ELECTRICITY SECTOR CLIMATE INFORMATION PROJECT

ESCI Project Final Report

JULY 2021

Australian Government
Department of Industry, Science, Energy and Resources

Australian Government
Bureau of Meteorology

CSIRO

AEMO
AUSTRALIAN ENERGY MARKET OPERATOR

Contents

Executive Summary

The ESCI project was funded by the Department of Industry, Science, Energy and Resources (DISER). It was delivered by the Commonwealth Scientific & Industrial Research Organisation (CSIRO) Climate Science Centre (CSC), the Australian Bureau of Meteorology (BOM), and the Australian Energy Market Operator (AEMO), the project's primary stakeholder, between March 2019 and June 2021.

ESCI project objectives

The project was initiated in response to the *Independent review into the future security of the National Electricity Market: Blueprint for the future* (known as the 'Finkel Review') which included Recommendation 2:11: 'In recognition of the increased severity of extreme weather, by end-2018 the COAG Energy Council should develop a strategy to improve the integrity of energy infrastructure and the accuracy of supply and demand forecasting.'

The objectives of the Project[1] were to:

1. Support improved planning and investment decisions for the electricity network;
2. Support decision-makers in the National Electricity Market to access and use tailored climate information to improve long-term climate risk planning by collaborating on existing information and planning processes. This will include identifying and, where possible, providing priority climate information that is critical to support these long-term planning processes;
3. Develop and demonstrate a best practice methodology for analysing climate change risks that can also be used by other sectors, for example telecommunications;
4. Contribute towards a longer-term vision for the next generation of climate projections and seamless climate and weather services; and
5. Improve information on likely future changes to extreme weather events such as heatwaves, wind, and maximum temperature thresholds, to inform analysis of long-term climate risk. A particular focus should be on concurrent and/or compounding extreme events.

Project outputs

Early consultation with the sector identified key climate risks and the need for a standard approach to risk assessment with credible, authoritative data.

The ESCI project delivered high resolution climate projection data to 2100 (5–12 km across the National Electricity Market (NEM), at sub-daily intervals). The ESCI data sets are based on existing climate models using downscaling methods and sophisticated statistical adjustment. These data sets provide the sector with a standard suite of information on key climate variables which will answer the most pressing questions on future climate risks. The ESCI data suite will also provide comparable assessments for the Australian Energy Regulator (AER) and other sector users. The ESCI project recommends that sector users engage with climate professionals to undertake a more comprehensive risk assessment for major investments or where the climate risk is deemed to be significant.

1 ESCI project—Collaboration Framework Deed. 11 February 2019. Schedule 2.

The ESCI project also delivered a 'best practice' standardised climate risk assessment framework for climate risk assessments for the electricity sector so that the impacts of climate change can be assessed and, where practicable, mitigated. The framework produced by the project includes:

- a five-step climate risk assessment method based on ISO 31000 and supported by User Guidance, designed to integrate with existing processes to assess other risks
- a website with access to recommended climate data sets and information, supported by comprehensive User Guidance
- exemplar case studies for using ESCI climate data in a risk assessment
- other supporting information: technical reports, a glossary, key climatology concepts relevant to the electricity sectors, webinars and training materials

Impact of the project

As the primary stakeholder of the project, AEMO has used the information provided by ESCI to work towards the incorporation of climate information into key planning documents for the sector, including the Integrated System Plan (ISP) and the Electricity Statement of Opportunities (ESOO). Appendix 8 of the AEMO 2020 ISP is a new stand-alone reference for climate change impacts and includes climate change resilience analysis and evaluation in its actions to enhance energy system resilience. AEMO scenarios in the new ISP all include climate change impacts and refer to specific greenhouse gas emissions pathways as underlying assumptions. As many sector decisions, including major investments, are governed by the AEMO ISP and other AEMO publications, AEMO adoption of climate change data will drive other parts of the sector to do the same.

Other impacts of the project are captured in comments from the ESCI Reference Group (ERG) members:

> 'The ESCI project provided us with a framework and climate data to help consider and quantify the implications of climate change on the energy sector. An important step forward to support the conversation of how to consider climate change in the NEM's planning and regulatory framework.'

> 'Making long-term investment decisions that incorporate climate risk is complex, as we are working with probabilities and likelihoods that span quite wide bands associated with various future climate scenarios. The ESCI project provides a consistent set of climate data and enables investment decisions to be aligned to a common risk framework. Working with the right data to inform risk assessments will ensure that the right investments in infrastructure are being made at the right time to address the inherent risks to intergenerational equity associated with a changing climate.
> The value in the ESCI project can only be realised with broad industry, community and regulatory acceptance to a consistent set of climate models and risk assessment framework.'

> 'I want to congratulate you for the ESCI project and its achievements. I enjoyed being part of a truly multi-disciplinary team and I learned a lot in every meeting. I also really appreciated how the team took on board all our feedback—it's not always the case with other projects. Looking forward to the next one!'

Key lessons

Importance of co-design and industry engagement The success of the project can be measured by the take-up from industry. Establishing the ESCI Reference Group and regular consultation with, testing by and feedback from the sector has been critical. A wide range of stakeholders were represented, including representation from the market operator (AEMO), Transmission Network Service Providers (TNSPs) and Distributed Network Service Providers (DNSPs), Energy Networks Australia (ENA), generators, consumer groups, consultants, academia and the Clean Energy Council. The group also invited observers from the AER and the Energy Security Board (ESB).

Scientific findings The ESCI project recognised that the predicted increase in the frequency and severity of extreme weather events will challenge Australia's electricity infrastructure. Five key hazards were identified, as shown in the table below.

Changing climate hazard	Electricity system vulnerability
Rising temperatures Increases in average and extreme temperature (very high scientific confidence)	Reduces generator and network capacity, increases demand, may increase maintenance and replacement costs
Increased frequency, severity and extent of bushfires Increase in extreme fire weather (medium–high confidence)	Threat to most assets, with a particularly high operational risk to transmission and distribution lines due to heat and smoke
Extreme winds Decrease in number of high wind events and cyclone frequency, possible increase in severe Category 4–5 cyclones (low–medium confidence)	High winds reduce the capacity and threaten the integrity of transmission lines, making them an important consideration for network capacity assessments and design specifications. Wind generation is sensitive to a reduction in average wind speed as well as to the frequency and magnitude of destructive gusts.
Increased variability or reduction in rainfall, dam inflows and flooding Decrease in winter/spring rainfall and increase in extreme rainfall events (medium confidence)	Reduces water available for hydro generation. Increases requirement for desalination and associated energy demand. Reduced soil moisture may increase damage from lightning and reduce thermal conductivity of underground power lines.
Compound extreme events Increase in frequency and magnitude (low confidence)	Extremes in multiple climate variables occurring simultaneously or in close sequence can cause substantial disruption. These events can be exacerbated by associated non-climatic factors such as infrastructure failure or staff fatigue.

While the project was asked to deliver limited downscaling to fill gaps identified in the climate projections, the ESCI project actually delivered a large step up in regional climate modelling for Australia, producing an ensemble of high resolution climate projection data (5–12 km across the NEM, at sub-daily intervals) to 2100. The project has provided improved information on likely future changes to extreme weather events, including heatwaves, wind, and maximum temperature thresholds, as well as providing data on changes to bushfire danger indicators, rainfall variation, dam inflows and solar radiation. The project has also made steps in helping the sector to improve its understanding of the risks and impacts of concurrent and/or compounding extreme events such as heatwaves and bushfires. It has also tailored guidance and insights to enable the electricity sector to assess climate risks and to plan for this future with greater confidence.

Legacy of the project The ESCI project has contributed significantly towards a longer-term vision for the next generation of climate projection data, making significant progress towards bridging the gap between large-scale climate models change impacts and translating those models to weather data at a local scale which can be accessed and used by the sector. As a result of the ESCI project, climate risk—including risk related to future weather—can now be consistently integrated into sector planning and risk modelling using a standard process and guidance.

Other applications The ESCI data suite has been identified as a key data source for the Australian Climate Service to assist in anticipating, planning for, managing and adapting to climate impacts. The ESCI data suite may also have other commercial applications beyond the electricity sector (e.g. insurance and agriculture).

Further work The work of the project highlights the need for climate risk assessments by critical infrastructure sectors and the ESCI climate risk assessment framework leads the way for other sectors to develop tailored climate information. Lessons learned from the project should be used to design subsequent projects.

The project would like to acknowledge the contribution from our electricity sector partners—in particular the members of the ERG for their contributions to shaping and testing the outputs of the project.

1. Introduction: the need for the project

The impacts of weather on a future energy system in a future climate will become increasingly significant and the ESCI project was initiated in response to the *Independent review into the future security of the National Electricity Market: Blueprint for the future* (known as the 'Finkel Review'), which included Recommendation 2:11: 'In recognition of the increased severity of extreme weather, by end-2018 the COAG Energy Council should develop a strategy to improve the integrity of energy infrastructure and the accuracy of supply and demand forecasting.'

The ESCI project was originally funded by the Department of Energy and Environment (DoEE), with the administration of the project moving to the Department of Industry, Science, Energy and Resources (DISER) in December 2019. The work was undertaken through a partnership between the Australian Electricity Market Operator (AEMO) and the Commonwealth Scientific & Industrial Research Organisation (CSIRO) and the Bureau of Meteorology (BOM). The project commenced in March 2019 and was concluded in June 2021.

The project has delivered tailored climate and extreme weather information for use by the electricity sector in assessing the risk that climate change presents to sector investments, system reliability and system resilience. It has also provided guidance and insights to enable the electricity sector to assess climate risks and to plan for the future with greater confidence.

As a result of the ESCI project, climate risk—including risk related to future weather—can now be consistently integrated into sector planning and risk modelling using a standard process and guidance.

1.1 Climate change relevance to the National Electricity Market

Weather and electricity are interconnected. Weather is the 'fuel' for solar, wind and hydro electricity generation. Electricity demand is strongly dependent on temperature. Electricity infrastructure performance is directly affected by weather hazards: The **Finkel Review** (p.64) observed that '[t]he NEM is particularly exposed to climate change impacts. Land warming and an increase in the frequency and intensity of extreme weather events can increase stress on the power system in several ways:

- Transmission and distribution networks are vulnerable to extreme weather events.
- High ambient temperatures reduce generator efficiency, and can lead to breakdowns and an increase in maintenance costs.
- Many elements in the power system have maximum operating temperatures above which they disconnect to avoid damage. These controls will be triggered more frequently and new investment may be required to make the equipment more resilient to high temperature events.'

Consultation with the sector, including the first ESCI workshop in April 2019, identified sector processes and decisions for which climate risk assessment is likely to be relevant:

- managing safety and reliability of assets in the future
- identifying the potential for asset and value destruction
- understanding the potential for changes in future cash flow and profitability
- understanding consumer outcomes from possible weather impacts on electricity supply and demand
- designing new asset specifications for future operating conditions
- calculating market benefits for regulated investments, considering changes to operating conditions of the integrated power system

While climate change information is most relevant for mid- to long-term planning (greater than 10 years), some climate risks are becoming apparent over shorter periods. Extreme temperatures are becoming more frequent (Figure 1), which has implications for consumer demand forecasts.

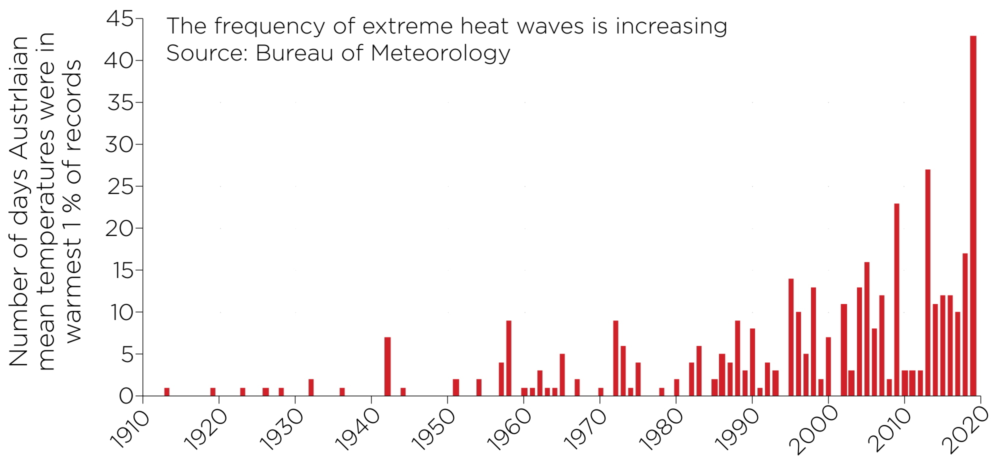

Figure 1 Number of days each year where the Australian area-averaged daily mean temperature for each month is extreme. Extreme daily mean temperatures are the warmest 1 per cent of days for each month, calculated for the period from 1910 to 2019 (State of the Climate Report 2020).

Early evidence of increasing bushfire risks (Figure 2) has implications for fuel load management.

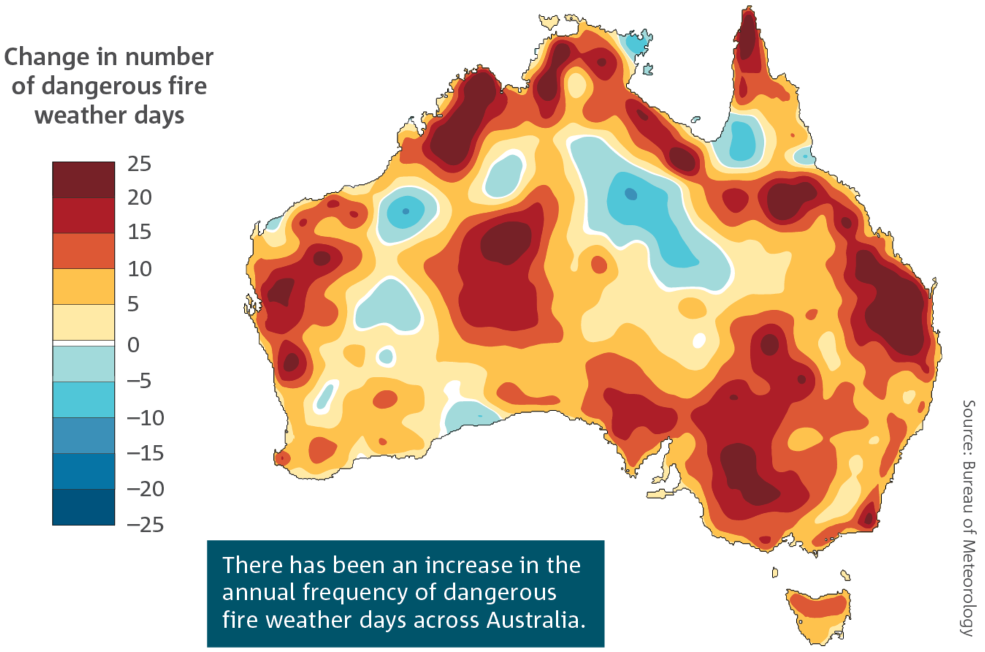

Figure 2 Change in the number of dangerous fire weather days from 1950 to 2010. (Source: Dowdy AJ (2020). 'Seamless climate change projections and seasonal predictions for bushfires in Australia' Journal of Southern Hemisphere Earth Systems Science 70:120–38. https://doi.org/10.1071/ES20001)

A reduction in cool season rainfall (Figure 3) which could contribute to bushfire risk also has implications for power supply from hydroelectric generation.

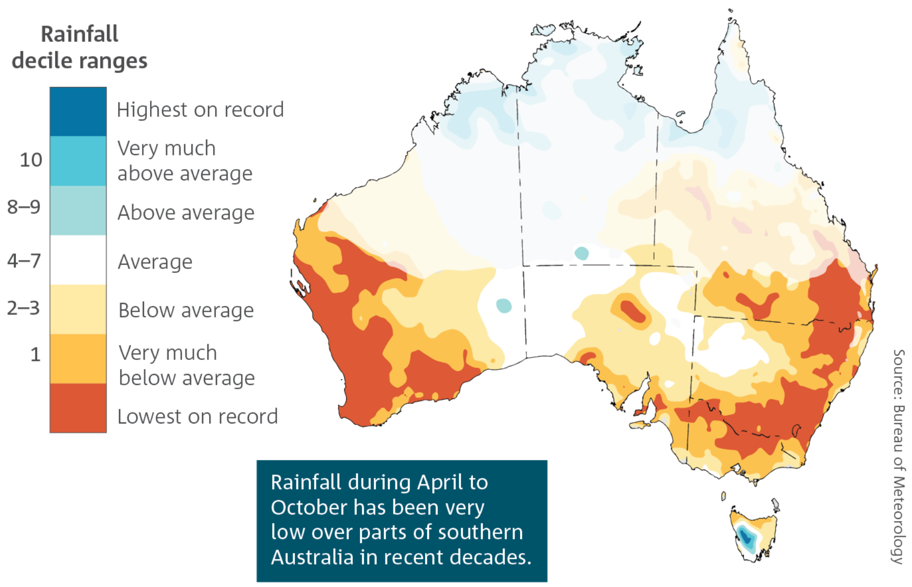

Figure 3 April to October rainfall deciles for the last 20 years (2000–2019).

1.2 Project objectives and project logic

Climate change is superimposed on natural weather and climate variability and while historical records provide a good indication of where risks may emerge, future risks are likely to be underestimated if climate change is not explicitly considered. The objectives of the Project,[2] therefore, were to:

1. Support improved planning and investment decisions for the electricity network;
2. Support decision-makers in the NEM to access and use tailored climate information to improve long-term climate risk planning by collaborating on existing information and planning processes. This included identifying and, where possible, providing priority climate information that is critical to support these long-term planning processes;
3. Develop and demonstrate a best practice methodology for analysing climate change risks that can also be used by other sectors, for example telecommunications;
4. Contribute towards a longer-term vision for the next generation of climate projections and seamless climate and weather services; and
5. Improve information on likely future changes to extreme weather events such as heatwaves, wind, and maximum temperature thresholds, to inform analysis of long-term climate risk. A particular focus was on concurrent and/or compounding extreme events.

A logic-based theory of action for the project is summarised schematically in Table 1. This approach maintains a clear connection from the project activities and outputs to the desired outcome.

2 ESCI project—Collaboration Framework Deed. 11 February 2019. Schedule 2.

Table 1 Project logic

Outcomes[3]	Improve the integrity of energy infrastructure and the accuracy of supply and demand forecasting
Interim outcomes	• AEMO uses tailored climate information in power and market modelling and includes output and commentary on long-term climate risk in ISP. • Regulatory submissions (e.g. the Regulatory Investment Test for Transmission (RIT-T)) use long-term climate change information as part of investment proposals. • Electricity generators, DNSPs and TNSPs use long-term climate change information in strategic planning and investment proposals.
Purpose	Improve climate and extreme weather information for the Australian electricity sector to manage three key risks: 1. Changes to fuel availability (wind, solar radiation, dam inflows) and electricity demand resulting in investment risk, and risk to system reliability and capacity; 2. Increased severity of individual extreme weather events with implications for long-term planning for reliability and system resilience; and 3. Unprecedented clustering of extreme weather events leading to compounding and cascading risks across the NEM with implications for resilience planning.
Objectives	1. Support improved planning and investment decisions for the electricity network. 2. Support decision-makers in the NEM to access and use tailored climate information to improve long-term climate risk. 3. Develop and demonstrate a best practice methodology for analysing climate change risks. 4. Contribute towards a longer-term vision for the next generation of climate projections and seamless climate and weather services. 5. Improve information on likely future changes to extreme weather events such as heatwaves, wind, and maximum temperature thresholds, to inform analysis of long-term climate risk. A particular focus should be on concurrent and/or compounding extreme events. 6. Raise awareness in the sector of the importance of climate change impact on the electricity sector.

3 From the Finkel Review recommendations which provided the impetus for the ESCI project

Outputs	• Scan of decision-making processes and climate risk • Inventory of existing gaps and needs • Climate risk assessment framework • Standardised climate risk analysis methodology • Case studies for heat, bushfire, wind, and extreme events	• Guidance material for target audiences • Communication products for target audiences • Weather / climate data on website • Capacity development, training and advice • Final report • Project evaluation reports
Activities	Project management, coordination and support Limited downscaling of global climate projections to fill existing knowledge gaps Standard methodology for projections likelihood (SMPL) assessment	• Stakeholder interviews and workshops • Iterative co-design and co-production of outputs • Communication, knowledge-brokering and evaluation • Collaborative partnerships with the sector

1.3 Guiding principles

Formal collaborating principles were agreed by the parties to the contract. These included using 'a standards-based approach … a clear definition of accountabilities … [and] a secure environment'.[4] The project also agreed to guiding principles for the development of outcomes for the sector:

- **Decision-centred approach.** This focused the work on understanding the decision-making context of the sector, the vulnerabilities of key assets and processes, and the objectives of stakeholders; providing information to inform those decisions, rather than pursuing a broad vulnerability scan. This ensured that effort and resources were focused on climate variables and impacts of most concern.
- **Address physical risk in long-term planning time frames.** While the need to mitigate against further climate change is driving major transitions in the electricity system, the project focused on providing climate information and guidance to assess physical risks only (see Figure 4).
  - the project primarily looked at the time frames in which physical risks are likely to have an impact across the sector choosing to assess changes in 20-year time slices from 2020 to 2100.

4 Schedule 3 of the Collaboration Framework Deed.

  - the project team provided climate information for greenhouse gas emissions Representative Concentration Pathways (RCPs) 4.5 and 8.5 as these provide the clearest guidance for physical risks and the extent and location of physical adaptation needed.[5]

- **Co-design with the sector.** AEMO was the primary collaborator from the sector as many sector decisions are guided by the AEMO ISP and other AEMO publications. Climate information is complex and therefore data sets and climate information products needed to be co-designed and iteratively produced with AEMO and in consultation with other key electricity sector stakeholders to ensure they are usable.

  - The information needed to be tailored to sector models, tested with users, and communicated in a way that encourages adoption, noting that the electricity sector is a highly quantitative sector and climate change is one of many risks that are considered in sector processes and decisions.

  - Co-design and co-production created champions in AEMO and in the sector, and this is likely to result in much higher levels of long-term transfer, acceptance, and integration of the outputs of the project into sector decision-making.

The ERG was established in May 2020 to enable consultation throughout the project with a group of partners who understood the complexities of the project and could contribute in a meaningful way to the evolution of the outputs.

5 ESCI project guidance strongly recommends that both low and high concentration scenarios are used in climate risk assessments. The Taskforce on Climate-related Financial Disclosure recommends using scenarios that give a global warming of 2 °C and 4 °C by the year 2100. RCP4.5 can be used for the 2 °C warming scenario as it indicates a 40 per cent chance of keeping warming below 2 °C, although the Climate Measurement Standards Initiative (2020), developed by Australian finance representatives, recommends using RCP2.6 for a 2 °C warming scenario and RCP8.5 for a 4 °C warming scenario. Historical cumulative carbon dioxide emissions are tracking RCP8.5 (Schwalm et al. 2020), which is no longer called 'business as usual' (Hausfather and Peters 2020), therefore the ESCI project partners chose RCP4.5 and RCP8.5 as the most useful scenarios for assessing both reliability and resilience risk for electricity infrastructure.
Up to the year 2050, that is within the lifetime of the AEMO Integrated System Plan, there is not much difference between the greenhouse gas concentrations and global warming estimates for the different RCPs; beyond 2050, the concentrations and global warming estimates diverge. (See also ESCI Key Concepts on the ESCI website)

Figure 4 Ways in which climate change presents a risk to the electricity sector.

Institutional risks

Failure of the institutions and organisations within the sector to consider climate change will produce financial, legal, governance and reputational impacts. Power service disruption could also have societal impacts, compounding institutional risk.

Supply side transition risks

As part of the global greenhouse gas emission reductions and changing technology prices, the portfolio of electricity generation sources is transitioning from fossil fuels to renewable sources like wind and solar. This transition increases the exposure of electricity supply to climate risks given the variable nature of most renewable resources, as well as changing transmission needs and impacting on reliability, system stability, system strength, fault levels and synchronous support.

Demand side transition risks

Between decarbonisation efforts and climate impacts, the needs of electricity users are likely to change. Impacts to residential consumption may include additional rooftop photovoltaic systems (PV) and electric vehicles. Impacts to business consumption may include additional desalination, further restructures of the economy and changing agricultural and industrial needs.

Physical risks

Electrical assets are installed throughout the country and are likely to be impacted by weather that differs from the historical expectation.

Physical risks include:

- changing wind, irradiance, precipitation and temperature patterns that affect the instantaneous supply/demand balance
- increases in extreme weather and compound weather events that impact the operability and failure rates of assets

This category was the focus of the ESCI project

1.4 Project structure

1.4.1 The Work Packages

The work of the project was divided into three packages which worked concurrently:[6]

- **Work Package A (WPA)** was designed as the focal point of all other Work Packages, with a mandate to consolidate, tailor, test with users, and communicate the information developed in other Work Packages to ensure it is fit for the intended use. This work included co-designing and iteratively producing that information with key electricity sector stakeholders, developing a standardised method for climate risk assessment for the sector, and providing guidance on how to use this method.
- **Work Package B (WPB)**: Led the initial work to identify priority climate information gaps for the sector. This work included (i) gathering available information on network vulnerabilities, risks and opportunities, (ii) developing an inventory of climate information, and (iii) matching the inventories to identify information needed to inform analysis of long-term climate risk. A particular focus of this Work Package was on concurrent and/or compounding extreme events, including running scenario exercises tailored to understanding the priority climate information gaps that decision-makers in the electricity sector recognise as critical to their long-term decision-making.

6 Summarised from the relevant Work Package Agreements—Schedule 2.

- **Work Package C (WPC)**: A main focus of this Work Package was to develop a standardised methodology for analysing climate change risks (the Standardised Methodology for Projections Likelihood (SMPL)). The WPC also focused on developing plausible and representative scenarios such as those tested in WPB, and developed climate model downscaling simulations to fill some of the data gaps identified by WPB. This included the first production of downscaling using a modelling approach recently developed in BOM, to complement other downscaling approaches available for Australia including new downscaling produced by CSIRO for this project. Additionally, a new method for calibration of projections was applied to make the project outputs more readily usable, based on removing biases for extremes.

The Work Packages were strongly linked, therefore the boundaries between them and the scope of work were necessarily porous and flexible (Figure 5). In January 2020, a project coordinator was appointed to manage the day-to-day coordination across the Work Packages, including delivery of milestones and project reporting (note: this task was originally envisaged as part of WPA).

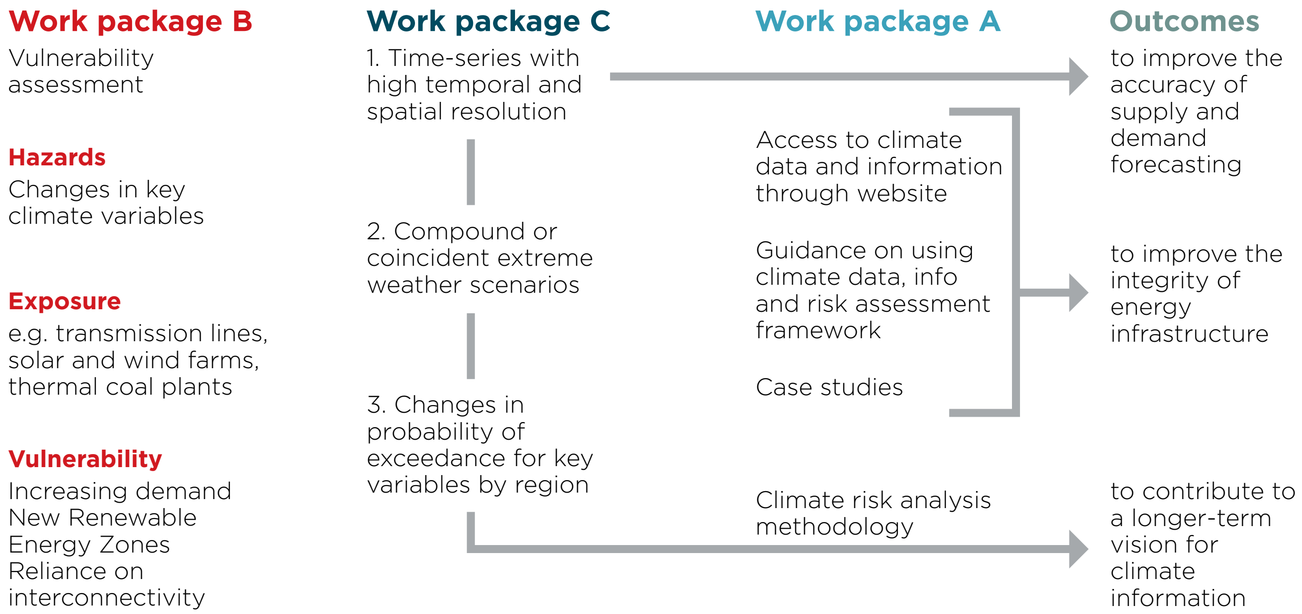

Figure 5 The work of the ESCI Work Packages approximately aligned with the program logic, although boundaries between the work packages was necessarily porous and flexible.

1.4.2 Project governance

The ESCI project employed a multi-tiered governance structure to ensure the project delivered on its objectives. Direction for the project was provided by a project steering committee, which was chaired by the Department of Industry, Science, Energy and Resources (DISER) as the project owner and included representatives from the contracted parties, BOM, CSIRO and AEMO. Delivery of the project was driven by a Work Package Committee, which provided oversight and direction for each of the work packages. An Industry Reference Group was established to provide a forum to engage directly with the sector and other key stakeholders. The formal governance arrangement for the project and the role of each tier of the governance structure is summarised in Table 2 (Terms of Reference and membership are given in Appendix A).

Table 2 ESCI project governance

Department of Industry, Science, Energy and Resources (DISER)	**Role:** Project funder, contract manager and decision-making authority for the project overall; for example, approving milestones and all project outputs
ESCI Steering Committee	**Role:** Provide advice and oversight of project deliverables, including milestones Approve Work Package plans and manage timelines of work Facilitate collaboration between the project organisations Identifying areas of risk in the Project and risk mitigation strategies **Membership:** The Steering Committee was chaired by DISER and included the project leads from BOM, CSIRO and AEMO. Work package leads and the ESCI project coordinator were invited as observers. Observer status was also extended to representatives from the Department of agriculture water and energy (DAWE) and the Department of Home Affairs. The Steering Committee typically met once every four to six weeks.
Work Package Committee	**Role:** Primary forum for cross-work package coordination. Engage in operational management for the Work Packages; for example, managing timelines of work and progress on deliverables Coordinate work on each of the key tasks across all Work Packages Coordinate across Work Packages where necessary to ensure smooth running and alignment of the Work Packages Regularly report progress on the Work Packages to the Steering Committee and, where required, escalate issues to the Steering Committee **Membership:** The Work Package Committee was chaired by the Project Coordinator and included the ESCI Work Package managers, science leads and the DISER Contract Manager. The Work Package Committee typically met once a month.
ESCI Reference Group (ERG)	**Role:** To integrate end-user and next-user perspectives into the outputs of the ESCI project and provide advice on the direction and output of the project Provide feedback on the type and format of climate information products and guidance material **Membership:** Fourteen participants from all parts of the sector by invitation. Included representation from AEMO, T/DNSPs, ENA, generators, consumer groups, consultants, academia and the Clean Energy Council. The group also included observers from the AER and ESB. The ERG met as required, based on the schedule of project deliverables.

2. Stakeholder participation

In addition to being a contracted party and member of the project Steering Committee, AEMO was the primary industry stakeholder and was actively engaged from the beginning of the project as a formal collaborator. In particular, AEMO was key to the first project outcome: improving the accuracy of electricity supply and demand forecasting (see Table 1, Project Logic).

Achieving the second project outcome: Supporting decision-makers in the NEM to access and use tailored climate information to improve long-term climate risk required engaging industry stakeholders beyond AEMO. The original plan was to do this via the Steering Committee, Work Package Committee and Work Package teams using a mix of approaches guided by the level of engagement needed to obtain maximum impact for the project (see Figure 6, Stakeholder map).[7] It became clear that this engagement was inadequate for co-design of project outputs. A Stakeholder Advisory Group (SAG) was proposed in the contract but never established and was superseded by the formation of the ERG.

Early engagement of stakeholders included:

- workshop 1 (May 2019)—an extreme event 'war gaming' workshop which was used to engage a broader set of stakeholders and to develop a vulnerability inventory for the sector
- workshop 2 (July 2019)—an exploration of challenges and data needs of the hydro-generation sector
- interviews with TNSPs and DNSPs in Nov/Dec 2019 to document decision-making processes, integration of risk assessments and understanding of climate change as a risk
- a data consultation workshop in February 2020 with broad representation from the sector

7 Details of the communications and knowledge-brokering program for the ESCI project are included in the final Communications, Monitoring and Evaluation Report.

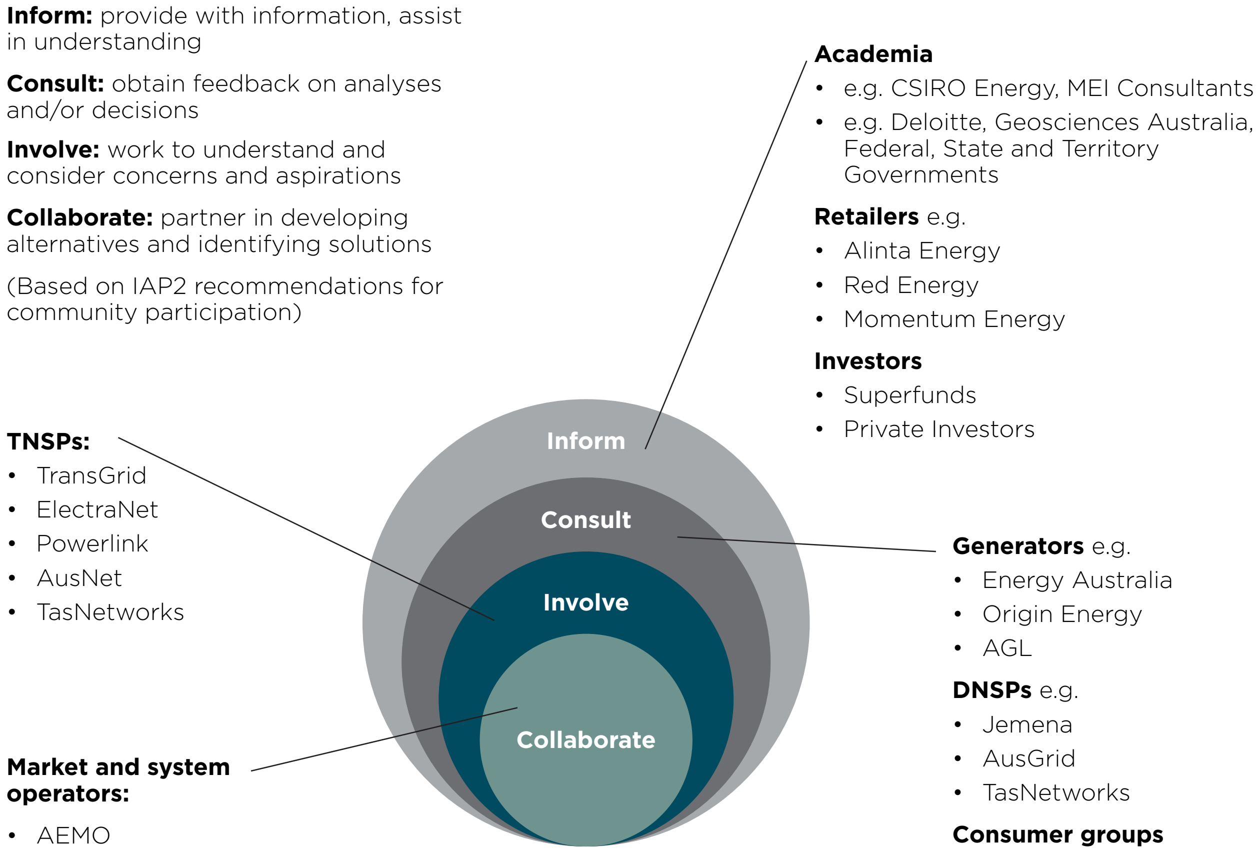

Figure 6 Sector participation map for the ESCI project based on the IAP2 public participation spectrum.

2.1 Introduction of the ERG

Interviews and interaction with the sector revealed that a strong foundational understanding of climate risk in the sector was generally absent, and so a substantial part of every meeting or interview was spent explaining climate projections and exploring their climate risks. In April 2020, the decision was made to form the ERG to partner in the co-design of the outputs of the project (ERG members are listed in Appendix A3).

The ERG was a group of people, from across the electricity sector and academia, who were familiar with the project, supported its goals and could provide ongoing feedback and advice. A group of 14 organisations representing a variety of industry stakeholders, including TNSPs, DNSPs, ENA, generators, consumer groups, consultants, academia and the Clean Energy Council agreed to join monthly meetings and to participate in ad hoc meetings on different topics, including the use of scenarios for decision-making for resilience, preferred data formats and to provide decisions with which to test the ESCI climate risk assessment method. This has proven to be a valuable resource for the project with the ERG providing frank and fearless advice and partnering with the project in case studies, data testing and the co-design of guidance material. ERG members, it is hoped, will also continue to be champions of the project and the use of project outputs for climate risk assessments for the sector.

2.2 Data release cycles

To meet the key objective of the project to 'help support decision-makers in the National Electricity Market to access and use tailored climate information to improve long-term climate risk planning', the climate information being developed by the project needed to be co-designed and iteratively produced in consultation with the sector stakeholders. There was also considerable pull from the ERG to see the climate data and test it. Therefore, the ESCI project team designed and initiated data and guidance testing in three cycles over the remaining life of the project. For each of the three ESCI test cycles (Table 3), formal evaluation was conducted with ERG and electricity sector participants to understand their key data requirements, use cases and preferences for data formats to assist the project refine the final data and guidance release.

Table 3 Data test cycle timing, content and evaluation priorities

Test cycle	Data sets included	Evaluation priorities
Test cycle 1 (November 2020)	Two types of gridded temperature data, averaged over 30 years centred on 2050, in two file formats, which can be read as maps, one climate model, one emission pathway Daily time-series for maximum temperature (30 years centred on 2050) (selected locations), one climate model, one emission pathway Future fire weather summary projections (selected locations)	Ease of use of different formats (preferences) Preference for different data visualisations Sector use cases for temperature data Training needs
Test cycle 2 (December 2020–January 2021)	Gridded monthly/seasonal/annual-average maximum temperature data for a number of future scenarios Gridded probability of exceeding extreme temperature thresholds Time-series for 13 climate variables over 30-minute intervals at specific locations Time-series of the Forest Fire Danger Index (FFDI) derived from four climate variables	Utility of data provided Accessibility of more complex formats (and much larger files) Preferences for visualising averages, uncertainty, variability, extremes Locations for point-based information (e.g. time-series) Standardised approach to choosing data for the sector Training needs
Test cycle 3 (March–April 2021)	Annual Recurrence Interval maps for • Temperature • Precipitation • Fire weather Time-series at 168 ESCI locations[8] (HRS stations for streamflow) Guidance on using other non-standard data sets in risk assessments Climate projections in netCDF format at 30 minute resolution for use in supply and demand modelling	Accessibility of data from the ESCI web portal Utility of the recommended data sets Useability of the data formats Level and usefulness of the guidance material

8 ESCI locations were identified early in the project as sites which cover major transmission lines, all renewable energy zones and major traditional supply sites and major demand centres. Additional sites can be derived from the netDCF data files.

The data test cycles guided the recommendation of data sets for the sector and the design of the guidance material (see section 4). Each data test cycle was shaped by feedback from the previous cycle, and key lessons included:

- Initial data releases did not hit the mark in terms of complexity of information and format of data—the project provided too much climate information and the data was in a format (netCDF files, coded variable names) which was unfamiliar to the sector and which clients generally found hard to use
- The most useful climate information was the maps of extreme temperature followed by the time-series at points of interest
- The sector is highly quantitative but sector users do not want to learn climate science; they want the climate information in a format that integrates easily with their modelling
- Sector representatives trust the climate scientists; they just wanted to know what data to use, not how to select from 40 different data sets
    - Most sector users wanted clear guidance on a small number of data sets that will address most questions and will help them to assess their climate risk
    - Data standardisation is critical in a regulated sector where the same data sets must be used to compare asset risk, mitigation options and impacts system-wide
- Guidance was too technical—it needed to be simplified, tailored to the sector (sector examples) and be quick to access (i.e. not a long document)

3. Climate information approach

Physical risk is defined by the Intergovernmental Panel on Climate Change (IPCC) as the combination of hazards, exposure and vulnerability.[9] The NEM covers a large geographical area which reaches from Queensland to Tasmania and through South Australia, and there are long interconnectors between population, industrial and other demand centres. Early consultation by the project with the sector supported the initial assessment of the Finkel Review that the NEM is widely exposed to extreme weather events, climate variability and climate change in the following ways:

1. Customer demand has long been highly responsive to weather
2. Changes in climate will occur over the lifetime of assets (~50 years)
3. Generation markets are transitioning away from thermal synchronous generators:
   i. Supply markets are also now highly responsive to weather
   ii. Loss of synchronous generation increases demands on forecasting and modelling
4. While electricity systems have always been built to withstand extreme weather, risk management processes may not be keeping up with the changes in weather extremes and interactions
5. New investments must consider location diversity, equipment design and ratings that are consistent with long term expectations

3.1 Key hazards for the electricity sector

In consultation with the sector, early in the project the team identified five high-priority hazards for the electricity sector, comprising four key climate variables as well as compound extreme events. These became the focus of the project outputs (Table 4).

9 OD Cardona, MK van Aalst, J Birkmann, et al. (2012). 'Determinants of risk: exposure and vulnerability' in Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (CB Field, V Barros, TF Stocker, et al. (eds)). A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 65–108 . https://www.ipcc.ch/site/assets/uploads/2018/03/SREX-Chap2_FINAL-1.pdf

Table 4 Changes in climate hazards that have an impact on the electricity system (with an indication of scientific confidence in the changes), and associated electricity sector vulnerabilities. (Source: ESCI Project Report on the first extreme event workshop, May 2019)

Changing climate hazard	Electricity system vulnerability
Rising temperatures Increases in average and extreme temperature (very high scientific confidence)	Reduces generator and network capacity, increases demand, may increase maintenance and replacement costs.
Increased frequency, severity and extent of bushfires Increase in extreme fire weather (medium–high confidence)	Threat to most assets, with a particularly high operational risk to transmission and distribution lines due to heat and smoke.
Extreme winds Decrease in number of high wind events and cyclone frequency, possible increase in severe Category 4–5 cyclones (low–medium confidence)	High winds reduce the capacity and threaten the integrity of transmission lines, making it an important consideration for network capacity assessments and design specifications. Wind generation is sensitive to a reduction in average wind-speed as well as to the frequency and magnitude of destructive gusts.
Increased variability or reduction in rainfall, dam inflows and flooding Decrease in winter/spring rainfall and increase in extreme rainfall events (medium confidence)	Reduces water available for hydro generation. Increases requirement for desalination and associated energy demand. Reduced soil moisture may increase damage from lightning and reduce thermal conductivity of underground power lines.
Compound extreme events Increase in frequency and magnitude (low confidence)	Extremes in multiple climate variables occurring simultaneously or in close sequence can cause substantial disruption. These events can be exacerbated by associated non-climatic factors such as infrastructure failure or staff fatigue.

Other climate hazards are of interest to parts of the sector; for example, coastal inundation is an issue for DNSPs with low-lying infrastructure and Queensland is concerned with tropical cyclones (TCs), however the project team did not focus on other hazards for a number of reasons:

- It did not present a systemic risk (e.g. coastal inundation)
- Climate science today cannot provide the quantitative climate information that the sector would use in risk assessments (e.g. TCs)

Good quality information on this hazard is already readily available (e.g. sea level rise, or for TCs and other hazards where trends cannot be confidently projected, good quality commentary is available through the National Environmental Sicnec Program (NESP) Hub).

The identification of the five key hazards has continued to be evaluated with the sector throughout the project and has remained robust. These informed the downscaling undertaken by the project and the development of the SMPL (WPC).

3.2 Filling data gaps for the sector

Early consultation with the sector indicated that it required climate information that preserved spatial and temporal correlations between weather variables as many assets are vulnerable to multiple hazards. Matching weather and climate data to AEMO planning tools (risk models) was considered to be the clearest path to achieving early outcomes on decision-making, but in the longer-term all parts of the sector needed to be able to integrate and use appropriate, credible and comparable data.

The most important gaps identified for the assessment of climate risk were:[10]

- A relative lack of high-resolution historical and national re-analysis data (hourly data at spatial and temporal scales that provide a coherent representation of extreme weather)
- Nationally consistent models at the spatial resolution needed to assess asset risk and load centre dependency (despite the availability of a wide range of dynamically and/or statistically downscaled climate projections for different parts of Australia)

Data at the resolution needed to integrate with demand and generation supply models—these use half-hour data across the year to capture multiple periods of system strain due to extremes (summer maximum, winter maximum, shoulder minimum)

- A suitably large suite or multi-model ensemble which captures low probability and high consequence weather sequences in the climate projections
- A lack of standardised methodologies for undertaking risk assessments across the sector
- Lack of a framework for mitigation planning for high-impact low-probability extreme compound weather events

The ESCI project team considered the strengths and weakness of existing data sets based on the Coupled Model Intercomparison Projects CMIP5 global climate models (GCMs) available from the Climate Change in Australia (CCiA) website and a decision was made to undertake additional downscaling.

The sector needs were met by applying regional climate models (RCMs) to eight CMIP5 GCMs that perform well over Australia and sample as much of the plausible range of projected change for all of Australia as possible[11] and one additional model (Access1.3). Because of the importance of the extremes of climate variable distributions (e.g. rare occurrences of high temperatures), and the need for calibrated data, downscaled data sets were made bias-free by applying a detailed calibration technique (Quantile Matching for Extremes (QME) (Dowdy 2020) (Table 5).

The RCMs have the potential to provide valuable regional-scale information on climate change. The three RCMs selected by the project are CCAM (Conformal Cubic Atmospheric Model) the Bureau of Meteorology Atmospheric high-resolution Regional Projections for Australia (BARPA) and the NSW and ACT Regional Climate Modelling project v1.5 (NARCliM).

10 Source: WPB vulnerability analysis and data inventory—based on a review of industry sources and the first scenario workshop.

11 https://www.climatechangeinaustralia.gov.au/en/obtain-data/application-ready-data/eight-climate-models-data/

Table 5: Available data sets for producing climate projections for ESCI using models drawn from the standard subset of CMIP5 GCMs suggested in CCiA (2015) Technical Report Box 9.2.[12] Resolutions, time periods and RCPs vary with the methods. Note: Delta-scaling is a statistical method to interpolating from GCM resolution to higher resolution.

Downscaling Method	CMIP 5 Model									Resolution		Time Period	RCP
	CNRM-CM5	ACCESS1.0	ACCESS1.3	CESM-CAM5	GFDL-ESM2M	HadGEM2-CC	CanESM2	MIROC5	NorESM1_M	Temporal	Spatial		
CMIP5 GCM	■	■		■	■	■	■	■	■	Daily and Monthly	200 km	2030, 2050, 2070, 2090	2.6/4.5/8.5
Delta-scaling	■	■		■	■	■	■	■	■	30 min	5 km	1980–2060	4.5 and 8.5
QME	■	■		■	■	■	■	■	■	Daily	5 km	1950–2099	4.5 and 8.5
ESCI CCAM-QME	■	■			■		■	■	■	30 min	12 km	1980–2100	4.5 and 8.5
BARPA-QME		■								30 min	12 km	1980–2060	8.5
NARCliM v1.5-QME			■				■			1 hour	50 km	1950–2100	4.5/8.5

This sophisticated set of techniques produces data sets that are as detailed and locally relevant as possible. In order to be confident in the results of this process, it was important to undertake a rigorous quality assurance process for the different data sets. This included:

1. Model evaluation of the current climate by NARCLIM, BARPA and CCAM
2. Description of the change signal from the RCMs and an explanation of the differences from the host models, especially for broad regions away from mountains and coasts
3. Representativeness of the change signal compared to the scientific assessment and the broader range of models, including
    i. averages of temperature, rainfall, wind, humidity and wind
    ii. changes to extreme statistics and phenomena

For climate model simulations, this process is also called model evaluation. Differences were identified and documented and considered to be scientifically credible; the results are published in the ESCI Technical Report on downscaling.

12 Also available at https://www.climatechangeinaustralia.gov.au/en/obtain-data/application-ready-data/eight-climate-models-data/

3.3 A recommended set of models for analysis

It can be time-consuming and complex to deal with data from many different models, and there was a clear message from the sector that it wanted guidance on a minimum set of data that could be used for risk assessment. This was addressed by considering the strengths and weaknesses of the data sets described above and the range of projected climate change in each, then recommending a subset of four models that sample key uncertainties and can be used in most risk assessments.[13] The minimum recommended data sets are listed in Table 6 and allow consistent and comparable analysis across the sector.

Table 6 ESCI project-recommended data sets. ESCI Guidance notes that best and worst cases are context-specific to the application and can be different for different regions of Australia. This default considers temperature and rainfall for most regions of Australia. Different downscaling and post-processing techniques give different results: other choices should be considered in addition wherever possible.

	Global Climate Model	Downscaling model	Northern Australia	Southern Australia	Eastern Australia	Inland (Rangelands)
1	GFDL-ESM2M	CCAM	Warm Dry	Warm Dry	Warm Dry	Hot Dry
2	CanESM2	NARCliM-j	Hot	Warm	Hot	Hot
3	ACCESS1.0	BARPA	Mid case	Mid case	Mid case	Mid case
4	NorESM1-M	CCAM	Warm Wet	Mid case	Warm Wet	Warm Wet

Figure 7 shows how the four selected data sets compare with the full set of 40 CMIP5 GCMs. The four suggested models are noted by the number and general description from Table 6, and the analysis in Figure 7 can be used to pick a 'best case/mid case/worst case', depending on the variables of interest.

Figure 7 illustrates that no subset of models can sample the full range of future climate projections, so the project recommends that, wherever possible, a wider range of climate model outputs should be used.

13 The recommended data sets are a simplified approach for an assessment of the materiality of the climate risk. The four models were selected to give a representative range for temperature—a key hazard for the electricity sector—and to provide coherence for other variables such as wind and solar radiation. The ESCI guidance material notes that the recommended data sets do not span the range of projections for hydrological applications or for fire weather. For these variables, and for more sophisticated analyses, the project recommends using an ensemble of climate models and downscaling techniques. All data sets listed in Table 5 are available through the ESCI website.

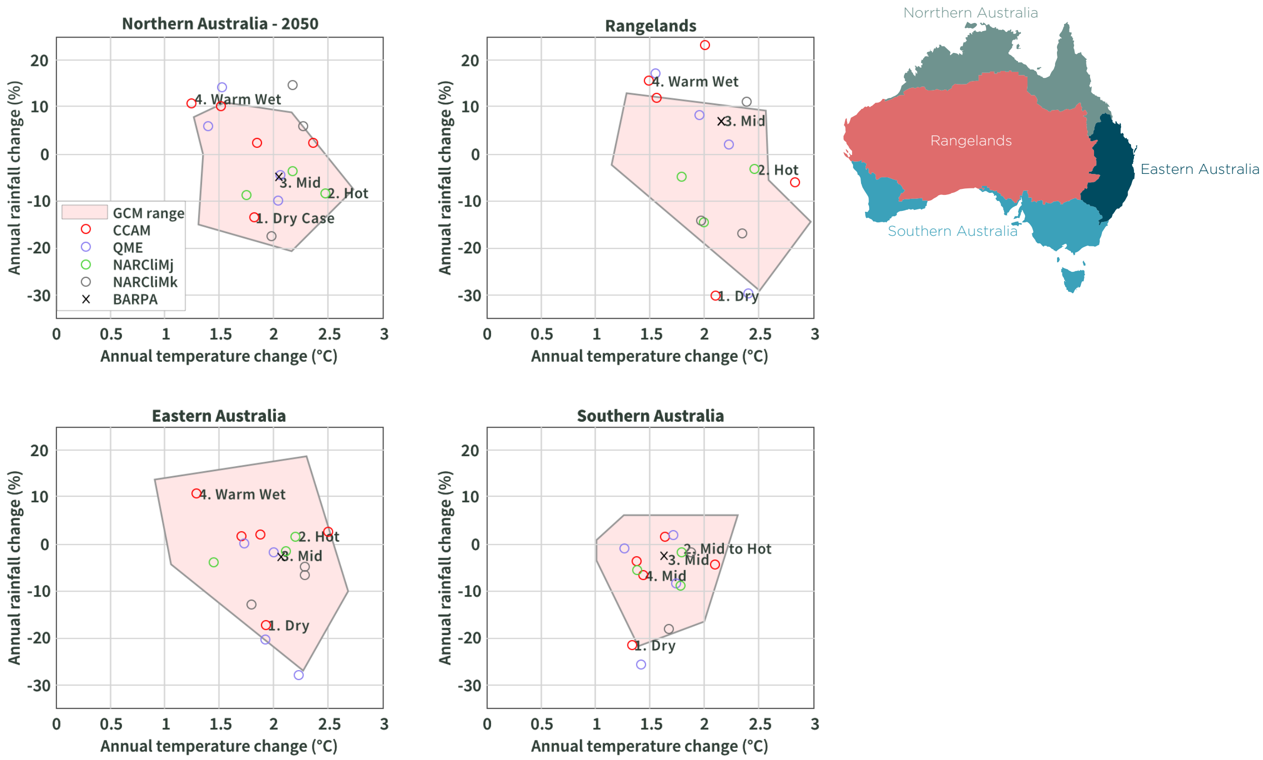

Figure 7 Projected change in annual temperature and rainfall between 1986–2005 and 2040–2059 under very high emissions pathway (RCP8.5) for four broad regions of Australia shown on the map. The polygon shows the range simulated by 40 GCMs in CMIP5 as reported in Climate Change in Australia, the markers show the 16 ESCI projections, differentiated by symbol. The four suggested models are noted by the number and general description from Table 6, the regions correspond to regions where the climate is expected to change in broadly similar ways—see small map below the charts for reference.

3.4 A standardised approach to assessing confidence in climate risk

The project was also required 'to develop and demonstrate a best practice methodology for analysing climate change risks (that can also be used by other sectors)'.

Projections for weather and climate extremes are challenging because the models have significant limitations in simulating the required physical processes. Consequently, the information required for electricity sector stakeholders is not as simple as just providing raw model output data. The team developed the SMPL, which built on earlier work by the ESCI team scientists, and compiled Lines of Evidence tables. The Lines of Evidence Tables provide evidence-based assessments of the likelihood and confidence in trends in the climate hazards, in support of the published climate information, based on physical process understanding, observations and model output.

The likelihood and confidence information will be used to inform climate risk assessment. For climate projections with low confidence (i.e. limited evidence and/or low agreement between lines of evidence) a qualitative best estimate could be appropriate. In some cases, the best estimate for future climate information might simply be 'an increase is more likely than a decrease' for a particular region. This is still valuable for sensitivity testing decision-making options. For projections with medium or high confidence, quantitative information is provided with a range of uncertainty and underlying assumptions.

More detailed information on the basis for understanding confidence and likelihood can be found in the ESCI Technical Report on the SMPL.

4. ESCI climate risk assessment framework

The ESCI contract required the development of a 'best practice' standardised climate risk assessment framework for identifying risks to critical NEM infrastructure and capacity based on an agreed international or Australian standard risk assessment methodology, customised to align with existing/proposed AEMO/NEM decision-making systems and procedures.

Risk assessment frameworks provide a consistent, structured and pragmatic approach to minimising harm and capturing opportunities. The ESCI project provides a credible, relevant, quality-assured framework to climate risk assessments for the electricity sector so that the impacts of climate change can be assessed and, where practicable, mitigated. This framework includes

- a five-step climate risk assessment method designed to integrate with organisational assessments of other risks, based on ISO 31000 and supported by a user guide
- a website with advice on selecting and using appropriate climate information with access to recommended data sets
- exemplar case studies to demonstrate how to use climate data in a risk assessment
- supporting information: technical reports, a glossary, key climatology concepts relevant to the electricity sectors, webinars and training materials

4.1 Integrating climate risk into sector decision-making

AEMO's ISP provides a roadmap for the NEM that aims to 'maximise net market benefits and delivery low-cost secure and reliable energy' while balancing the risks and costs of decision-making. External risks to the power system include:[14]

- Investment risk given technological evolution and economic development
- Federal and State policy choices
- Global security risk which may dampen demand for energy-intensive exports

Beyond the external risks, the industry must manage internal risks including:

- Rapidly changing community expectations and use
- Operational risks (maintaining system reliability and security)
- Under- or over-investment in assets, and return on investment
- Direct and indirect health and safety risk
- Internal cost of externalities—insurance, remediation, compliance and legal costs

An important design consideration for the ESCI Climate Risk Framework, therefore, was that the assessment of physical risk from climate risk could be easily integrated into existing sector risk assessment processes.

14 AEMO (2020). 2020 Integrated System Plan. https://aemo.com.au/en/energy-systems/major-publications/integrated-system-plan-isp/2020-integrated-system-plan-isp

4.2 The ESCI Climate Risk Assessment Framework

The ESCI Climate Risk Assessment Framework was developed through extensive co-design with the sector.

The contract provided a number of starting references: *ISO 31000 Risk Management*, the *Taskforce for Climate-related Financial Disclosure (TCFD)*, the APS *Climate Compass* model and CSIRO's *Climate Risk Information and Services Platform (CRISP*). The literature review also identified *ISO 14090 Adaptation to Climate Change* as a key standard; it forms the basis of other climate risk assessment frameworks such as *Climate Compass, NDRRF, CAPF, RAPTA* and the *US DOE Climate Resilience Planning Framework*.

The ESCI project initially proposed a climate risk framework based on ISO 14090 as it considers a system-level risk assessment and encourages iteration at frequencies consistent with planning processes or external changes. However, consultation with electricity sector stakeholders indicated that this was confusing; the sector simply wanted guidance on how to incorporate an assessment of climate risk into existing risk assessment and decision-making processes, many of which are guided by regulatory frameworks.

Further consultation indicated a preference for a simple methodology based on ISO 31000. This continued to be tested in the sector-led case studies and a final revision included varying from the naming of the ISO 31000 steps to make the framework more intuitive. Figure 8 shows the final version.

Figure 8 The ESCI Climate Risk Assessment Framework.

4.3 Recommended climate information products for the sector

To match sector decision-making needs, the project grouped climate information outputs into three categories identified through the data release cycles as priorities:

1. **Extreme thresholds for key climate variables** (Figure 9) which are important to generation and transmission. The project provides spatial visualisations (maps) of the 5-, 10-, and 20-year return period (i.e. the average recurrence interval (ARI)) at the highest available resolution (generally 12 km) for the key variables, using a broad ensemble of climate models, to indicate how extremes of these climate variables are likely to change with climate change. This is expected to meet most climate risk assessment needs, in particular to inform resilience assessments.
2. **Time-series of key climate variables with high temporal and spatial resolution** used to understand market opportunity and asset-level system reliability. These time-series can be derived from large, gridded (netCDF format) data sets made available through the project, but as this is not a format used by most sector stakeholders involved in the co-design process, 168 locations around the NEM were identified as important[15] and time-series for all variables were provided at these locations.[16]
3. **High-impact weather scenarios used to stress test system resilience**. Plausible extreme/compound weather scenarios based on global climate model projections and supported by expert understanding of the current climate and global warming, providing a representation of synoptic weather and extreme events. (This is covered in section 5.)

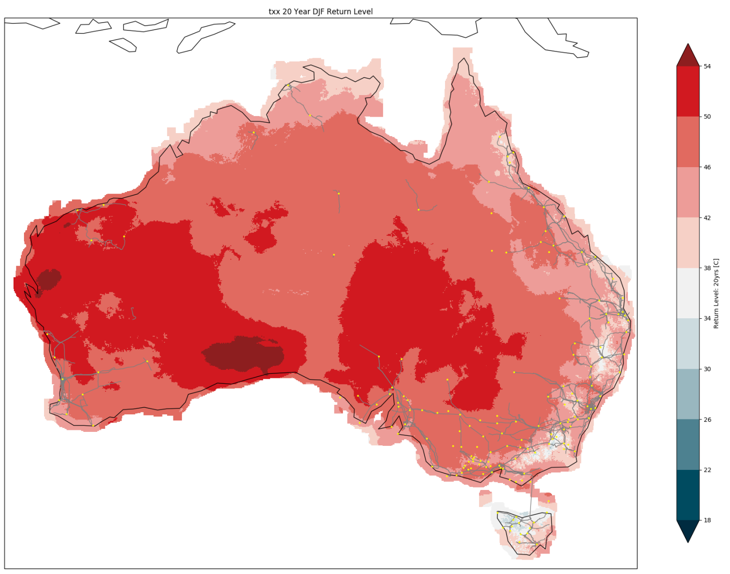

Figure 9 1-in-20 year (ARI) maximum summer temperatures for the CanESM2 model for the time period 2060–2079 and RCP8.5. Downloaded from the ESCI data portal. The highest temperature band (dark red) indicates 54 °C.

Appendix C provides a register of climate data assets delivered by the project.

15 These locations include supply locations including all Renewable Energy Zones (REZ), major demand centres, and major transmission lines.

16 The ARI maps and the recommended data sets include the key variables: max/min temp, Forest Fire Danger Index (FFDI), severe wind risk, rainfall and streamflow. Other variables of interest are available in the time-series; for example solar radiation, wind speed and direction at 150 m and 250 m, surface pressure and dewpoint.

4.4 Exploration of key hazards via major case studies

To demonstrate the application of the ESCI products, and to continue the co-design and co-evaluation process, exemplar case studies were developed by the project to achieve three main objectives:

1. To explore the use of new climate information and inform the work of the project
2. To support and inform the development of the guidance documents
3. To provide practical demonstration of the climate risk framework

The confidence, likelihood and resolution of the information produced for different climate hazards is very different so the project team decided to pursue separate case studies for each of the major hazards: extreme heat, bushfire risk, extreme winds, and compound extreme events. The case studies were structured around the ESCI Climate Risk Assessment Framework. The case study process included a risk assessment with a sector partner and then a series of interviews with individuals from relevant parts of the sector to explore whether the framework provided information of relevance to the sector.

Project-led exemplar case studies

- Impact of extreme heat on variable renewable energy
- Contribution of bushfire weather to choosing transmission line routes
- Severe convective wind risk to transmission lines
- Using case studies of compound extreme events for resilience decision-making

In addition, the team worked with members of the ERG to identify exemplar case studies that were based around decisions and hazards relevant to different parts of the sector. These sector-led case studies either used data that is currently available (on CCiA website) or used data that had already been developed and tested in the major case studies. These case studies tested the utility of the climate risk assessment framework and provided input to the design of the ESCI Climate Risk Framework User Guidance.

Sector-led case studies

- Use of quantile matching in predicting electricity demand
- Using extreme temperature projections to predict distribution line de-rating
- Soil moisture projections for use in planning lightning strike grounding and thermal buffering of underground lines
- Planning hydro generation using streamflow projections
- Planning for distributed energy resources using bushfire weather projections

Summary factsheets derived from the case studies illustrate what can be achieved by using the ESCI Climate Risk Assessment Framework and data and are a key part of the guidance for the sector.

Most of the case studies are documented in technical reports that walk through the climate risk assessment framework. This includes building a model of the quantitative relationship between weather and system or asset performance using historical data and selecting appropriate climate information for an analysis of future risk. Examples of risk mitigation were provided in industry interviews. These technical reports can be found on the ESCI website attached to the case studies.

4.5 Guidance products

ESCI project recommendations and guidance material, including the minimum recommended set of climate models, was extensively tested with the sector in the three data release cycles and using the case studies.

The materials accessible through the portal (Figure 10 and Appendix C) include:

- A data portal where the ESCI climate information and recommended data sets, are available as well as access to other useful data sets. The data selector page includes easily accessible advice on choosing appropriate data.
- Access to the ESCI User Guidance, which can be accessed as web pages and as downloadable PDFs.
- Short explanations of relevant climatology concepts, such as representative concentration pathways for greenhouse gas emissions, understanding climate uncertainty, scaling data to represent RCP2.6, and how the recommended data sets were derived.
- Exemplar case studies demonstrating how the Climate Risk Assessment Framework could be used in practice.
- Technical reports from the project including reports on downscaling validation, the SMPL and publications by project scientists in support of the project outputs.
- Support materials including a glossary and recorded webinars and informational videos.

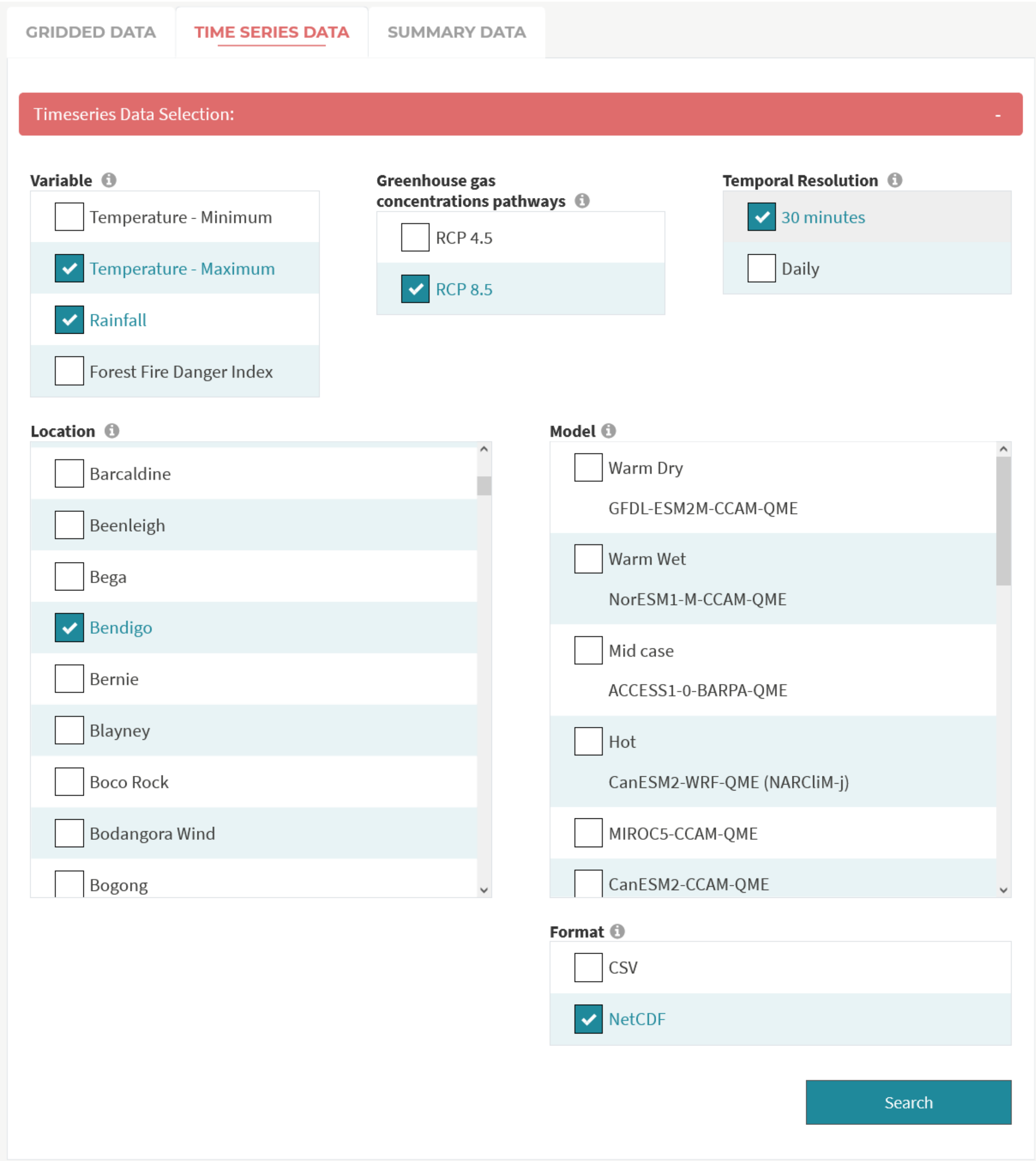

Figure 10 The ESCI climate data access page hosted on the CCiA website. The ESCI portal is designed to be stand-alone, with key concepts and support tailored to the electricity sector.

5. Scenarios for extreme and compound events

Extreme and compound weather events are a major concern to the electricity sector. The work of the ESCI project in this area (WPB) was to:

1. Establish the best climate information that can be provided on extreme and compound weather events that will threaten the electricity sector in the future.
2. Test whether the climate information provided by the project on extreme and compound weather events is in a form usable by the sector.
3. Conduct scenario exercises and industry focus groups to explore how these findings could inform the electricity sector's climate risk decision making.[17]

The project produced an initial compound event case study for use in the first ESCI Workshop in May 2019. This case study was derived from historic weather events with an incremental increase to take account of underlying climate drivers to reflect the expected influence of climate change. It was used to explore system vulnerabilities, which then informed the work of the rest of the project.

The workshop and subsequent engagement identified the need for quantitative case studies (extreme weather events presented as a data set of coincident weather variables), which include probability information. This information would be used by the sector to estimate the cost and consequence of extreme events as an input to investment planning decisions.

The ESCI team has demonstrated a methodology for identifying extreme and compound events in the climate projections and provided the sector with a quantitative case study of a compound weather event based on the weather 'signature' of 'Black Saturday' in February 2009. This case study was used in six sector focus groups to explore:

- how decisions to support system resilience in the face of extreme events are made;
- whether the information that can be provided by climatology can be used to inform these decisions; and
- what decision-making practices would need to change to use this information more effectively to support power system resilience.

The project found that current decision-making practices, guided by the Regulatory Investment Test for Transmission/Distribution (RIT-T/D) framework, work well for events which have a limited geographic extent and include probability information. For widespread events, and rare extreme or compound events, the lack of probability information means that the impact of these events cannot be considered in regulatory investment decision-making.

All sector focus groups, and international best practice, indicated that having a set of case studies of compound weather events for consistent use across the sector, provided by a credible authority would be desirable. Stress testing operational and planning decisions to increase system resilience, using these

17 The original project plan was to test the use of extreme and compound event information via workshops, however Covid-19 made it impossible to hold face-to-face workshops so the project team redesigned the work as a series of focus groups. Focus groups were conducted by discipline (e.g. policy analysts) or sector (e.g. finance industry). The details and outcomes are available in the ESCI Technical Report on compound event decision-making.

case studies, will need to be considered as part of electricity sector long-term planning. This set of case studies should be produced in collaboration with market bodies, and in further consultation with the sector.

The qualitative (narrative) and quantitative (extracted from the climate projections) compound weather case studies developed by the project are available through the project (the information on these cases studies is provided in the technical report *Making decisions using extreme/compound events*). These can already be used across the sector for stress testing, and could also be used to assess resilience of alternate investment options that may, in all other aspects, deliver similar benefits. The quantitative compound weather case study developed by the project, which provides a fully characterised compound extreme event of a multi-jurisdictional heatwave followed by catastrophic fire weather, was used by AEMO in the extreme event case study published in its 2020 Electricity Statement of Opportunities.[18]

Producing a suite of quantitative case studies from the climate projections is a very resource-intensive exercise. The innovative approach piloted by the project through the development of the ESCI case studies has demonstrated that it can be done, however this would require a very large ensemble of climate projections and significant scientific resources. A comprehensive suite of case studies which sample the full range of likely events and which test the full range of sector vulnerabilities, with estimates of the probability of *any* high-impact compound weather event occurring is beyond the resources of the ESCI project. This analysis is likely to be of broad benefit to other sectors, including emergency management, insurance and agriculture. The project recommends that future work address this information gap.

The ESCI exemplar case study on using compound weather case studies in decision-making and the full report from WPB can be found on the ESCI portal.

18 AEMO (2020). Electricity Statement of Opportunities. https://aemo.com.au/-/media/files/electricity/nem/planning_and_forecasting/nem_esoo/2020/2020-electricity-statement-of-opportunities.pdf?la=en&hash=85DC43733822F2B03B23518229C6F1B2

6. Project monitoring and evaluation

The evaluation activities of the project were informed by the project logic (Table 1) with the goal of monitoring whether the project is achieving the desired impact. Active internal monitoring and evaluation by the project allowed the project to correct course as required to meet stakeholders' needs (stakeholders in this case identified in Figure 6 as those in the 'involve, collaborate and consult' categories).

An independent evaluation of the project to monitor whether the project processes were on track and to assess how well the project was equipped to meet its objectives was commissioned by DISER and was undertaken by the National Climate Change Adaptation Research Facility (NCCARF). The internal monitoring and evaluation and the external evaluation processes were complementary, and the results of the evaluations have been provided in the project Monitoring and Evaluation Report.

6.1 NCCARF evaluation of the project

The NCCARF evaluation surveyed the Department of Environment and Energy Project Board in December 2019, conducted interviews with project team members on a quarterly basis, interviewed steering committee members, and conducted a broad survey of electricity sector stakeholders.

The baseline evaluation indicated that the project was well placed to succeed. The industry has a good level of awareness of climate change risks, with individual organisations already assessing climate risks and implementing adaptation plans. The greatest climate threats to the industry were seen to be changes in extreme events, bushfires, increasing heat and simultaneous or compound events. New climate information and decision support tools were being sought by the sector which, at that stage, had a low awareness of the CCiA website. NCCARF concluded that there was sufficient scope and resources available to the project to meet stakeholder needs and that the project's approach to meeting its objective was well-reasoned and likely to be effective. However, NCCARF evaluation suggested the need to draw on additional expertise for aspects of knowledge brokering and communication. The project team was also encouraged to expand its engagement with the sector beyond AEMO and to improve its governance, processes and administration arrangements to deliver future milestones on time. The NCCARF evaluation also identified challenges in maintaining cohesion across the Work Packages, and a clear need to ensure the project team was (largely) working towards the same goals.

In response to this feedback, a project coordinator was appointed to manage and maintain project cohesion and to coordinate the delivery of the milestones. The ESCI project team also established the ERG to improve engagement with the sector and it expanded plans to test the climate risk assessment framework through the Reference Group. The WPA team was also expanded to include additional knowledge brokers and user experience design expertise from the CSIRO specialist unit, Data61.

The project team continued to consult with NCCARF to steer the project towards a successful conclusion. At the time of this report NCCARF had not delivered its final project evaluation.

6.2 Internal monitoring and evaluation

Internal evaluation focused on monitoring stakeholder engagement by evaluating all stakeholder engagement activities (consistent with the complexity of the activity) for success/suitability from the stakeholders' perspectives. Evaluation objectives were to:

- Provide feedback loops to ensure that stakeholder response is shaping the output of the project to meet stakeholder needs, and that the kind of engagement is effective for the intended purpose.
- Provide evidence as to how well the project is addressing its objectives, realising expected outcomes and facilitating tangible path to impact.
- Formal evaluations of project activities. This process ensures adequate reflection and learning from activities so that the project team continuously improves the co-design and knowledge-brokering process.

The ongoing evaluation steered the development of the climate risk assessment method and the climate risk framework. A survey was conducted of electricity sector stakeholders in July 2020 to guide the outputs of the project. A detailed account of the internal monitoring and evaluation activities and outcomes can be found in the project Monitoring and Evaluation Report.

6.3 Delivery vs contract

In the 2018–2019 budget, the Commonwealth provided funding to address the Finkel Review recommendation 2.11 to develop a strategy to improve the integrity of energy infrastructure and the accuracy of supply and demand forecasting, in recognition of the increased severity of extreme weather. The ESCI project commenced in March 2019 with a budget of $5.85 million and the aim of providing improved climate and extreme weather information for the electricity sector. Table 7 provides a summary of the ESCI project objectives and outcomes, and how the project has delivered on those objectives. Despite the impact of COVID 19, the project was successfully completed in June 2021, within the contracted budget and project deadlines.

Table 7 Summary of delivery against project objectives and outcomes (from Project Logic)

	Objectives and outcomes	ESCI Project delivery
Interim outcomes	• AEMO uses tailored climate information in power and market modelling and includes output and commentary on long-term climate risk in ISP • Regulatory submissions (e.g. RIT-T) use long-term climate change information as part of investment proposals • Electricity generators, DNSPs and TNSPs use long-term climate change information in strategic planning and investment proposals	• AEMO is integrating climate information in its forecasting and major documents (see section 7.2) • The AER has been briefed on the project and is invited as an observer to the ERG. The project has recommended standardised climate information for use in risk assessments to allow comparison across the sector • The project has been invited to give executive-level briefings at AGL, TransGrid and Powerlink. Exemplar case studies are being used by ENA in training their members.
Objectives	• Support improved planning and investment decisions for the electricity network • Support decision-makers in the NEM to access and use tailored climate information to improve long-term climate risk • Develop and demonstrate a best practice methodology for analysing climate change risks • Contribute towards a longer-term vision for the next generation of climate projections and seamless climate and weather services • Improve information on likely future changes to extreme weather events such as heatwaves, wind and maximum temperature thresholds, to inform analysis of long-term climate risk. A particular focus should be on concurrent and/or compounding extreme events. • Raise awareness in the sector of the importance of climate change impact on the electricity sector	• Webinars and training are increasing capability. Guidance on the ESCI climate risk assessment method has been delivered and tested with the sector • Sector-led case studies support integration of climate risk into sector organisations and provide exemplars for other sector representatives • An integrated climate risk framework and climate risk assessment method based on ISO 31000 has been tested with the sector and published on the ESCI website • The ESCI downscaling and recommended data set has contributed to Australia-wide data sets. Lessons from ESCI are integrated into NESP 2.0 and the Australian Climate Service. • Improved climate information on key hazards has been developed and delivered. Decision-making on compound extreme events was explored and recommendations were made for further work. • The establishment of the ERG created champions for the work across the sector. Presentations at many levels, recorded webinars, collaboration with ENA on climate change education and a final newsletter to the sector is planned to raised awareness

The ESCI project will leave an enduring resource for the sector to assess climate risks and to plan for the future with greater confidence.

A detailed account of how the project delivered against the contractual obligations is given in Appendix D. The project Monitoring and Evaluation Report also provides further detail on how these outcomes were assessed, including quantitative measures (where applicable).

6.4 Delivering contracted milestones

Following the recommendations of the NCCARF evaluation in October 2019 and the experience of the team in submitting the first few milestone documents, the project governance structure was modified and a project leader was appointed. The project leader was responsible for coordinating the effort across the three Work Packages and ensuring the timely delivery of project milestones (Table 8).

Table 8 Project milestone completion

Milestone	Achieved	Due date	Details
Milestone 1	Delivered on time	31 March 2019	Communications and knowledge-brokering plan (CKB Plan). Project management update.
Milestone 2	Delivered on time	17 May 2019	Delivery of completed inventory work, first scenario exercise completed, plan for other scenario exercises. Update on modelling work.
Milestone 3	Delivered on time	18 October 2019	Implement CKB Plan, progress on case studies, standardised climate risk assessment framework and guidance. Progress on scenario exercises and downscaling.
Milestone 4	Delivered on time.	14 February 2020	Implement CKB Plan, progress on case studies, standardised climate risk assessment framework and guidance. Further scenario exercises completed, progress on downscaling.
Contract variation request	Agreed	February 2020	Impact of Covid-19 made it impossible to deliver final scenario exercise in person. Contract variation agreed to accept focus groups and report in lieu, delivery date extended to October 2020.
Milestone 5	Delivered on time.	15 May 2020	Implement CKB Plan, updates to CCiA website, draft of standardised methodology (SMPL).
Contract variation request	Declined	July 2020	Request for project extension because of impact of Covid-19 based on team member productivity and stakeholder engagement. Declined by Steering Committee.
Milestone 6	Delivered on time.	16 October 2020	Implement CKB Plan, progress on final case stud(ies), final draft of SMPL. Final report on WPB scenario exercises delivered.
Contract variation requested	Agreed	October 2020	Request to defer the submission of WPC's final report (incl. standardised methodology and its communication) and associated payment from February 2021 to May 2021 to allow for validation and peer review.

Milestone	Achieved	Due date	Details
Milestone 7	Delivered on time.	12 February 2021	Climate risk framework completed including case studies; draft of final project report; final report on SMPL; downscaling work completed.
Milestone 8	Reports delivered end of May	14 May 2021	This report, the final Communications report and the Final technical reports from WPC delivered end of May. Monitoring and Evaluation report and final update to CCiA (ESCI Portal) delivered mid-June.
Contract variation requested	Agreed, for delivery end of May	April 2020	Additional time requested on the delivery of ESCI portal to allow inclusion of feedback from the sector.

The project was ultimately completed within the June 2021 deadline, with the final outputs published about two weeks after the contracted delivery date.

7. Impact of the project

In December 2019 NCCARF surveyed industry stakeholders as input to the Baseline Report. They found that '[w]hile the sector is well versed in managing uncertainty and planning around a range of scenarios, there was a clear sense that they were looking for information to start the process of introducing climate change into decisions. Understanding climate impact assessment was seen as a new skill even if the data is available. There was some concern that long-term planning methods were not yet sufficiently matured, and this included a need to improve skills in developing scenarios for uncertainty.'

Conclusions from early stakeholder engagement were consistent with and expanded on the NCCARF findings. The project team made the following observations:

- There is a high level of interest in climate change as a threat to assets and operations. NSPs in particular are looking for credible data on climate trends in a form that can be included in their planning.
    - Moving from decisions based on history to decision-making for a very different future is profoundly challenging and requires retooling of models and decision frameworks
    - Climate risk assessments are not currently required by investors, insurers or regulators
    - The sector is interested in both trends for key variables—temperature, wind, rainfall—which affect reliability, and changes in the likelihood and magnitude of extremes (1-in-10/20-year events) which affect resilience. However, these two impacts are covered by different regulations, which complicates how the sector manages these risks.
- All parts of the sector remain concerned about extreme and compound weather events.
    - Extreme events, including coincident events such as multi-jurisdictional heatwaves, are likely to become more frequent

- Scenarios for resilience need to be co-designed with the sector as not all extreme/compound weather events translate into a high impact event for the sector
- The sector is highly quantitative, and most investment decisions rely on cost-benefit analysis. If probabilities can't be assigned to an event then the sector does not currently have decision-making frameworks that can accommodate this (particularly the regulated parts of the sector)

- Climate risk is just one of many potential shocks the sector faces so climate information and a climate risk assessment need to be structured *as inputs* to current industry risk models.
  - ESCI delivered time-series with 30-min resolution to match AEMO supply and demand models
  - ESCI risk assessment method follows ISO 31000 as that is the industry standard
  - Guidance includes integration with regulated investment cases
- There was concern among the T/DNSPs that it will be very hard to supply the level of quantitative certainty that the AER requires to approve investment for resilience. With this in mind an AER representative was invited to sit on the ERG. The project team also engaged with the AER to brief them on the project design and outputs and sector concerns, and to provide them with an opportunity to discuss the framework and climate information provided to the sector.

7.1 Impact of climate change on the grid

While the exemplar case studies conducted by the project were not intended to provide a comprehensive assessment of the sector's vulnerability to climate risk, they highlight the importance of considering climate change in NEM decision-making. Findings suggest that in planning time frames, multiple incremental power system changes guided by future climate information may enable the delivery of a more reliable and resilient network.

The importance of the case studies was demonstrated by the high level of engagement from the ERG. For example, TransGrid (Case study 2 below) took a narrow example of the impact of high temperatures on transmission lines and expanded it to cover its whole network, leading the work and engaging with a team across the organisation.

Three case studies illustrate the engagement and impact of the ESCI project for the sector:

1. AEMO worked with the project team to apply quantile matching to CCAM 30-min data sets for temperature to assess the impact of rising temperatures on demand. The forecasting team found that the impact was small but significant with about 2.5 per cent impact on maximum demand over the next 30 years. Climate trends have been integrated into AEMO ongoing forecasting
2. TransGrid worked with the project team to use temperature projections to assess the derating of its network over the next 30–50 years. They used scenario analysis to assess theoretical line de-rating on peak summer days under an RCP2.6, RCP4.5 and RCP8.5 scenario, finding that rising peak summer temperatures could result in theoretical line de-rating of up to 6 per cent.

3. The project team led a case study to assess the risk of severe convective winds on the transmission network with AusNet Services in Victoria. Severe convective winds have caused major electricity system events in recent years and is the most common cause of transmission tower failures. The project took this insight to compare a new severe convective wind diagnostic with historical tower failures. A high degree of correlation was found, demonstrating the value of the new diagnostic for risk assessment.

7.2 AEMO integration with forecasting and major documents

A primary channel for supporting improved planning and investment decisions for the electricity network is to integrate climate information into AEMO's key planning documents for the sector: the Integrated System Plan (ISP) and the Electricity Statement of Opportunities (ESOO).

AEMO forecasting is improving its quantification of climate risks in integrated market modelling. One of the challenges of this work is to transition supply and demand forecasting models from being based on 10 historical years, to using inputs that include a climate change signal. An additional challenge is to move from modelling inputs designed around observation stations to using the additional information available in gridded data.

The AEMO December 2020 Review of the 2019 Demand, Supply and Reliability Forecasts (the 'accuracy report', Chapter 8)6 includes five ways in which AEMO is improving forecasting as a result of the ESCI project:

1. including climate trends in demand modelling
2. an improved wind generation model—section 8.2.4 in the AEMO Review (using the relationship between wind power output and weather variables developed as part of the ESCI heat case study)
3. solar power supply modelling that takes temperature and temperature trends into account
4. including temperature impacts in line rating models—section 8.2.5 in the AEMO Review (Inter-regional transmission element forced outage rate model—this is implementing the lessons from the bushfire and wind case studies);
5. compound extreme weather case studies (this is documented in the ESCI extreme event case study).

These improvements are currently out to consultation, but AEMO expect these to be fully implemented by the 2021 ESOO.

The sector will be encouraged to consider climate change through the scenarios proposed in the 2021–22 Inputs, Assumptions and Scenarios Report.[19] 'These scenarios take into consideration the major sectoral uncertainties affecting the costs, benefits and need for investment in the NEM';[20] each scenario is associated with an RCP and an SSP (Shared Socioeconomic Pathways).[21]

19 AEMO (2019). 2019–20 Scenarios, inputs, assumptions. https://aemo.com.au/en/energy-systems/major-publications/integrated-system-plan-isp/2022-integrated-system-plan-isp/current-inputs-assumptions-and-scenarios%20

20 AEMO (2020). Current Inputs, Assumptions and Scenarios. https://aemo.com.au/en/energy-systems/major-publications/integrated-system-plan-isp/2022-integrated-system-plan-isp/current-inputs-assumptions-and-scenarios p.4

21 IPCC Data Distribution Centre. Definition of Terms Used Within the DDC Pages. https://www.ipcc-data.org/guidelines/pages/glossary/glossary_s.html

In order to support this ongoing work, Appendix 8 of the AEMO 2020 ISP is a new standalone reference for climate change impacts, and includes climate change resilience analysis and evaluation in its target actions to enhance energy system resilience (see Table 9).

Table 9 AEMO actions to enhance system resilience, including resilience in the context of climate change. (This is an extract from Table 12 from AEMO 2020 ISP Appendix 8: Resilience and Climate Change, July 2020)

Category	Description	Target date
Risk analysis and evaluation	Incorporate a broader selection of climate change trends in modelling input. In doing so, economic market benefits, reliability, and operability assessments will capture a broader suite of climate risks when the system is operating under mostly normal conditions. Improvements include: Updated wind generation model to better capture high wind and temperature cut outs. Updated thermal generation model to improve the capture of high-temperature effects as temperatures rise. Updated line rating and failure model to improve the capture of transmission performance and outcomes in a changing climate.	2022 ISP
Risk analysis and evaluation	Explore a range of extreme weather and energy system case studies to stress test the system beyond normal operating conditions. Use this analysis to explore implications on energy system planning, optimal outcomes and system resilience. Differentiate between more and less resilient risk mitigation solutions and build an evidence base for additional changes to planning standards and risk management approaches.	ISP

7.3 Ongoing impact and engagement at the senior officer level

In order to encourage adoption of climate change risk analysis as best practice by the industry the ESCI team has worked towards:

- Senior-level endorsement by key stakeholders
- Broad awareness in the industry
- Ease of accessibility by the industry

To this end the team has supported a comprehensive multifaceted communications program that included:

- Presentations to senior executive and boards
- A series of webinars to the sector
- ESCI-led industry training on climate change risk—recorded to provide ongoing guidance
- Engagement with the AER to brief it on the ESCI project and the recommended climate data sets
- The ESCI website where the project's digital assets are available to the sector

The communications program is described in detail in the final project communications report.

8. Gaps and limitations of the project

Every project has areas which stakeholders or partners would like to have addressed but which are beyond the time or resources available. Some of these were explicitly beyond the scope of the project and some were identified during the project as gaps which should be addressed by the sector in the future

8.1 Out of scope

- A comprehensive vulnerability assessment of the national electricity market to climate change. While the case studies and stakeholder consultation provide some indication of how and where the infrastructure is vulnerable to climate change, the project made no assessment of the points of greatest vulnerability.
- Integrating long-term climate modelling data with short-term weather forecasts, that is, making the data suite more 'operational' for the sector. ESCI climate data is designed to inform long-term planning and strategic decisions—20–50 years. In some cases these data are relevant to operational decisions; for example, the findings on trends in bushfire weather and the occurrence of severe convective winds. This led to considerable interest in integrating the climate projections with weather forecasts as an ongoing service. However, this was out of scope for the project.
- Ongoing climate model refinement and maintenance. The climate data supplied by the project used CMIP5 climate models. CMIP6 climate models will provide an updated perspective on future climate but are not yet available at the conclusion of the project. There are no plans or resources for updating the project data outputs, however the current climate information based on existing models will remain relevant for some time.
- Providing support for the sector beyond June 2021 (e.g. developing a suite of additional maps and tables for bespoke locations or time periods). The ESCI project was in many ways a pilot project, raising the awareness and capability of the sector and providing climate data that would answer the most pressing questions facing the sector. The project recommends that sector representatives continue to consult with climate scientists for tailored and expert climate information, in particular when assessing climate risk for large projects or where the risk is significant. This ongoing support was not envisioned as part of the project.
- Trouble-shooting CCiA or data access on NCI. This is expected to be provided (within reason) by the partner agencies.

8.2 Key gaps

Stakeholders have suggested that more detailed information is needed on some hazards:

- Understanding bushfire risk, not just fire weather (may be met by the Australian Fire Danger Rating System (AFDRS) due for release in 2022).
- Further understanding of extreme wind risk, how it is changing with climate change (may be provided through further research by BOM scientists).
- Information on additional hazards, for example coastal inundation, lightning strike (may be available from the NESP).
- Compound and extreme events, both climate information and industry processes and practices (may be provided through the Australian Climate Service (ACS)).

Stakeholder engagement and knowledge-brokering is needed to continue to embed the use of climate information in sector practices:

- There has been limited engagement with energy generation and retail sectors.
- There has been limited reach into the sector beyond the ERG; more training and knowledge-brokering is needed to ensure usability and acceptance of climate information as part of a risk assessment.
- The support of the AER is needed for the use of climate information in investment decisions.

8.3 Lessons on providing 'climate as a service'

Lessons on specific parts of the project have been included in the sections above on the data release cycles (section 2.2) and on monitoring and evaluation (section 7). The ESCI project was intended to demonstrate the use of climate information by critical sectors, and as a pilot for this approach the work has offered some additional insights on providing 'climate information as a service':

- Co-development with the sector is critical to adoption, standardisation and identifying formats that work for the sector. Comfort with using the data takes time. Trust is important.
  - Guidance needs to be simple, tailored to the sector (sector examples) and quick to access (not a long document).
  - Initial data releases did not hit the mark in terms of complexity of information and format of data.
    - The sector wanted more guidance on the 'best' climate data to use, and to know that everyone was using roughly the same data, with variables and file names in plain English for ease of use.
    - Most wanted high resolution maps in jpg or png format, not gridded data in netCDF format which they found unfamiliar and hard to use.
    - Maps of changing hazards for resilience thinking, time-series of multiple variables for reliability assessments (very few engineering questions are single hazard, need e.g. temperature + wind or wind + solar).
  - Having a reference group was critical to ongoing development as we had a well-informed group whose contribution to co-design was increasingly specific.

- Sector representatives trust the climate scientists; they just want to know what data to use (not how to pick between 40 different data sets).
  - The sector does not want a choice of many different data sets; they want one or two that will address most questions and will help them to assess the materiality of the risk (ESCI recommends that for very high-value investments, and where climate risks are material, expert advice should be sought).
    - Want to be able to 'bracket' the future—low/mid/high projections.
    - Synthesised products (maps of where values will be exceeded) are very useful—wanted intervals into the future (we provided 20-year intervals).
    - Time-series of bias-corrected data are important so that they can compare with the way they already use data—for example, temperature de-rating calculations for power lines uses the 15 hottest days over the last 15 years.
  - Standardisation is important, particularly in a regulated sector. Using the same data sets means clients can compare asset risk, mitigation options and impacts system-wide. Calibration of projections data to remove bias, including for extremes, is useful for sector applications and also helps standardise data from different modelling approaches.
- Climate scientists tend not to think in terms of providing an end-to-end service.
  - There is a strong preference to upskill the sector in climate science so that clients are better informed about using a wide range of data. However, while the sector is highly quantitative, in the co-design process the sector representatives said that they do not want to learn climate science; instead they just want the climate information to integrate with their modelling systems. Creating a requirement that data users understand climate science in detail is a barrier to adoption of the use of credible climate information.
  - The biggest data gaps were in downscaling that matches sector business needs (e.g. 30-min resolution) and in providing probability information for compound events. This will change for every sector, so early articulation of business needs will be important to effective provision of climate information.
  - There is no standard approach to things like climate information formats, colour scales, historical baselines, or to choosing representative data sets, therefore tailoring climate information to users was very inefficient as these factors had to be developed.

9. Vision for the future

The ESCI project was initiated so that the electricity sector could assess the impacts of weather on a future energy system in a future climate. As a result of the ESCI project, climate risk—including risk related to future weather—can now be consistently integrated into sector planning and risk modelling using a standard process and guidance.

In addition, the project proponents were asked to deliver the project in a way that informed other sectors, and to provide a vision for the future. This section covers:

- A vision for how the work on ESCI will inform climate and extreme weather work in other sectors
- A vision for how to close the gaps described in section 8 above
- A vision for how to maintain and upgrade the climate data sets and materials available to the sector

9.1 Informing work in other sectors

The ESCI project has delivered nationally consistent, high-resolution climate projection data (5–12 km across the NEM, at sub-daily intervals, to 2100). It has also (in partnership with the sector) tailored guidance and insights to enable the electricity sector to assess climate risks and to plan for this future with greater confidence.

This work has informed the planning for the recently announced ACS which will help its customers to improve understanding of the threats posed by a changing climate and natural hazards, to limit the impacts now and in the future. Insight from the ESCI project has been used by the Department of Home Affairs, by DISER and in other ways by the four agencies that have come together to establish the ACS.

9.2 Closing the remaining gaps

Some of the gaps identified by the ESCI project require industry action and some relate to the development and provision of improved climate information.

Recommended industry actions include:

- Develop resilience metrics, risk tolerances and decision frameworks for using extreme event case studies to identify and prioritise investment for resilience.
- Additional knowledge brokering to support the integration of climate change information into sector decision-making. This could include ongoing training and additional presentations to boards and industry conferences. ENA has contracted the CSIRO to provide climate education workshops which start to address this gap for the networks.
- Further conversations with the AER about integrating climate information as a standard part of investment decisions.
- A systematic assessment of sector vulnerability to climate change and associated with this a reassessment of engineering standards to include the influence of climate change.
- Ongoing integration of advances in climate information into sector decision-making. This could include integrating new information into the ESCI portal on CCiA.
- Integration of electricity sector needs into larger projects, such as the new ACS.

The electricity sector would benefit from further work into some climate hazards:

- Ongoing work is needed into bushfire risk and severe wind risk and how this will change in the future;
- A process or service to produce extreme event case studies (this is likely to be provided by the ACS);
- Convective scale modelling (< 4 km) for key areas, such as demand and supply centres, and key variables, for example rainfall. This could provide better information on hazards such as thunderstorms and lightning.

9.3 Maintaining currency of materials for the sector

The ESCI project information is available through the CCiA website together with a series of case studies that illustrate how future weather scenarios can be used by the sector to assess exposure to climate risk. However, the materials have been generated at a point in time, and will not be updated beyond the end of the project.

Climate models are constantly being updated, as different modelling groups around the world incorporate higher spatial resolution, new physical processes and biogeochemical cycles. These modelling groups coordinate their updates around the schedule of the Intergovernmental Panel on Climate Change (IPCC) assessment reports.[22] These coordinated efforts are part of the CMIP. The 2013 IPCC Fifth Assessment Report featured climate models from CMIP5, used in the ESCI data sets, while the new state-of-the-art CMIP6 models are planned for the upcoming 2021 IPCC Sixth Assessment Report. The data sets generated from CMIP5 models will remain valid but the sector should be aware of, and access where possible, the additional information and updated science available through CMIP6 models.

In additional to new GCMs, the Sixth Assessment Report of the IPCC will feature new climate scenarios, or 'pathways' that examine how global society, demographics and economics might change over the next century. They are collectively known as the 'Shared Socioeconomic Pathways' (SSPs).[23] These differ from and are complementary to RCPs which describe different levels of greenhouse gases and the associated radiative forcing but which purposefully did not include socio-economic 'narratives'. RCPs are used in the ESCI guidance to describe future climate scenarios, but SSPs will increasingly be used to describe future climate pathways and are already used in AEMO ISP scenarios. These should be considered and combined with RCPs wherever possible.

Work on providing climate projections based on CMIP6 GCMs and SSPs is already happening in BOM, CSIRO and other climate science hubs, however this is not being tailored for the electricity sector in the way that the Commonwealth-funded ESCI project has done. Some of this work will be collected under the umbrella of 'NextGen' national climate projections; this is work being undertaken by the National Environmental Science Program (NESP 2.0) and will be shaped

22 Text in this paragraph is largely drawn from the CarbonBrief website. CarbonBrief (2019). 'CMIP6: The Next Generation of Climate Models Explained'. https://www.carbonbrief.org/cmip6-the-next-generation-of-climate-models-explained#:~:text=CMIP6%20represents%20a%20substantial%20expansion,that%20each%20model%20will%20run

23 CarbonBrief (2018). 'Explainer: How "Shared Socioeconomic Pathways" Explore future Climate Change'. https://www.carbonbrief.org/explainer-how-shared-socioeconomic-pathways-explore-future-climate-change

by how climate projections are used, by whom, and for what purpose.[24] This in turn has been influenced by the work and outputs of the ESCI project. Further iterations of the data for electricity-sector specific requirements will need to be funded. The sector is very diverse, with different ownership and funding models. Sector leaders such as AEMO, ENA and other members of ERG, in consultation with AER and DISER, should consider what funding models could enable this resource to be maintained for sector needs.

24 CSIRO (2018). Workshop Report: 'NextGen Climate Change Projections'. https://publications.csiro.au/rpr/download?pid=csiro:EP183014&dsid=DS2#:~:text=The%20NexGen%20of%20climate%20projections,high%2Dresolution%20modelling%20and%20downscaling

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Appendix A

A1 Steering Committee

Specific roles and responsibilities of the Steering Committee are:

- Approval of Work Package Plans and/or Business Cases for Work Packages
- Review of project milestones across all Work Packages, and making recommendations on the milestones to the [Commonwealth] delegate when requested
- Facilitating implementation of the Collaboration Principles including the interfaces arising between the Work Packages and collaborating parties
- In consultation with the Work Package Committee, identifying areas of risk in the Project and risk mitigation strategies
- Identifying issues or responding to issues raised by Collaborating Parties that may impact on this Deed and identifying and implementing proposed solutions
- Discussing the admission of new parties
- Reviewing publicity
- Participating in, and providing advice when requested, in relation to the dispute resolution procedure with the aim of resolving disputes
- Referring matters/issues to [the Commonwealth] for endorsement or further approval prior to taking further action
- Facilitating coordination of and engagement with, providing direction to, and considering feedback from, the ESCI Reference Group
- Providing detailed advice and recommendations for project implementation to [the Commonwealth]
- Engaging in operational management for the project, for example managing timelines of work
- Reporting on project implementation, including issues, risks, timeframes and deliverables
- Escalating issues to the [Commonwealth] delegate as required.

The current membership of the Steering Committee is:

Organisation	Representative
DISER	Martin Squire (Chair) Oliver Story Daniel Church (Contract Manager) Josh Peck (Secretariat)
BOM	Kate Vinot Judith Landsberg (ESCI Coordinator—observer) Andrew Dowdy (WPC observer) David Jones (WPB observer)
CSIRO	Richard Mattear Mandy Hopkins (WPA observer) Marcus Thatcher (WPC observer
AEMO	Nicola Falcon Ben Jones (observer)
DAWE (observer)	Anthony Swirepik Felix Bowman-Derrick
Home Affairs (observer)	Andrew Kiley Lib Clarke

A2 Work Package Committee

All ESCI Team managers and science leads and the DISER Contract Manager will meet in Work Package Committee once a month. Work Package Committee is the primary forum for cross-work package coordination and will be chaired by the Project Coordinator.

Specific roles and responsibilities of the Work Package Committee are:

- Operational management of the relevant Work Package Agreement/s, for example managing timelines of work and progress on deliverables
- Coordinating across all Work Packages where necessary to ensure smooth running and alignment of the Work Packages
- Implementation of the Collaboration Principles
- Identifying issues or responding to issues raised by participants and implementing proposed solutions
- Reporting to the Steering Committee as required, and where required escalating issues to the Steering Committee
- Providing strategic direction and decision-making capacity across all Work Packages
- Addressing items from the risk and issues database and recommending action/s
- Negotiating and tracking any contributions between participants
- Managing any proposed changes to the Agreement
- Ensuring service delivery implementation is maintained, monitored and reviewed on a regular basis.

Work Package Teams also meet on a regular basis to coordinate development and implementation of Work Package planning across all project partners, and to inform the functions of the Work Package Committee.

A3 ESCI Reference Group

The ESCI Reference Group (ERG) was a group of people, from across the electricity sector, who were familiar with the project, supported its goals and could provide ongoing feedback and advice. Twelve stakeholders from across the industry, from academics, to representatives of networks and generators, accepted an invitation to the ESCI Reference Group. In addition a representative from the Australian Electricity Regulator joined as an observer and Nicola Falcon from AEMO represented the Steering Committee.

The ESCI team is grateful for their contribution of a significant amount of their time, expertise and contacts into their companies over the course of the final year of the project.

Appendix B: Lessons from the ESCI project

These points are collected from different parts of the document for easy reference.

B1 The electricity sector and climate change

- There is a high level of interest in and anxiety about climate change as a threat to assets and operations. NSPs in particular are looking for credible data on climate trends in a form that can be included in their planning.
  - Moving from decisions based on history to decision-making for a very different future is profoundly challenging and requires re-tooling of models and decision frameworks.
  - Climate risk assessments are not currently required by investors, insurers or regulators.
  - The sector is interested in both trends for key variables—temperature, wind, rainfall—which will affect reliability, and changes in the likelihood and magnitude of extremes (1-in-10-/20-year events) which will affect resilience. These are covered by different regulations.
- All parts of the sector remain concerned about extreme and compound weather events.
  - Extreme events, including coincident events such as multi-jurisdictional heatwaves, are likely to become more frequent.
  - Scenarios for resilience need to be co-designed with the sector as an extreme/compound weather event does not necessarily translate into a high-impact event for the sector.
  - The sector is highly quantitative, and most investment decisions rely on cost–benefit analysis. If probabilities can't be assigned to an event then the sector does not currently have decision-making frameworks that can accommodate this (particularly the regulated parts of the sector).
- Climate risk is just one of many potential shocks the sector faces so climate information and a climate risk assessment needs to be structured *as an input* to current industry models.
  - ESCI delivered time-series with 30-min resolution to match AEMO supply and demand models.
  - ESCI risk assessment method follows ISO 31000 as that is industry standard.
  - Guidance includes integration with regulated investment cases.
- There was concern among the T/DNSPs that it will be very hard to supply the level of quantitative certainty that the AER requires to approve investment for resilience.

B2 Providing 'climate as a service'

- Co-development with the sector is critical to adoption, standardisation and identifying formats that work for the sector. Comfort with using the data takes time. Trust is important.
    - Guidance needs to be simple, tailored to the sector (sector examples) and quick to access (not a long document).
    - Initial data releases did not hit the mark in terms of complexity of information and format of data.
        - Sector wanted more guidance on the 'best' climate data to use, and to know that everyone was using roughly the same data, with variables and file names in plain English for ease of use.
        - Most wanted high resolution maps in jpg or png format, not gridded data in netCDF format which they found unfamiliar and hard to use.
        - Maps of changing hazards for resilience thinking, time-series of multiple variables for reliability assessments (very few engineering questions are single hazard, need e.g. temp + wind or wind + solar).
    - The Reference Group was critical to ongoing development as we had a well-informed group whose contribution was increasingly confident (and should have been set up earlier in the project).
- Sector representatives trust the climate scientists; they just want to know what data to use (not how to pick between 40 different data sets).
    - The sector does not want a choice of many different data sets; they want one or two that will address most questions and will help them to assess the materiality of the risk (ESCI recommends that for very high-value investments, and where climate risks are material, expert advice should be sought).
        - Want to be able to 'bracket' the future—low/mid/high projections
        - Synthesised products (maps of where values will be exceeded) are very useful – wanted intervals into the future (we provided 20-year intervals)
        - Time-series of bias-corrected data are important so that they can compare with the way they already use data—for example, temperature de-rating calculations for power lines uses the 15 hottest days over the last 15 years.
    - Standardisation is important, particularly in a regulated sector. Using the same data sets means clients can compare asset risk, mitigation options and impacts system-wide.

- Climate scientists tend not to think in terms of providing an end-to-end service.
  - There is a strong preference to upskill the sector in climate science so that they are better informed about using a wide range of data. However, the sector is highly quantitative but clients do not want to learn climate science, they just want the climate information to integrate with their modelling. Creating a requirement that data users understand climate science is a barrier to adoption of credible climate information.
  - Biggest data gaps were in downscaling that matches sector business needs (30-min resolution, bias correction on the extremes) and in providing probability information for compound events.
  - There is no standard approach to things like climate information formats, colour scales, historical baselines, or to choosing representative data sets, therefore tailoring climate information to users was very inefficient as these factors had to be developed.

Appendix C: ESCI asset register

Product	Description

Website pages:	• Landing page with interactive site map
	• About the ESCI project
	• Risk Assessment overview
	• Data portal with access to (see data listing below)
	  - Intensity and frequency maps
	  - Time-series
	  - Summary tables
	• ESCI User Guide (see below)
	• Case studies (see below)
	• ESCI Publications
	  - Project reports (see below)
	  - Academic publications
	• Learning and Support
	  - Key climatology concepts
	  - Glossary
	  - Climate training
	  - Webinars
	  - Slide pack for use within sector orgs

Climate risk assessment framework and user guide	The ESCI Climate Risk Assessment Framework is used as the organising structure for the User Guide which is in steps—available on the website and downloadable: • Step 1: Understand context • Step 2: Identify historical climate risk • Step 3: Analyse future climate risk • Step 4: Compare and prioritise climate risk • Step 5: Treat risk
Case studies	Four project-led case studies to test the use of hazard information: • Bushfire risk and transmission routes • Extreme heat and VRE • Severe winds and transmission risk • Compound events Five sector-led case studies to illustrate the use of the ESCI Climate Risk Framework • Bushfire risk and DER • Extreme heat and transmission lines • Trends in temperature and demand • Soil moisture and infrastructure • Streamflow and hydro

Product	Description
Project reports	• Decision-making using extreme/compound events • Workshop exploring system vulnerabilities to extreme weather event • Workshop on hydro-generation inflow forecasting • Downscaling technical report • Technical reports on the Standardised Methodology for Projections Likelihood • Project final report
Project data output	

Frequency and intensity maps
 	
Recommended climate data sets:
• GFDL-ESM2M-CCAM-QME
• CanESM2-NARCliM-j-QME
• ACCESS1.0-BARPA-QME
• NorESM1-M-CCAM-QME
	Format: png and netCDF
	• RCP4.5 and RCP8.5, annual and seasonal data
	• 2-, 5-, 10- and 20-year average recurrence interval (ARI)
	  - Tmin
	  - Tmax
	  - Rainfall
	  - FFDI
	  - Streamflow
	  - Soil moisture
	• Days over 35 °C, 40 °C, 45 °C
	• Days over 25, 50 FFDI
	• Climatology time slices:
	  - 1986–2005 (observed and model)
	  - 2020–2039
	  - 2040–2059
	  - 2060–2079
	Also
	  - Ensemble versions of frequency maps
	  - Severe convective wind risk maps (historical only)

Product	Description
Summary data available for four recommended climate data sets	By state, NRM cluster and nationally

Time-series
• Recommended data sets +
• NorESM1-M - CCAM
• CanESM2 - CCAM
• ACCESS 1.0 - CCAM
• GFDL-ESM2M - CCAM
• ACCESS 1.0 - BARPA
• ACCESS 1.0 - WRF (NARClim J v 1.5)
• CanESM2 - WRF (NARClim J v 1.5)
• ACCESS 1.3 - WRF (NARClim J v 1.5)
• ACCESS 1.0 - WRF (NARCliM K v 1.5)
• CanESM2 - WRF (NARCliMK v 1.5)
• ACCESS 1.3 - WRF (NARCliMK v 1.5)
	Format: .csv and netCDF
	• 168 'ESCI locations'
	• RCP4.5 and RCP8.5
	• Up to 13 variables
	• 1980–2100
	  - 30 min
	  - Hourly
	  - Daily
	  - Seasonal
	  - Annual
	(Note: not all timescales or variables available for all data sets)

Appendix D: Contract vs delivery detailed assessment

* Where specifically referenced, statistics are from a survey of 130 sector stakeholders, 52 surveys were returned (July 2020).

Contract	Sector needs*	ESCI Project output
WPA contract		
1.3.2 provide guidance on how to use the standardised methodology developed during this Work Package.	Standardised approach to choosing appropriate climate information and credible data sources Only 40 per cent say that they want a separate climate risk assessment framework (see note 2) as they have existing frameworks.	a. 'best practice' climate risk assessment method based on international standards 31000 and 14090. b. Recommended approach to identifying appropriate weather scenarios, climate information and data sets for their risk analysis (Climate Risk Assessment Framework).
1.5.2 the full range of communication and knowledge-brokering activities that will be required to achieve the objectives of the Project, including:	Engagement across all parts of the sector.	Prioritised engagement with AEMO and TNSPs involved and inform the rest of the sector as per the stakeholder engagement map in the C&KB plan (Figure 6).
(i) Development of guidance documents, tested through case studies with the AEMO, and then communicated with the broader electricity sector. (ii) Updates to the CCiA website to include a targeted user-friendly version of the tailored climate information and guidance developed and/or updated during the course of this Work Package. The updates should be co-produced with key stakeholders and, wherever possible, should be progressively managed and released over the life of the Work Package, so that information is made available on the website as it is developed.	64 per cent of survey respondents view guidance as useful or critical (note 3). Team identified four key case studies to test use of climate data and need for guidance. Sector partners contributed a further five exemplar case studies with the support of the project team.	Guidance output developed and tested through three data release cycles. All parts of sector engaged, not just AEMO. Lessons from case studies inform the climate risk assessment framework and the guidance. Tailored climate data are being made available through CCiA.

Contract	Sector needs*	ESCI Project output
(iv) Training for electricity sector stakeholders, on using the data sets or CCiA website.	The sector has asked for webinars (60 per cent), online learning (50 per cent) and single-day workshops for technical staff.	Four webinars presented, with good attendance, and recorded. Four hours of training were developed, delivered and recorded for future support.
(v) Collaboration with participants and advice in decision-making processes to provide operational data-use support, and test suitability of information and guidance.	The sector has not asked for advice in decision-making processes except for extreme and compound weather events.	Project team worked through five sector-led case studies which will be used as exemplars for sector climate risk assessment.
(vi) Tailored provision of long-term climate information (also known as 'knowledge-brokering'). This may include data, guidance, interpretation and facilitation activities.	ERG asked for early release of data for testing. This was delivered in November 2020 and followed by two further rounds of testing.	A suite of climate information products (synthesised from the data sets) has been through three rounds of testing and case studies and is to be made available on the ESCI web portal
(vii) Development of: tools (if required), and processes for monitoring and evaluating the impact of the delivered products and services.	n/a	All major processes (e.g. focus groups, project meetings, case studies) went through a formal evaluation process which was documented and saved on the project internal site. External monitoring and evaluation was also carried out by NCCARF three times during the project and UTS (at the end of the project)
1.5.3 Write easy-to-follow guidance that steps out the methodology developed in Work Package Agreement Part C Schedule 2 as a standardised best practice approach for analysing long-term physical climate risk in the electricity sector. (a) Co-produce the guidance with the Australian Energy Market Operator and DoEE (now DISER). (b) The guidance should be consistent with international best practice.	See 1.3.2	Same as 1.3.2 a. 'best practice' climate risk assessment method based on international standard b. Guidance written on recommended approach to identifying appropriate scenarios, climate information and data sets for their risk analysis (ESCI Climate Risk Assessment Framework)

Contract	Sector needs*	ESCI Project output
(c) The guidance should be phrased in a way that can be applied to other sectors.	Not applicable.	• Guidance based on international frameworks means it is applicable to other sectors. • Consultation with projects such as the Climate Measurements Standards Initiative (CMSI) ensures consistency. • Developing and recommending data sets specifically for the sector new in Australia and could be used by other sectors but would be likely to require consultation and tailoring.
(d) The guidance should include: 1.1 Identification of vulnerabilities. 1.2 Standardised methodologies for identifying and ranking climate risks for known infrastructure or system vulnerabilities. 1.3 Descriptions of what 'best practice' would look like in terms of complete data to facilitate projections and risk assessments.	Sector has primarily asked for help in identifying the best available climate information, tailored for the decision, and usable in their own internal processes. CMSI recommends freezing the exposure and vulnerability 'as of today' before they use technology.	• Project did not include a comprehensive vulnerability assessment, but initial vulnerability inventory remained robust throughout the project and guided case studies. • Step 3 of the guidance describes best practice in identifying climate data and recommends data sets tailored to sector needs • Step 4 of the guidance steps through prioritizing climate risk in the context of other risks.
e) The guidance should include a climate risk framework and be based on and leverage off existing work such as Climate Compass, CRISP, and other relevant work where appropriate.	Only 40 per cent say that they want a climate risk assessment framework as they will use their own internal frameworks and methods for risk assessment.	See 1.3.2 a) The project is providing a 'best practice' climate risk assessment method based on international standards 31000 and 14090. This has been informed by CRISP and Climate Compass and many other frameworks (see section 3.4).

Contract		Sector needs*	ESCI Project output
WPB Contract			
1.2.3	Develop a vulnerability inventory for the National Electricity Market.	n/a	Delivered in Milestone 2 in May 2019.
1.2.4	Develop an inventory of existing science-based data and information products that could be used to meet the electricity sector's needs. Analyse the inventory, and draw on insights from other activities, to provide advice to the Steering Committee on how existing data can inform decision-making, and where the gaps and major limitations are.		
1.2.5	(a) i) Focus on how extreme weather and climate information is currently used in AEMO's longer-term decisions about where to place the infrastructure needed to support the network, as detailed in Integrated System Plan groups 1, 2 and 3.	30 time-series of temperature and other key variables into the future.	Gridded data developed and produced in consultation with AEMO for use in forecasting. Extreme/compound weather case study example developed and used to test decision-making processes.
1.2.5	(a) iv) Provide input and suggestions for whether and how AEMO's current approaches/methods/ practices could be improved, within scope of the Work Packages.	Conversion of nine historical weather years—repeated into the future—to projections.	168 locations identified to match current forecasting locations (and other key locations) and time-series produced and used in the 2020 ISP.
1.2.6	1.2.6 Provide a short report to AEMO and DoEE (now DISER) on potential improvements to the electricity sector's long-term climate risk decision making using existing science (if any).		Delivered in Milestone 1, March 2019.
1.2.7	Develop and run a targeted scenario exercise ('war gaming' style) that is based on one or more critical location(s) for new interconnections for infrastructure development and/ or REZs.	69 per cent of survey respondents want information on extreme weather events. This is consistent with widespread concern about extreme and compound weather events.	Qualitative (descriptive) scenario of future compound event delivered and tested in workshop 1, May 2019. Hydro projections workshop delivered in July 2019. Because of Covid-19, final workshop was delivered as a series of focus groups and subsequent report.

Contract		Sector needs*	ESCI Project output
1.2.9	Develop and deliver up to four further targeted scenarios and/or case studies (as needed) to extend to further locations, and/or to include improved accuracy of climate information that may have been developed by tasks in Work Package Agreement Part C. Provide a report from these scenario exercises to the Australian Energy Market Operator and DoEE (now DISER), detailing how these findings could inform the electricity sector's climate risk decision-making.	Information on return period of **extreme** weather events (single variable, e.g. heatwaves, rainstorms). Standardised set of case studies of **compound** weather events.	Project has provided average recurrence interval maps for **extremes** for key variables (e.g. temperature). Delivered one further quantitative case study of a **compound** weather event. Conducted six focus groups to test the use of **compound** weather case studies in electricity sector decision-making. Concluded that the needs of the sector exceed the resources of the program—WPB report provides recommendations for further work.
WPC			
1.3.1	Development and delivery of a standardised methodology that demonstrates good practice for using available climate information to analyse climate change risks in the electricity sector. The methodology must be tested and repeatable. 1.1 The methodology should include how to identify and assess climate risk, consequence, likelihood, and timing. 1.2 ... The methodology should be co-produced with key stakeholders to ensure its usability and effectiveness.	See WPA 1.3.2 above: Sector wants standardised approach to choosing appropriate climate information and credible data sources (note 1).	a. Standardised methodology for assessing projections likelihood. b. Suite of tailored, downscaled data products, evaluated and validated c. A recommended approach to identifying appropriate scenarios, climate information and data sets for their risk analysis. All three of these outputs are new and innovative for the sector. The data outputs have been tested and co-produced with the sector in the case studies and data release cycles.

Contract		Sector needs*	ESCI Project output
1.5	If feasible, also consider how the methodology could be more broadly applicable, for example to other sectors, and ensure it is written in a way that could be easily utilised by other sectors. If possible, this methodology should seek to enable companies to assess and report climate risks consistent with the recommendations of the Taskforce on Climate-related Financial Disclosures.	n/a	The standardised methodology produced by the project is consistent with, and extends, the work of the CMSI which aligns with the TCFD. Output 1.3.1 a) above is broadly usable, b) can be used but may need to have the guidance material adapted by other sectors, c) is broadly usable but has not been tested with other sectors
1.3.2	Undertake targeted climate model downscaling of the key pieces of long-term climate information defined in Work Package Agreement Part B Schedule 2. The aim of this is to enhance existing information and make it usable to AEMO to help inform their long-term climate risk decision-making.	Asked for by the sector—both tailored, downscaled data sets and climate information products derived from them.	Provided for the whole sector, not just AEMO.
1.1	If possible within the constraints of the above specifications and Work Package resourcing, potential future changes to compound and/or concurrent extreme events should also be considered.	See WPB 1.2.8 above. Sector would like a full set of case studies of extreme events.	The needs of the sector exceed the resources of the program—WPB report provides recommendations for further work—the ESCI project can provide an approach to developing compound case studies but this needs to be done with broad consultation with AER and across the sector.
1.2	The communication of results of the downscaling should, if possible, be usable for other sectors and/or groups.	n/a	See 1.3.1 (v) above.
1.3	The downscaling activity should align with and, where possible, contribute towards plans for further development of climate projections in Australia, for example through the National Environmental Science Programme's Earth Systems and Climate Change Hub's Next Generation Projections Project.		Aligns with the work of NESP 2.0, NextGen projections and the Climate and Resilience Services Australia initiative.