RELIABILITY PANEL AEMC

REVIEW

Reliability Panel AEMC

Directions paper

Review of the form of the reliability standard and administered price cap

30 November 2023

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About the Reliability Panel

The Panel is a specialist body within the Australian Energy Market Commission (AEMC) and comprises industry and consumer representatives. It is responsible for monitoring, reviewing and reporting on reliability, security and safety on the national electricity system, and advising the AEMC in respect of such matters. The Panel's responsibilities are specified in section 38 of the National Electricity Law.

Acknowledgement of Country

The AEMC acknowledges and shows respect for the traditional custodians of the many different lands across Australia on which we all live and work. We pay respect to all Elders past and present and the continuing connection of Aboriginal and Torres Strait Islander peoples to Country. The AEMC office is located on the land traditionally owned by the Gadigal people of the Eora nation.

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Summary

1 The national electricity market (NEM) is undergoing a significant transition. The characteristics and behaviours of the new system need to be understood so that system reliability can be maintained at a level that consumers value.

2 During the previous Reliability Standard and Settings Review (RSSR) carried out in 2022, the Reliability Panel (Panel) found that the nature and characteristics of reliability risks may be changing towards the end of 2028 (i.e. the 2022 RSSR period). The Panel, therefore, recommended that a further review be carried out with more detailed analysis to consider whether the form of the standard was still fit-for-purpose for consumers and the power system while the system is in transition and beyond.

3 The Panel commenced this *Review of the form of the reliability standard and administered price cap* (Review) in March 2023. The purpose is to:

- better understand the characteristics of unserved energy (USE) and the nature of the risks as the power system transitions
- determine if the current form adequately reflects the changing reliability risk profile, or whether alternatives need to be considered.

4 The Panel is also reviewing the potential need for a new, more flexible form of the APC to ensure it remains fit-for-purpose in the long term for a range of scenarios.

5 The focus of this Review is on the form of the standard rather than its level and scope. To do this, this Review will be used to gain insights into the changing reliability risk as the NEM transitions.

6 This Directions Paper presents the key findings and insights gained from the Panel's work and seeks stakeholder feedback on the following:

- the results from the simulation modelling carried out to better understand the changing nature of the reliability risk and its implications for the form of the reliability standard
- the Panel's initial consideration of the value of customer reliability and any changes that may result from the different risks and reliability characteristics and the proposals for further investigations to gain further insights as the project proceeds
- shortlisted options for the form of the APC for further consideration in the next stage of the Review.

Key findings from the simulation modelling and analysis in this paper

7 Since the publication of the Issues Paper, the Panel has been modelling the potential changes to the characteristics of unserved energy as the NEM transitions. This model explores the changing conditions under which there is unserved energy.

8 Our approach was to take a model of the NEM based on the Australian Energy Market Operator's (AEMO's) Electricity Statement of Opportunities (ESOO) and Integrated System Plan (ISP) and to remove capacity in each financial year such that the model is more likely to produce unserved energy events. This deliberately under-resourced system model has materially less generation than is forecast in planning documents such as the ISP. This was done to create a larger data set from which to study the possible characteristics of unserved energy in the future.

9 The model used by the Australian Energy Market Commission (AEMC) contrasts with the ISP, which describes future market development that will maintain reliability, and the ESOO, which highlights opportunities given only known developments.

10 We emphasise that this work is not a forecast, but a simulation of a virtual future power system that is deliberately constructed to create insights about its unserved energy profile. It is an extreme scenario that was used for providing a more useful sample size for detailed analysis. It cannot be used to draw any conclusions about the reliability of the system in the future as this is not the purpose of the modelling and analysis presented.

11 The Panel's simulation modelling has generated four key insights regarding the changing characteristics of reliability as the system transitions. The information in this paper is provided for stakeholders' consideration and feedback on their implications on the form of the reliability standard.

12 Our findings demonstrate the continuing importance of the reliability framework in the future and that the changing nature of the system means we should consider if an alternative to current arrangements is needed. There will be a need for reliability settings that deliver the required mix of flexible capacity (including firm sources and short and long-duration storage) to manage variable renewable energy (VRE) resource availability periods driven by weather conditions.

If USE events do occur, they may be longer and/or deeper

13 Our modelling suggests that if they occur, individual unserved energy events may have the potential to be longer and deeper as the NEM transitions. However, an increase in the risk of large USE events does not mean an increase in the overall level of reliability risk in the power system. Rather the profile of the reliability risk changes so that any reliability shortfalls may be rarer but larger as the system transitions.

Unserved energy may shift from mainly being in summer to winter

14 The modelling results show a trend where USE events may shift from occurring predominantly in the summer to predominantly during the winter. This is consistent with the changing technology mix and dependence on combined resources that have the greatest likelihood of reduced output in the winter periods.

USE events may be driven increasingly by weather

15 The modelling indicates that as the NEM transitions, USE events may be increasingly driven primarily by weather patterns. Over time, the NEM's increased dependence on weather-dependent generation has a greater impact on the severity of unserved energy than do generator forced outages.

Events may spread across the day rather than just appearing in the evening peak

16 The modelled results indicate that the time of day during which USE occurs may also be shifting. USE events in the early years of the modelling horizon, when the level of VRE in the NEM is relatively low, occur almost exclusively during high demand periods that correspond with the evening peak between 5 pm and 9 pm.

17 As the levels of VRE in the NEM grow, and factors such as rooftop solar increasingly affect customer demand, the occurrence of USE may spread more widely across the day. While the evening peak, post sunset, remains the period with the highest proportion of USE, it is notable that USE becomes more apparent overnight and in the morning as the duration of USE events extends.

Understanding how customers value the changing nature of reliability is a key part of the Review

18 This Review is specifically considering the form of the reliability standard, and not the level to which it is set. Changing the form of the reliability standard needs to consider the fundamentals of the changing supply and demand conditions, the needs of the future power system with the value customers place on reliability and their preferences for the treatment of risk and uncertainty. If the characteristics of USE and the risk profile of reliability is changing then understanding how customers view and value this change will frame the need for a change in the form of the standard.

19 This work will be the foundation on which the form of the standard can be developed and tested. More importantly, it will provide the framework to establish the appropriate values for the standard and the market settings that deliver incentives to maintain reliability. It is important that work to understand customer perception be carried out in parallel to this Review to ensure that relevant information is available to inform this work.

20 There is currently a well-established method for understanding how customers value reliability that has been developed over the life of the NEM. The Australian Energy Regulator's (AER's) values of customer reliability (VCR) methodology is a central component that allows the AER to estimate, for each region, customers' willingness to pay to avoid an outage of a given duration (up to 12 hours), timing (season, day of the week and time of the day) and scale(localised or widespread). The methodology is periodically reviewed, and the VCR values are updated annually. Among other things, the VCR allows customer value to be attributed to the typical characteristics of reliability that have been evident in the power system to date. As the future energy system has different characteristics, and greater uncertainty, consumer preferences for risk will also be important to understand for this Review.

21 The Panel is working closely with the AER as it develops its approach for the upcoming 2024 VCR review. In our discussions with the AER, we have noted that it would be ideal if their approach could reflect the new information on unserved energy events from our modelling, by including additional questions in their survey.

There are several processes that need to come together before any new standard can be implemented

22 In this Review, the Panel may decide to recommend a change in the form of the reliability standard to reflect different types of reliability risk that may emerge as the NEM transitions. However, there are several processes that need to be completed to implement any recommendations. These work together to ensure that any new standards or settings reflect the value customers place on reliability.

1. The Panel is carrying out this Review to determine if the nature and extent of changes to reliability risks in the future warrants a change in the metrics of the reliability standard, and to test how well the existing form of the standard functions in relation to the behaviour of the new system as the NEM transitions. The Panel will make this recommendation by **mid-2024**.
2. At the same time, the AER has started preparing for the 2024 VCR review and will commence its survey work in early 2024. There is an opportunity for the AER to consider the key findings from this Review when examining the values consumers place on the range of outcomes they may experience as the NEM transitions. The Panel is working closely with the AER and the

AER has indicated that it may consider possible adjustments to its work based on our modelling results. The AER is required to complete its work by the **end of 2024**.

3. The Panel will need to submit a rule change request to the AEMC if it recommends any changes to the form. With the insights from the Panel's Review of the form and the AER's VCR work, the AEMC will be able to assess the costs and benefits of the proposed standard, and how customers may value the new reliability outcomes. The AEMC will then decide on the new form of the standard to be reflected in the National Electricity Rules (NER). This work would need to be completed in **early 2025**.
4. The AEMC would then task the Panel to carry out the 2026 Reliability Standard and Settings Review on the final form of the standard. As with the current standard, the Panel would seek to balance reliability against cost. The Panel can use the VCR and any insights from that work to recommend the level of the standard and settings. The RSSR project must be completed by **30 April 2026**.
5. The Panel would then submit a rule change to give effect to its recommendations. This would need to be completed by the end of 2026. Once finalised, the market will implement the new standard and settings, to commence on **1 July 2028**.

Submissions are due by Friday, 19 January 2024 with other engagement opportunities to follow

23 Stakeholder feedback on this Directions Paper will be instrumental in laying a strong foundation for the Panel's decision-making in the next stage of the Review. The Panel invites feedback from stakeholders in response to this Directions Paper by **19 January 2024**.

24 After the Directions Paper, the Panel will publish a Draft Report for the Review in **April 2024**. This report will set out the Panel's draft recommendations on this Review based on the findings and evidence outlined in this Directions Paper.

25 The terms of reference for this Review state that the Panel should provide its final advice in a report to the AEMC by February 2024. The AEMC has now granted an extension of the Review timeframe so that the Draft Report can be published in April 2024 and the Final Report in June 2024.

26 The extension was necessary to complete the modelling and analysis presented in this Directions Paper. The Panel intends to finalise this Review in June 2024 to allow sufficient time for the 2026 RSSR to consider any necessary changes to the form of the standard and APC.

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1 Introduction

1.1 The AEMC has tasked the Reliability Panel with reviewing the form of the reliability standard and administered price cap

In March 2023, the Australian Energy Market Commission (AEMC) issued terms of reference that requested that the Reliability Panel (Panel) provide advice on the form of the reliability standard.[1] This followed the Panel's 2022 Reliability Standard and Settings Review (RSSR) which recommended a review to consider changing the form of the reliability standard.[2]

The Panel considered it is necessary to review whether a simple expected value reliability standard is appropriate in the context of the energy transition. As the national electricity market (NEM) transitions, the reliability risk profile is changing.

The Panel considered that an alternative form of the reliability standard may be necessary to reflect the risk of large, but unlikely, events. A new form may better reflect the reliability risk profile in the future power system.

The Panel also identified that understanding the value of customer reliability in the changing energy system would be an important consideration for the form of the standard.

The terms of reference also requested that the Panel review the form of the administered price cap (APC). In the 2022 RSSR, the Panel identified the potential need to change the APC following the Australian Energy Market Operator's (AEMO's) market suspension and the administered pricing period (APP) in June 2022.[3] The Panel considered a range of options in the March 2023 Issues Paper.[4] It is continuing to assess these options based on stakeholder feedback.

1.2 The timeline for the Review has been extended to mid-2024

The terms of reference for this Review state that the Panel should provide its final advice in a report to the AEMC by January 2024.[5]

The AEMC has now granted a request by the Panel to extend this timeline so that the Draft Report can be published in April 2024 and the Final Report in June 2024. The extension was necessary to complete the detailed modelling and analysis presented in this Directions Paper.

The Panel intends to finalise this Review in June 2024 to allow sufficient time for the 2026 RSSR to consider any necessary changes to the form of the standard and APC.

1.3 The Panel conducted initial engagement on how to progress this Review

The Panel published an Issues Paper for the Review in March 2023.[6]The Issues Paper set out the scope and purpose of the Review. It identified several key concepts and issues that the Panel considered important in determining whether new a form of the standard is needed and sought stakeholders' feedback on these key issues for the Review.

1 AEMC Terms of Reference to the Reliability Panel, 'Reliability Panel review of the form of the reliability standard and APC', 2023.
2 Reliability Panel, '2022 Reliability Standard and Settings Review', final report, 2022, p. 44.
3 Reliability Panel, '2022 Reliability Standard and Settings Review', final report, 2022, pp. 97-98.
4 Reliability Panel, 'Review of the form of the reliability standard and APC', Issues Paper, 2023, pp. 38-39.
5 AEMC Terms of Reference to the Reliability Panel, 'Reliability Panel review of the form of the reliability standard and APC', March 2023, p.3.
6 Reliability Panel, 'Review of the form of the reliability standard and APC', Issues Paper, 2023.

- **Emerging tail risk |** In a reliability context, 'tail risk' refers to large unserved energy (USE) outcomes that have a low probability of occurring but could have a significant impact if they do happen. As the NEM transitions, current reliability risks may also change and may include a higher tail risk that may warrant changing the current form to reflect the changing reliability risk profile.
- **The trade-off between reliability and affordability |** Setting an efficient level of the standard requires balancing reliability and affordability for consumers — as increased reliability is associated with investment in new capacity and operating costs. Likewise, any new form of the standard should be selected with this trade-off in mind.
- **The value that customers place on reliability |** The Panel uses the value of customer reliability (VCR) to determine the level of the standard. Given that customers' views and valuing of emerging changes to reliability are yet to be tested, understanding this in the context of the changing reliability outcomes is a relevant consideration to assess the need for a new form of the standard.
- **The current form of the standard |** The existing reliability standard is risk neutral and only considers the magnitude of unserved energy, without any provision for timing, duration, or depth. A new form could place more weight on tail risk or reliability events of certain types if there is a need.
- **Factors changing reliability risk as the NEM transitions |** The NEM's transition may present a different and more diverse set of reliability risks, such as variability of supply and reserves, seasonal and weather-driven impacts on supply and demand, correlation between variable renewable energy (VRE) supply sources including rooftop photovoltaics (PV), and energy limits on storage and demand response.
- **Potential for weather risk |** Weather conditions will strongly influence energy production in the future NEM, and weather may become a more significant driver of reliability events. In particular, this may arise during dark doldrums where both wind and solar generation are low for several days at a time.

The Issues Paper noted the potential need for a new, more flexible form of the APC to ensure it remains fit for purpose in the long term for a range of scenarios. The paper requested stakeholders' feedback on possible options for the form of the APC. It also described the Panel's approach to assessing options for the form of the reliability standard and APC.

The Panel received 18 submissions and stakeholders provided input regarding the changing nature of reliability risk, whether this is a need to change the form, possible alternative forms, and the APC. Stakeholders who provided submissions were generally supportive of the Panel carrying out a review of reliability in the NEM, including modelling. A more detailed summary of stakeholder feedback is provided in chapter 2 of this paper.

1.4 The Panel seeks stakeholder feedback on key findings and insights to inform the Draft Report

Building on stakeholder feedback to the Issues Paper, the Panel has carried out further work to gather additional evidence and insights on the form of the reliability standard and the APC.

The key objective of this Directions Paper is to present the key findings and insights gained from the Panel's further work and seek stakeholder feedback. This will allow the Panel to develop its draft recommendations on the standard and APC.

Specifically, the Directions Paper seeks stakeholder feedback on the following:

- the results from the simulation modelling carried out to better understand the changing nature of the reliability outcomes and its implications for the form of the reliability standard
- the Panel's further consideration of the value of customer reliability and the implications for considering the form of the reliability standard under the current Review
- shortlisted options for the form of the APC for further consideration in the next stage of the Review.

Stakeholder feedback to this Directions Paper will be instrumental in laying a strong foundation for the Panel's decision-making in the next stage of the Review.

The Panel will publish a Draft Report for the Review in **April 2024**. This report will set out the Panel's draft recommendations, including whether a change to the form of the standard is required, and the preferred options for the new form. It will also include a draft recommendation for the form of the APC. The Draft Report will seek stakeholders' feedback on the draft recommendations.

The Panel expects to publish the Final Report in June 2024 and will submit any necessary rule changes to the AEMC. Following any rule changes, the 2026 RSSR will then consider the level of the standard and the implementation approach.

1.5 How to make a submission

The Panel invites feedback from stakeholders in response to this Directions Paper by **19 January 2024**.

Electronic submissions must be lodged online through the AEMC's website using the link entitled 'lodge a submission' and reference code 'REL0086'. Submissions will generally be published in full on the AEMC's website, subject to any claims of confidentiality. Our treatment of the content of your submission is further explained on that page.

The submission must be on letterhead (if submitted on behalf of an organisation), signed and dated. If choosing to make a submission by mail, the submission must be on letterhead (if submitted on behalf of an organisation), signed and dated, and posted to:

Reliability Panel

c/- Australian Energy Market Commission

PO Box A2449

SYDNEY SOUTH NSW 1235

2 The key issues for the Review and stakeholder feedback

In March 2023 the Panel released an Issues Paper outlining the key issues for this Review. The Panel received 18 stakeholder submissions and this chapter provides a summary of feedback on the key issues.

2.1 There is broad agreement that the NEM is transitioning

2.1.1 The issue

The Panel's Issues Paper identified that the NEM is undergoing a significant transformation. It is shifting from a centralised and predominantly thermal energy system to a more decentralised and complex one, characterised by high levels of VRE and storage.[7]

2.1.2 Stakeholder views

Stakeholders universally agreed with the Issues Paper's description of the NEM transitioning from a primarily capacity-limited thermal power system to a high-VRE, energy-limited power system to meet net zero and renewables targets.

However, stakeholders expressed a diverse range of views on the implications of this transition for the reliability risk profile and the form of the reliability standard. This is discussed in more detail in section 2.2 below.

2.2 There are mixed views on the implications of the NEM's transition for the form of the reliability standard

2.2.1 The issue

The Panel's Issues Paper noted that the NEM's transition may change the shape of the reliability risk distribution. Further, the reliability risk profile may shift from more frequent, lower impact events to less frequent, more extensive, 'tail risk' events.[8] Such change in the risk profile could be driven by several factors, including:

- the introduction of battery storage and VRE generation with availability dependent on factors including weather and geographic dispersal
- increasing consumer energy resources that are changing demand patterns.[9]

Stakeholders were asked whether the current reliability standard, which uses a simple expected USE based on a mean value, can effectively reflect the potential changes in the NEM's reliability risk profile.

The paper also sought stakeholders' feedback on the potential need for a new form of the reliability standard, such as one that incorporates a 'tail risk' metric in combination with the existing expected value of USE metric.

7 Reliability Panel, 'Review of the form of the reliability standard and APC', Issues Paper, 2023, p. 1; p. 4.
8 Tail risk refers to the risk of large, low probability outcomes reflected in the 'tail' of a probability distribution.
9 Reliability Panel, 'Review of the form of the reliability standard and APC', Issues Paper, 2023, pp. 10-14.

2.2.2 Stakeholder views

Stakeholders' views varied significantly regarding the implications of the NEM transition on the reliability risk profile and the need to change the form of the reliability standard.

Among the total of ten stakeholders who expressed a view on these issues, five stakeholders broadly supported the Issues Paper's characterisation of the issues with the current reliability standard.[10]That is, the change in the NEM to a high VRE, energy-limited power system may change the nature of reliability risks in the NEM, particularly associated with 'dark doldrum' events.[11]

These stakeholders also agreed that there is a need for the Panel to undertake further work to assess the adequacy of the current form of the reliability standard in addressing the changing reliability risks and consider whether a new form is necessary.

On the other hand, there were another five stakeholders who questioned the description in the Issues Paper of tail risk as a challenge to be managed in the reliability framework.[12]These stakeholders noted:

- The changes being seen in the NEM do not necessarily imply greater tail risk. Furthermore, since reliability risk will become a function of a greater number of smaller firming units, several stakeholders suggested that tail risk may even decline.[13]
- Tail risk is already captured by expected USE and therefore changes to the nature of reliability risk do not require a change to the form of the reliability standard. Expected USE is a probability-weighted measure and thus necessarily accounts for tail events according to their USE impact and likelihood of occurring.[14]

The Australian Energy Council (AEC) engaged Endgame Economics to produce a report, 'Form of the Reliability Standard – Prepared for the Australian Energy Council – Final Report'.[15] This report was subsequently endorsed by the Energy Users Association of Australia (EUAA).[16]

The report contends that the changes occurring in the NEM as we transition to an energy-limited, high-VRE market are not sufficient to make the case for changing the form of the reliability standard. The report notes that this is because the potential changes to the NEM's distribution of USE do not necessarily change the underlying economics which inform the reliability standard.[17]

The AEC-Endgame Economics report also addresses the marginal value of USE in relation to two attributes of USE: duration and frequency. The paper explains the relationship between duration and the value customers place on reliability in detail, providing two ways in which the case for change fails in this particular regard. Firstly, Endgame Economics emphasises the role of rotational load-shedding in bifurcating the duration of outages at a system-wide level and the duration of reliability outages experienced by customers. Secondly, they highlight some empirical evidence of a decline in the marginal value of USE as the duration of outages increases.[18] The AEC-Endgame Economics paper's discussion of the value of customer reliability is outlined in more detail in section 2.4.

10 Submissions to Issues Paper: AEMO, p. 6; Hydro Tasmania, p. 1; PIAC, p. 1; Snowy Hydro, p. 1; Stanwell, p. 1.

11 Dark doldrums, also referred to as dunkelflaute, VRE droughts, or anticyclonic gloom, are extended periods in which there is an unusually widespread and prolonged reduction of both sunlight and wind, which results in an extended period of lower-than-expected VRE production.

12 Submissions to Issues Paper: AEC, p. 1; AGL, p. 1; CS Energy, p. 2; EUAA, pp. 1-2; Shell Energy, pp. 1-2.

13 Submissions to Issues Paper: EUAA, p. 2; Shell Energy, p. 2; AEC, p. 3.

14 Shell Energy submission to Issues Paper, p. 2.

15 Endgame Economics for the AEC, submission to Issues Paper.

16 EUAA additional submission to Issues Paper.

17 Endgame Economics for the AEC, submission to Issues Paper, pp. 43-44.

18 Endgame Economics for the AEC, submission to Issues Paper, p. 11.

2.3 More data is needed to better understand the nature of unserved energy in the future power system

2.3.1 The issue

To assess options for the form of the reliability standard, the Panel needs to understand how the reliability risk profile could change as the NEM transitions to a higher VRE penetration system.

The Issues Paper proposed a modelling approach that would produce simulated USE data for a potential future energy system. This approach would involve constructing a future-generation fleet based on AEMO's Integrated System Plan (ISP), and then testing this against different conditions such as dark doldrum weather patterns.[19]

The Issues Paper also noted that the development of new metrics to augment or replace the existing reliability standard will require further modelling, which is to be progressed for the Draft Report.

The Panel requested stakeholders' feedback on the proposed modelling approach, including the concept of overlaying realistic dark doldrums on the ISP, and whether to apply random or tailored forced outages to thermal generators in the model.

2.3.2 Stakeholder views

Stakeholders broadly supported the Panel's proposed modelling approach to better understand the nature of unserved energy as the NEM transitions.

AEMO supported the modelling approach outlined in the Issues Paper but noted that the ISP forecasts very little USE due to the amount of new capacity in the plan. Therefore, AEMO suggested the modelling approach for the Review should consider removing plant from the ISP to examine USE more effectively.[20]

AEC and EnergyAustralia noted there may be value in expanding the weather reference year data beyond the current 12 years used in AEMO's Electricity Statement of Opportunities (ESOO) and creating wind and solar traces that would more accurately reflect forward weather patterns to 2040.[21]

AGL, Shell Energy and the AEC expressed some support for the modelling exercise as a means of better understanding the nature of reliability in the future NEM. However, they did not agree with the Panel's characterisation of the shortcomings of the current reliability framework. Instead, they considered that the issues set out in the Issues Paper highlighted a need for updated modelling and operationalisation of the reliability standard, not a new form.[22]

Only ENGIE commented on whether the modelling should include random forced outages for thermal plants. ENGIE's view was that random forced outages should be included, as they are in the ESOO.[23] It also considered that the inputs and assumptions should be consulted before the commencement of the modelling exercise.[24]

EUAA and Shell Energy suggested that the base case should be modelled with the efficient level of firming resources across a range of market settings.[25] Snowy Hydro noted that AEMO's use of 10%

19 Reliability Panel, 'Review of the form of the reliability standard and APC', Issues Paper, 2023, pp. 24-28.

20 AEMO submission to Issues Paper, p. 11.

21 Submissions to Issues Paper: AEC, p. 3; EnergyAustralia, pp. 2-3.

22 Submissions to Issues Paper: AEC, p. 1; AGL, p. 1; Shell Energy, p. 1.

23 ENGIE submission to Issues Paper, p. 5.

24 ENGIE submission to Issues Paper, p. 3.

25 Submissions to Issues Paper: EUAA, p. 2; Shell Energy, p. 2.

probability of exceedance (PoE) demand traces in the modelling could lead to an understatement of reliability risks moving forward, as reliability events could be triggered by demand levels higher than 10% PoE.[26]

In response to stakeholder feedback, the Panel has undertaken further modelling work to better understand the changing nature of the reliability risk as the NEM transitions. Chapters 4 and 5 of this Directions Paper outline further information about the modelling methodology, limitations and the key findings for stakeholder feedback.

2.4 It is important to assess the implications of the NEM's transition on how consumers experience and value reliability

2.4.1 The issue

The Panel's Issues Paper noted the importance of considering the potential implications of the NEM's transition on how consumers experience and value reliability. Given that customers' views and valuing of emerging reliability risks have yet to be tested, understanding the value of customer reliability in the context of the changing reliability risk is a relevant consideration to assess the need for a new form of the standard.

While the primary focus of the current Review is the form of the reliability standard, such considerations will also be a valuable input into how the level of the standard may be set through future processes, including the AER's VCR process and the Panel's RSSR.

The Issues Paper noted that the current reliability standard, as implemented by the AEMC, assumes consumers are risk-neutral and do not place different values over event timing, duration or depth. This means the reliability standard does not currently recognise variation in consumers' willingness to avoid different types of unserved energy events (even though this variation is in some cases already estimated by the AER). Instead, it assumes that a consumer is indifferent between:

- events on weekdays vs. weekends, winter vs. summer, nights vs. daytime
- seven day-long events and one week-long event
- two back-to-back events vs. two comparable events several months apart.

Under the previous thermal generation system, the simplification of the value of customer reliability by the AEMC may have been an appropriate approximation. However, as the NEM continues to transition, there is a question as to whether this approximation remains fit for purpose currently, and into the future. In the historical energy system characterised by the one-way flow of energy from large, centralised, mostly thermal generating plant and simpler planning needs, this approach was appropriate. As the NEM is modernised, there is a question about whether a USE metric implemented by the AEMC that treats all unserved energy equally irrespective of time will be fit for purpose in the future.

In this context, the Panel asked stakeholders whether the current form of the reliability standard is appropriate to reflect the value of customer reliability, particularly considering the potential changes to the nature of reliability risks in a future power system.

26 Snowy Hydro submission to Issues Paper, p. 2.

2.4.2 Stakeholder views

Stakeholders generally agreed that the value consumers place on reliability is a relevant consideration for assessing the need to change the form of the reliability standard:

- ENGIE considers that a change to the form of the standard would only be justified if there was evidence that the current framework failed to sufficiently capture VCR.[27]
- The Public Interest Advocacy Centre (PIAC) considers that the VCR should be a central anchor to the reliability standard and that the cost of a marginal reliability unit should be equal to the amount consumers are willing to pay for it, regardless of the form of the standard.[28]
- Origin Energy considers that it will be important to adequately consider whether consumers place a higher value on reliability on a per MWh basis than is currently reflected in the standard given the nature of the underlying events (e.g. their timing, duration and frequency), noting any reliability event that does occur would be managed through rotational load shedding.[29]
- Stanwell and ENGIE noted that the shortcomings of the VCR would need to be better defined and proven to justify a change to the form of the reliability standard.[30]
- The Australian Energy Regulator (AER) identified that there are synergies between this Review and the AER's 2024 VCR work and expressed a desire to engage with the AEMC and the Panel over the course of the Review.[31]

While stakeholders broadly agreed that the value of customer reliability was a relevant consideration for the current Review, there were mixed views on whether any changes to the form are required to better reflect the value consumers place on reliability currently and into the future.

Several stakeholders considered the current form of the reliability standard to be adequate and unlikely to require any significant changes unless there is strong evidence to the contrary.[32] These stakeholders noted that:

- the current VCR methodology is robust, and its value is a good estimation of consumer willingness to pay for reliability[33]
- changing the form could result in an unnecessary tightening of the level of the reliability standard, potentially beyond a level that reflects consumer willingness to pay[34]
- there is some evidence suggesting consumers' marginal valuation of outages will likely decrease rather than increase with longer-duration or repeat outage events[35]
- most outages that customers experience are system security and network outages as opposed to reliability events[36]
- moving to a risk-averse reliability metric could create a preference aggregation problem due to the controlled nature of rotational load-shedding[37]

27 ENGIE submission to Issues Paper, p. 4.
28 PIAC submission to Issues Paper, pp. 4-5.
29 Origin Energy submission to Issues Paper, p. 1.
30 Submissions to Issues Paper: Stanwell, p. 2; ENGIE, p. 4.
31 AER submission to Issues Paper, pp. 1-2.
32 Submissions to Issues Paper: Shell Energy, pp. 1-2; EUAA, p. 1; p.4; AEC, p. 1; CS Energy, pp. 2-3; Origin Energy, p. 1; ENGIE, pp. 3-4.
33 Submissions to Issues Paper: AEC, p. 1; EUAA, p. 1.
34 Submissions to the Issues Paper from AEC, p. 2; ENGIE, p. 4; Shell Energy pp. 1-2.
35 Endgame Economics for the AEC, submission to Issues Paper, pp. 24-29.
36 Endgame Economics for the AEC, submission to Issues Paper, pp. 21-22.
37 Endgame Economics for the AEC, submission to Issues Paper, p. 6.

- potential changes to the values of customer reliability can be accommodated within the existing form by revising the operationalisation of the current standard.[38]

On the other hand, some stakeholders, including PIAC and AEMO, presented the view that the current VCR and the form of the standard may not adequately reflect how consumers value reliability currently and into the future. In particular, it was noted that:

- the addition of a tail metric to the reliability standard will better reflect the value of customer reliability, and the VCR should be the basis of the new form of the standard for both typical and atypical years[39]
- in a future system with significant variability of reliability outcomes, there is a question as to whether the current VCR is still fit for purpose.[40]

Considering stakeholder feedback, the Panel has undertaken an initial desktop review of the international literature on the value of customer reliability for emerging reliability risks in an increasingly renewable power system. However, we acknowledge that further work will be required during this Review to better understand these implications. The findings from this desktop review are outlined in section 3.4 for stakeholders' consideration and feedback.

2.5 Consideration of the form of the APC is needed to deliver predictability and stability

2.5.1 The issue

The Panel is reviewing the form of the APC to ensure it is fit for purpose both in today's NEM and in the future. This is in response to the market suspension of June 2022, where the APC did not effectively serve its purpose of incentivising generators to make themselves available.

The Issues Paper proposed several options for the form of the APC, including that it could:

- retain its current form (i.e. a fixed value which may be updated every four years)
- be indexed to the gas APC
- be dynamically indexed to a gas price series such as the Short Term Trading Market gas hub prices or the Australian Competition and Consumer Commission's liquefied natural gas netback price series
- consist of two fixed levels where it is only increased to the upper fixed level if triggered by a defined circumstance
- be indexed to the Consumer Price Index (CPI).

The Issues Paper sought stakeholders' feedback on these options. The Panel also asked stakeholders how the APC impacts long-term commercial decision-making and whether changing its form would impact market certainty, particularly regarding the contracts market.

2.5.2 Stakeholder views

Stakeholder submissions considered that the market conditions of June 2022 would have been prevented by having a sufficiently high level of the APC.[41] Stakeholders also generally agreed on the importance of stability in the APC for the liquidity and efficiency of contract markets. AEMO was the only stakeholder to consider that the APC did not have a material impact on long-term

38 CS Energy submission to Issues Paper, p. 2.

39 PIAC submission to Issues Paper, pp. 3-4.

40 AEMO submission to Issues Paper, pp. 8-9.

41 AFMA submission to Issues Paper, p. 5.

commercial decision-making and that changes to the APC in the order of those seen recently would have little impact on contract markets.[42]

In terms of the options outlined in the Issues Paper, there was no support amongst submissions to link the APC to dynamic fuel prices, with stakeholders citing the impacts on the ability of market participants to hedge against price volatility caused by uncertainty in the level of the APC. In particular, the Australian Financial Markets Association (AFMA) highlighted that:[43]

> When pricing swaps and caps market participants currently have confidence that during periods of extreme volatility, [the] APC will limit their potential exposure. For [the] APC to continue to perform this role over the long term, the market needs to have certainty about when administered pricing will apply and the price it will apply at. AFMA is concerned that the options proposed in the review introduce greater complexity and do not provide this certainty.

Industry stakeholders further noted that ensuring the APC is sufficient to cover the short-run marginal costs of the marginal generator during APPs requires direct consideration of fuel costs for gas-fired generators. However, several stakeholders acknowledged a more technology-neutral approach may be important to accommodate the possibility of another technology representing the marginal generator in the future.[44] To this end, Shell Energy noted:[45]

> As a market, we should not presume to know with absolute certainty which technologies will act as the marginal generator in years to come... For this reason, Shell Energy considers a technology neutral approach to setting the APC may be necessary. This approach would provide adequate incentives for all supply side resources to continue to offer for dispatch during an APP.

Most stakeholders who commented on the form of the APC considered that the current form should be kept or that the APC should be indexed to CPI. However, Snowy Hydro supported linking the APC to the gas APC and Shell Energy was open to several options including linking to the gas APC or the market price cap (MPC).[46]

In response to stakeholder feedback, the Panel has shortlisted two options for the form of the APC to be considered further through the Review process. The two options are:

- retaining the current form of the APC
- indexing the APC to CPI.

Chapter 6 sets out the Panel's reasoning for selecting these two options and seeks stakeholder feedback.

42 AEMO submission to Issues Paper, p. 20.

43 AFMA submission to Issues Paper, p. 2.

44 Submissions to Issues Paper: Shell Energy, p. 4; AFMA, p. 3; Origin Energy, p. 2.

45 Shell Energy submission to Issues Paper, p. 4.

46 Submissions to Issues Paper: Snowy Hydro, p. 3; Shell Energy, p. 4.

3 Further consideration of the value of customer reliability

3.1 Understanding how customers value reliability is a key part of the reliability framework

The existing reliability standard is expressed as the 'expected' amount of USE.[47] It is expected USE since assessing the reliability standard requires modelling a forecast of future system operations. The current reliability standard of 0.002 per cent expected USE for the NEM is set at the maximum forecast unmet energy due to reliability issues for each financial year, as a proportion of the total energy supplied in a region. USE is the amount of energy that is not supplied but required (or demanded) by consumers due to a shortage of generation or interconnection, which results in supply interruptions for consumers (i.e. an energy shortfall).

The current reliability framework considers the value of customer reliability in defining the level of the reliability standard. The Panel does this through recommending a USE level that minimises the total operating and investment costs and the value customers are willing to pay for USE. The AER's VCR is an essential part of this framework. It examines the value consumers place on reliability by considering the amount they are willing to pay to avoid an incremental unit of USE in each region of the NEM.

The VCR for each region is expressed in $/kWh and is reflective of willingness to pay to avoid USE for residential and business consumers with connections less than 10MVA (megavolt-amperes), as well as for businesses with connections over 10MVA. The AER uses a combination of survey techniques to derive these figures. VCR values are used to estimate customers' willingness to pay to avoid the expected level of USE, which is balanced against operational and investment costs to calculate the appropriate level of the reliability standard.

The Panel must have regard to any VCR determined by the AER which is considered relevant when conducting the four-yearly review of the reliability standard and settings. This periodic review enables the Panel to consider whether the level of the standard and settings remain suitable for the market arrangements and to ensure they continue to meet the requirements of the market, market participants and consumers.[48]

Under the National Electricity Rules (NER), the AER must complete its next iteration of the VCR review and update by the end of 2024.[49]

The current Review of the form of the reliability standard aims to gain insights into the changing reliability risk as the NEM transitions. There is an opportunity for the AER to consider the key findings from this Review when examining whether the current VCR methodology remains fit-for-purpose as the NEM transitions. As such, the Panel is working closely with the AER so that it may consider whether our modelling results warrant any adjustments to the AER's VCR methodology. The outcome of the AER's 2024 VCR review and update may then help inform consideration of the efficient level of the standard to be determined in the 2026 RSSR.

47 NER Clause 3.9.3C(a).

48 NER Clause 3.9.3A; NER Clause 8.12.

49 NER Clause 8.12.

3.2 There are several processes that need to come together before any new standard can be implemented

The Panel has carried out further work on how the value of customer reliability may inform the assessment of the form of the standard, and to what extent the consideration of the value of customer reliability falls within the scope of the current Review.

Reliability standards have three main aspects: form, level and scope.

- the **form** is the method by which reliability is measured
- the **level** specifies the acceptable value of the metrics that comprise the form of the standard
- the **scope** defines what does and does not count towards the NEM's reliability performance.

The focus of this Review is on the form of the standard rather than its level and scope. However, the Panel may consider broader implications that are relevant to the consideration of the level and scope of the standard.

We consider there are two limbs to reliability metrics, including 1) types of possible reliability scenarios, and 2) how much consumers are willing to pay to avoid those types of events.

The Panel considers that the question that is directly relevant to the intended scope of the current Review is the first limb referring to the types of possible reliability scenarios as the NEM transitions. A more specific question on how much consumers value reliability in the context of these events can be considered in relation to the level of the standard.

That said, in this Review, the Panel may decide to recommend a change in the form of the reliability standard to reflect different types of reliability events that may emerge as the NEM transitions. However, there are several processes that need to be completed to implement any recommendations. These work together to ensure that any new standards or settings reflect the value customers place on reliability.

1. The Panel is carrying out this Review to determine if the nature and extent of changes to reliability risks in the future warrants a change in the metrics of the reliability standard. The Panel will make this recommendation by **mid-2024**.
2. At the same time, the AER is about to commence its 2024 VCR review and update work. As noted above, we are working closely with the AER as they consider whether any changes to the VCR methodology may be needed to reflect our modelling results. The AER is required to complete its work by the **end of 2024**.
3. The Panel will need to submit a rule change request to the AEMC if it recommends any changes to the form. With the insights from the Panel's Review on the form and the AER's VCR work, the AEMC will be able to assess the costs and benefits of the proposed standard, and how customers may value the new reliability risks. The AEMC will then decide on the new form of the standard to be reflected in the NER. This work would need to be completed in **early 2025**.
4. The AEMC would then task the Panel to carry out the 2026 Reliability Standard and Settings Review on the final form of the standard. As with the current standard, the Panel would seek to balance reliability against cost. The Panel can use the VCR and any insights from that to recommend the level of the standard and settings. The RSSR project must be completed by **30 April 2026**.
5. The Panel would then submit a rule change to the AEMC to give effect to its recommendations. This would need to be completed by the end of 2026. Once finalised, the market will implement the new standard and settings, to commence on **1 July 2028**.

3.3 Changing the form needs to balance the needs of the future power system and the current the value of customer reliability

At the conclusion of this Review, the Panel may recommend a change in the form of the reliability standard to reflect the changing reliability risk in the future power system. Indeed, the Panel's recommendation in the 2022 RSSR was that such a change may warrant a reliability standard that incorporates an additional metric for 'large USE' or 'tail' events in combination with the existing expected value of USE metric.[50]

If the Panel determines the form needs to change, the 2026 RSSR would set the level of the standard, accounting for the 2024 VCR findings and potentially other related work. Consistent with the current standard, the Panel would seek to balance reliability against cost. If it is found that consumers do not (yet) value reliability against unserved energy events more highly as the power system transitions (e.g. longer or more widespread unserved energy events), the Panel could recommend a level of the new standard in a way that imposes minimal additional reliability costs on consumers.

A change may be required to future-proof the reliability standard and set up a fit-for-purpose standard that can address the changing nature of reliability risk. Changing the form now could provide certainty to the market on how we will set the standard and associated settings into the future.

However, as noted earlier, the effect of these events on how consumers value reliability is a fundamental part of the reliability standard and settings. The Panel will consider if a change in the form is needed to reflect the changing nature of reliability over time. This does not mean that the value of the additional metric would impose would be substantially higher. Over time, through successive RSSR processes, this would be adjusted in the same way the standards and settings are adjusted today.

3.4 The Panel has done a desktop literature review on the value of customer reliability and its implications for the form of the reliability standard

The Panel has commissioned Professor Pierluigi Mancarella of the University of Melbourne to undertake a desktop review of the existing literature and international case studies that are relevant to the consideration of the value of customer reliability for emerging reliability risks in an increasingly renewable power system.

Professor Mancarella obtained insights from international studies on whether customers may value these kinds of risks and events and identify them as material enough to consider paying the costs to prevent and/or be insured against. These insights help inform the discussion about possible changes in the form of the reliability standard.

The desktop review has identified that the international literature on the value of customer reliability on emerging risks is relatively scarce and that more work is needed on the topic. Among many international projects, research activities and the academic literature reviewed, several have been selected as most relevant.[51] Of particular interest was a series of projects conducted in the

50 Reliability Panel, '2022 Reliability Standard and Settings Review', final report, 2022, p. 44.

51 Electricity North West, 'Value of Lost Load to Customers', 2019; M Ovaere et al., 'How detailed value of lost load data impact power system reliability decisions', Energy Policy 132 (2019) 1064–1075; W Gorman, 'The quest to quantify the value of lost load: A critical review of the economics of power outages', The Electricity Journal 35 (2022) 107187.

United Kingdom led by Electricity North West, the local network operator in the area of Greater Manchester.

The results from the desktop review suggest that consumers may value emerging reliability risks and the existing risk of events differently. The value of customer reliability over different kinds of reliability risks may change in the presence of non-typical events. This may cause them to attach a higher value to certain reliability events. In simpler terms, this means that the customer value of reliability may vary between different kinds of reliability risks after they have experienced such risks.

The desktop review has also identified that consumers with distributed energy resources and electrified demand, as well as consumers in areas potentially more prone to weather-driven interruptions (e.g. in rural areas), may value reliability more than following traditional 'average' assessments.

In addition, large-scale and lengthier interruptions could increase the perceived Value of Lost Load (VoLL), when compared to shorter, limited-scale interruptions, especially in the presence of additional electrified services such as for transport.[52] It was also found that increasing the frequency of interruptions within a year, for example, due to rolling blackouts in certain areas, could increase the value that customers would attach to their reliability.

The desktop review has also found that the numerical value of the VoLL could change dynamically with the perceived level of reliability in a certain area, being lower for higher levels of reliability and higher for lower levels of reliability. Hence, if, for example, rotational load shedding was to be implemented in certain regions, the reliability level would then change for different consumer groups, which in turn would change their VoLL. The desktop review has noted it is important to consider this behavioural feedback loop particularly because it may be a lengthy learning process, potentially leading to inefficient system management and investment decisions.

Question 1: Further consideration of the value of customer reliability

Do stakeholders have feedback on how the value of customer reliability should be considered under the current Review, considering its intended scope?

Do stakeholders agree with how the consideration of the values of customer reliability by the Panel and AEMC can be sequenced and aligned with the existing work program under the reliability framework, including the AER's VCR and the Panel's 2026 RSSR?

Do stakeholders have any feedback on the findings from the desktop review?

52 Some international projects have undertaken the valuation of the value of customer reliability in the form of an assessment of the so-called VoLL, which broadly corresponds to the VCR that is used in Australia.

4 Modelling and analysis methodology

Since the publication of the Issues Paper, the Panel has commenced its modelling to explore the potential changes to the characteristics of unserved energy as the NEM transitions.

4.1 The Panel has modelled the changing nature of reliability risks in the evolving NEM based on a simulation, but this is not a forecast

A key objective of this Review is to better understand the changing nature of the USE as the power system transitions, and an effective way of achieving this was to analyse a system where the risks of USE were artificially increased.

The Panel has undertaken the modelling based on a simulation of a virtual future power system that is deliberately constructed to create insights about its unserved energy profile. These results, however, are not a projection or a forecast of whether the future power system will, or will not, meet the reliability standard. Instead, the simulations examine the composition or distribution of different types of reliability events in an extreme but unlikely future, to better understand the nature of the reliability events the system could face under stress.

To be clear, the Panel is not suggesting that reliability will be worse as the market transitions. Rather, the nature of reliability may change, and with this new information, we can explore ways to mitigate these risks through the reliability standard and settings.

Our modelling approach was to take a model of the NEM based on AEMO's ESOO and ISP, and to remove capacity in each financial year such that the model is deliberately under-resourced with respect to capacity and energy. Simulations with this under-resourced system model will result in outcomes materially different to planning documents such as AEMO's ISP. Given that unserved energy is inherently rare, this was deliberately done to produce larger and more numerous unserved energy events, providing a larger basis from which to study the characteristics of unserved energy in more detail.

As noted earlier, the Panel's observations are based on simulations. In practice, however, market signals would inevitably drive additional investment to avoid these scenarios, given the necessary market settings (one of the Panel's key responsibilities).

That said, the purpose of this simulation modelling is to identify possible reliability risk circumstances and characteristics in a system where energy availability is more correlated to weather than it is currently. This allows for the profiling the nature of possible risks through scenario analysis but does not consider how likely or frequently such risks will materialise (i.e. it is not forecasting the likelihood or probability of such reliability risks actually occurring in the future power system). Further information is available in section 4.4.

The remaining sections in this chapter outline the model design, setup and key assumptions (section 4.2 and section 4.4). The modelling also includes several sensitivity cases to investigate the impact of factors such as interconnection and weather conditions on unserved energy (section 4.3). Plans for future work are discussed in section 4.6. Following this, chapter 5 analyses the depth (size), duration, and timing of the modelled USE events to understand how their characteristics change as more thermal generation in the NEM is replaced with VRE and battery storage.

4.2 We developed the AEMC USE Simulation Model (AUSM)

Given the generation profile of the NEM will have changed significantly in 2028, and will continue to do so post-2028, the AEMC engaged Cornwall Insight Australia (CIA) to help to develop a model that helps to answer the following question:

> How is the USE profile expected to change and does this mean the current reliability measure requires refinement from 2028?

Working in PLEXOS, CIA established a reference model for the period up to 30 June 2028, and started exploring USE profiles from 1 July 2028 to the end 30 June 2043 to capture profiles for increasing levels of VRE penetration.

This model is set up to run 11 reference years that have different weather patterns and 10 forced outage samples to generate a range of stochastic outcomes.

As noted, the scope of this work is not to model the future of the NEM, but rather to simulate the properties of unserved energy from various potential future NEM configurations. In this regard, the model has been designed to produce USE levels beyond what would be reasonably expected to better understand USE characteristics.

4.2.1 Establishment of the base model that is broadly based on the ESOO

AEMO's ESOO provides an outlook of supply adequacy through to the 2032 financial year using a PLEXOS model that simulates the NEM under different demand and supply scenarios.

AEMO publishes the data sets on which the ESOO is based. The data set for the 'February 2023 update to the 2022 ESOO' was established in the August 2022 ESOO and was the latest available prior to the start of this investigation.[53] As such, the August 2022 ESOO model serves as the structural starting point for the AUSM. Since the AUSM is an exploratory simulation, the recently released 2023 ESOO does not invalidate the Panel's analysis and nor will any future updates to the ESOO.

It is worth stressing that while the model was heavily influenced by both the ESOO and the ISP, the AUSM is not a statement of opportunities nor a future system plan. The results produced by the AUSM are not a commentary on either publication, or the hypothesised future NEM.

4.2.2 Augmentation of the base model with additional information

In addition to information from the ESOO, the AUSM also uses information from AEMO's ISP and Inputs, Assumptions and Scenarios Report (IASR).

The AEMC has also received additional data from AEMO and made some specific variations to ESOO assumptions. This primarily comprised properties to extend the ESOO assumptions beyond the 10-year horizon and variations including:

- generation build by technology
- Renewable Energy Zone (REZ) limits and augmentations
- build-aligned closures
- the set of 50% PoE traces
- Snowy 2.0 unconstrained operation
- doubling of the southerly VIC-NSW transmission limit

53 AEMO, 'Update to 2022 Electricity Statement of Opportunities', 2023; AEMO, '2022 Electricity Statement of Opportunities', 2022.

- turning off some long-term constraints
- converting the 8-hour duration batteries to 4-hour duration batteries.

4.3 Sensitivities

Several sensitivities were run to provide a broader range of results and a more nuanced view of USE characteristics under slightly different assumptions.

The sensitivity scenarios performed include:

- **Demand variation** — to understand the change in characteristics of USE events under lower demand.
- **Delayed interconnection** — to compare a lower level of interconnection and how it may impact the USE characteristics.
- **Reduced depth of long-duration storages** — to show whether deep storage is needed for longer events, even though their short-term capacity may be met by distributed consumer-based resources.
- **Accelerated decarbonisation** — to capture a sensitivity with a greater push for decarbonisation, and how the rapid removal of dispatchable capacity will impact USE.
- **Alternate technological development** — to capture an increase in the dispatchable capacity for Hydrogen or equivalent technology, accompanied by an equivalent capacity reduction in the REZ VRE in the modelling.
- **Significant dark doldrums** — to assess the following:
  - the impact of VRE patterns derived from an extended VRE availability dataset provided by Griffith University[54]
  - the impact of the lowest doldrums in the greater horizon, outside the standard set of reference years.

Further information about the sensitivity scenarios is available in appendix A.4.

4.4 Key limitations of the modelling

During the modelling exercise, several limitations were identified, including those related to the use of PLEXOS software. Further information about the key model limitations is available in appendix A.6.

Uncertainty over the impact of climate change on future weather patterns is a key limitation of this analysis. Like AEMO's published ISP and ESOO models, the AUSM used 11 reference years. In the dark doldrum sensitivity, one of these reference traces was altered to simulate historical events from the Griffith data set to capture more extreme climactic conditions. However, no new synthetic weather forecasts were used. Given the connection that has been drawn between weather conditions and USE the choice of weather reference years and VRE conditions, particularly dark doldrums is important. Further research is planned on the available weather data to gauge dark doldrum probabilities (see section 4.6 on bootstrapping) and potentially, working in conjunction with AEMO on generating synthetic weather references.

Additionally, as this model is not a forecast, all observed results must be considered acknowledging they were synthesised using unrealistic versions of the NEM. That is, this is based

54 See appendix A.1.2 for more details on the Griffith University dataset, and appendix A.5.6 for more details on the dark doldrum sensitivity.

on a simulation of a deliberately under-resourced power system (see appendix A.3), such that additional investment may avoid or shorten any modelled USE events.

The results presented in chapter 5 cover the NEM regions of New South Wales (including the Australian Capital Territory), Queensland, Victoria, and South Australia. The AUSM also included Tasmania, but there was little to no USE in that region due to its extensive hydro capacity. This is despite the capacity reductions mentioned in section 4.1. Further details are provided in appendix A.3.

> **Question 2: Modelling methodology and limitations**
>
> Do stakeholders have any feedback on the Panel's modelling approach?

4.5 Key definitions and assumptions in analysing the modelling results

The results of the AUSM model have been characterised under a number of different lenses in order to isolate effects and understand the results more clearly.

A range of assumptions and definitions have been adopted for the purpose of analysing the modelling results as summarised in this section below and explained in more detail in appendix B.

4.5.1 Defining the characteristics of the USE events

The characteristics of the USE events have been defined as follows:

- **Duration** — measured in hours, refers to either *event duration* (hours between the start and end of a cluster of events — see section 4.5.2) or *USE Duration* (total hours of USE within a cluster of events).
- **Depth** — measured in MW, refers to the half-hourly values reported in the modelling.
- **USE** — measured in MWh, refers to the energy lost in the event. For comparison purposes, in most cases in this report USE is reported as one of two ratios: the *USE event demand ratio*, which is the ratio of USE that occurred in an event to the total demand in the event, or the *USE annual demand ratio* which is event USE as a percentage of total annual regional demand.
- **Mean time between events** — measured in days, refers to the average number of days between USE events. While this has not been reported to date, it may form part of future analysis on the form of the standard and in the subsequent Reliability Settings and Standards Review.

4.5.2 'Clustering' of USE events

The modelling simulations were based on 30-minute dispatch intervals and therefore a single USE event could span one or many consecutive 30-minute intervals.

As many of the simulated events occur because of weather conditions over many days and, in particular, may relate to solar cycles, consecutive USE events with less than 16 hours between the end of one event and the start of the next have been "clustered" together. For example, two 6-hour USE events separated by a period of 6 hours will be clustered, giving an event duration of 18 hours but a USE duration of only 12 hours.

The 16-hour buffer window was chosen for the following reasons:

- it captures events that impact morning and evening peaks over consecutive days

- isolated short events are unaffected
- long events remain and a longer buffer window does not extend the longest USE events
- other characteristics of USE do not change materially with a longer buffer window.

4.5.3 Defining VRE penetration

In this paper, VRE penetration refers to the percentage of total capacity made up of utility-scale wind, solar and batteries, and does not include hydro.

While the AUSM model has been constructed loosely based on the VRE capacity construction program as detailed in the ISP, the variations are primarily the removal of capacity across the NEM to generate more USE events. Therefore, the changing characteristics of USE are presented with respect to the level of VRE penetration rather than time. Since the AUSM model is not a forecast of USE, presentation of data with dates is likely to be misleading.

It is also important to note that whenever results are presented in this Directions Paper through the lens of increasing VRE penetration, several other variables are also changing. For example, as this stage of the modelling comprises a longitudinal study, demand is generally increasing. As generation retires and new developments are added, the capacity of different technologies and the relative technology mix is also changing. Analysis for the Draft Report may include additional sensitivities and control cases to isolate the impact of VRE penetration from other variables (see section 4.6).

4.5.4 Defining 'dark doldrum' periods and related assumptions

The dark doldrum sensitivity was specifically designed to test significant VRE doldrums, with a dark doldrum period defined as any period in which the three-day rolling average NEM-wide VRE output was more than two standard deviations below the seasonal mean.

The determination of long-duration dark doldrums was based on an 82-year data set of wind and solar data from Griffith University based on atmospheric conditions.[55] This dataset provided nominal hourly output data for 27 wind and 30 solar projects within mainland REZs, as defined by AEMO in the 2022 ISP.

With data for so many wind and solar locations, there were usually several in each REZ. In this case the nominal values for each were aggregated to provide a single averaged nominal profile for wind and solar in each REZ. The locational diversity then smoothed the resulting REZ trace and was combined with ISP capacity development information from which dark doldrum periods could be readily identified.

Further information about the key definitions and assumptions used in constructing the dark doldrum sensitivity is available in appendix A.5.6.

4.5.5 Applying AEMO's definition of 'large USE events' instead of 'tail' or 'extreme' events

In undertaking this modelling, we have adopted several key assumptions and definitions. These include using AEMO's definition of 'large USE events' in analysing the Panel's modelling results instead of using other definitions, such as, 'tail' or 'extreme' events. This definition aligns with the AEMO's definition of a 'large USE event' provided in the 2023 ESOO.[56]

55 J Gilmore, T Nelson and T Nolan, 'Quantifying the risk of renewable energy droughts in Australia's National Electricity Market (NEM) using MERRA-2 weather data', Griffith University Centre for Applied Energy Economics & Policy Research, 2022.

56 A large USE event typically is referred to when the level of expected USE is above the reliability standard, or equivalent to about between 10 and 12% of average regional demand being unserved for a period, say for five to eight hours. This could be in a single event or reflect several USE events over multiple days.

The design of the AUSM, which features material reductions in capacity, successfully produced a large number of USE events. Some trends were clear from the raw data, others it was clear would be dramatically affected by the relative levels of supply in any instance. We designed a normalisation or calibration approach to moderate the annual USE back to a reference level to moderate the capacity removed in each year. Using the Reliability standard as the benchmark, the process revealed the trends without requiring simulations. A more complete description of the calibration process is provided in appendix A.4.

Question 3: Key definitions and assumptions in analysing the modelling results

Do stakeholders consider that the definitions and assumptions used here are appropriate for characterising USE events now and into the future?

4.6 Further work planned for the next stage of the Review

This Directions Paper outlines the findings from the Panel's modelling and analysis work undertaken to date. The main purpose of this paper is to build a strong base of evidence and supporting rationale to seek stakeholder feedback to inform the Panel's recommendations in the Draft Report.

In undertaking the modelling and analysis work, the Panel has identified the areas of additional work to further improve the quality and strength of evidence supporting the Panel's recommendations.

These additional areas of work include bootstrapping weather to gauge the probability and scale of dark doldrum probabilities. Creating a larger data set of renewable generation availability through bootstrapping should generate a probability distribution for wind and solar combinations. This will inform the assessment and characterisation of dark doldrums and provide a possible basis for gauging their scale and probability for future market development scenarios.

Other areas of further work currently planned include:

- examining higher VRE penetrations in a single financial year
- testing the characteristics of USE from other dark doldrums and look for a correlation between the doldrums' probability and USE severity
- exploring changes to the USE characteristics given alternative technology mixes based on new scenarios to test additional capacity from conventional thermal generation, short and long-term storage and VRE overbuild[57]
- continuous improvement and testing of the existing results.

Question 4: Further work planned for the next stage of the Review

Do stakeholders have any feedback on the additional modelling and analysis work needed to inform the Panel's consideration of the form of the reliability standard?

57 Existing scenarios predominantly tested reductions in capacity from existing technologies.

5 Key findings from the simulation modelling and analysis

This chapter outlines the Panel's key findings from the modelling and analysis discussed in Chapter 4. For each finding we outline the implications and supporting evidence. However, it is important to note that the findings are a result of trends appearing in the AEMC's under-resourced NEM model derived from the ISP. The future power system may look quite different.

This model cannot generate any conclusions regarding the probability of USE events occurring in a realistic future system. Rather, it is designed to generate an understanding about the changing characteristics of the USE distribution.

5.1 If USE events do occur, they may be longer and deeper

5.1.1 Key findings and implications

The modelling suggests that if they occur, USE events may have the potential to be longer and deeper as the NEM transitions. This comes from our observations that both the typical USE events and the largest events that might be expected tend to become longer and deeper as the transition in the model advances. This does not mean that reliability risk or the overall amount of USE would increase in the future NEM, but rather the same amount of USE might be concentrated in a smaller number of events.

One of the questions of interest for stakeholders is whether there would be increased tail risk in the future NEM. Further work is required to make a fully informed judgement about tail risk in the NEM. However, we have found that the proportion of large events generated by the model increases as the NEM moves towards higher VRE penetration. A 'large USE event' in this report means an event that exceeds the current reliability standard by itself, as explained in section 4.5.5.

These effects are linked to the changing nature of unserved energy as the NEM transitions. USE events in the future may be a moderate overnight or day-long shortage triggered by low wind conditions during the winter months, rather than a failure to meet a summer afternoon demand spike due to outages of thermal plant (see section 5.2, section 5.3, and section 5.4 below). This type of event has the potential to be longer and deeper than those experienced in the past, potentially requiring longer-duration firming capacity to mitigate.

The observation of longer and deeper events in the modelling means that the reliability risk profile may be different in the future NEM, as anticipated by the 2022 RSSR.

This finding demonstrates the importance of the reliability framework in a future VRE-driven system. There will be a need for reliability settings that deliver the required mix of diverse variable renewables, and flexible capacity (including firm sources and short and long-duration storage) to deliver the level of reliability that customers value. This is due to the possibility of low VRE resource availability periods driven by weather conditions. The potential for deeper or prolonged reliability events will be a key consideration in our recommendations for the form of the standard and in future decisions regarding the level of the standard.

An increase in the risk of large USE events does not mean an increase in the overall level of reliability risk in the power system. Rather, it reshapes the risk profile so that within a defined standard with a constant overall level, the contribution of large USE events becomes more significant and replaces other existing risk types. That is, the composition or profile of the reliability risk changes, rather than the level of the overall risk. While this may not of itself be a reason to change the form of the standard it is likely to contribute to a change in the way it is identified and quantified. A key issue for consideration therefore is whether the current form of the reliability standard is adequate to address the increasing trend towards larger USE events compared to other factors.

5.1.2 Caveats and limitations

Caution is needed in interpreting this finding. While the modelling shows a potential change in the profile of the reliability risk, it does not quantify the potential change in the overall risk.

The Draft Report will consider alternative approaches to understanding the changing risk of large USE events. This may include:

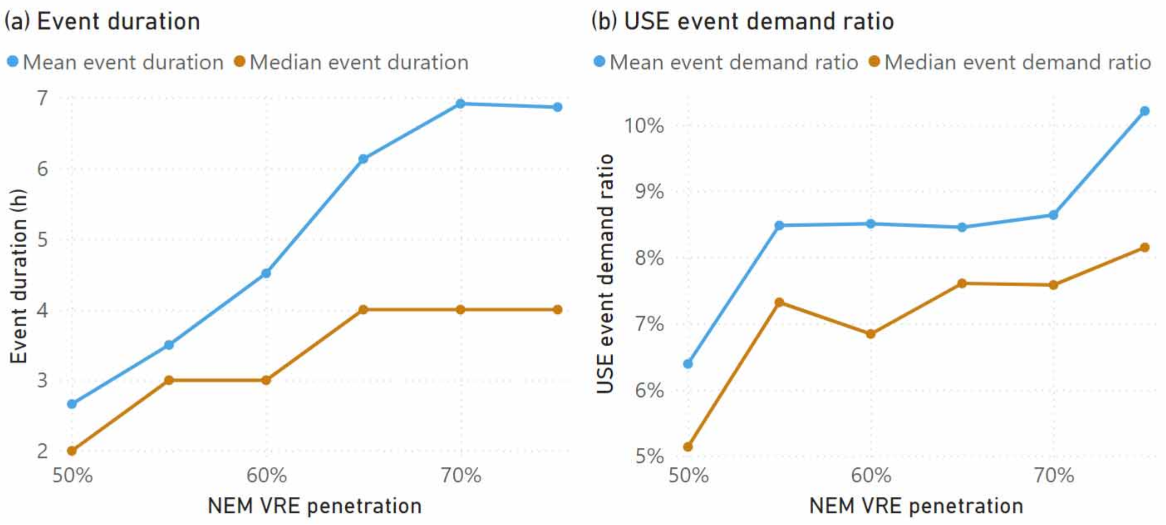
- running more targeted models to isolate the impact of adding or removing different types of capacity to change the technology mix
- quantifying the risk of the underlying weather conditions from the available data
- simulating more years at higher VRE penetration to gain more information about the system's behaviour at those levels.

5.1.3 Supporting evidence

The modelling suggests that the average depth and duration of USE events may increase as the NEM transitions.

Figure 5.1(a) shows the mean and median event duration plotted against the NEM-wide VRE penetration. The event duration has a clear increasing trend up to at least 70 per cent VRE installed capacity. The event Duration represents the total time between the beginning and end of an event. The clustering process applied to the USE data 'joins' USE events where there is less than 16 hours between the end of one event and the start of the next. As such there will be a difference between the number of hours of USE in an event and the event duration.

Figure 5.1: In an under-resourced system, the average depth and duration of USE events could increase with higher levels of VRE penetration



Note: This chart presents event durations for clustered events, so an event duration of seven hours, for example, does not imply seven continuous hours of unserved energy.

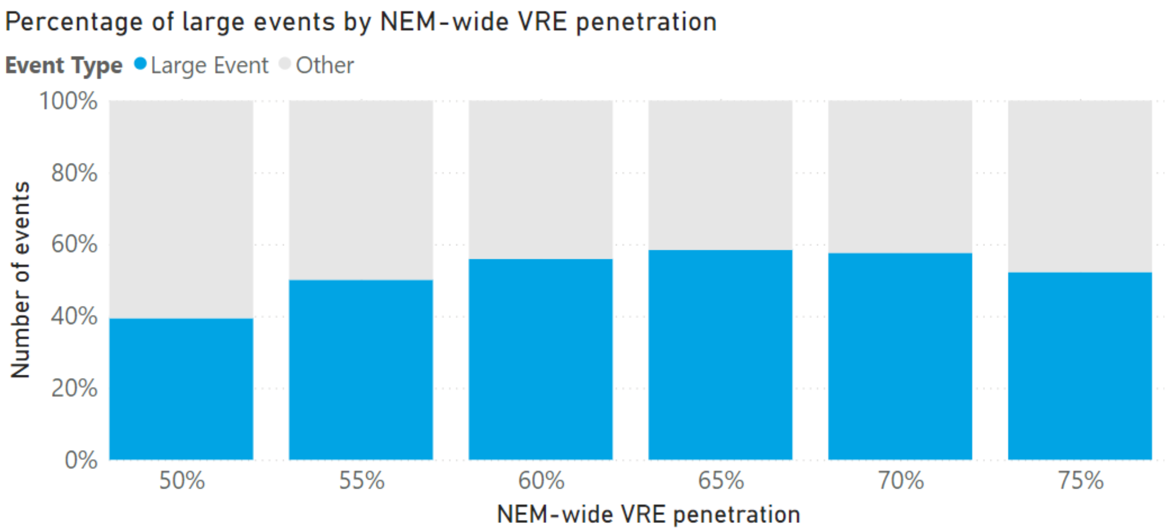
Figure 5.1(b) shows that the mean and median USE Event Demand ratio also increase with NEM-wide VRE penetration. The USE Event Demand ratio represents the ratio of the amount of USE compared to the total customer demand during the event. Note that this chart and all others in this chapter are based on results that have been calibrated using the first calibration approach described in appendix A.4. Note that in both cases the mean is greater than the median, suggesting a skewed distribution. Trends beyond 70 per cent are based on materially fewer simulated outcomes and may be affected by significant variation in the technology mix across the regions, and may not be statistically significant.

One key issue for the Review is whether tail risk will increase as the NEM transitions. While the AUSM generated a diverse range of reliability events, there are too few events to define a distribution or tail. However, the larger events that it did generate are of particular interest.

For this Review, a large USE event is a single event that exceeds the reliability standard after applying clustering (see section 4.5). That is, the event USE must exceed 0.002 per cent of annual regional demand. Using this definition, the modelling shows that a greater proportion of large USE events occur as the system transitions.

Figure 5.2 shows the number of large events as a proportion of all USE events for each level of NEM-wide VRE penetration, using the calibrated (calibration approach 1) results. There is an upwards trend showing that the proportion of large events increases with the percentage of VRE in the NEM. Again, trends beyond 70 per cent may not be statistically significant as they are based on materially fewer simulated outcomes and may be affected by significant variation in the technology mix across the regions.

Figure 5.2: In an under-resourced system, the share of large USE events increases.



Note: At the highest level of NEM VRE penetration (75 per cent) there is a slight downtick. This is likely due to being a much smaller sample size, as fewer periods were simulated at these levels.

It is important to note that this chart represents the percentage of all USE events in the model which are large USE events and does not imply anything about the overall likelihood of these events or the total amount of USE that would be expected. While these results may be affected by confounding factors from the design of the model, regional differences in technology mix and the effect of weather events, the data appears to show that in a future high-VRE system, USE events may be longer or deeper, or both.

The analysis also found that even when calibrating to a tighter reliability standard than the current level (by compensation with more generation capacity), the proportion of large events remains high. This suggests that the increase in the relative number of large events could correlate with the changing nature of USE drivers. Additional research in this area is a priority for the Review's draft recommendations.

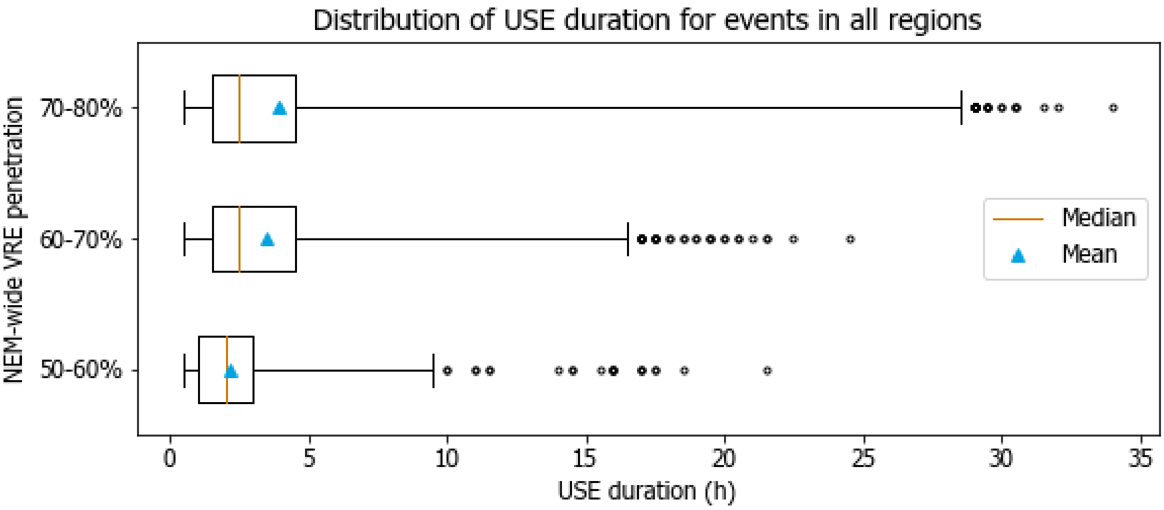
The modelling produced USE events with a wide range of depths and durations. The distributions of USE events (both calibrated and uncalibrated) are asymmetric with many smaller events and relatively few very large events, suggesting a tail.

Figure 5.3 confirms that the distribution of USE duration is skewed, with the regional means greater than the median values. For all levels of VRE penetration we can observe that the shortest 25 per cent of events lie between 30 minutes and two hours with the most common USE durations all being less than 4 hours. Taken at face value, the length of the longest one per cent of events is significant even at lower penetrations. While concerning, this is consistent with the finite probability of major unserved energy events that exists even in a power system dominated by conventional generating capacity.

Figure 5.3 suggests an increasing trend in the USE duration of the longest reliability events as the market evolves. However, substantial extra analysis will be required before the Panel can draw conclusions of greater confidence, with strict controls on key variables such as demand, capacity, and the regional and NEM-wide technology mix. If results such as this can be reproduced for a range of well-controlled scenarios, this would support a conclusion of a longer reliability tail. The probability of such events and the adequacy of the reliability standard to address that situation will be tested to a greater extent in the next stage of research.

The longest USE event from the calibrated results is less than two days. This occurs in an event of 39 hours total duration, with 35 hours of USE within the event. There were concerns leading up to this Review that dark doldrums could lead to sustained energy shortages of a week or more. At this stage, the modelling results do not support that concern.

Figure 5.3: In an under-resourced system, the longest reliability events may become longer



Note: The ends of the box represent the 25th and 75th percentiles, that is, half of events fall within the box. The median and mean are marked as shown. In this case, the right-most whiskers (short vertical lines) indicate the 99th percentile and the left-most whiskers indicate the minimum value. These values were chosen to emphasise the top 1 per cent of events in terms of USE duration. Events in the top 1 per cent are shown as small circles.

This chart is based on calibrated data as described in appendix A.4.

Question 5: If USE events do occur, they may be longer and deeper

Do stakeholders agree with the interpretation of the analysis, including its key finding? Do stakeholder consider any additional or alternative analysis is necessary?

Do stakeholders believe that this finding has implications for the form of the reliability standard?

Do stakeholders have views on the broader implications of this finding on the reliability framework?

5.2 As the NEM changes, reliability risks may shift from mainly being in summer to winter

5.2.1 Key findings and implications

Results from the AUSM revealed a trend where USE events may shift from occurring predominantly in the summer to predominantly during the winter.

This is consistent with the changing technology mix and dependence on combined resources that have the greatest likelihood of reduced output in the winter periods. Currently, the highest risk periods typically occur during short high-demand periods during the height of summers where a forced outage or equipment failure could cause USE, particularly after sunset when PV is not available.

The AUSM results indicated that during winter, despite lower demand, extended periods of low wind and solar may result in shortfalls. The shift therefore is highly correlated with the changing availability of the resources for power generation.

In a VRE-dominated power system, the winter output of solar, both residential and grid scale, is naturally lower. The reduced energy provision from that resource reduces the surplus capacity to recharge storages. For example, a series of cloudy days with little wind may allow storage to recharge to an extent, but reduced wind capacity due to low wind conditions after sunset results in the stored energy being quickly exhausted to support customer demand overnight.

This situation is made clearer in the simulation modelling as the levels of wind and solar have been deliberately reduced to study the impact of such events. In a more adequately provisioned system, these outages may have characteristics like those in the simulated system with significantly reduced capacity but would only occur in significant dark doldrum periods.

This is a clear shift away from the current paradigm in which USE is more likely to occur during periods of unusually high demand coincident with reduced thermal plant availability from unplanned maintenance or forced outages.

5.2.2 Caveats and limitations

This finding is a result of trends appearing in the AEMC's under-resourced NEM model derived from AEMO's ISP. The future power system will look different from what has been modelled.

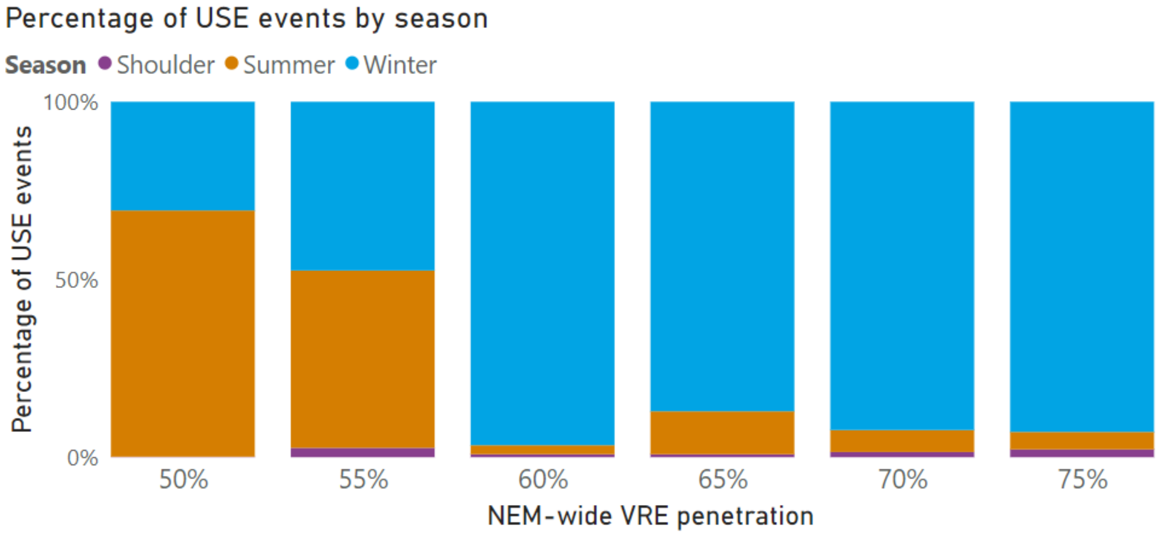
The finding that USE may become more predominant in winter is consistent with the other findings in the model. USE events may become increasingly driven by weather conditions during which the resources available to VRE generators are well below seasonal averages. Importantly, because of the shorter days and greater probability of cloud cover, these weather conditions are more likely to occur in winter. Therefore, we consider the finding to be robust.

5.2.3 Supporting evidence

The trend of USE events moving predominantly to winter months as the NEM transitions is clear across all the modelled results.

Figure 5.4 below show the percentage of unserved energy events occurring in different periods of the year as the VRE penetration in the region increases.[58]

Figure 5.4: In an under-resourced system, the seasonal pattern of USE events may change with increasing levels of VRE penetration



Note: This chart is based on calibrated data as described in appendix A.4.

While the penetration of VRE in each region differs, the broad trend is constant across all regions – i.e. as the NEM transitions, the proportion of USE events in winter compared to other periods also increases.

It is worth noting that Queensland is the only region that continues with a more significant proportion of summer events for VRE penetration greater than 65 per cent. This appears to be related to the capacity reductions made in New South Wales and the impact of at least one reference year for Queensland having a significant period of low VRE during summer.

Question 6: Reliability risks may shift from mainly being in summer to winter

Do stakeholders agree that the results presented in this paper support this finding, or is there further work needed?

Do stakeholders consider the shift in seasonality of the USE events has implications on what the form of the reliability standard should be?

58 Note that in this chart, Summer represents months from December to March (inclusive) and Winter represents months from May to August (inclusive).

5.3 USE events may be driven increasingly by weather

5.3.1 Key findings and implications

The simulation modelling indicates that as the NEM transitions, USE events may be increasingly driven primarily by weather patterns. The impact of these weather patterns on USE may be more severe as the NEM transitions.

Specifically, the modelling identified the following key insights related to weather:

- as the NEM transitions, reference years (driven primarily by temperature and weather) may have a far greater impact on the mean time between events, depth and duration of USE events than forced outage samples or demand traces
- 'dark doldrums' or periods of very low wind and solar availability may significantly impact the depth and duration of USE events
- as the proportion of VRE in the system increases, the impact of these dark doldrums or periods of low wind and solar availability on the depth and duration of USE events may also increase.

The AUSM base model and its sensitivities were constructed such that the impact of differing temperature profiles and weather patterns on USE characteristics could be studied. Specifically, the model was run using 13 different reference years, 11 of which were provided by AEMO, and two of which were constructed using an extensive 82-year dataset of VRE availability provided by Griffith University. (See appendix A.5.6 for more information on how this sensitivity was constructed.)

These differing reference years are constructed using historical data and correspond to different profiles of grid-scale wind and solar availability, rooftop PV generation, and regional demand. Running the AUSM over a horizon of increasing levels of VRE penetration and several different reference years (which are primarily dependent on weather and temperature), provides information on how significantly differing weather patterns impact USE characteristics.

For the purpose of this finding, a 'dark doldrum' is defined as a period in which total renewable availability is more than two standard deviations away from the seasonal average. More work will be undertaken to define a 'dark doldrum' more strictly for the Draft and Final Reports.

5.3.2 Caveats and limitations

These findings are based on a small number of samples – 11 reference years, two additional dark doldrum periods, 10 stochastic forced outage samples and two demand profiles. To understand the range of outcomes that differing weather patterns can have on USE, further modelling may need to be done using a larger sample size.

We will also use the Griffith dataset to generate a larger dataset of dark doldrums to understand the likelihood of these events, and to run additional sensitivities on a wider range of low wind and solar periods. The data set will also be used to try to create a probability distribution of wind and solar events. See section 4.6 for a more complete description of the bootstrapping analysis.

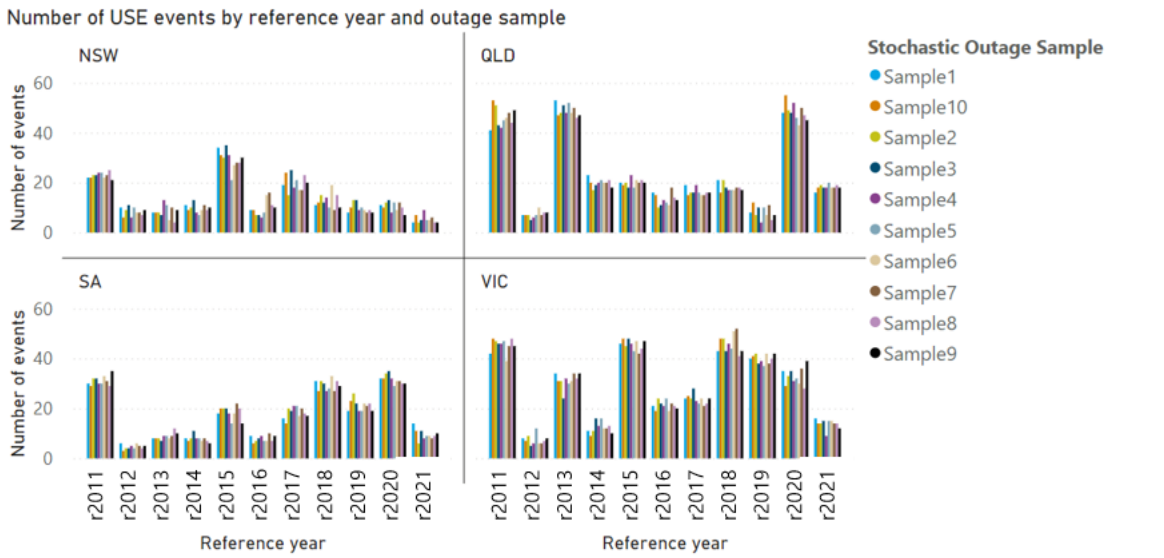
5.3.3 Supporting evidence

Reference years may drive USE outcomes more so than forced outage rates or demand traces

The AUSM model base case was run using 11 different reference years and 10 different outage samples. Each outage sample represents a different Monte Carlo simulation of the forced outage rates associated with each thermal generation.[59]

Figure 5.5 below shows the number of USE events generated for different reference years and stochastic outage samples, where the reference year is grouped on the x-axis, and the colour of the bar represents the forced outage sample.

Figure 5.5: In an under-resourced system, weather conditions in a given year appear to drive USE outcomes more than plant outages



For the same region and reference year, there is some variability in the number of events generated by different forced outage samples. However, this is very small compared with the variability between reference years. This effect is also clear when comparing the variability of duration and USE annual demand ratio. This is explored in more detail in appendix C.

The modelling has also found that as the NEM transitions to a higher VRE system, the impact that different demand traces have on USE outcomes becomes insignificant. This is also described in more detail in appendix D.1.

This result is likely due to USE moving predominantly from summer to winter and being spread out across the day. A significant factor that may be exacerbating this is AEMO's current methodology for constructing the 10% PoE and 50% PoE demand traces. The approach most notably affects the seasonal peaks and troughs during summer and winter but leaves demand periods outside those periods largely unchanged.

59 The Monte Carlo simulation provides multiple possible outcomes and the probability of each from a large pool of random data samples.

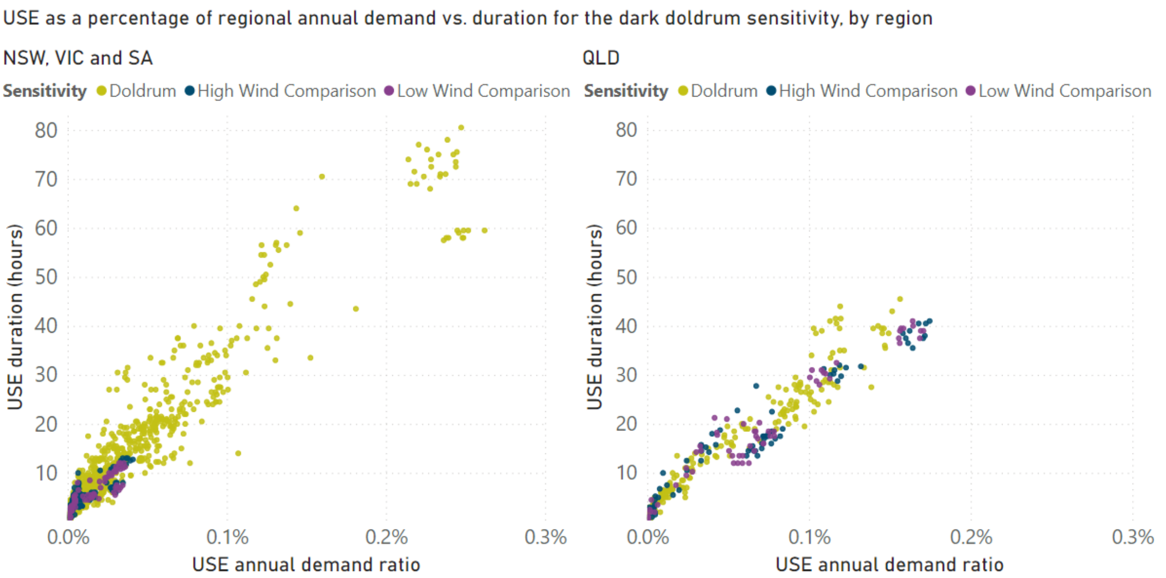
'Dark doldrums' or periods of very low wind and solar availability may impact the depth and duration of USE events

This finding is clear in the results of the model from low wind and solar periods in the base case, and through the impact of the dark doldrum sensitivity in which two NEM-wide dark doldrum periods were modelled. The three dark doldrums in the 82-year Griffith University data that resulted in higher USE events represented much lower resource conditions than those found in AEMO's 11-year wind and solar traces. Linked clearly to the depth of the reductions in resource availability for the renewable energy generators, examining the correlation between the characteristics of USE events and weather needs further research.

The dark doldrum sensitivity examined the impact of two of the three NEM-wide dark doldrums identified. For the purposes of this modelling, the dark doldrums were defined as periods where the three-day rolling average NEM-wide renewable output was more than two standard deviations below the seasonal average.

Figure 5.6 below uses the uncalibrated data and shows the USE as a percentage of regional annual demand (USE annual demand ratio) and duration of USE events for the dark doldrum sensitivity compared with the comparison runs. The chart on the left-hand side shows New South Wales, Victoria, and South Australia events, and the chart on the right-hand side shows Queensland events. We note that the details of how this sensitivity and the comparison runs were constructed are outlined in appendix C.

Figure 5.6: In an under-resourced system, dark doldrum conditions impact USE outcomes significantly and the impact varies by region



The uncalibrated data provides a relative measure but exaggerates the scale of the USE events because it is very sensitive to the generation remaining in the under-resourced model. Uncalibrated data was used here because we are interested in the relative overall levels of USE, whereas calibration would by design adjust the total USE in each case to a similar level (that of the existing reliability standard). Figure 5.6 shows that the rare dark doldrum events have a material impact on USE in the under-resourced AUSM model. These results cannot be taken as absolute. In reality, in a more adequately planned and balanced system, the levels of USE resulting from a doldrum event would be different. However, this scenario highlights that there are potentially rare but significant events that will impact USE outcomes and require careful consideration.

For New South Wales, Victoria and South Australia, it is very clear that the dark doldrum event in the Griffith data caused more USE events, and these events had a much greater duration and ratio of USE to annual demand.

This is not the case for Queensland, as the dark doldrum sensitivity produced slightly less severe events than the comparison runs (which use the reference year 2013). Further investigation showed that the dark doldrum event identified in the Griffith data at the NEM level was less severe in Queensland, while the Queensland reference year 2013 included a period of low wind and solar availability.

The increase in the USE annual demand ratio, duration and frequency of USE events in the dark doldrum sensitivity compared with the comparison periods for regions outside Queensland indicates that the dark doldrum conditions may produce much more severe USE events.

The fact that in Queensland the differences are less dramatic does not weaken this finding, since the Queensland comparison year also included a period of low wind and solar availability. When we compare the severity of USE in the reference year 2013 to other reference years it is clear that the reference year 2013 does produce more severe USE events. This is explored in more detail in appendix C.

As the VRE penetration in the system increases, the impact of these periods of low wind and solar availability on the depth and duration of USE events may also increase

The modelling has also demonstrated that as the VRE penetration in the system increases (as a proportion of total capacity), the extent to which low renewable energy availability, including dark doldrum periods, impacts USE also increases.

The supporting evidence for this finding is explored in more detail in appendix C.

Question 7: USE events may be driven increasingly by weather

Do stakeholders agree that the results presented in this paper support this finding, or is there further work needed?

Do stakeholders consider an increase in the impact of weather on USE events has implications on what the form of the reliability standard should be?

Do stakeholders have views on the broader implications of this finding on the reliability framework, such as how AEMO forecasts USE in the future ESOO?

5.4 Events may spread across the day rather than just appearing in the evening peak

5.4.1 Key findings and implications

The modelled results indicate that as the NEM transitions, the time of day that USE events occur may also be shifting. The early years of the modelling horizon in which there is a relatively low level of VRE in the NEM show that unserved energy events occur almost exclusively in the evening peak between 5 pm and 9 pm.

As the modelled NEM transitions, this USE begins to spread out across the day, with a lower relative proportion occurring in the evening peak. While the evening peak remains the period with the highest proportion of USE overall, it is notable that because the USE events may be longer their impact may extend overnight and into the following morning.

This widening of the USE distribution over time is primarily driven by the increase in the duration of the events. USE events were historically short, caused by plant outages coinciding with very high demand. As the NEM transitions, USE events may become more prolonged, driven by dark doldrums.

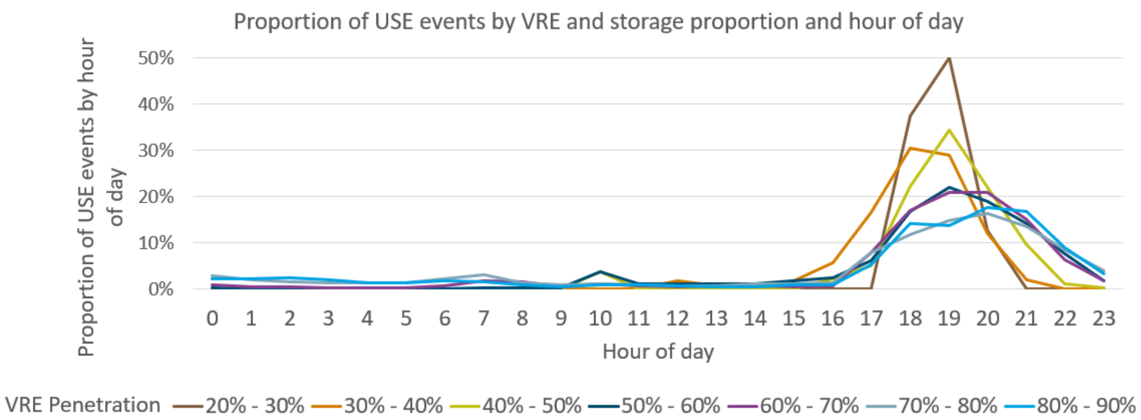
5.4.2 Caveats and limitations

The finding that USE may spread out across the day is consistent with the other findings in the model in that USE events may become increasingly driven by poor weather conditions. These poor weather conditions are more likely to be longer in duration and occur outside of evening peak. Therefore, the finding is considered robust, with a high degree of confidence in the results.

5.4.3 Supporting evidence

Figure 5.7 below shows the proportion of USE events occurring by hour of day throughout the simulation period for the calibrated results, where the colour of each area represents different levels of VRE penetration in a region. The results have been aggregated to include USE events for all mainland states.

Figure 5.7: As the NEM transitions to higher VRE penetrations, there is a broadening of USE events



The AUSM model demonstrates that as the NEM transitions, the proportion of USE events that occur between 6 pm and 9 pm remains high. However, there is also a spreading out of USE at all times of the day. When the proportion of VRE in the system is low (<65 per cent), over 79 per cent of USE events occurred between 6 pm and 9 pm. It is worth noting that when VRE penetration increases this proportion decreases to 62 per cent.

The proportion of USE in the middle of the day remains low due to higher solar output but it is not negligible. We note that there is a slight spike in USE at 10 am for lower levels of VRE penetration. This is a result of how batteries are modelled in the AUSM, where their daily horizon begins at 10 am each day. In reality, this spike would likely be smoothed out across the morning.

A combination of significant levels of solar and storage can be effective at meeting the evening peak demand provided there is a sufficient surplus in the middle of the day. The surplus allows storage technologies to charge, in turn supporting the system to meet an evening peak.

That said, the challenges occur when:

- there is insufficient daytime surplus to recharge storage levels
- an extended energy shortfall over a number of days reduces the level of energy stored in longer-term storage, affecting the energy available at evening peaks
- there is insufficient capacity in flexible or storage technologies to meet peak demand for sufficient duration in the absence of any concurrent wind generation
- long-duration pumped hydro is unable to fully discharge its storage fast enough leading to high state of charge values during USE events
- wind energy output is low overnight in periods where low solar during the day has left storages unable to adequately charge to cover the difference between variable supply and demand.

Question 8: Events may spread across the day rather than just the evening peak

Do stakeholders agree that the results presented in this paper support this finding, or is there any further work needed?

Do stakeholders consider the change in the timing of USE events has implications on what the form of the reliability standard should be?

5.5 The sensitivity analysis supports the key findings from the modelling

A key finding from this analysis is that sensitivities broadly support the key findings and insights from the modelling. These sensitivities served as a stress test for the model, generating USE events at differing levels of interconnection and technology mix. Under these conditions, the four key insights identified in the previous sections still hold true.

As outlined in section 4.3, we have designed various sensitivities to understand, in broad terms, how differing demand profiles, technology mix and interconnection impact the levels and characteristics of USE. They are not designed as a forecast to assess the likelihood of unserved energy risk if specific projects were to be delayed or accelerated.

Specifically, the modelled sensitivities included:

- demand variation (Sensitivity 1)
- delayed interconnection (Sensitivity 2a)
- delayed interconnection with additional batteries (Sensitivity 2b)

- reduced depth of long-duration storages (Sensitivity 3a)
- reduced depth of long-duration storages with additional distributed virtual power plant (VPP) and vehicle-to-grid (V2G) resources (Sensitivity 3b)
- accelerated decarbonisation (Sensitivity 4a)
- accelerated decarbonisation with additional wind (Sensitivity 4b)
- alternative technological development (Sensitivity 5a)
- alternative technological development with reduced VRE capacity (Sensitivity 5b)
- significant VRE doldrums (Sensitivity 6 – results are discussed in section 5.3).

The results are presented primarily as the overall change in total depth (in MW) or duration (in hours of USE) compared to the base case. These comparisons are either done at the region, or at the financial year. Even though this model is not a forecast of USE outcomes in any given year, the financial year is presented in these results as these sensitivities were necessarily run over different horizon periods.

In addition, the results of these sensitivities as the NEM transitions to a higher VRE penetration system also included that:

- the impact of using a 50% PoE demand profile as opposed to a 10% PoE profile on USE outcomes may become less significant
- additional interconnection may be of critical importance in mitigating USE, however, it may be less effective in winter periods as opposed to summer periods
- generation technologies that are based on a more abundant fuel supply may be better at mitigating USE events than technologies that are energy-limited
- distributed batteries may be effective at mitigating USE events
- halving the duration of pumped hydro storage may not have a significant impact on USE outcomes.

Further information about the detailed sensitivity results is available in appendix D.

Question 9: Sensitivity analysis

Do stakeholders have any feedback on the sensitivities and the results of the sensitivity analysis?

6 Shortlisted options for the form of the APC

The Panel is proposing to shortlist two options for the form of the APC for further consideration and stakeholder feedback. The two options are:

- retaining the current form of the APC
- indexing the APC to CPI – noting that the MPC and cumulative price threshold (CPT) are currently indexed to CPI.

The Panel considers that alternative forms of the APC, such as a link to dynamic fuel prices, a link to the gas APC, or a trigger mechanism for increasing the APC, should not be considered further in this Review.

In shortlisting these options, the Panel has considered stakeholder feedback on the Issues Paper as outlined below. A detailed summary of stakeholder feedback is provided in section 2.5.

6.1 The APC should be predictable to avoid adverse impacts on contract markets

The Panel agrees with most stakeholders that price uncertainty caused by a dynamic APC would have material impacts on the efficient operation of contract markets. Uncertainty in the level of the APC creates additional price risk for market participants.

This would in turn lead to higher costs for consumers, as the risk premium created by such uncertainty is ultimately passed onto consumers, or a reduction in the liquidity of contracts markets.

As many stakeholders identified, the options of linking the APC to dynamic fuel prices or having a trigger mechanism to increase the APC would create uncertainty and adverse market conditions.

6.2 The form of the APC should be technology-neutral

As noted by some stakeholders, gas-fired generators may not always represent the marginal generator in periods of reliability risk in the future. Batteries, for example, have no fuel costs but would require a sufficiently high level of the APC to discharge at a higher price than they have paid to charge.

The Panel considers that a more technology-neutral approach to the APC is desirable to ensure the effective operation of administered pricing without the adverse impacts of uncertainty in the level of the APC. This means the preferred form of the APC would be one that does not depend directly on gas prices or the gas APC.

6.3 The higher level of the APC may resolve the issues that triggered this Review

As discussed in the Issues Paper, the form of the APC came under consideration following the APP and market suspension in June 2022. The level of the APC was not sufficient for some generators to recover their marginal operating costs, yet those generators were needed to meet system demand, and ultimately operated under AEMO directions.

In November 2022, the AEMC temporarily increased the APC from \$300/MWh to \$600/MWh until 1 July 2025.[60] The AEMC has recently made a draft rule that would maintain the APC at this level

60 AEMC rule change, 'Amending the administered price cap', final determination, 2022.

until 30 June 2028.[61] This differs slightly from the Panel's recommendation in the 2022 RSSR which was to set the APC at $500/MWh.[62] The final determination for this rule change (*Amendment of the Market Price Cap, Cumulative Price Threshold and Administered Price Cap)* is to be published on 7 December 2023.

The options raised in the Issues Paper included linking the APC to dynamic fuel prices as a means of ensuring that generators could recover marginal costs during APPs.

Stakeholders, however, generally considered that market conditions like those of June 2022 would be prevented by a sufficiently high level of the APC. The Panel has considered this feedback and does not intend to take the dynamic fuel price linking option further in this Review.

The Panel has narrowed down the options for the form of the APC to the current form and indexation to CPI. These options were selected because stakeholders indicated that other options raised in the Issues Paper were not preferable, for the reasons discussed above.

Question 10: Shortlisted options for the form of the APC

Do you agree with the Panel's proposal to shortlist these two options as noted above? If so, which option do you prefer?

What do you consider to be the relative benefits and risks of the shortlisted options?

61 AEMC rule change, 'Amendment of the Market Price Cap, Cumulative Price Threshold and Administered Price Cap', draft determination, 2023.

62 Reliability Panel, '2022 Reliability Standard and Settings Review', Final Report, 2022.

A Development of the modelling

This appendix describes the development of the AEMC USE Simulation Model (AUSM) in more detail. The AEMC engaged Cornwall Insight Australia (CIA) to assist in developing the AUSM.

A.1 Model setup and assumptions

The AUSM is a model of the NEM constructed in PLEXOS using AEMO's 2022 ESOO as a basis, with certain modifications as described below.

The model uses renewable generation and demand data from 11 historical reference years (the same as used in the ESOO) to account for the effects of varying weather conditions. It also uses 10 forced outage samples to introduce a level of random capacity failure and create more examples of USE events to analyse. The following subsections outline additional datasets provided by AEMO and Griffith University, that were integrated into the model.

A.1.1 AEMO's Integrated System Plan

The 2022 ISP was used to estimate the build-out capacity profile of VRE generators identified in REZ and non-REZ locations over time.[63]

The REZs are areas with potentially high-quality renewable energy resources, where VRE projects can be developed together to utilise the economies of scale, and where targeted transmission upgrades can be made to unlock those resources. These were developed by AEMO in consultation with stakeholders ahead of the 2018 ISP.[64]

A.1.2 Griffith University's VRE generation dataset

A dataset of 82 years of nominal VRE (solar and wind) generator output in REZs across the NEM was developed and expanded by Griffith University to the longer-duration ERA-5 weather data series in 2022.[65]

Griffith University shared this dataset with the Panel to provide a broader set of weather patterns that could be experienced in the NEM, which may not otherwise be captured in AEMO's reference year traces.

This data was used for a sensitivity in which two dark doldrum periods were extracted from the Griffith dataset and simulated in the AUSM. The Draft Report may include more extensive statistical analysis of this dataset to understand the likelihood of different weather conditions including dark doldrum events.

Details on how the dark doldrum sensitivity was constructed using this dataset are given in appendix A.5.6.

A.1.3 AEMO's Inputs, Assumptions and Scenarios Report

Information from the Draft 2023 IASR was used to update model properties in the AUSM.[66] This update was needed as the base model (using the 2022 ISP) was related to the 2021 IASR which is now out of date. The Final 2023 IASR has not been incorporated into the model as it was released

63 AEMO, '2022 Integrated System Plan', 2022.

64 AEMO, '2018 Integrated System Plan', 2018.

65 J Gilmore, T Nelson and T Nolan, 'Quantifying the risk of renewable energy droughts in Australia's National Electricity Market (NEM) using MERRA-2 weather data', Griffith University Centre for Applied Energy Economics & Policy Research, 2022.

66 AEMO, 'Draft 2023 Inputs, Assumptions and Scenarios Report', 2022.

midway through this Review (28 July 2023) and did not include any major changes that would be relevant to this modelling exercise.[67] The AUSM is not designed to be a forecast of the future of the NEM, so minor updates to the IASR would not impact the overall findings.

A.2 Additional Data and Assumptions

The AEMC received additional data from AEMO which was not included in the ESOO or ISP datasets to extend short-term ESOO-related properties to a longer-term model, including:

- additional generation build by technology
- REZ limits and augmentations
- build-aligned closure dates
- the set of 50% PoE demand traces.

The following additional assumptions have also been integrated into the model based on CIA's evaluation of the market, the AEMC's discussions with AEMO, and the need for strategies to mitigate modelling limitations:

- **Snowy 2.0 unconstrained operation**: This is assumed due to the complexity of adapting NEMDE-style (NEM dispatch engine) constraints to future network topology. It is assumed that the network build will be done in such a way to optimise the use of Snowy 2.0 so that it is fully utilised.
- **Doubling of the southerly VIC-NSW transmission limit**: Like the assumptions around Snowy 2.0, it is assumed that the network will have adapted to enable full southerly flow from Snowy 2.0 to provide the capacity to support the Victorian region.
- **Turning off certain technical constraints after 2033:** Technical constraints created for the 2022 ESOO began excessively binding in the AUSM as new capacity and changing market conditions emerged. The AUSM also included REZ limits taken from the ISP, and we expect that any constraints in place at the end of the modelling horizon would have a different formulation to those in the 2022 ESOO.[68] For these reasons, the AUSM uses the REZ limits exclusively instead of near-term thermal and stability constraints which would become inaccurate. This decision was made acknowledging that significant transmission upgrades were being modelled as per the 2022 ISP which would fundamentally shift the technical constraints in the system.
- **Halving the duration of eight-hour batteries:** The 2022 ISP build-out is optimised to a least-cost whole of system objective. As such, it heavily favours eight-hour duration battery storages. As the goal of the AUSM is to generate a significant sample of USE, these eight-hour battery durations were halved. This also reflects current real NEM build trends.
- **Adding additional capacity:** Additional capacity was added to Victoria, South Australia and Queensland to align with future projects and government policy, and to balance out the reduction in capacity applied to REZs (described in appendix A.3):
  - Additional offshore wind capacity and open-cycle gas turbine (OCGT) capacity was added to Victoria from FY32 (financial year 2032) onwards.
  - Capacity of large OCGT generators in South Australia was increased from FY2030 as a proxy for South Australia's Hydrogen Plan.

67 AEMO, '2023 Inputs, Assumptions and Scenarios Report', 2023.

68 The last constraint in the 2022 ESOO began on the full commercial use date of Project EnergyConnect.

- Capacity of the North Queensland pumped hydro generator was also increased in FY2035 and FY2040 as a proxy for the Queensland Energy and Jobs Plan (QEJP) (announced after the ISP was published).

A.3 Removing Capacity to Generate USE

Once the base model was set up and validated for its accuracy and suitability, generation capacity was iteratively removed from REZ locations. The aim was to generate USE as close to the reliability standard as possible in as many years as possible.

This delivered a data set of USE events that can be used to investigate the shape, profile and specific characteristics of these events.

This work does not consider the economic perspective of the generation capacity reduction. That is, whether the applied reduction in generation capacity triggers a revenue-positive investment response to build out new generation projects. This would require a much more extensive input dataset to be built into the model and is out of scope for this Review.

The amount of capacity removed from REZ locations was such that an indicative spread of USE events was observed across the modelling horizon in each region, ranging from non-existent to significant. The final reduction in REZ capacity across the horizon that was used in the AUSM, by region, is given below, where the percentage reduction is applied equally to all new REZ capacity:

- **New South Wales** – 30 per cent reduction
- **Victoria** – no reduction
- **South Australia** – 30 per cent reduction
- **Queensland** – no reduction
- **Tasmania** – 70 per cent reduction

The reason for the differences between regions is that each region has a very different capacity buildout and technology mix. These reduction values were determined through an iterative approach in which different values were tested until we observed a sufficient level of USE in each region to comprehensively study the USE characteristics.

In particular, the AUSM creates little to no USE in Tasmania despite the removal of 70 per cent of REZ capacity in that region. This is because Tasmania has a large amount of existing hydro generation capacity relative to its expected demand. Removing further generation capacity from Tasmania would cause excessive USE in Victoria and other states, as there would be less energy available to export via Basslink. As a result, this paper does not present any USE results for Tasmania. However, the inclusion of Tasmania in the AUSM is critical to modelling USE in the NEM as a whole.

A.4 Results calibration to provide a basis for examining trends in the AUSM

Comparing different levels of VRE penetration in a model with material reductions in capacity over time and isolating effects related to that capacity variation requires some post processing. While some of the trends were clear from the raw data, others, such as the duration and level of USE, appeared to be influenced by the overall levels of electricity supply in each financial year modelled.

A calibration approach was designed to moderate the USE values and major events so that the trends related to relative levels of VRE capacity would be revealed. Calibrating the results to the existing reliability standard was considered most appropriate as it is a known quantity.

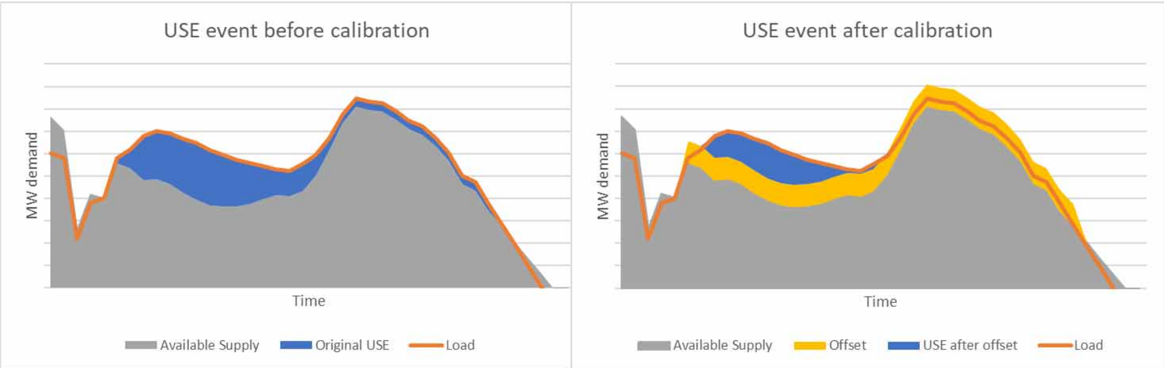
Practically, this approach tested the total average annual USE in each region. Where that level was greater than the reliability standard, an adjustment was made to the capacity in post-processing such that the standard was achieved.

This calibration step reprocessed the results for each scenario individually. It involved summing the USE in a financial year and reintroducing a fixed ‘offset’ that reduced the USE in each interval until the total annual USE was equal to the reliability standard. Offsets were not needed for some years and scenarios as the total USE was already less than the existing 0.002 per cent reliability standard.

The adjustments made through the fixed offset removed some of the smaller events (those for which the offset was as large as or larger than the level of USE in any given interval) and reduced the depth and duration of larger events. Some long events were also broken into multiple shorter, less deep events.

Figure A.1 below shows how the offset changes the level of USE, the duration and the depth of an event.

Figure A.1: Applying a fixed offset reduces the depth and duration of USE events



Although the technique was not complex, we trialled two different calibration methods. One was equivalent to the way reliability is tested in the ESOO and the second was to average the calibrations for each of the different reference years.

- **Approach 1:** calculates an overall annual offset for each scenario, region, and financial year by averaging individual offsets for each reference year across all forced outage samples.[69]
- **Approach 2:** calculates an overall annual offset for each scenario, region, and financial year by considering all reference years and forced outage samples at the same time.[70]

This approach ensures that the average USE in each scenario and financial year is strictly at or below the standard. This does not mean that every event or individual sample is at the reliability standard, as many samples will have no unserved energy.

69 That is, an offset was determined that brought the USE for the events in all the samples combined for each scenario, region, financial year, and reference year back to the standard. The overall annual offset for the scenario, region, and financial year was then determined as the average of the offsets for each reference year. This approach reduces the depth and duration of USE events considerably whilst maintaining variability between the reference years. While the individual offsets would result in USE at or below the reliability standard, the financial year result and individual events could still be materially above the standard.

70 That is, an offset was calculated in the way that AEMO would determine if a financial year had satisfied the reliability standard. It calculates an offset that brings the average cumulative USE for all reference years and forced outage samples for a scenario, region, and financial year back to, or below, the reliability standard.

Both approaches produce results that broadly support the overall findings. However, all charts and graphs in this paper that refer to calibrated data are using the first approach as it does not reduce the variability in USE events as significantly as the second approach.

The Panel recognises that this process is not without limitations. Adding capacity back without simulation does not reproduce the dispatch optimisation that would allow capacity to be shared between regions. However, it does provide a consistent mechanism to facilitate the comparison of USE characteristics over time and different technology mixes.

A.5 Sensitivities Setup

This section describes in more detail the sensitivities that were set up as part of the modelling exercise.

A.5.1 Sensitivity 1 — Demand Variation

This sensitivity was set up using 50% PoE demand traces rather than 10% PoE demand traces to understand the changes in the characteristics of USE events under lower demand. This sensitivity also acts as a proxy for substantial demand side participation at times of peak demand, as the biggest difference between the two sets of traces is that the demand peaks are amplified in the 10% PoE traces. This sensitivity was modelled for four snapshot financial years: FY30, FY35, FY40 and FY43.

A.5.2 Sensitivity 2 — Delayed Interconnection

Part (a) of this sensitivity models the impacts of a three-year delay to the interconnector projects VNI (Victoria-New South Wales interconnector), Marinus I, Marinus II, and QNI (Queensland-New South Wales interconnector). Part (b) simulates an accelerated uptake in short-duration storage technologies (potential response from the market) during the period affected by the delays (2028-2037). This sensitivity is used to compare a lower level of interconnection and how it may impact the USE characteristics, exploring the potential value of increased transmission in mitigating USE. Part (b) is used to understand how the characteristics of USE change when more short duration storage capacity comes into the market to potentially make up for reduced interconnection. This sensitivity was modelled for the period FY29 to FY36.

A.5.3 Sensitivity 3 — Reduced Depth of Long-Duration Storage

Part (a) of this sensitivity models the impact of halving the duration of storage for new pumped hydro capacities (QEJP, Cethana, etc). Part (b) of the sensitivity was to add an additional 20 per cent capacity to wind generators and to extend the capacity of all VPP and V2G generators beyond 2033 as a market response to lower pumped hydro capacity. Note that the assumptions around VPP and V2G capacity are derived from the 2022 ESOO. This sensitivity was modelled for the period FY38 to FY43.

A.5.4 Sensitivity 4 — Accelerated Decarbonisation

Part (a) of this sensitivity was to bring forward the retirement date of all fossil fuel-based gas generators by five years. Part (b) was to bring forward the build dates of new wind objects by five years to compensate. This sensitivity is designed to understand the impact of accelerated decarbonisation on USE characteristics, and how additional wind resources can impact USE under this scenario. This sensitivity was modelled for four snapshot financial years: FY30, FY35, FY40 and FY43.

A.5.5 Sensitivity 5 — Alternate Technological Development

Part (a) of this sensitivity was to increase the capacity of new gas build by 5 per cent of the overall VRE capacity in each year, as a proxy for a build of hydrogen generation. This sensitivity is designed to explore the value of a dispatchable technology in the future of the NEM. Part (b) of the sensitivity reduced the capacity of all VRE objects by 20 per cent of the base case build to further investigate the value of hydrogen generation in a scenario with less VRE capacity. This sensitivity was modelled for four snapshot financial years; FY30, FY35, FY40 and FY43.

A.5.6 Sensitivity 6 — Significant dark doldrums

This sensitivity was designed to understand the impact of dark doldrum periods on the characteristics of USE. Examples of dark doldrum periods were identified in the Griffith University dataset, detailed in appendix A.1.2.

For this analysis, a dark doldrum period was defined as any period in which the three-day rolling average NEM-wide VRE outputs (solar and wind totals combined) were more than two standard deviations below the seasonal mean. Using this methodology, we identified three dark doldrums: two eight-day periods in May 1992 and in May 2010, and a seven-day period in June 1972. Due to timing and resource constraints, only the two periods in May were modelled, however, the 1972 event may be considered in the Draft Report.

The dark doldrum scenario was constructed by substituting the REZ solar and wind generation profiles from April to June of 1992 and 2010 respectively into the AEMO 2013 VRE reference year profiles. As the Griffith data only provided information for REZs and not all NEM locations, each non-REZ VRE generator had to be mapped into the closest REZ to serve as a basis for comparison. The demand profiles for the reference year 2013 were also adjusted to incorporate the potential rooftop solar impact on grid demand. The 2013 reference year was selected as it appeared to have the closest VRE availability profile to 1992 and 2010 considering the NEM as a whole.

AEMO's wind and solar profiles also include high and low REZ VRE annual construction and output files for each REZ. These high and low profiles were used to construct two reference scenarios against which the two Griffith 1992 and 2010 sensitivities would be tested.

The dark doldrum sensitivity was modelled for the period April to June in financial years 2030, 2035, 2040 and 2043. It comprised the high and low reference scenarios and the sensitivity simulations with the 1992 and 2010 dark doldrums.

A.6 Modelling Limitations

The model that was used in this work comes with several limitations. Some are a result of the choice of modelling tool (PLEXOS), and some are due to limitations in data availability. These limitations are described below:

- **Perfect foresight**: This property has the greatest impact in our study on the utilisation of storage units. To mitigate this, and like the approach currently under consideration by AEMO, we have reduced the total energy storage available.
- **Restricting storages** to a predetermined state of charge targets: To mitigate this, we have shifted the solve window for modelling away from midnight to 10 am, when resource availability should be at its average daily peak.
- **Minimum interval lengths of 30 minutes:** No mitigation methods were attempted, but we acknowledge that real USE events are highly unlikely to fit neatly into 30-minute intervals.

- **Programmatic responses to events:** No mitigation methods were attempted, but we acknowledge that the actual running of the network and participants still has a human component that will react in a different way than software does.
- **Use of only historical weather patterns, which do not consider future climate conditions:** A range of reference years and other historical years were used to capture the scope of known climactic conditions, however, no new synthetic weather forecasts were used.

Additionally, as this model is not a forecast, all observed results must be considered acknowledging they were synthesised using under-resourced versions of the NEM. This means that the USE events modelled are likely more significant than events that would occur in reality. While the findings of this study, including the potential for longer and deeper events, are important, they do not show any need for additional actions to mitigate reliability risk. This report seeks to explore the characteristics of USE events, which are a possibility in any energy system, rather than indicate how often USE events are likely to occur in the future.

B Key definitions and assumptions

B.1 Defining the characteristics of the USE events

The results from the AUSM have been characterised under several different lenses in order to isolate effects and understand the results more clearly. The following definitions have been used:

Duration - measured in hours, refers to either event duration or USE duration as follows:

- *Event duration* refers to the number of hours between the start and finish of the event or cluster event.
- *USE duration* refers to the number of hours in an event or cluster with USE. USE duration is less than or equal to event duration.

Depth - measured in MW, refers to the half-hourly values reported in the modelling.

- At this stage the depth of the event has not been a specific focus of the analysis but will be more important in the next stage of analysis for the draft report.

USE - measured in MWh, refers to the energy lost in the event. This report predominantly measures USE as a ratio of event USE to either annual demand (consistent with the formulation of the existing reliability standard) or energy lost during the event or cluster event.

- *USE annual demand ratio* - The total USE of an event or cluster as a proportion of the regional annual load (this is so that the USE can be compared with the reliability standard).
- *USE event demand ratio* - The total USE of an event as a proportion of the total regional load during the event.

Mean time between events - measured in days, refers to the average number of days between USE events.

- While this variable is related to the frequency of events, it has not been a specific focus of the analysis at this stage. It may be more important in the next stage of analysis for the Draft Report.

B.2 Defining VRE penetration

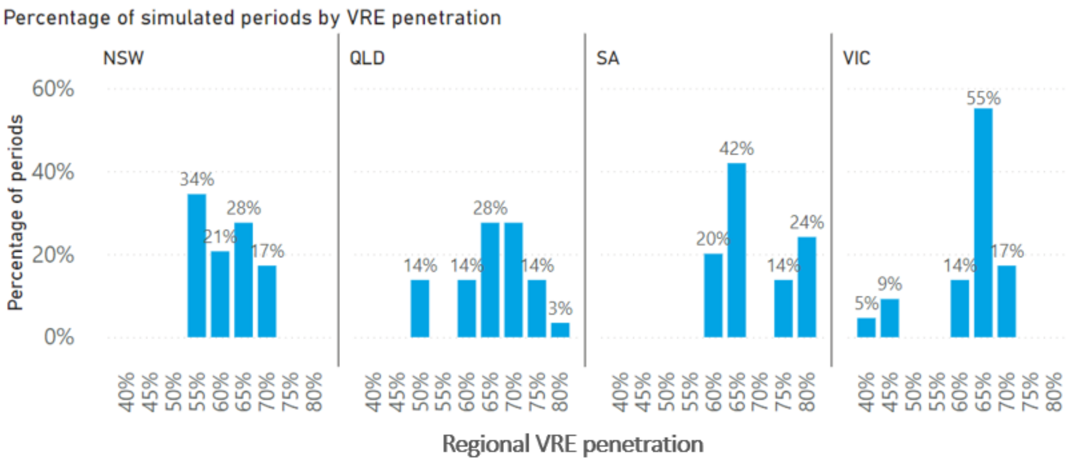
While the AUSM is loosely based on the ISP's VRE capacity construction program, some capacity was removed across the NEM to generate a larger sample of USE events to study, as discussed in chapter 4 and appendix A.3.

To reduce the likelihood of this analysis being considered a forecast, the changing characteristics of USE are presented with respect to the level of VRE penetration rather than with respect to time. VRE penetration refers to the percentage of total electricity capacity (not including distributed energy resources) that is made up of utility-scale wind, solar and batteries. The AUSM is not designed to be a USE forecast, and so any presentation of data with dates is likely to mislead readers.

Note however that whenever results are presented through the lens of increasing VRE penetration, other confounding variables are also changing. For example, as this stage of the project comprises a longitudinal study, demand is generally also increasing, and as generation retires and new developments are added the relative technology mix in each region changes as well. Analysis for the Draft Report may include additional sensitivities and control cases to isolate the impacts of VRE penetration from those of other variables.

Figure B.1 below describes the relative number of time periods (financial years) modelled at different levels of VRE penetration for each state.

Figure B.1: The percentage of total periods simulated in the AUSM at different levels of VRE penetration differs by region



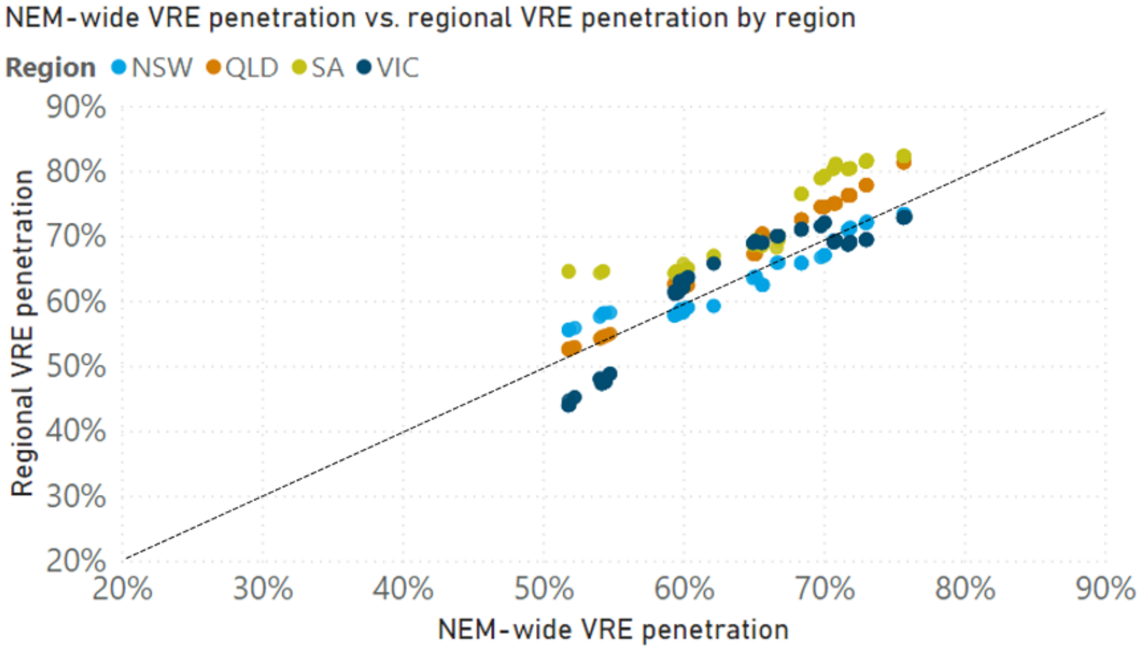
The proportion of VRE simulated in the model differs by region for the following reasons:

- the existing technology mix differs in each NEM region
- the buildout of new VRE capacity in each region differs according to the ISP (on which this model is loosely based)
- a different reduction in VRE capacity was applied to each region to generate sufficient USE events (see appendix A.3).

Sections of this paper also present changing USE characteristics at different levels of NEM-wide VRE penetration, rather than at regional-level VRE penetration. This measure is more appropriate when presenting NEM-wide data.

Figure B.2 below shows the relationship between regional VRE penetration and NEM-wide VRE penetration for different regions. Each dot represents an event at each level of regional and NEM-wide VRE penetration. Note that there are only a small number of dots visible on the chart since many events occur at the same levels of VRE penetration.

Figure B.2: In the AUSM, each region has different levels of regional VRE penetration compared with NEM-wide VRE penetration



The black dotted line represents points where regional VRE penetration would be equal to NEM-wide VRE penetration. Dots above the line mean that the VRE in the region is higher than the overall NEM levels, and dots below the line mean that the region has lower VRE penetration than the NEM.

Note that South Australia and Queensland generally have higher regional VRE penetration compared with the NEM, whilst New South Wales and Victoria generally have lower regional VRE penetration compared with the NEM.

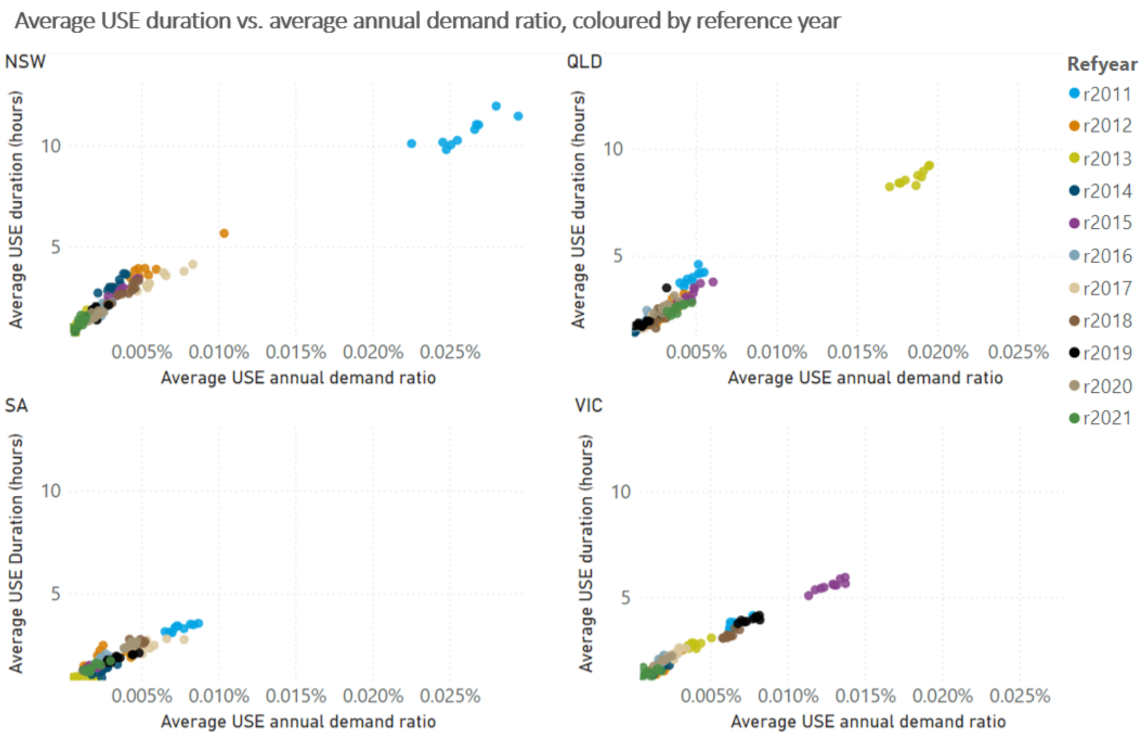
C Supporting evidence for finding that USE events may be driven increasingly by weather

As discussed in section 5.3 of this report, the modelling indicates that USE events may be increasingly driven primarily by weather patterns as the NEM transitions. In this section we provide further supporting evidence for this finding.

C.1 Reference years may drive USE outcomes more so than forced outage rates or demand traces

It was shown in section 5.3 that weather conditions in a given year tend to influence USE outcomes more strongly than plant outages (see Figure 5.5). This effect is also demonstrated in Figure C.1 which shows the average USE annual demand ratio and average duration of USE events. Each dot represents a different sample, and the colour represents the reference year. This illustrates that the choice of reference year, rather than the forced outage sample, accounts for most of the variability in duration and USE annual demand ratio.

Figure C.1: In an under-resourced system, weather may cause more variability in USE duration and USE depth than plant outages do



Note: This chart uses calibrated data as described in appendix A.4.

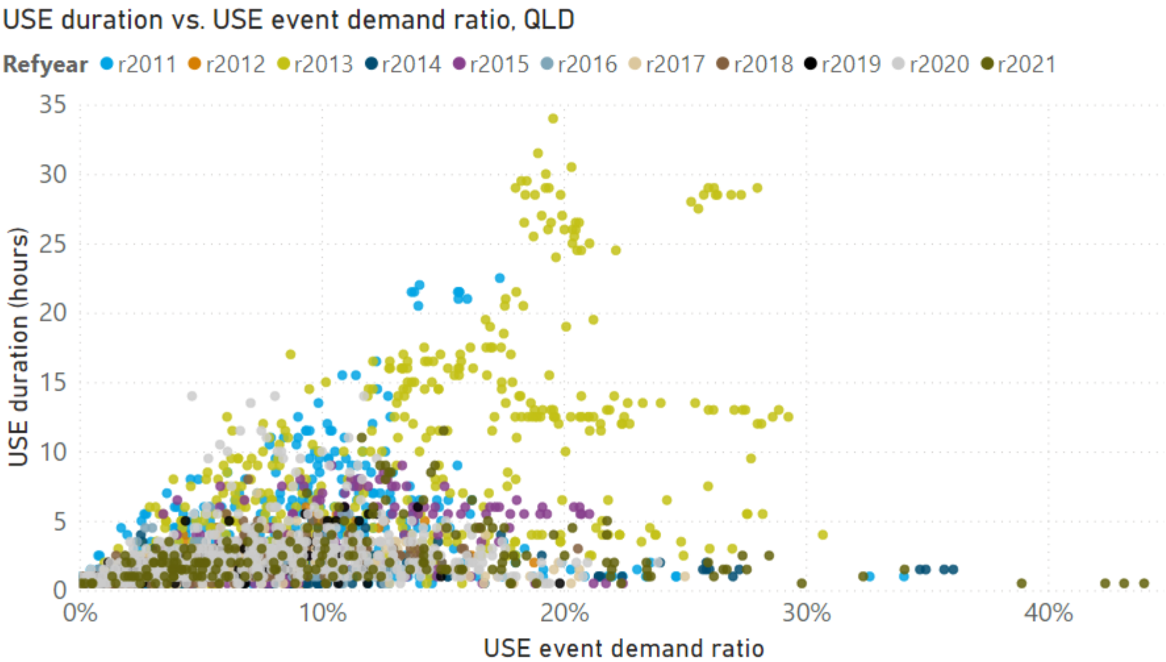
Figure C.1 highlights the fact that larger outlier USE events are driven by distinct reference years, as there is a reference year for each of New South Wales, Queensland, and Victoria which sits outside the bulk of the distribution. By contrast, all the forced outage samples for the same reference year (represented by dots of the same colour) tend to cluster together and do not produce similarly large outliers.

C.2 Dark doldrums may significantly impact the depth and duration of USE events

The dark doldrum sensitivity provides additional evidence for the increased influence of weather conditions on reliability risk in the future NEM. The increase in the USE annual demand ratio, duration and frequency of USE events in the dark doldrum sensitivity compared with the comparison periods for regions outside Queensland indicates that dark doldrum conditions produce significantly larger USE events compared to normal weather conditions (see Figure 5.6).

The fact that in Queensland the differences are less dramatic does not weaken this finding, since the comparison year (2013) also included a period of low wind and solar availability in Queensland. When we compare the depth, duration and number of USE events in reference year 2013 to other reference years it is clear that reference year 2013 does indeed produce more severe USE events. Figure C.2 shows Queensland unserved energy events by reference year, where the y-axis is the USE duration in hours and the x-axis is the USE event demand ratio for the calibrated data.

Figure C.2: Reference year 2013 had a significant impact on the depth and duration of USE events in Queensland

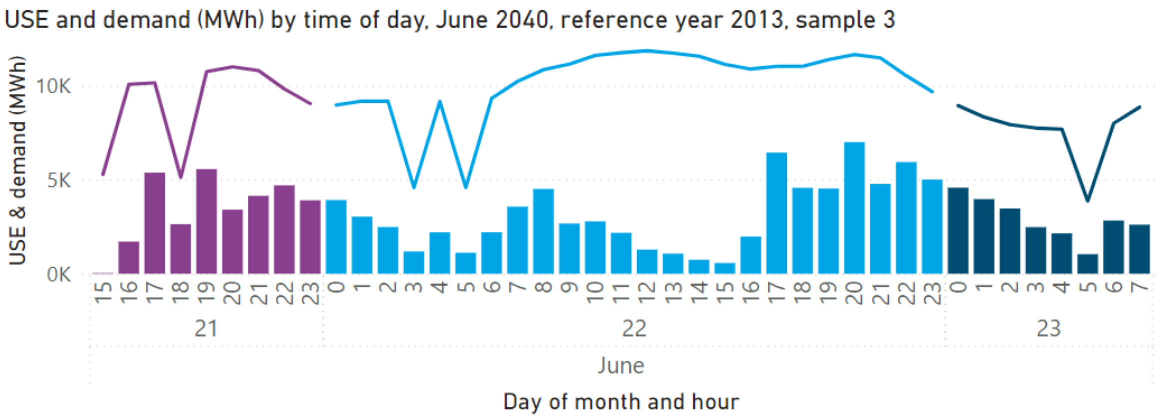


Note: This chart includes some very large events of 25-30 hours USE duration and 25-30 per cent USE event demand ratio. While these events may be severe, we emphasise that they have been generated in a deliberately under-resourced model of the NEM and are extremely unlikely to occur in reality. This chart uses calibrated data as described in appendix A.4.

This is also demonstrated when analysing the average wind, solar and demand conditions in Queensland throughout June in reference year 2013.

Figure C.3 shows the amount of USE during a large USE event in Queensland using reference year 2013, where the bars represent USE in MWh and the line represents regional demand in MWh. The event lasts from 3:30 pm on June 21 until 7:30 am on June 23. This USE event is shown as modelled in FY 2040, but a similar event appears in every financial year and across all forced outage samples. This was the only USE event in June of FY2040.

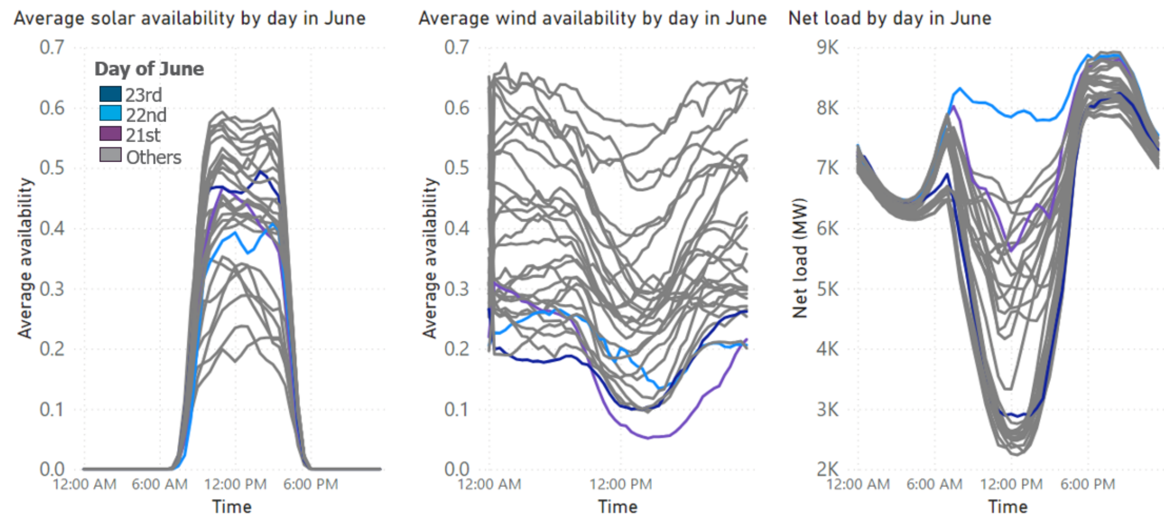
Figure C.3: Reference year 2013 produced a large USE event in Queensland in June



Note: Bars indicate the USE in each hour of the day and the line indicates the total demand for Queensland in that hour. This chart uses calibrated data as described in appendix A.4.

Figure C.4 shows the average solar rating across all units, the average wind rating across all units, and the Queensland net load (that is, excluding self-consumption of distributed PV), with each line representing a different day in June for reference year 2013. The days of the USE event shown in Figure C.3 are highlighted in Figure C.4 by blue and purple lines.

Figure C.4: The wind, solar, and demand traces in QLD in June using reference year 2013 show low wind and co-incident high demand during the USE event compared to other days in June



Note: This chart uses calibrated data as described in appendix A.4.

It is evident that the long, deep USE event of 21-23 June is driven by higher-than-average operational demand coincident with lower-than-average wind availability. The high demand is driven partly by low distributed PV generation in turn.

The Draft and Final Reports for this Review may include further investigation of these dark doldrum periods to understand their impacts on USE in more detail.

D Sensitivity results

The results of the modelled sensitivity cases are described in this appendix. We have designed these sensitivities to understand in broad terms how differing demand profiles, technology mix and interconnection impact the characteristics and relative levels of USE. They are not designed as a forecast for the likelihood of reliability events if specific projects were to be delayed or accelerated.

The broad results of these sensitivities as the NEM transitions to a higher VRE penetration system are as follows:

- the impact of using a 50% PoE demand profile as opposed to a 10% PoE profile on USE outcomes may become less significant (appendix D.1)
- additional interconnection may be very important in mitigating USE, however, it may be less effective in winter periods as opposed to summer periods (appendix D.2)
- generation technologies with an abundant, on-demand fuel supply may be more effective for mitigating USE than energy-limited technologies (appendix D.6 to appendix D.9)
- distributed batteries may be effective for mitigating USE events (appendix D.3, appendix D.5)
- halving the duration of pumped hydro storage may not have a significant impact on USE outcomes (appendix D.4).

The other finding from the sensitivities is that they support the broader key insights of the model. These sensitivity cases served as a stress test for the model, generating USE events at differing levels of interconnection and technology mix. Under these conditions, the four key insights identified in chapter 5 still hold true.

In the detailed sensitivity results outlined below, results are presented primarily as the overall change in total depth (in MW) or duration (in hours of USE) compared to the base case. These comparisons are either done at the region level, or at the financial year level. Even though this model is not a forecast of USE outcomes in any given year, we present the results in terms of the financial year as these sensitivities were necessarily run over different periods. Note that the results presented below are uncalibrated as this allows us to compare the relative overall levels of USE in the sensitivities and the base case.

Refer to appendix A.5 for the details of each sensitivity case.

D.1 Sensitivity 1 Results — Demand Variation

This sensitivity examines the impact of a lower demand trace, as developed by AEMO, on the depth and duration of unserved energy. This sensitivity was only simulated for a selection of financial years: 2030, 2035, 2040, and 2043. This was due to time and modelling resource constraints and we believe that four snapshot years at differing levels of VRE penetration provide enough evidence to make directional conclusions.

This sensitivity used AEMO's 50% PoE demand traces whereas the base case simulation used 10% PoE traces. The primary difference is that 50% PoE traces have lower maximum and minimum demand than 10% PoE, while the overall shape is similar. In the context of reliability, the differences in maximum demand are the most relevant.

Table D.1 shows the difference between the base case and the 50% PoE sensitivity in terms of the change in total depth and total USE duration.

Table D.1: Depth and duration impact of 50% PoE demand traces relative to the base case

Modelled financial year	Total depth relative to Base (MW)	Total USE duration relative to Base (hours)
2030	25%	41%
2035	101%	108%
2040	107%	104%
2043	100%	102%

Source: some source details
Note: A value above 100 per cent (e.g. 107 per cent) indicates that the sensitivity produced 7 per cent more of the metric (e.g. 7 per cent more MW of USE for depth), and that a value below 100 per cent indicates that the sensitivity produced less of the metric (e.g. 25 per cent means that the sensitivity only produced 25 per cent as much MW as the base case).

The change in demand trace from 10% PoE to 50% PoE materially reduced USE in the early part of the horizon, but after 2035 the impact is far less significant and even appears to reverse. This shift coincides with the shift from predominantly summer USE events to predominantly winter USE events that is described in section 5.2.

The reason that modelling with different demand traces has little or no effect on winter USE events is that the primary difference between the traces is the maximum (and minimum) demand, rather than an overall shift in energy consumption. This means that when peak demand is the driver of reliability risks, such as in traditional summer periods, the difference between 10% PoE and 50% PoE traces is likely to be material. However, as reliability risk shifts towards winter and becomes increasingly driven by energy supply variability, rather than peak demand, the impact is greatly diminished.

D.2 Sensitivity 2a Results — Delayed Interconnection

This sensitivity modelled a delay of three years in key interconnection projects and upgrades, specifically VNI West, Marinus, and QNI. As these projects are focused on the early years of the modelling horizon, Financial Years 2029 to 2035 were simulated, which cover the timelines of these four projects. All delays were simulated at the same time so the impacts of the delays overlap with each other.

Note that while this sensitivity models the delay of specific ISP interconnection projects, the purpose of this finding is not to assess the viability of an individual project, but rather to understand the broader impact of interconnection on USE levels in a high VRE penetration system.

Table D.2 shows the difference between the base case and Sensitivity 2a in terms of the change in total depth and total USE duration by region.

Table D.2: Depth and duration impact of modelled interconnector delays relative to the base case by region

Region	Total depth relative to base (MW)	Total USE duration relative to base (hours)
NSW	107%	100%
QLD	231%	224%
SA	136%	111%
VIC	118%	122%

At a high level, the impact on depth and duration is stronger in Queensland than in other states. This is despite the fact that most states have delays to their interconnection infrastructure in this sensitivity scenario. The delay in the modelled QNI upgrade, from FY2033 to FY2036, is the cause for these characteristics varying. This is a product of the summer reliability risk that still exists in Queensland for the period of the QNI delay, while other regions shift more quickly to predominantly winter reliability risk.

If reliability risk occurs in summer, where USE events tend to be driven by high demand, there is likely to be high VRE availability in at least some parts of the NEM. In these circumstances, interconnection with other regions has increased value as it allows access to more diverse sources of energy. In winter, however, when events are influenced more strongly by low VRE availability, there may not be surplus energy available from connected regions even if there is additional import capacity. Hence, interconnection could have a somewhat reduced impact on improving reliability outcomes if winter events dominate.

This does not mean that interconnection has no part to play in the transition to increased variable energy, as material benefits can still be seen in all regions in terms of reliability as well as other benefits not discussed in this report. However, the efficacy of additional import capacity may be lower in winter periods of reliability risk, and other technologies may have a greater impact in preventing or reducing USE.

D.3 Sensitivity 2b Results — Delayed Interconnection with Additional Batteries

This sensitivity attempted to compensate for the reduced ability to import energy from neighbouring regions, simulated in Sensitivity 2a, by increasing battery storage. This scenario was modelled for the same period as Sensitivity 2a (2029-2035).

Table D.3 shows the difference between Sensitivity 2b and Sensitivity 2a in terms of the change in total depth and total USE duration by financial year.

Table D.3: Depth and duration impact of additional batteries relative to delayed interconnection scenario

Modelled financial year	Total depth relative to Sensitivity 2a (MW)	Total USE duration relative to Sensitivity 2a (hours)
2029	73%	92%
2030	79%	86%
2031	81%	89%
2032	92%	95%
2033	99%	103%
2034	92%	89%
2035	95%	98%

Overall, the additional short duration storage notably improved USE outcomes compared to Sensitivity 2a in the earlier years, but the effect becomes insignificant by the end of the period modelled. Again, this likely occurs because the main risk of USE events shifts from summer to winter as the NEM transitions.

Batteries can mitigate reliability risk by allowing excess energy from periods of high VRE availability to be used in periods of low VRE availability. On the other hand, interconnection mitigates the risk by allowing regions to access more diverse sources of generation, in terms of both geography and technology mix. In the specific instance of winter USE events with delayed interconnection, batteries are not an effective substitute for interconnection. When there is a risk of USE events in summer, there is likely to be additional energy available during the day that can be shifted using batteries to meet peak demand. However in winter, there may be less surplus energy during the day when solar forms a large part of generating capacity, so batteries may not be able to charge sufficiently for the evening peak.

D.4 Sensitivity 3a Results — Reduced Depth of Long Duration Storage

When examining the impact of halving the duration of pumped hydro storage (mostly 24 hours reduced to 12 hours), no variation beyond stochastic variation was observed. This observation held for each financial year modelled and each NEM region. This suggests that the second 12 hours of pumped hydro storage has limited value from a reliability perspective.

Table D.4 shows the difference between Sensitivity 3a and the base case in terms of the change in total depth and total USE duration by financial year.

Table D.4: Depth and duration impact of reduced depth of long duration storage scenario relative to the base case

Modelled financial year	Total depth relative to base (MW)	Total USE duration relative to base (hours)
2039	101%	105%
2040	100%	98%
2041	100%	100%
2042	102%	103%
2043	102%	102%

D.5 Sensitivity 3b Results — Reduced Depth of Long Duration Storages with Additional Distributed VPPs and V2G

Extending the modelling of VPPs and V2G beyond what is found in the ESOO to align with the 2022 ISP results in 11.3 GW of additional short-duration storage in the NEM by the end of the modelling horizon (2043). With a commensurate 20 per cent increase in REZ VRE, this additional energy and freely optimised localised energy storage resulted in significant reductions in both the depth and duration of USE events. Note that this is a large amount of extra energy and storage, so these results are not particularly surprising.

The impact of this additional energy and storage is a large reduction in the depth and duration of USE. There is some small variation across the modelling period and between regions, with South Australia seeing the largest decrease in the depth of USE (by 84 per cent relative to the base) and Queensland seeing the smallest decrease (65 per cent).

Table D.5 shows the difference between Sensitivity 3b and the base case in terms of the change in total depth and total USE duration by financial year modelled.

Table D.5: Depth and duration impact of reduced depth of long duration storage plus additional VPPs and V2G scenario relative to the base case

Region	Total depth relative to base (MW)	Total USE duration relative to base (hours)
2039	30%	31%
2040	27%	27%
2041	24%	23%
2042	28%	26%
2043	26%	28%

D.6 Sensitivity 4a Results — Accelerated Decarbonisation

This sensitivity was to bring forward the retirement date of all fossil fuel-based gas generators by five years. It had the strongest impact on the depth and duration of USE compared to other scenarios, increasing the depth and duration by a total of 447 per cent and 417 per cent respectively over the 5 snapshots years of modelling.

Table D.6 shows the difference between Sensitivity 4a and the base case in terms of the change in total depth (in MW) and in terms of the change in total USE duration (in hours) by financial year modelled.

Table D.6: Depth and duration impact of accelerated decarbonisation scenario relative to the base case

Modelled financial year	Total depth relative to base (MW)	Total USE duration relative to base (hours)
2030	306%	293%
2035	301%	325%
2040	226%	233%
2043	633%	584%

This sensitivity appears to produce a large increase in both the depth and duration of USE, with an average increase in the total depth of USE events by 447 per cent compared with the base case, and an increase in total hours of USE by 417 per cent compared to the base case.

D.7 Sensitivity 4b Results — Accelerated Decarbonisation with Additional Wind

Sensitivity 4b accelerated the ISP wind buildout by five years to make up for the five-year delay in gas exits. This acceleration was effective at reducing USE to similar levels as the base case in earlier years of the modelled horizon while some thermal generation remained in the system. However, once the NEM transitions to the system of higher VRE penetration in the later years the impact of the accelerated wind buildout becomes less effective.

Table D.7 shows the difference between Sensitivity 4b and the base case in terms of the change in total depth and total USE duration (in hours) by financial year modelled.

Table D.7: Depth and duration impact of accelerated decarbonisation with additional wind scenario relative to the base case

Modelled financial year	Total depth relative to base (MW)	Total USE duration relative to base (hours)
2030	105%	109%
2035	175%	196%
2040	152%	149%
2043	384%	384%

D.8 Sensitivity 5a — Alternate Technological Development

The overall impact of adding dispatchable capacity, such as hydrogen generation, at 5 per cent of the total VRE buildout is a substantial decrease in USE event outcomes. This holds across all regions, seasons, and levels of VRE penetration. The reduction in depth and duration of USE events is stronger once higher VRE penetrations are achieved. This is evident in Table D.8 which shows the difference between Sensitivity 5a and the base case in terms of the change in total depth and total USE duration by financial year modelled.

Table D.8: Depth and duration impact of alternate technological development scenario relative to the base case

Modelled financial year	Total depth relative to base (MW)	Total USE duration relative to base (hours)
2030	41%	44%
2035	21%	21%
2040	23%	26%
2043	19%	24%

D.9 Sensitivity 5b Results — Alternate Technological Development with Reduced VRE

Even with an equivalent capacity reduction in VRE to compensate for additional firm dispatchable capacity, the overall effect was still a 58 per cent and 55 per cent total reduction in depth and duration respectively compared to the base case. Similar effects across regions and timelines were seen compared to Sensitivity 5a.

Table D.9 shows the difference between Sensitivity 5b and the base case in terms of the change in total depth and total USE duration by financial year modelled.

Table D.9: Depth and duration impact of alternate technological development with reduced VRE scenario relative to the base case

Modelled financial year	Total depth relative to base (MW)	Total USE duration relative to base (hours)
2030	83%	84%
2035	46%	53%
2040	50%	52%
2043	34%	36%

Abbreviations

AEC	Australian Energy Council
AEMC	Australian Energy Market Commission
AEMO	Australian Energy Market Operator
AER	Australian Energy Regulator
AFMA	Australian Financial Markets Association
APC	Administered Price Cap
APP	Administered Pricing Period
AUSM	AEMC USE Simulation Model
CIA	Cornwall Insight Australia
CPI	Consumer Price Index
CPT	Cumulative Price Threshold
DER	Distributed energy resources
ESOO	Electricity Statement of Opportunities
EUAA	Energy Users Association of Australia
FY	Financial year
IASR	Inputs, Assumptions and Scenarios Report
ISP	Integrated System Plan
MPC	Market Price Cap
MVA	Megavolt-amperes
NEM	National Electricity Market
NEMDE	NEM dispatch engine
NER	National Electricity Rules
OCGT	Open-cycle gas turbine
Panel	Reliability Panel
PIAC	Public Interest Advocacy Centre
PoE	Probability of exceedence
PV	Photovoltaic
QEJP	Queensland Energy and Jobs Plan
QNI	Queensland-New South Wales interconnector
REZ	Renewable Energy Zone
RSSR	Reliability Standard and Settings Review
USE	Unserved energy
V2G	Vehicle-to-grid
VCR	Values of Customer Reliability
VNI	Victoria-New South Wales interconnector
VoLL	Value of Lost Load
VPP	Virtual power plant
VRE	Variable renewable energy