ELECTRICITY SECTOR CLIMATE INFORMATION PROJECT

ESCI Climate Risk Assessment Framework

User Guide

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Australian Government
Department of Industry, Science, Energy and Resources

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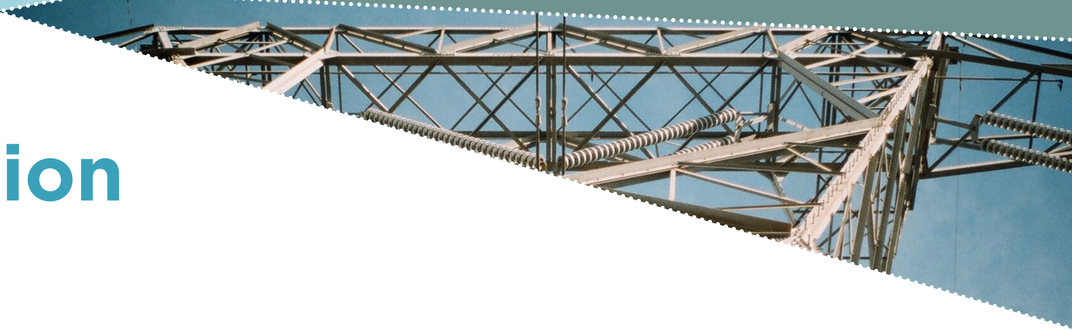
CSIRO

AEMO
AUSTRALIAN ENERGY MARKET OPERATOR



Introduction

Overview

The impacts of weather on a future energy system in a future climate will become increasingly significant. Using a standard framework for a climate risk assessment provides a consistent, structured and pragmatic approach for minimising harm and capturing opportunities.

The ESCI climate risk assessment framework follows the International Standard ISO 31000 for Risk Management, starting with understanding the context, then identifying and analysing the climate risk, prioritising risks, and then determining how to mitigate the key risks. The suite of tools developed by the Electricity Sector Climate Information Project (ESCI) can be used to integrate climate risk consistently into sector planning and risk modelling using a standard process.

Introduction

The guidance is structured around the 5-step ESCI Climate Risk Assessment Framework. The framework has been designed and tested by key electricity sector stakeholders and climate experts in CSIRO and the Bureau of Meteorology, with support from the Department of Industry, Science, Energy and Resources. The guidance includes recommending climate data, case studies showing how the climate risk assessment framework and associated data have been used, and other supporting documentation.

The Electricity Sector Climate Information (ESCI) project provides guidance for electricity sector stakeholders on using climate information in risk assessments.

While the framework is aimed at the electricity sector, it can be used by other sectors to incorporate climate risk into decision-making.

Why is climate risk assessment needed?

The International Standard ISO 31000 for Risk Management defines risk as the ‘effect of uncertainty on objectives’.[1] For the electricity sector, the National Electricity Objective (AEMC 2019) is:

to promote efficient investment in, and efficient operation and use of, electricity services for the long-term interests of consumers of electricity with respect to:

- price, quality, safety and reliability and security of supply of electricity
- the reliability, safety and security of the national electricity system

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[1] ISO 31000 (2018) Risk Management https://www.iso.org/iso-31000-risk-management.html

Context for using the climate risk assessment framework

There is clear evidence that the climate has been changing (BoM and CSIRO, 2020). Australia has warmed by 1.4 °C since 1910 (Figure 1), with less rainfall in the south and east and more rainfall in the north. Impacts on the electricity system have been felt through extreme weather events such as heatwaves, floods, wind-storms, droughts and fires.

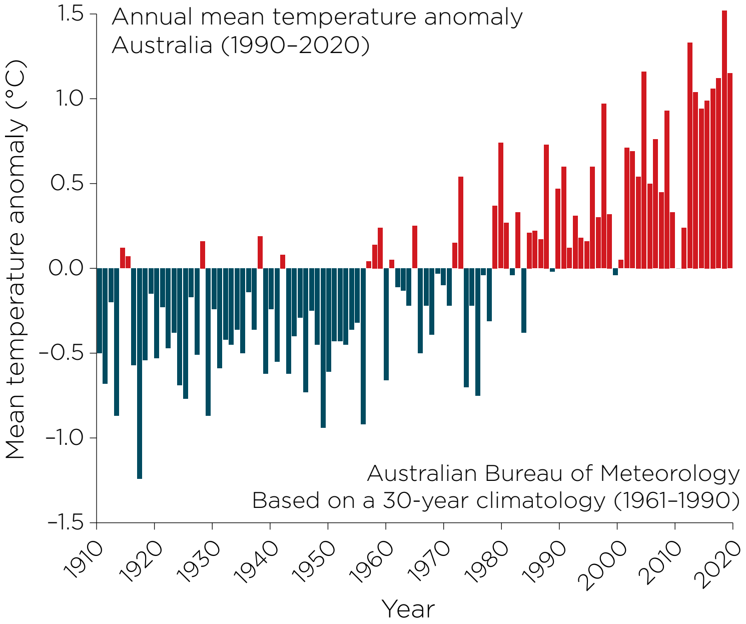

Figure 1: All parts of the electricity sector, from generation to transmission and supply to demand, are sensitive to heat. Increasing average and extreme temperatures due to climate change present an operating environment different from the past. (Source: Bureau of Meteorology Climate change and variability: Tracker: Australian timeseries graphs)

Climate change is creating new risks for businesses (Table 1). For example, high temperatures increase electricity demand and affect all electricity supply infrastructure; as temperatures rise with climate change, the risks to the sector will also rise.

The development of the ESCI climate risk assessment framework

The framework provides detailed and context-specific guidance on conducting a climate risk assessment. The method uses the approach taken for most risk assessments in the sector, so allows climate risk to be seamlessly incorporated into decision-making. It integrates relevant information from:

- International Standard *ISO 31000 Risk Management*, which provides a general framework that is widely used internationally
- International Standard *ISO 14090 Adaptation to Climate Change*, which is consistent with ISO 31000 and well aligned with climate risk assessment for the electricity sector
- the *Australian Climate Compass*, which is also consistent with ISO 31000, with a focus on climate risk assessment for policy and programs
- Australia's *National Disaster Risk Reduction Framework*
- Australian Standard *AS 5334 Climate change adaptation for settlements and infrastructure*
- Climate Risk and Resilience Guidance Manual (Energy Networks Australia 2015), a detailed guide to risk assessment for energy networks that provides advice that can be used by other parts of the sector

Table 1: The risks that climate change poses to the electricity sector

Physical risks

- Electrical assets are likely to be affected by weather that differs from the historical expectation.
- Physical risks include:
  - changing wind, irradiance, precipitation and temperature, affecting the instantaneous supply and demand balance
  - increases in extreme weather and compound weather events that affect the operability and failure rates of assets

This category is the focus of the ESCI project

Supply-side transition risks	Demand-side transition risks	Institutional risks
As part of global greenhouse gas emission reductions and changing technology prices, electricity generation is transitioning from fossil fuels to renewable sources such as wind and solar. The intermittent nature of these sources affects the operability of systems, as well as transmission needs, reliability, system stability, strength, fault levels and synchronous support.	Climate change and decarbonisation will affect electricity users and their needs. Impacts to residential consumption may include additional rooftop PV and electric vehicles. Impacts to business consumption may include additional desalination, further restructuring of the economy and changing agricultural and industrial needs.	Failure of sector institutions and organisations to consider climate change will produce financial, legal, governance and reputational impacts.

Potential applications of a climate risk assessment include:

- prioritising climate risks that require mitigation
- managing asset safety and reliability risks
- managing the potential for asset or value destruction
- managing the potential for changes in cash flow or profitability
- managing consumer outcomes from the integrated power system
- designing new asset specifications for future operating conditions
- calculating market benefits attributable to regulated investments, considering changes to operating conditions of the integrated power system

Climate change is superimposed on natural weather and climate variability, and while historical records provide a good indication of emerging risks, future risks are likely to be underestimated or may appear in new locations. Climate risks to the electricity sector are likely to be most relevant in strategic or planning time frames (5–50 years). However, some impacts are already evident and are relevant to operational time frames (1–5 years).

What does the framework cover?

The framework covers the analysis of physical climate risks, defined by the Intergovernmental Panel on Climate Change (IPCC) as the combination of hazards, exposure and vulnerability (Cardona 2012). Exposure is the presence of people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected by a hazard. Vulnerability refers to the propensity of assets, systems and consumers to experience adverse effects. This may be the result of design or engineering, or the inability to adapt, such as a community not being able to move out of the way of a hazard such as a fire or flood.

The ESCI project provides information on the intensity and frequency of weather and climate hazards.[2] For a complete risk assessment, exposure and vulnerability need to be considered. For example, the National Energy Market (NEM) has long interconnectors between population, industrial and other demand centres. Thus, the NEM is widely exposed to extreme weather events, climate variability and climate change.

The ESCI Climate Risk Assessment Framework has 5 steps (Figure 2).

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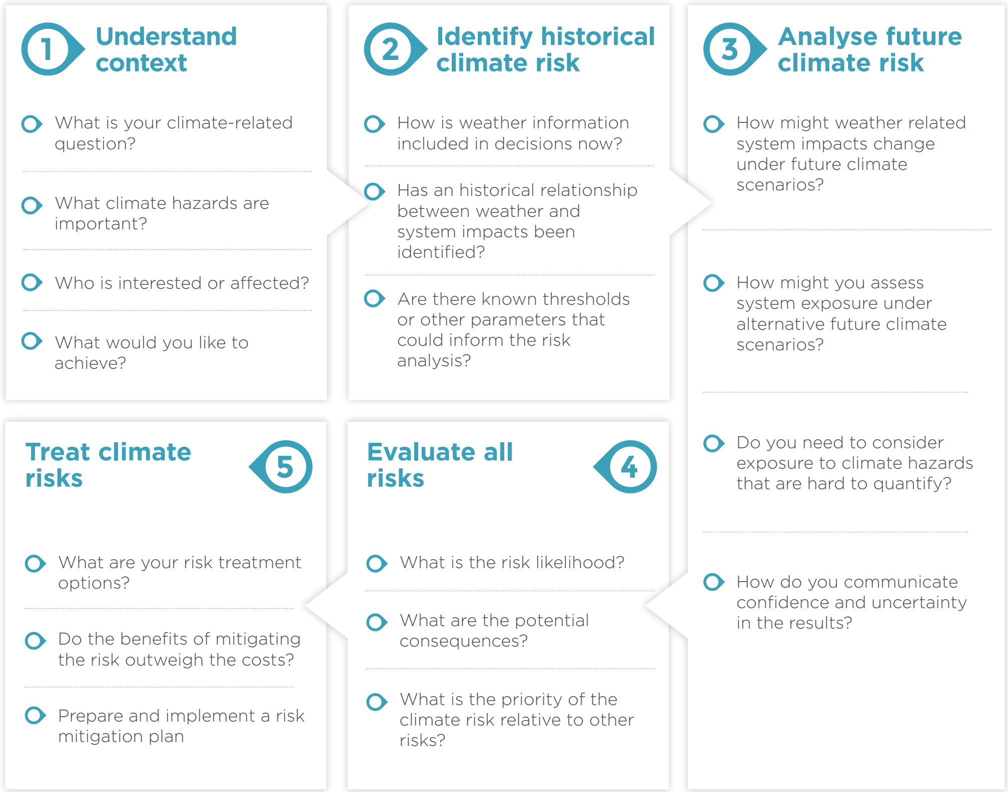
[2] Note, a *hazard* could be a change in a climate *variable*—for example, temperature is a *variable*, but an extreme temperature is a *hazard*.



1 Understand context

- What is your climate-related question?
- What climate hazards are important?
- Who is interested or affected?
- What would you like to achieve?

2 Identify historical climate risk

- How is weather information included in decisions now?
- Has an historical relationship between weather and system impacts been identified?
- Are there known thresholds or other parameters that could inform the risk analysis?

3 Analyse future climate risk

- How might weather related system impacts change under future climate scenarios?
- How might you assess system exposure under alternative future climate scenarios?
- Do you need to consider exposure to climate hazards that are hard to quantify?
- How do you communicate confidence and uncertainty in the results?

4 Evaluate all risks

- What is the risk likelihood?
- What are the potential consequences?
- What is the priority of the climate risk relative to other risks?

5 Treat climate risks

- What are your risk treatment options?
- Do the benefits of mitigating the risk outweigh the costs?
- Prepare and implement a risk mitigation plan

Figure 2: The ESCI Climate Risk Assessment Framework

The 5 steps for climate risk assessment are:

1 Understand context

This takes a decision-centred approach involving broad stakeholder engagement which focuses on understanding the vulnerabilities of key assets, systems and consumers, and the purpose of the risk assessment. The ESCI project provides guidance on climate information that can be used to scan quickly for exposure and vulnerability to climate hazards.

2 Identify historical climate risk

Risk identification builds upon the initial scan in step 1 by developing a deeper understanding of the historical relationships between weather, climate and electricity system performance. This step produces a statistical model describing the relationship between weather, climate and performance and will define the temporal and spatial scale of interest. Relevant engineering standards and performance standards should be considered and can help identify the metrics for use in the analysis.

3 Analyse climate risk

This step uses the model developed in Step 2 and the purpose of the risk assessment to identify climate scenarios of interest. The most appropriate climate projections can then be used to determine how the asset or system performance is likely to be affected in the future. Because of the complexity of projecting future climate, the ESCI project provides recommendations on suitable climate information and associated confidence and uncertainty.

4 Evaluate all risks

Climate change is only one risk to be considered in electricity sector planning. This step involves comparing all material risks by assessing consequences and likelihoods and producing a risk rating matrix. This helps to rank or prioritise risks that require treatment. Risk evaluation may lead to further risk analysis or a decision not to undertake risk treatment. Organisations should define criteria to evaluate the significance of current and future climate risks, consistent with criteria used for other types of risk.

5 Treat climate risk

Risk treatment involves developing and selecting one or more options for modifying the risk, which may then need an investment case or a change in process. Selecting a risk treatment requires consideration of the costs and benefits of reducing the risks and the tolerance for residual risks. Factors that contribute to the cost-benefit analysis include effectiveness, robustness, practicality, economic efficiency, co-benefits, equity and greenhouse gas emissions. Large-scale investment cases will need to follow regulatory frameworks to be approved by the Australian Energy Regulator.

How should the assessment framework be used?

Risk assessment is an iterative process. Depending on the work your organisation has undertaken on climate risks, the risk management processes involved and the objectives and resources available, the climate risk assessment may range from simple to complex. You should start with a simple, rapid and qualitative assessment to prioritise where detailed effort may be needed in a subsequent assessment, also referred to as a 'scan cycle' (CSIRO 2018). If this has already been completed, you may wish to undertake a more comprehensive assessment. It is unlikely that you will work sequentially through each step in the method. You will probably repeat some steps as you develop your understanding of climate risks and fine-tune your objectives.

The ESCI project user guide includes detailed information on the assessment framework steps and how to integrate historical and projected climate information. ESCI case studies provide worked examples of using the climate risk assessment framework to assess exposure to future risk.

The steps of the ESCI project user guide include detailed information for each of the framework steps.

The ESCI website provides access to high resolution climate projection data: 5–12 km across the NEM, at sub-daily intervals, to 2100. It includes insights which enable users to choose appropriate data and to plan for this future with greater confidence

ESCI case studies show how the tools available on the website have been used in a climate risk assessment—accompanying documents step through the case study process in detail. *Note: every business, location and asset combination is different, so the case studies do not provide a comprehensive overview of electricity system vulnerabilities and should not be used be used to inform operational decision-making*.

Key concepts provide as-needed insights into climatology concepts used in analysing climate risk, as well as information on how the climate data were evaluated and the recommended data sets chosen.

The ESCI Website: www.climatechangeinaustralia.gov.au/esci

References

AEMC (2019) *Applying the energy market objectives*. Australian Energy Markey Commission. https://www.aemc.gov.au/sites/default/files/2019-07/Applying%20the%20energy%20market%20objectives_4.pdf

BoM and CSIRO (2020) State of the Climate Report. https://www.csiro.au/-/media/OnA/Files/State-of-the-Climate-2020.pdf

Cardona, O.D., van Aalst, O.D., Birkmann, J. et al. Determinants of risk: exposure and vulnerability. In: *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation.* A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). (: Cambridge University Press, 2012) 65–108. https://www.ipcc.ch/site/assets/uploads/2018/03/SREX-Chap2_FINAL-1.pdf

CSIRO (2018) *Climate Compass—A climate risk management framework for Commonwealth agencies. https://www.environment.gov.au/system/files/resources/1f56cd3f-dd0f-4f4e-9f14-66ceca36125b/files/climate-compass-climate-risk-management-framework-commonwealth-agencies.pdf*

Energy Networks Australia (2015) *Climate Risk and Resilience - Industry Guidance Manual. https://infostore.saiglobal.com/en-au/Standards/ENA-Doc-036-2015-1126977_SAIG_ENA_AUS_ENA_AUS_2613924/*

1 Understand context

Overview

Climate variability and change present a risk to the electricity sector now and in the future. Risk from climate change is defined as the combination of hazard (e.g. changes in the weather), exposure (e.g. asset location) and vulnerability (e.g. the likelihood that the asset will be damaged or not function). The ESCI project recommends a 5-step approach to climate risk assessment that starts with establishing the context. This involves:

- identifying climate-related decisions or questions
- conducting a quick scan to confirm which climate hazards are most important
- identifying internal and external stakeholders who can contribute and/or should be involved in decision-making,
- defining the purpose of the risk assessment—this will help define the scope and key metrics for evaluating risk and will guide the selection of the appropriate future climate scenario

Figure 1: The ESCI Climate Risk Assessment Framework

What is at risk?

The ESCI Climate Risk Assessment Framework (Figure 1) supports high-level decisions such as corporate strategic direction, or system-wide assessments on investing for resilience to extreme weather events. The Framework can also be applied to activities such as developing maintenance plans for a particular asset class.

The first step is to identify if the activities under consideration are at risk from a changing climate.

Weather is the state of the atmosphere on short timescales, from seconds to days. Climate is the average weather, usually considered over 20–30 years to allow for year-to-year variability (see Figure 2). Climate change is having a significant influence on weather, especially extreme weather events.

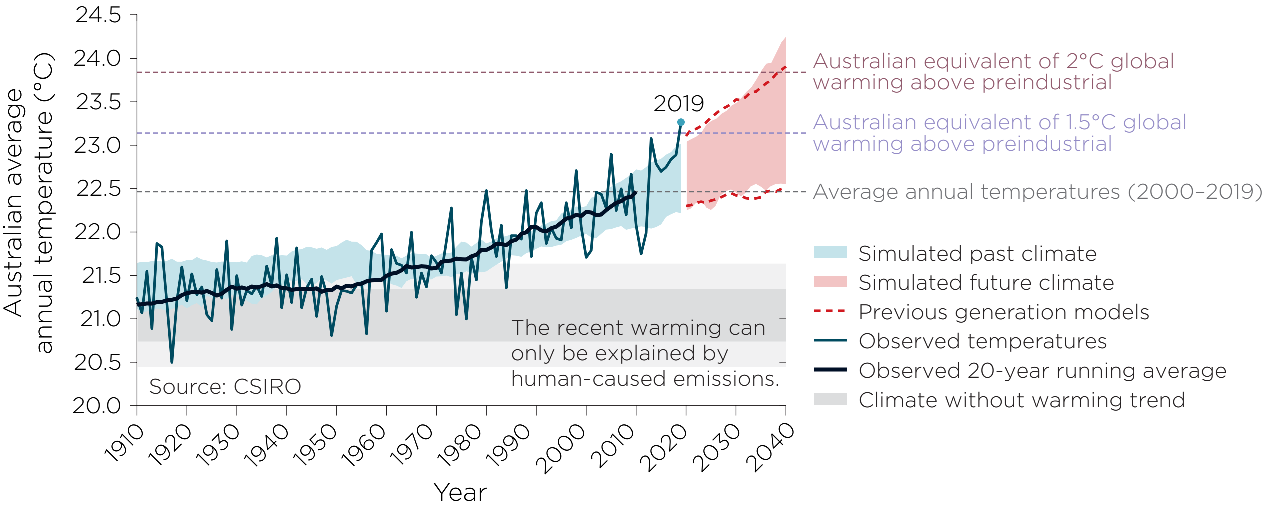


Figure 2: Australian average temperature observed and simulated from climate models. Past and future bands show the range of 20-year running average of climate model outputs. Source: BoM and CSIRO 2020

Weather and electricity are interconnected. Weather is the 'fuel' for solar, wind and hydro-electricity generation and electricity demand is strongly dependent on temperature. Electricity infrastructure performance is affected by extreme events such as high temperatures, droughts and severe winds. Climate risk should therefore be considered as part of:

- System reliability. The behaviour of systems and networks changes when weather is outside normal operating conditions. For example, decreasing soil moisture could have an impact on the ability of underground power lines to carry specified current.
- Investment cases if projected asset performance changes significantly. For example, projected rainfall decreases may affect the business case for new hydro-generation assets.
- System resilience. Compound and extreme weather events are increasing in frequency and magnitude, threatening assets and whole-of-system performance. For example, the increasing frequency of extreme bushfires may require a reassessment of maintenance or operating practices.

Figure 3 provides an ESCI project example of the risk extreme heat poses to variable renewable energy. The figure shows the relationship between wind farm output (black line), wind speed (blue line) and temperature (red line) during a very hot day. The wind farm shuts down during peak demand (and peak pricing) hours from 12 pm. This behaviour could change the investment case for the wind farm.

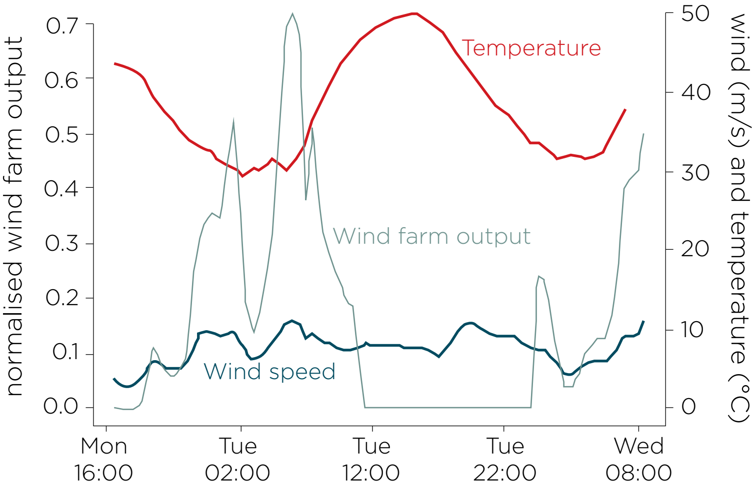


Figure 3: Impact of high temperatures on wind farm output for an Australian wind farm. As temperatures increase, electricity demand tends to rise, but with extreme high temperatures wind farm output may decrease. (Source: ESCI case study—extreme heat and variable renewable energy)

What climate hazards are important?

Climate change is likely to significantly increase some risks as both weather hazards and exposure may change. A scan should be undertaken for areas, processes and assets that could be affected by a changing climate (see Table 1); this provides a rapid, first pass appraisal of the main climate risks, identifies priorities for further work and indicates whom to involve.

Climate data and analyses need not be considered at this point, just high-level summaries such as regional tables or maps of climate change (NESP 2020) (see sidebar on climate information products useful for identifying climate hazards). Past climate-related impacts will also provide guidance on important hazards.

Table 1: Examples of climate hazards for different components of the electricity sector, and relevant case studies

Component	Hazard	ESCI case study
Assets for distribution and transmission	Bushfire, extreme temperature and severe convective wind Reduced soil moisture (increases impedance and reduces thermal conductivity)	Bushfire risk Severe convective wind risk Soil moisture variability Extreme heat risk
Solar or wind power generation	Extreme heat, changes in solar irradiation and wind	Extreme heat risk
Hydro power generation	Reduced streamflow into dams	Streamflow variability
Thermal coal power generation	Extreme heat, causing over-heating of cooling water and reduced supply	
AEMO system reliability modelling	Extreme temperatures, affecting all aspects of supply	Extreme heat risk Bushfire risk Streamflow variability Compound extreme events
Impacts on communities	Bushfires Hailstorms and floods Extreme and compound climate events	Bushfire risk (distributed energy resources) Compound extreme events

Consider creating a simple table that lists

- historical climate hazards and impacts
- projected changes in hazards, exposure and vulnerability over the next 30–80 years
- future risks
- potential risk mitigation options

The risk identification process is best run as a brainstorming session among a group of diverse stakeholders who understand the interdependencies within and between operations, assets, weather and climate.

ESCI case studies (available on the ESCI website) provide examples of climate risk assessments for electricity system assets, processes or system decisions. Asset and operation locations are unique and can only be assessed on a case-by-case basis. However, the case studies can help identify climate sensitive decisions.

Who is interested or affected?

Climate change will affect both internal and external stakeholders, therefore both should be engaged early in the process to ensure that the risk assessment meets all needs and considers all aspects of risk and opportunity.

Internal stakeholders

You should gather information from different functional areas of the organisation, based on the aim of the risk assessment. Consider:

- technical experts to provide information on engineering specifications or maintenance schedules
- quantitative expertise if the team expects to do a 'deep dive' into detailed climate information
- investment or policy questions will require relevant internal experts
- technical and strategic expertise to explore future network mitigation options

Senior managers or executives may already be considering climate change, for example, as part of a net zero emissions or risk mitigation plan, so decision-makers should be engaged to ensure that their needs and expectations are met. If climate risk is still in the early stages of discussion, you may need to provide additional background information.[1]

External stakeholders

There are a range of external stakeholders who should be considered at the beginning of your climate risk assessment.

If the decision includes a large network investment, the Australian Energy Regulator will be a key stakeholder. When using climate change information, consider engaging with the regulator to ensure that they agree with the approach, including the way in which confidence and uncertainty in the climate projections are expressed.

Investment analysis decisions may be triggered by proposed rules and advice from the Australian Energy Market Commission (particularly regarding their objective of maintaining system security and wholesale electricity reliability).

Asset versus system risk

Climate change will present new and varied operating conditions that may require innovative adaptation. The systemic nature of most risk reduction strategies (such as strategic redundancy) means that an asset-by-asset approach to risk management is generally inappropriate and inefficient. For example:

- a climate risk metric that measures the potential impact of climate risk on a single electricity pole or line will not capture mitigation strategies that reduce load on that line
- mitigating bushfire risk on 2 lines built side by side may measure the benefits of load reduction to minimise the joint probability of outage but will not capture the potential benefits of building the lines in different corridors
- customer outages sometimes occur in hot conditions when demand increases and multiple assets fail, reducing supply, so a risk assessment that considers only supply adaptation may not consider changes in demand or transmission
- an assessment on a single generator may identify the risk to facility profitability but will not capture the changed probability of outages from the impact on all generators, or the potential benefits of installing storage (for example) elsewhere in the system

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[1] The ESCI project has created communications material that can be used with senior executives and board members (available on the ESCI website: www.climatechangeinaustralia.gov.au/esci).

State pricing and regulatory authorities (e.g. IPART and ESC) may need to be involved given their focus on retail network pricing and regulation.

Climate risk is a system risk and so AEMO and other market participants may respond to changing conditions in a way that has an impact on ranking the adaptation options.

There may be other organisations such as Energy Networks Australia that have conducted similar risk assessments and could be an excellent source of advice.

Financial institutions are encouraged, and increasingly expected, to disclose climate-related risk in projects they support so they should be considered as stakeholders.[2,3,4]

Insurers are particularly concerned about the increasing severity and frequency of extreme weather events. An organisation demonstrating that they have considered and mitigated climate risk in their asset and system management practices or investments may obtain reduced premiums to protect against climate hazards.

Retailers and consumers are important stakeholders, so you should consider how to engage them early in the risk assessment.

What would you like the risk assessment to achieve?

Consider the drivers for the risk assessment. While future system performance may be the primary focus of a climate risk assessment, there may be other motivating factors. For example, are you complying with a directive from management to consider climate risk? Are you responding to interest and pressure from external stakeholders? The World Economic Forum (World Economic Forum, 2021) ranks weather and climate risk among the highest likelihood and impact global risks (see Figure 4), which is resulting in increased scrutiny from inside and outside companies.

A meeting with key stakeholders may reveal additional objectives. Is there an immediate sense of urgency to address climate risks because impacts are already apparent? If so, list some examples of climate hazards and impacts. Are there potential opportunities in a changing climate?

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[2] *Climate-Related and Other Emerging Risks Disclosures: Assessing Financial Statement Materiality Using AASB Practice Statement 2* (AASB, AUASB, 2018).

[3] The Task Force on Climate-related Financial Disclosure (TCFD) provides a framework and recommendations on disclosing financial risk TCFD (2017). ***Recommendations of the Task Force on Climate-related Financial Disclosures***. Task Force on Climate-related Financial Disclosures, https://www.fsb-tcfd.org/wp-content/uploads/2017/06/FINAL-2017-TCFD-Report-11052018.pdf

[4] *Proposals to Enhance Climate-Related Disclosures by Listed Issuers and Clarification of Existing Disclosure Obligations* (Financial Conduct Authority, 2020).

Top 10 risks in terms of **Likelihood**	Top 10 risks in terms of **Impact**
🟩 1 Extreme weather	🟩 1 Climate action failure
🟩 2 Climate action failure	🟧 2 Weapons of mass destruction
🟩 3 Natural disasters	🟩 3 Biodiversity loss
🟩 4 Biodiversity loss	🟩 4 Extreme weather
🟩 5 Human-made environmental disasters	🟥 5 Water crisis
🟪 6 Data fraud or theft	🟪 6 Information infrastructure breakdown
🟪 7 Cyberattacks	🟩 7 Natural disasters
🟥 8 Water crisis	🟪 8 Cyberattacks
🟧 9 Global governance failure	🟩 9 Human-made environmental disasters
🟦 10 Asset bubbles	🟥 10 Infectious diseases

Categories

- 🟦 Economic
- 🟩 Environmental
- 🟧 Geopolitical
- 🟥 Societal
- 🟪 Technological

Figure 4: In 2020, the World Economic Forum Global Risks Report put extreme weather and climate change risk at the top of its most likely, and highest, world economic impacts (World Economic Forum, 2021)

Being clear about goals and objectives will help to determine the metrics that will be used to assess the risk (Step 2), the climate scenario(s) to explore (Step 3), and potential risk treatment options (Step 5).

Document the process

It is important to document the discussion and key decisions. Climate risk assessments will need to be revisited as the science improves and as the economic, technological, demographic and political landscape changes. Careful documentation is also important to support the legitimacy of stakeholder consultation.

Iterative nature of climate risk assessments

Climate projections are based on global climate models that are regularly updated. These coordinated efforts are part of the Coupled Model Intercomparison Project (CMIP), supported by the World Climate Research Program. The ESCI project climate information products are based on CMIP Phase 5 climate models, with new climate models being assessed in CMIP Phase 6. As these new models become available, the climate information provided by ESCI will still be relevant but new information should be assessed.

> A climate risk assessment conducted on a decision today will need to be repeated *from the beginning* the next time that decision is assessed.

Finally, the National Electricity Market is dynamic; although AEMO's Integrated System Plan (ISP) takes a 20-year view of the NEM, the ISP is reissued every 2 years as the grid evolves in response to policy, economic, population and technology changes. These changes should be included in climate risk assessments.

References

BoM and CSIRO (2020) State of the Climate Report. https://www.csiro.au/-/media/OnA/Files/State-of-the-Climate-2020.pdf

NESP (2020) *Scenario analysis of climate-related physical risks for buildings and infrastructure: climate science guide*. https://climate-kic.org.au/our-projects/cmsi/

World Economic Forum (2021). The Global Risks Report 2021 (16th edition) A report by the World Economic Forum in partnership with Marsh McLennan, SK Group and Zurich Insurance Group. https://www.qbusiness.pl/uploads/Raporty/globalrisk2021.pdf

Climate information products useful for identifying climate hazards

The ESCI project produced climate information products that provide an overview of climate change and more detailed information. These are available from the ESCI website and can be used to scan for future climate hazards. These include:

maps showing how the return period for extreme hazards (such as high temperature, extreme rainfall, high fire weather days) may change over the coming decades under different climate scenarios

summary tables showing how key climate variables are likely to change in different regions

case studies of climate risk assessments for electricity sector assets and decisions

2 Identify historical climate risk

Overview

Climate risk analysis and evaluation for investment and planning decisions require an understanding of the historical relationship between weather and climate and asset/system performance. Climate projections can then be used to help estimate future performance.

An assessment of the risk that climate change presents to an organisational process begins with an examination of the historical impacts of weather and climate. This is Step 2 of the ESCI Climate Risk Assessment Framework (Figure 1).

How is weather included in system decisions now?

The objective of Step 2 is to identify, or develop models for, the relationship between performance and weather that can be used with climate projections to estimate future performance risks.

There may already be industry models that can be applied, such as design specifications or statistical models that describe the relationship between energy supply and temperature (Figure 2).

Figure 1: The ESCI Climate Risk Assessment Framework

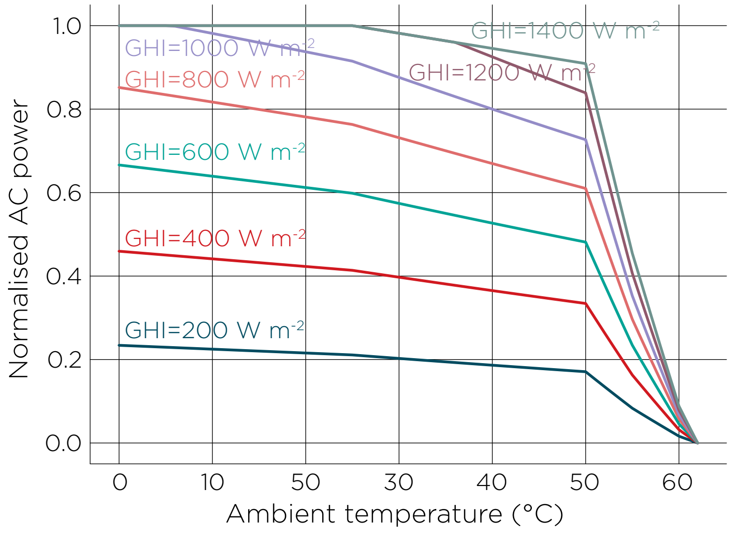

Figure 2: Power conversion models developed for the ESCIcase study on extreme heat risk (variable renewable energy). The solar farm model[1] describes output as a function of global horizontal irradiance (GHI) and temperature. GHI is the shortwave radiation received from above by a horizontal surface. Direct normal irradiance (DNI) and wind speed are included in the model but not shown on the graph.

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[1] Developed using the tool PVLIB (Holmgren et al. 2018) and PVWatts calculator for solar outputs (Dobos 2014). The model assumes a single axis tracking installation using the following configuration: SMA Sunny Central 850CP XT inverter and a DC-to-AC ratio of 1:2.

Has an historical relationship between weather and performance been identified?

If industry models do not already exist, building a model that captures the relationship between weather and performance is usually quite straightforward. The impact of weather is already built into many processes and asset specifications. Examples include line ratings based on ambient temperature, and vegetation clearing scheduled during an historically low-bushfire-risk season.

There are likely to be organisational records that relate system impacts to weather. For example, structural failures (Figure 3) can be related to severe convective winds (Figure 4).

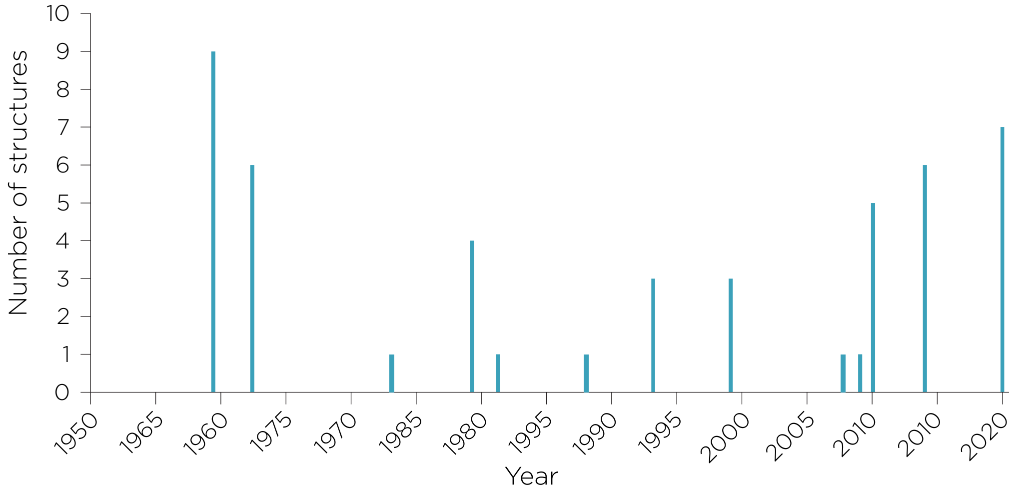

Figure 3: Transmission tower structure functional failure history. (Source: AusNet, AMS 10-77 Transmission Line Structures. 2023-27 Transmission Revenue Reset, Section 3)

The Bureau of Meteorology supplies quality-assured historical weather and climate data[2]. For each climate variable of interest, try to establish a statistical relationship with historical asset/system performance. This could be a simple linear regression with the fit providing an estimate of uncertainty. Another common statistical method is Monte Carlo analysis which deals with uncertainty through assigning a probability curve of likely outcomes. This can be used wherever there is a range of input data, such as the frequency and timing of a weather event. For example, a transformer's performance relative to temperature can be calculated using Monte Carlo simulations informed by probability curves based on historical climate information.

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[2] The ESCI project has used the years 1986–2005 as a baseline for climate projections (consistent with the IPCC), but data are available back to 1980 (earlier for hydrology) on the ESCI website.

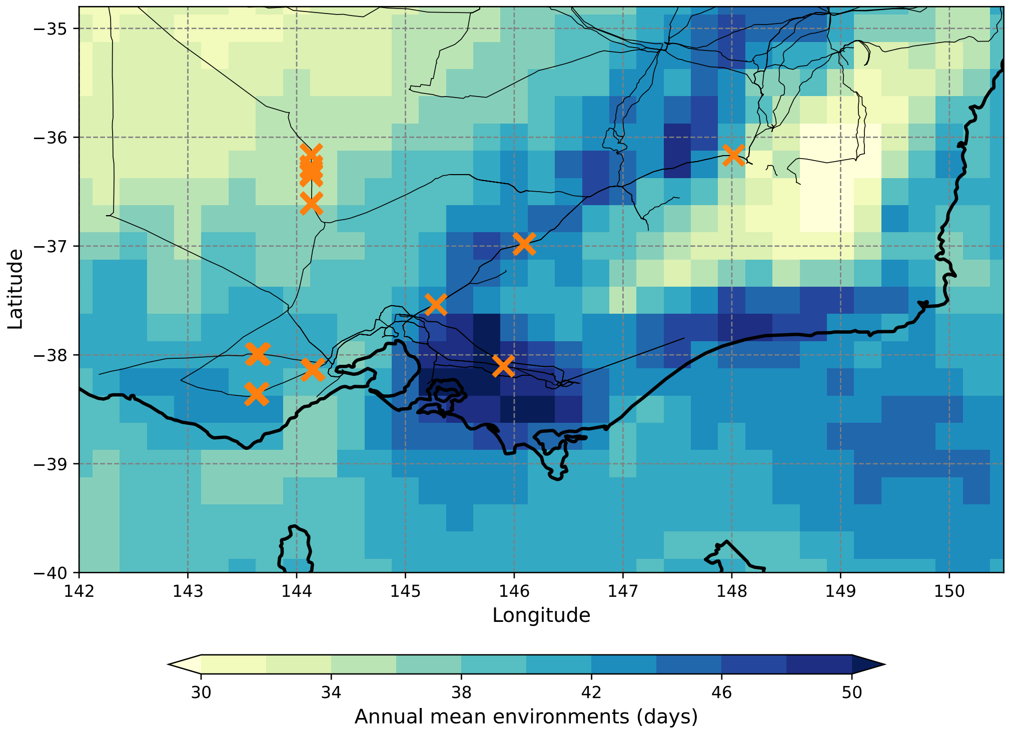

Figure 4: Mean historical frequency of conditions favourable for severe convective winds compared with outage events (11 events, 1959–2020). Source: BoM analysis (Brown, 2021) and AusNet Services data used as part of the ESCI Case Study on the risk severe convective winds present to transmission lines.

Identify important parameters for the risk analysis

When identifying historical weather and climate hazards, be specific about hazard thresholds associated with impacts, such as temperatures over 45 °C or wind-gusts above 30 m/s. Consider also whether averages or extreme values are most relevant. Identify the temporal resolution that is needed for the historical analysis, as the same resolution (if possible) will be used for future climate analysis. Half-hourly temperature data may be needed for demand modelling and sub-hourly wind data for wind-stress or power modelling. Daily/monthly fire weather data may be most useful, and seasonal streamflow data may be appropriate for hydro-generation modelling.

Spatial scale is also important. Historical weather and climate information may be available only at specific locations, such as Bureau of Meteorology real-time monitoring sites, which provide daily maximum and minimum temperatures. These locations may not be close to your areas of interest, limiting the value of the data. Future climate information is available on a 5-km grid, and as time-series for 168 locations across the national electricity market—check how well these correspond to the locations for historical asset/system performance data sets.[3]

Once you have developed a model of the relationship between historical climate and asset/system performance, and identified important parameters for the analysis of future risk, then you are ready to move on to Step 3: Analyse Future Climate Risk.

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[3] The ESCI project also provides historical and projected summary data for regions with similar climates across Australia.

References

Brown A and Dowdy A. ‘Severe convection-related winds in Australia and their associated environments’ (2021) 71(1). *Journal of Southern Hemisphere Earth Systems Science* 30–52.

Dobos AP (2014) *PVWatts version 5 manual* (No. NREL/TP-6A20-62641). National Renewable Energy Lab (NREL), Golden, CO.

Hersbach H, Bell B, Berrisford P, et al. ‘The ERA5 global reanalysis’ (2020) 146(730) *Quarterly Journal of the Royal Meteorological Society* 1999–2049. doi:10.1002/qj.3803.

Holmgren WF, Hansen CW and Mikofski MA. ‘pvlib python: A python package for modeling solar energy systems’ (2018) 3(29) *Journal of Open Source Software* 884.

Australian Government
Department of Industry, Science, Energy and Resources

Australian Government
Bureau of Meteorology

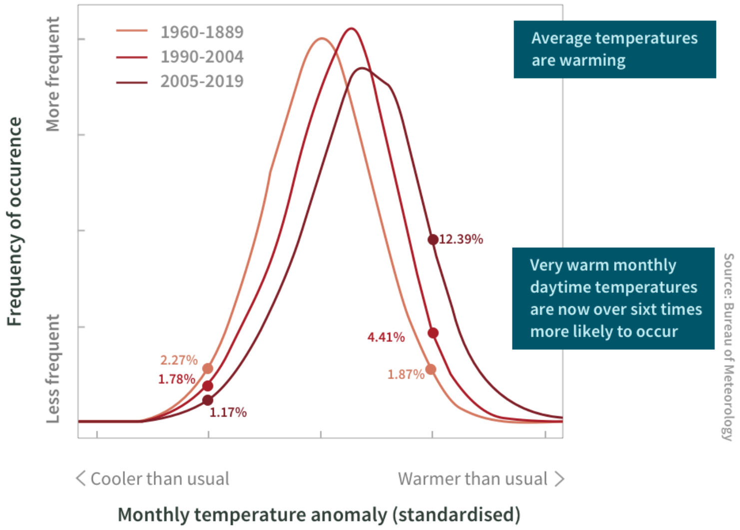
CSIRO

AEMO
AUSTRALIAN ENERGY MARKET OPERATOR

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.



Average temperatures are warming

Very warm monthly daytime temperatures are now over sixt times more likely to occur

Source: Bureau of Meteorology

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.

1 Understand context

2 Identify historical climate risk

3 Analyse future climate risk

4 Evaluate all risks

5 Treat climate risks

Figure 2: The ESCI Climate Risk Assessment Framework

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 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.

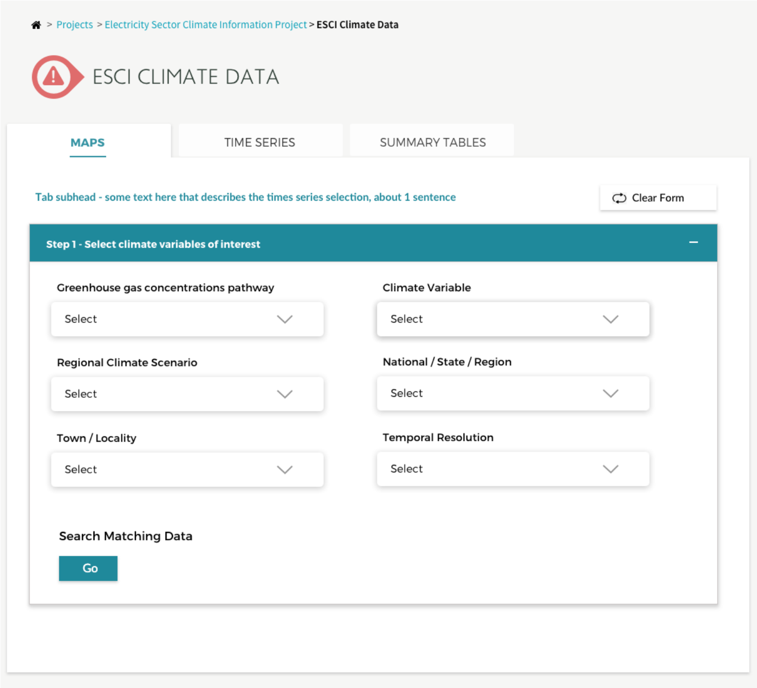
Where the climate risk assessment suggests a significant risk, or where a high value investment is involved, the advice of climate experts should be sought.

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]



Tab subhead - some text here that describes the times series selection, about 1 sentence

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.

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[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.

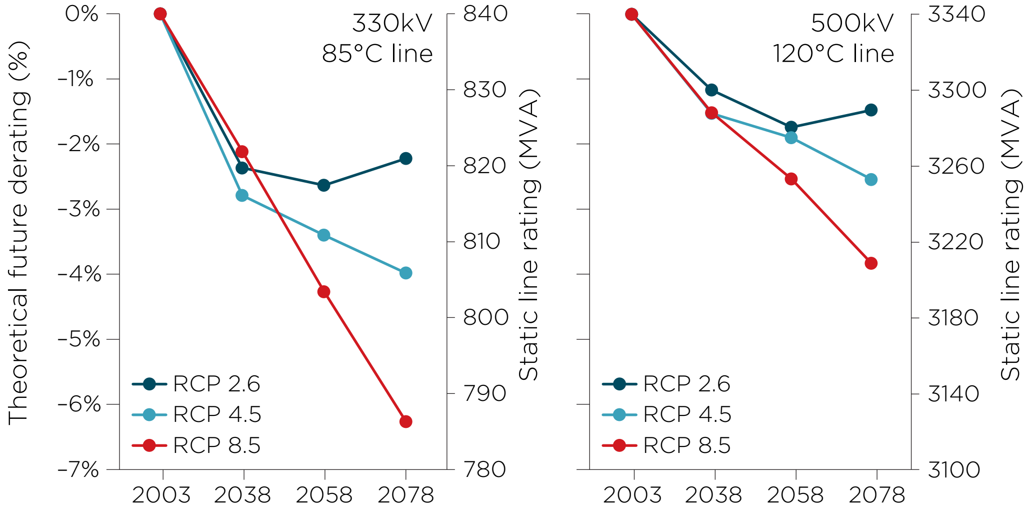

Figure 4: Projected de-ratings for a 330kV, 85 °C line (left), and a 500kV, 120 °C line (right) in New South Wales under 3 climate scenarios (RCP 2.6, 4.5 and 8.6) using 4 climate models for each scenario. (Source: ESCI case study—the impact of extreme temperatures on transmission lines.)

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.

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[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).

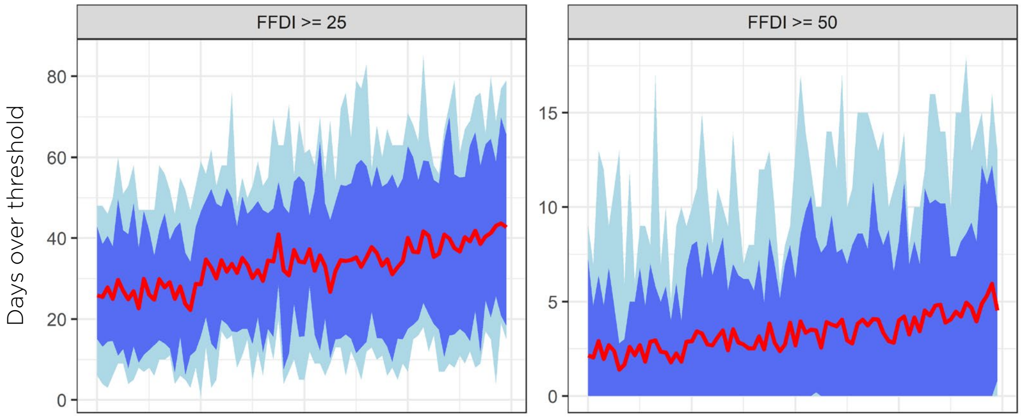

Figure 5: Time series of days per year when the forest fire danger index is over 25 ('very high fire danger') and 50 ('severe fire danger') near Adelaide, projected from 2020 to 2100. (Source: ESCI case study—bushfire risk and transmission). These plots combine the time series from 8 different climate 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]

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[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.

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[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]

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[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.

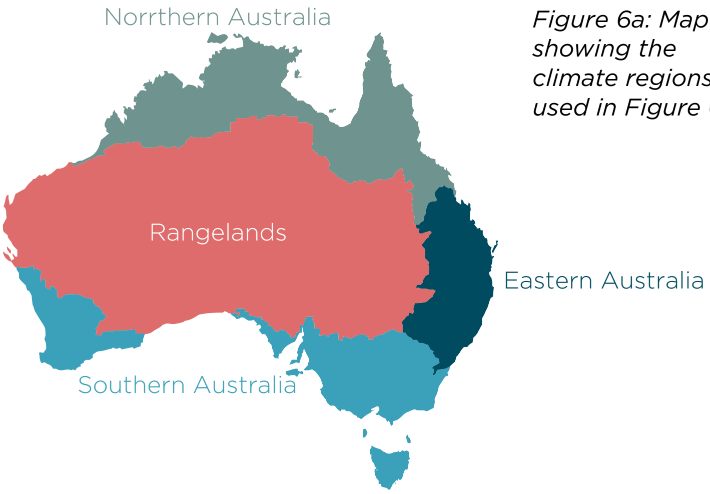

Figure 6a: Map showing the climate regions used in Figure 6b

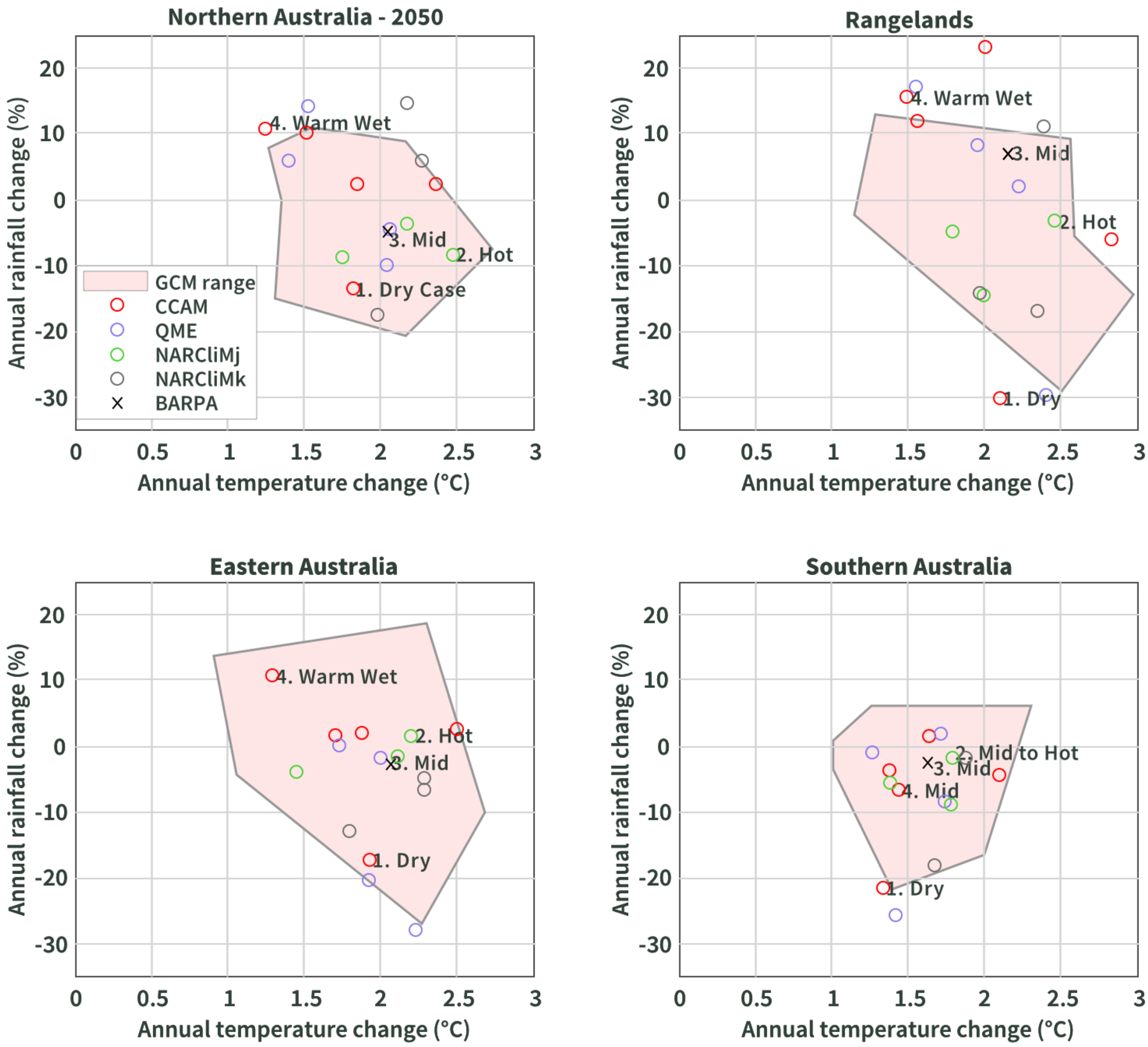

Figure 6b: Projected change in annual temperature and rainfall between 1986–2005 and 2040–2059 under very high emissions pathway (RCP8.5) for 4 broad regions of Australia shown in Figure 6a. The polygon shows the range simulated by 40 CMIP5 GCMs as reported in Climate Change in Australia (CSIRO and BoM 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]

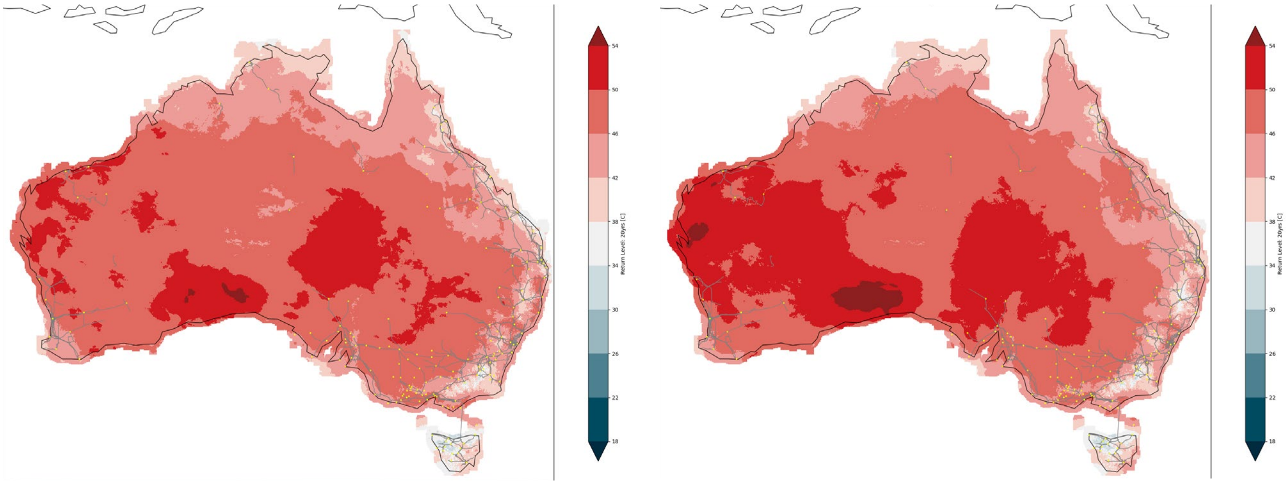

Figure 7: 1-in-20-year maximum temperatures for the summer months (Dec–Feb) for 20-year time-slices centred on 2050 (left) and 2070 (right). The data are from the CanESM2-CCAM-QME data set derived using RCP 8.5. The top red bar represents temperatures higher than 54 °C.

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

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[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).

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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]

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[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

③ Analyse future climate risk – unquantified hazards

Overview

Steps 2 and 3 of the ESCI Climate Risk Assessment Framework(Figure 1) assume that quantitative climate information is available, and projected changes in most hazards of interest to the electricity sector can be quantified with medium to high confidence. However, there is a high level of uncertainty in some climate hazard projections either because climate models do not agree on the trends or the hazards are rare (e.g. extreme and compound events) and further research is needed.

Despite these limitations, there is information available on these hazards that can provide an indication of whether the risk they present is likely to be material in future.

Figure 1: The ESCI Climate Risk Assessment Framework

What climate products and data are required by the sector?

The ESCI project data has focused on 4 climate hazards:

- rising temperatures
- increasing intensity of bushfire weather
- increased incidence of severe convective winds
- increased variability of dam inflows

Information on how these hazards are likely to change can be provided with medium to high confidence (except for severe convective winds), and Steps 2 and 3 will provide a robust analysis of future risk.

For some climate hazards, however, there is low confidence in projected changes, or these changes are difficult to quantify. Information on these hazards is provided below.

Why is the influence of climate change on some hazards difficult to quantify?

Uncertainty in the influence of climate change on hazards can be due to several factors, for example, the phenomena may be rare, resulting in few observations and some physical processes are not well-understood by current science (e.g., aspects of how lightning forms). Many dangerous weather events are a result of atmospheric processes operating at scales of less than 1 km so global climate models, with a resolution of around 100–150 km, cannot represent them. Detailed evaluation of extreme weather processes, and indices constructed from these processes, may be used to provide an indication of how these hazards are likely to change in the future. For example, climate information used in the ESCI case study and technical report on severe convective winds is derived from broad-scale indices of weather phenomena.[1]

Extreme weather events that occur simultaneously or in close succession (e.g. fires across multiple regions, or fire followed by floods) are called compound events. The combination of extreme events that are already rare makes the probability hard to assess. In future, large ensembles of climate projections could be explored to identify classes of extreme compound events and estimate the probability of them occurring; however, this is very computationally intensive. At present, climate science can provide well-characterised examples of these events, extracted from historical data and climate projections, but in general cannot provide probability information for future compound events.

Qualitative risk analysis

The historical relationships between weather/climate and asset/system performance that were developed in Step 2 of the ESCI Climate Risk Framework are still of use for an assessment of climate risk when hazards are hard to quantify.

The information below (and cited sources) provides qualitative information, such as an indication that the risk is increasing or decreasing or that some events, such as tropical cyclones, may strike new locations. If infrastructure is already operating at or near the limit of its capacity then qualitative information may be sufficient to indicate that risk mitigation is needed. If confidence in the projection is low (e.g. tropical cyclone intensity), then sensitivity analyses can be conducted with the relationship developed in Step 2 to identify at what point an impact threshold may be crossed.

For compound extreme events, there are several ways that case studies from climate projections can be used for a risk analysis:

- The Brattle Group (Chang, 2020) identified 3 types of planning approaches: expected value; identifying the ‘least regrets’ option for investment decisions; and ’robust planning’ to ensure that the worst outcomes can be managed with the least cost.
- A ‘least worst’ assessment is used for electricity planning in the UK and is applied when it is difficult or inappropriate to attach probabilities to future scenarios (Zachary 2016). It involves ’quantifying the worst possible outcomes for a set of strategic choices, and then identifying the choice with the “least-worst” outcome. In other words, a “least-worst regrets” solution finds the safest path that avoids the worst possible outcomes’ (Sanders 2016).

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[1] The intention is to apply these indices to assess future severe convective wind risks; this work is ongoing.

This is a pragmatic option that avoids having to weight views of the future subjectively.[2]

- Lloyd's insurance market requires insurance syndicates operating in the market to use a suite of 'realistic disaster scenarios' to stress-test their portfolio.[3] These scenarios are geographically diverse and vary by asset and peril.[4] This stress-testing is intended to identify common points of vulnerability in portfolios.

More information on case studies of extreme compound events is given below and a description of the use of these in the electricity sector appears in the ESCI Technical Report on compound events and in the associated ESCI case study.

The National Environmental Science Program has developed relevant information on a number of hazards,[5] summarised below.

Tropical cyclones

On average, about 11 tropical cyclones form or move into the Australian region each year (Figure 2). The number has decreased significantly in recent decades. This decrease is thought to be due to a combination of climate change and natural variability.

Climate models project a decrease in the number of tropical cyclones, but an increase in the proportion of severe tropical cyclones. There is high confidence that extreme rainfall and extreme wind speeds caused by tropical cyclones will increase, and rising sea levels will increase coastal impacts. There is low confidence in projected changes in the number of severe cyclones (Category 4–5) and the possible poleward shift.

More information on tropical cyclones is available through the website of Climate Change in Australia website (www.climatechangeinaustralia.gov.au) and NESP ESCC Hub (2020).

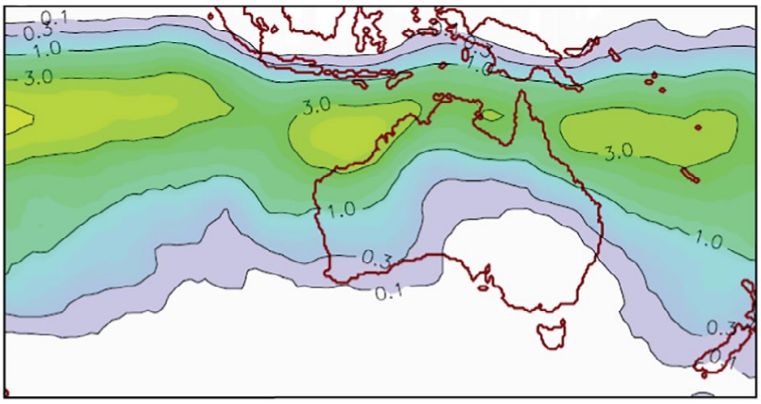

Figure 2: Average number of tropical cyclones per year. Tropical cyclone tracks are sourced from the Bureau of Meteorology, as well as government agencies in neighbouring countries 1982–2017. Source: https://onlinelibrary.wiley.com/doi/abs/10.1002/wcc.602.

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[2] Network Options Assessment Methodology Review, UK National Grid https://www.nationalgrideso.com/document/174231/download.

[3] https://www.lloyds.com/market-resources/underwriting/realistic-disaster-scenarios-rds.

[4] See, for example, RDS 2020 Scenario Specification, 2020. https://www.lloyds.com/-/media/files/market-resources/underwriting/2-rds-scenario-specification--january-2020.pdf?la=en.

[5] Available at http://nespclimate.com.au/new-information-on-extreme-weather-and-natural-hazards-in-our-changing-climate/.

Hailstorms

The annual average number of days with large hail (greater than 25 mm diameter) varies considerably between different locations in Australia and there is limited information on giant hail (greater than 50 mm diameter), which causes the most damage (Dowdy 2020).

Large hail occurs more often (5–10 events annually) in the central east than elsewhere in Australia, with up to 5 events annually for regions around major cities, although there are significant discrepancies between studies.

The influence of climate change on hail is uncertain due to the limited historical measurement period and the ability of climate models to represent the physical processes required for simulating hail events (including fine-scale convective processes and microphysics). There is some indication of a poleward shift in suitable conditions for hail occurrence. The influence of climate change on hail represents a significant gap in knowledge.

Thunderstorms and lightning

Thunderstorms are small-scale weather systems associated with hazards such as lightning, hail, extreme winds, tornadoes, extreme rainfall and flash flooding. Thunderstorms can disrupt power networks, damage property and cause injury or loss of life. Lightning can cause bushfires, leading to a range of further impacts to communities, businesses and ecosystems.

Thunderstorms in Australia occur predominantly during warmer months, with more activity in the north and east of the continent. Thunderstorms can combine with other weather events such as tropical cyclones (Figure 3), east coast lows and cold fronts, resulting in more extreme weather conditions from those compound events (Dowdy and Catto 2017). From 1979 to 2016, there is some evidence that thunderstorms and dry lightning decreased in spring and summer in northern and central Australia, decreased in the north in autumn, and increased in the south-east in all seasons.

Climate models indicate a potential increase in future thunderstorm frequency for parts of eastern Australia, while changes for other regions are more uncertain. Extreme rainfall caused by thunderstorms is likely to increase in intensity resulting in increased flood risk factors in some cases.

More information on this topic is available through the NESP ESCC Hub (2020).

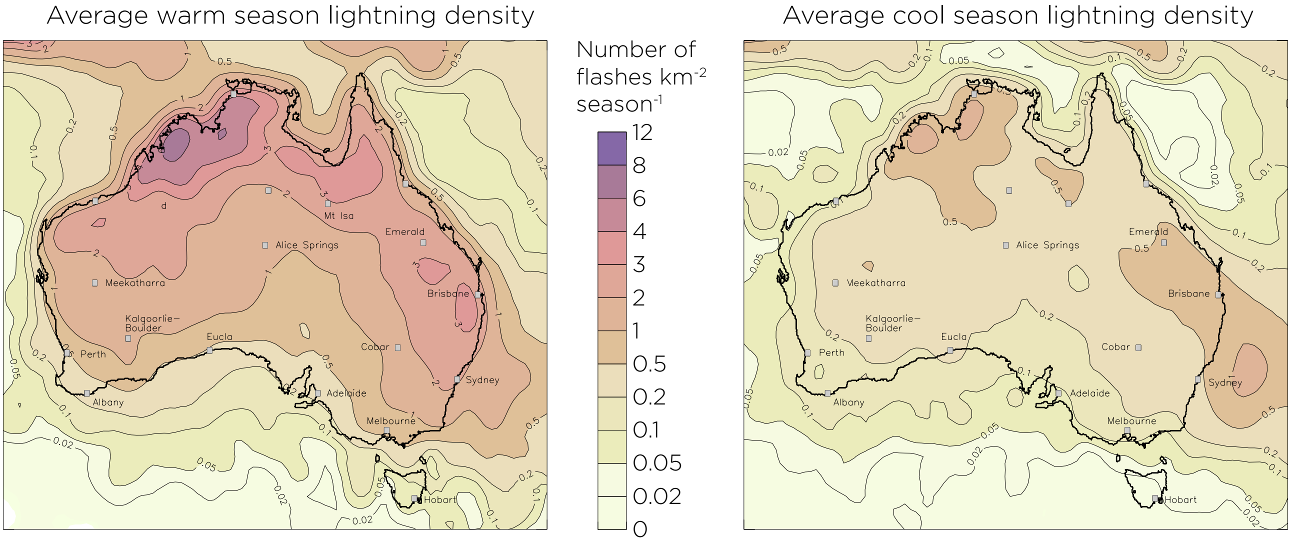

Figure 3: Thunderstorm climatology for Australia as indicated by satellite observations of lightning. Cloud-to-ground lightning flashes (average number per square kilometre) are shown for the years 1995–2012. (Source: Dowdy and Kuleshov 2014)

Flooding

NESP ESCC Hub (2020) states that there are considerable uncertainties regarding trends and projections of some kinds of flood events but the risk factors for other flood events, such as coastal flooding exacerbated by sea level rise, can be projected with high confidence. The increased atmospheric moisture content due to global warming can increase rainfall extremes, thereby increasing flood risk caused by localised severe thunderstorms. However, the relationship between increased rainfall and flood (depth, extent or speed of flow) may not depend only on increased rainfall. Additional risk factors include soil moisture content, runoff and snowmelt.[6] Furthermore, other activities can have large influences on flood risk, particularly including water management and land-use changes (such as changes to reservoir infrastructure or operations).

Weather systems that contribute to floods include thunderstorms, fronts, troughs and low-pressure systems, and in some regions, tropical cyclones and east coast lows.

Rising sea levels are likely to increase the risk of flooding in coastal and estuarine regions as storm surges and extreme wave activity both contribute to flooding potential.

Extreme sea levels

Global average sea level has risen by over 20 cm since 1880 and is rising at around 3.6 mm per year (IPCC 2019). Around Australia, relative sea level rose 3.4 mm/year 1992–2019 (Watson et al. 2020) (Figure 4).

Sea level is projected to rise more rapidly this century than last (very high confidence). Projections are available from CSIRO and BoM for selected locations, years and RCPs. The IPCC (2019) updated global average sea level rise estimates for the year 2100 are 29–59 cm for low emissions (RCP2.6) and 61–110 cm for high emissions (RCP8.5). These estimates are slightly higher than those published in 2013 because they account for accelerated loss of ice from Antarctica. The implications for extreme sea levels around Australia have not yet been assessed.

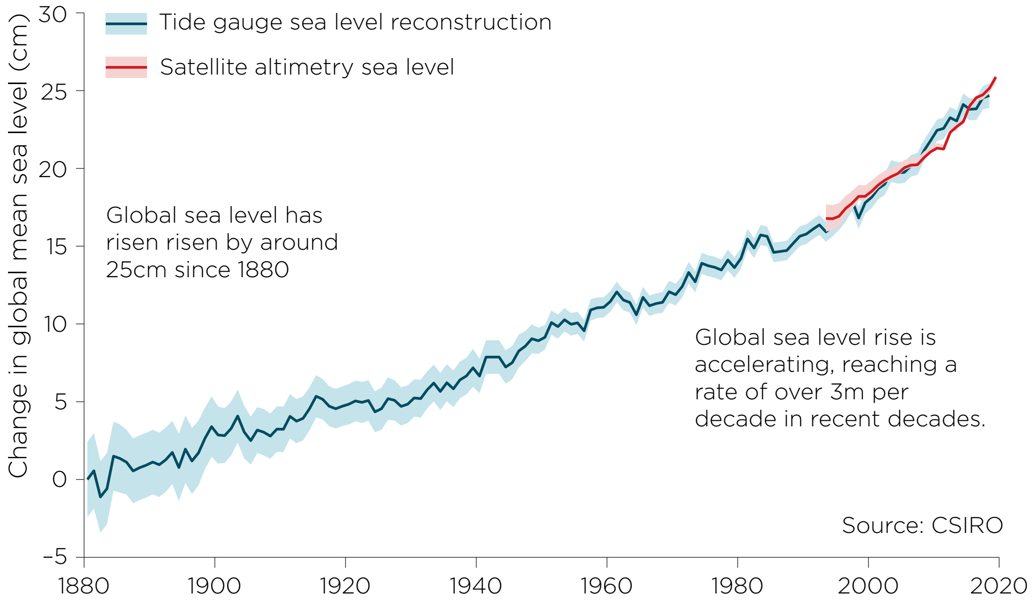

Figure 4: Annual global sea level change from 1880 in tide gauge data (1880–2019, blue line, shading indicates confidence range), and annual sea level changes in satellite altimetry (1993–2019, orange line). (Source: BoM State of the Climate 2020)

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[6] The ESCI project provides data on soil moisture and streamflow trends intensity and frequency.

East coast lows

East coast lows are low-pressure systems that affect south-east Australia and can cause hazards including damaging winds, prolonged heavy rainfall, flooding and very rough seas. The more intense events can lead to injury, loss of life, infrastructure damage and large insurance losses, as well as benefits such as contributing to water resources in this densely populated region.

East coast lows occur on average about 22 times per year. There is large year-to-year variability in the number, with no clear trend over recent decades. Climate models project fewer east coast lows. The projections show larger reductions for higher greenhouse gas emission scenarios. However, rising sea levels are likely to increase the impact of large waves on coastal regions, and extreme rainfall is predicted to increase in intensity resulting in increased risk of flooding. There are still considerable uncertainties in scientific understanding of how some east coast low characteristics may change, including the intensity of extreme wind and wave direction.

More information on this topic is available from NESP ESCC Hub (2020) and a recent review study (Dowdy, 2019).

Extreme and compound extreme weather events

Extreme events have always been part of Australia's variable climate. However, climate change is expected to lead to changes that will produce 'significant property, personal and economic damage and hardship' (Bruyère et al. 2019).

The frequency of extreme temperatures, extreme rainfall and extreme fire danger days has increased in recent decades (BoM and CSIRO 2020) (Figure 5 shows historical changes in extreme temperature events).

Australia's climate is influenced by the El Niño Southern Oscillation, the Indian Ocean Dipole and the Southern Annular Mode.[7] These 3 global climate phenomena fall into or out of phase, leading to extreme rainfall and temperature variability. Climate change adds strong trends in both temperature and rainfall as well as unpredictable changes in the underlying drivers; for example, climate modelling provides evidence for a potential doubling in the occurrences of extreme El Niño events (Cai et al. 2014).

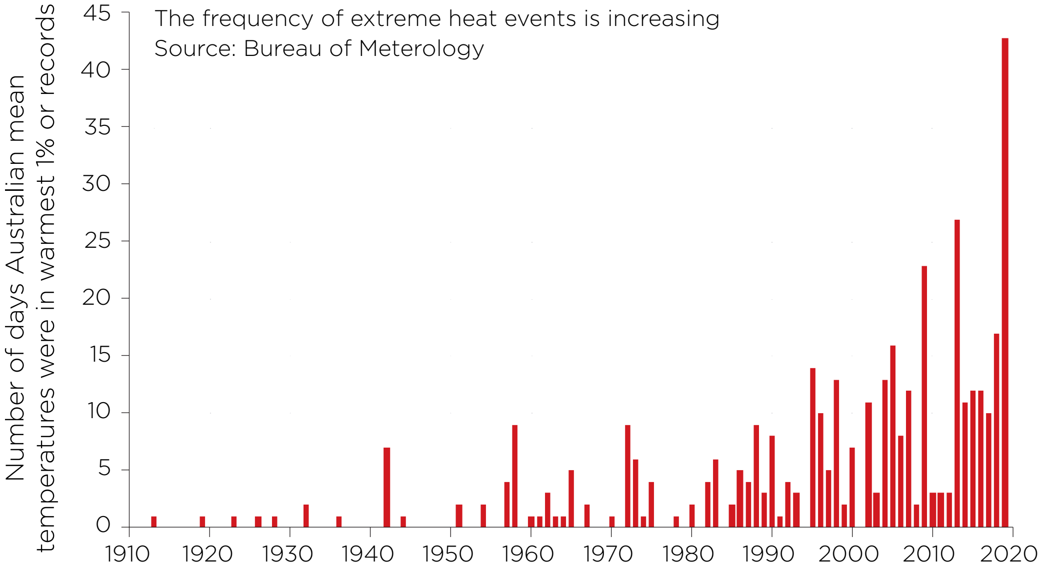

Figure 5: Number of days each year where the Australian area-averaged daily mean temperature for each month is extreme. Extreme daily mean temperatures are the warmest 1 per cent of days for each month, calculated for the period from 1910 to 2019. (Source: BoM State of the Climate 2020)

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[7] See ESCI Webinar *The influence of climate change on the Australian Bushfire Season* for more explanation of how the underlying phenomena affect weather extremes.

Some of the expected changes include:[8]

- increased frequency of large-scale heatwaves and record high temperatures
- longer fire season with more extreme fire danger days
- reduced annual rainfall, particularly during the cooler months in southern Australia
- an increase in heavy daily rainfall intensity
- increased frequency of coastal storm surge inundation as sea levels rise
- a reduction in the total number of tropical cyclones but an increase in the proportion of high intensity storms

> The predicted increase in the frequency and severity of extreme weather events will challenge Australia's electricity infrastructure.

While individual events or localised weather extremes pose local or asset-specific risks, compound events in which multiple adverse impacts occur concurrently or in quick succession pose challenges to whole of system resilience. Severe compound (multiple impacts) and extreme events result in widespread exposure to hazards and severe consequences for consumers. There is the additional risk of compounding failure of other systems, such as transport and telecommunications (Cainey 2019). The ESCI technical report on decision-making for extreme and compound events presents more information on this subject.

Examples of compound extreme events include:

- the heatwave in late January and early February 2009, followed by the devastating 'Black Saturday' bushfires in Victoria
- a multiple tornadic storm event in September 2016 that led to the loss of power for 850,000 customers ('Black System')

Extreme weather case studies should be used to test the impact of extreme and compound events on the national electricity market. An example of this is given in the ESCI case study on system impacts of extreme and compound weather events.

A scenario approach, using multiple scenarios to identify common points of system weakness or mitigation benefit, is consistent with recommendations from financial and insurance risk management processes, such as the Taskforce for Climate Related Financial Disclosure (TCFD), and the National Disaster Risk Reduction Framework (Department of Home Affairs 2019).

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[8] See for example http://www.bom.gov.au/climate/extremes/ and http://nespclimate.com.au/new-information-on-extreme-weather-and-natural-hazards-in-our-changing-climate/.

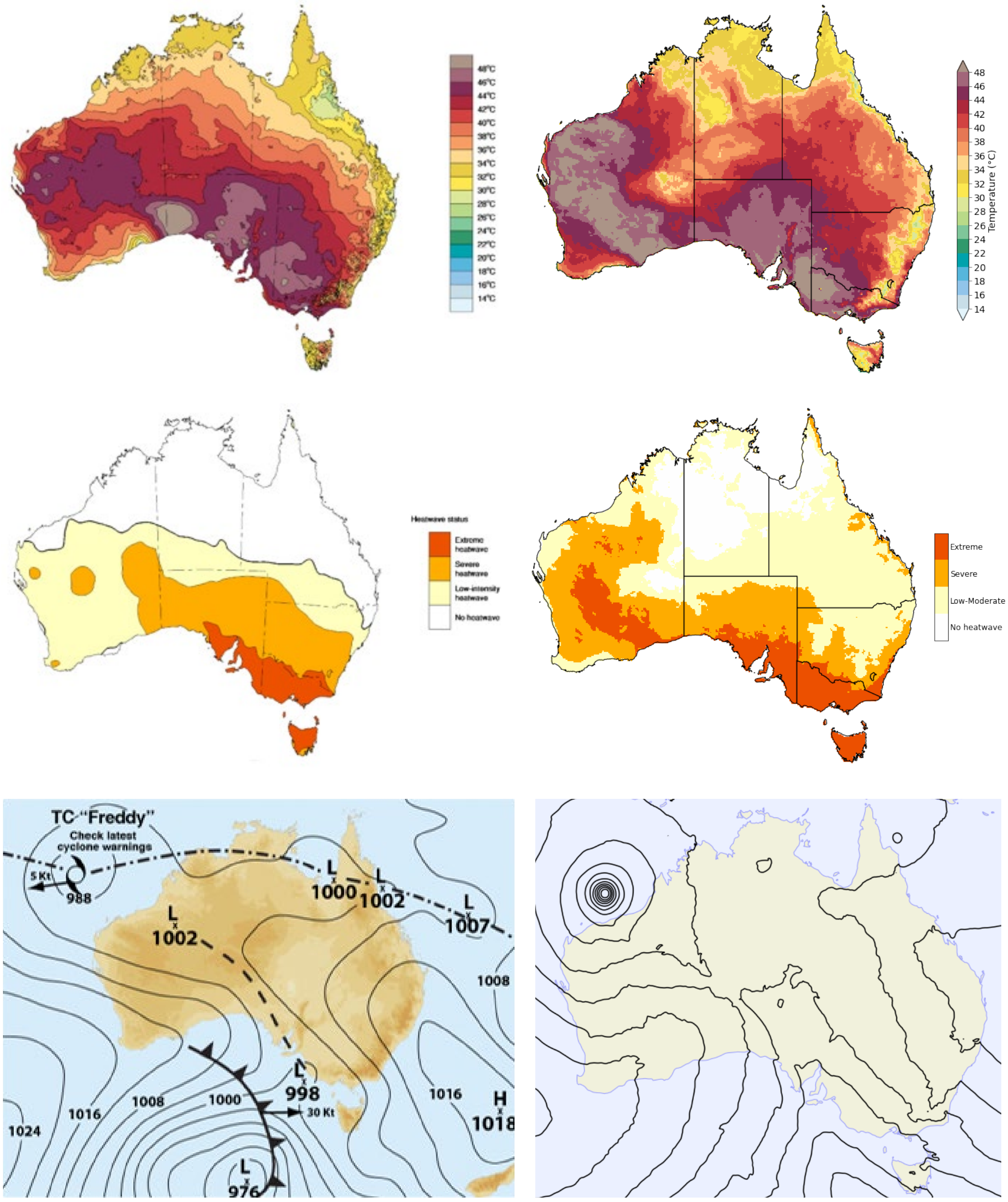
Case study of an extreme weather event

To develop a quantitative case study for use in stress-testing, the ESCI project identified an event in the climate projections with the synoptic characteristics of 'Black Saturday'. This included a multi-jurisdictional heatwave followed by a strong cold front, driving high winds and low humidity, in southeast Australia (see Figure 6).

The scenario[9] for the year 2031 includes conditions that in most cases exceeded those of 2009:

- drought preceding the event, and dangerously high Forest Fire Danger Index in some parts of the NEM
- 6 days of multi-jurisdictional heatwave in conditions warmer than the present; a significant difference from the 2009 event is the extreme heat up the south-eastern seaboard
- a strong cold front, producing strong winds

This event was used in the ESCI case study on extreme compound events.



Maximum temperature

Excess Heat Factor Loading (EHFL)

Synoptic map (mean sea level pressure)

Figure 6: Comparison of climate conditions for Black Saturday, 2009 (left) with the ESCI project 2031 case study (right)

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[9] See ESCI Technical Report on using extreme and compound case studies for decision making.

References

BoM and CSIRO (2020) *State of the Climate 2020*. Bureau of Meteorology and Commonwealth Scientific Industrial Research Organisation.

Bruyère C, Holland G, Prein A et al (2019). *Severe weather in a changing climate*. Insurance Australia Group and National Center for Atmospheric Research, November. https://www.iag.com.au/sites/default/files/documents/Severe-weather-in-a-changing-climate-report-011119.pdf.

Cai W, Borlace S, Lengaigne M et al. 'Increasing frequency of extreme El Niño events due to greenhouse warming' (2014) 4 *Nature Climate Change* 111–16. https://doi.org/10.1038/nclimate2100.

Cainey JM. 'Resilience and reliability for electricity networks' (2019) 131 *The Royal Society of Victoria* 44–52, 10.1071/RS19005.

Chang J, Donohoo-Vallett P, Ruiz P et al. *Potential for Incorporating Climate-Related Risks into Transmission Network Planning; a review of frameworks and responses*. Prepared for the Australian Electricity Market Operator, June 2020. https://aemo.com.au/-/media/files/major-publications/isp/2020/brattle-group-report.pdf?la=en.

Department of Home Affairs (2019). *Climate and Disaster Risk: What they are, why they matter and how to consider them in decision making. 3 Guidance on Scenarios* https://www.aidr.org.au/media/6932/04-scenarios.pdf.

Dowdy A and Catto J. 'Extreme weather caused by concurrent cyclone, front and thunderstorm occurrences' (2017) *Science Reports* 40359. https://doi.org/10.1038/srep40359.

Dowdy AJ and Kuleshov Y. 'Climatology of lightning activity in Australia: spatial and seasonal variability' (2014) 64 *Australian Meteorology and Oceanography Journal* 103–8.

Dowdy AJ, Pepler A, Di Luca A et al. Review of Australian east coast low pressure systems and associated extremes. (2019) 53 Climate Dynamics 4887-4910. doi.org/10.1007/s00382-019-04836-8

Dowdy AJ, Soderholm J, Brook J et al. 'Quantifying hail and lightning risk factors using long-term observations around Australia' (2020) 125(21) *Journal of Geophysical Research: Atmospheres* 2020JD033101. https://doi.org/10.1029/2020JD033101

IPCC (2019). : IPCC Special Report on the Ocean and Cryosphere in a Changing Climate https://www.ipcc.ch/srocc/cite-report/.

NESP ESCC Hub (2020). Scenario analysis of climate-related physical risk for buildings and infrastructure: Climate science guidance. Climate Measurement Standards Initiative, 12 pp. https://uploadsssl.webflow.com/5f1bdaf710347301b0c01fd4/5f5c2f4cb000cab9c03025d8_CMSI%20-%20Climate%20Science%20Technical%20Summary.pdf.

Sanders D, Hart A, Ravishankar M et al. An Analysis of Electricity System Flexibility for Great Britain (London: Carbon Trust/Imperial College, 2016). https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/568982/An_analysis_of_electricity_flexibility_for_Great_Britain.pdf

Watson P. 'Updated mean sea-level analysis: Australia' (2020) 36(5) Journal of Coastal Research 915–31

Zachary S (2016). Least worst regret analysis for decision making under uncertainty, with applications to future energy scenarios. https://www.researchgate.net/publication/305779725_Least_worst_regret_analysis_for_decision_making_under_uncertainty_with_applications_to_future_energy_scenarios.

4 Evaluate all risks

Overview

Climate change represents a challenge to the electricity sector. For example, Figure 1 shows how the fire season has advanced by nearly 3 months in one location over the last 70 years, potentially reducing the amount of time available for line maintenance and the reduction of fuel loads. The ESCI climate risk assessment framework (Figure 2) provides a systematic approach to climate risk assessment. Step 4 is to evaluate all risks, e.g. to compare climate risk with other risks, and it combines an assessment of risk likelihood with an assessment of the consequence using a risk rating matrix to compare different risks and identify priority risks. This will form the basis of the assessment of risk treatment options (Step 5). Evaluations should be conducted for different climate scenarios and different investment or adaptation options to assess whether one performs significantly better than others.

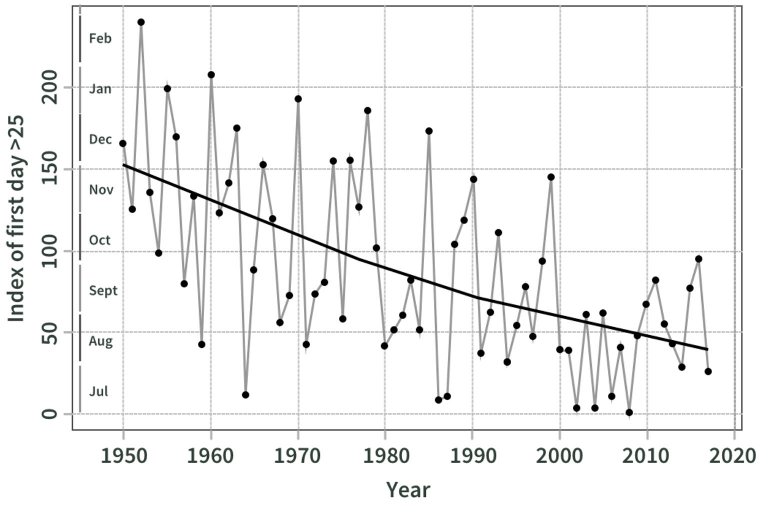
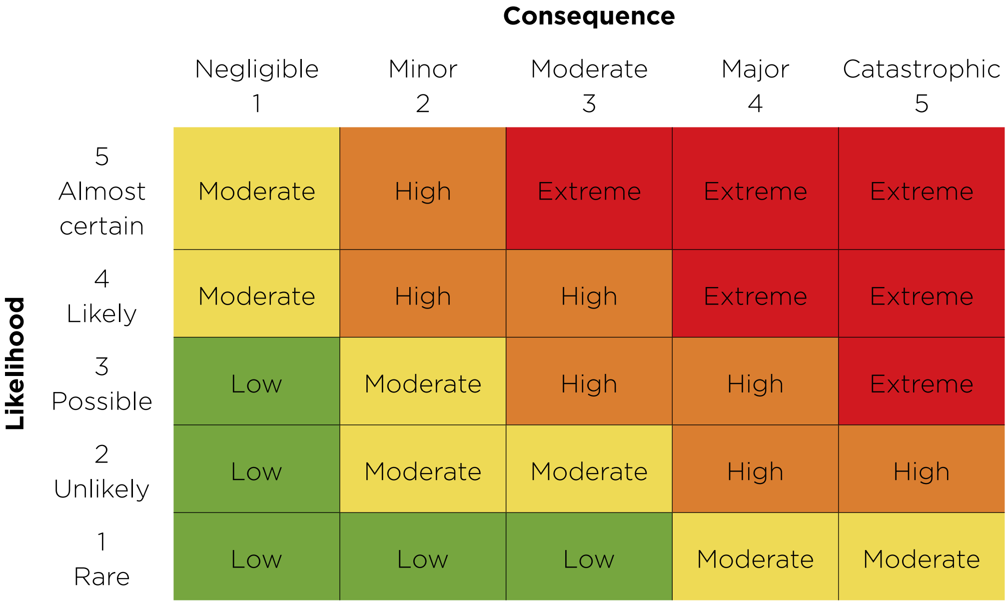


Figure 1: Climate change has already brought longer fire seasons. Earliest day with high fire danger, south-coastal NSW. Note: locations vary considerably and so this should not be considered indicative of changing fire seasons across the country. (Source: BoM internal analysis)

Figure 2: The ESCI Climate Risk Assessment Framework

Constructing a risk matrix

Risk evaluation is based on the outcomes of a risk analysis (Step 3 in the Framework). The consequences on system performance and/or the financial implications are combined with likelihood (or probability) of the event occurring to produce a risk rating matrix (Figure 3). This is a tool to rank or prioritise the risks and to consider risk mitigation options (Step 5). Extreme risks have highest priority for immediate action, high risks may require more detailed research and planning to determine the treatment, moderate risks may require changes to design standards and maintenance, and low risks may be managed through routine maintenance. Risk evaluation may lead to further, or more detailed, risk analyses if rankings are unclear.



Consequence

Likelihood	Negligible 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
5 Almost certain	Moderate	High	Extreme	Extreme	Extreme
4 Likely	Moderate	High	High	Extreme	Extreme
3 Possible	Low	Moderate	High	High	Extreme
2 Unlikely	Low	Moderate	Moderate	High	High
1 Rare	Low	Low	Low	Moderate	Moderate

Figure 3: Typical risk rating matrix, which involves combining the likelihood of a particular risk with the consequence.

Some criteria may be related to legal and regulatory requirements, or the organisation's climate risk management policy. The organisation should consider the:

- nature and magnitude of the consequences of climate-related risks and how they will be measured
- secondary consequences in terms of human safety and health, loss of utility, financial impact and disruption
- aversion to certain types of consequences
- timing and timeframe of the consequences
- persistence and reversibility of the consequences

The organisation should define criteria to evaluate the significance of current and future climate risks, consistent with criteria used for other types of risk.

Defining consequence

Table 1 provides examples of risk consequence criteria that may be used in risk evaluation. These criteria are consistent with the National Electricity Objective, which considers price, quality, safety, reliability and security.

Table 1: Risk criteria for qualitative measurement of consequences (Modified from Standards Australia 2013, AS-5334)

Consequence	Infrastructure, Service	Social	Governance	Financial	Environmental	Economic
Insignificant	Not affected	Not affected	Not affected	Not affected	Not affected	Not affected
Minor	Minor disruption/ repairs requiring early renewal of 10–20% of infrastructure	Minor disruption or health impacts for employees or customers	Concern raised by regulators requiring a response	Higher operating costs. Financial loss of <10%	Minor impacts	Minor impact due to disruption of service
Moderate	Moderate disruption and repairs requiring early renewal of 20–50% of infrastructure	Frequent disruption or health impacts for employees or customers	Investigation by regulators requiring management changes	Moderate financial loss of 10–50%	Moderate damage including local ecosystems. Some remedial action may be required	Moderate impact on local economy, with some impact on wider economy
Major	Major disruption and repairs requiring early renewal of 50–90% of infrastructure	Severe disruption or health impacts including serious injuries or fatalities	Notices issued by regulators for corrective action. Senior management responsibility questioned.	Major financial loss of 50–90%	Significant damage. Remedial action likely	Major impact on local economy, spreading to wider economy
Catastrophic	Significant damage and/ or complete loss of service requiring early renewal of >90% of infrastructure	Emergency response required. Total disruption and multiple fatalities.	Major policy shifts. Change to legislation and senior management.	Extreme financial loss of >90%	Extreme damage, including loss of species, habitats or ecosystems. Extensive remedial action likely.	Extreme impacts on local, regional and state economies

Defining Likelihood

Table 2 provides likelihood metrics according to Standards Australia AS-5334 and the Intergovernmental Panel on Climate Change (IPCC) that can be used as a basis of an evaluation.

Likelihood	Probability (AS-5334)	Probability (IPCC)
Almost certain	> 90%	> 99%
Likely	60–90%	66–100%
Possible	40–60%	33–66%
Unlikely	10–30%	0–33%
Rare	< 10%	< 1%

Table 2: Probabilities for various likelihood definitions according to Standards Australia AS-5334 and the Intergovernmental Panel on Climate Change (IPCC 2013)

Evaluation in practice

A climate risk evaluation can be undertaken through an expert elicitation process, via interviews or through surveys. There may be differing views about consequences and likelihoods so iteration may be required to reach consensus. Table 3 provides some examples of the likelihood and consequence of different climate risks from the Energy Networks Australia climate risk and resilience manual (ENA, 2014)[1] and Table 4 shows where these climate risks may occur in a corresponding example risk matrix.

Table 3: Consequences and likelihoods for selected climate hazards (Modified from ENA, 2014)

Hazard	Consequence	Likelihood	Risk rating
Rainfall	R1: Floods that result in damage to sub-stations and indirect damage to overhead wires, underground pipes and cables (Major)	Likely	High
	R2: Seasonal average rainfall changes can cause maintenance and repair issues to underground cables and pipes (Moderate)	Possible	Moderate
	R3: Drought can reduce thermal buffering of underground cables and can cause indirect damage to overhead structures (Moderate)	Possible	Moderate
Temperature	T1: Extreme temperatures may alter peak demand and reduce the efficiency of overhead lines, cables and transformers (Major)	Likely	High
	T2: Average temperature changes may reduce the efficiency of overhead lines, cables and transformers, and increase the sag of overhead lines (Major)	Likely	High
Fire	F1: Fires may affect overhead lines and wooden poles (Major)	Likely	High
Wind	W1: Extreme wind speeds can damage overhead networks (Major)	Likely	High
	W2: Average wind speed changes and increased frequency and intensity of extreme wind events can damage overhead lines and cause over-voltages, affecting transformers (Major)	Possible	High

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[1] EXHIBIT 15-010.008 - EAU.500.001.0128 - Attachment Q10_A1 to Dr Jill Cainey's witness statement - ENA Climate Risk and Resilience Industry Guidance Manual. Royal Commission into National Natural Disaster Arrangements.

		Consequence				
		Insignificant	Minor	Moderate	Major	Catastrophic
Likelihood	Almost certain	🟩	🟨	🟧	🟥	🟥
	Likely	🟩	🟨	🟨	🟧 R1, T1, T2, F1, W1	🟥
	Possible	🟩	🟩	🟨 R2, R3	🟧 W2	🟥
	Unlikely	🟩	🟩	🟨	🟨	🟧
	Rare	🟩	🟩	🟩	🟨	🟨

Table 4: Risk rating matrix based on consequence and likelihood. Green represents low risk, yellow moderate risk, orange high risk and red extreme risk (Modified from ENA 2014)

Other risks, such as economic, policy, technology and litigation risks, can be placed on the same risk matrix—doing so will help establish the priority for treatment of climate risk (Step 5).

Completing the matrix for a range of climate risks may require Step 3: Analyse Future Climate Risk, to be repeated to consider multiple coincident hazards or non-linear system responses. The power system response to a climate hazard will depend on asset and infrastructure configurations, engineering specifications and the location and vulnerability of consumers. A small change in climate could result in major impacts on the electricity system. For example, solar panels, wind farms and the Basslink Interconnector have temperature thresholds beyond which function drops off sharply.

Conclusion

Climate risk is one of a number of risks facing the electricity sector. A risk matrix can be used to prioritise climate risk against other business risks, but developing a plan to treat these risks through mitigation or adaption requires a cost-benefit analysis. This is likely to vary for different businesses and is described in Step 5: Treat Climate Risk.

If the climate risk identified is significant, or the risk treatment option is expensive, the ESCI project recommends seeking advice from expert climatologists to help analyse the climate risk and conduct sensitivity analyses to identify potential thresholds associated with major impacts.

References

ENA (2014). Climate risk and resilience: industry guidance manual. Energy Networks Association.

Stocker TF, Qin D, Plattner G-K et al (eds). IPCC. Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (Cambridge: Cambridge University Press, 2013). WG1AR5_SPM_FINAL.pdf (ipcc.ch).

5

Treat climate risks

Overview

Physical risks to the electricity sector associated with climate change are likely to be most relevant in strategic or planning timeframes (10–50 years). However, some impacts are already evident and have relevance in operational time frames (1–5 years) (Figure 1).

Figure 1: Climate hazards are increasing globally in ways that will have an impact on risk mitigation options. In 2018 simultaneous wildfires in Australia and California limited fire-fighting capabilities shared between the United States and Australia. Fires in (top) Bega Valley, NSW and (bottom) California both occurred in August 2018. (Sources: ABC and SFGate)

1 Understand context

2 Identify historical climate risk

3 Analyse future climate risk

4 Evaluate all risks

5 Treat climate risks

Figure 2: The ESCI Climate Risk Assessment Framework

The ESCI climate risk assessment framework (Figure 2) takes a decision-centred approach and is aligned with International Standard ISO 31000. Step 5 assumes that the climate risk has been assessed, evaluated and prioritised in the context of other risks (Step 4 of the ESCI Climate Risk Assessment Framework) and involves the assessment of risk treatment options. Risk treatment includes mitigation or adaptation and should result in lowering the impact of the risk on the system or process or reducing the chance of occurrence.

Risk mitigation or adaptation is measured as improvements in reliability, savings in capital costs, savings in operating costs, benefits for customers or benefits to the environment. For example, the metric for assessing effective risk treatment may be the improvement to system reliability in a region experiencing reduced network capacity resulting from increasing temperatures.

The cost-benefit analysis and modelling required to justify investment will be different for different electricity sector organisations; some parts of the sector will need to satisfy regulatory requirements.

Every risk treatment option will have associated costs and benefits which will be assessed against the National Electricity Objectives:

To promote efficient investment in, and efficient operation and use of, electricity services for the long-term interests of consumers of electricity with respect to:

- price, quality, safety and reliability and security of supply of electricity
- the reliability, safety and security of the national electricity system

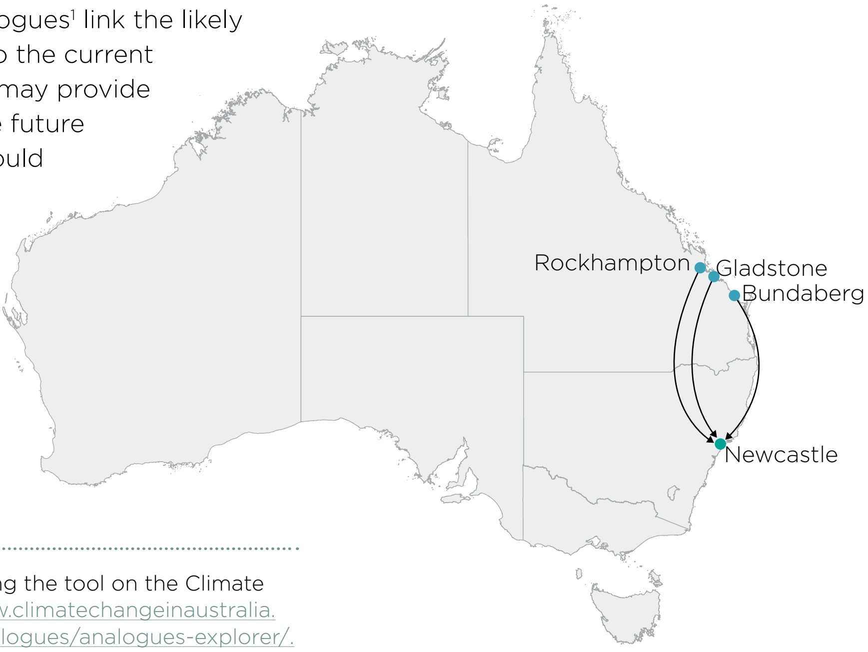
Considering risk treatment options

According to AS 5334 (Climate change adaptation for settlements and infrastructure), treatment involves:

1. selecting one or more adaptation options
2. deciding whether residual risk levels would become tolerable; if not tolerable, planning a new action or set of actions
3. assessing whether the actions are commercially and technically feasible and able to be implemented in time to meet the need

Climate analogues are a useful tool for brainstorming possible risk responses. Climate analogues[1] link the likely future climate in a place of interest to the current climate experienced elsewhere. This may provide insights into network challenges. The future climate of Newcastle, for example, could resemble the climate experienced today in the north-east coast of Queensland (Figure 3). Therefore, a future network in Newcastle could be modelled on the existing network in Bundaberg or Rockhampton.

Figure 3: The climate analogues tool in the Climate Change in Australia website suggests that by 2090, under the RCP 8.5 scenario, the climate of Newcastle will be more like that of Bundaberg, Gladstone or Rockhampton.



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[1] Climate analogues can be identified using the tool on the Climate Change in Australia website https://www.climatechangeinaustralia.gov.au/en/projections-tools/climate-analogues/analogues-explorer/.

Cost-benefit analysis

An optimal treatment that maximises the net economic benefit compared with other risk responses can be established through cost-benefit analysis:

i. Establish a base case where the risk treatment is not implemented and business-as-usual activities are continued. Although the base case may eventually result in failure of a system or asset (that would not be realistically allowed to occur), its purpose is to provide a reference for comparing the performance of different risk responses.

ii. Calculate the cost of a risk mitigation option and model the system with that option in place. (Establishing the relationship between the system and key climate hazards is covered in Step 2, and Step 3 describes how to quantify future climate impacts.)

iii. Quantify the benefits by comparing the scenario established in step ii with the base case.

iv. Repeat ii and iii for other mitigation or adaptation options.

v. Compare the costs and benefits of all mitigation or adaptation options using a risk matrix (see Step 4 of the ESCI climate risk assessment framework).

Organisations that are required to submit investment tests for regulatory approval may have to adopt inputs from AEMO’s inputs, assumptions, and scenarios report[2] when modelling risk treatment options. Risk responses should accord with frameworks for the system or process being assessed, such as the AER’s Cost Benefit Analysis Guidelines or regulatory investment test for transmission and application guidelines.[3]

Evaluating climate costs is likely to involve running statistical models under different climate scenarios (covered in Step 2) to estimate costs, including for maintaining, repairing, upgrading and replacing assets. The cost of customer service disruption due to asset failure may also need to be included. This type of analysis requires information about:

- weather event thresholds that trigger impacts
- the cost of impacts associated with historical weather events
- statistical response functions that describe the relationships between weather, asset and system performance, and associated costs
- projected changes in weather events

Cost-benefit modelling is expected to use ‘reasonable scenarios’; it is strongly recommended that both moderate and severe climate change scenarios are used for climate change risk assessments.[4] The ESCI project recommends using RCP4.5 (moderate pathway) and RCP8.5 (very high pathway), noting that RCP2.6 is similar to RCP4.5 until about the year 2040, with divergence after about 2050. Finally, the benefits arising in each scenario must be weighted by the probability

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[2] 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.

[3] https://www.aer.gov.au/networks-pipelines/guidelines-schemes-models-reviews/regulatory-investment-test-for-transmission-rit-t-and-application-guidelines-2010

[4] Refer to the guidance for Step 3: Analyse Future Climate Risk, and ESCI Key Concepts—choosing representative emissions pathways (RCPs) for more information on constructing climate scenarios and choosing appropriate RCPs.

of that scenario occurring. The preferred option is then the risk response that maximises the net economic benefit compared with other risk responses.

The Energy Networks Australia climate risk and resilience manual (ENA, 2016) provides examples of cost-benefit analysis for different climate change scenarios. The sensitivity of results to different discount rates (e.g. 3–10%) should be tested.

High-impact low-probability events may be investigated as a separate scenario. The ESCI project can provide quantitative modelling of extreme compound events (see e.g. Figure 4), although it is challenging to provide probability information on an event involving simultaneous occurrence of a number of rare extremes. However, such modelling can still be used to derive estimates of the system performance, and therefore economic costs (and benefits of risk treatment). The ESCI Technical Report on extreme and compound events provides a more complete discussion, see also ESCI case study summary on modelling the impact of extreme events for an example of this approach.

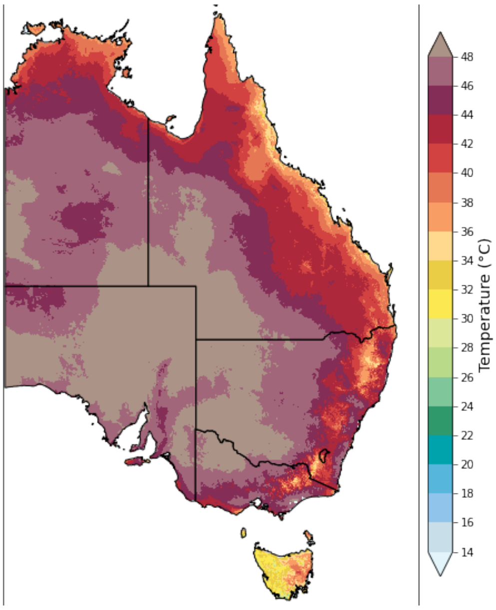

Figure 4: The ESCI project provides example scenarios of extreme weather events that may occur in the future. These high-impact low-probability events may be investigated as a separate scenario for cost benefit analyses. BARPA reginal climate model downscaling of ACCESS1-0 for RCP8.5 to 5km resolution. The top of the scale represents surface temperatures above 48 degrees Celsius for January 2066

References

ENA (2014). Climate Risk and Resilience—Industry Guidance Manual. Energy Networks Australia. https://infostore.saiglobal.com/store/Details.aspx?productID=1811054.

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