ELECTRICITY SECTOR CLIMATE INFORMATION PROJECT

③ Analyse future climate risk – quantified hazards

Overview

Our future climate will be different from that of the past and the impact of weather on a future energy system in a future climate will become increasingly significant. For example, Figure 1 shows that a small shift in mean temperatures will result in a large shift in the frequency of higher than usual temperatures, which is an important hazard for electricity infrastructure.

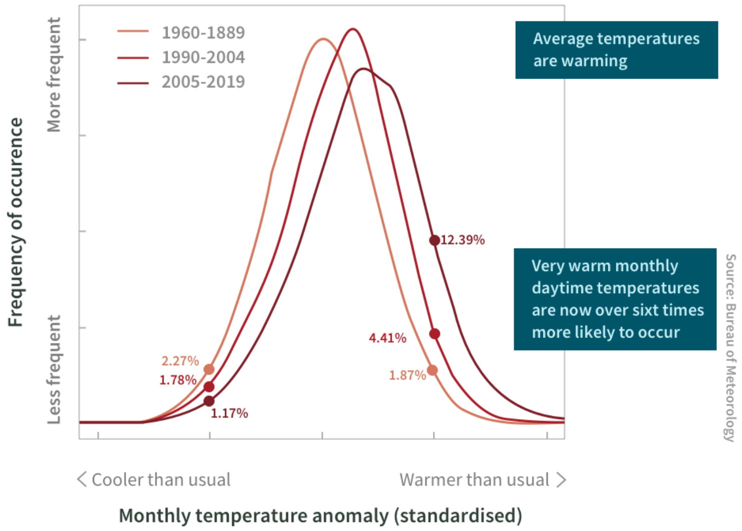

Figure 1: Small mean temperature changes can dramatically change the incidence of very high temperatures. In this example, an increase of less than 1 °C in mean temperature leads to a six-fold increase in monthly days 2 °C higher than average.

Step 3 of the ESCI Climate Risk Assessment framework (Figure 2) provides a standard process and guidance which allows risk related to future climate to be consistently integrated into sector planning and risk modelling. This step uses the relationship between performance and historical weather conditions established in Step 2 to analyse performance in a future climate.

Determining future climate risk requires careful selection and comparison of climate scenarios. The ESCI project has delivered high-resolution climate projection data, 5–12 km across the NEM, at sub-daily intervals, to 2100. The project recommends a minimum standard climate data set, tailored

Figure 2: The ESCI Climate Risk Assessment Framework

for the electricity sector, that can be used for most risk assessments. The use of standard data allows comparison of risk assessments across the sector for investment decisions and system-wide risk assessments and captures uncertainty in the future climate. The recommendation is not intended to be restrictive but facilitates efficient production of reliable information.

Where the climate risk assessment suggests a significant risk, or where a high value investment is involved, the advice of climate experts should be sought.

Defining the scope

Choosing appropriate climate information for the risk analysis depends on a number of parameters—some of which were considered in Step 2:

- *What is the key hazard?* Is the historical performance dominated by a single hazard (e.g. high temperature) or multiple hazards (e.g. power line transmission ratings are affected by both wind and temperature)?
- *Are thresholds more important or is the range of variance important?* Thresholds could include, for example, performance above 45 °C, or engineering built to withstand 1 in 100-year events. Variance can be explored with time series, available as daily, monthly, annual or sub-daily data.
- *What time frame is important?* This is likely to be guided by the lifetime of the asset (e.g. next 20 years or next 50 years).
- *What greenhouse gas emissions pathway is most relevant?* This will depend to some extent on the purpose of the risk analysis. The project recommends scenario analysis using at least 2 pathways.

These questions can be used to select appropriate climate data through the the ESCI website (Figure 3).[1]

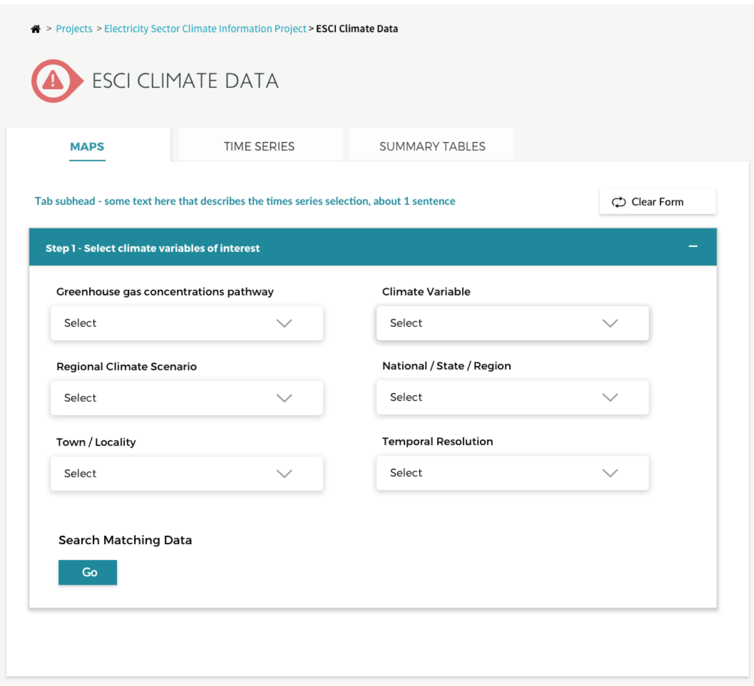

Figure 3: The ESCI Climate Data portal allows users to select a range of climate information. The most appropriate climate information depends on the scope of the analysis and outcomes of Step 2 in the ESCI Climate Risk Assessment Framework.

1 In some cases the most appropriate information can be found in the broader Climate Change in Australia (CCiA) website. Data on the ESCI portal have been tailored so that they are more likely to address electricity sector questions: see Key concepts—ESCI recommended data sets.

Conducting a climate risk analysis

Future climate risk can be assessed using the model developed in Step 2 which captures the historical relationship between weather/climate and asset/system performance. This model can use projected climate data as an input to estimate future asset/system performance.

Climate projections are, by definition, uncertain therefore the ESCI project recommends 2 ways of expressing uncertainty: a) using different climate scenarios; b) using a collection ('ensemble') of climate models. These 2 methods can be combined (Figure 4 shows an analysis using 3 climate scenarios and 4 climate models).

Using climate scenario analysis

The Intergovernmental Panel on Climate Change (IPCC) describes changes in the future climate using 'representation concentration pathways' (RCPs) for greenhouse gas emissions.[2] Climate scenarios are derived from climate model simulations driven by representative concentration pathways and provide information about projected changes in variables such as temperature, rainfall and windspeed. Figure 4 shows a climate risk analysis of the impact of future temperature trends on transmission line ratings[3] using RCP2.6, RCP4.5 and RCP8.5.

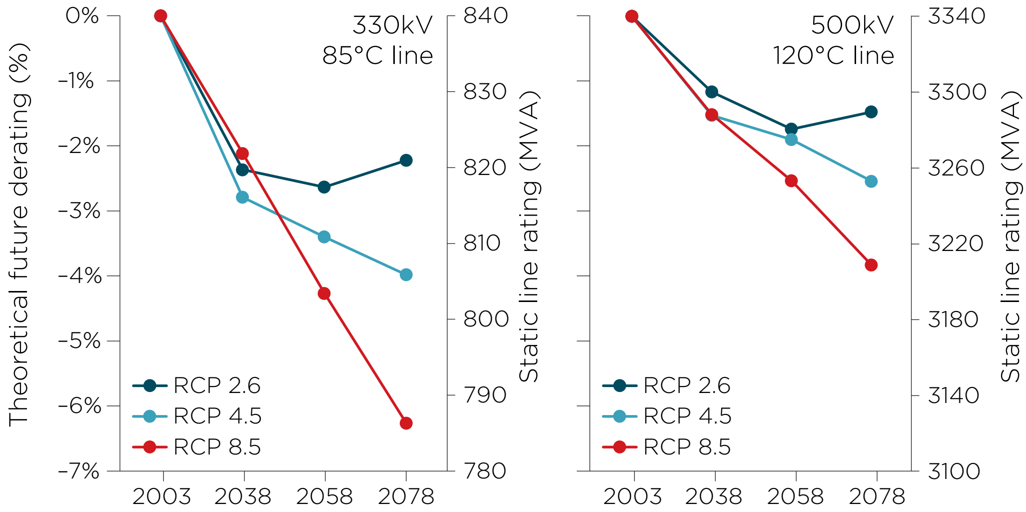

Figure 4: Projected de-ratings for a 330kV, 85 °C line (left), and a 500kV, 120 °C line (right) in New South Wales under 3 climate scenarios (RCP 2.6, 4.5 and 8.6) using 4 climate models for each scenario. (Source: ESCI case study—the impact of extreme temperatures on transmission lines.)

Using an ensemble of climate models

The plausible range of a future climate variable can also be estimated by using data derived from an ensemble of climate models. If the analysis uses a single climate variable (e.g. temperature), then the data from an ensemble of climate models can provide a probability distribution for the future range of that variable (see Figure 5) and therefore the range of future system performance. For example, a transformer's performance in a future climate can be estimated using the historical relationship derived in Step 2 and a Monte Carlo simulation informed by the range of potential future temperatures taken from several different climate models.

2 Covered in detail in the ESCI key concept—Choosing representative emissions pathways. The pathway number represents the 'radiative forcing' or warming potential of the greenhouse gas concentration in watts per square metre.

3 See ESCI case study—The impact of extreme heat on transmission lines.

It is very important to note that if the risk assessment requires multiple climate variables (e.g. if both wind and temperature are important), then the analysis of the system or asset performance in a future climate should be done for each climate model and the uncertainty assessed by comparing the output of these analyses to give the range of future performance. It is not appropriate to combine data from different climate models (e.g. wind data from one climate model and temperature data from a different model) as individual climate models have internally consistent climatology. Combining variables from different climate models can produce implausible results (e.g. snow on a hot day).

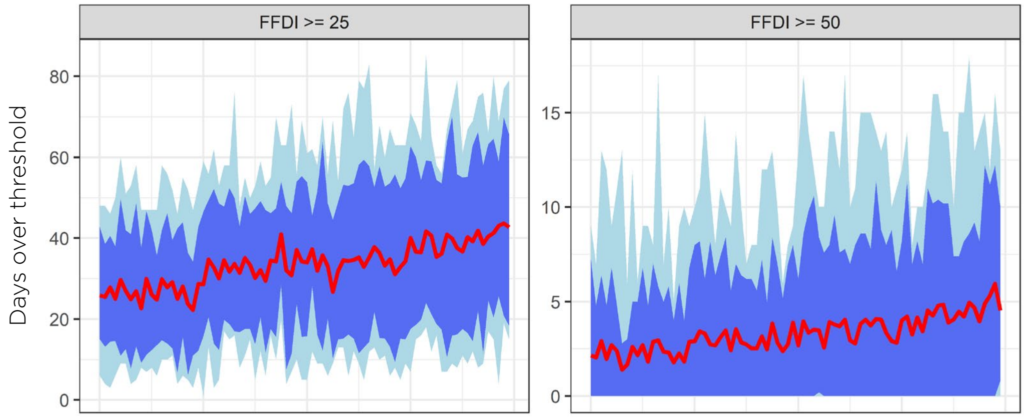

Figure 5: Time series of days per year when the forest fire danger index is over 25 ('very high fire danger') and 50 ('severe fire danger') near Adelaide, projected from 2020 to 2100. (Source: ESCI case study—bushfire risk and transmission). These plots combine the time series from 8 different climate models, using RCP8.5, with the light blue showing the range for all models, the dark blue showing the range for 80% of the models and the red line showing the median value.

Climate data tailored to electricity sector needs are available on the ESCI website. Additional or alternative climate information can be accessed from a number of sources, the most credible and comprehensive being the Climate Change in Australia web portal.[4,5] Other relevant information sources include the CMSI climate science guidance[6] and the NESP Earth Systems and Climate Change Hub.[7]

More information on choosing future climate scenarios and climate data sets for the analysis is presented below.

Choosing RCPs

Representative concentration pathways are plausible future scenarios but are not predictions; they depend on a range of assumptions about contributions to climate change. For example, will we continue to burn fossil fuels at an ever-increasing rate, or will we continue shifting towards renewable energy?

The 4 most commonly used RCPs range from very high (RCP8.5) through to very low (RCP2.6) future greenhouse gas concentrations.[8]

4 www.climatechangeinaustralia.gov.au/

5 See ESCI Key Concepts—Using Climate Change in Australia.

6 https://climate-kic.org.au/our-projects/cmsi/

7 http://nespclimate.com.au/publications/

8 The ESCI project provides data sets for RCP4.5 and RCP8.5. However, a simple scaling approach can be used to adjust these data sets to provide data for an RCP2.6 scenario. See ESCI key concepts—scaling data sets for RCP 2.6.

Table 1 provides guidance for how to match the selection of the RCP to the purpose of the risk assessment. The ESCI project recommends that a climate risk analysis should use 2 pathways: RCP4.5, a moderate pathway, and RCP 8.5, a very high pathway.

Table 1: Time frames and recommended RCPs for different purposes

Purpose of risk assessment	Timeframe and RCP
Physical risk assessment as part of a financial reporting requirement	TCFD[9] recommends using scenarios that give a global warming of 2 °C and 4 °C by the year 2100. The CMSI guidance[10] recommends using RCP2.6 for a 2 °C warming scenario and RCP8.5 for a 4 °C warming scenario.* However, RCP4.5 has a 40% chance of keeping global warming below 2 °C by 2100 so it is also worth considering.
Stress-testing the performance of an asset or system or process in a future climate	Consider the greatest plausible changes for the key hazards, which are likely to be provided by using RCP 8.5. (The ESCI case study on extreme compound events can also provide stress-testing scenarios.)
Assessing the likely range of performance of a future investment**	A range of RCPs and climate models should be used to assess asset or system performance. ESCI provides recommendations on 'worst/ best case' scenarios to use in these risk assessments.[11]
An exploration of the system performance under different AEMO ISP scenarios (see sidebar)	The AEMO ISP provides scenarios for the next 20 years,[12] each of which is associated with a different RCP*. For example, the 2021 IASR 'Central' scenario is associated with RCP4.5, the 'diversified technology' scenario is associated with RCP2.6 and the 'slow growth' scenario is associated with RCP7.0.

Notes

* The differences in RCPs and global warming are small up to 2040, with the differences becoming more important from 2050.

**Climate variability over the next 1–10 years is strongly influenced by natural variability;[13] climate models have limited predictive skill over this period so historical risk can be a good guide.

9 TCFD (2017) The use of scenario analysis in disclosure of climate-related risks and opportunities. https://assets.bbhub.io/company/sites/60/2020/10/FINAL-TCFD-Technical-Supplement-062917.pdf

10 https://www.cmsi.org.au

11 See ESCI Key Concepts—ESCI Recommended data sets—testing and validation.

12 AEMO 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

13 See ESCI key concepts—Climate projection confidence and uncertainty.

Climate models and downscaling

Global climate models (GCMs) are rigorous, complex and well-tested representations of physical processes in the climate system. The models run on supercomputers that provide solutions for multiple variables, time scales and regions. The models are constantly being updated as the science of climate change advances. There are 40 CMIP5[14] climate models accepted by the IPCC as authoritative. The ESCI project uses 6 of these[15] that perform well in the Australian region.

GCMs have coarse spatial resolution (about 100–150 km between data points), which limits their ability to simulate small-scale processes including extreme weather events. The GCMs can be downscaled[16] using high-resolution regional climate models that may provide additional insights and the potential for better information about extreme weather events.

The ESCI project generated 16 data sets from the GCMs using regional climate models (RCMs): the cubic conformal atmospheric model (CCAM, developed by CSIRO); the Bureau of Meteorology Atmospheric high-Resolution Projections for Australia (BARPA); and NARCliM (NSW and ACT Regional Climate Modelling) developed by a NSW Government partnership. The data sets are augmented by a tailored post-processing technique called quantile matching for extremes (Dowdy, 2020), which produces data sets that are 'application-ready' (free of bias compared to observations and available on a 5 km grid) and appropriate for the analysis of changes to averages as well as climate extremes at the daily timescale.

The ESCI project recommends using a minimum of 4 data sets which can be considered representative of 4 climate futures, described by general terms like hot, wet, dry, warm (Table 2). Depending on the region of interest, stakeholders can choose data sets that represent the range of possible future climate scenarios.

Table 2: The global climate model and downscaling model used to generate the 4 recommended data sets, and the general categorisation of the 'climate future' that each model produces. The regions are shown in the map in Figure 6a

	Global climate model	Downscaling model	Northern Australia	Southern Australia	Eastern Australia	Inland (Rangelands)
1	GFDL-ESM2M	CCAM	Warm, Dry	Warm, Dry	Warm, Dry	Warm, Dry
2	CanESM2	NARCliM-j	Hot	Warm	Hot	Hot
3	ACCESS-1.0	BARPA	Mid case	Mid case	Mid case	Mid case
4	NorESM1-M	CCAM	Warm, wet	Mid case	Warm, wet	Warm, wet

The 4 recommended projections can be seen in relation to the wider range of 40 GCMs in scatterplots of temperature and rainfall change (Figure 6b). The 4 models don't span the entire range in every case; a subset of just 4 models can't achieve this. These recommended data sets provide a minimum standard that can be used in most risk assessments, enabling consistency and comparability.[17] They are relevant to the electricity sector and are scientifically credible.[18]

14 See ESCI Key Concept - CMIP6 models

15 Downscaling is also provided for Access1.3 using NARCliM. Access1.3 was not identified in the CCiA Technical Report as performing well in the Australia region.

16 Downscaling may not always add value and has important limitations—for more information, refer to ESCI key concepts factsheet: climate models and downscaling (also Virgilio 2020 and Fiedler 2021).

17 Suggested additional cases for Southern Australia are ACCESS-1.0-NARCLIMk-QME (dry future) and CanESM2-CCAM-QME (hot future), also available through the ESCI portal.

18 See Key concepts—ESCI Recommended data sets—testing and validation.

Data for other climate models, including high-resolution regional downscaling, are provided via the ESCI website and can be used to supplement the recommended minimum data sets. It is always good to use as many of the model outputs as is practical, since using more models and data sets explores more of the plausible 'uncertainty space' in climate change.

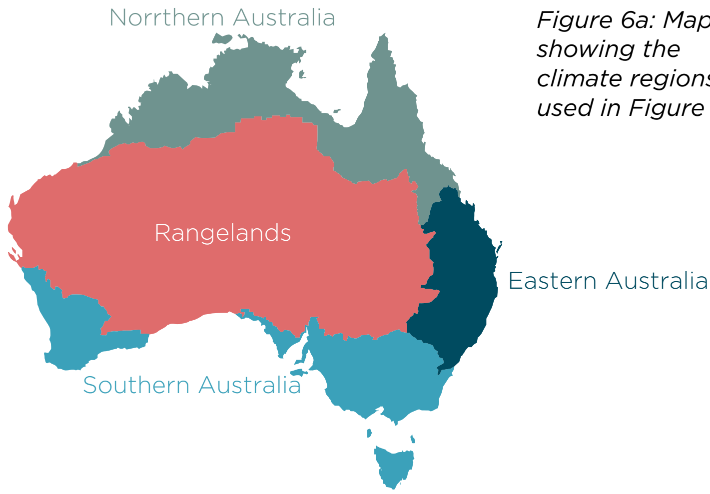

Figure 6a: Map showing the climate regions used in Figure 6b

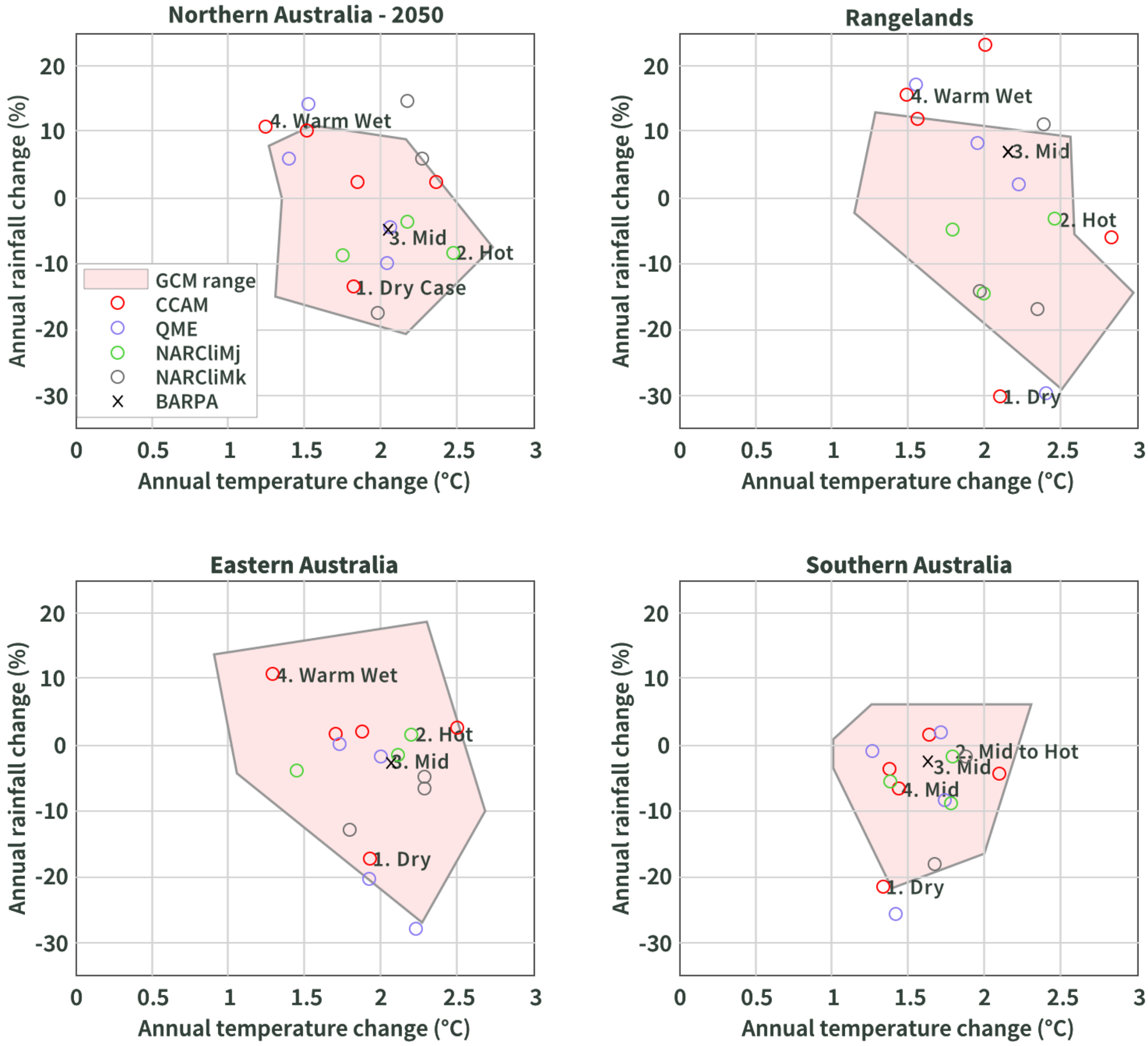

Figure 6b: Projected change in annual temperature and rainfall between 1986–2005 and 2040–2059 under very high emissions pathway (RCP8.5) for 4 broad regions of Australia shown in Figure 6a. The polygon shows the range simulated by 40 CMIP5 GCMs as reported in Climate Change in Australia (CSIRO and BoM 2015), and the markers show the 16 ESCI projections, differentiated by symbol. The recommended data sets are numbered 1–4.

Climate information products for use in risk assessments

The ESCI project provides a range of climate information that can be used for different risk assessments.

Gridded data

Extreme weather events can be analysed by frequency or intensity. Intensity can be displayed as maps of events with 2-, 5-, 10- or 20-year average recurrence intervals (ARI).[19] Frequency can be displayed as maps of the number of days per year exceeding specified thresholds (e.g. days over 40 °C). Data are available on a 5 km grid. Frequency and intensity maps are provided both from single models, for use when comparing multiple variables, and from an ensemble of all available model simulations[20] for use in comparing extreme values of single hazards such as extreme temperature or rainfall.[21]

Figure 7 shows examples of 1-in-20-year ARI maps for maximum temperature in 2050 and 2070 for RCP8.5. A similar map can be produced from the same model for rainfall and for bushfire weather.[22]

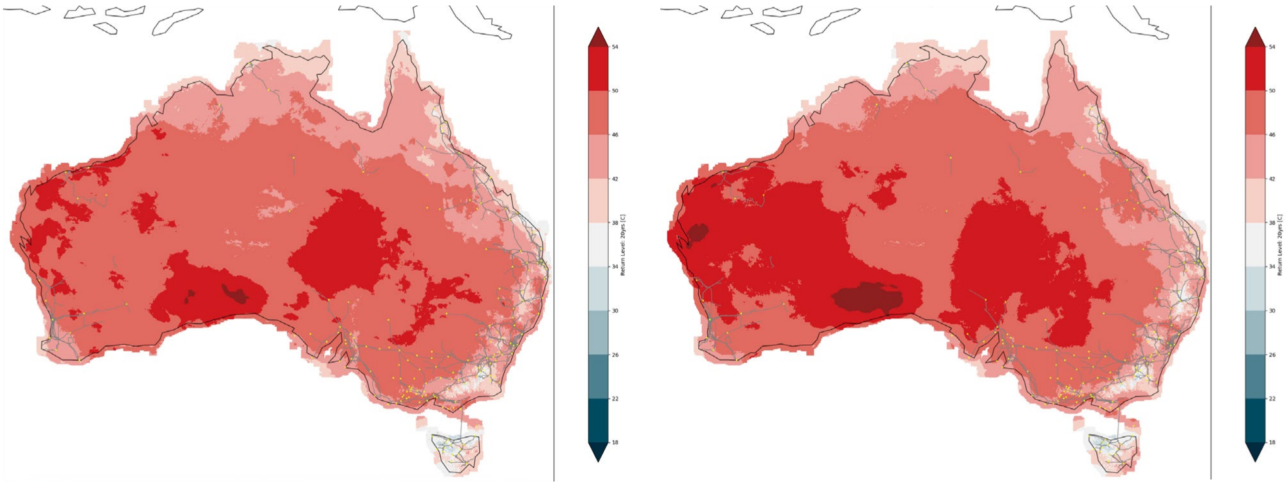

Figure 7: 1-in-20-year maximum temperatures for the summer months (Dec–Feb) for 20-year time-slices centred on 2050 (left) and 2070 (right). The data are from the CanESM2-CCAM-QME data set derived using RCP 8.5. The top red bar represents temperatures higher than 54 °C.

Gridded data for severe convective windspeed includes only current climate, as projections for future climate are highly uncertain, but ESCI research has provided significant new insight on the climatology of this hazard (Brown and Dowdy 2021)[23].

Time series

19 See ESCI Key Concepts—Deriving average recurrence interval (ARI) maps.

20 Technically, for an ensemble of climate models these are not maps but are visualisations of a statistical surface where each grid-cell is calculated separately so the data on the extremes for each cell may come from different climate models. Relative risk cannot be assessed from one cell to the next—time-series at relevant locations should be used to compare asset risk by location.

21 Average recurrence interval gridded data constructed from an ensemble of climate projections provides more stable information on extreme hazards but should *only* be used for single variable problems—see Conducting a climate risk analysis—and may be biased towards extremes.

22 Gridded data are available as images (PNG format) or netCDF files. NetCDF format files are very large files which can be viewed using ArcGIS software and which include information on all relevant climate variables so that the different climate variables can be viewed as layers.

23 See ESCI case study on severe convective wind risk.

The ESCI website provides simulated weather time series (from sub-daily to annual intervals) from 1980 to 2099 at 168 locations across the National Electricity Market, with a focus on urban centres, major transmission routes and renewable energy zones. Historical weather data from the Bureau of Meteorology are also available for 1980–2020. The historical weather data should be used in Step 2 to establish a relationship between weather and asset/system performance. Simulated weather data for 1980–2020 have similar statistical properties but the sequence of weather events is different.

Summary tables

Summary statistics have been tabulated for selected climate variables, seasons, 20-year periods, RCPs and locations. These tables can provide a quick reference to the scale of expected change and can be displayed and downloaded in Excel format from the ESCI website.

Understanding confidence and uncertainty in climate projections

There are 3 main sources of uncertainty in climate projections:[24]

- Natural climate variability. This includes internal variability in daily weather, seasonal–annual climate (e.g. El Niño and La Niña), and decadal climate (e.g. Pacific Decadal Oscillation). This is the dominant source of uncertainty over the next 1–10 years.
- How regional weather and climate respond to changing greenhouse gas and aerosols concentrations. This information is derived from climate models, each of which provides a different simulation of future weather and climate at a given location.
- How greenhouse gas and aerosol concentrations may change in response to socio-economic change, technological change, energy transitions, and land-use change. This is described using representative concentration pathways (see Conducting a climate risk analysis). This is the largest source of long-term uncertainty.

Confidence in the validity of the climate projection for any single variable is based on the type, amount, quality and extent of agreement of different lines of evidence for future climate information (this includes climate process understanding, theory, published data, models and expert judgment).[25] Confidence is expressed qualitatively as very low, low, medium, high or very high. Where there is limited evidence with low agreement, confidence is low. Where evidence is robust with high agreement, confidence is high.

The ESCI project provides a rigorous assessment of confidence in projections for key climate hazards (summarised in Table 3).

24 ESCI Key Concept—Climate projection confidence and uncertainty includes a table quantifying the ranges of uncertainty and confidence ratings for selected climate variables, 20-year periods, RCPs and regions.

25 The ESCI Technical report on the standardised methodology for projections likelihood describes the science behind the confidence and likelihood projections and expert assessment for 3 key hazards: rising temperatures, bushfire risk and severe convective winds.

Table 3: Summary of confidence in future changes to key hazards

Hazard	Confidence
Increases in average and extreme temperature	Very high
Decreases in winter and spring rainfall in southern Australia	High
Winter rainfall decreases in the east	Medium
Increase in extreme daily rainfall	Medium
Increases in extreme fire weather days	High confidence except in the east where there is medium confidence
Decreases in the number of east coast lows	medium
Increases in severe windspeeds	low

Conclusion

The ESCI project has delivered high-resolution climate projection data (5–12 km across the NEM, at sub-daily to daily intervals, to 2100). It has also tailored guidance and insights to enable the electricity sector to select appropriate data to assess climate risks and to plan for the future with greater confidence. The steps in the ESCI Climate Risk Assessment Framework, with the information available through the Climate Change in Australia website, allow climate risk to be integrated consistently into sector planning and risk modelling.

Limitations of climate information

Climate projections are based on global and regional climate models that use mathematical representations of the laws of physics, such as conservation of mass, energy and moisture. These models are rigorously evaluated against historical climate data. However, climate information derived from models is intrinsically uncertain. Important limitations are:

- **Near-term climate risk (10–20 years)**
  In this time frame the climate is dominated by natural variability. Climate projections can provide numerical precision, which should not be confused with accuracy. Recent observations may provide a good indication of near-term climate risk although underlying trends, particularly in temperature and extreme weather, may be material.

- **Asset-scale climate risk (< 10 km)**
  Information on this spatial scale requires 'downscaling' based on statistical or dynamical models. Downscaling provides spatial resolutions of 5–10 km, potentially improving the simulation of regional climate change near topographical features; the ability of downscaling techniques to add value to global climate models should be supported by evidence.

- **Weather-scale phenomena**
  Many dangerous weather events, such as tropical cyclones and hailstorms, are a result of atmospheric processes operating at scales of less than 1 km, so climate models use parameterisations to estimate these processes. Therefore, models provide information about broadscale environmental conditions associated with weather phenomena. Detailed evaluation of extreme weather and climate indices is needed to determine whether statistical corrections are necessary.[26]

- **Extreme events**
  Extreme and compound extreme weather events are, by definition, rare and can cause significant impacts. Extreme threshold magnitudes and frequencies can be calculated from historical and projected weather data, but the sample sizes are often small, so there are substantial uncertainties. Scenarios of extreme and compound event case studies from historical and projected data can be used to assess possible risks so that mitigation options and resilience can be considered.[27]

26 For example, in the analysis of extreme winds; see ESCI case study and technical report on severe convective wind risk.

27 For example, see ESCI case study on compound extreme event, also the Technical Report on decision-making using extreme/compound event case studies.

References

Brown, A., & Dowdy, A. (2021). Severe convection-related winds in Australia and their associated environments. *Journal of Southern Hemisphere Earth Systems Science*, *71*(1), 30-52.CSIRO and Bureau of Meteorology (2015) *Climate Change in Australia Information for Australia's Natural Resource Management Regions: Technical Report*, CSIRO and Bureau of Meteorology, Australia.

Dowdy, A.J. 'Seamless climate change projections and seasonal predictions for bushfires in Australia' (2020) *Journal of Southern Hemisphere Earth Systems Science*, *70*(1), 120-138, https://doi.org/10.1071/ES20001

Di Virgilio G, Evans JP, Di Luca A, et al. 'Realised added value in dynamical downscaling of Australian climate change' (2020) 54 *Climate Dynamics* 4675–92. https://doi.org/10.1007/s00382-020-05250-1.

Fiedler T, Pitman AJ, Mackenzie K, et al. 'Business risk and the emergence of climate analytics' (2021) 11(2) *Nature Climate Change* 87-94.

A glossary of terms used in this and other modules is available on the ESCI website. 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

For more information

CSIRO: www.csiro.au/en/Contact
BOM: energy@bom.gov.au