicated by the darker line. The range of uncertainty due to different sites and different climate models is shown by the shaded envelope.

Further work

This analysis uses maximum consensus climate models (four for RCP4.5 and 8.5, two for RCP2.6) to assess the impact of climate change on transmission line ratings. To improve the robustness of the analysis further, a greater number of models could be used, in line with the study by Bartos and colleagues (2016), providing a more accurate average (or median) de-rating, and a clearer picture of the variability between models.

This analysis has focused on comparing theoretical ratings of lines using a 1988–2003 baseline period. In most cases, transmission lines were rated many years prior, increasing the potential for higher than expected theoretical de-ratings.

To understand how rising temperature will affect the network from an operational point of view, analysis of projected line loadings and its coincidence with maximum temperature and low wind speeds should be considered. This supports the ongoing investigation and use of Dynamic Line Ratings into the future.

In this ESCI case study, detailed downscaled projection data have been applied in an engineering sense to model infrastructure response. This work provides evidence of the need to consider the effects of climate change more broadly in the electricity sector to ensure that the system can continue to be operated safely and reliably into the future.

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