ELECTRICITY SECTOR CLIMATE INFORMATION PROJECT

Draft Case Study

Heat Impacts on Variable Renewable Energy Generation Output

The Electricity Sector Climate Information Project is a collaboration between the Bureau of Meteorology, CSIRO and the Australian Energy Market Operator. The project goal is to improve the reliability and resilience of the National Electricity Market to the risks from long-term climate change and extreme weather.

MAY 2020

Australian Government
Department of the Environment and Energy

CSIRO

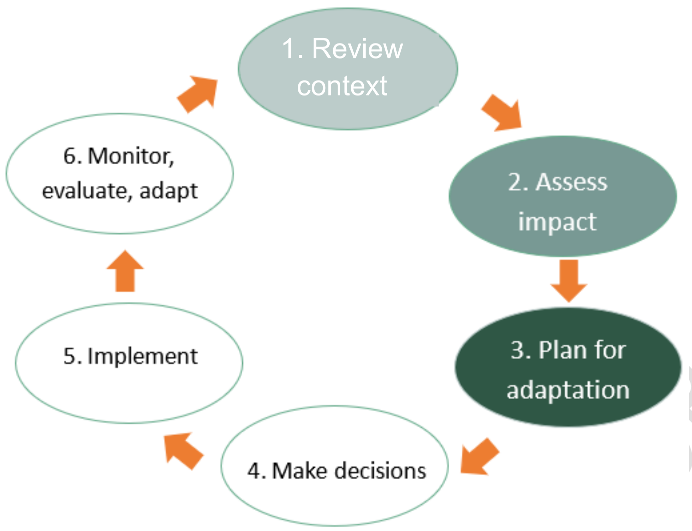
AEMO
AUSTRALIAN ENERGY MARKET OPERATOR

Australian Government
Bureau of Meteorology

Case Study Purpose: To demonstrate application of the climate risk management framework and guidance.

Variable renewable energy (VRE) generation sources like wind and solar are making an increasing contribution to the supply of energy in the National Electricity Market (NEM). Extreme heat routinely ranks as the highest climate vulnerability for both electrical and mechanical power system components. Extreme heat is a major driver of customer demand, and outages during high demand periods leave consumers vulnerable and incur large societal impacts. The purpose of the case study is to demonstrate the application of the ESCI risk framework by exploring the vulnerability of VRE generators to increases in extreme heat arising from projected climate change.

The ESCI risk framework is shown below and explores the first three steps in most detail



Review context
Identify vulnerabilities and exposure
Understand key decisions

Assess Impact
Use tailored climate information to quantify physical impact

Plan for adaptation
Generation adaptation pathways
Quantify and evaluate against objectives
Identify system changes needed

Review Context

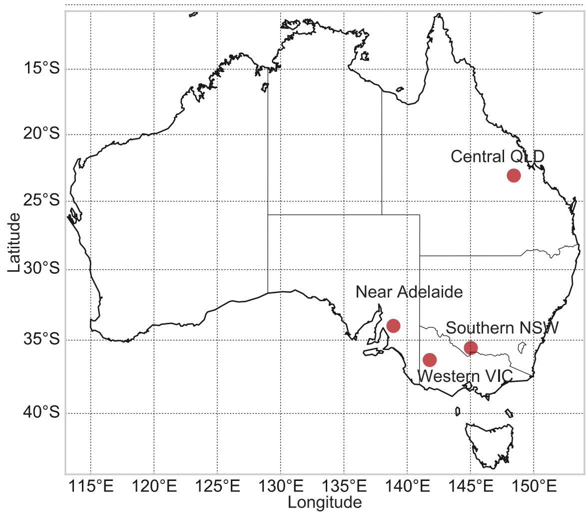
An early vulnerability scan was undertaken by the project, eliciting vulnerabilities from sector representatives in response to the projected trends in key climate variables. In the case of heat, climate models predict increases in average and extreme temperatures with a high level of agreement. Both wind farm and solar farm output is known to be impacted by temperature and may therefore be affected by climate change trends. Transmission networks are also known to be impacted by temperature, and may constrain generation output, however the case study scope is limited to generation impacts only.

Heat impacts on solar and wind farms present a risk to two kinds of decisions. These decisions both consider the impact during peak demand periods, which are typically driven by the customer response to high temperatures and are also associated with high wholesale energy prices.

> **Investment Risk** – If generator output declines against expectation, either on average, or during peak demand periods, owners and investors may receive less revenue than expected. If material, this may reduce the viability of new projects, or reduce the profitability of existing projects.
>
> **Reliability Risk** – If generator output declines against expectation during peak demand periods, the reliability of the system may be lower, possibly increasing the risk of unserved energy.

Assess Impact

This section steps through the process for assessing the impact of the investment and reliability risks identified. Four sites have been selected for demonstration across the NEM, where VRE generators are located, or are likely to be in the future based on the 2020 draft ISP forecasts.



The assessment assumes no changes to generator specifications over time. This process can be used multiple times to identify the change in risk pre to post mitigation, for example, should specifications change. For this case study only the untreated risk is calculated to asses materiality and identify possible mitigation options.

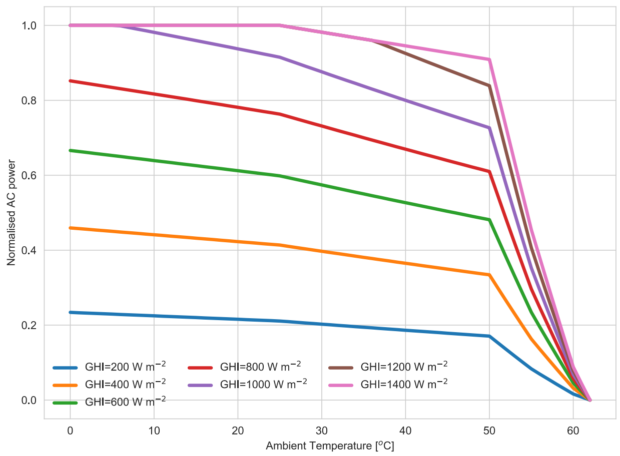
The assess impact section is further described in three steps: Establish the relationship, Projections, and Summary.

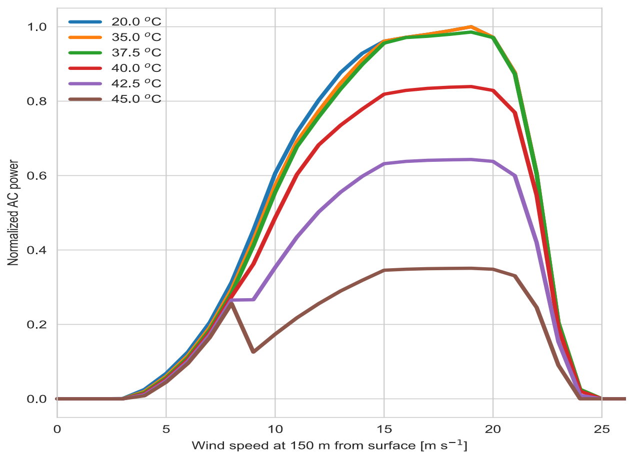
Establish the Relationship

A qualitative assessment may yield insight on the materiality of the risk, but a quantitative assessment is required to fully appreciate the multiple interactions between weather variables. To start, we need to understand the relationship between weather variables and power output.

A solar farm model[1] was selected that adequately describes the relationship between weather variables and generator output for typical installations at time of publication. Wind farm models are less widely available, probably due to the variation in performance between wind farms. For the purposes of this case study, a model was developed by AEMO using the observed performance of numerous operational wind farms.

The following two graphs depict the power conversion models developed for this case study. The solar farm model describes output as a function of Global Horizontal Irradiance (GHI), Direct Normal Irradiance (DNI, not shown on the graph), temperature, wind speed at 10m (not shown on the graph). The wind farm model describes output as a function of wind speed at 150m and temperature.



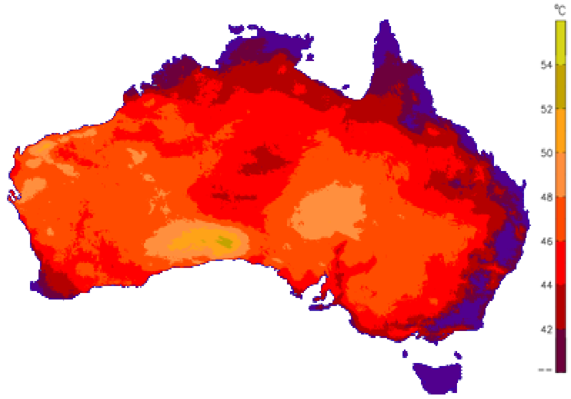


[1] Developed in the PVLIB (Holmgren et al., 2018) and PVWatts (Dobos, 2014) models assuming a single axis tracking installation using SMA Sunny Central 850CP XT inverter and a DC-to-AC ratio of 1.2.

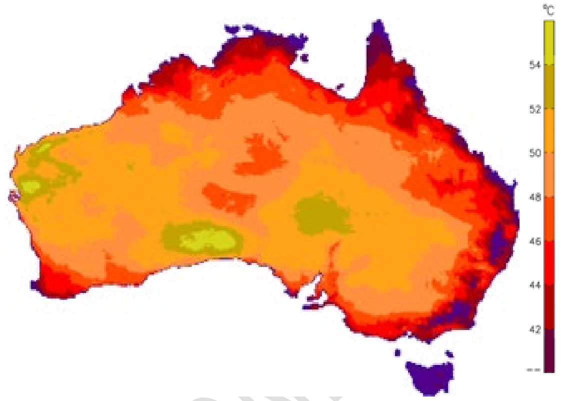
Projections (Simplified)

The project has developed maps and tables that demonstrate the projected change in a 10% probability of exceedance (POE) temperature. This temperature is expected to be exceeded one in every ten years. These maps can be used in combination with the power conversion models to identify the maximum projected change in generator output at the time of a 10%POE temperature.

10%POE temperature 1961-2020



10%POE temperature 2021-2080



	Near Adelaide	Western VIC	Southern NSW	Central QLD
1961-2020 Temperature (°C)	44	46	44	42
2021-2080 Temperature (°C)	48	48	48	44
1961-2020 Wind Farm Output	~40%	~15%	~40%	~65%
2021-2080 Wind Farm Output	~0%	~0%	~0%	~40%
1961-2020 Solar Farm Output	~76%	~74%	~76%	~78%
2021-2080 Solar Farm Output	~72%	~72%	~72%	~76%

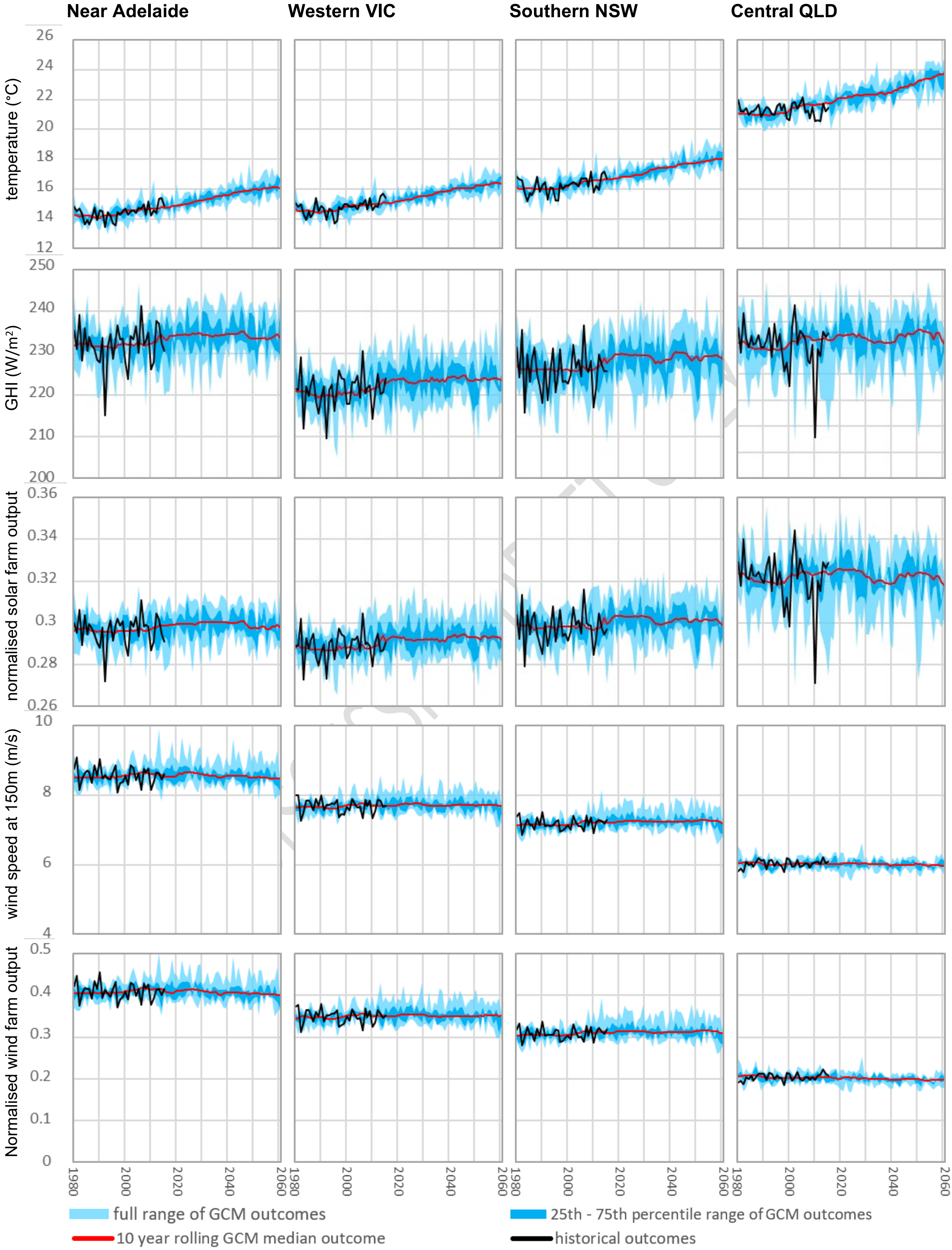
Thus, we can conclude that for a solar farm in Western Victoria which has a historic 10%POE temperature of 46 °C, this will increase to 48 °C in the next 60 years. Given the relationship between temperature and power output in the solar model described above (assuming GHI of 1000 W/m2) maximum output on a 10%POE temperature sunny day would drop from historic output of ~74% of capacity to ~72% in the future. For a wind farm in a similar location output would drop from ~15% to zero (assuming wind speed of 15 m/s).

Projections (Comprehensive)

Climate projections can also be made available in time series. Statistical or dynamic downscaling of global circulation models (GCMs), can provide simulations of 'future weather' at a higher spatial and temporal resolution than available in the GCMs. These simulations preserve the relationships between the weather variables over time. This case study uses 30-minute simulations of 'future weather' from CSIRO's CCAM model. By assessing generator output at high temporal resolution, the risks can be assessed at all time intervals identified as relevant for planning purposes, while preserving the projected interaction between weather variables.

Six GCMs are employed here to represent the plausible range of future climate pathways. CCAM timeseries data for each GCM, run under a high future greenhouse gas emission scenario (RCP8.5), was made available for the period 1980 – 2060. A historical series was also developed for comparison using CCAM downscaled ERA-Interim reanalysis. The following figure depicts the range of timeseries produced by the different GCMs for a range of input and output variables. The 30-minute weather input and generation output data are given as an annual mean.

Trends in key variables and generator output – ANNUAL MEAN

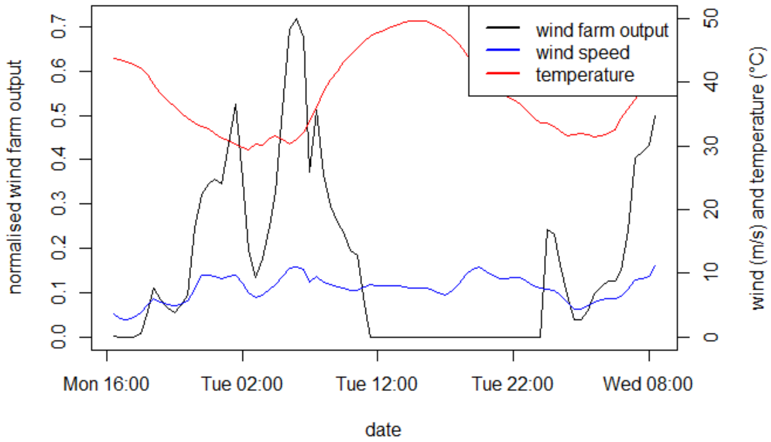


From these annual mean timeseries and underlying analyses we can note:

- Annual mean temperatures are predicted to increase in all regions with a high level of agreement amongst the GCMs.
- The annual mean levels of solar irradiance may increase slightly in the southern regions although there is not strong agreement amongst the GCMs. Solar resources are best in the South Australian and Queensland sites.
- Annual solar farm output predominantly follows the trends in solar irradiance, showing that possible increases in irradiance have a larger impact on annual output compared to temperature.
- Annual mean wind speed is predicted to remain steady with high levels of agreement amongst the GCMs. The South Australian and Victorian sites have the best wind resources.
- Annual wind farm output shows no trend in response to climate variables. The high level of agreement amongst the GCMs for temperature and wind speed results in a high level of agreement for stationary output over the prediction horizon.

To assess the impact on VRE output during peak demand, the 30-minute modelling was filtered to analyse the impacts. For this study, peak demand periods were defined as the top 5 hottest days per year between 12pm and 7pm AEST, a time period likely to capture the timing of daily maximum temperature and the timing of maximum electricity demand. The 30-minute weather input and VRE generation output is then summarised as a mean result for the peak demand study period (average of 70 thirty-minute market periods per year).

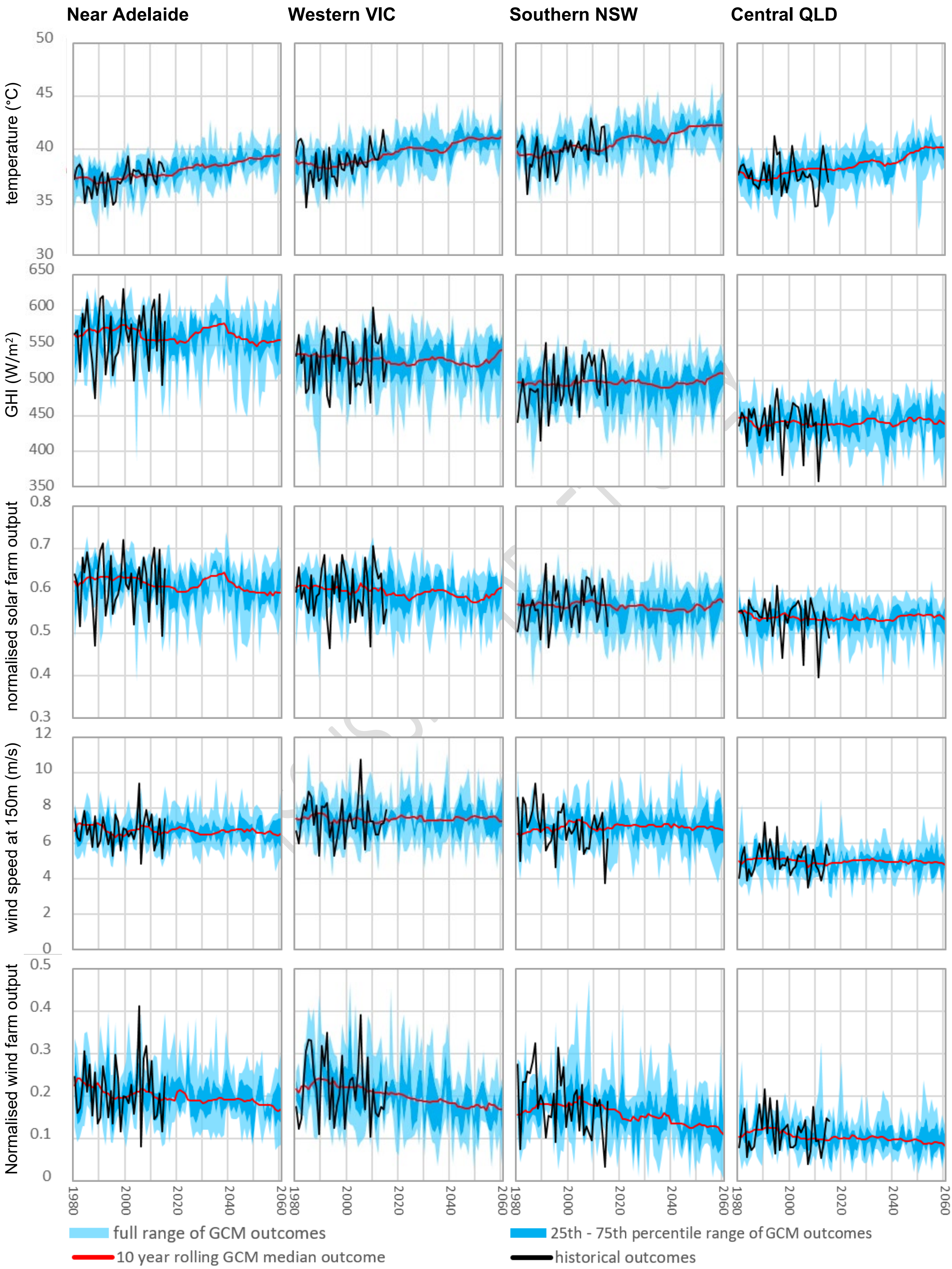
The graph to the right shows indicative wind farm output on one of the hottest days in the sample. On this simulated Tuesday, extreme temperatures cause the shutdown of wind farms, with restoration later in the evening. Mean output during the identified peak demand period is zero. Amongst the top five days, averaging of days with less extreme heat results in a non-zero mean output.



The following figure shows the peak period timeseries for input and output variables. Considering this analysis, we can note:

- Temperatures during peak demand periods are predicted to increase in all regions with a high level of agreement amongst the GCMs. Peak temperatures are higher in Victoria and New South Wales.
- The levels of solar irradiance during this period is higher than the annual average and there is disagreement amongst the GCMs about how this may change.
- Solar farm output during peak demand periods shows a slight downward trend
- Mean wind speed during peak demand periods are predicted to remain steady with expected year to year variability demonstrated by the GCMs.
- Wind farm output during peak demand periods shows a distinct downward trend in response to climate variables. While the GCMs show high levels of expected year to year variability, there is high levels of agreement regarding the trend, with steepest trends in the regions with the hottest maximum temperatures.

Trends in key variables and generator output – PEAK PERIOD MEAN



Impact summary

The simplified projections that assessed the change in output expected on a 1-in-10 year temperature day indicated that, during high temperatures, wind had the greatest potential for output reductions. Solar de-rating was limited in the temperature ranges estimated for the four NEM locations.

The comprehensive projections confirmed this finding, further concluding that long term solar output may increase in some locations due to possible increases in irradiance. It was also confirmed that, without changes to generator specifications, wind farm output during peak demand periods may fall, while average outputs would likely remain unchanged.

Adaptation Planning

Adaptation planning involves a second scan to identify possible risk mitigation options and adaptation pathways. These options should be assessed and evaluated against objectives to ascertain materiality. If helpful, the risk analysis step can be repeated assuming mitigation options have been implemented to help evaluate the risk reduction attributable to each mitigation option. In this case, several risk mitigation options have been identified; these include:

- Increasing the robustness of VRE specifications to heat (investment and reliability risks)
- Including on-site energy storage to support VRE output (reliability risk)
- Procuring additional dispatchable capacity, or demand side participation (reliability risk)
- Increasing transmission connections to better support regional energy transfers (reliability risk).

Investment Risk

To ascertain materiality, numerous VRE project developers were interviewed. These interviews largely validated the analysis and indicated that investment risks were likely immaterial under current market rules and conventions. For developers and owners, the heat impacts on projected revenue was deemed small relative to other revenue risks like price and marginal loss factor volatility. There may however be growing financial incentives to increase generator availability during peak demand periods for the purposes of the Retailer Reliability Obligation. Climate risks that result in the destruction of the asset or their insurability, like floods, fire and wind events, were perceived to be of more significance. In the case of solar developers, projected increases in solar irradiance may increase output.

Reliability Risk

Further interviews were conducted with AEMO and other industry representatives to ascertain the materiality on system reliability projections. Medium-term and long-term system reliability is considered in AEMO outputs including the ESOO and ISP. Year to year volatility in the combined peak demand contribution of VRE generators is well considered, however the uncaptured downward trend in this contribution is likely to result in an overestimation in the reliability of the electricity system on extremely hot days. In future periods where VRE generators collectively supply larger portions of total energy, this overestimation is material, particularly for wind. To address this risk, the identified mitigation options will need to be considered. Further work would be required to identify the lowest cost pathway, whether that be enhanced VRE specifications, or the procurement of additional capacity.

The identification of quantified lowest cost pathways can only be assessed using integrated power system and market modelling. Through the introduction of the Retailer Reliability Obligation, electricity retailers have an enhanced obligation for the contracting of available capacity during peak demand periods, should a reliability gap be identified. As such, retailers may benefit from a greater understanding of the cost of enhancing VRE specifications relative to the procurement of dispatchable capacity or demand side participation.

Confidence in the climate projections and sources of uncertainty

While there are a number of sources of uncertainty for future climate projections, including the potential impact of policy responses affecting future greenhouse gas (GHG) emissions, there is a high degree of confidence that, with increases in GHGs, temperatures will increase in future.

Levels of confidence in projections rely on consideration of multiple lines of evidence, drawn from understanding of the underlying physical processes that influence weather and climate. This project is undertaking careful assessment and presentation of these processes as they vary for different climate variables across the different regions in Australia.

Next Steps

The goal of the ESCI project is to provide frameworks and data to support risk analyses and decision making by electricity sector stakeholders. This case study provides a worked example of how this can be done but is not intended to provide recommendations for risk mitigation options. Four other case studies are expected to follow, including:

- The climate impact of bushfires on transmission line outage rates.
- The climate impact of wind gusts on transmission line failure rates.
- A study on the system reliability and resilience risks that arise from a multi-jurisdictional heatwave and high wind event identified in climate projections.
- The impact of reducing rainfall and increasing rainfall variability on the availability of hydro generation.

The data used to prepare this case study is an interim output of the ESCI project. Time series data for key renewable energy variables and sites, and maps of temperature exceedance probabilities over the NEM, will be provided to electricity sector stakeholders as part of the output of the ESCI project in mid-2021.

The ESCI team would like to thank the industry representatives that participated and contributed to this case study.

Acronyms

Acronym	Description
CCAM	**Conformal Cubic Atmospheric Model,** a global stretched grid model, that has been focused on Australia. CCAM has been used to downscale relevant GCMs to finer temporal and spatial resolution, outputting numerous variables of interest for power system modelling.
ESOO	**Electricity Statement of Opportunities**, AEMOs 10-year outlook of system supply adequacy.
GCM	**Global Circulation Model**, A three-dimensional global model that projects the atmospheric response to certain greenhouse gas concentrations.
GHG	**Greenhouse Gas,** A gas in the atmosphere that absorbs and emits radiant energy back towards the earth.
GHI	**Global Horizontal Irradiance,** the amount of solar irradiance falling on a surface horizontal to the surface of the earth. Measured in watts per square meter.
ISP	**Integrated System Plan**, a whole-of-system plan that provides an integrated roadmap for the development of the NEM.
NEM	**National Electricity Market**, the wholesale electricity market and physical power system that operates in NSW, ACT, QLD, SA, VIC and TAS.
RCP	**Representative Concentration Pathway**, a possible scenario of emissions that results in a certain atmospheric concentration of greenhouse gasses. This case study explores RCP8.5, which is a high emissions pathway.
VRE	**Variable Renewable Energy**, generators such as wind and solar.

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