CASE STUDY FACT SHEET

ELECTRICITY SECTOR CLIMATE INFORMATION PROJECT

Extreme weather: Exploring power system resilience to coincident extreme heatwave and bushfires

This case study was conducted as part of the Electricity Sector Climate Information (ESCI) project. The goal of this project was to improve the reliability and resilience of the National Electricity Market to the risks from climate change and extreme weather.

The case studies were designed to demonstrate the use of the ESCI Climate Risk Assessment Framework and the selection and application of climate information for long-term risk decision-making for the sector.

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: www.climatechangeinaustralia.gov.au/en/projects/esci/esci-case-studies

Every location, business and asset combination is different. This case study is intended as guidance for conducting a risk assessment, not as an assessment of system risk or to provide information of use in operational decision making.

The case study was developed by AEMO with the support of ESCI project staff.

Purpose

To demonstrate the use of climate data and to provide an example of using the ESCI Climate Risk Assessment Framework (Figure 1), in particular the application of compound extreme event data to stress test the resilience of the power system.

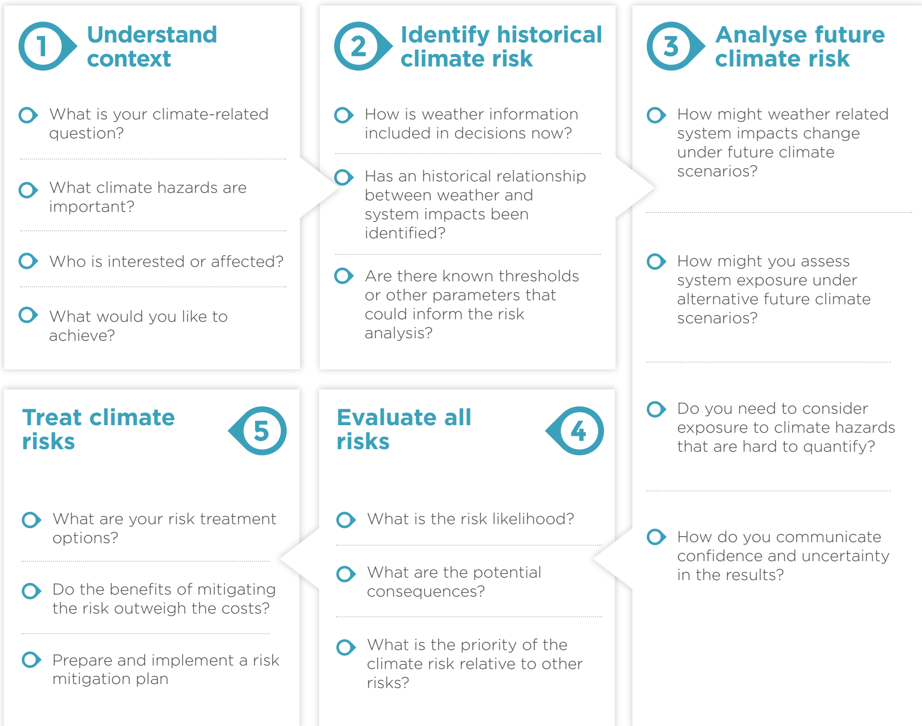


Figure 1 ESCI Climate Risk Assessment Framework, based on International Standard ISO 31000 'Risk Management' and Australian Standard AS 5334 'Climate change adaptation for settlements and infrastructure'.

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

Australian Government Department of Industry, Science, Energy and Resources

Australian Government Bureau of Meteorology

CSIRO

AEMO AUSTRALIAN ENERGY MARKET OPERATOR

Extreme events could be rare occurrences of single phenomena such as tornadoes or down-drafts, or of single variables, such as extended heatwaves. Compound extreme events are considered in climatology to be 'two or more events occurring simultaneously, [that] can lead to high impacts, even if the two single events are not extreme per se'.[1] This has been expanded by Zschleischler and colleagues (2018) as '[t]he combination of multiple drivers and/or hazards that contributes to societal or environmental risk'.

This document provides an overview of a case study where a compound extreme event identified in the climate projections is modelled to assess the impact on the National Electricity Market (NEM) and test system resilience. More detail on the use of compound extreme event projections is available in the ESCI Technical Report on decision-making using extreme event case studies.

Understand context

Disasters occur when the impacts of extreme natural events ('natural hazards') exceed the capacity of local systems to cope. Evaluating resilience for the power system requires a different approach from evaluating reliability. Reliability is highly measurable based on known parameters and the actual and simulated performance of the power system. Resilience is challenging to measure and requires a design-centred approach to understand vulnerability and exposure.

Climate science can supply case studies of extreme compound weather events to support decision-making. Single variable extremes (such as extreme rainfall or extended heatwaves) can be extracted from climate model projections which provide some information on recurrence intervals or probability. Compound extreme events can be more challenging as it is essentially meaningless to provide probability information for a combination of already rare events in a changing climate. For this reason, the compound events demonstrated in this case study do not include probability information, however they are considered plausible from both a meteorological and power system perspective.

Identify historical climate risk

An additional challenge is the non-linearity of the power system response to weather events; the system may continue to work within normal bounds until it fails quickly, and potentially catastrophically, as a result of a localised or extreme event. For example, on 28 September 2016, South Australia (SA) experienced a 'system black' event with widespread power outages as the result of localised damage to two transmission lines from tornadoes 170 km apart.[2]

The power system response to compound events will depend on asset and infrastructure configuration, engineering specifications and the location and vulnerability of consumer populations. A small change in climate could result in major impacts for the electricity system; for example, some infrastructure, including (but not exclusively) solar panels, wind farms and the Basslink Interconnector have temperature thresholds beyond which function drops off sharply.

The purpose of a case study is to identify and stress test geographic parts of the network which are particularly susceptible to these events. This case study considers the risk of a coincident extreme heatwave and bushfire event on power system performance. Figure 2 demonstrates the process deployed, in which impacts are explored in response to a particular meteorological simulation as input to decision-making (risk treatment).

Figure 2 The process of converting meteorological data into actionable information. (Adapted from Brayshaw 2018)

The case study does not make recommendations on how to mitigate the specific risks but identifies design characteristics useful in a power system that would be able to resist, absorb or recover from a wide variety of hazards. It demonstrates how individual case studies can be used to answer questions about the resilience of the power system.

1 SI Seneviratne, N Nicholls, D Easterling, et al. (2012). 'Changes in climate extremes and their impacts on the natural physical environment' in Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [CB Field, V Barros, TF Stocker, et al. (eds)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 109–230

2 Australian Energy Market Operator (2017). Black System South Australia 28 September 2016. https://www.aemo.com.au/-/media/Files/Electricity/NEM/Market_Notices_and_Events/Power_System_Incident_Reports/2017/Integrated-Final-Report-SA-Black-System-28-September-2016.pdf

Analyse future climate risk

The weather event chosen for this case study is taken from the global climate model CanESM2 under a high emissions scenario RCP8.5,[3] which has been downscaled with CCAM to increase the resolution over Australia and enable a better representation of weather around topography. While the event was found in the simulated year 2045, the case study is set in the 2030–2031 financial year. Given the natural variability of the Australian climate, this is a plausible timing. The time frame facilitates system modelling based on the Central 2020 Integrated System Plan (ISP) Scenario.[4]

The event was identified by using meteorological indicators associated with extreme fire events such as 'Black Saturday' in 2009. It involves a 'low-intensity' heatwave across most of the National Electricity Market (NEM), with Sydney and Canberra experiencing a 'severe heatwave' and Adelaide, Melbourne and Hobart experiencing an 'extreme heatwave'.[5] The heatwave breaks down over the southern part of the NEM following the passage of a very strong frontal system.[6] This system has an associated change in wind direction as well as wind gusts, providing an environment conducive to devastating fire conditions (analogous to Black Saturday and Ash Wednesday).

The scenario presented is a hypothetical future scenario; that is, the dates on graphs are not factual and are included for reference only. While the events are designed to be slightly beyond those captured in the recent historical record, the magnitude of the heat experienced is similar to recent significant historical heatwaves (e.g. 2009, 2014), however heatwaves of this magnitude/classification compounding temporally over all major power demand centres are unprecedented.

Here we outline a sequence of weather and climate events, natural hazards and NEM vulnerabilities tested at each stage of the case study.The average daily mean temperatures in the months preceding the case event (September–January) were warmer than the average conditions experienced in the period 1980–2010 (Figure 3).

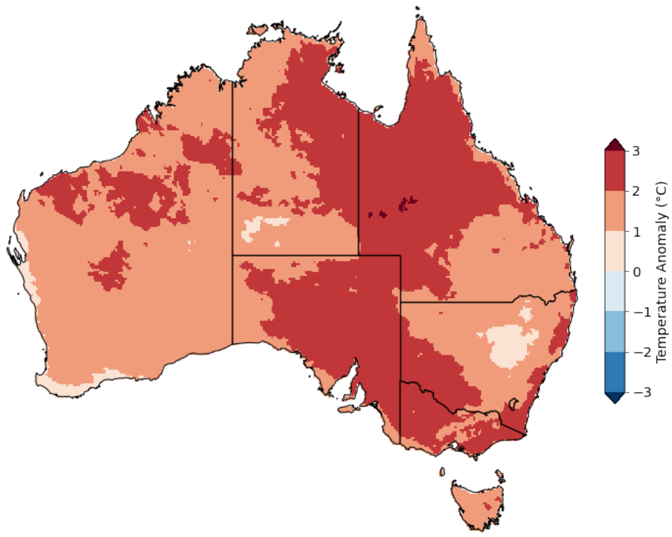


Figure 3 Average daily mean temperature anomalies in degrees Celsius; (September–January) from 2030–2031 scenario relative to 1980–2010. (Source: BOM Climate Tracker)

The highest maximum temperatures modelled during the case study event are similar to, or warmer than temperatures recorded in significant historical heatwave events (Figure 4). While temperatures are extreme across Australia, note the very hot conditions along the eastern seaboard during the future event (large left-hand plot) relative to historical events (two right-hand plots) which would impact several major demand centres simultaneously.

In addition to the high daytime temperatures, the event identifies very high excess heat factor loadings[7] (Figure 5, left-hand plot); again, these are similar to conditions recorded during significant historical heatwave events (two right-hand plots).

3 RCP8.5 was chosen as a high global warming scenario in order to provide an event to stress test the power system. See ESCI Key Concepts—Choosing representative emissions pathways.

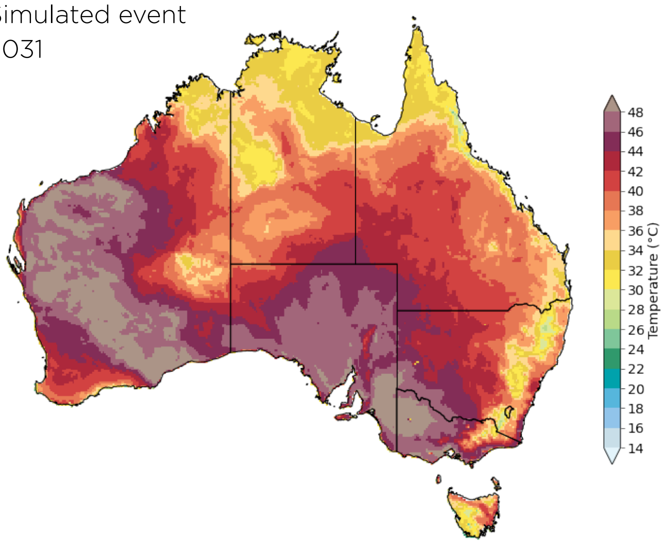
4 Australian Energy Market Operator (2020). Draft 2021 Inputs, Assumptions and Scenarios Report. https://aemo.com.au/-/media/files/electricity/nem/planning_and_forecasting/inputs-assumptions-methodologies/2021/draft-2021-inputs-assumptions-and-scenarios-report.pdf?la=en

5 Heatwave classifications and Bureau of Meteorology (BOM) standard terminology.

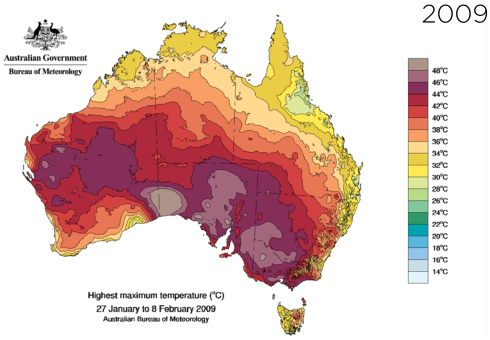
6 Reeder et al. (2015) found that the most catastrophic fire conditions in recent history in southern Australia have been associated with particularly strong summer cold fronts. 'Rossby waves, extreme fronts and wildfires in southeastern Australia' Geophysical Research Letters. doi:10.1002/2015GL063125.

7 Excess Heat Factor (Nairn and Fawcett 2014) uses the average of the maximum and minimum (daily) temperature over a three-day period as a measure of heatwave intensity.

Simulated event 2031



2009



2014

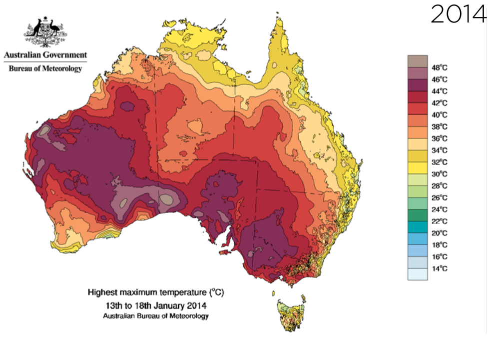
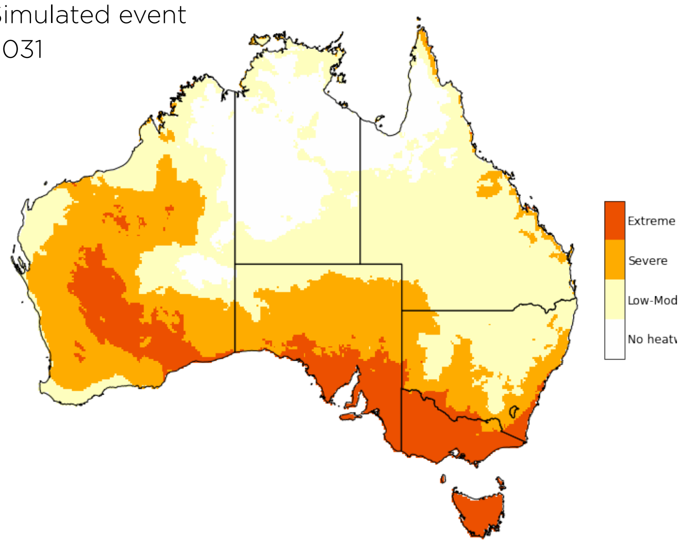
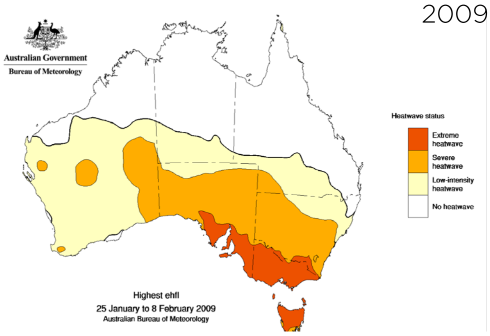


Figure 4 Day 4, January 2031, southern parts of the NEM experience extreme temperatures. (Source of historical data: BOM Climate Tracker)

Simulated event 2031



2009



2014

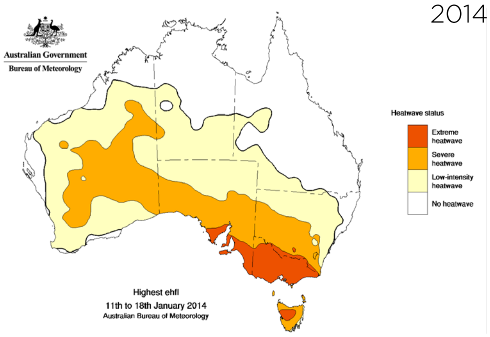


Figure 5 Excess heat factor values for the future event and for similar historical events. (Source: BOM Climate Tracker)

The frontal system passing over south-eastern Australia in the case study event is at least as strong as the systems associated with significant historical fire weather events (e.g. Black Saturday and Ash Wednesday) (Figure 6).

The weather events contribute to a high fire risk, especially in the key transmission corridors between Victoria (VIC) and New South Wales (NSW). The Forest Fire Danger Index (FFDI) peaked on Day 8 due to the passage of a strong frontal system over south-eastern Australia. These modelled FFDI values are similar to those of recent significant heatwaves and fire events (Figure 7).

Demand

Given the conditions, maximum demand was modelled by the Australian Energy Market Operator (AEMO) as slightly higher than a 1-in-10-year forecast, with more periods of high demand. High temperatures across multiple NEM regions (NSW, VIC and SA) create a high total NEM demand and puts more pressure on supply in every region, with less spare capacity to share between regions.

Figure 8 shows the maximum daily temperature and electricity supplied for each region. We see that the highest demands correspond to the high-temperature days on 23 and 24 January in VIC, NSW and SA. Demand on 25 and 26 January drops significantly due to lower temperatures and also due to lower weekend loads.

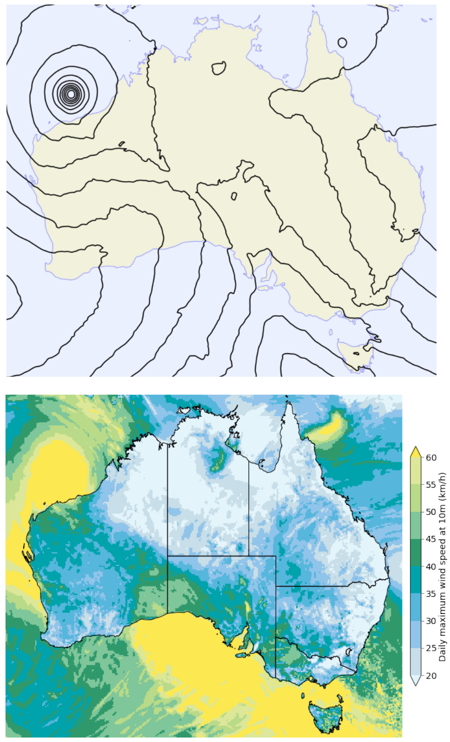


Figure 6 Strong frontal system passing over south-eastern Australia, January 2031.

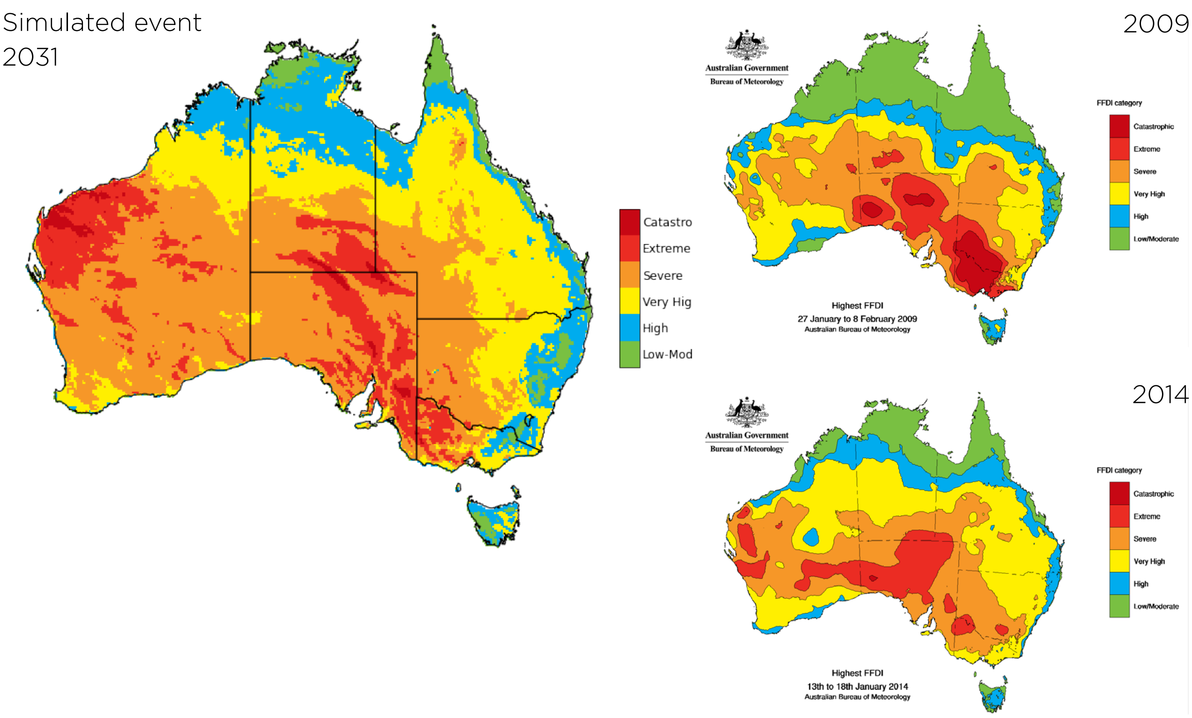


Figure 7 Forest Fire Danger Index for the simulated event compared with historical events. (Source for historical data: BOM Climate Tracker)

Line ratings

As with generators, line ratings normally decrease with temperature. In this case study, line ratings were reduced on the days during extreme heatwave conditions.[8] The ratings were based on normal minimum ratings (these line ratings will be based on the synthetic weather temperature data in future extreme compound event case studies).

Generator capacities

As temperatures exceed those previously experienced, some generators will come under increased stress. Currently, AEMO models generator capacity for three given temperature ranges depending on the region they are located. As temperatures exceed the upper temperatures provided, many generators will have reduced generation capacity (consistent with historical data). To incorporate this effect in the case study, the capacity of all generators was reduced below Summer 10 POE[9] capacity for the days of extreme high temperature. The capacity reductions applied for this case study are illustrative as this data are not currently collected; in future studies these will be refined based on measured outcomes.

Intermittent generation

Solar and wind generation profiles were created based on the weather outputs from the model developed for the ESCI case study on extreme heat and Variable Renewable Energy (VRE). Wind speeds, irradiance levels and temperatures were all considered when creating these profiles.

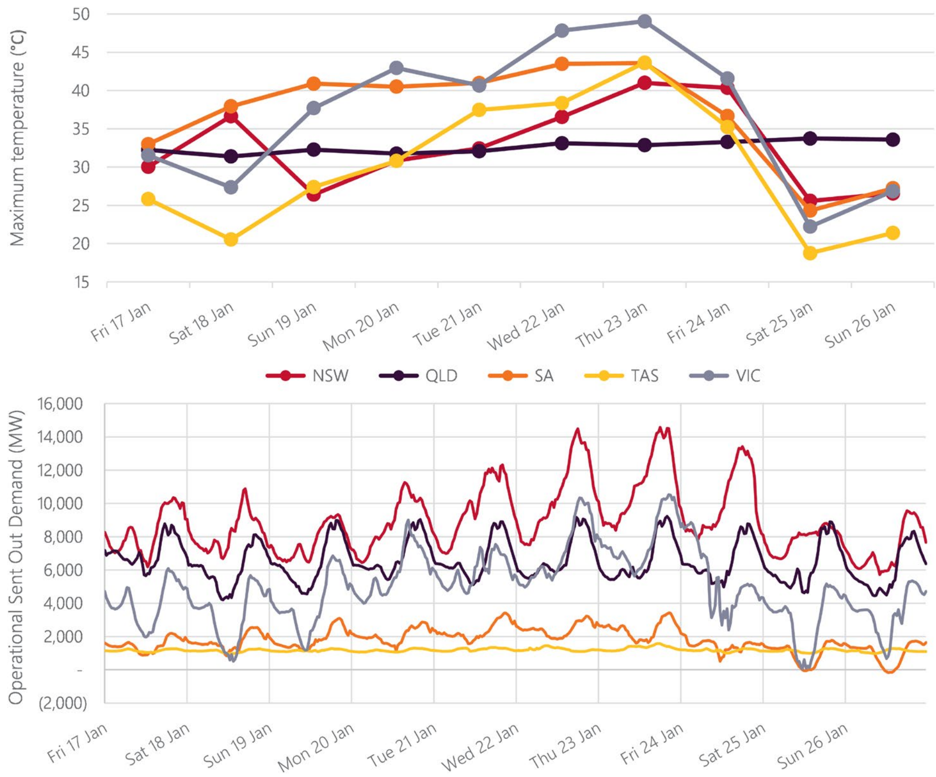


Figure 8 Maximum temperature over the days of the 'event' in 2031 (upper graph) and electricity supplied ('operational sent out demand') on the corresponding days (lower graph) (modelling by AEMO).

Transmission outages due to bushfire

Transmission pathways can be damaged or shut down by extreme weather events such as flooding, high winds, hailstorms and fires. The particular weather pattern selected in this study represents conditions associated with extreme bushfire risk (hot, dry and windy). The case study simulated a bushfire affecting transmission paths across VIC to NSW for a two-week period beginning at the start of the heatwave.

Other impacts

This case study did not look at impacts that could be caused by other extreme weather events such as drought, flooding or storm damage. Modelling of impacts for a range of extreme and compound weather events might identify common points of vulnerability which could be addressed to increase resilience. The analysis also does not identify any system security or stability issues which may occur under this event.

8 See also ESCI case study—The impact of climate change on transmission line ratings.

9 10 POE—Probability of exceeding a specified temperature once in every 10 years. A common metric for infrastructure engineering assessments.

Compare and prioritise against other risks

This case study explores the impact on consumer outcomes of a heatwave and bushfire event set in the year 2031 using the system state from the Central 2020 ISP Scenario (Figure 9), that includes generation and transmission investments required to meet the lowest cost objectives of the scenario. As this weather pattern has a high fire risk, a sensitivity of both with and without a fire which affects transmission between VIC and NSW was modelled.

NEM modelling unserved energy outcomes

The USE (unserved energy) during normal weather years is expected to be close to zero. The amount of USE in the 'Without bushfire' scenario was moderate compared to USE occurring in the 'With bushfire' scenario. USE occurs in NSW, VIC and SA where the heatwave occurs; supply and demand are much tighter in these three regions compared to Queensland (QLD) and Tasmania (TAS). The 'With bushfire' scenario resulted in significant USE in NSW (Figure 10).

Figure 11 shows that the extreme heatwave weather event created a risk of USE during two or three days in VIC and NSW. When the potential damage of a bushfire was included this created nine days where there was USE in NSW. The USE on additional days shows that extreme temperatures and extreme demand levels are not needed to cause USE in the event these transmission lines are unavailable due to bushfire.

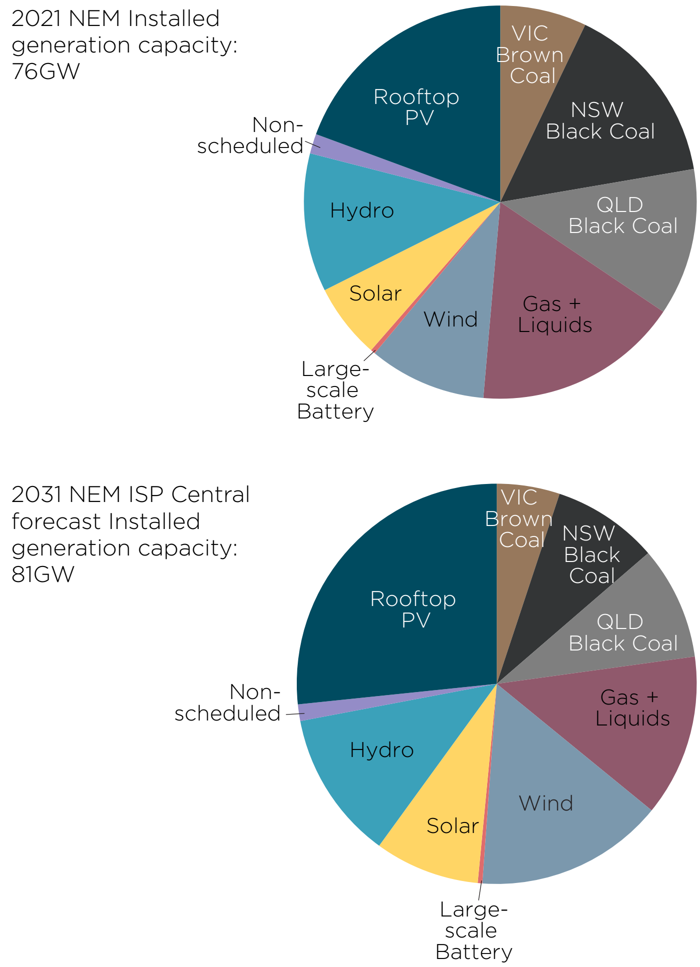


Figure 9 AEMO 2020 ISP Central scenario showing capacity build outcome in 2031.

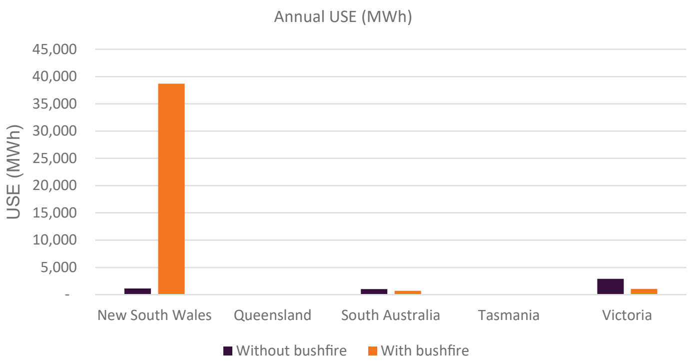


Figure 10 Annual unserved energy (USE) in the NEM in 2031 due to the modelled event.

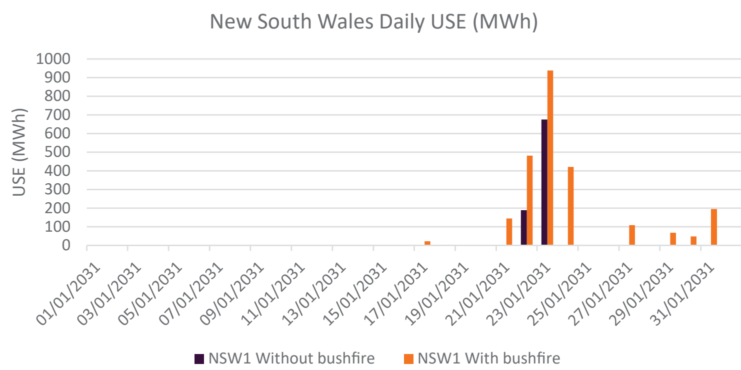


Figure 11 Daily USE in NSW due to bushfires compounding a heatwave event throughout the study.

Although the focus of this study was looking at USE there are also many system security, strength and operability issues to which weather events may contribute. Some risks to these operability issues are:

- predictability—as weather variation increases along with system reliance on solar and wind generation, demand and supply all become harder to predict.
- low demand—high solar irradiance and the increased photovoltaic (PV) generation can lead to situations where regional demand becomes low (or negative), causing numerous system security issues on the power system.
- While the lowest cost pathway identified in the ISP central scenario is likely to produce good outcomes in average conditions, the case study demonstrated that extreme events in a changing climate may result in undesirable outcomes.

Discussions on how to evaluate the risks from extreme compound events against other potential power system risks are ongoing. Given the difficulty of providing probability information for any single extreme compound event, conventional scenario analysis and cost-benefit analysis are not appropriate for this assessment. AEMO intends to model system impacts from a range of plausible, future extreme compound events to reach an assessment of overall risk to the system and to identify potential risk mitigation options.

Risk treatment: a brief discussion of adaptation options

While this case study did not propose any potential improvements to the NEM system, the AEMO 2020 ISP identified six design characteristics necessary for a resilient power system with sufficient flexibility to resist, absorb or recover quickly from such events:

- robust asset specification
- redundancy and operational flexibility
- effective control systems
- islanding capability (system that can run independently of the NEM)
- geographical diversity
- generation source diversity and the ability to forecast

This study showed that a bushfire in the VIC to NSW transmission passage leading to transmission outages has the potential to cause a significant increase in the risk of USE in NSW. Bushfire prevention or mitigation around transmission pathways in different areas could help reduce the probability of bushfires damaging transmission. Improved repair times could also help limit the time transmission lines are down.

Without bushfires the risk of USE is not as extreme, but the coincident higher temperatures in several regions at once create higher demand and lower supply levels than under 'historic' conditions used in current modelling. This leads to a higher risk of USE than under standard reliability forecast runs. Options to help offset USE include increases or changes in supply type (more battery or non-intermittent supply), which could improve generation supply during these periods. Network improvements that allowed higher line limits in high temperature periods would also improve reliability. Demand-side programs could also reduce pressure on the system during high temperature periods by reducing the demand needed.

Heatwaves are a significant public health issue resulting in high mortality rates. This case study used an extreme heat event and focused on system issues, but acknowledges that as temperatures rise with climate change, the public health impacts of USE may also rise.

Conclusion

Using compound extreme event case studies allows users to stress test the power system, and to explore possible vulnerabilities and risk management solutions. While the studies do not provide immediate input to quantitative cost-benefit analysis studies, they allow for numerous questions to be answered including:

- Is the risk of this event material?
- How does this event align with societal tolerance for impacts?
- What solutions might mitigate these risks?
- How do proposed investments perform in extreme events?

AEMO is planning to develop more case studies/ scenarios based on a range of extreme weather scenarios, including scenarios that will affect different parts of the electricity system. These scenarios will test the resilience of the electricity system in a way that is not fully captured under current modelling assumptions. A range of different scenarios and events will give AEMO an idea of what type of weather events may have significant impact on consumers and where major vulnerabilities may lie. It will also show which extreme weather events may not cause any problems.

Additional weather hazards that are correlated with recognisable weather patterns will be used to compound other modelled extreme weather scenarios. These hazards could include modelling damaged infrastructure caused by flooding, fires, hail, dust storms or severe convective winds.

This approach will be tested with the AEMO forecasting reference group and other consumer forums.

For further information

See Technical Report on Decision-making for extreme and compound weather events, ESCI Case Study—The impacts of extreme heat on variable renewable energy, and ESCI Case Study—Extreme temperature risk to transmission lines.

References

Australian Energy Market Operator (2017). Black System South Australia 28 September 2016. https://www.aemo.com.au/-/media/Files/Electricity/NEM/Market_Notices_and_Events/Power_System_Incident_Reports/2017/Integrated-Final-Report-SA-Black-System-28-September-2016.pdf

Australian Energy Market Operator (2020). Draft 2021 Inputs, Assumptions and Scenarios Report. https://aemo.com.au/-/media/files/electricity/nem/planning_and_forecasting/inputs-assumptions-methodologies/2021/draft-2021-inputs-assumptions-and-scenarios-report.pdf?la=en

Brayshaw DJ (2018). 'The nature of weather and climate impacts in the energy sector'; in A Troccolo (ed.) ***Weather and Climate Services for the Energy Industry***. https://doi.org/10.1007/978-3-319-68418-5

Dowdy AJ (2020). 'Seamless climate change projections and seasonal predictions for bushfires in Australia' Journal of Southern Hemisphere Earth Systems Science 70(1):120–38.

McArthur AG (1967). 'Fire behaviour in Eucalypt forests.' Forestry Timber Bureau Australia. https://catalogue.nla.gov.au/Record/2275488

Nairn JR and Fawcett RJB (2015). 'The excess heat factor: a metric for heatwave intensity and its use in classifying heatwave severity' International Journal of Environmental Research and Public Health 12:227–53.

Reeder MJ, Spengler T. and Musgrave R (2015). 'Rossby waves, extreme fronts and wildfires in southeastern Australia' Geophysical Research Letters. doi:10.1002/2015GL063125

Seneviratne SI, Nicholls N, Easterling D, et al. (2012). 'Changes in climate extremes and their impacts on the natural physical environment' in Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [CB Field, V Barros, TF Stocker, et al. (eds)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 109–230

Zscheischler J, Westra S, van den Hurk BJJM et al. (2018). 'Future climate risk from compound events; Nature Climate Change 8:469–77. https://doi.org/10.1038/s41558-018-0156-3