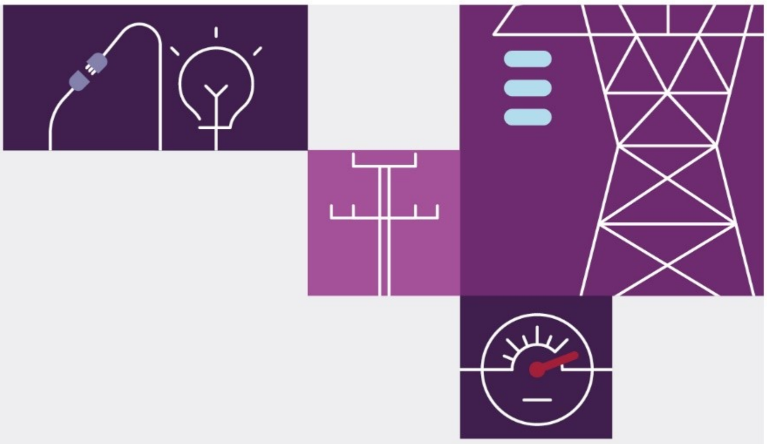
Appendix 2. Generation and Storage Development Opportunities

June 2024

Appendix to the 2024 Integrated System Plan for the National Electricity Market



Important notice

Purpose

This is Appendix 2 to the 2024 Integrated System Plan (ISP) which is available at https://aemo.com.au/energy-systems/major-publications/integrated-system-plan-isp. AEMO publishes the 2024 *Integrated System Plan* (ISP) pursuant to its functions under section 49(2) of the National Electricity Law (which defines AEMO's functions as National Transmission Planner) and its supporting functions under the National Electricity Rules. This publication is generally based on information available to AEMO as at 1 May 2024 unless otherwise indicated.

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Modelling work performed as part of preparing this publication inherently requires assumptions about future behaviours and market interactions, which may result in forecasts that deviate from future conditions. There will usually be differences between estimated and actual results, because events and circumstances frequently do not occur as expected, and those differences may be material.

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Version control

Version	Release date	Changes
1	26/6/2024	First release

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ISP Appendices

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Executive summary

AEMO's *Integrated System Plan* (ISP) is a roadmap for the transition of the National Electricity Market (NEM) power system, with a clear plan for essential infrastructure that will meet future energy needs. The ISP's optimal development path (ODP) sets out the needed generation, storage and network investments to transition to net zero by 2050 through current policy settings and deliver significant net market benefits for consumers.

This appendix presents the ISP development opportunities for electricity generation and storages in the optimal development path (ODP) for three scenarios – *Step Change*, *Progressive Change* and *Green Energy Exports*. These scenarios reflect different levels of economic and technical change over the coming decades, investments in consumer energy resources (CER), and pace of decarbonisation from other sectors affecting the NEM through electrification. All scenarios incorporate the effects of various federal and state public policies relevant to the energy transition as outlined in the 2023 *Inputs, Assumptions and Scenarios Report* (IASR) that meet the National Electricity Rules (NER) requirements and the Australian Energy Market Commission's (AEMC's) emissions target statement[1] that reflects the updated national energy objectives.

This appendix also presents the impact of sensitivities to key assumptions on generation and storage development opportunities.

ISP development opportunities in generation and storage across scenarios

With coal retiring, renewable energy connected with transmission, firmed by storage and backedup by gas-powered generation is the least-cost way to supply electricity to homes and businesses throughout Australia's transition to a net zero economy. In the NEM's transition to 2030:

- Coal capacity is forecast to at least halve, from 21 gigawatts (GW) currently to approximately 11 GW of capacity for *Step Change* and *Progressive Change*, and to 6 GW in *Green Energy Exports*. These reductions are driven by emissions reduction policies and various renewable energy (VRE) targets.
- Renewable energy generation from wind and solar technologies is forecast to grow throughout the outlook period, complementing the assumed development of CER. NEM-wide utility-scale VRE developments reach 47 GW, 55 GW, and 99 GW in *Progressive Change*, *Step Change*, and *Green Energy Exports*, respectively. This scale of development is driven by VRE targets as well as the need to supply bulk energy to replace retiring coal generation, and to meet forecast load growth.
- To firm the variable renewable generation, 14-20 GW of new dispatchable resources are forecast to be needed, while continued availability of 11 GW of existing gas-powered generation (GPG) provides important backup to these renewable and storage resources.

The pace of the transition varies across scenarios, and by 2049-50:

- All, or nearly all, coal-fired capacity is forecast to retire.
- Almost 100% of the electricity consumed will be supplied by renewable energy forms, but flexible gas will be needed to back up renewable generation and storage technologies by operating when renewable resources

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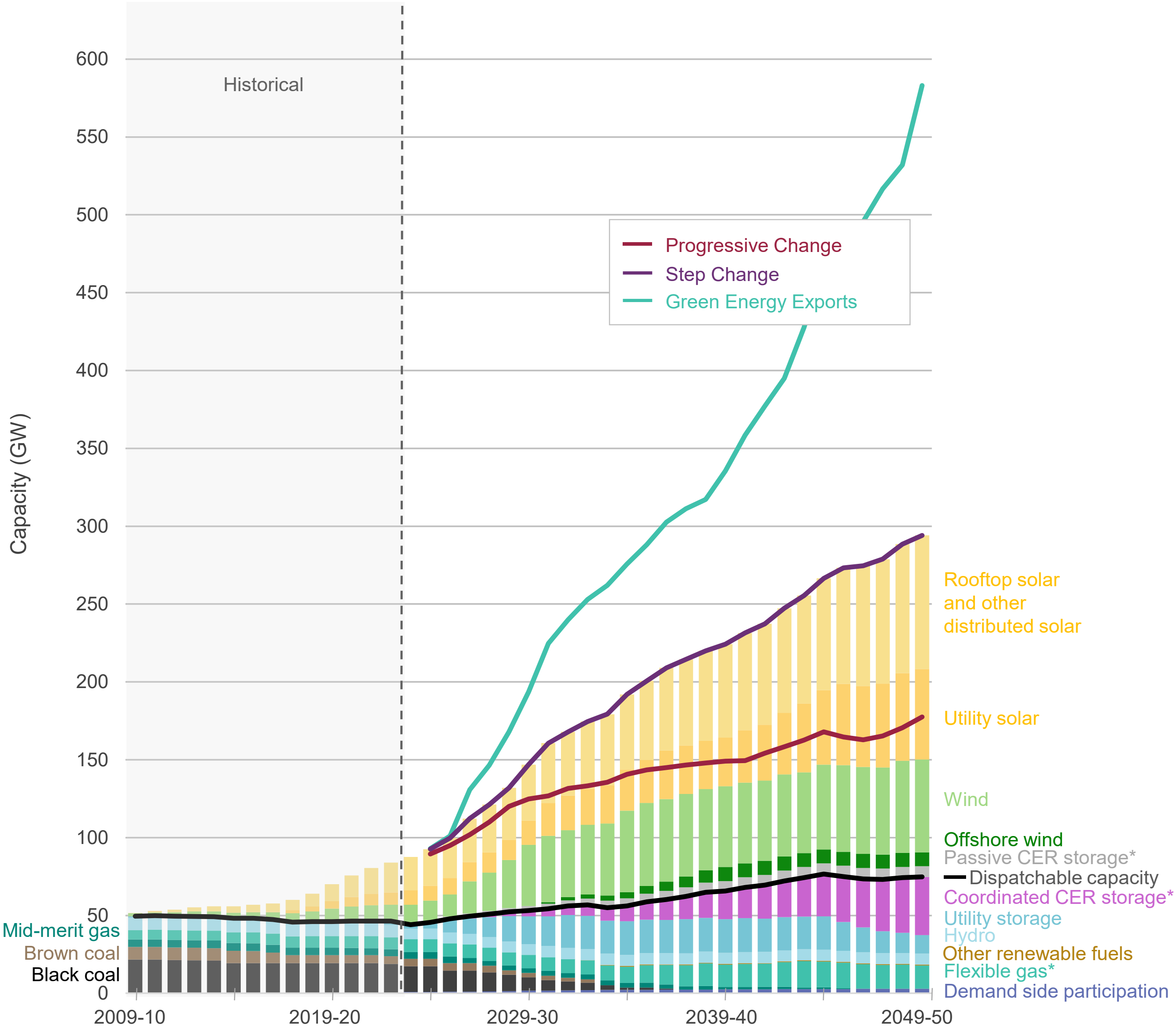
[1] AEMC, *Emissions Target Statement under the National Energy Laws*, September 2023, at https://www.aemc.gov.au/sites/default/files/2023-09/AEMC%20Emissions%20targets%20statement%20-%20final%20guide%20September%202023.pdf.

are low, more likely in winter periods as solar resources reduce with the 'shorter' days. By 2050, 11 GW of new GPG is forecast to be needed to provide this backup role, which will be critical to maintain reliability during dark and still weather conditions.

- Significant dispatchable storages at various storage depths will be needed to firm the renewable generation mix and the level of consumer battery sources assumed. Up to 50 GW/646 gigawatt hours (GWh) in *Step Change,* 23 GW/566 GWh in *Progressive Change,* and 74 GW/846 GWh in *Green Energy Exports* of utility-scale storage and coordinated CER storage capacity will help firm renewables and respond to dispatch signals.

Figure 1 shows the generation and storage development projected in the three scenarios for the ODP.

Figure 1 Historical and forecast generation and storage capacity across the three core scenarios, 2009-10 to 2049-50 (GW)



Notes: "Flexible gas" includes gas-powered generation and potential hydrogen capacity. "CER storage" means consumer energy resources such as batteries and electric vehicles. Projections for "Rooftop solar and other distributed solar" and "CER storage" are forecast based on unit costs, consumer trends and assumptions about payments received to participate in the electricity market.

Changes implemented since the Draft 2024 ISP

Since the Draft 2024 ISP was published and consulted on, several projects have reached 'committed' or 'anticipated' commitment status based on the February 2024 Generation Information update. Additional developments are also forecast in response to the expanded Capacity Investment Scheme (CIS).

Relative to the Draft 2024 ISP, AEMO has included greater consideration of the capacity of gas infrastructure to provide fuel reliably for flexible gas generators, resulting in a minor relative reduction in flexible gas capacity development, with more VRE development complemented by energy storage developed towards the end of the outlook period.

Other changes reflected in this 2024 ISP are consideration of uncertainty of weather patterns, detailed analysis of GPG production in the short term, updated transmission -related assumptions, and improvements to demand modelling.

Sensitivity confirms the level of generation and storage developments needed to support the transition

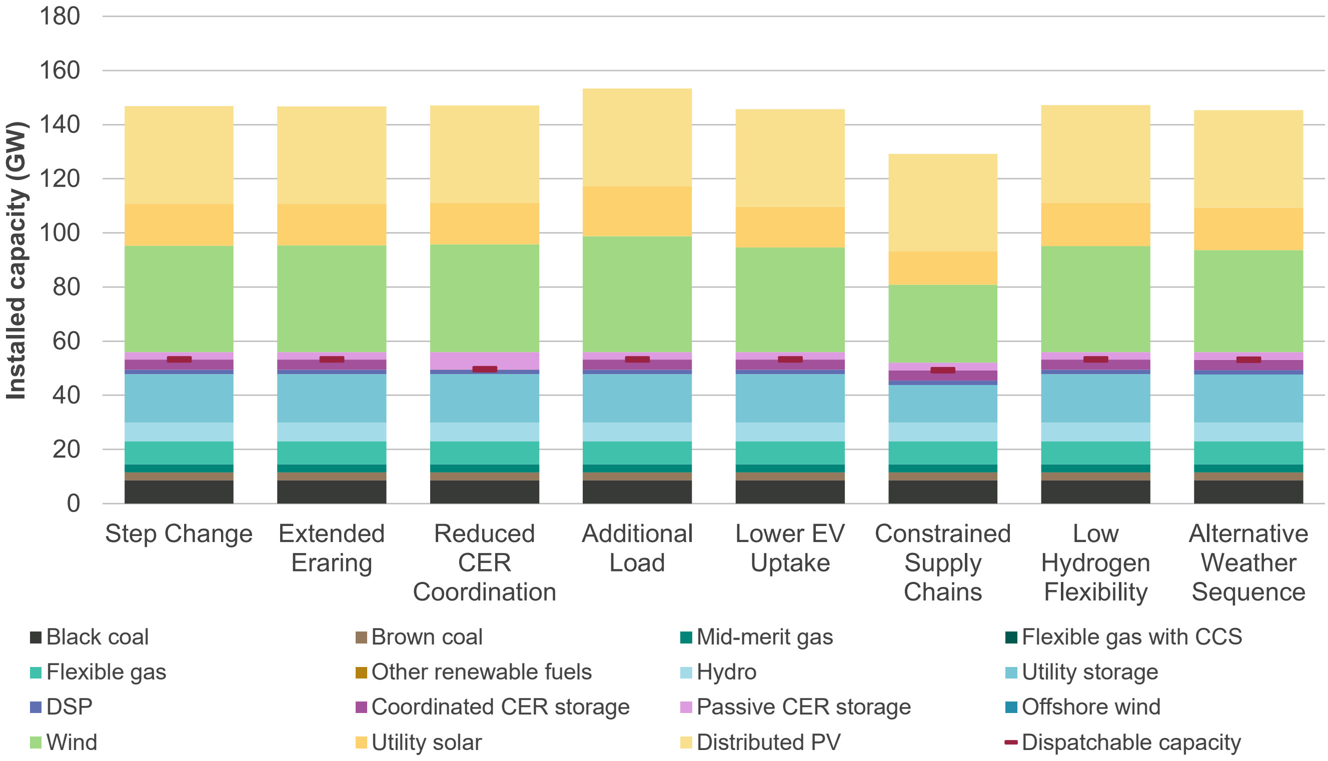
AEMO's modelling demonstrates that the ODP provides appropriate resilience and robustness to future uncertainties, using a scenario planning approach and assessment of individual uncertainties through sensitivity analysis. The additional sensitivities modelled in the 2024 ISP explore a range of risks and uncertainties beyond those included in the Draft 2024 ISP, including:

- Alternative assumptions around levels of coordination of consumer energy resources, growth in potential additional industrial load, and electric vehicle (EV) uptake.
- Alternative assumptions around electricity supply availability and the potential challenges of delivery.
- Impact of having lower hydrogen production flexibility.

As shown in Figure 2, the scale of wind and utility-scale solar development is resilient to alternative assumptions assessed in the sensitivity analysis though the degree of developments varies across sensitivities.

The change in assumptions in some sensitivity analyses have greater impact on the medium-term generation and storage outlook, such as the *Constrained Supply Chains* sensitivity where delay in transmission and cost increases reduce the projection for the early part of the outlook period. The *Additional Load* sensitivity, which captures emerging industrial load in South Australia and New South Wales, reflects the highest impact on the generation and storage outlook by 2049-50, while lower EV market penetration is projected to lead to lower developments compared to *Step Change*.

Figure 2 Generation and storage capacities by 2029-30 in *Step Change* and sensitivities to *Step Change*



Sensitivity analyses performed in the Draft 2024 ISP are not revisited in this Appendix, as the results are largely expected to remain similar to those in the Draft 2024 ISP. Instead, the 2024 ISP applies new sensitivity analyses on uncertainties that were identified from stakeholder feedback to the Draft 2024 ISP.

AEMO's 2024 ISP includes numerous appendices to provide more information on development, storage and transmission opportunities and benefits. In particular, Appendix 6 contains the cost-benefit analysis (CBA) implemented on these scenarios and sensitivities.

A2.1 Introduction

Sections 4, 5 and 6 of the 2024 ISP set out the ISP development opportunities for electricity generation and storages to enable the NEM's ongoing transformation to support a net-zero emissions economy by 2050.

This appendix supplements the 2024 ISP with additional detail on these development opportunities, in particular:

- A2.2 details the impacts of changes since the Draft 2024 ISP.
- A2. summarises the generation and storage development needs across the three ISP scenarios.
- A2.4 provides more detailed examination of generation and storage development for each scenario and illustrates the impact of transmission augmentations on those developments.
- A2.5 details the impact of the various sensitivities to key assumptions to those development opportunities.
- A2. summarises the sensitivity analyses implemented in the Draft 2024 ISP.

This appendix presents a NEM-wide view, and regional breakdowns where appropriate, of these developments. The ISP examines several alternative candidate development paths (CDPs) in determining the optimal development path (ODP). The outcomes presented in this appendix are based on CDP14, being the 2024 ISP's ODP. See Appendix 6 for further details on the justification of this CDP as the ODP.

This appendix is also complemented by the Generation and Storage Outlook Workbooks[2], which provide details of the capacity developments, energy generated, and retirement outlook for all relevant NEM regions. The workbooks also present emissions outcomes and comparisons of costs between alternative CDPs.

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[2] At https://aemo.com.au/consultations/current-and-closed-consultations/draft-2024-isp-consultation.

Key changes from the Draft 2024 ISP

AEMO has incorporated several changes since publication of the Draft 2024 ISP in response to stakeholder feedback, legislative changes, and recent market developments, including:

- Inclusion of emissions reduction as a class of market benefits by including a Value of Emissions Reduction (VER).
- Considerations of gas infrastructure capacity limitations, and revision to short-term gas generation forecasts to align with the 2024 *Gas Statement of Oportunities* (GSOO).
- Consideration of uncertainty pertaining to weather patterns.
- Inclusion of the latest committed and anticipated projects as per the February 2024 Generation Information release.
- Inclusion of the expanded Capacity Investment Scheme (CIS) targets.
- Changes to earliest in-service dates (EISD) and costs of several transmission projects, including consideration of some additional (smaller) transmission projects.
- Change in the subregional allocation of demand in New South Wales to improve the distribution of electricity consumption across the sub-regions observed historically, on average.
- Changes in hydrogen production assumptions, with load for green steel production carved out form other region’s loads and modelled in Sydney, Newcastle and Wollongong subregion to reflect proposed projects.
- Changes to the modelling of coordinated CER to improve the accounting of round-trip efficiency losses.

These changes have necessitated re-analysis of the scenarios and introduced additional potential actionable transmission augmentations since the Draft 2024 ISP for consideration.

A2.1.1 Interpreting the graphics in this appendix

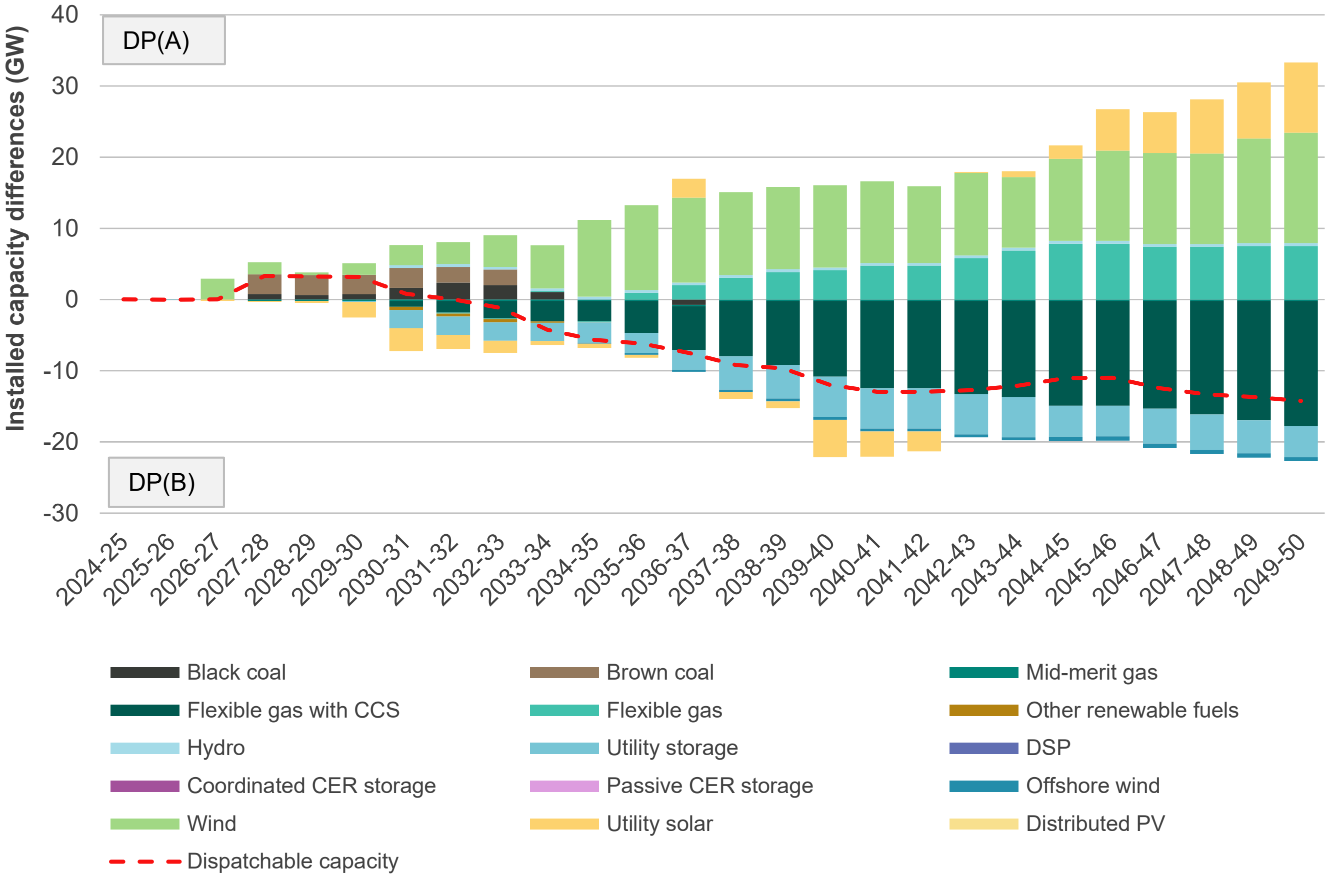
This appendix presents a number of charts comparing the projected capacity and generation over the outlook period of two different CDPs, or of a sensitivity and a CDP, as shown in the example figure below.

When interpreting the sample chart in Figure 3:

- The stacked columns show the projected values for different technologies on an annual basis.
- A positive value indicates the higher total capacity in the first development path, DP(A), relative to DP(B) – which in some cases, is the counterfactual DP or the impact of a sensitivity. A negative value indicates higher capacity in DP(B). For example, the yellow bar indicates there is higher capacity of wind in DP(A) relative to DP(B).
- The line represents the projected total dispatchable capacity.
- The market modelling performed covers an outlook period until 2051-52 but for the purpose of the reporting in this appendix, outcomes until 2049-50 only are presented.

- 'Distributed PV' described in this appendix refers to the combination of rooftop PV and other distributed solar generation.

Figure 3 Example interpretation of forecast capacity differences used in this appendix



A2.2 Impacts of the changes since the Draft 2024 ISP

AEMO has incorporated several changes since the publication of the Draft 2024 ISP in response to stakeholder feedback, legislative changes, and market developments. This section presents a discussion of each of these major changes, with a focus on those that are relevant to the generation and storage development opportunities.

Inclusion of emissions reduction benefits

Emissions reduction benefits are considered as an additional class of benefits calculated using the interim methodology for calculating the Value of Emissions Reduction (VER) agreed by Energy Ministers in February 2024[3], and in accordance with the Australian Energy Regulator's (AER's) CBA Guidelines[4] and the *ISP Methodology*[5]. This treatment is consistent with AEMO's obligation to have regard to the emissions reduction element in the National Electricity Objective (NEO)[6] and new NER requirements[7], and is consistent with the guidance provided by the AER[8].

Among the changes since the Draft 2024 ISP, the inclusion of the VER as a class of market benefits has the largest impact to the weighted net market benefits of various alternative development paths. However, because its inclusion does not impact the operation or development selections of the ISP, the generation and storage developments are not impacted by its inclusion.

Consideration of existing gas infrastructure's capacity limitation

The 2024 ISP re-confirms that there is a key need for flexible GPG to back up energy storage as a critical provider of dispatchable capacity and energy in periods of peak demand and during periods of low renewable energy output. However, GPG needs adequate fuel supply to provide a resilient and reliable strategic reserve under all conditions, especially during winter when heating demand is high and gas networks have the tightest balance of supply and demand before GPG requirements.

Stakeholder feedback on the Draft 2024 ISP raised concerns around the implications of the volume of gas required for GPG on the gas system. In response to this feedback, AEMO has applied additional constraints on GPG development and operation requirements to reflect limitations of the gas system to supply fuel at times considering daily gas production limits to reflect the historical availability of gas for electricity generation purposes. This constraint has been applied to gas generators in the southern regions (New South Wales, Victoria, South Australia, and Tasmania); Queensland gas generators were assumed to have greater access to domestic gas

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[3] At https://www.aemc.gov.au/sites/default/files/2024-03/Attachment%204%20VER%20MCE%20Statement%20for%20Commission%20200324.pdf.

[4] At https://www.aer.gov.au/system/files/AER%20-%20Cost%20benefit%20analysis%20guidelines%20-%2025%20August%202020.pdf.

[5] At https://aemo.com.au/-/media/files/stakeholder_consultation/consultations/nem-consultations/2023/isp-methodology-2023/isp-methodology_june-2023.pdf?la=en.

[6] See https://www.energy.gov.au/energy-and-climate-change-ministerial-council/working-groups/energy-governance-working-group/incorporating-emissions-reduction-objective-national-energy-objectives.

[7] See the AEMC's rule change to harmonise the national energy rules with the updated NEO, at https://www.aemc.gov.au/rule-changes/harmonising-national-energy-rules-updated-national-energy-objectives-electricity.

[8] See AER guidance on valuing emissions reduction, at https://www.aer.gov.au/industry/registers/resources/guidelines/valuing-emissions-reduction-final-guidance-may-2024.

supply. To further firm the operation of GPG, on-site liquid fuel storages were included for new GPG developments to ensure even greater fuel supply security.

This approach included:

- Maximum daily delivery limits from the 2024 GSOO[9] in *Progressive Change* and *Step Change*. These limits represent an estimate of gas capacity for GPG connected to southern regions of the East Coast Gas System. The limits vary by scenario to reflect alternate assumptions regarding domestic gas supply for heating, cooking and commercial purposes. These limits have not been applied to *Green Energy Exports*, because this scenario includes a strong level of electrification, green hydrogen availability and biomethane to support decarbonisation efforts. As such, it is internally inconsistent with the scenario settings.
- If gas supply is limited (as represented by the above constraint), secondary fuels (back-up diesel fuel for example) were assumed to be available at the diesel fuel cost outlined in the 2023 IASR. This secondary fuel is available for all new entrant GPG, and is incurred when total gas generation is above the daily limits described above. This represents the ability of GPG to switch to alternative liquid fuels when gas is not readily available.
- On-site liquid fuel storages with sufficient capacity for 14 hours of continuous operation on diesel fuel were considered as additional capital cost to new entrant flexible gas.

Figure 4 Forecast daily gas offtake and overall daily gas limits for southern regions (New South Wales, Victoria, South Australia and Tasmania) for the ODP and counterfactual DP in *Step Change*, 2044-45 (TJ/day)

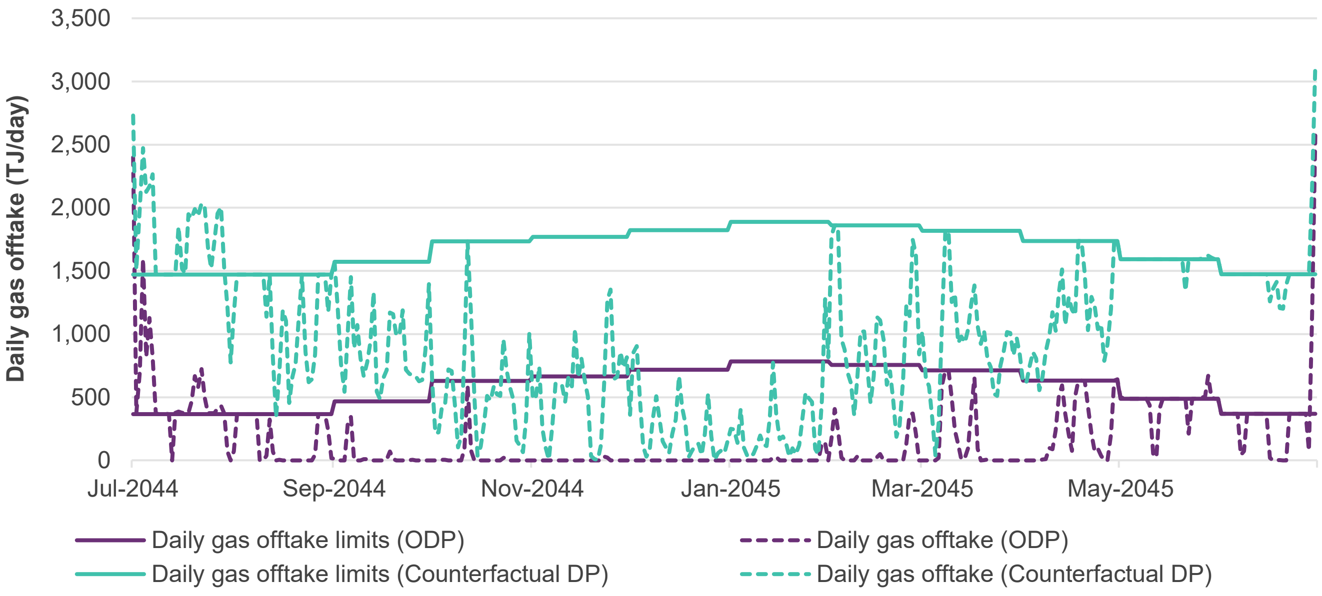

Figure 4 shows the daily gas offtake and relevant offtake limits for electricity generation in 2044-45 in the ODP in *Step Change*. GPG fuel requirements exceed the daily gas limits on several occasions, with secondary fuels being required to be used on these days to meet system needs.

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[9] At https://aemo.com.au/-/media/files/gas/national_planning_and_forecasting/gsoo/2024/aemo-2024-gas-statement-of-opportunities-gsoo-report.pdf?la=en.

For *Step Change* and *Progressive Change's* counterfactual DPs, a higher daily gas delivery limit was considered. This higher offtake limit was applied because AEMO considered it reasonable for the counterfactual DP – which does not invest in transmission infrastructure – to instead invest in gas infrastructure. The increased gas limit may be met through various gas system developments, including development of southern uncertain gas reserves and resources, import terminal development in southern regions, and additional pipeline and storage infrastructure. AEMO deems this reasonable to assume given the greater reliance on GPG if no major transmission augmentations occur.

Consideration of these gas infrastructure limits result in greater wind and utility-scale solar developments across NEM regions throughout the outlook period (see Section A4.8 for more detailed analysis on impacts of the gas adequacy on system operability). Despite gas infrastructure limitations, development of flexible gas capacities to provide back-up supply to renewable energy is still considered effective and efficient in this 2024 ISP.

Consideration of uncertainty pertaining to weather pattern

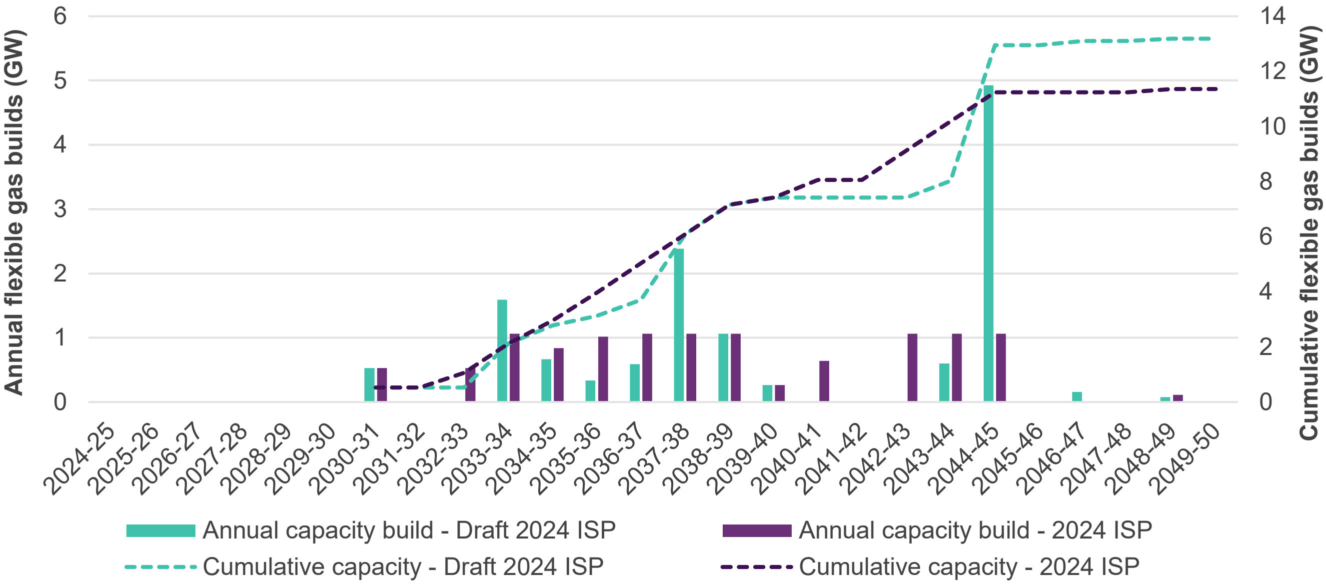
Stakeholders raised concerns that development of the flexible gas capacities are strongly influenced by AEMO's 'rolling reference year' approach to simulate weather pattern uncertainty assumed in the Draft 2024 ISP. The rolling reference year approach ensures that many weather patterns are considered across the forecast horizon, but may introduce model foresight of challenging weather conditions. In particular, a low-VRE output year, which was forecast to occur in 2044-45, drove a need for 5 GW of new flexible gas capacity to be developed ahead of 2044-45 (see Section A4.5 in Appendix 4 for a detailed analysis on NEM resilience to severe droughts).

In considering that feedback, AEMO performed sensitivity analysis with a repeating weather pattern that represented poor renewable generation availability throughout the capacity outlook period. In this sensitivity, higher levels of flexible gas generation may be required as early as the 2030s (see Section A2.5.7). This suggests that the choice of weather pattern sequence in the Draft 2024 ISP may have underestimated the need for additional dispatchable capacity across the horizon to maintain reliability of the system, earlier than forecast in the Draft 2024 ISP.

Recognising that the timing of poor weather conditions is unpredictable, AEMO implemented a new constraint to ensure more gradual development of dispatchable capacity earlier than the mid 2040s than was observed in the Draft 2024 ISP. This capacity, developed as flexible gas despite the application of additional gas constraints described above, ensures greater resilience to weather pattern uncertainty by developing more strategic reserve across the forecast horizon.

Figure 5 shows the annual flexible gas builds to 2049-50 in *Step Change* in the Draft 2024 ISP and the 2024 ISP.

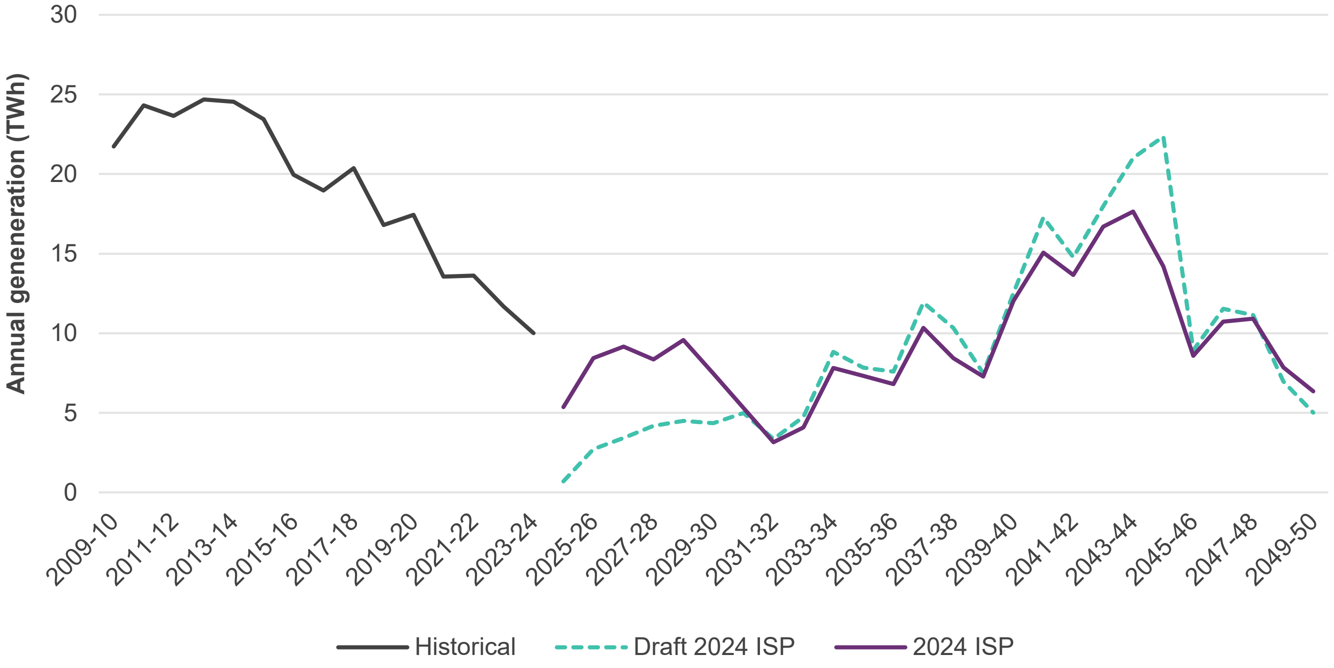
Figure 5 Annual flexible gas build to 2049-50 in *Step Change* in the Draft 2024 ISP and 2024 ISP (GW)



Reflecting detailed analysis of gas generation in the short to medium term

Feedback on the Draft 2024 ISP pointed out that there is underestimation of the volume of gas generation to 2029-30 and that the forecast is not reflective of historical GPG operation in the NEM. In response, AEMO has aligned the short-term operating level of GPG with time-sequential modelling (matching the 2024 GSOO), resulting in a GPG forecast more aligned with historical values and expected forecast drivers; see Figure 6.

Figure 6 Annual gas generation, Draft 2024 ISP and 2024 ISP (terawatt hours (TWh))

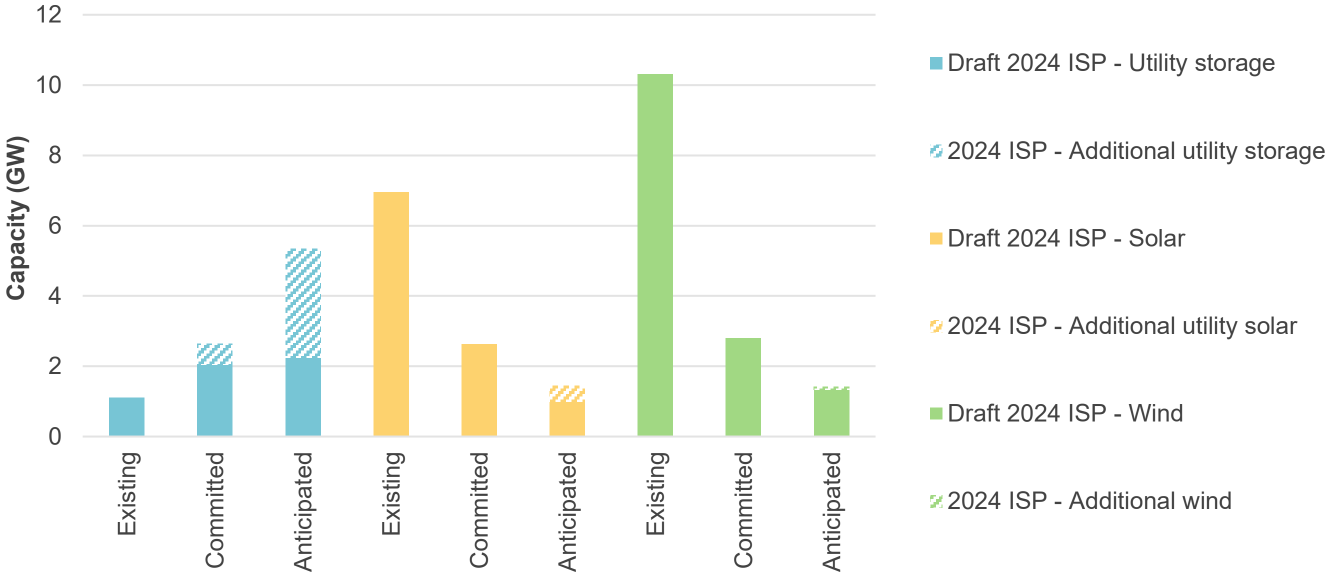


Reflecting latest committed and anticipated projects as per the February 2024 Generation Information update

The 2024 ISP reflects generator and storage projects' commitment status as per the February 2024 Generation Information update (see Figure 7 below). This includes around 3.7 GW of newly anticipated large-scale storage capacity, as well as 490 megawatts (MW) of solar and wind since the Draft 2024 ISP. This update also includes changes in capacity and 'full commercial use dates' (FCUD) for generators and storages already included in the Draft 2024 ISP.

This anticipated and committed capacity has resulted in the earlier development of utility-scale storage capacity, leading to other minor variations in overall capacity developments.

Figure 7 Changes in the generator and storage projects status, Draft 2024 ISP vs 2024 ISP



Inclusion of the expanded renewable energy and emissions targets

- The recently announced expanded CIS, which targets 23 GW of renewable energy and 9 GW of clean dispatchable capacity across Australia by 2030, is reflected in this 2024 ISP. Additionally, an amended renewable energy build to 2029-30 has been adopted to align with expectations for the execution of the CIS and state renewable energy targets. This change in the short-term uptake of VRE also recognises stakeholder feedback on short-term development challenges.
- This adjusted trajectory to meet the expanded CIS contributes to slower development to 2027-28 and faster development in 2028-29 and 2029-30 to meet the requirements of the 82% target by 2030 in *Progressive Change* and *Step Change*[10].
- The average VRE build as a result is forecast at 4.7 GW per year, 6.0 GW per year, and 13.4 GW per year for *Progressive Change*, *Step Change,* and *Green Energy Exports*, respectively.

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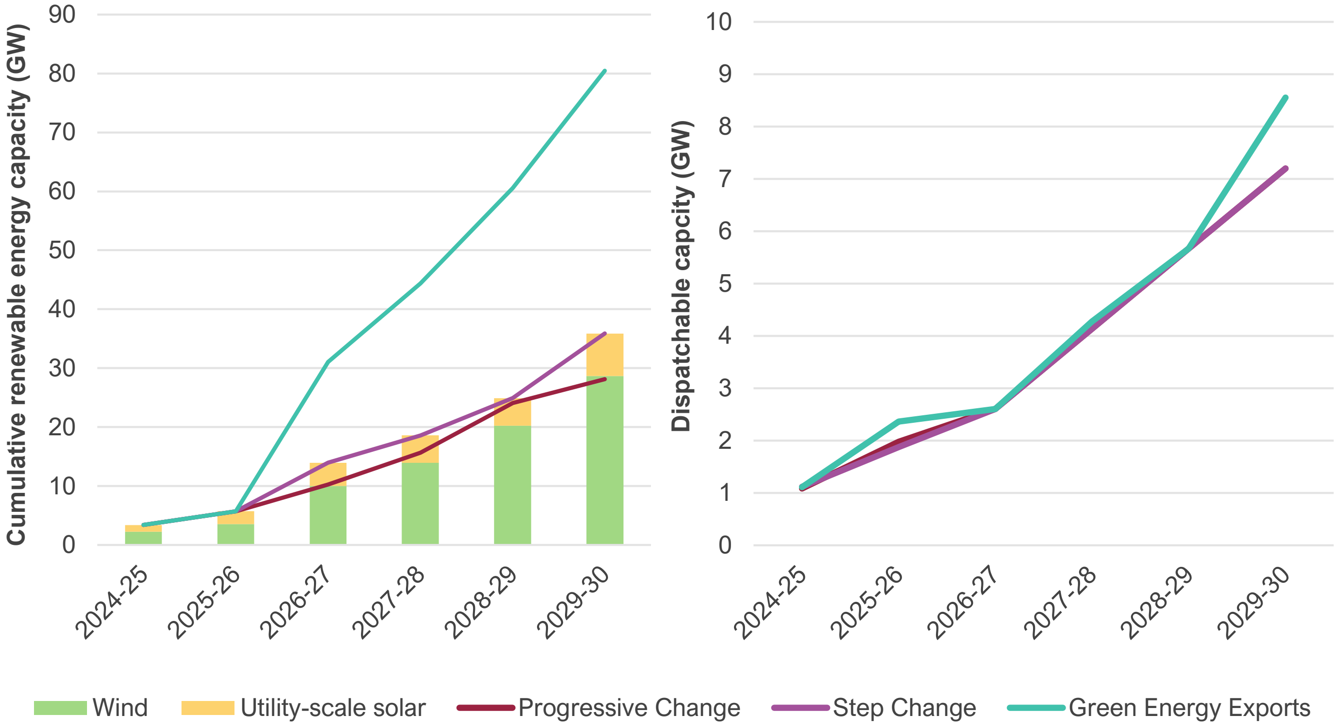
[10] No change has been applied to *Green Energy Exports*, given the rapid pace of change required over the short to medium term.

Figure 8 **Annual VRE and clean dispatchable builds, 2024 ISP compared to the Draft 2024 ISP (GW)**



Updates to the allocation of demand across New South Wales subregions

- Following the publication of the Draft 2024 ISP, AEMO has improved the distribution of electricity consumption across the NEM, particularly in New South Wales. The ISP model includes several sub-regions within New South Wales, and the updated allocations improve the sub-regional demand proportions relative to historically observed load distributions. The sub-regional demand proportions in New South Wales have been updated to represent proportions consistent with average load conditions[11] in the region (see Figure 9), resulting in greater load being represented in Southern New South Wales than was modelled in the Draft 2024 ISP.
- The revised regional demand distribution in New South Wales results in a shift 0.6 GW of utility-scale storage builds from the Sydney, Newcastle, and Wollongong subregion to Central New South Wales and Central South Australia subregions. This revision also resulted in lower flexible gas builds by 0.4 GW from 2030-31 to 2032-33.

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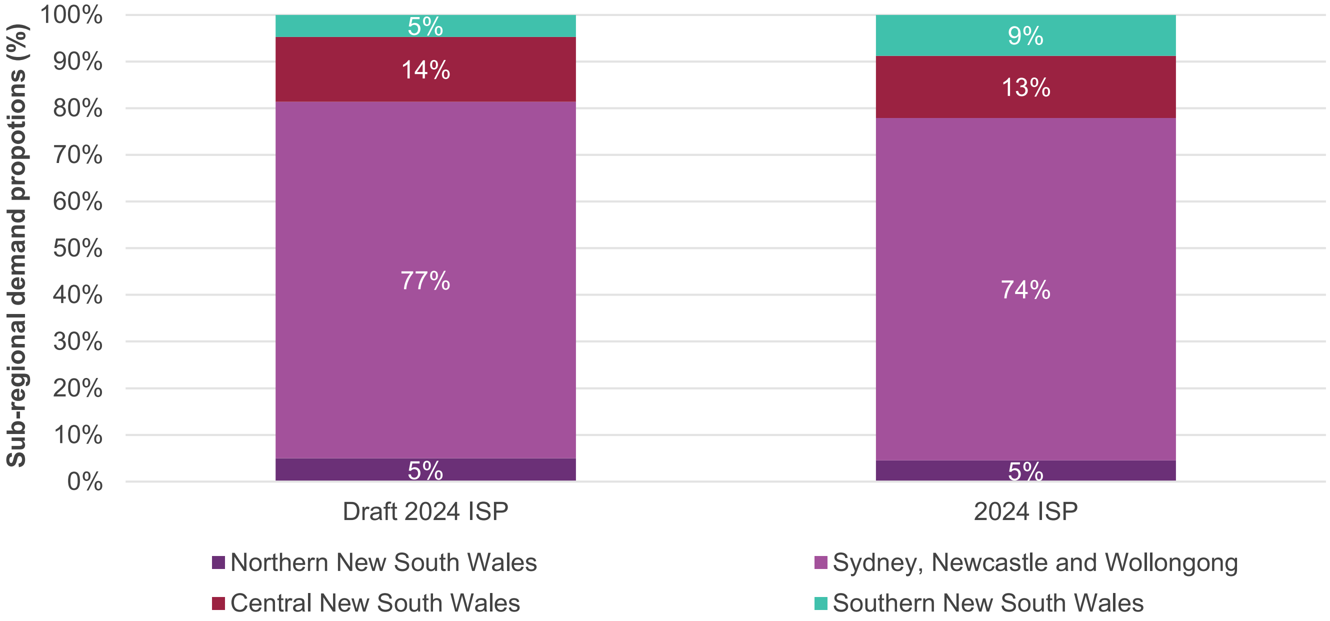
[11] The Update to the 2023 Electricity Statement of Opportunities (ESOO), published in May 2024, discusses a similar adjustment made to sub-regional demand proportions in New South Wales. The adjustments applied in the ESOO focus on periods of maximum demand, as reliability risks are usually exclusively during peak demand periods. As such the load distributions in this ISP differ from those presented in the ESOO, with the ISP focusing on overall investment needs.

Figure 9 Demand proportions applied in the 2024 ISP compared to the Draft ISP (%)



Changes to the modelling of coordinated CER to improve the accounting of losses

Since publishing the Draft 2024 ISP, AEMO identified that the round-trip efficiency of coordinated CER battery systems was applied twice, resulting in a double-counting of storage losses for these devices. AEMO has corrected this error in the 2024 ISP. Additionally, coordinated CER storages now are operated to a maximum of one full cycle per day to reflect more realistic operating behaviours.

This adjustment reduces the energy consumed by batteries, therefore less VRE is required in the 2024 ISP to meet consumer load, all else being equal.

Aligning hydrogen load forecast with proposed projects in *Green Energy Exports*

- For the 2024 ISP, AEMO has made the following minor improvements to assumptions for modelling hydrogen production:
- Adjustments to Mid-North and North South Australia network constraints to reflect the location of Whyalla electrolyser load including the South Australian ‘Hydrogen Jobs Plan’ developments. These adjustments were applied to all scenarios, but they do not result in material change in capacity developments in *Step Change* and *Progressive Change*, due to lower hydrogen demand.
- In the *Green Energy Exports* scenario, greater hydrogen production and additional green steel load were allocated in the Sydney, Newcastle, and Wollongong sub-region in response to stakeholder feedback. This included additional electrical load for green steel furnaces from 2031-32 and additional hydrogen load for green steel production from 2039-40.
- These improvements have resulted in changes to the regional allocation of export hydrogen and green steel loads in the *Green Energy Exports* scenario compared to the Draft 2024 ISP, with reduced export hydrogen allocations in South Australia, Tasmania and Northern Queensland, and reduced green steel loads in Queensland, South Australia, and Tasmania.

Changes to transmission project assumptions

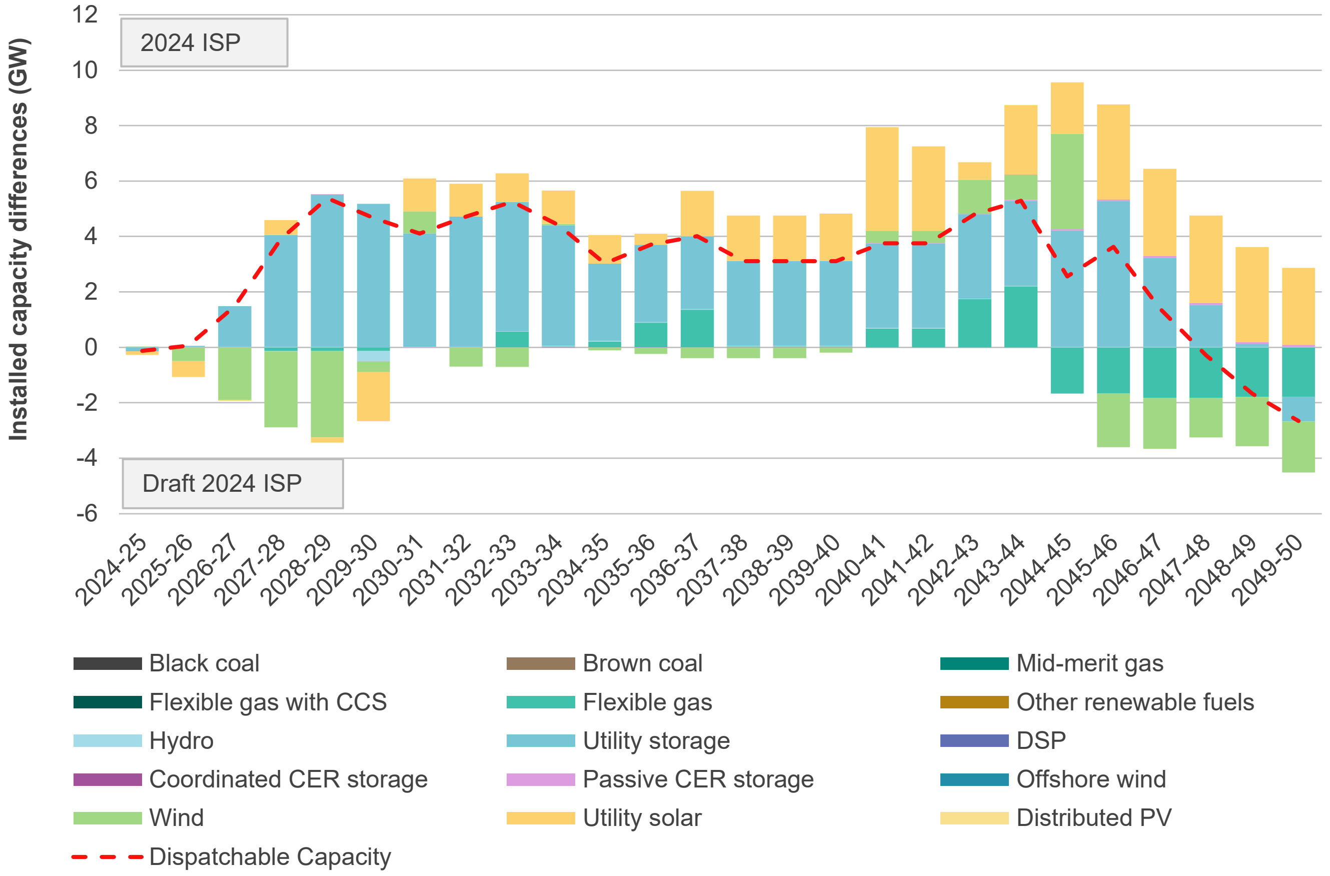
Updates to several transmission assumptions have been applied in the 2024 ISP, including changes to EISD and costs of transmission projects. As a result, the optimal generation and storage developments for all CDPs have slightly changed.

Net impact of changes since the Draft 2024 ISP

The impacts of these changes since the Draft 2024 ISP vary by scenario. Figure 10 shows the net impact on generation and storage development opportunities in the ODP in *Step Change*. As the figure shows, less wind is now developed to 2030, while the additional committed and anticipated storage projects reported in the February 2024 Generation Information update increase available storage and lead to some changes in utility-scale solar developments over the medium and long term.

Additional utility-scale storage capacity above what was projected in the Draft 2024 ISP are also a product of the clean dispatchable capacity target of the expanded CIS. The earlier and gradual development of flexible gas in the 2030s to 2040s is a result of the consideration of weather uncertainty and the need to increase resilience to potential poor weather conditions.

Figure 10 **Overall impact of input changes and model improvements on forecast capacity developments to 2049-50 in *Step Change*, 2024 ISP assumptions compared to Draft 2024 ISP assumptions (GW)**



Section A2.4 presents the impact of updated assumptions on capacity developments for individual scenarios.

A2.3 A rapidly evolving NEM will transform energy supply

Similar to the 2022 ISP, the 2024 ISP forecasts that the supply of electricity in the NEM will transition from a generation mix dominated by coal-fired generation to a supply with very high renewable energy penetration supported by energy storages, transmission developments, hydro power, GPG, and CER. As this transition supports a net zero emissions economy, NEM developments will need to replace, and add to, the existing generation fleet to meet growing demand and the additional load associated with electrification of other high-emitting sectors.

The NEM is projected to be composed of technologically and geographically diverse generation and storage resources, connected by transmission developments (outlined in Appendix 5), including:

- Renewable energy – including VRE generators (predominantly solar and wind farms) to provide much of the required electricity generation in a low-emissions NEM.
- Energy storages – to manage intermittency and periods of high and low renewable energy generation, and to support the power system. Deeper storages will also be needed to provide energy shifting capabilities, particularly to support higher consumption during winter months (see Appendix 4).
- GPG – to firm renewable energy and provide flexible operation, particularly during periods of low VRE output.
- CER, including distributed PV, battery systems and EVs. These will connect to the distribution system, and if appropriately coordinated (for battery and vehicle devices) then the scale of utility-scale storage development opportunities will likely be impacted.

A2.3.1 The development of the NEM is influenced by policy targets

Several of the policies included in the 2024 ISP target specific aspects of NEM development, including:

- Powering Australia Plan – the 82% renewable energy target by 2030. The 82% target will be influenced by the level of forecast electricity consumption.
- The expanded CIS – this targets development of 32 GW of new clean dispatchable and renewable capacity nationally, including 23 GW of renewable energy and 9 GW of clean dispatchable capacity. This target has been scaled down in the ISP based on an estimated 80% NEM share.
- Emissions budgets and targets in NEM jurisdictions – this includes several state commitments to emissions reduction and the federal *Climate Change Act*'s 43% emissions reduction target. The 2024 ISP includes an overall carbon budget to meet these targets and to reach net zero by 2050 (see the 2023 IASR Assumptions Workbook[12] and Section 3.2 of AEMO's 2023 IASR[13] for more details).
- Jurisdictional policy and law, including:
  - Queensland Energy and Jobs Plan – including the Borumba Dam Pumped Hydro development, classified as 'anticipated' in this 2024 ISP.

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[12] At https://aemo.com.au/en/energy-systems/major-publications/integrated-system-plan-isp/2024-integrated-system-plan-isp/current-inputs-assumptions-and-scenarios.

[13] At https://aemo.com.au/-/media/files/major-publications/isp/2023/2023-inputs-assumptions-and-scenarios-report.pdf?la=en.

  - New South Wales Infrastructure Investment Objectives (IIO) – including storage and renewable energy developments in New South Wales.
  - Victorian energy and climate-related policies, including the offshore wind target.
  - Tasmanian Renewable Energy Target – requiring 200% renewable generation capability by 2040.

A2.3.2 A changing generation mix to service consumers

Across all ISP scenarios, significant capacity of new VRE generation is expected to transform the NEM into a low-emissions energy system, underpinning the decarbonisation of Australia's economy. Table 1 presents the capacity mix for all scenarios where the transmission investments under each scenario follow the transmission developments of the ODP. This includes the following actionable projects that are expected to be developed within their respective actionable windows (see Appendix 5 and Appendix 6 for more details):

- HumeLink.
- Sydney Ring North (Hunter Transmission Project).
- New England Renewable Energy Zone (REZ) Transmission Link (New England REZ Network Infrastructure Project).
- Victoria – New South Wales Interconnector West (VNI West).
- Project Marinus.
- Gladstone Grid Reinforcement.
- Queensland SuperGrid South.
- Queensland – New South Wales Interconnector (QNI) Connect.
- Hunter-Central Coast REZ Expansion (Hunter-Central Coast REZ Network Infrastructure Project).
- Sydney Ring South.
- Waddamana to Palmerston transfer capability upgrade.
- Mid North South Australia REZ Expansion.

Table 1 shows the significant scale of generation and storage development opportunities forecast in the ODP. It shows utility-scale VRE growing from 19 GW currently to 127 GW in *Step Change* by 2049-50, and to 86 GW and 374 GW respectively in *Progressive Change* and *Green Energy Exports.* This is 44%, 49%, and 65% of the total installed capacity for 2049-50 for *Step Change*, *Progressive Change*, and *Green Energy Exports*, respectively. In all ISP scenarios, there is at least about a quadrupling of VRE by 2049-50.

Newer technologies such as offshore wind and hydrogen gas turbines have been developed to achieve at least the objectives of government policies, such as the Victorian Offshore Wind Target[14], South Australian Hydrogen and Jobs Plan[15], and Queensland Energy and Jobs Plan[16].

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[14] At https://www.energy.vic.gov.au/renewable-energy/offshore-wind-energy/for-industry-and-developers.

[15] At https://www.ohpsa.sa.gov.au/projects/hydrogen-jobs-plan#:~:text=The%20Government%20of%20South%20Australia,200MW%20of%20power%20generation.

[16] At https://www.treasury.qld.gov.au/programs-and-policies/queensland-renewable-energy-and-hydrogen-jobs-fund/.

For more detail of relevant policies, see the 2023 IASR[17].

Table 1 Installed capacity (GW) in 2023-24, 2029-30, 2039-40, and 2049-50 by scenario

Technology	Actual[A]	*Step Change*			*Progressive Change*			*Green Energy Exports*		
	2023-24	**2029-30**	**2039-40**	**2049-50**	**2029-30**	**2039-40**	**2049-50**	**2029-30**	**2039-40**	**2049-50**
Black coal	16.4	8.7	0.0	0.0	7.3	3.1	1.7	4.6	0.0	0.0
Brown coal	4.8	2.8	0.0	0.0	3.4	0.6	0.0	1.1	0.0	0.0
Mid-merit gas	4.1	3.1	1.5	0.2	2.6	1.5	0.2	3.1	1.5	0.2
Flexible gas with carbon capture and storage (CCS)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Flexible gas	7.2	8.5	14.4	14.8	8.5	8.3	10.1	8.5	12.0	14.4
Hydro	6.8	6.8	7.1	7.1	6.8	7.1	7.1	6.8	7.1	7.1
Utility-scale storage	2	17.9	21.7	12.0	18.2	23.8	19.3	19.2	29.4	29.5
Coordinated CER storage	0.2	3.7	18.1	37.3	0.2	1.4	4.1	4.5	22.9	44.4
Passive CER storage	0.7	2.8	6.3	6.9	1.5	2.8	4.0	3.7	8.0	8.9
Offshore wind	0.0	0.0	9.0	9.0	0.0	9.0	9.0	0.0	9.0	9.1
Wind	10.8	39.3	51.9	59.5	32.2	33.9	41.3	64.8	98.2	136.8
Utility-scale solar	8.4	15.6	31.2	58.3	15.0	19.5	36.2	34.6	73.1	228.5
Distributed PV	21.3	36.1	60.2	85.7	27.7	36.3	42.3	40.8	70.1	98.6
Other renewable fuels	0.0	0.0	0.5	0.5	0.0	0.0	0.1	0.0	0.5	0.5
DSP	0.9	1.6	2.5	2.9	1.4	1.8	1.9	2.0	3.7	5.0

A. Based on February 2024 Generation Information update which was used in the modelling. These figures may be slightly different to those in the 2024 ISP main report, which were based on the May 2024 Generation Information update. At https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/forecasting-and-planning-data/generation-information.

Transitioning from coal and mid-merit gas generation

The Federal Government has committed to an economy-wide emissions reduction target of 43% below 2005 levels by 2030 and a net zero emissions economy by 2050. This emissions reduction target is underpinned by an 82% target share of renewable energy by 2030. On 23 November 2023, the Federal Government also announced additional support[18] for the development of 32 GW of new capacity nationally, including 23 GW of renewable energy and 9 GW of clean dispatchable capacity.

Simultaneously, the electrification of transport, households, and industries, as well as the emergence of domestic hydrogen production is forecast to provide a significant contribution to achieving a net zero economy, and lead to higher electricity consumption across the NEM over the outlook period compared to the 2022 ISP. Similar to the 2022 ISP, coal-fired generation is forecast to decline, due to the impact of emissions reduction and renewable

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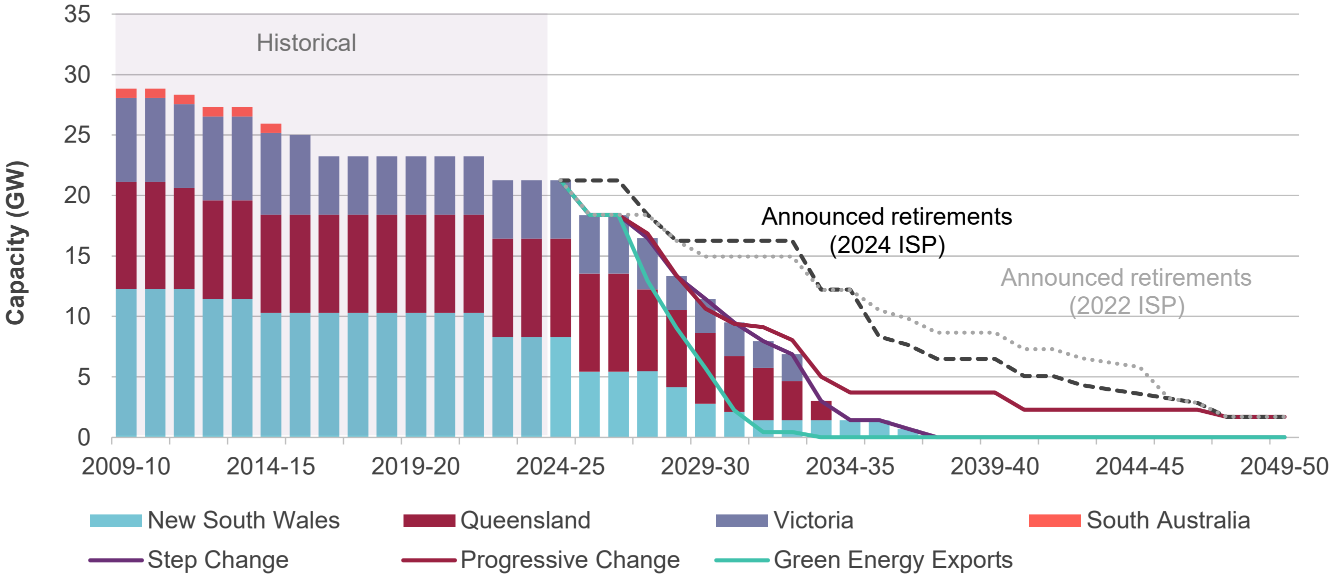
[17] At https://aemo.com.au/en/energy-systems/major-publications/integrated-system-plan-isp/2024-integrated-system-plan-isp/current-inputs-assumptions-and-scenarios.

[18] At https://www.dcceew.gov.au/energy/renewable/capacity-investment-scheme.

energy targets at federal and state levels. Figure 11 demonstrates the historical and forecast coal closure outlook in *Step Change* against the announced retirement schedule for the NEM's coal generation fleet, and comparing with other scenario projections in the 2024 ISP.

Similar to the Draft 2024 ISP, over three-quarters of current coal capacity is forecast to retire in *Step Change* within the next 10 years, with all coal withdrawn by 2037-38. Coal capacity is forecast to retire earlier than current announcements, but slower than was forecast in the Draft 2024 ISP, to improve reliability outcomes. Generation from mid-merit gas plants is also forecast to decline as they approach their retirement dates, with renewable generation broadly compensating for the lost energy production from both technologies.

Figure 11 Historical and forecast coal retirements, 2009-10 to 2049-50 (GW)

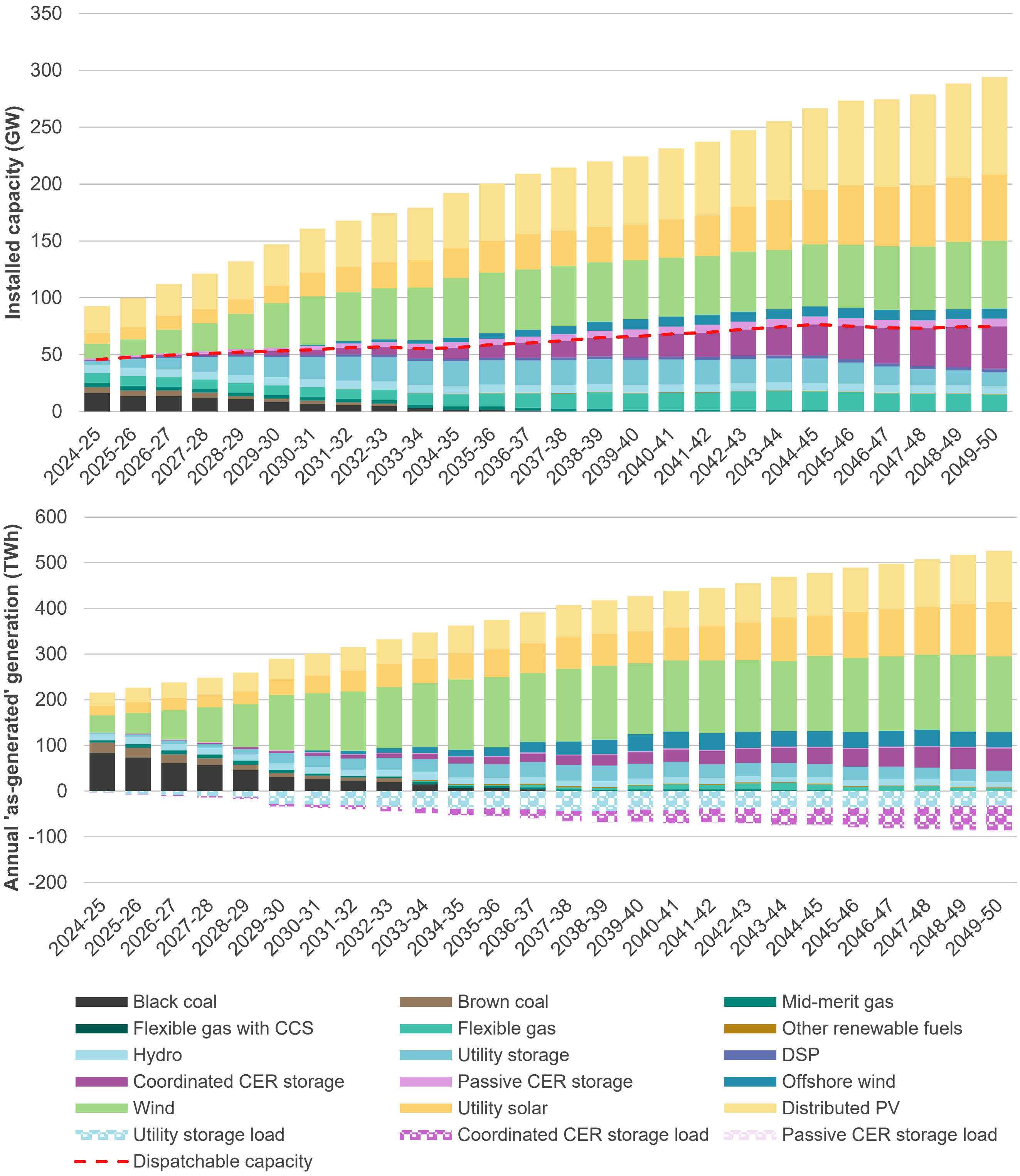


Note that the recent announcement on the extension of Eraring Power Station to August 2027 is reflected in the 'announced retirements' in this chart, but not in the modelling (shown by the bars).

Figure 12 below (showing *Step Change*) shows that new VRE, storage, and GPG development is forecast to meet consumers' energy, security and reliability needs. In terms of generation capacity, utility-scale VRE and distributed PV capacities are forecast to ramp up to replace retiring coal-fired generation and contribute to supplying increasing load. In 2029-30, coal-fired generation capacity represents only 8% of the total capacity, and by 2037-38 completely retires in *Step Change*.

Figure 12 also shows that the energy generated from renewable generators is expected to increase. In 2029-30, projected total generation from solar capacity (utility-scale solar and distributed PV) is 30% (79 terawatt hours (TWh)) of the NEM's total generation, while wind generation makes up 47% (121.3 TWh). By 2034-35 – five years later – these are forecast to grow to 38% (118 TWh) and 55% (168.6 TWh) respectively.

Figure 12 NEM-wide installed capacity (top) and energy generation (bottom), *Step Change*, 2024-25 to 2049-50 (GW and TWh)



Generation from flexible gas is also forecast to increase over the outlook period, as it provides a critical role in firming the intermittency of renewable generation and providing dispatchable resources when required, particularly during periods of low renewable resource availability, such as during the winter.

More information on the key role of flexible gas, and the complementary importance for energy storages, is provided in Appendix 4.

The scale of storage development opportunities to shift surplus renewable generation on an intra-day, inter-day, or longer seasonal basis is an emerging important consideration for storage developers.

A2.3.3 Energy storages are needed to complement renewable energy

Additional storage developments, distributed across the NEM, will be needed to complement the large amount of VRE to provide dispatchable and firm source of supply. AEMO defines the following diverse classes of storage:

- **Coordinated CER storage** – includes behind-the-meter battery installations that are enabled and coordinated via virtual power plant (VPP) arrangements. This category includes VPP-coordinated EVs with vehicle-to-grid (V2G) capabilities.
- **Passive CER storage** – includes non-aggregated behind-the-meter battery installations designed to support customer's own load.
- **Shallow storage** – includes utility-scale energy storage with durations less than four hours. The value of this category of storage is more for capacity, fast ramping, and frequency control ancillary service (FCAS) (not included in AEMO's modelling) than for its energy management capability.
- **Medium-depth storage** – includes energy storage with durations between four and 12 hours (inclusive). The value of this category of storage is in its intra-day energy shifting capabilities, driven by the daily shape of energy consumption by consumers, and the diurnal solar generation pattern.
- **Deep storage** – includes energy storage with durations greater than 12 hours. The value of this category of storage is in covering VRE lulls (long periods of lower-than-expected VRE availability) and seasonal smoothing of energy over weeks or months.

Figure 13 presents forecast NEM-wide storage capacity by depth to 2049-50 in *Step Change*:

- The chart on the left shows the installed capacity of all storages (GW), demonstrating the scale of CER storage assumed and the required additional utility-scale storage developments to complement wind and utility-scale solar penetration.
- The chart on the right presents the energy storage capacity (in GWh) for selected years, and demonstrates the significant difference in storage capacity relative to the discharge capacity figure. While Snowy 2.0 and Borumba Dam Pumped Hydro provide strong contributions, medium-depth and deep storages are developed beyond those committed and anticipated projects, to meet policy targets and to support the energy shifting needs of a high wind and utility-scale solar system.

Deep storage developments (beyond the committed Snowy 2.0 and anticipated Borumba Dam Pumped Hydro) occur from the 2030s to complement and firm wind and utility-scale solar developments and to provide sufficient dispatchable capacity to maintain reliability as coal capacity retires. With greater consideration of gas infrastructure limits and weather uncertainty, greater storage development is now forecast relative to the Draft 2024 ISP.

In the longer term, existing, committed, and anticipated battery solutions (which are typically shallow) will reach their own point of retirement, and renewal of these assets may not be needed given the scale of CER coordination and additional deep storage that is forecast in the last years of the outlook period. At that point, additional shallow solutions will be less valuable than dispatchable capacity that can better support the need for seasonal energy production in months with higher consumption and reduced renewable resources. The 2024 ISP develops more flexible gas from the 2030s to service these gaps, however, deeper storages would be another alternative.

Figure 13 NEM-wide storage installed capacity (left) and energy storage capacity (right), *Step Change*, 2024-25 to 2049-50 (GW and GWh)

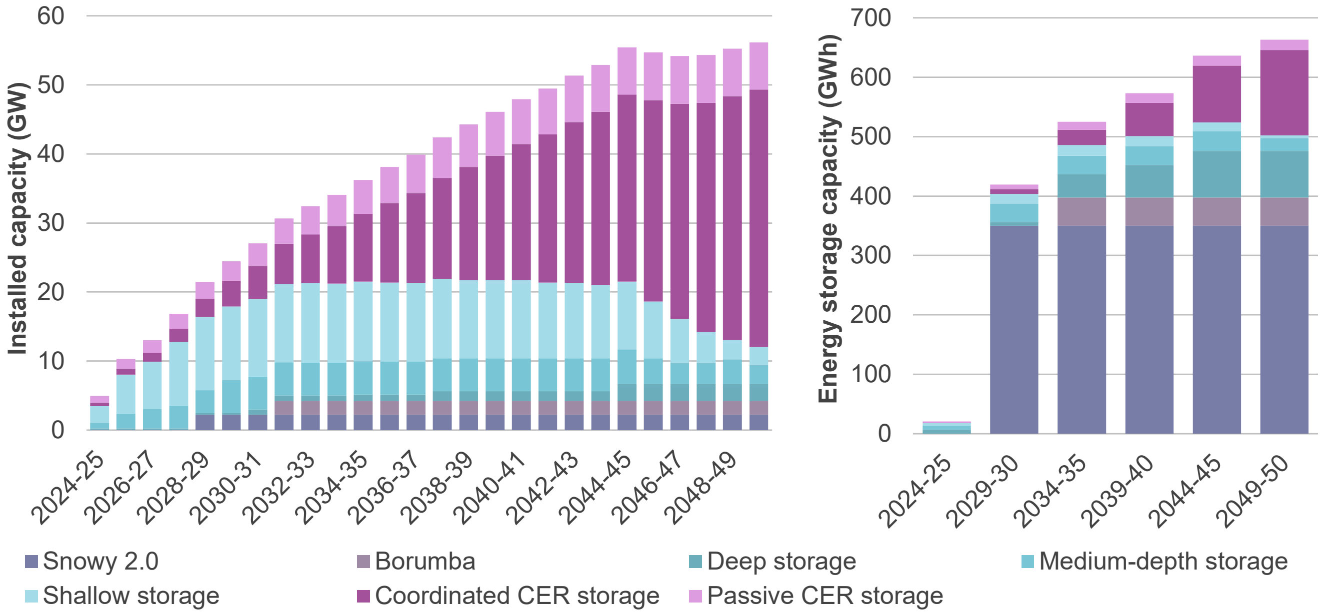
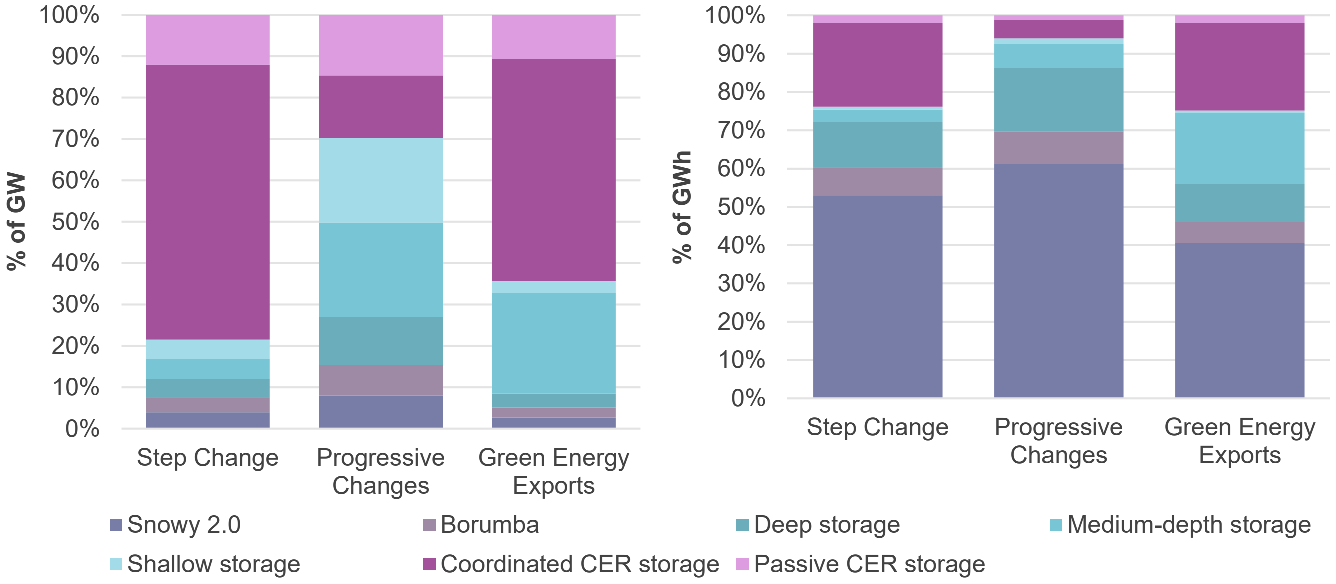


Figure 14 presents the mix of energy storage capacity forecast to be required to complement and firm wind and utility-scale solar developments across the three core scenarios.

Figure 14 Mix of energy storage type by scenario in 2049-50 – storage installed capacity (left) and energy storage depth (right) (%GW and %GWh)



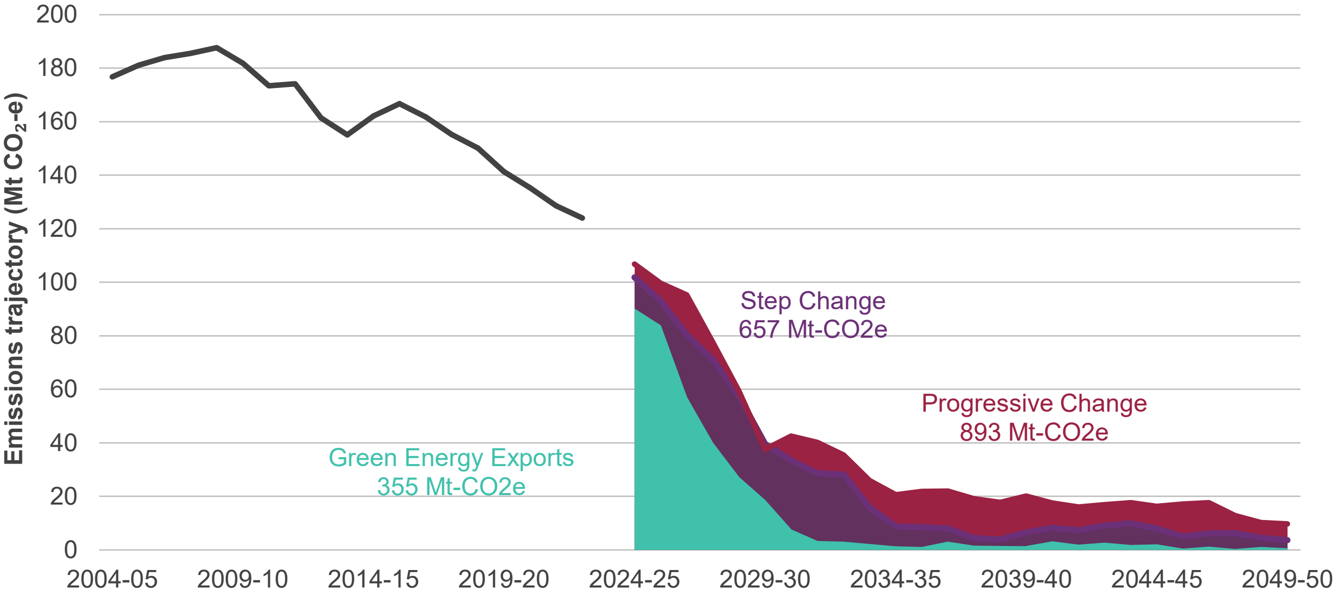
This figure highlights that the scale of CER uptake is significant, because it will offset the need for more shallow and medium-depth utility-scale storage – as shown by the lower CER forecast in *Progressive Change* compared with *Step Change* requiring a significantly larger proportion of utility-scale storage at varying depth.

A2.3.4 The low emissions-intensity future of the NEM

The transformation of the NEM to support Australia's transition to a net zero emissions economy by 2049-50 is forecast to rely on strong wind and utility-scale solar uptake, reducing the electricity sector's emissions intensity under all ISP scenarios, as shown below in Figure 15 and Figure 16. The current set of public policies that support renewable energy development and emissions reduction, and apply in all scenarios, drive the emissions pathways in *Progressive Change* and *Step Change* in particular, with divergence emerging as the scenarios navigate alternative paths to net zero by 2050 after achieving these policies to 2030 (and 2035 in some cases).

Figure 15 shows forecast emissions trajectories to 2049-50 across all scenarios.

Figure 15 Actual and forecast annual NEM-wide emissions by scenario, 2004-05 to 2049-50 (Mt CO_2-e)



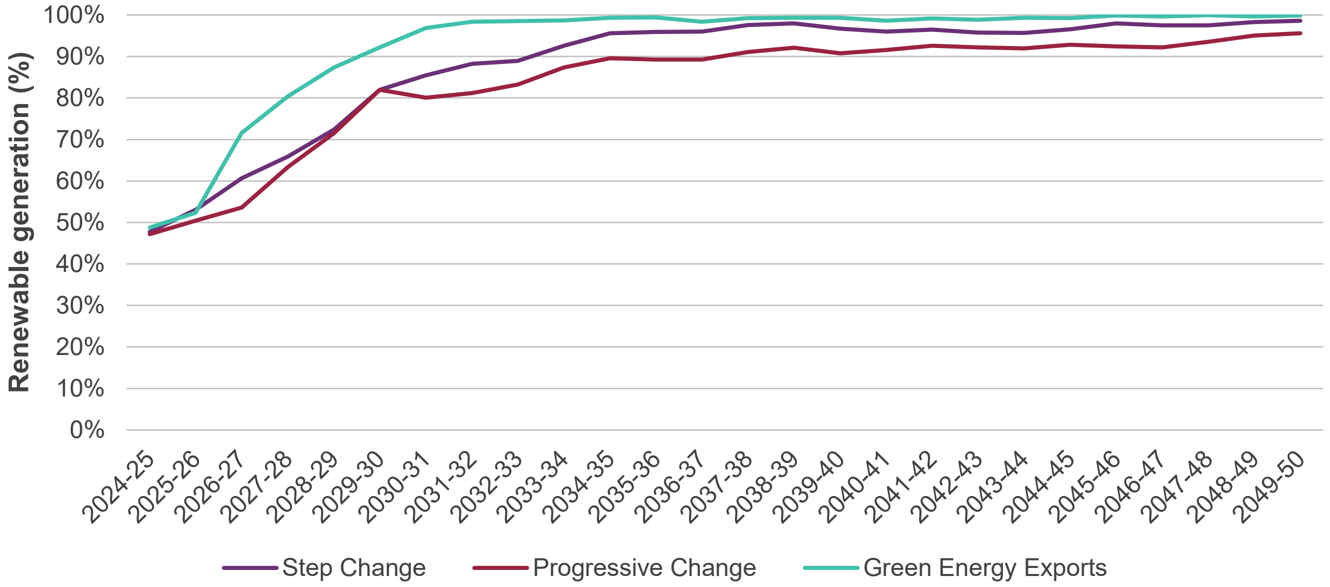
Due to the strong decarbonisation goal in *Green Energy Exports*, its trajectory is significantly lower than the other two scenarios. From the 2030s in *Step Change* and *Progressive Change*, the pace of emissions reduction across scenarios diverges, driven by differing development scales of VRE to support the pace of electrification across the economy.

In *Step Change* and *Green Energy Exports*, significant and rapid change to the NEM's generation mix to achieve the scenarios' emissions reduction objectives is required. This leads to the forecast retirement of most thermal generation in the late 2020s and early 2030s (see Sections A2.4.1 and A2.4.3). By 2029-30, NEM emissions are forecast to reduce by 77% in *Step Change* (from 176 million tons of carbon dioxide equivalent (Mt CO_2-e) in 2004-05 to 40 Mt CO_2-e in 2029-30), and by 90% in *Green Energy Exports* (from 176 Mt CO_2-e in 2004-05 to 18 Mt CO_2-e in 2029-30). By 2049-50, emissions are forecast to be just 4 Mt CO_2-e and 0.5 Mt CO_2-e in *Step Change* and *Green Energy Exports*, respectively.

In *Progressive Change*, emissions reductions are forecast to occur more gradually from the 2030s compared to *Step Change* and *Green Energy Exports*, as less decarbonisation ambition is featured in this scenario beyond current public policies. Up to this point, various renewable energy targets provide the key driver for sufficient VRE developments to reduce emissions, which results in a 78% fall in emissions between 2004-05 and 2029-30.

Figure 16 presents the forecast level of renewable energy penetration to 2049-50 by scenario. Complementing Figure 15, it demonstrates the increasing role of wind and utility-scale solar to reduce emissions over the next 25 years. All scenarios achieve the 82% Powering Australia Plan objective of 82% renewable energy by 2030, and in *Step Change* the share of generation from renewable sources is forecast to reach 99% by 2049-50.

Figure 16 Evolution of the annual share of total generation from renewable sources, from capacity outlook model, by scenario, 2024-25 to 2049-50



A2.4 Generation and storage development opportunities across scenarios

This section outlines the optimal mix of generation and storage for each scenario. The installed capacity forecast differs within each scenario depending on the speed of emissions reduction, coal retirements and energy consumption forecast. The magnitude of wind and utility-scale solar developments is supported by various renewable energy targets, and it reaches 47 GW, 55 GW, and 99.4 GW in *Progressive Change*, *Step Change*, *Green Energy Exports*, respectively, by 2029-30. By 2049-50, wind and utility-scale solar developments diverge across scenarios more significantly, as 86 GW, 127 GW and 374 GW in *Progressive Change*, *Step Change*, and *Green Energy Exports* are developed respectively.

A2.4.1 *Step Change*

Step Change is centred around achieving a scale of energy transformation that supports Australia's contribution to limiting global temperature rise to below 2°C compared to pre-industrial levels, and compatible with 1.5°C depending on actions taken in other sectors. This scenario includes a strong contribution from consumers in the transition with strong continued investments in CER, which are highly coordinated through aggregators or other providers. In this scenario, there is also strong transport and industrial electrification, as well as increased investments in energy efficiency measures.

Generation and storage development in *Step Change*

The generation capacity forecast (shown in Figure 17) projects that:

- To 2029-30:
  - Wind and utility-scale solar developments are driven by renewable energy and decarbonisation policies such as the Powering Australia Plan, the extended Capacity Investment Scheme and various regional renewable energy targets, as well as the modelled NEM emissions budgets.
  - The renewable energy development is complemented by development of storages, at utility-scale and by consumers.
- By 2049-50:
  - All coal-fired and mid-merit gas-powered generation is forecast to retire. The development of VRE to replace the retiring coal fleet is prominent, complemented with continued uptake of CER assets.
  - New firm capacity developments, in the form of energy storages of various depths (as well as CER devices that provide shallow storage solutions), are required to support a high VRE penetration.
  - Flexible gas generation provides further resilience and improves reliability, particularly in providing both peak capacity and energy at times when VRE resources are low (see Section A4.8 on Appendix 4 for more detailed analysis on gas-powered generation operation).

Figure 17 Forecast NEM installed capacity, *Step Change*, 2024-25 to 2049-50 (GW)

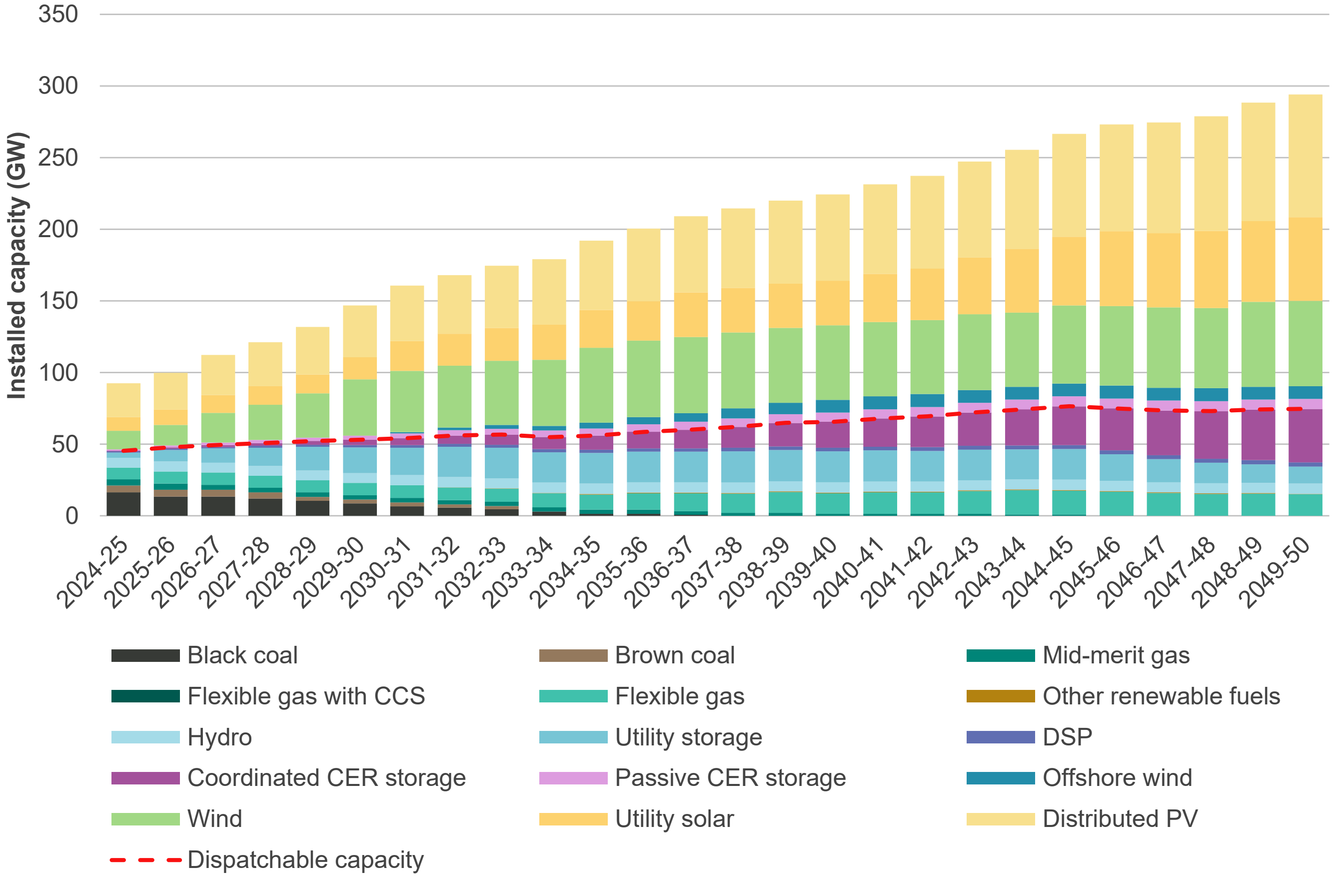
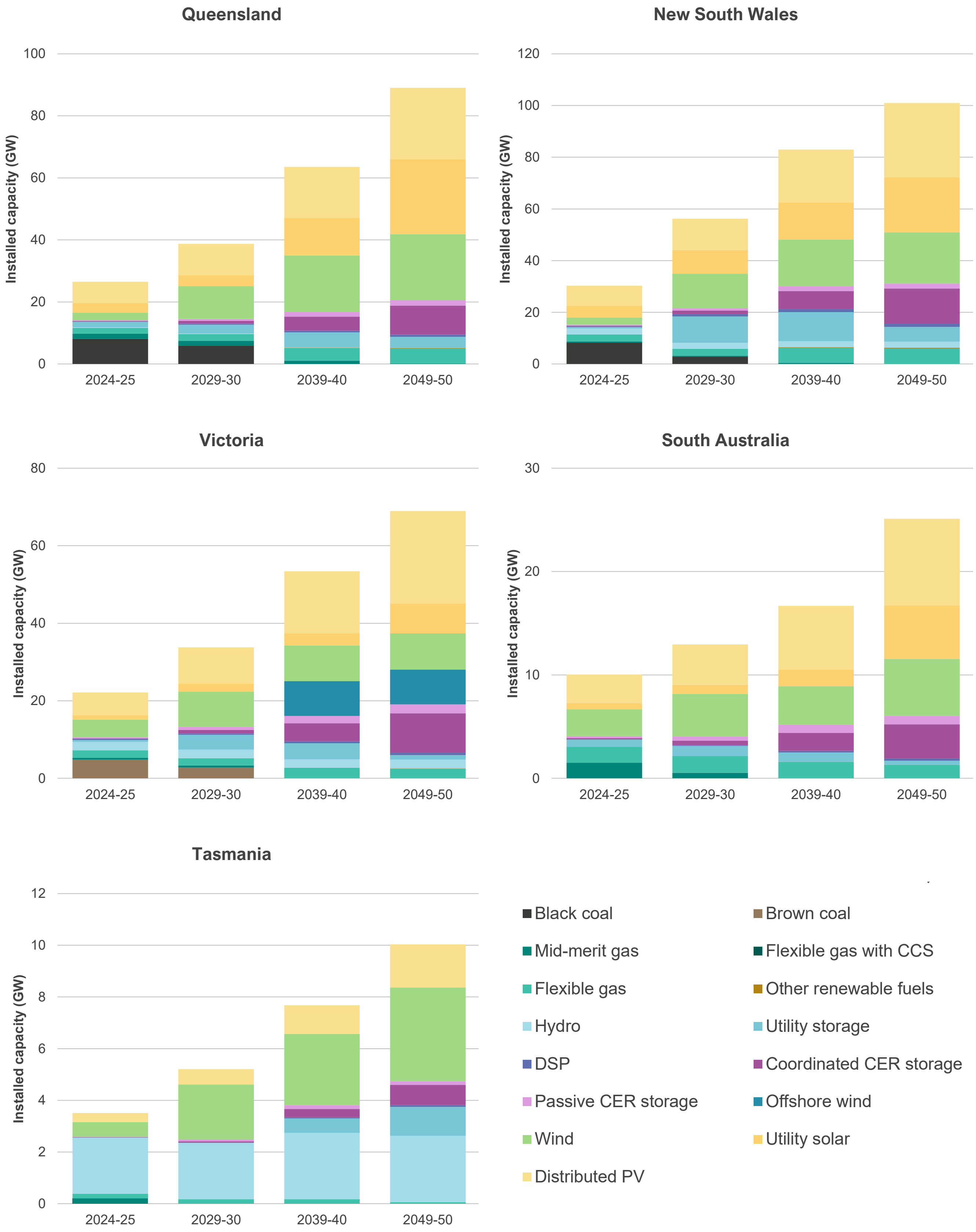


Figure 18 below shows capacity development in *Step Change* at the regional level in the outlook period.

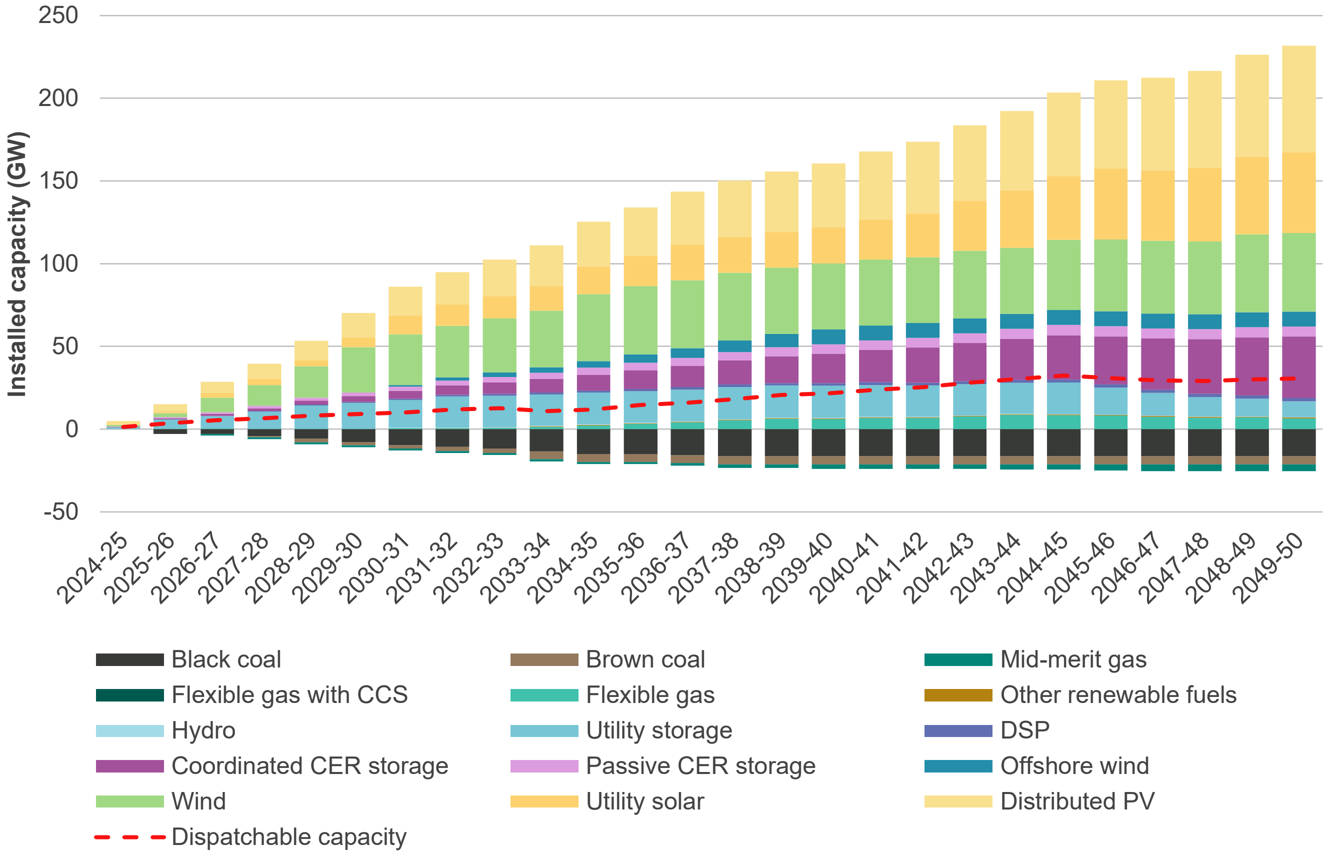
Figure 18 Forecast regional generation capacity for selected years to 2049-50, *Step Change* (GW)



New VRE capacity replaces coal to serve growing demand

Figure 19 shows the change in installed capacity over time. A positive value in the chart indicates a net addition in installed capacity relative to current levels, while a negative value indicates a net reduction due to either an early retirement or a closure due to an asset reaching its announced closure date.

Figure 19 Forecast relative change in installed capacity compared to 2023-24, *Step Change*, 2024-25 to 2049-50 (GW)



Key highlights include:

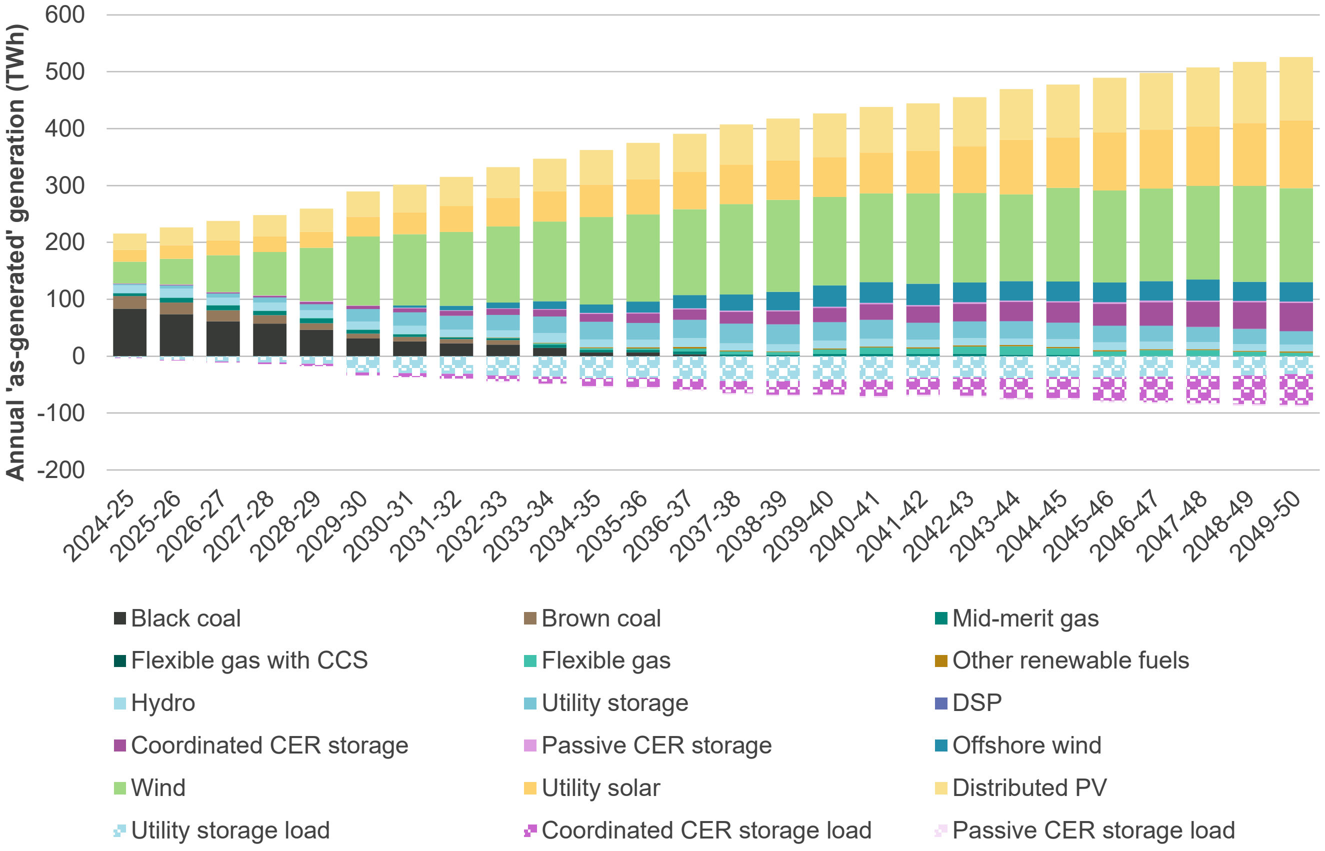
- Significant development in new VRE generation is forecast throughout the outlook period, replacing retiring coal and gas capacity. By 2049-50, the NEM is forecast to need approximately 115 GW of new utility-scale VRE capacity to replace retiring generation and to meet increasing energy demand despite strong adoption of energy efficiency measures. There is significantly greater capacity of VRE than is retired from coal (and gas) generation due to the difference in anticipated production from both technologies. Wind and solar generators operate with a much lower output, on a per MW of installed capacity basis, than what has been historically provided from coal generators yet still represent the most cost-efficient solution for new energy supply when firmed by storage and gas investments and connected with transmission (as confirmed in this modelling).
- Consumer storages increase the flexibility of the customer load, helping smooth the customer load profile and manage shorter periods of generation availability shortage, particularly if these assets are coordinated in their operation. Additional utility-scale storage is required to manage extended periods of high demand or low VRE output, particularly with development of deeper storages to shift surplus renewable energy over longer

durations. This is important to maintain a power system that is resilient to weather-related extremes (see Appendix 4 for more detailed analysis on operational challenges of a high VRE penetration grid).

- Increasing dispatchable capacity is forecast to meet a rising peak demand and service a changing reliability risk profile with greater winter energy consumption and lower renewable energy production.

Figure 20 shows the forecast generation mix in *Step Change*.

Figure 20 Forecast annual generation, *Step Change*, 2024-25 to 2049-50 (TWh)



The following are additional insights on the changing capacity mix discussed above:

- As described in Section A4.3 of Appendix 4, it is projected that periods of over 100% VRE potential[19] (that is, periods in which available VRE generation exceeds forecast demand) will occur regularly by 2025, and in 2029-30, there is projected to be sufficient VRE to supply all load 25% of the time. By the mid-2030s, renewable energy generation is forecast to meet the needs of consumers almost entirely across the year, with energy storages managing daily and seasonal variability and with firming support through flexible gas-powered generation.
- Use of energy storages will be key to maintaining reliability and security across all operational timeframes, but it will lead to an increase in overall load due to the round-trip inefficiency of charging and discharging.

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[19] VRE potential may not equate to VRE dispatch. The share of potential resource that is dispatched depends on a range of market factors including bidding behaviours, maintenance and forced outages.

- As the power system transitions and as synchronous generation is displaced by inverter-based resources (IBR), the provision of essential power system security services will need to evolve (see Appendix 7).

Firming the NEM will require a mixture of technologies and storage durations

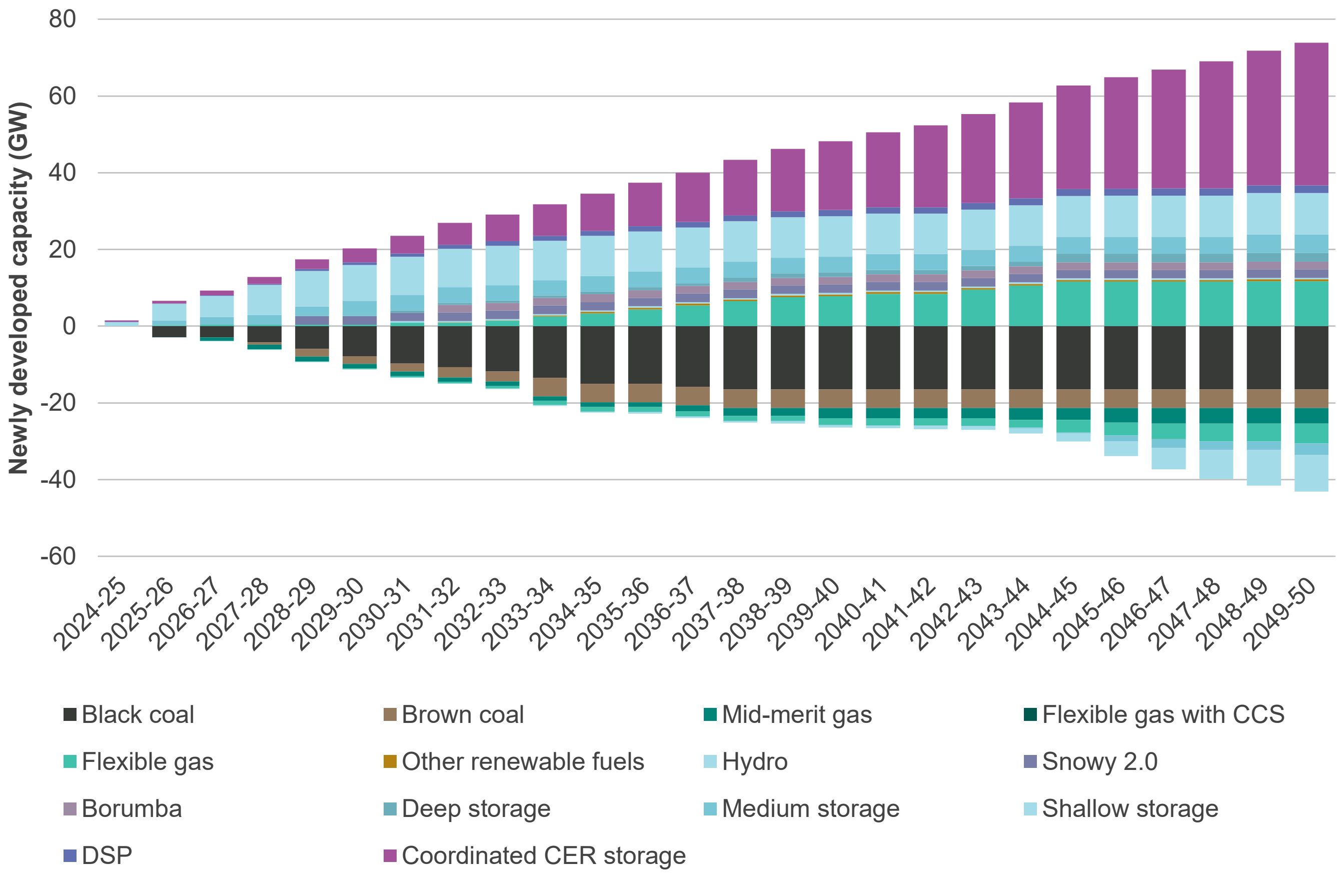
The increasing uptake of coordinated CER technologies in *Step Change* – particularly battery and EVs with appropriate charging and discharging capabilities – are forecast to meet the primary need for intra-day load variability in VRE and demand. This distributed technology is complemented by a suite of deeper utility-scale storage developments to support an increasing scale of dispatchable technologies, and replace the dispatchable capacity provided by retiring thermal plant.

Approximately 11 GW of flexible gas generation is also developed by 2049-50. This is slightly less than in the Draft 2024 ISP (by approximately 2 GW), due to the consideration of gas infrastructure constraints, but is developed with greater recognition of the need to provide sufficient resilience to weather volatility that is inherently uncertain in its timing. The 2024 ISP smooths the GPG build to accommodate this need, relative to the Draft 2024 ISP. This new flexible gas capacity complements existing peaking capacity, supports firming requirements, and provides additional dispatchable capacity to assist in meeting growing peak demand.

In addition, in *Step Change* the proposed Cethana pumped hydro project in Tasmania is developed to provide additional deeper storage to southern regions. It complements Gippsland offshore and Tasmanian onshore wind production, providing accessible storage for local renewable energy when the South East Victoria transmission corridor is constrained. The Cethana project is developed in every scenario, in 2044-45 in *Progressive Change* and late 2030s *in Green Energy Exports*.

Figure 21 shows the forecast development of dispatchable technologies, reinforcing the important role for new flexible gas, as well as storages (shallow and medium-depth, to complement the committed and anticipated Snowy 2.0 and Borumba Dam Pumped Hydro).

Figure 21 Forecast relative change in dispatchable capacity compared to 2023-24, *Step Change*, 2024-25 to 2049-50 (GW)

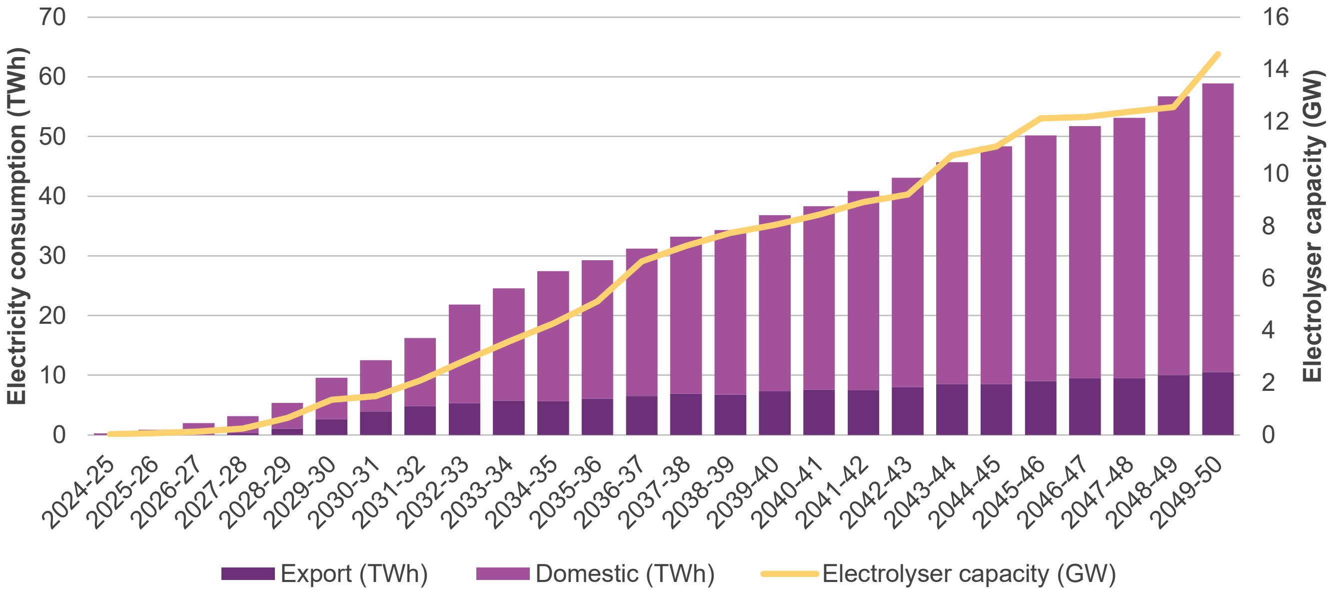


Hydrogen developments

The ISP modelling considered hydrogen developments for domestic use, for export as ammonia, and for the production of green steel. The assumed domestic and export hydrogen demands were modelled as loads with sufficient flexibility to optimise production volumes within a monthly timeframe, assuming sufficient hydrogen storage capacity to manage variable daily production levels and hydrogen consumption patterns. This results in some inherent flexibility to operate when surplus renewable generation is available and to balance the cost of production capacity with operating expenses.

Figure 22 presents the assumed total electricity consumption to 2049-50 for hydrogen (used for domestic use and export) in *Step Change*. On the secondary y-axis, it shows that by 2049-50, around 15 GW of electrolyser capacity is developed. Several state governments have released strategies setting out their paths for developing a hydrogen industry and announced funding for hydrogen-related projects in their respective states, including the Renewable Fuels Scheme in New South Wales, the Hydrogen Jobs Plan in South Australia, and the Queensland Energy and Jobs Plan in Queensland. The forecast growth in hydrogen production exceeds those objectives progressively over the forecast horizon, as outlined in the 2023 IASR, providing sufficient eventual hydrogen for domestic use (supporting industrial decarbonisation and potential export opportunities).

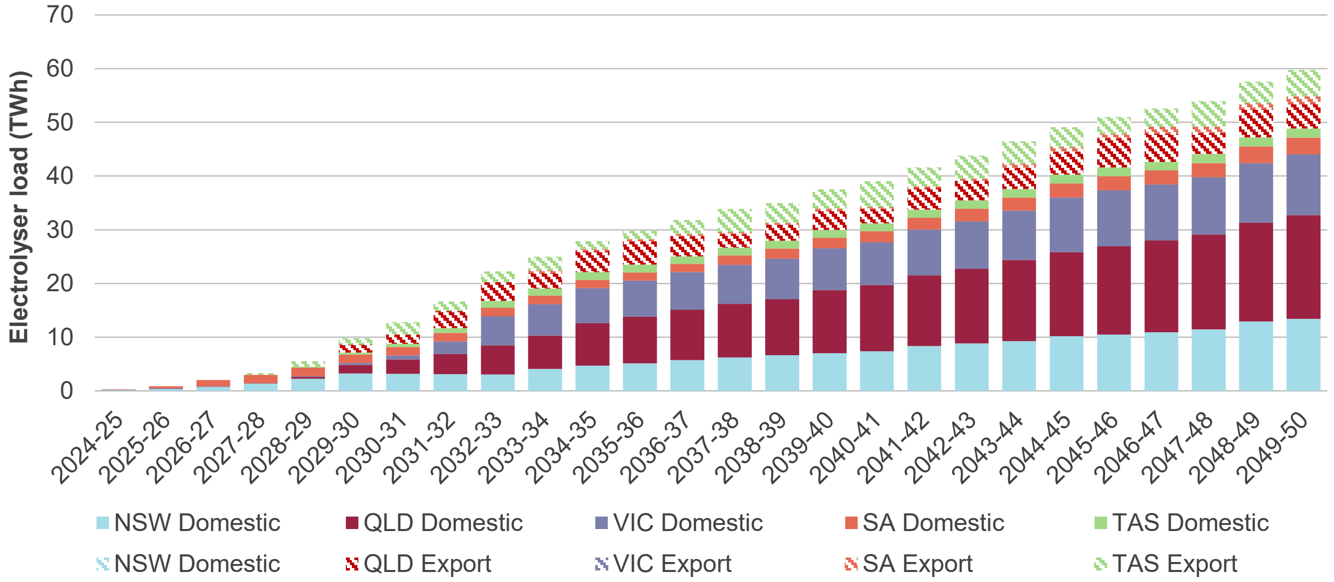
Figure 22 **Electricity consumption associated with hydrogen production and ammonia conversion, *Step Change*, 2024-25 to 2049-50 (TWh and GW)**



Section A2.5.6 discusses the *Low Hydrogen Flexibility* sensitivity, which assesses the impact of inflexible hydrogen demand, resulting in a much higher load factor for hydrogen production. The development of electrolyser capacity is determined by balancing the capital costs of the electrolyser investments and costs associated with VRE, utility-scale storage and transmission developments with operational flexibility. Sufficient electrolyser capacity is endogenously developed considering these cost trade-offs to enable flexible utilisation of between 40-60% on average.

The location of hydrogen production for export shows that geographical diversity of electrolyser investments minimises system costs, enabling the utilisation of excess renewable generation spread across the NEM; see Figure 23.

Figure 23 **Regional allocation of hydrogen developments by 2049-50, *Step Change***



Future generation mix in *Step Change* without transmission developments

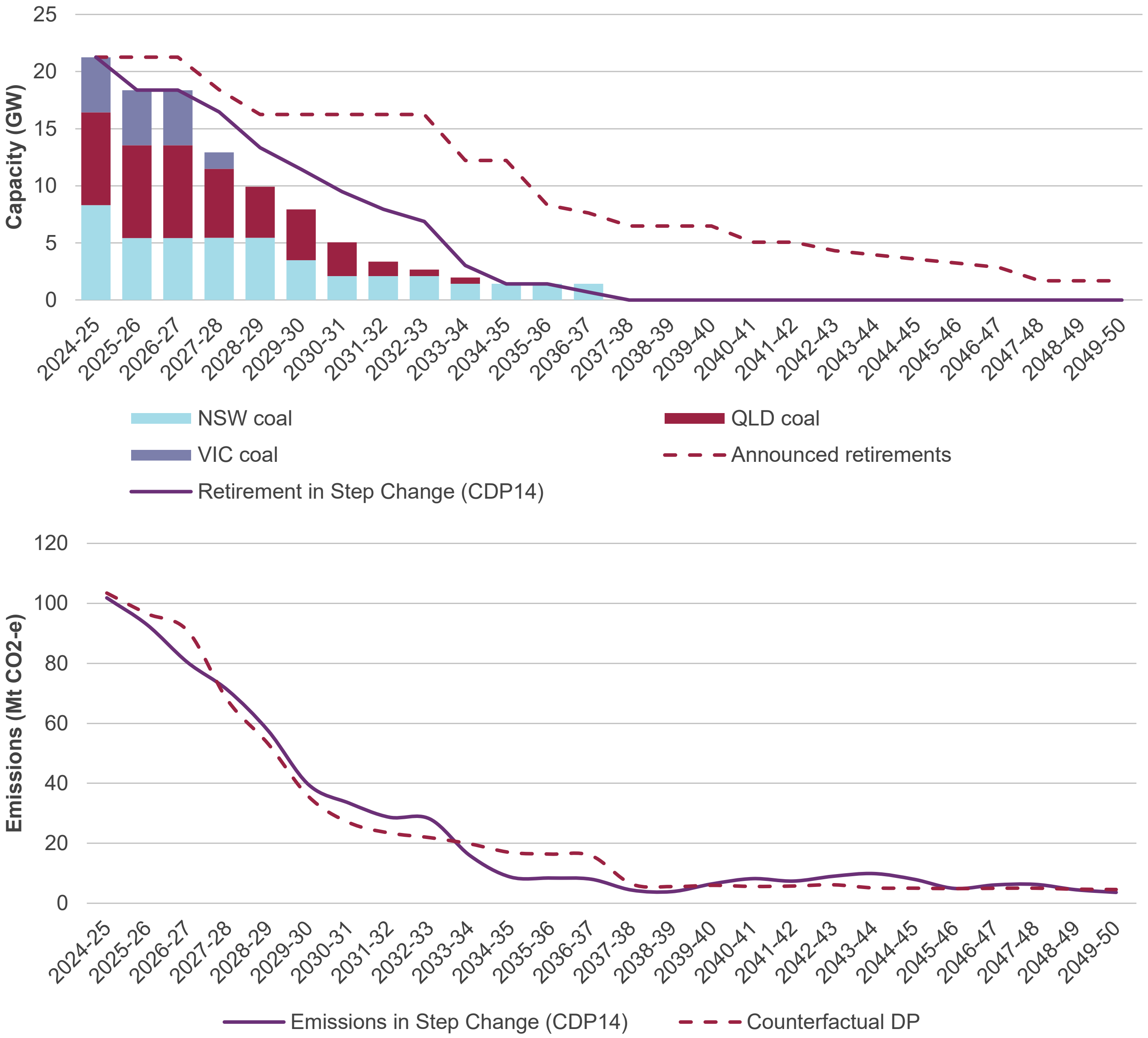
Impact of transmission development on coal retirements

The 2024 ISP identifies material savings to consumers through the expansion of the transmission network (see Section A6.4 in Appendix 6 for more details on the CBA). Transmission investments help transition to a lower emissions energy system by improving access to renewable energy developed in REZs and reducing potential VRE curtailment due to transmission limitations. In times of VRE curtailment, coal or gas may need to generate instead, resulting in higher emissions.

In the absence of transmission expansion, coal generators may need to reduce to seasonal operation or retire earlier to enable achievement of the carbon budgets that still apply. Where transmission hosting capacity exists, more rapid development of VRE may be needed, and other low emissions technologies, such as carbon capture and storage (CCS), will also be needed when insufficient access to VRE development options remains. Appendix 6 demonstrates the higher system costs that would eventuate if this were developed in place of the ODP's generation and storage developments.

Figure 24 below shows a comparison between coal retirements in the counterfactual DP which does not expand transmission (bars) and CDP14 (the 2024 ISP's ODP) (solid line), contrasted with the announced closure dates (dashed line). Below the figure is a comparison in the emissions trajectory between the counterfactual DP and CDP14.

Figure 24 Forecast coal retirements (top) and emissions trajectory (bottom) to 2049-50, *Step Change* counterfactual DP (GW and Mt CO_2-e)



In the counterfactual DP, limitations to REZ access require a more diverse mix of technologies to meet the future needs of the NEM. From the 2030s in particular, investments in flexible gas with CCS are projected to be required across the NEM to provide dispatchable capacity while operating within the emissions budget if transmission expansion is not developed. Figure 25 shows the evolution of this generation mix in *Step Change's* counterfactual DP.

Figure 25 Forecast NEM generation capacity, *Step Change* counterfactual DP, 2024-25 to 2049-50 (GW)

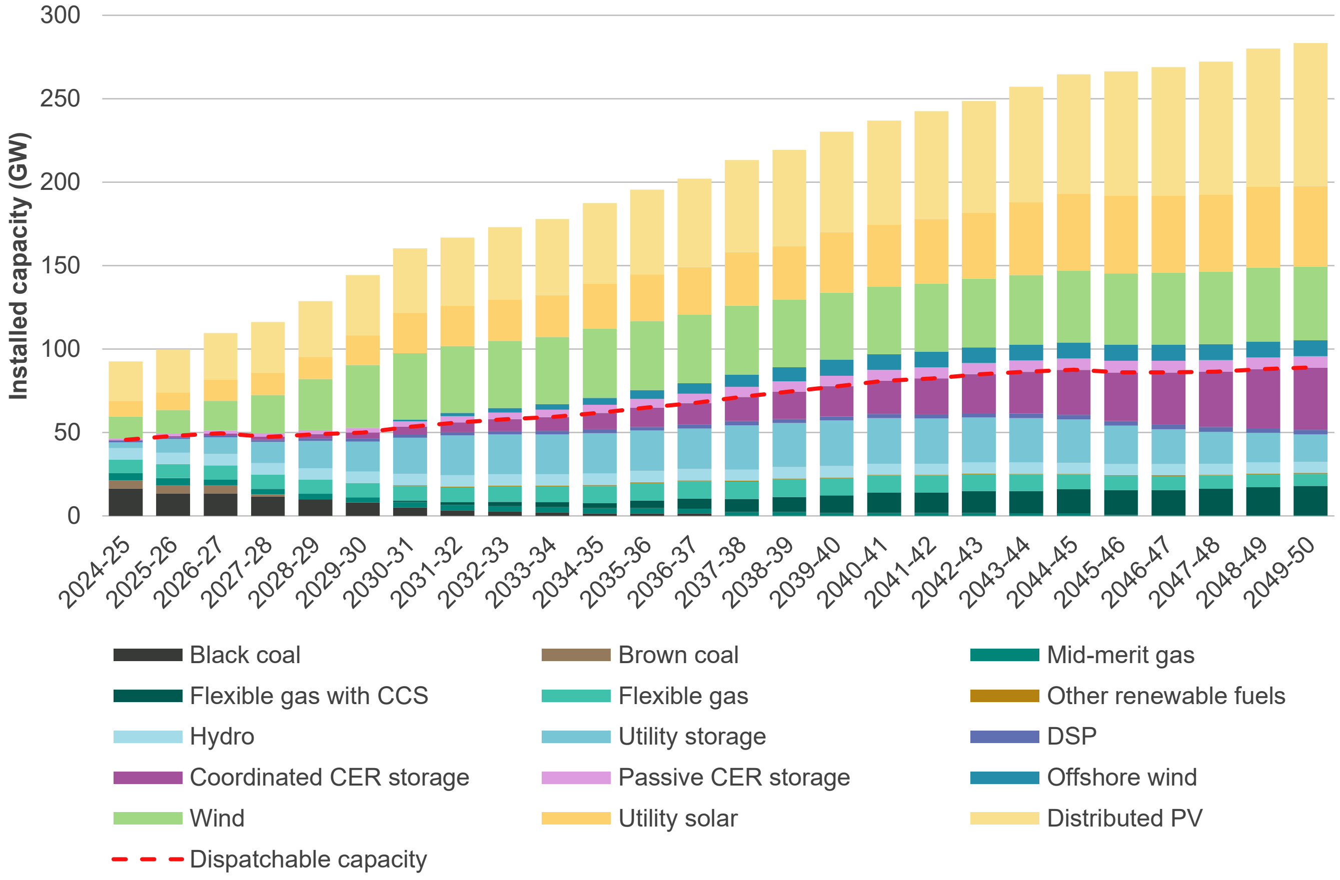
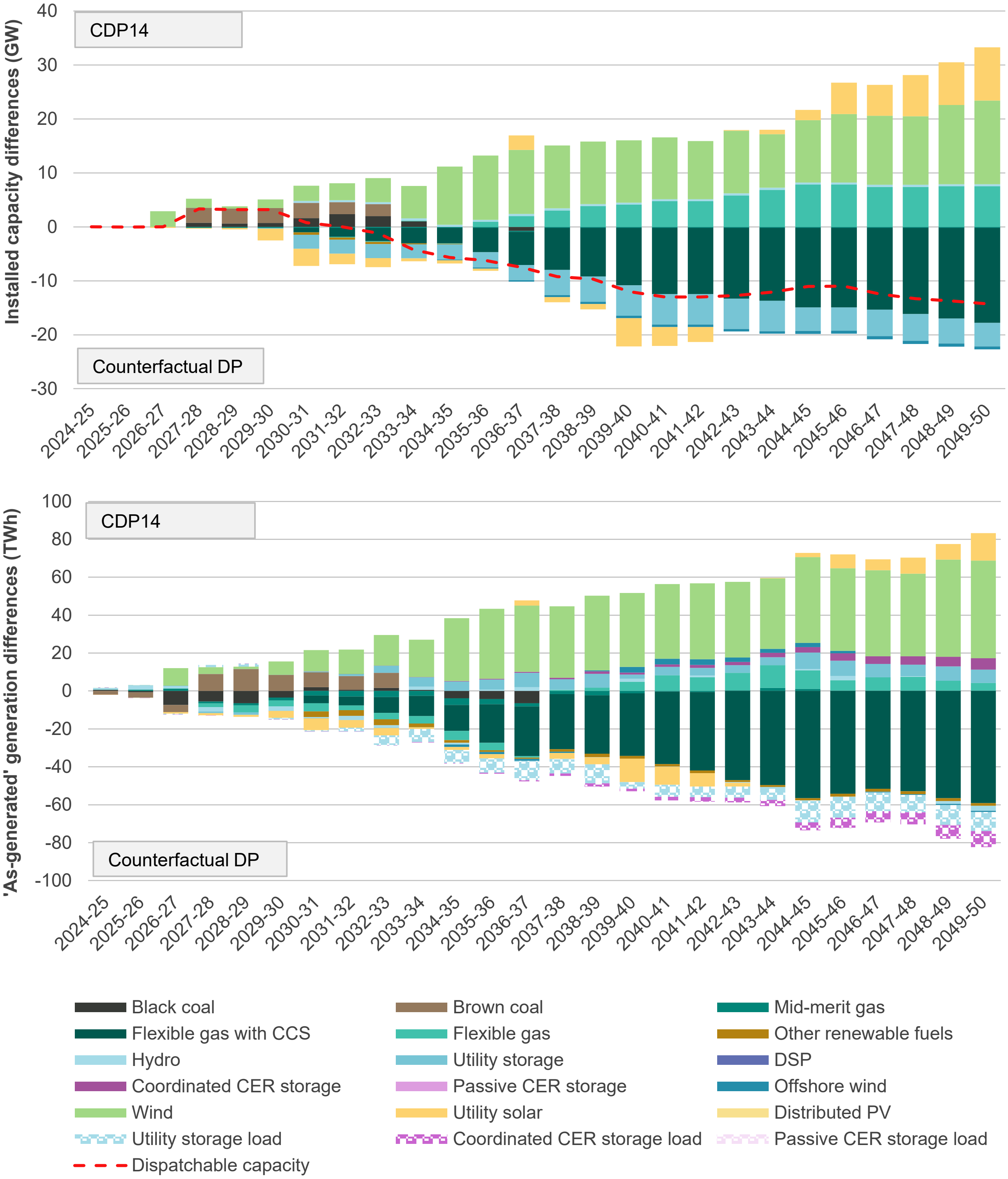


Figure 26 below shows the differences in capacity and generation developments in *Step Change* between CDP14 and the counterfactual DP. A positive value indicates higher total installed capacity in CDP14.

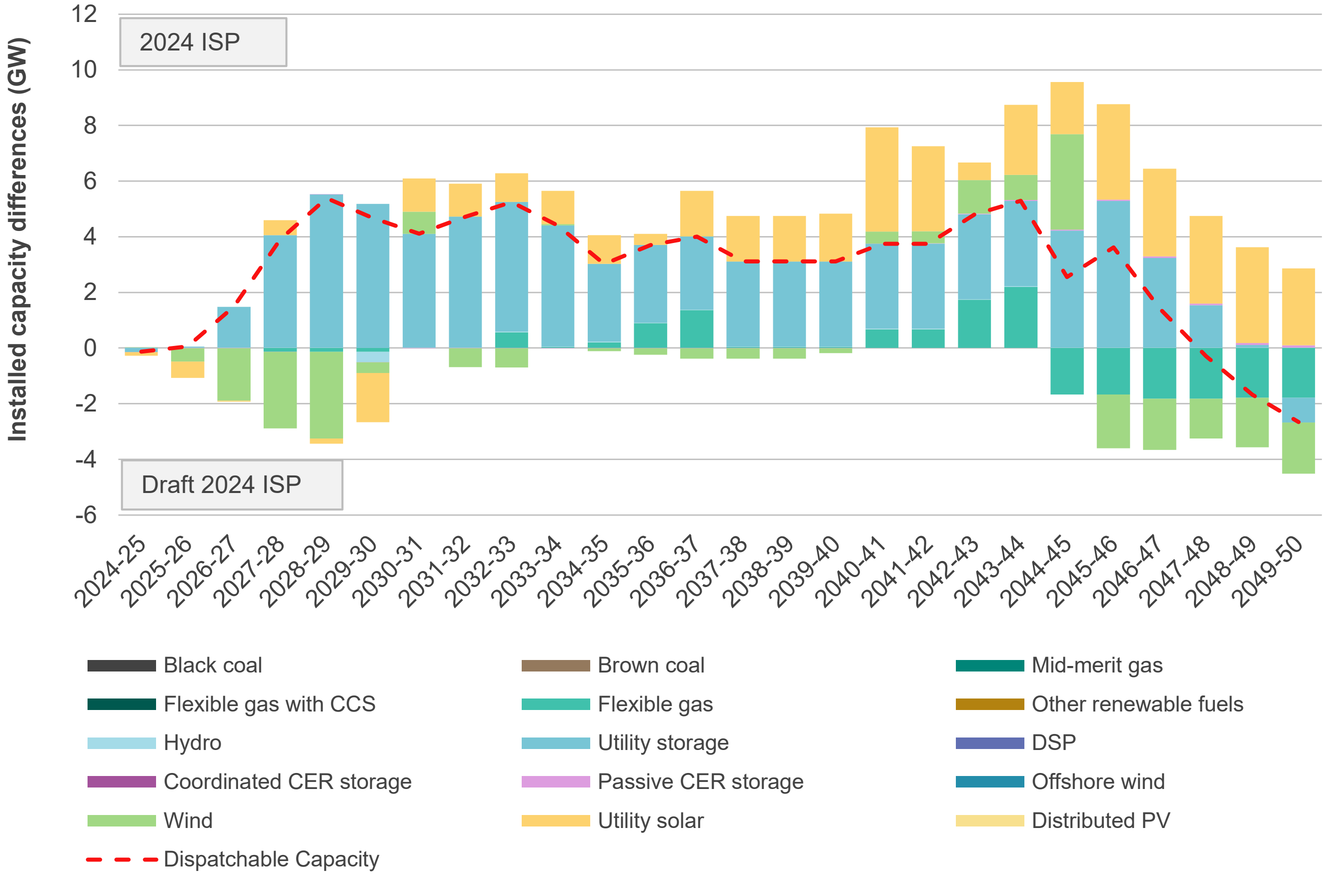
Figure 26 Forecast capacity developments (top) and generation (bottom) to 2049-50 under counterfactual DP compared to *Step Change* (GW and TWh)



Capacity development in *Step Change* compared to the Draft 2024 ISP

Since the Draft 2024 ISP, there has been an increase in storage developments due to the inclusion of newly committed and anticipated storage projects reported in the February 2024 Generation Information update and development of new storage capacity to meet CIS clean dispatchable capacity targets. Figure 27 demonstrates that in adjusting the pace of development to meet the Powering Australia Plan and CIS targets, there is a slower rate of wind development in the near term. Over the long term, more developments in storage are forecast relative to the Draft 2024 ISP, as a result of gas infrastructure considerations, which enables greater investment in solar generation.

Figure 27 Forecast NEM generation capacity to 2049-50 in the *Step Change*, 2024 ISP assumptions compared to the Draft 2024 ISP assumptions (GW)



A2.4.2 *Progressive Change*

Progressive Change explores the challenges of meeting Australia's current climate commitments to the Paris Agreement of an economy-wide 43% emissions reduction by 2030 and net zero emissions by 2050 amid economic conditions that are more challenging than in *Step Change*.

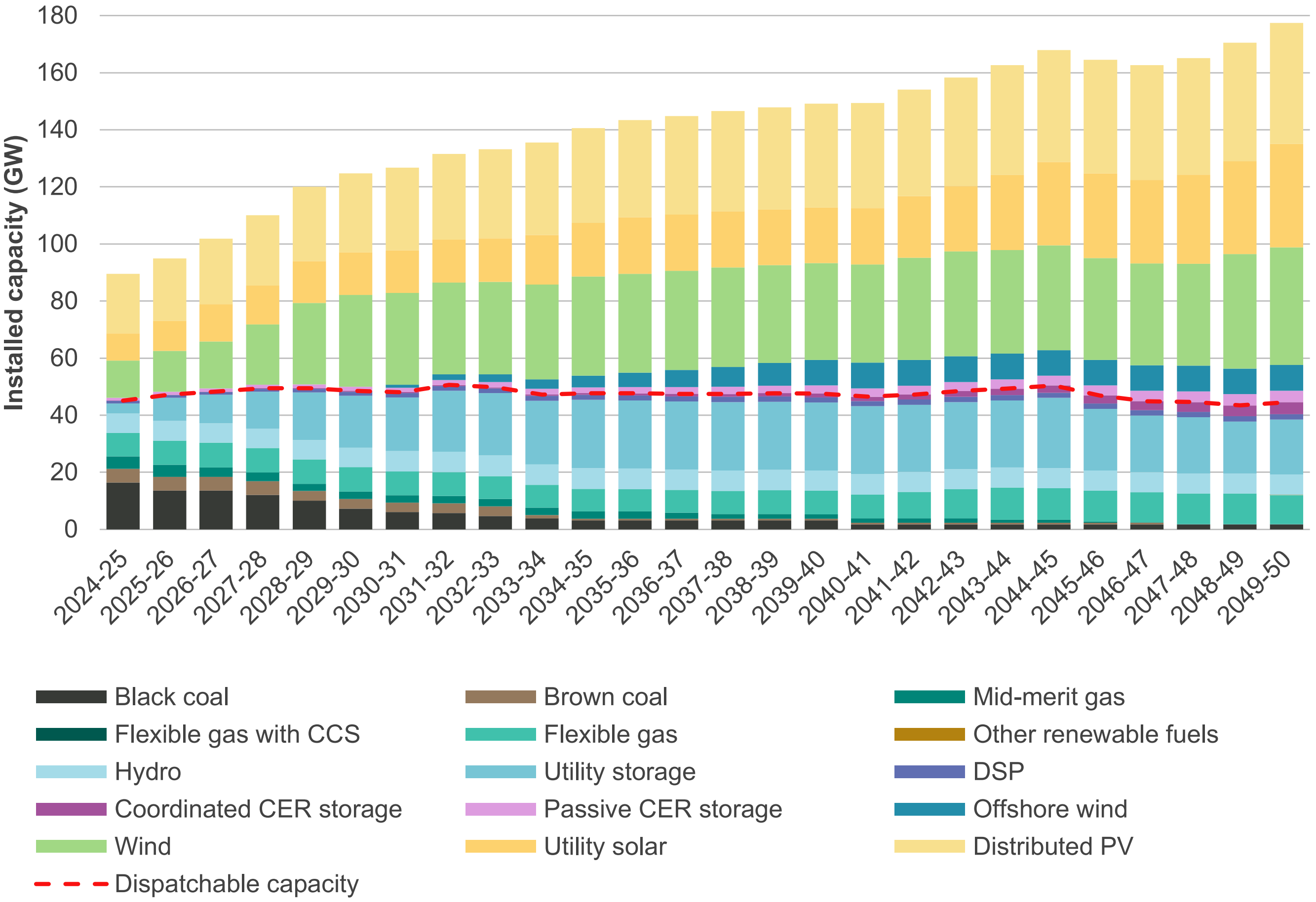
In this scenario, transformational energy sector investments to meet policy objectives continue but economic and international factors place industrial loads at greater risk, and lesser consumer investments are anticipated.

This section describes the developments that are forecast in *Progressive Change*.

Generation and storage development in *Progressive Change*

Figure 28 presents the forecast capacity mix for the NEM across the outlook period to 2049-50.

Figure 28 Forecast NEM installed capacity, *Progressive Change*, 2024-25 to 2049-50 (GW)



The generation capacity forecast projects that:

- To 2029-30:
  - Renewable energy policies at federal and state level will drive continued investments in VRE developments across the NEM.
  - Coal-fired capacity is forecast to reduce more slowly than in *Step Change* but is still forecast to approximately halve from current levels as new renewable energy developments and additional energy storage increase.
- By 2049-50:
  - Less than 2 GW of coal capacity is forecast to be operational as a result of achieving the scenario's carbon budgets. For Australia to be net zero while retaining small amounts of coal capacity, other solutions such as carbon sequestration in the land-use sector would be needed (as outlined in the 2023 IASR).

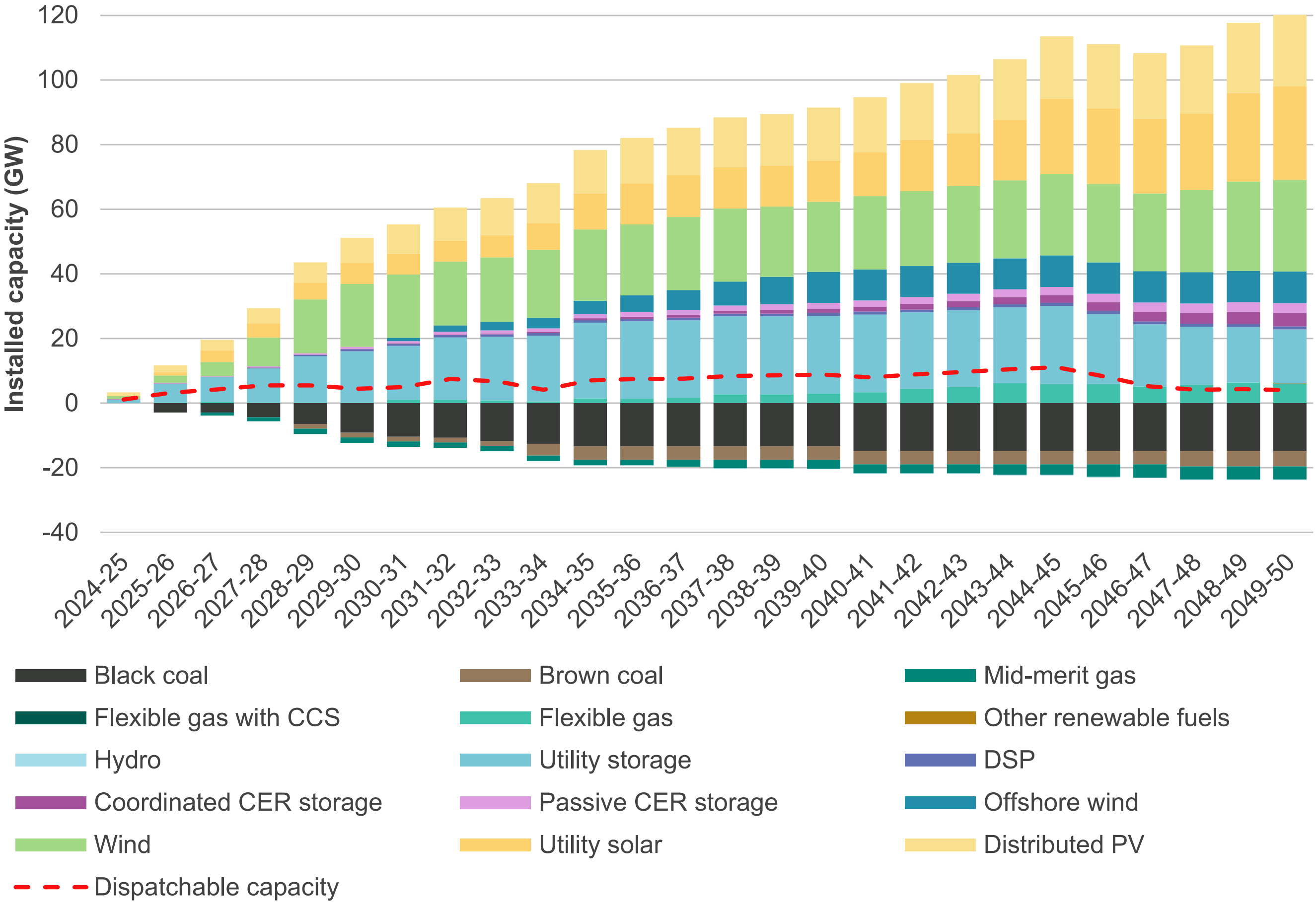
- Development of VRE continues in all regions to replace retiring coal, with new storage developments of various depths supporting the renewable energy transition.
- Flexible gas generation continues to provide a key role in maintaining reliability and operability over the long term, supporting extended periods of low wind and solar output.

VRE development supports load growth

Figure 29 shows the cumulative change in investment and withdrawal by technology type forecast over the outlook period. Key highlights include:

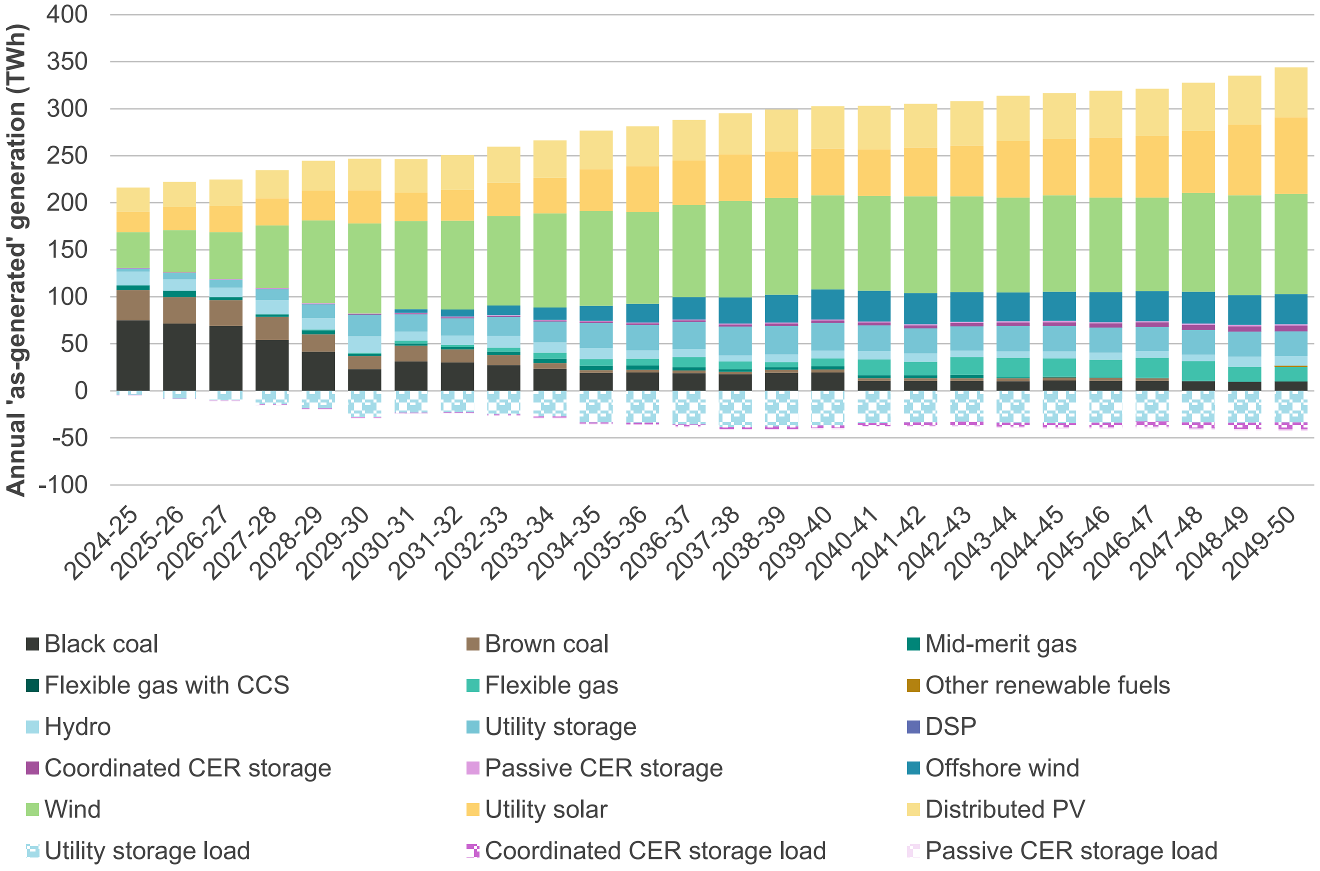
- Coal retirements are forecast to be replaced by a combination of VRE, utility-scale storage and CER. Retiring gas-powered generators are generally replaced by new flexible gas developments to provide firming support.
- By 2049-50, in addition to over 40 GW of distributed PV, the NEM is forecast to need over 70 GW of new utility-scale VRE to replace existing capacity and to meet increasing energy consumption. This is complemented by 16 GW of new utility-scale energy storage in addition to CER storages.

Figure 29 Forecast relative change compared to 2023-24 in installed capacity, *Progressive Change*, 2024-25 to 2049-50 (GW)



In terms of energy production, Figure 30 demonstrates the very different energy mix expected relative to today. Renewable energy is forecast to expand to approximately 95% of energy generated by 2049-50. The projected split of VRE by 2049-50 is approximately 54% wind, 28% utility-scale solar and the remainder from distributed PV.

Figure 30 Forecast annual generation, *Progressive Change*, 2024-25 to 2049-50 (TWh)

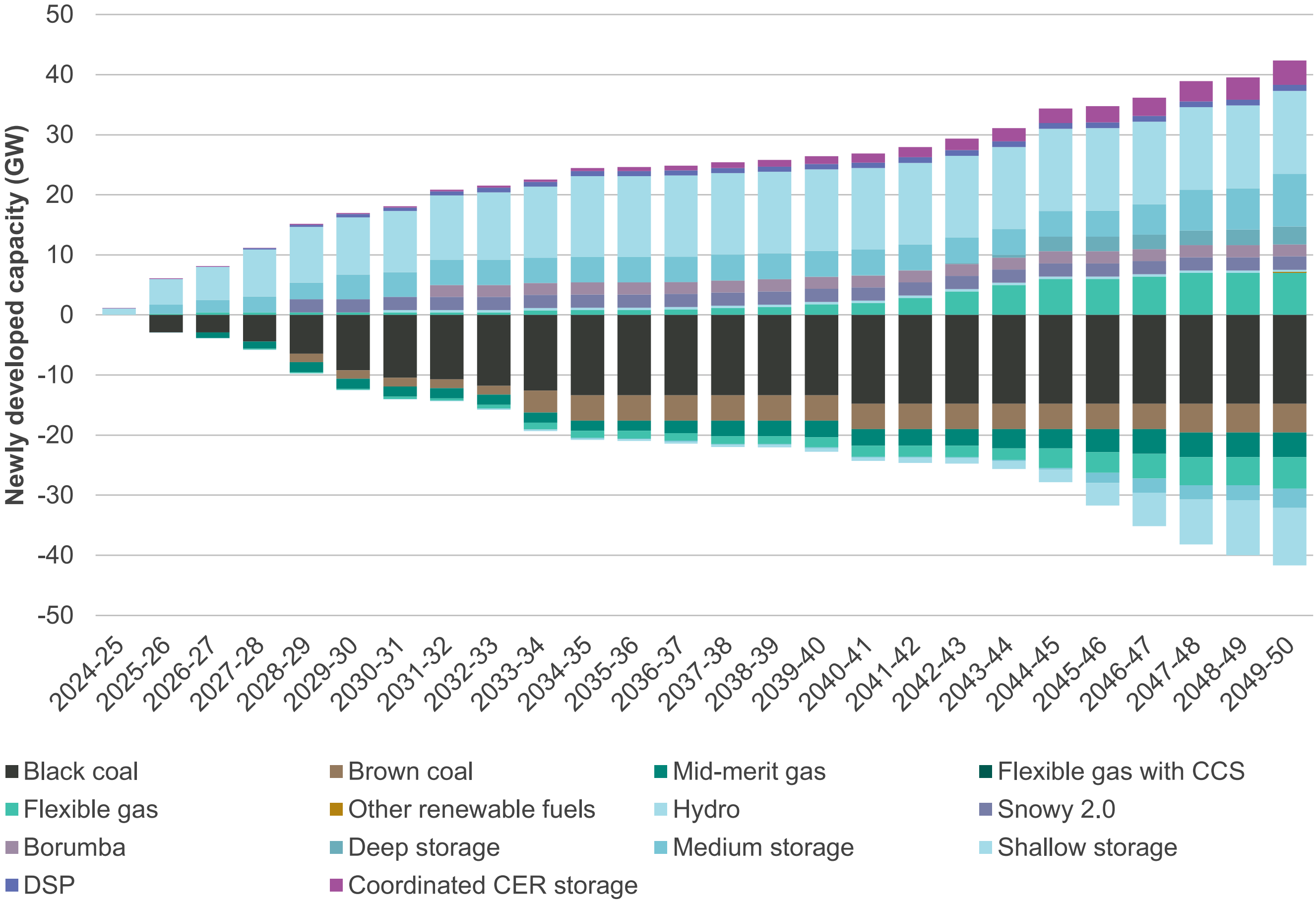


Firming the NEM will require a mixture of technologies and storage durations

Consistent with the findings for *Step Change*, significant expansion of various storage technologies is forecast. Flexible gas provides further dispatchable capacity and complements the energy generated by VRE developments.

Figure 31 demonstrates the change in dispatchable capacity forecast across the outlook period, with only about 10% of the current capacity of coal still operating, and with retiring gas generation largely being replaced by new flexible gas.

Figure 31 **Forecast relative change compared to 2023-24 in dispatchable capacity, *Progressive Change*, 2024-25 to 2049-50 (GW)**



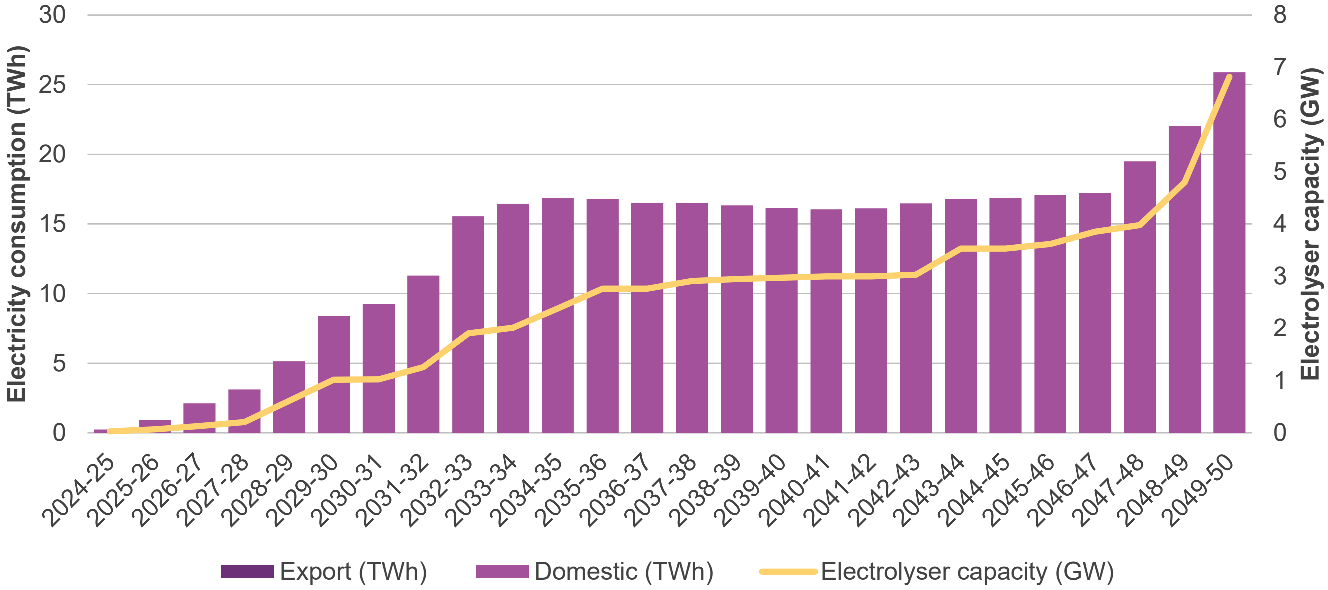
Hydrogen developments

In *Progressive Change,* hydrogen developments over the coming decades are for domestic use only, as discussed in the 2023 IASR.

Several state governments have released strategies setting out their paths for developing a hydrogen industry and some have committed funding for hydrogen-related projects in their respective states, including the Renewable Fuels Scheme in New South Wales, the Hydrogen Jobs Plan in South Australia, and the Queensland Energy and Jobs Plan in Queensland. The forecast growth in hydrogen production incorporates these objectives over the forecast horizon, as outlined in the 2023 IASR.

Figure 32 demonstrates the forecast scale of electricity consumption for hydrogen production. While it represents an emerging opportunity at reasonable scale by 2050, this scenario's hydrogen development is less than half the growth of *Step Change* (see Figure 22).

Figure 32 Electricity consumption associated with hydrogen production for domestic use, *Progressive Change*, 2024-25 to 2049-50 (TWh and GW)



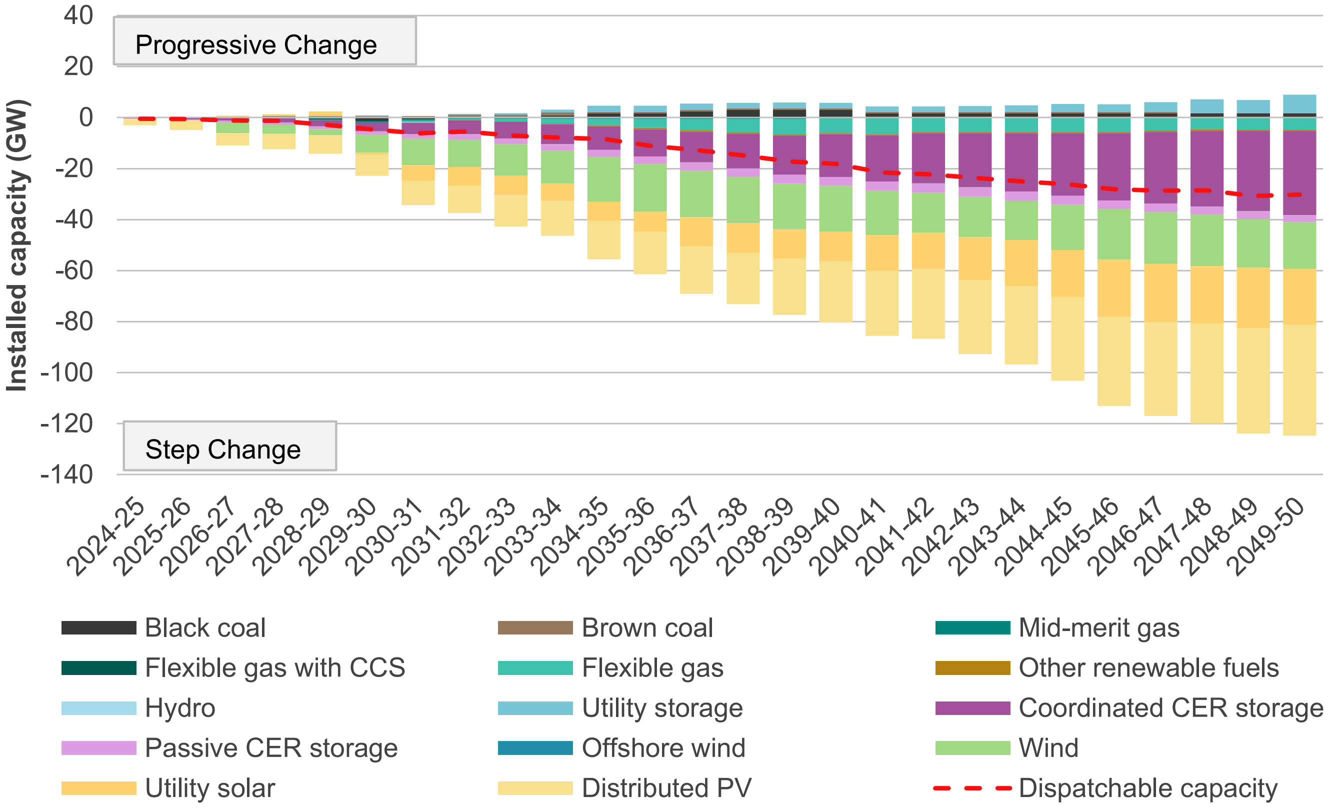
Contrasting *Progressive Change* with *Step Change*

Figure 33 below presents the capacity difference between the results for *Progressive Change* and *Step Change*. By the end of the outlook period, the difference between the scenarios reflects the strong contribution from costumers with higher coordinated CER and higher distributed PV uptake in *Step Change. Progressive Change* features a lower economic outlook, lowering generation requirements, with less industrial load relative to business and residential loads in the longer term.

The key differences from results in *Step Change* are:

- The slower emissions reduction objectives in *Progressive Change* decrease the speed at which VRE is developed (beyond relevant policy-based targets) and slows the retirement of existing coal generators. By the end of the outlook period, the difference in VRE capacity between scenarios increases due to the differences in demand and a tighter emissions budget leading to more VRE developments in *Step Change*.
- *Progressive Change* includes both lower uptake of CER technologies and less coordination of CER storage devices (residential battery systems and EVs that are capable of V2G operation), which increases the need for utility-scale storage developments in the long term, relative to *Step Change*.

Figure 33 Forecast capacity development to 2049-50 under *Progressive Change* compared to *Step Change* (GW)



Future generation mix in *Progressive Change* without transmission developments

Impact of transmission development on coal retirements

Coal retirements in the counterfactual DP for *Progressive Change* follows the same trajectory as CDP14. below shows this equivalent coal retirement schedule in *Progressive Change* with and without transmission augmentations, but still faster than announced retirements.

Similar to *Step Change*, without transmission augmentation, there is a higher reliance on GPG over the outlook period as VRE generation is curtailed due to transmission congestion. This leads to a slightly higher emissions trajectory up to 2029-50.

Figure 34 Forecast coal retirements (top) and emissions trajectory (bottom) to 2049-50, *Progressive Change* counterfactual DP (GW and Mt CO_2-e)

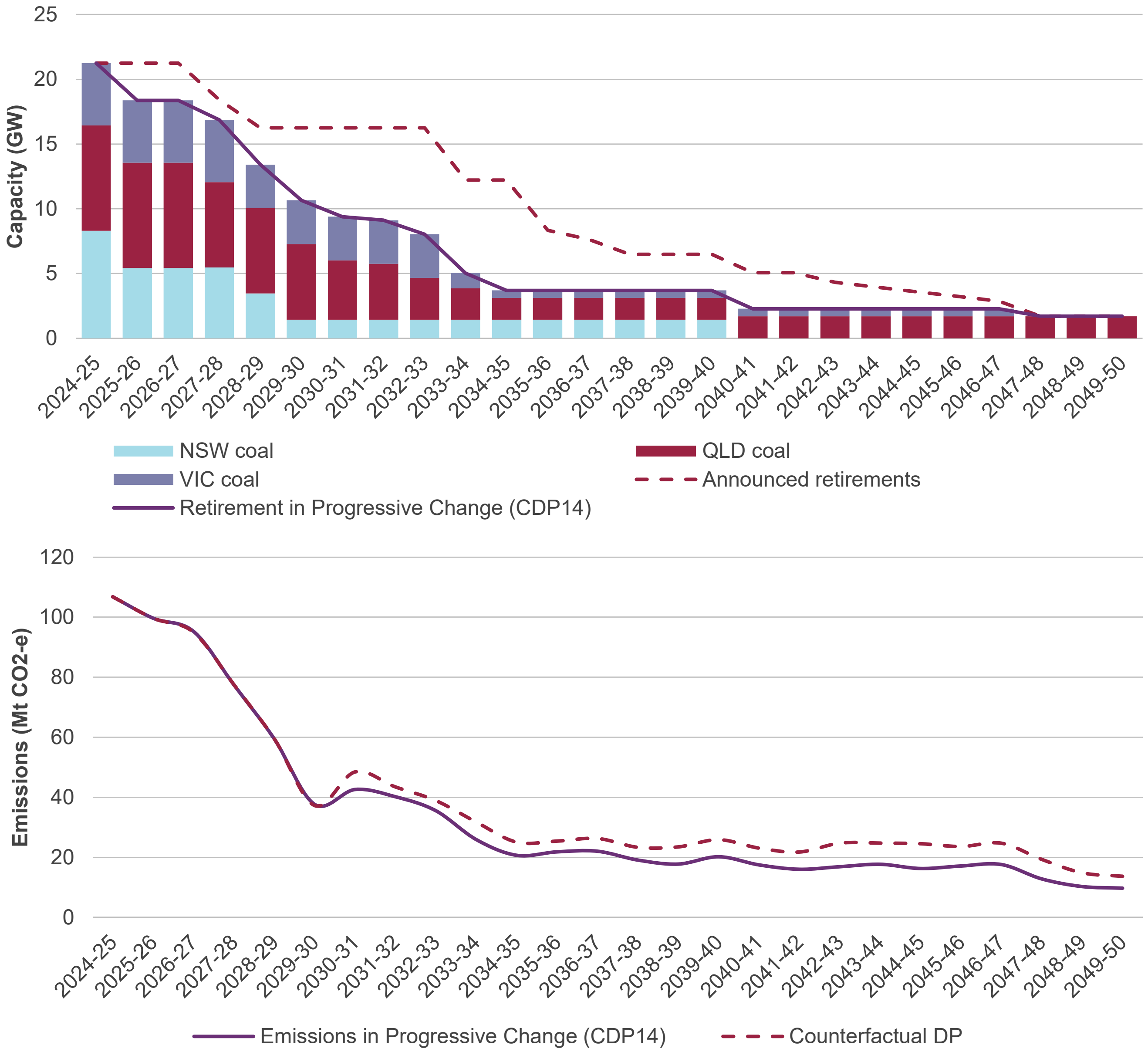
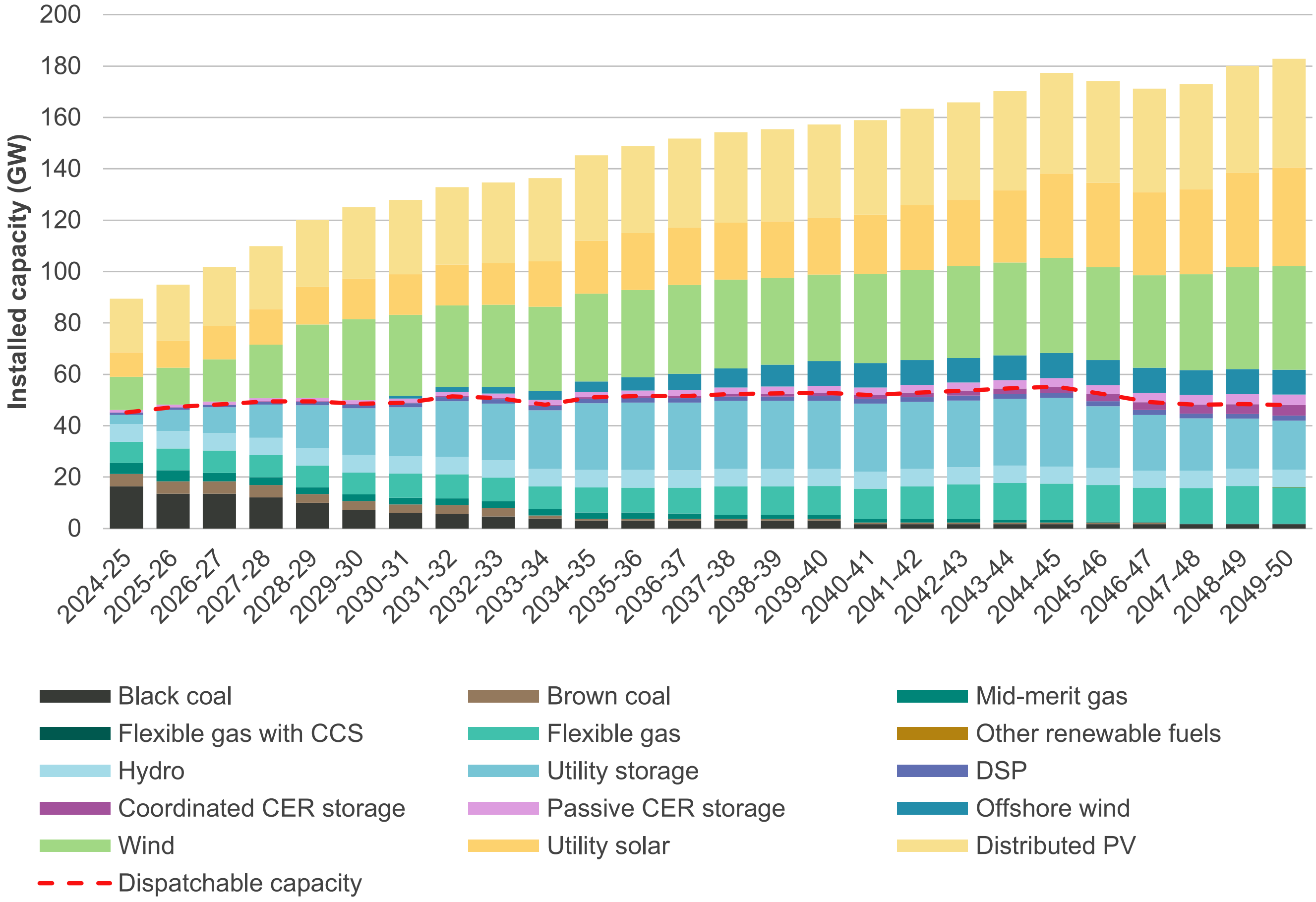


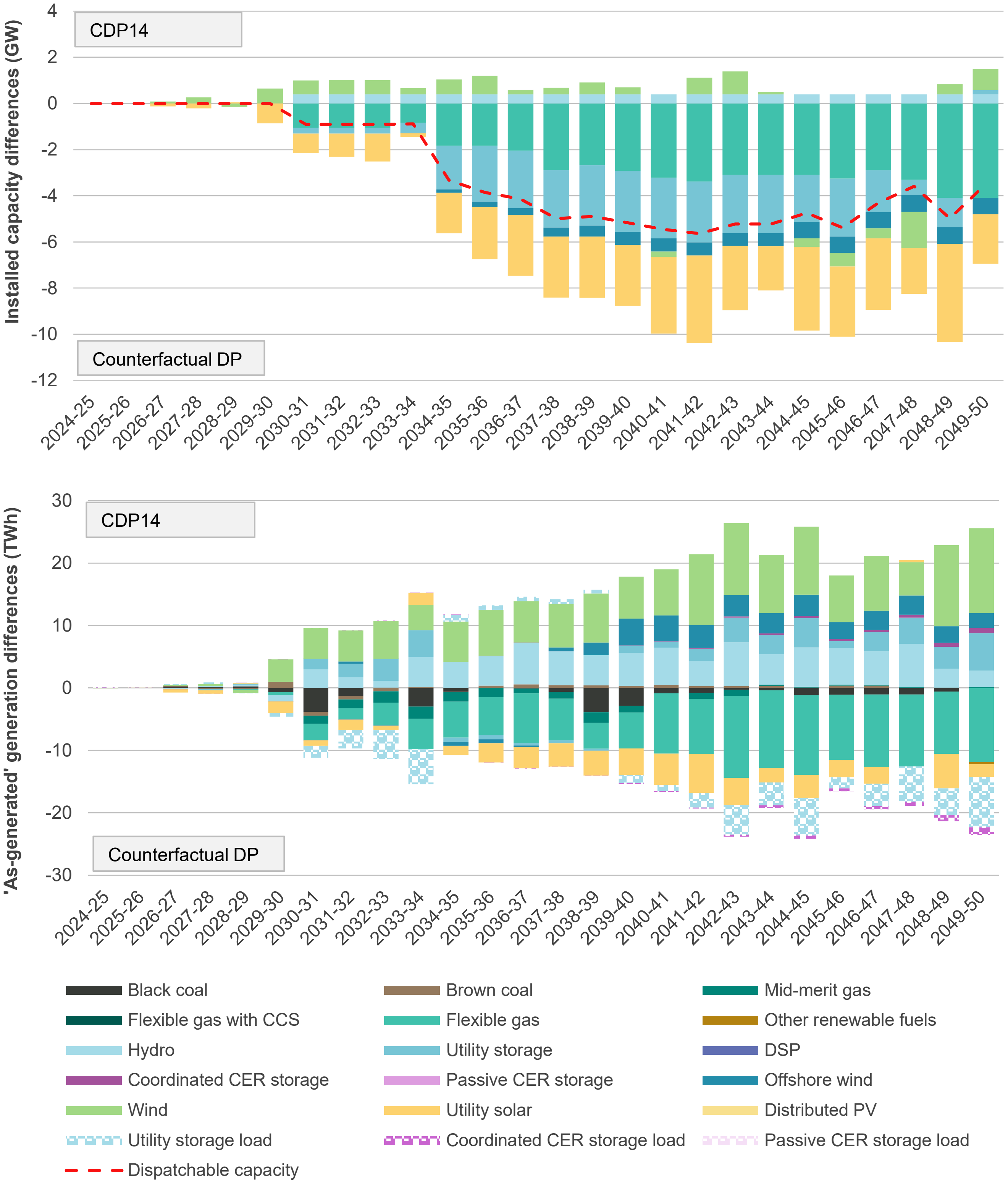
Figure 35 below shows that the counterfactual DP incorporates slightly higher development of VRE until 2029-30 as the lack of transmission development forces development in locations with lower resource quality. From the early 2030s, gas-powered generation and storage play an increasing role in meeting consumer energy needs. As observed in *Step Change*, transmission limitations lead to greater reliance on other technologies that are more able to connect to existing transmission near loads, but at higher overall cost.

Figure 35 Forecast NEM installed capacity, *Progressive Change* counterfactual DP, 2024-25 to 2049-50 (GW)



For comparison, Figure 36 presents the difference in installed capacity and dispatched generation between CDP14 and the counterfactual DP, demonstrating a greater role for gas and storage.

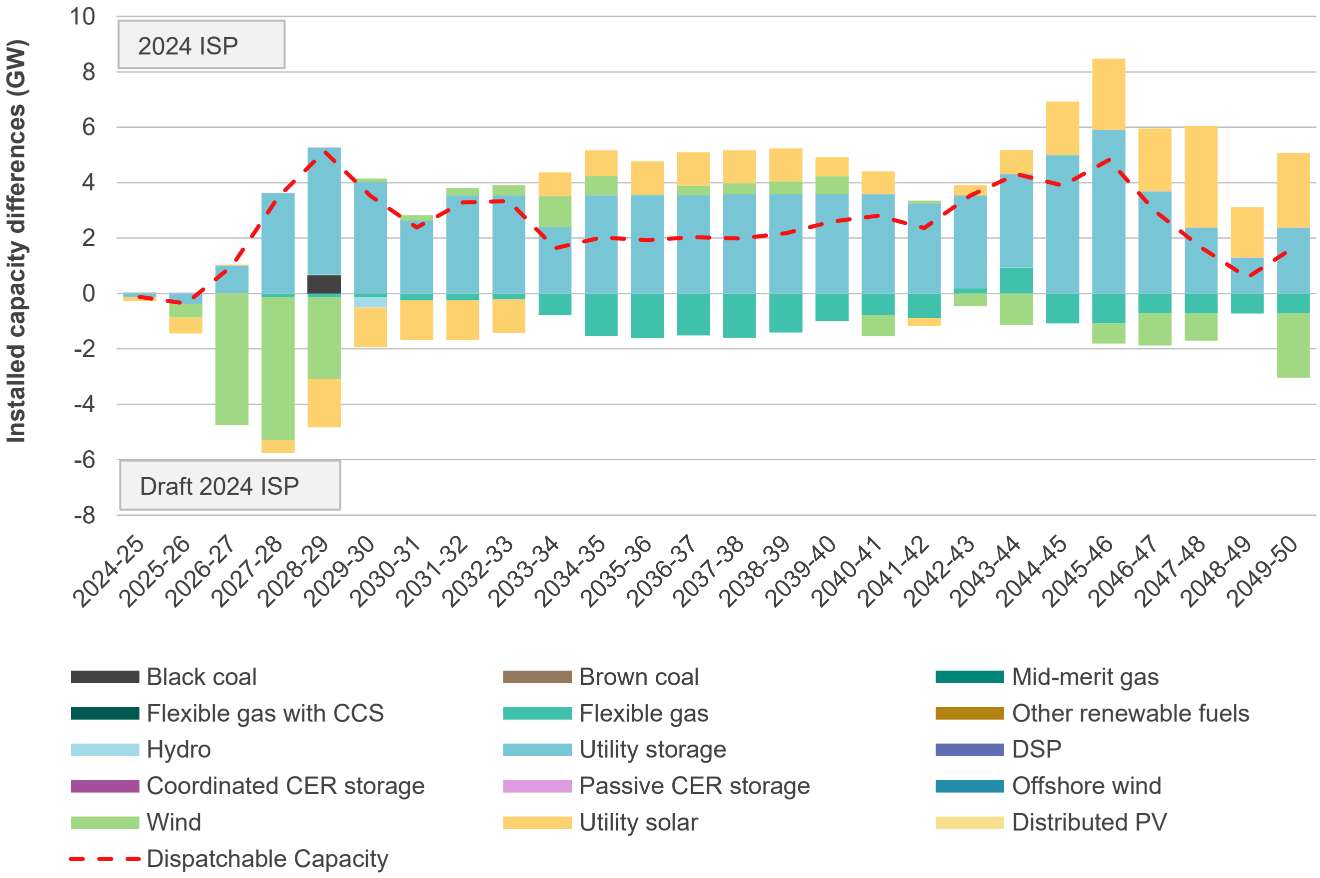
Figure 36 Forecast capacity developments (top) and generation (bottom) to 2049-50 under counterfactual DP compared to *Progressive Change* (GW and TWh)



Capacity development in the *Progressive Change* scenario compared to the Draft 2024 ISP

Changes in the capacity development in *Progressive Change* are influenced by similar influences to *Step Change*, for example the newly committed and anticipated developments. In addition, newly actionable transmission projects in the 2024 ISP delay or defer some generation and storage capacity in this scenario.

Figure 37 Forecast NEM generation capacity to 2049-50 in *Progressive Change*, 2024 ISP assumptions compared to the Draft 2024 ISP assumptions (GW)



A2.4.3 *Green Energy Exports*

The *Green Energy Exports* scenario represents a world with strong emissions reduction targets which lead to even faster transition of Australia's economy to net zero, including domestic and export opportunities for hydrogen and other green energy products.

Generation and storage development in *Green Energy Exports*

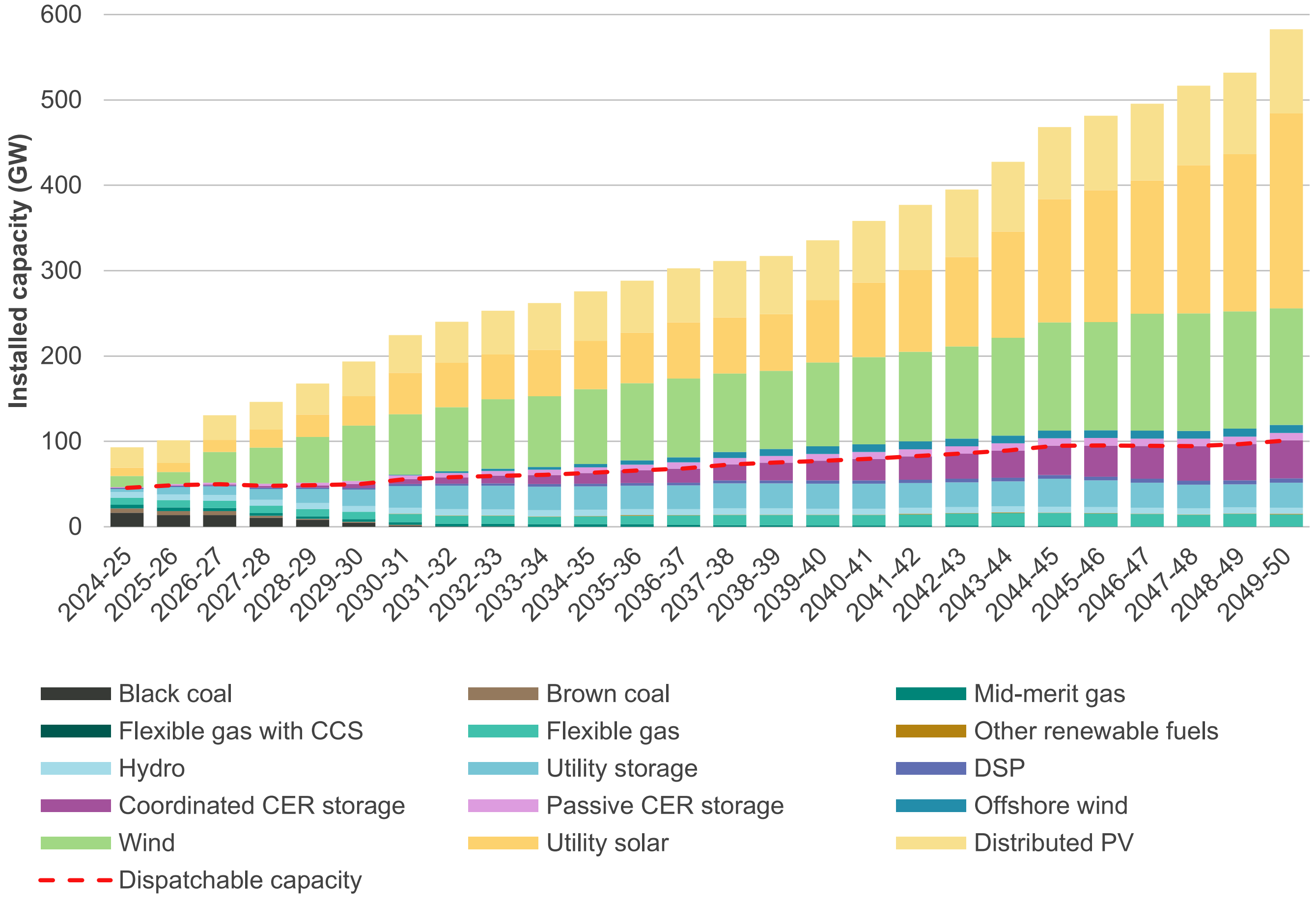
In *Green Energy Exports*, the outlook for generation developments includes:

- To 2029-30:
  - The strong carbon budget ensures significant coal retirements in the near term, with only 6 GW of coal capacity forecast to be operating by 2029-30 (73% lower than existing capacity).

  - To offset the coal retirements, significant utility-scale VRE developments are forecast given the fast rate of change and stronger energy consumption. From almost 20 GW installed today, approximately 100 GW would need to be in place by the end of the 2020s – 40 GW more than that in *Step Change*.
- By 2049-50:
  - Over 370 GW of utility-scale VRE is forecast to meet a significantly larger NEM electricity consumption need, with strong hydrogen production for export and domestic use, and green steel production assumed in the scenario.
  - Approximately 135 GW of electrolyser capacity is needed to meet both export and domestic hydrogen demand.

Figure 38 illustrates the scale of generation development under this scenario.

Figure 38 Forecast NEM installed capacity, *Green Energy Exports*, 2024-25 to 2049-50 (GW)



VRE development accelerates due to significantly higher consumption forecast.

Figure 39 shows the cumulative change in technology type over time. Key highlights include:

- Early retirements are forecast to be replaced by a combination of VRE, energy storage and CER. Retiring GPGs are generally replaced by new flexible gas developments to provide ongoing firming support and offset coal retirements.

- By 2049-50, in addition to over 95 GW of distributed PV, the NEM is forecast to need over 360 GW of new utility-scale VRE to replace retiring capacity and to meet increasing energy consumption from electrification and new industry. This is complemented by nearly 30 GW of new utility-scale energy storage and around 11 GW of new flexible gas, in addition to CER storage.

Figure 39 Forecast relative change in installed capacity compared to 2023-24, *Green Energy Exports*, 2024-25 to 2049-50 (GW)

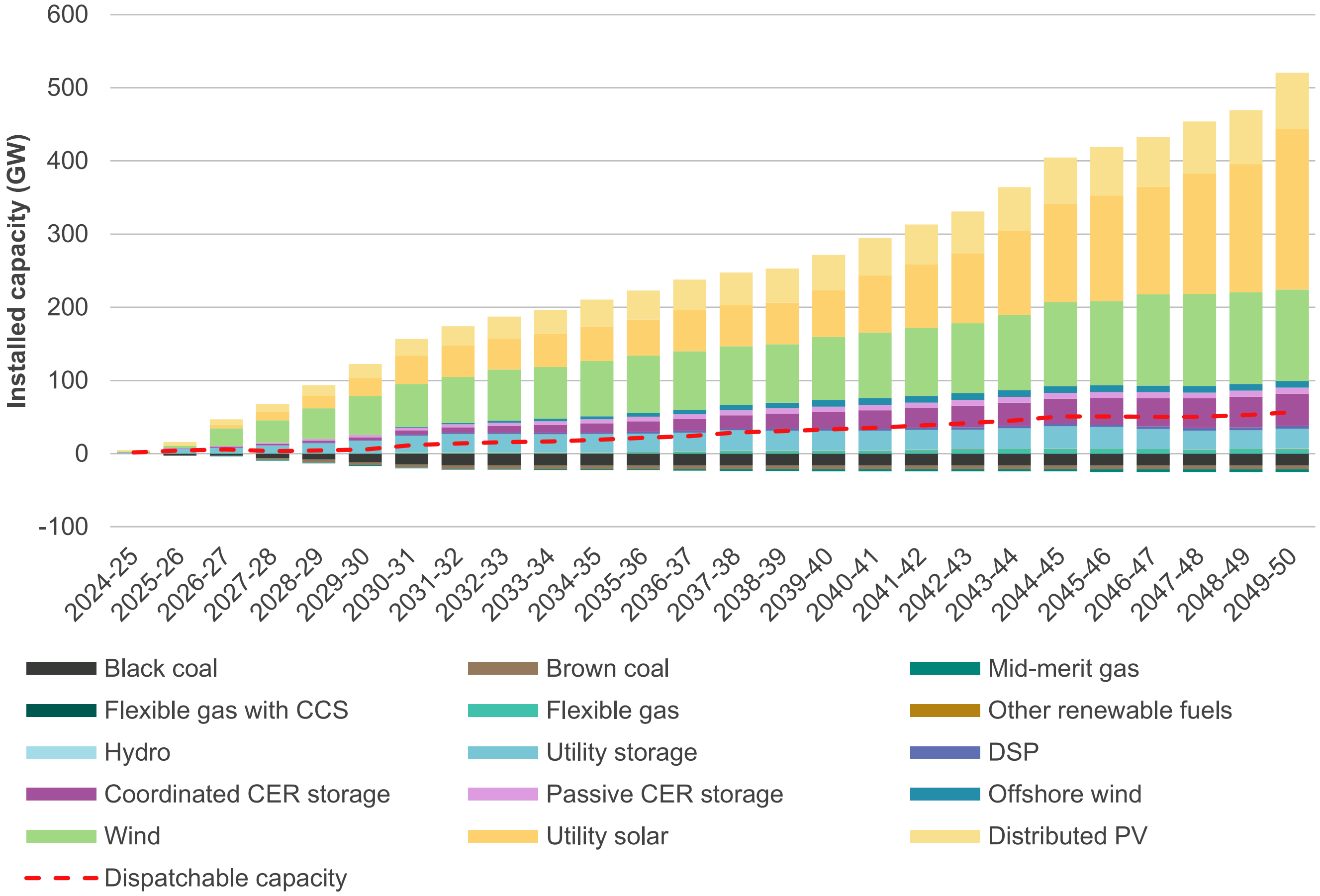
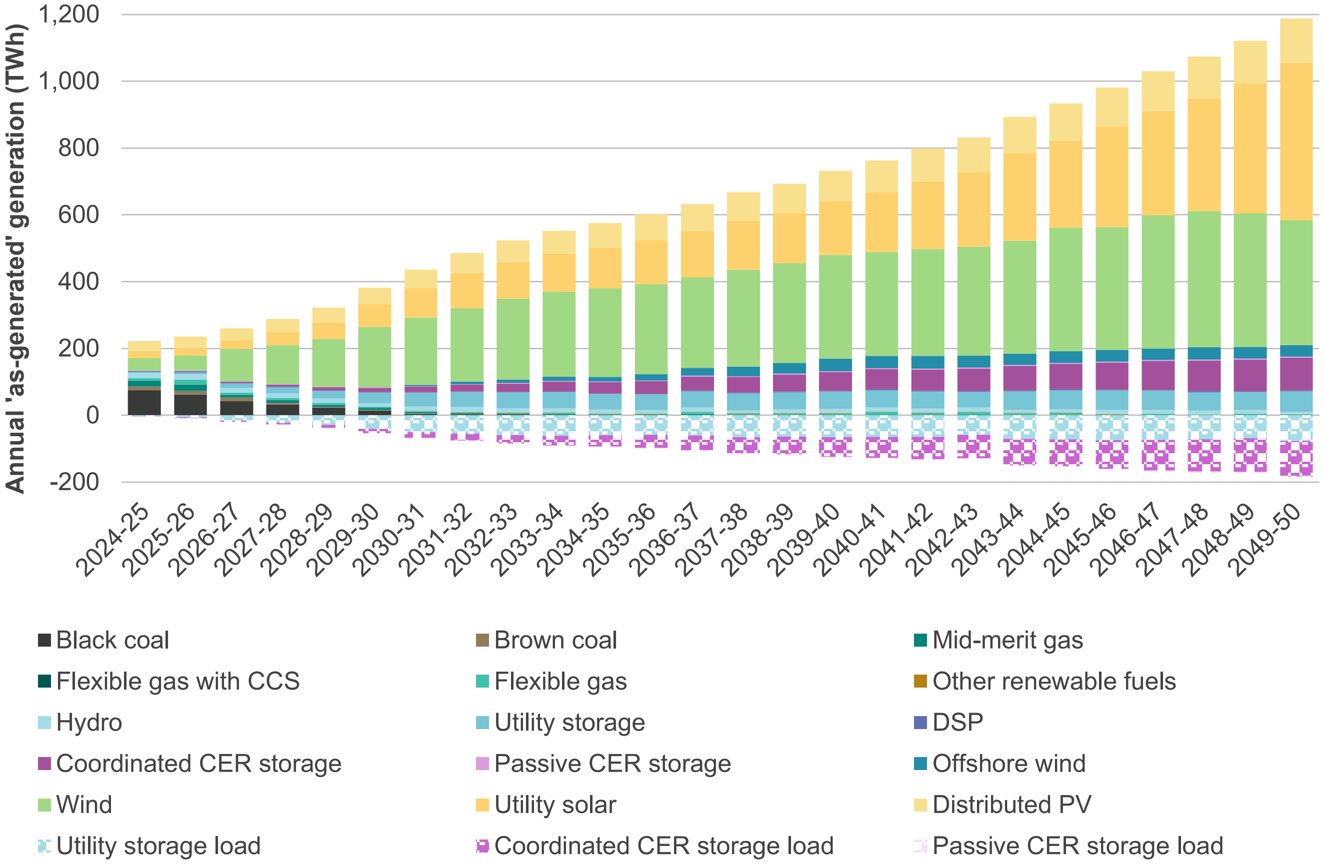


Figure 40 demonstrates the vastly expanded energy mix relative to today's energy system. Renewable energy is forecast to expand to approximately 100% of energy generated by 2049-50. The projected split of VRE by 2049-50 is 40% wind, 46% utility-scale solar and 13% distributed PV.

Figure 40 Forecast annual generation, *Green Energy Exports*, 2024-25 to 2049-50 (TWh)

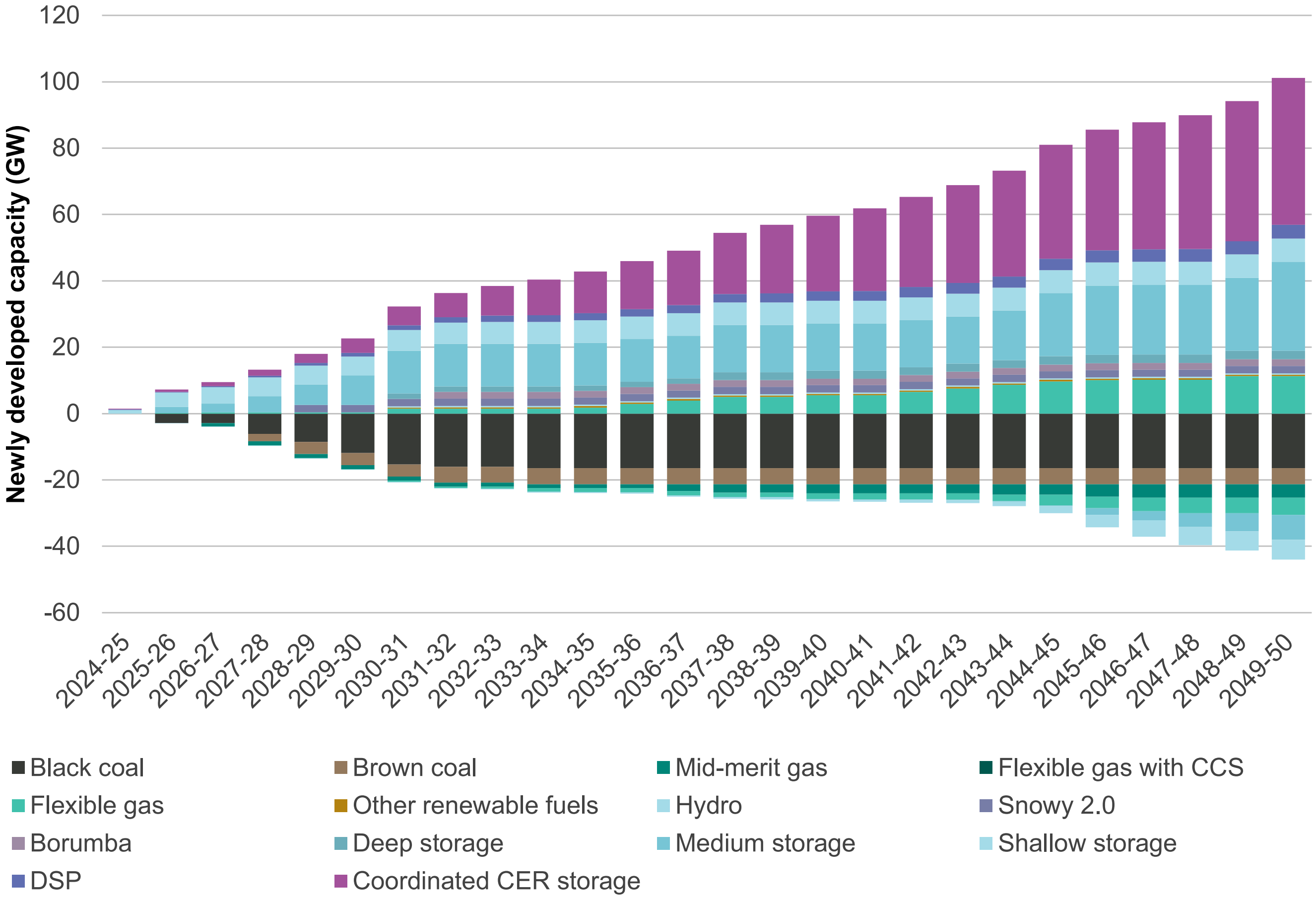


Consistent with findings for *Step Change*, significant expansion of various energy storage technologies complemented by flexible gas generation is forecast.

Figure 41 demonstrates the projected change in dispatchable capacity across the outlook period.

By the early 2030s, all coal capacity retires, and approximately 8 GW of existing gas has also retired by the late 2040s. The high uptake of CER storage is complemented by medium-depth and deep utility-scale storages to firm the additional renewable energy developments. Gas generator retirements are generally replaced by new flexible GPG. With significant electrolyser developments, the scenario features a material capacity of potentially flexible load.

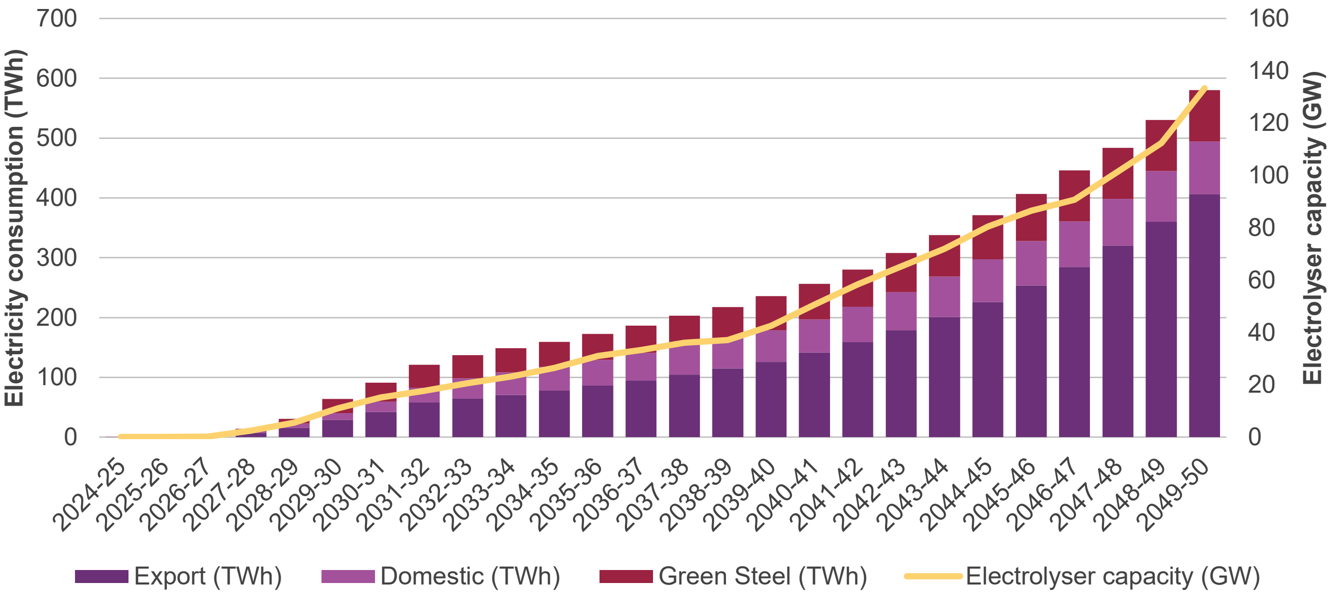
Figure 41 **Forecast relative change in dispatchable capacity compared to 2023-24, *Green Energy Exports*, 2024-25 to 2049-50 (GW)**



Hydrogen developments

Green Energy Exports is characterised by significant forecast hydrogen production. Figure 42 presents the assumed total electricity consumption to 2049-50 for hydrogen production (used for domestic use, export, and green steel production), including that used for ammonia conversion. The scenario assumes a scale of electricity consumption for hydrogen production purposes over 500 TWh larger than that assumed under *Step Change* by 2049-50.

Figure 42 Electricity consumption associated with hydrogen production, ammonia conversion and green steel production, *Green Energy Exports*, 2024-25 to 2049-50 (TWh and GW)



In this scenario, over 130 GW of electrolyser capacity is developed by 2049-50 to meet almost 600 TWh of electricity load. The utilisation factors of electrolysers in this scenario are similar to those in *Step Change* (40-60%).

The improvements made in hydrogen modelling assumptions under the *Green Energy Exports* scenario, as described in Section A2.2, resulted in changes to the regional allocations of export hydrogen load and green steel load compared to the Draft 2024 ISP, impacting South Australia, New South Wales and Victoria in particular.

Similar to the results for *Step Change*, geographical diversity of electrolyser investments is found to minimise system costs, with Queensland providing the greatest export opportunity (80%), followed by Tasmania (10%) and South Australia (5%) (see Figure 43).

While hydrogen production may potentially provide a flexible operational profile, additional firm supply is still needed. Approximately 11 GW of flexible gas is developed later in the outlook period in part to meet loads associated with hydrogen production that are less flexible than the electrolysers, including ammonia production facilities for export, and electric-arc furnaces for green-steel manufacturing[20]. Operational flexibility to follow the availability of renewable resources is an important means to lower overall system costs but does not consider the financial challenges or risks to the hydrogen producer. It is assumed that an electrolyser can modify its energy consumption pattern to align with energy production from VREs, while still meeting monthly production targets.

AEMO received stakeholder feedback on this assumption, with stakeholders concerned that consumers of hydrogen may not be reasonably able to consume hydrogen this flexibly, and significant hydrogen storage would be required to maintain a high load factor for these industrial facilities. Section A2.5.6 discusses a new *Low*

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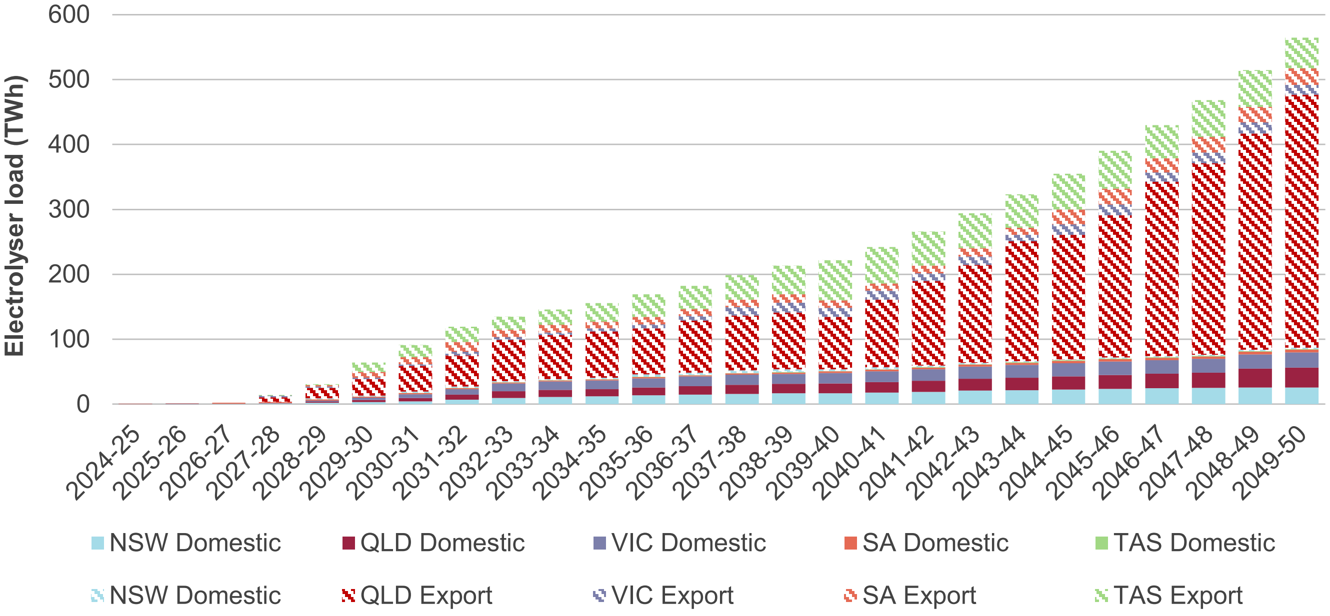
[20] The degree to which these loads can operate flexibly to avoid the need for significant additional firm electricity supplies will remain an uncertainty until the technologies mature.

Hydrogen Flexibility sensitivity, which assesses the impact of inflexible hydrogen demand, resulting in a much higher load factor for hydrogen production. The sensitivity has been performed on *Step Change*.

Figure 43 Regional allocation of hydrogen developments by 2049-50, *Green Energy Exports*



Contrasting *Green Energy Exports* with *Step Change*

Figure 44 below presents the capacity difference between the developments for *Green Energy Exports* and *Step Change*. By the end of the outlook period, total installed capacity in the former is nearly twice that of *Step Change*, as demand for green energy products grows to almost 600 TWh.

The key differences from the results in *Step Change* are:

- The tighter emissions reduction objectives in *Green Energy Exports* speed up the pace at which VRE is developed and hastens the retirement of existing coal capacity.
- The higher energy consumption in *Green Energy Exports* drives more firming capacity and more VRE generation, with more utility-scale solar and wind generation developed. By 2049-50, firm capacity technologies such as hydro generation, GPG and storage make up a slightly lower proportion of the total capacity mix in *Green Energy Exports*, due to the assumed flexibility of the majority of the load associated with hydrogen demand in this scenario.

Figure 44 Forecast capacity development to 2049-50 under *Green Energy Exports* compared to *Step Change* (GW)

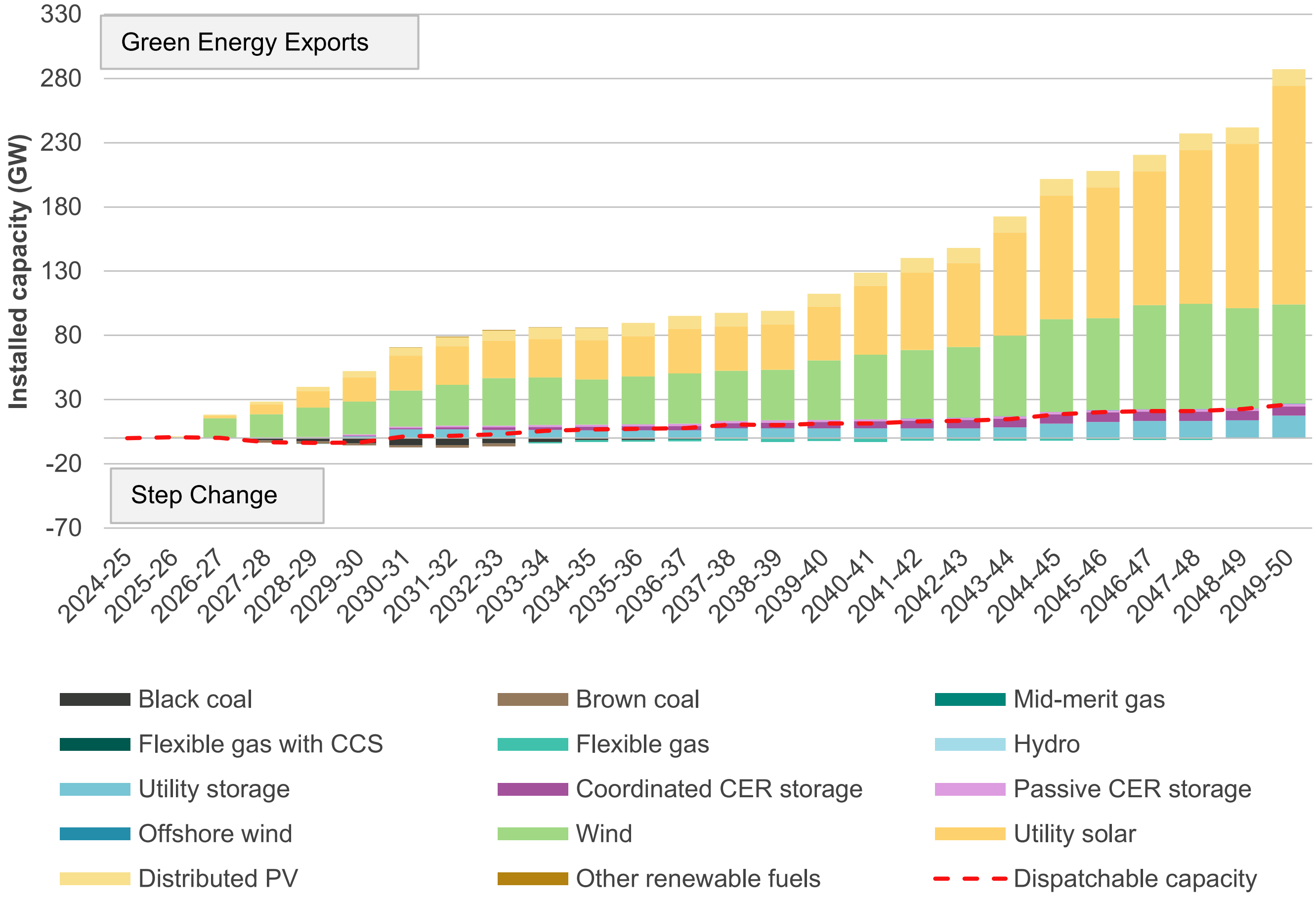
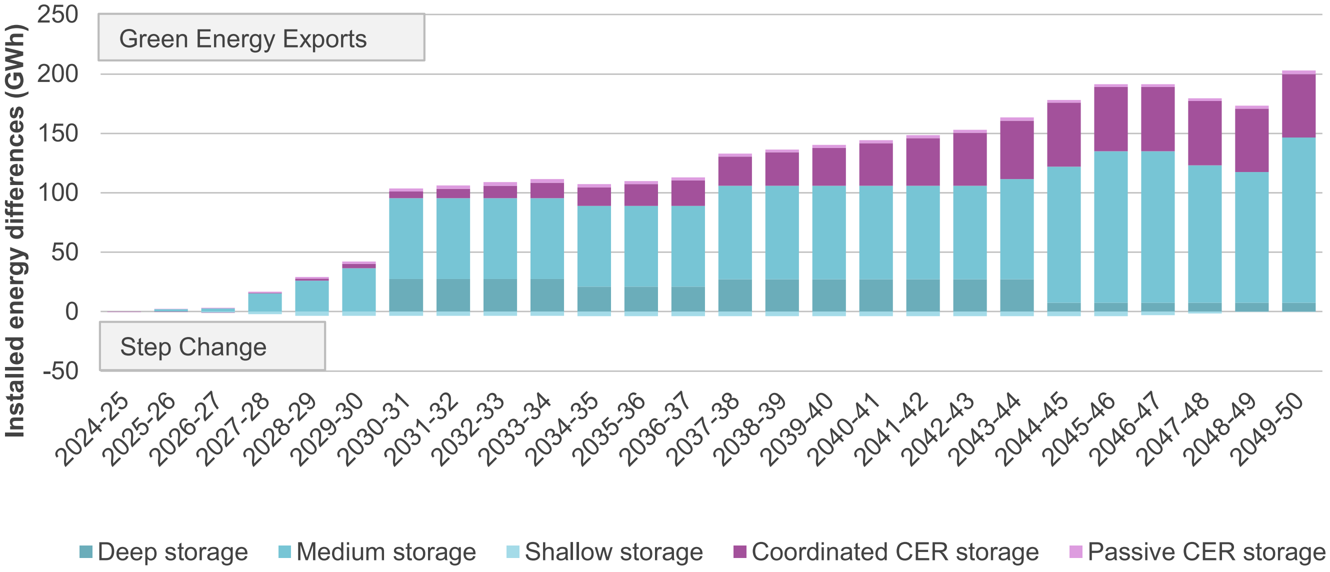


Figure 45 shows energy storage developments in *Green Energy Exports* compared to *Step Change*. From the early 2030s towards the end of the outlook period, there is more need for medium-depth and deep energy storage developments in *Green Energy Exports* than in *Step Change*, due to higher energy consumption forecasts, despite the higher uptake of CER storage. By 2049-50, there is 166 GWh more storage capacity in *Green Energy Exports* relative to *Step Change,* while the NEM demand forecast is 541 TWh higher in *Green Energy Exports*.

Figure 45 Energy storage capacity developments to 2049-50 under *Green Energy Exports* compared to *Step Change* (GWh)



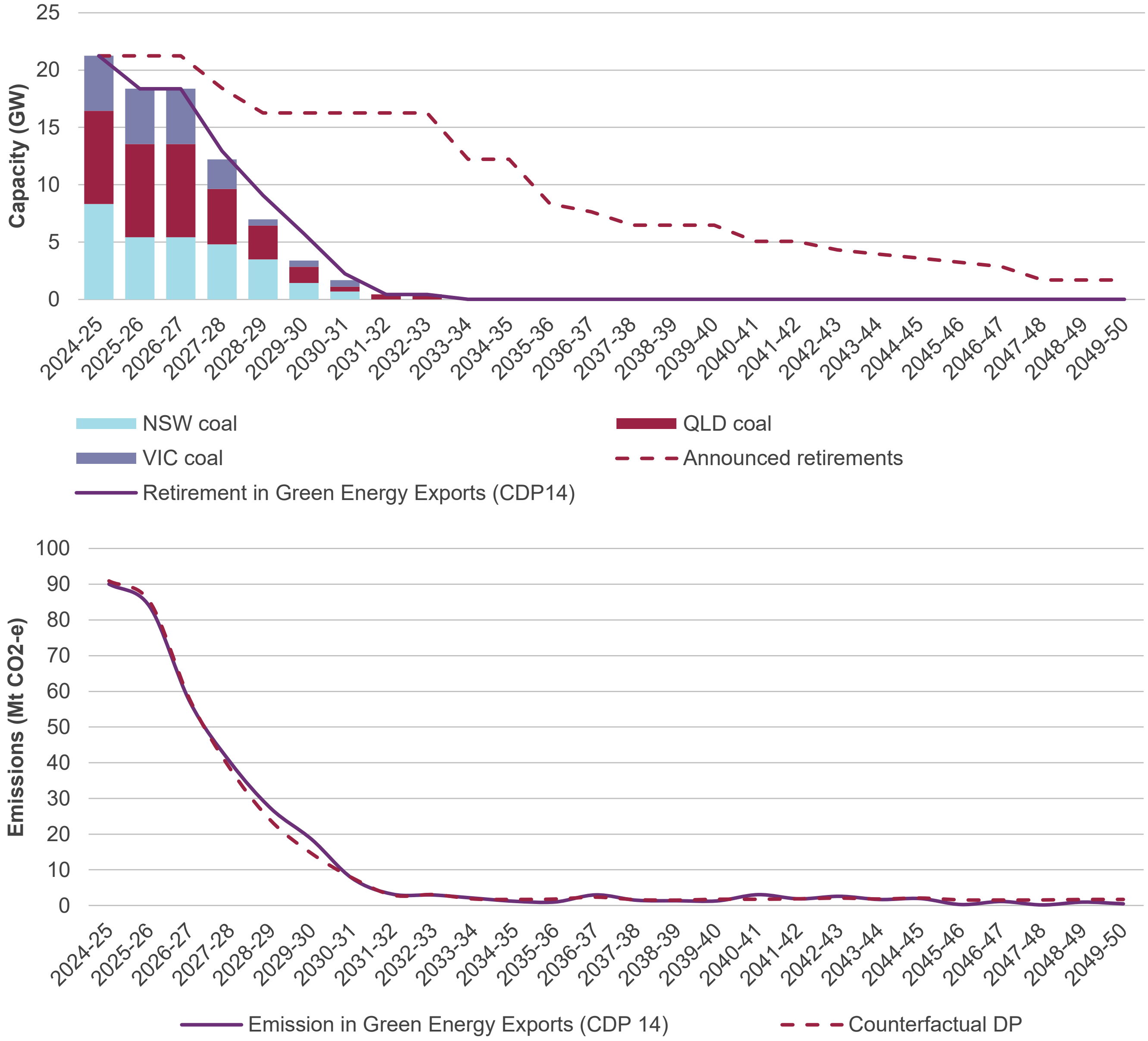
Future generation mix in *Green Energy Exports* without transmission developments

Impact of transmission development on coal retirements

As a result of the emissions budgets, coal is retired earlier in the counterfactual DP than in CDP14. As with *Step Change*, without transmission augmentation, there is a higher reliance on CCS in the later part of the outlook period as VRE generation is curtailed due to transmission congestion, leading to even earlier coal closures to enable greater headroom in the emissions budget.

Figure 46 below contrasts the coal retirement schedule forecast under *Green Energy Exports* with, and without, transmission augmentation.

Figure 46 Forecast coal retirements (top) and emissions trajectory (bottom) to 2049-50, *Green Energy Exports* counterfactual DP (GW and Mt CO$_2$-e)



Without access to new and large REZs, the scale of hydrogen production would not be achievable within the emissions budget. This counterfactual DP therefore allows targeted transmission development to support energy supply between REZ and export ports only (which could be privately-owned assets if required); broader transmission development to support domestic consumers is not available, consistent with the counterfactual DP approach in other scenarios.

The forecast capacity mix in the counterfactual DP is shown in Figure 47.

Figure 47 **Forecast NEM installed capacity, *Green Energy Exports* counterfactual DP, 2024-25 to 2049-50 (GW)**

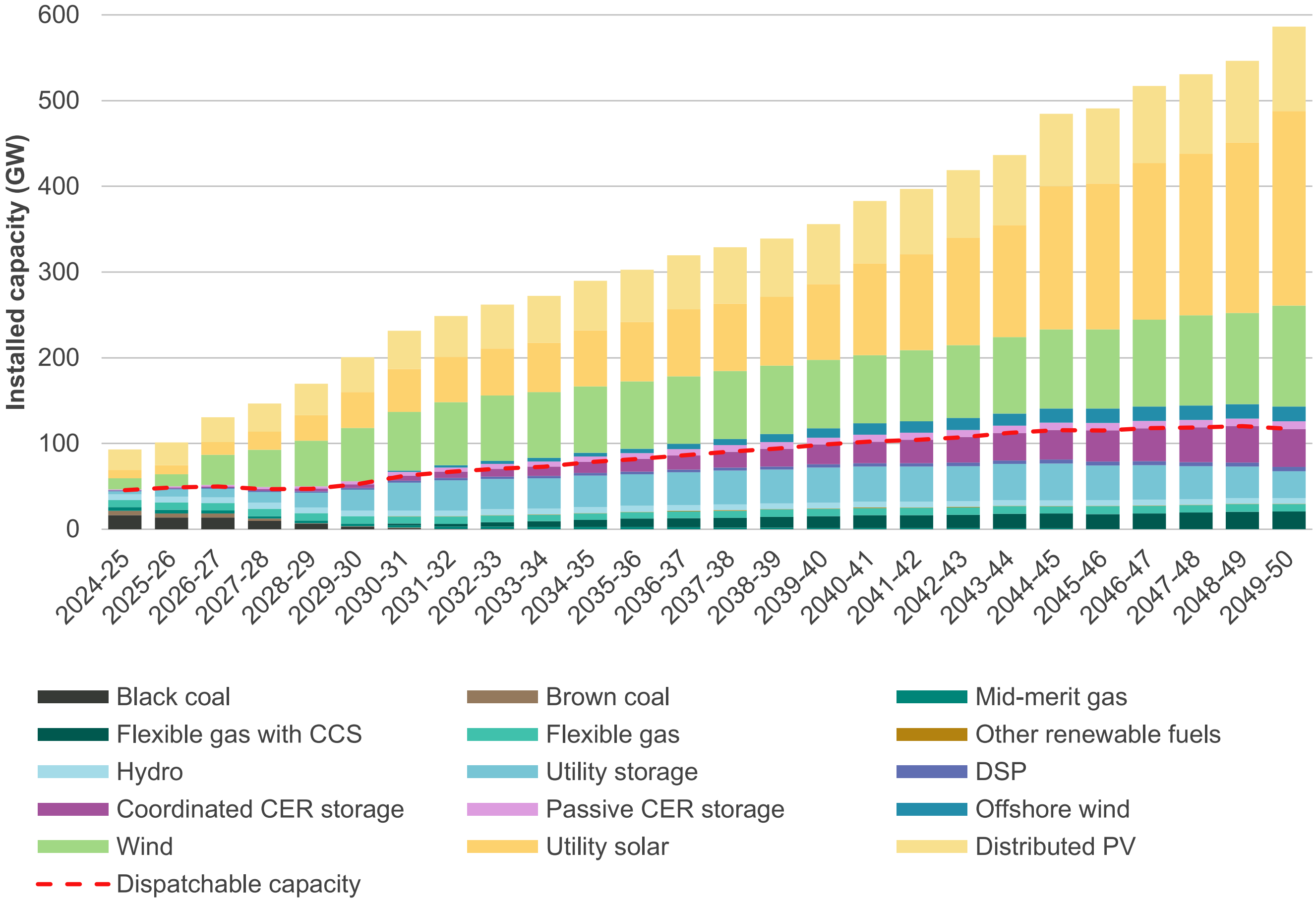
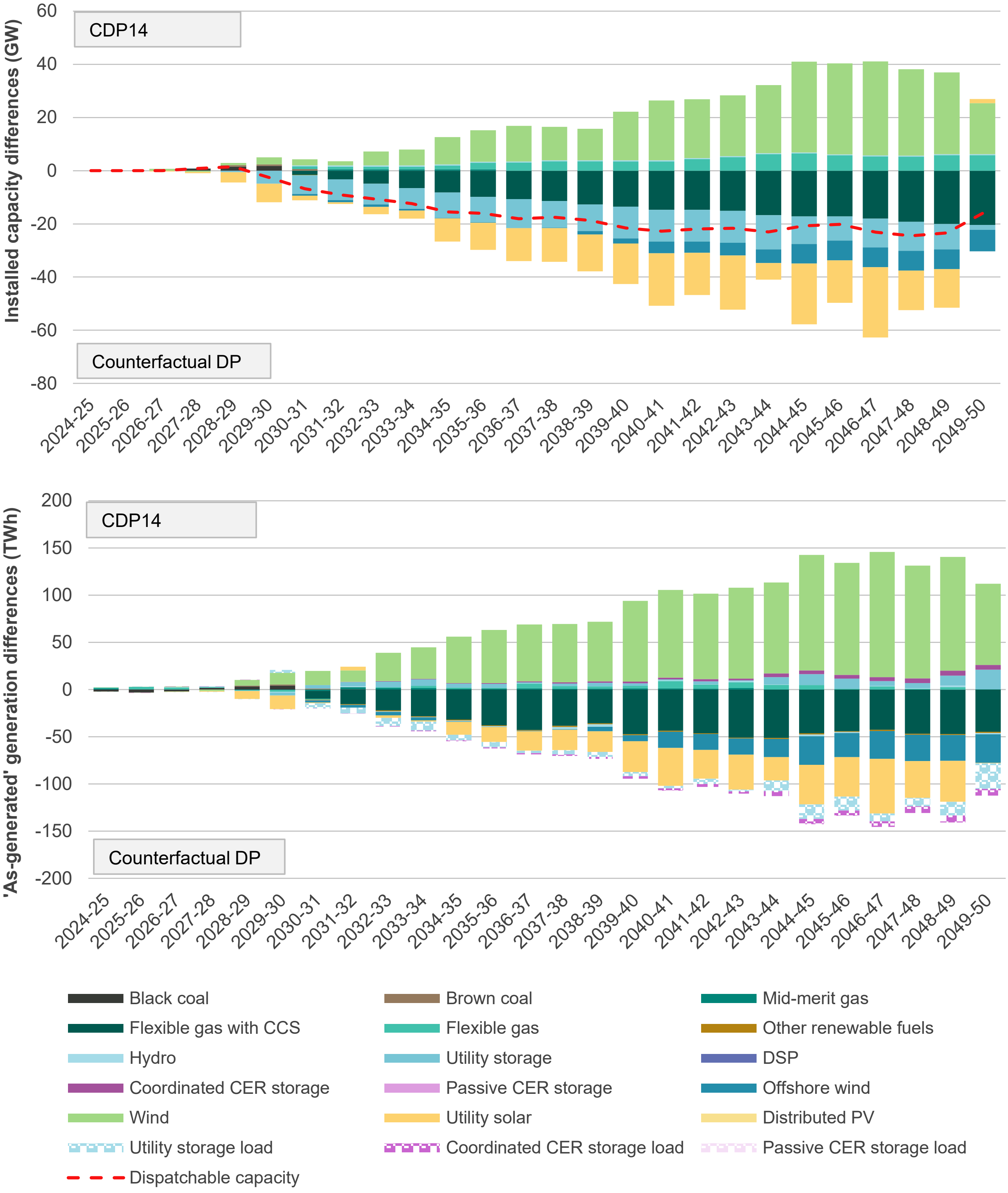


Figure 48 demonstrates the differences in capacity and generation development between CDP14 and the counterfactual DP. Without transmission expansion to support domestic consumers, onshore wind development would be heavily curtailed and greater development of gas with CCS, utility-scale solar, and offshore wind would be needed. Greater storage development is also necessary without the expansion of the transmission system to reduce potential congestion and share surplus capacity between regions.

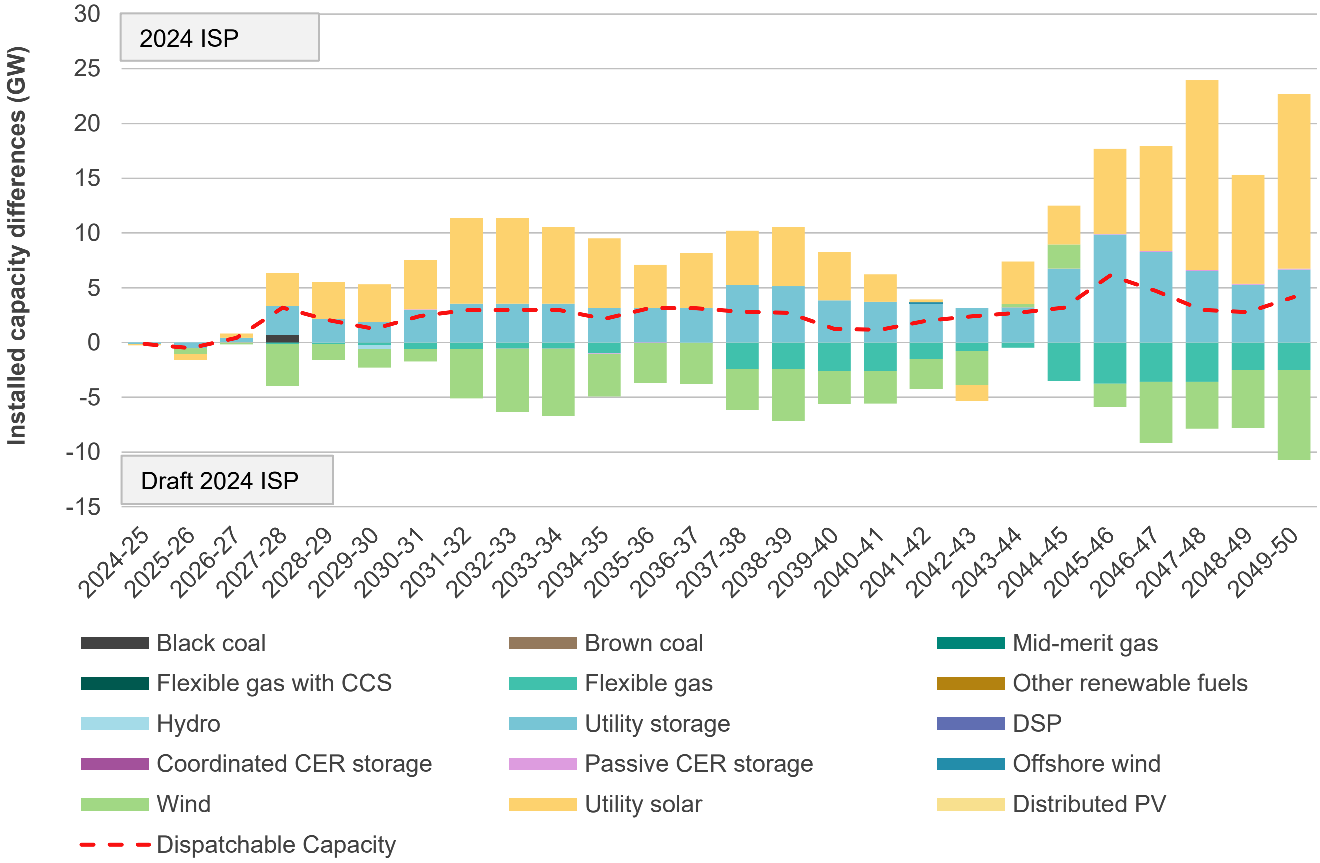
Figure 48 **Forecast capacity developments (top) and generation (bottom) to 2049-50 under counterfactual DP compared to *Green Energy Exports* (GW)**



Capacity development in the *Green Energy Exports* scenario compared to the Draft 2024 ISP

As shown in Figure 49, the 2024 ISP's updated modelling has produced greater investment in solar generation, given the greater availability of storage capacity with newly committed and anticipated developments, substituting for wind development throughout the outlook period compared to the Draft 2024 ISP. The availability of storage and limitations affecting gas infrastructure has also a lessening impact on GPG developments in the long term.

Figure 49 Forecast NEM generation capacity to 2049-50 in the *Green Energy Export*, 2024 ISP assumptions compared to the Draft 2024 ISP assumptions (GW)



A2.5 Extended sensitivity analysis on generation and storage development opportunities

This section outlines the differences between the generation and storage developments in the 2024 ISP's sensitivity analyses. The impact of these sensitivities on net market benefits is explored in depth in Appendix 6, which explores the cost-benefit analysis of the ISP (see Section A6.8). Additional information on the capacity developments, energy generated, retirement outlook and emissions outcomes for the sensitivities is also included in the Generation and Storage Outlook Workbooks[21].

As shown in Figure 50, the scale of wind and utility-scale solar development is resilient to alternative assumptions tested in the sensitivity analysis. Compared to *Step Change*, supply chain limitations limit the capability to develop sufficient VRE by 2030 to meet policy targets, but otherwise the developments are similar over the next decade, given policy drivers apply consistently in these sensitivities. If additional industrial loads develop in South Australia and New South Wales then more generation and storage developments would be needed by 2029-30, while a lower EV uptake will lead to lower developments compared to *Step Change*.

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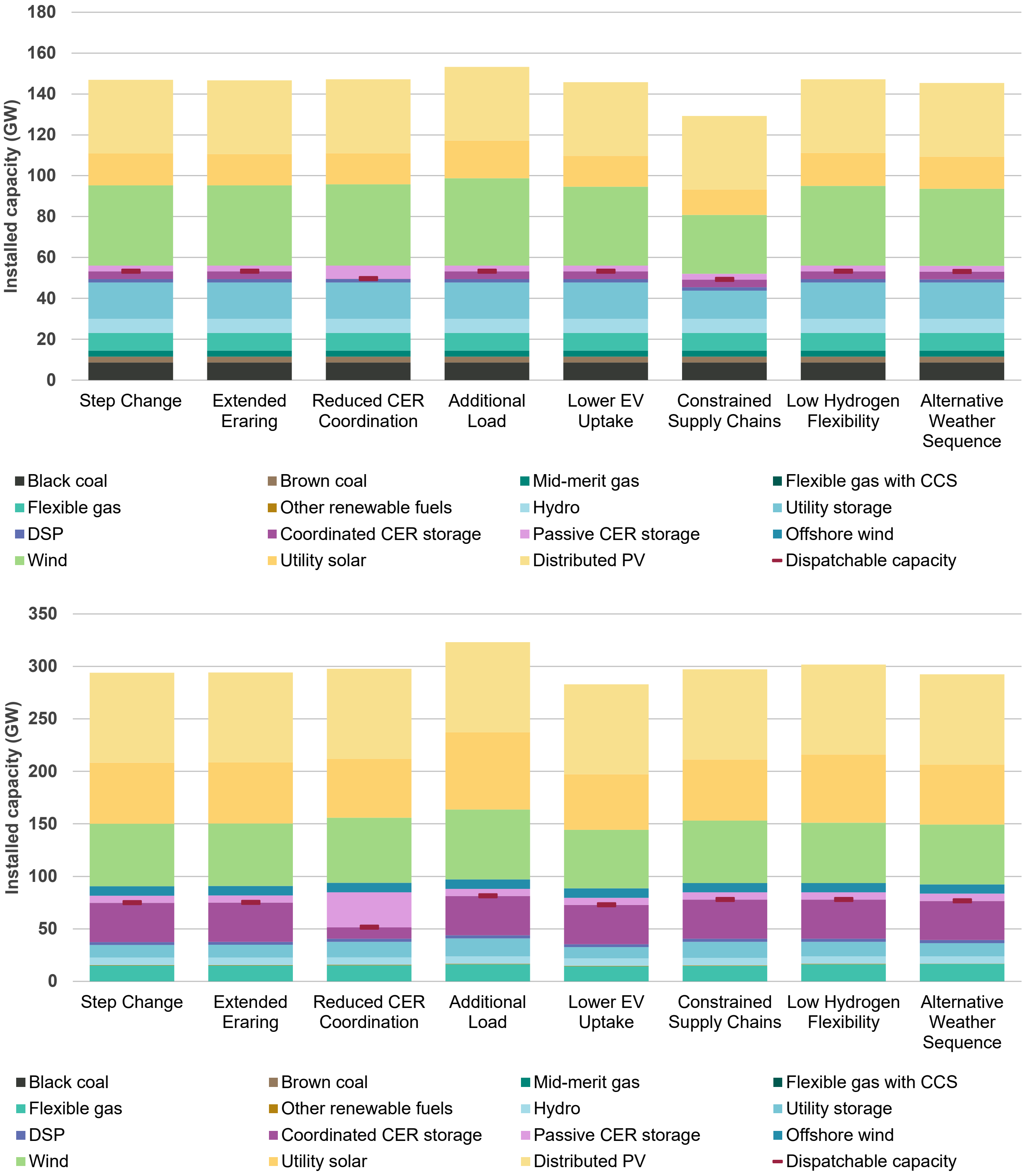
[21] At https://aemo.com.au/consultations/current-and-closed-consultations/draft-2024-isp-consultation.

Figure 50 **Generation and storage capacities by 2029-30 (top) and 2049-50 (bottom) in *Step Change* and sensitivities to *Step Change***



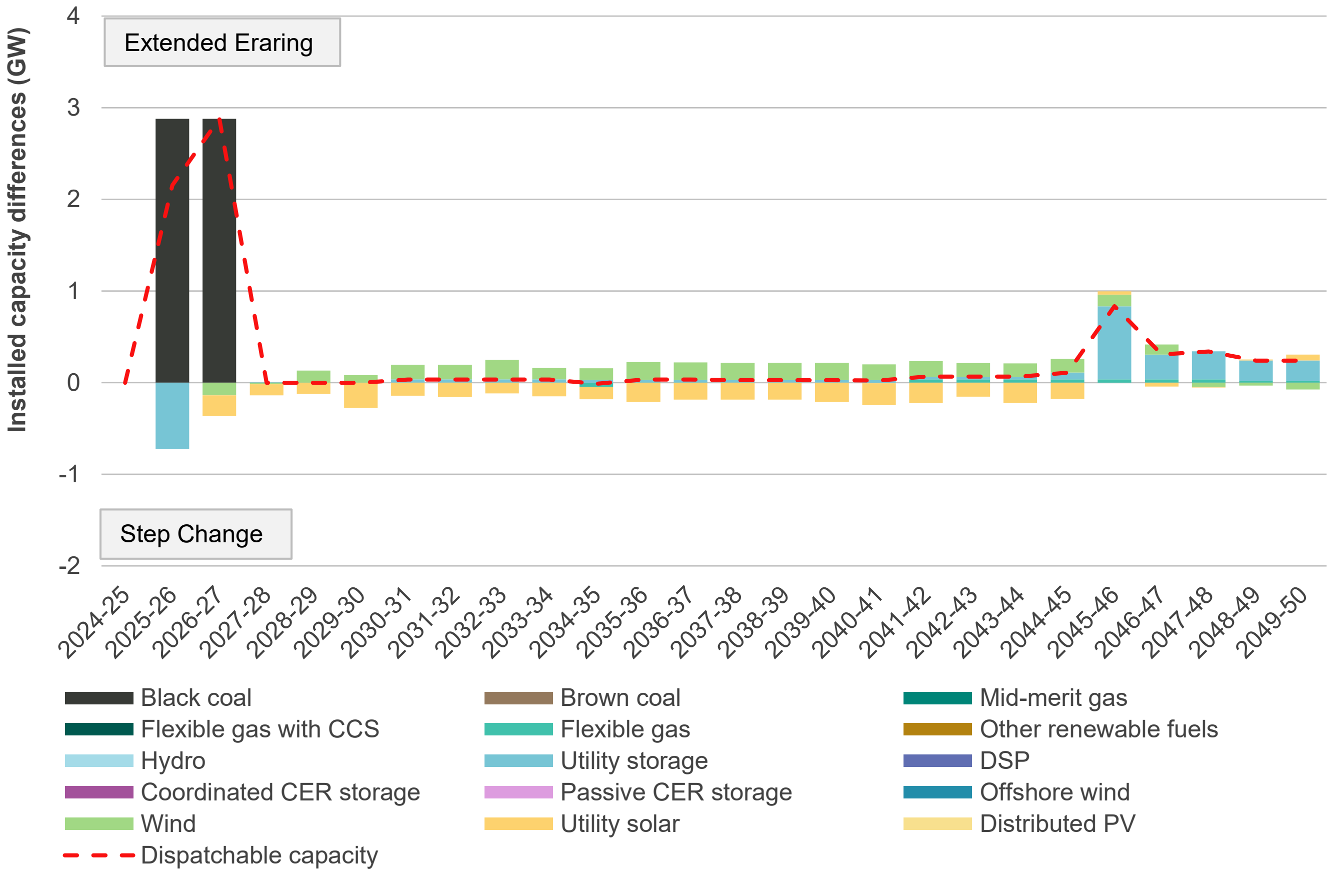
Sensitivity analyses performed in the Draft 2024 ISP have not been re-forecast, as AEMO has preferred to focus additional analysis on those sensitivities identified to address feedback from stakeholders to the Draft 2024 ISP consultation. The Draft 2024 ISP sensitivity analysis is republished in Section A2..

A2.5.1 *Extended Eraring*

The *Extended Eraring* sensitivity demonstrates the effect of extending the operation of Eraring Power Station by two years to August 2027. In this scenario, the need for immediate investment in utility-scale storage in New South Wales is significantly reduced as extending the operation of the plant's four coal units improves reliability outcomes while providing significant electricity production capability (Eraring provided approximately 18% of New South Wales's electricity needs in 2022-23) in the near term.

The agreed delay to the power station closure reduces reliability risks in the near term, but the forecast impact on capacity investments in the long term is minimal, as shown in Figure 51.

Figure 51 Forecast capacity developments to 2049-50 under the *Extended Eraring* sensitivity compared to *Step Change* (GW)



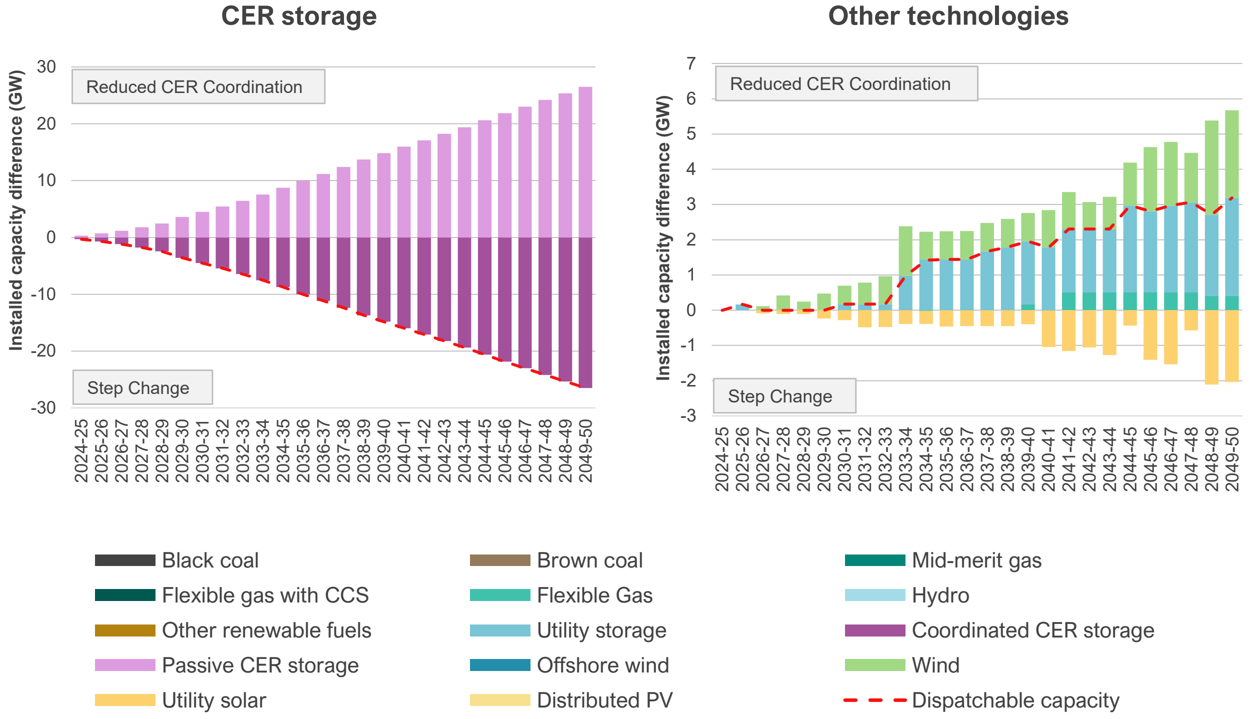
A2.5.2 *Reduced CER Coordination*

The *Reduced CER coordination* sensitivity examines the impact of lower coordination of consumer-owned storage devices, specifically stationary household batteries that can be coordinated into VPPs. This sensitivity explores the extent of utility-scale investments needed if the forecast level of coordination in the *Step Change* scenario is not achieved.

The scenario collection includes a range of CER coordination settings, as outlined in the 2023 IASR. For *Step Change*, growth in coordinated stationary CER batteries increases from approximately 31% of the relatively small number of stationary CER batteries forecast in 2024-25, to 57% by 2030, 70% by 2040 and 80% by 2050. This represents a significant increase in potentially avoidable investment with appropriate coordination, so long as appropriate technical, communications and operational solutions are developed, and social licence grows. As identified in Appendix 6, significant savings in utility-scale investments are forecast, with approximately $4.1 billion higher net market benefits in *Step Change* than in this sensitivity (see Appendix 6).

These benefits accrue primarily through avoided utility-scale developments. If there is no further coordination of forecast CER uptake – that is, if the forecast 26.7 GW of coordinated stationary CER storage by 2049-50 in *Step Change* was assumed to operate passively instead to meet individual consumer needs – additional utility-scale investments would be needed. As Figure 52 shows, additional dispatchable capacity is needed to support the passive stationary CER batteries, including medium-depth and deep storage (2.8 GW), flexible gas (0.4 GW), and wind capacity (2.5 GW) by 2049-50.

Figure 52 Forecast capacity developments to 2049-50 under the *Reduced CER Coordination* sensitivity for CER storage (left) and other technologies (right) compared to core *Step Change* (GW)



A2.5.3 *Additional Load*

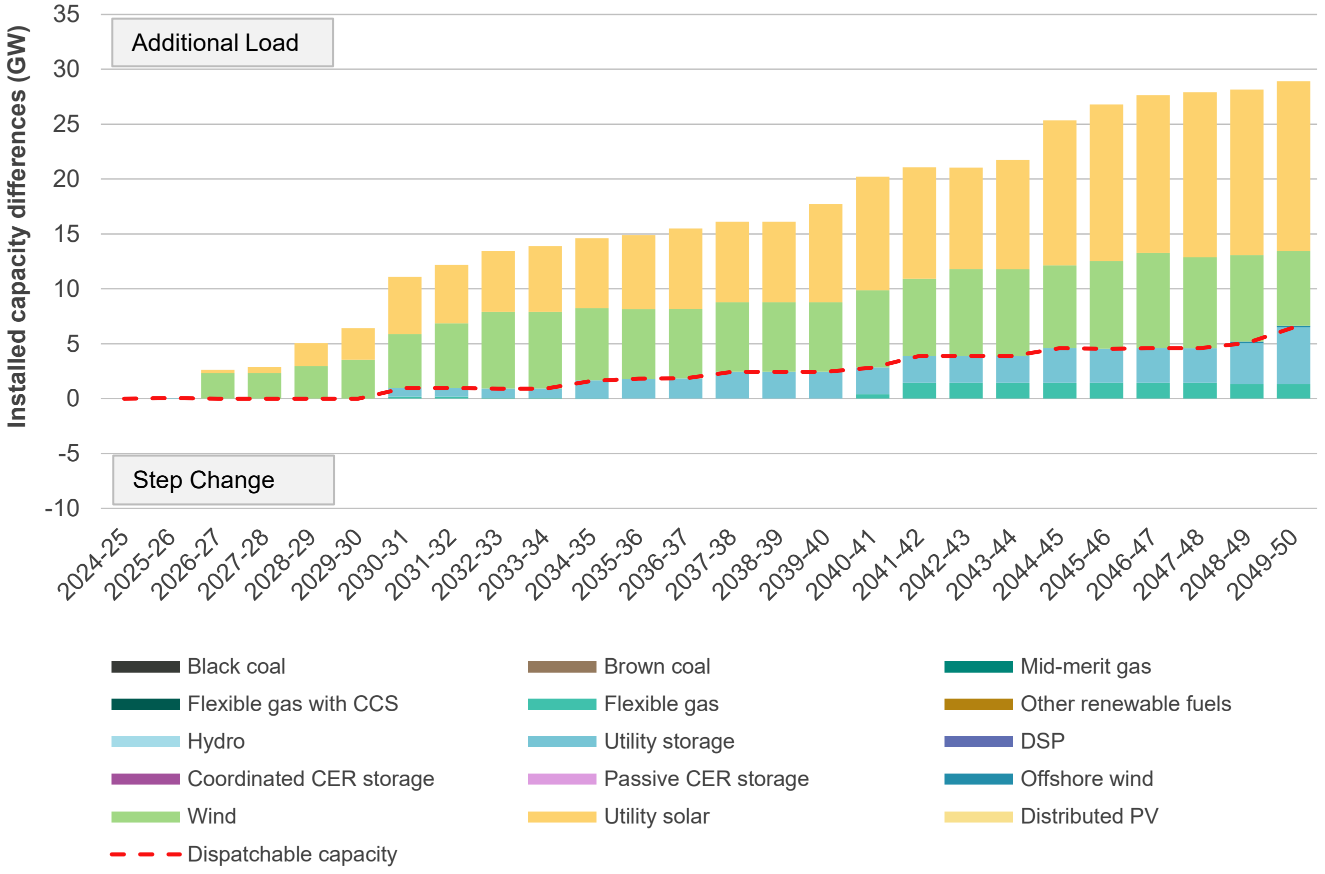
The *Additional Load* sensitivity examines potential large industrial load developments in South Australia and New South Wales that are yet to sufficiently develop to be included in the *Step Change* scenario. These potential load developments may also support additional transmission investment to minimise system costs (see Appendix 6). In this sensitivity, the focus on South Australia and New South Wales opportunities refers to:

- Industrial load expansion and hydrogen production in the north of South Australia, including the Eyre Peninsula. In this sensitivity, additional loads are forecast to increase electricity consumption by 13 TWh in 2029-30 and 16 TWh by 2049-50. The load growth may encourage network expansions to lower system costs, specifically in Eastern Eyre Peninsula, Northern and Mid-North South Australia.

- Industrial decarbonisation across New South Wales and particularly in the Sydney, Newcastle and Wollongong load centre to implement decarbonisation[22], including green steel production opportunities. The sensitivity included additional electricity consumption of approximately 2.6 TWh in 2029-30, increasing to almost 20 TWh by 2049-50. The load growth may encourage network expansions to lower system costs, specifically in the Central-West Orana and Hunter-Central Coast REZs.

Figure 53 illustrates the relative capacity growth trajectory in the NEM in this sensitivity relative to the *Step Change* scenario. To accommodate the assumed industrial load, forecasts for 2032-33 indicate a significant increase in wind (7.0 GW) and utility-scale solar (5.5 GW) developments complemented by 900 MW of additional utility-scale storage capacity, mostly in northern South Australia. Developments in New South Wales are forecast towards the end of the outlook period, aligning with the slower ramp in load growth assumptions in that region. An additional 3.7 GW of wind and 6.8 GW of utility-scale solar is forecast in the sensitivity in New South Wales by 2049-50.

Figure 53 Forecast capacity developments to 2049-50 under the *Additional Load* sensitivity compared to *Step Change* (GW)



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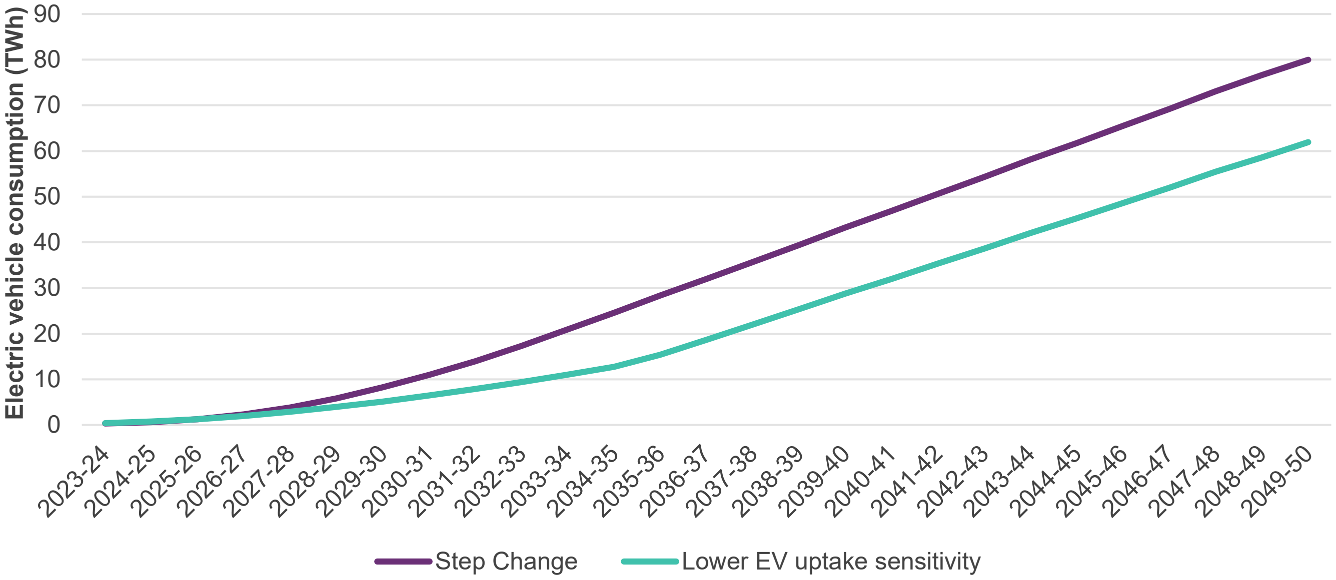
[22] At https://www.energy.nsw.gov.au/business-and-industry/programs-grants-and-schemes/industrial-decarbonisation-plans-for-the-Hunter-and-Illawarra.

A2.5.4 *Lower EV Uptake*

The *Lower EV uptake* sensitivity examines the impact of reduced EV uptake compared to *Step Change.* As shown in Figure 54 the sensitivity results in lower energy demand than in *Step Change*. The decreased charging load from EVs, particularly during peak periods, contributes to lower capacity investment across various technologies required to support the network.

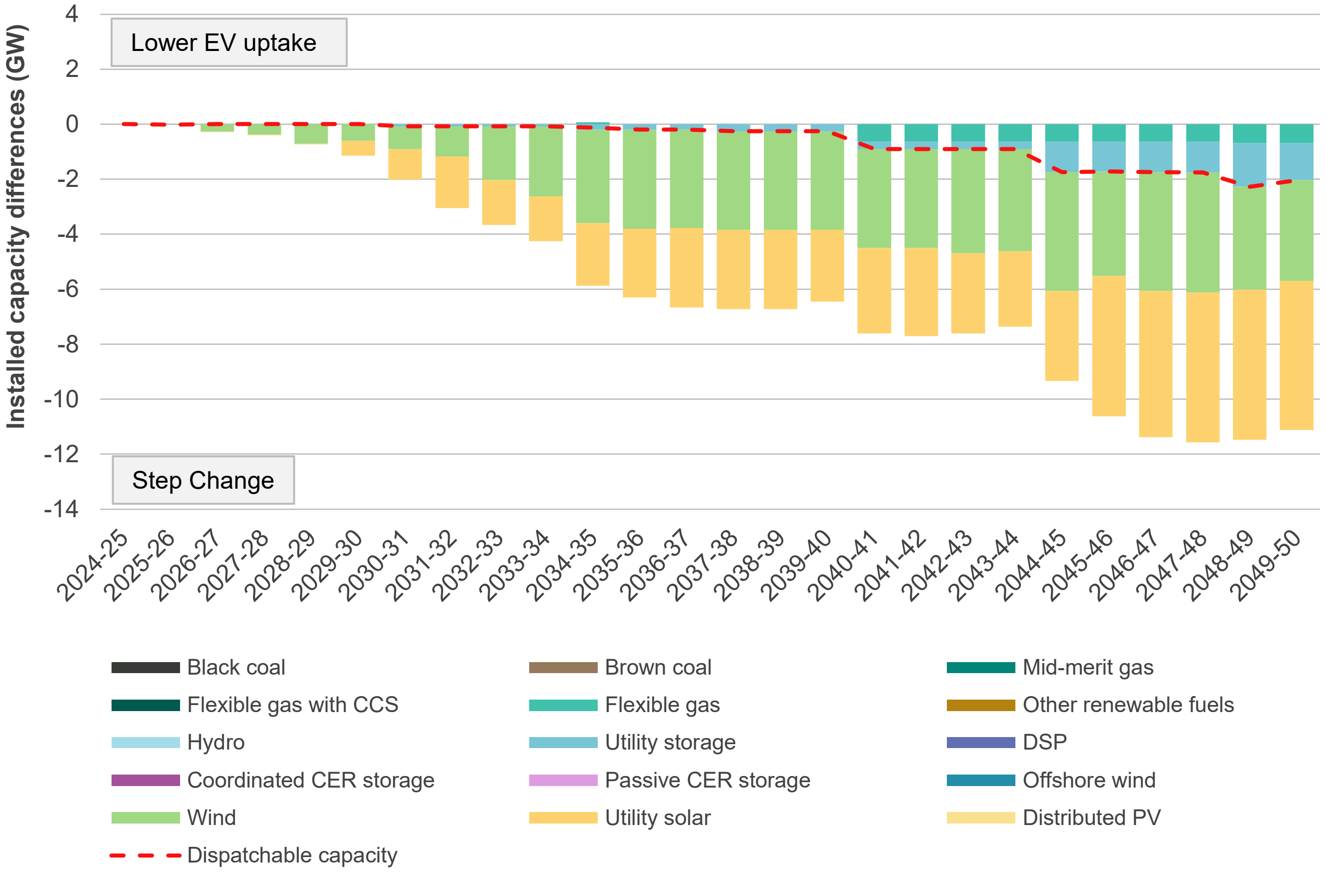
The lower EV market penetration is forecast to reduce energy consumption by 23% to 62 TWh by the end of the outlook period. The most significant reductions take place in the nodes representing major population centres – in Sydney, Newcastle and Wollongong, in Southern Queensland, and in Victoria.

Figure 54 Electric vehicle consumption, *Step Change* and *Lower EV Uptake* sensitivity



As shown in Figure 55, by 2049-50, the reduced charging load from EVs is expected to result in less solar (5.4 GW), wind (3.7 GW), utility-scale storage (1.3 GW), and flexible gas (0.7 GW) developments.

Figure 55 Forecast capacity developments to 2049-50 under the *Lower EV uptake* sensitivity compared to *Step Change* (GW)



A2.5.5 *Constrained Supply Chains*

The *Constrained Supply Chains* sensitivity revises assumptions made in the sensitivity of the same name in the Draft 2024 ISP; see Section A2.4.5 of the Draft 2024 ISP. The updated inputs reflect stakeholder feedback and are as follows:

- NEM-wide annual build of additional generation and storage developments is equal to the assumptions applied in the Draft 2024 ISP (at 4 GW per annum until 2029-30). This limit has now been increased by 2 GW annually until 2034-35, when it reaches 14 GW. This extended limit beyond 2029-30 was not modelled in the Draft 2024 ISP under the assumption that supply chains would have resolved by then. The sensitivity now increases the limit gradually, in recognition of a more moderate pace to resolve the supply chain constraints.
- The delay to the EISD for transmission augmentation options and REZ augmentations (excluding committed and anticipated projects) has been increased from two to three years.
- Generation and storage build cost increases of 30% until 2034-35, reflecting the uncertainty in build cost forecasts from the GenCost report[23].

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[23] The 2024 ISP uses cost forecasts from the 2022-23 publication of the GenCost report, at https://www.csiro.au/en/research/technology-space/energy/GenCost.

- Transmission build cost increases ranging from 12% to 50% until 2034-35, reflecting the upper bound of the cost estimation accuracy classes for each transmission project in the *Transmission Expansion Options Report*[24]; see Appendix 6 for further details.
- The impact of this sensitivity is most pronounced in the early years of the outlook period when the most restrictive development limits apply. Due to time delays and cost increases, forecast reduction in developments can be observed across various technologies, particularly wind and solar. This sensitivity does not assume delayed coal closures to accommodate the supply chain constraints on new developments.
- The constraint on supply chains would impact on the ability to meet emissions budgets and federal and state renewable energy and storage targets. In this sensitivity, the NEM-wide renewable energy share is only 68% by 2029-30, short of the Powering Australia Plan's 82% target, and emissions to 2049-50 are approximately 109 Mt CO2-e above the NEM emissions budget for that period. With the expected reduction in VRE generation (37 TWh) by 2029-30, combined coal and gas generation (34 TWh) increases to meet demand, representing higher utilisation of existing fossil fuel resources.

As shown in Figure 56, minimal additional developments are projected prior to 2034-35. After this period, investment in solar in the sensitivity catches up to the scale of development in the scenario. For several years more solar generation is developed earlier to attempt to reduce emissions further given the earlier ineffectiveness to reduce emissions to within the carbon budget.

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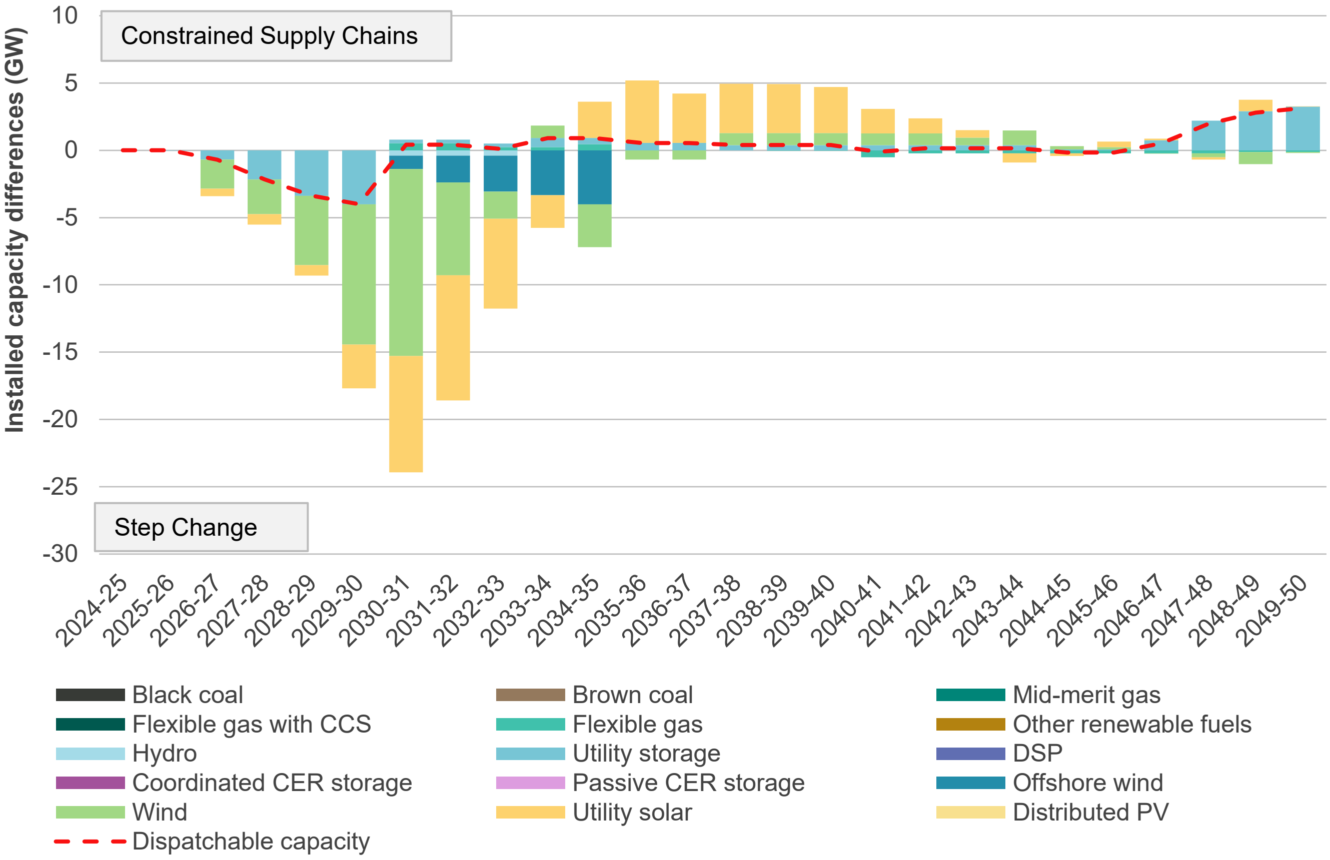
[24] At https://aemo.com.au/-/media/files/major-publications/isp/2023/2023-transmission-expansion-options-report.pdf?la=en.

Figure 56 Forecast capacity developments to 2049-50 under the *Constrained Supply Chains* sensitivity compared to *Step Change* (GW)



A2.5.6 *Low Hydrogen Flexibility*

In response to submissions to the Draft 2024 ISP, AEMO has implemented sensitivity analysis that assumed flexible electrolyser operation is balanced to meet daily production targets, rather than monthly production targets that apply in the scenario and applied in the Draft 2024 ISP. This change recognises that the ISP does not quantify or account for the scale of hydrogen storage that would be needed to realise the flexible production forecast in the 2024 ISP scenarios, assuming that hydrogen loads (industrial facilities for example) are less capable or likely to operate flexibly.

Figure 57 shows that if hydrogen production is needed to follow daily production targets, there would be a need for about 6.7 GW, 1.3 GW and 1.8 GW more solar, flexible gas and utility-scale storage capacity (mostly deep) respectively by 2049-50 compared to *Step Change.* The additional storages are needed to maintain adequate supply for reduced load flexibility; this confirms that if hydrogen demand were to be inflexible, storage (for hydrogen or electricity) will be needed.

Stakeholders also raised concerns about the technical and economic consequences of operating electrolysers at low utilisation factors (as observed in the Draft 2024 ISP). After applying a daily balancing approach, hydrogen utilisation remained at approximately 40-60%, meaning that while the balancing of hydrogen production across the month was more reasonable, there still was a reasonably variable use of electrolyser capacity to produce the daily production requirement. Further analysis has been conducted to address this feedback, with electrolysers forced to have a much higher utilisation factor (90%). Stakeholders have also raised concerns about the relatively low and declining electrolysers utilisation factors projected in the Draft 2024 ISP.

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Figure 57 Forecast capacity developments to 2049-50 under the *Low Hydrogen Flexibility* sensitivity compared to *Step Change* (GW)

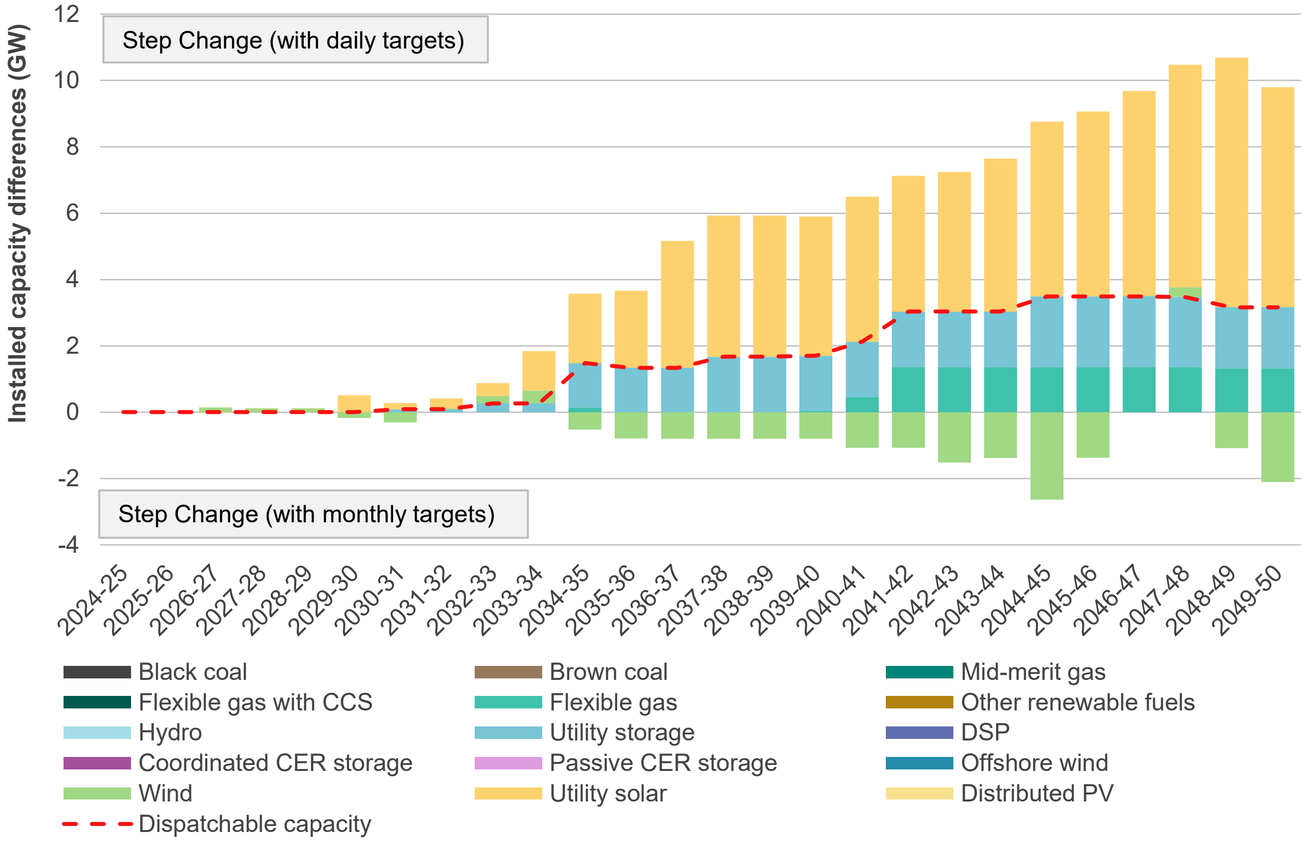


Figure 58 further illustrates that higher electrolyser utilisation factors (90%) combined with daily hydrogen production requirements is forecast to need greater renewable energy and an even greater amount of utility-scale storage.

Figure 58 Forecast capacity developments to 2049-50 under the *Low Hydrogen Flexibility* using 90% utilisation factor requirement compared to optimal utilisation factor (GW)

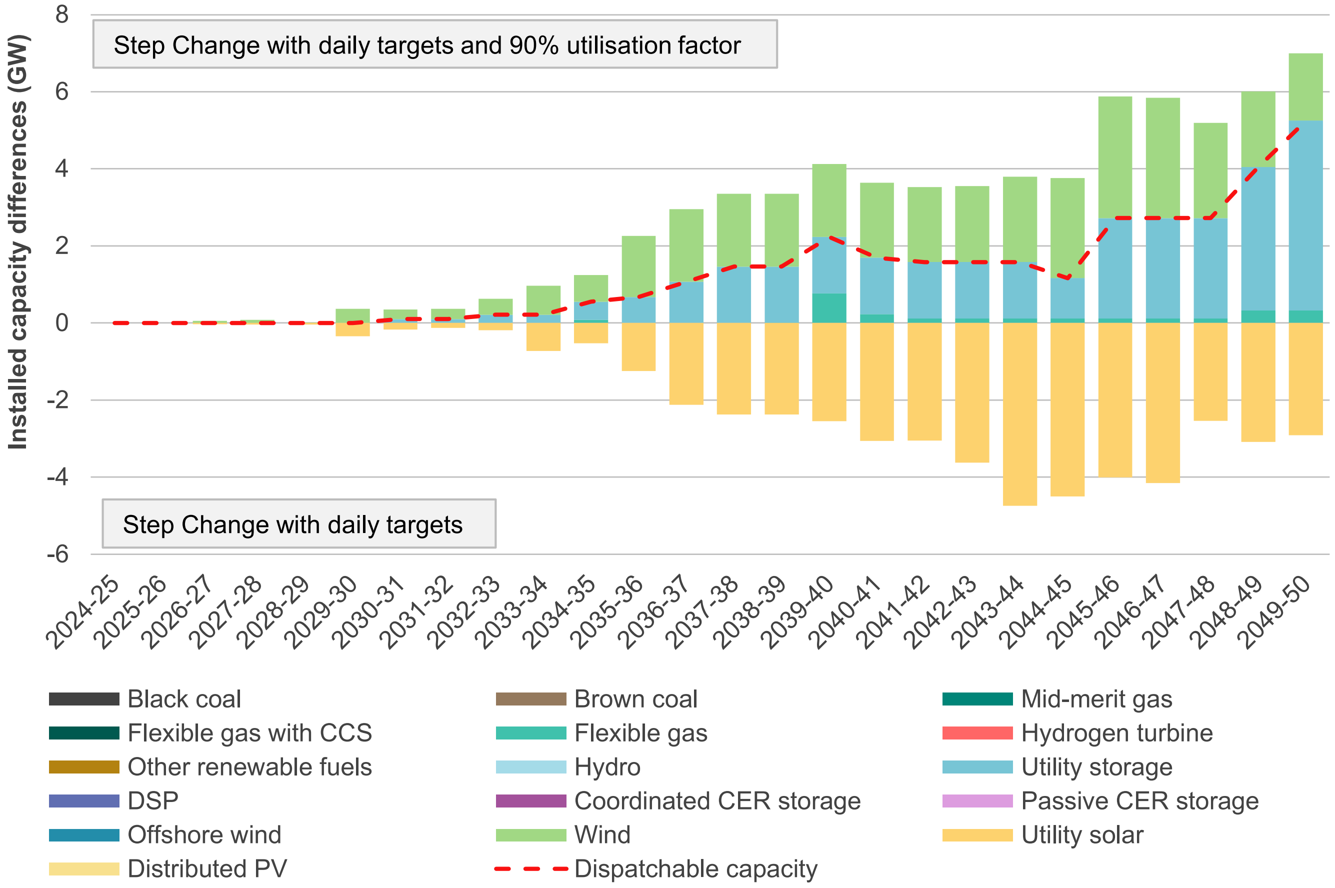


Figure 59 compares the additional capacity developed compared with the core assumption of the scenario for two cases given below:

- Daily balancing of hydrogen load with optimized electrolyser utilisation.
- Daily balancing of hydrogen load with a higher utilisation rate of 90% for electrolysers.

Between the two cases, the case that requires daily balancing targets and a higher utilisation factor requires the highest capacity development to meet inflexible hydrogen demand without the need for multiple days' worth of hydrogen storage.

As seen in Figure 60, daily balancing results in a similar profile to that of a monthly target, with electrolysers taking advantage of the additional installed capacity but no significant change in the load shape. Exogenously forcing a 90% utilisation rate has a much more significant impact, underpinning the requirement of higher levels of utility-scale storage to provide more continuous supply of electricity to the electrolysers across the day.

Figure 59 Forecast additional capacity developments to 2049-50 under the *Low Hydrogen Flexibility* cases compared to *Step Change* (GW)

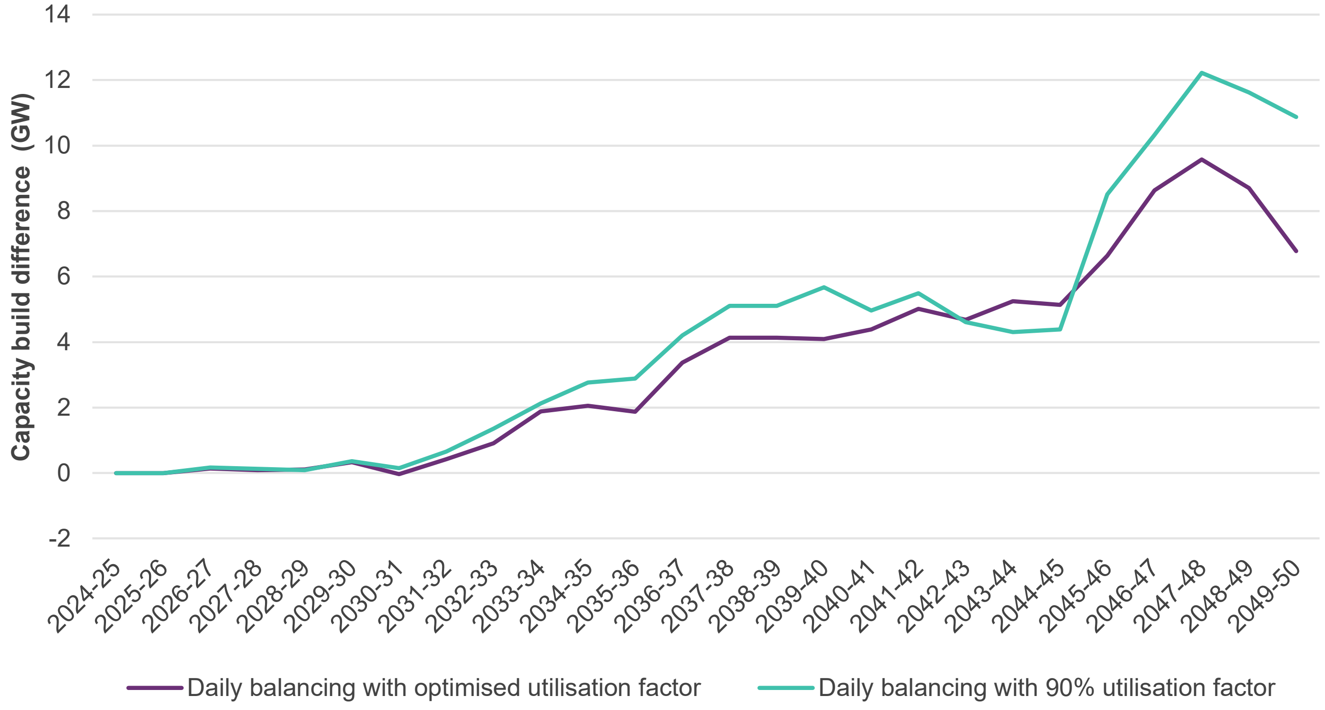
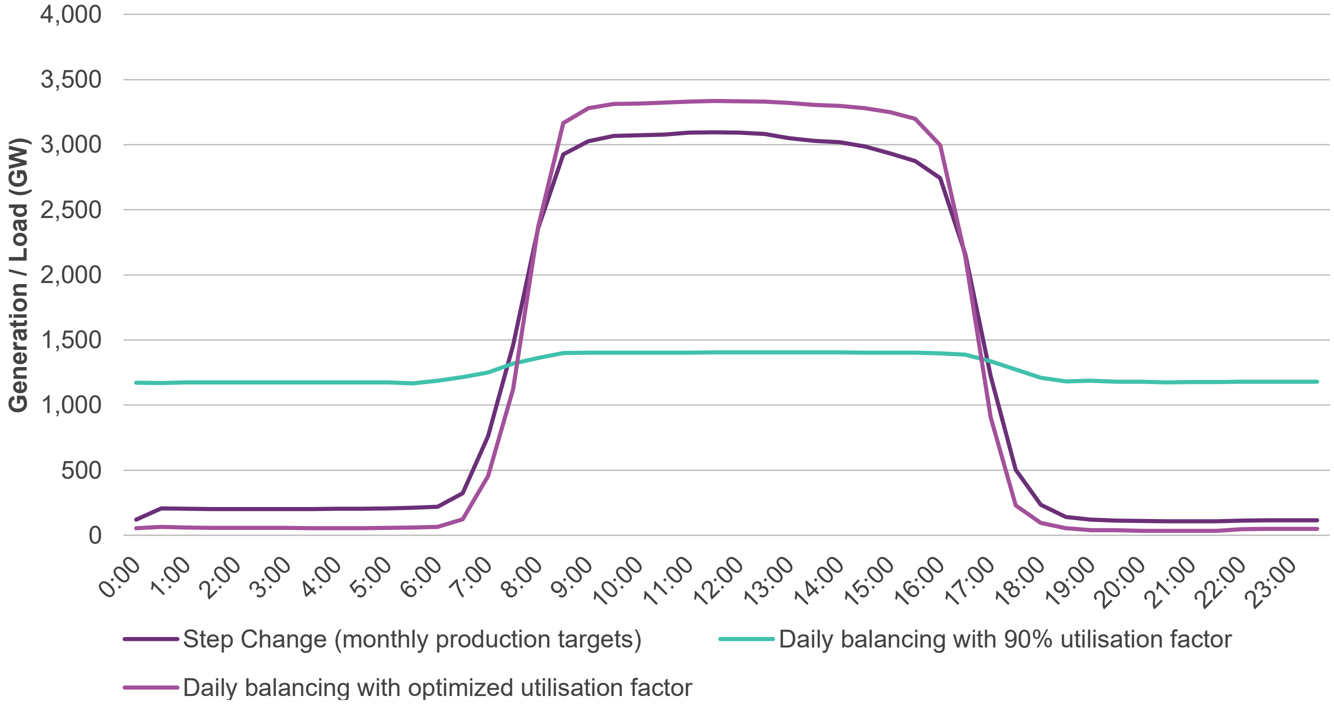


Figure 60 Average annual diurnal consumption profile of domestic electrolyser in Central Queensland in 2049-50 under the *Low Hydrogen Flexibility* sensitivity compared to *Step Change* (GW)



A2.5.7 *Alternative Weather Sequence*

The *Alternative Weather Sequence* sensitivity simulated the resilience of the generation development path with consistently poor weather conditions being experienced in the NEM. The sensitivity was designed to examine the risk that the ISP models can benefit from having some long-term foresight of upcoming weather patterns that may not be achievable. In the scenarios (as outlined in the *ISP Methodology*), AEMO modelled weather variability by combining demand and renewable energy historical data from multiple years and sequencing these years to ensure the development horizon has some exposure to recent weather patterns, known as rolling reference years.

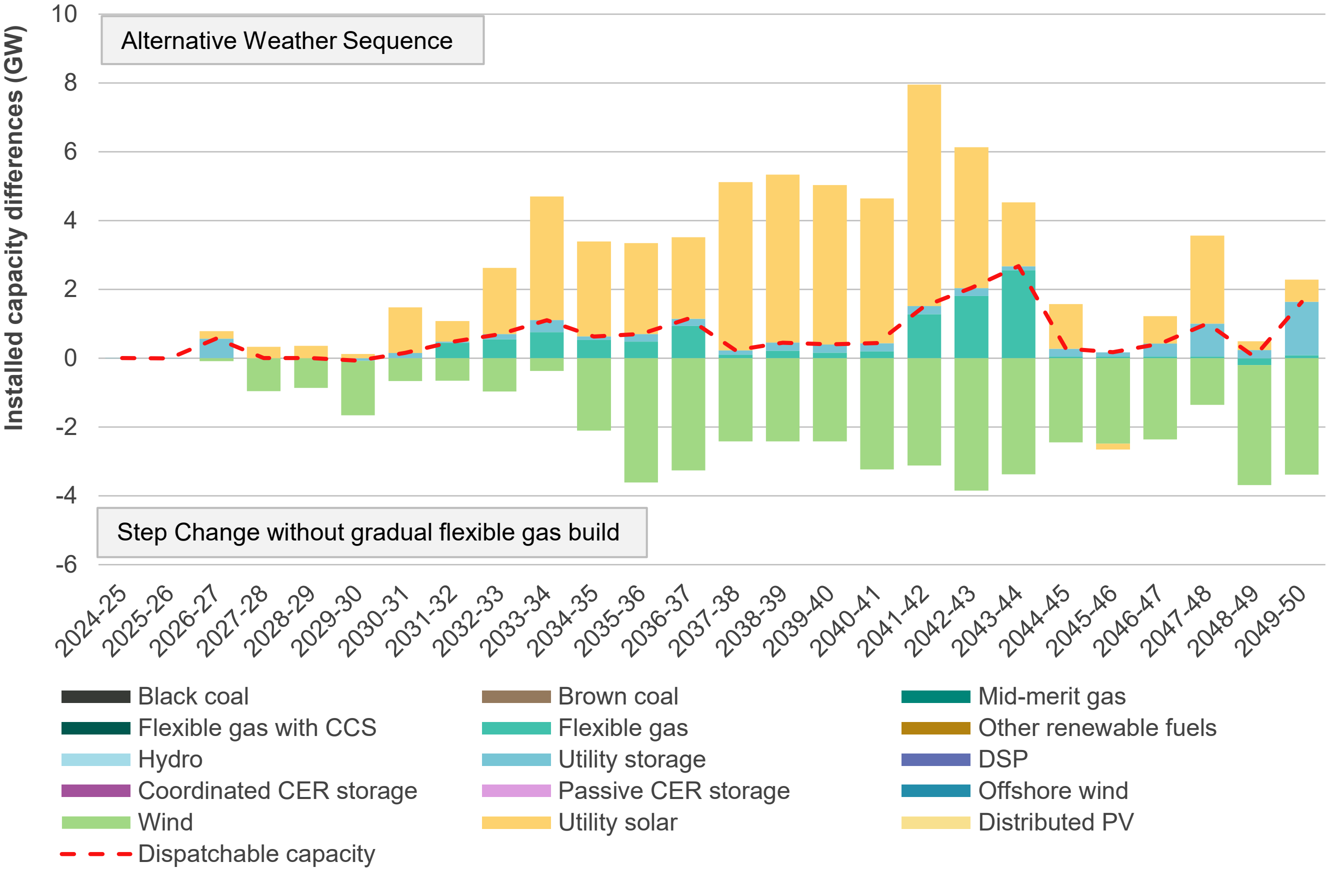
For this specific analysis, the rolling reference years were replaced with a repeating single year representing the poorest renewable energy yields across the historical reference years (from 2010-11). This sensitivity therefore helps assess the energy mix's resilience to unpredictable sustained weather-related challenges – large variations in developments would suggest that a given year may be less resilient to poor weather conditions.

This sensitivity did not include the annual constraint on flexible gas developments that aims to account for uncertainty pertaining weather patterns. That constraint has been designed with the core weather sequence in mind, and would not be appropriate to apply here because the sensitivity is not seeking to trade off between firming from storage and flexible gas, but rather identify the dispatchable capacity response of either form.

Figure 61 compares *Step Change* (without the constraint that smooths flexible gas development) to isolate the impact of the change in weather pattern to the capacity development. In this sensitivity, less development in wind generation is forecast, with greater utility-scale solar forecast given the less volatile and more predictable nature of solar generation. More flexible gas and deep storage is also required under these sustained low-weather-yield conditions.

This sensitivity confirms that the approach to manage weather uncertainty, which is achieved by applying a gradual development in flexible gas (as discussed in Section A2.2), is reasonable. It demonstrates that renewable energy droughts affect wind generation most and that a mixture of utility-scale solar, utility-scale storage, and flexible gas would be required to compensate for lower production from variable renewable technologies.

Figure 61 Forecast capacity developments to 2049-50 under the *Alternative Weather Pattern* sensitivity compared to *Step Change* without the annual constraint on flexible gas developments that aims to account for uncertainty pertaining weather patterns (GW)



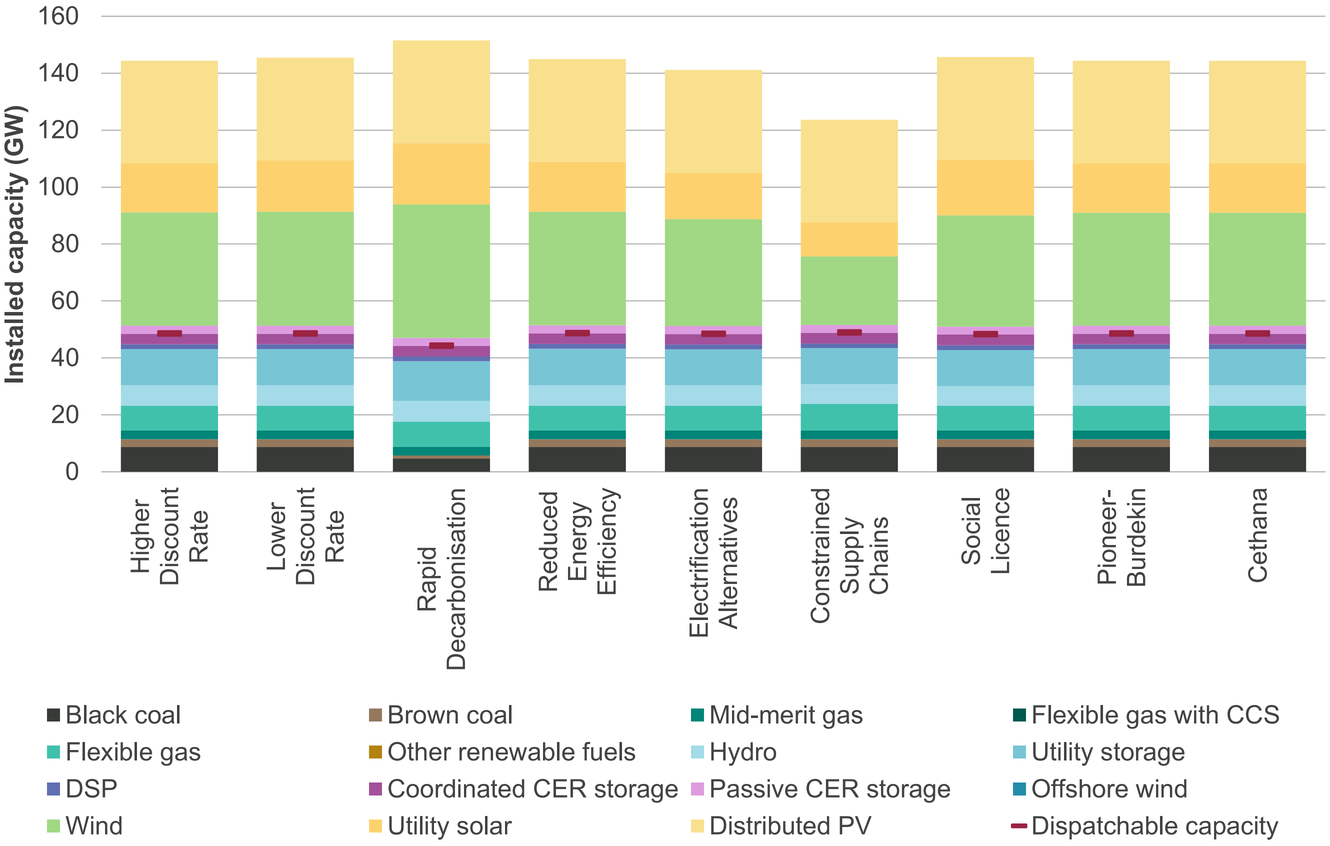
A2.6 Sensitivity analysis implemented in the Draft 2024 ISP

This section summarises and re-presents the sensitivity analysis in the Draft 2024 ISP. Note that the changes since the Draft 2024 ISP have not been implemented in the sensitivities in this summary, because the result and conclusions are largely expected to remain similar.

Figure 62 shows that by 2029-30:

- There is 1.1 GW greater generation and storage requirements if there were lower discount rate than what was assumed in the Draft 2024 ISP's *Step Change*; and minimal change if there were higher discount rate.
- Rapid decarbonisation in the Draft 2024 ISP's *Step Change* scenario would require 7.1 GW more generation and storage as coal capacities exit faster.
- Lower energy efficiency uptake in the Draft 2024 ISP's *Step Change* scenario would require 0.5 GW more generation and storage as there would be higher energy consumption.
- Electrification alternative in the Draft 2024 ISP's *Step Change* scenario would lower the generation and storage required developments by around 3.2 GW.
- *Constrained supply chains* would limit development until 2029-30, while *Reduced social licence* (affecting transmission development) would lead to a delay in transmission and greater development of utility-scale renewable generation in other locations.
- Development of Pioneer-Burdekin Pumped Hydro Project and Cethana Pumped Hydro Energy Storage would allow further VRE developments in their regions.

Figure 62 Re-presentation of the generation and storage capacities by 2029-30 for the ODP sensitivity analysis implemented in the Draft 2024 ISP



Glossary

This glossary has been prepared as a quick guide to help readers understand some of the terms used in the ISP. Words and phrases defined in the National Electricity Rules (NER) have the meaning given to them in the NER. This glossary is not a substitute for consulting the NER, the Australian Energy Regulator's (AER's) Cost Benefit Analysis Guidelines, or AEMO's *ISP Methodology*.

Term	Acronym	Explanation
Actionable ISP project	-	Actionable ISP projects optimise benefits for consumers if progressed before the next ISP. A transmission project (or non-network option) identified as part of the ODP and having a delivery date within an actionable window. For newly actionable ISP projects, the actionable window is two years, meaning it is within the window if the project is needed within two years of its earliest in-service date. The window is longer for projects that have previously been actionable. Project proponents are required to begin newly actionable ISP projects with the release of a final ISP, including commencing a RIT-T.
Actionable New South Wales project and actionable Queensland project	-	A transmission project (or non-network option) that optimises benefits for consumers if progressed before the next ISP, is identified as part of the ODP, and is supported by or committed to in New South Wales Government or Queensland Government policy and/or prospective or current legislation.
Anticipated project	-	A generation, storage or transmission project that is in the process of meeting at least three of the five commitment criteria (planning, construction, land, contracts, finance), in accordance with the AER's Cost Benefit Analysis Guidelines. Anticipated projects are included in all ISP scenarios.
Candidate development path	CDP	A collection of development paths which share a set of potential actionable projects. Within the collection, potential future ISP projects are allowed to vary across scenarios between the development paths. Candidate development paths have been shortlisted for selection as the ODP and are evaluated in detail to determine the ODP, in accordance with the ISP Methodology.
Capacity	-	The maximum rating of a generating or storage unit (or set of generating units), or transmission line, typically expressed in megawatts (MW). For example, a solar farm may have a nominal capacity of 400 MW.
Committed project	-	A generation, storage or transmission project that has fully met all five commitment criteria (planning, construction, land, contracts, finance), in accordance with the AER's Cost Benefit Analysis Guidelines. Committed projects are included in all ISP scenarios.
Consumer energy resources	CER	Generation or storage assets owned by consumers and installed behind-the-meter. These can include rooftop solar, batteries and electric vehicles (EVs). CER may include demand flexibility.
Consumption	-	The electrical energy used over a period of time (for example a day or year). This quantity is typically expressed in megawatt hours (MWh) or its multiples. Various definitions for consumption apply, depending on where it is measured. For example, underlying consumption means consumption being supplied by both CER and the electricity grid.
Cost-benefit analysis	CBA	A comparison of the quantified costs and benefits of a particular project (or suite of projects) in monetary terms. For the ISP, a cost-benefit analysis is conducted in accordance with the AER's Cost Benefit Analysis Guidelines.
Counterfactual development path	-	The counterfactual development path represents a future without major transmission augmentation. AEMO compares candidate development paths against the counterfactual to calculate the economic benefits of transmission.
Demand	-	The amount of electrical power consumed at a point in time. This quantity is typically expressed in megawatts (MW) or its multiples. Various definitions for demand, depending on where it is measured. For example, underlying demand means demand supplied by both CER and the electricity grid.
Demand-side participation	DSP	The capability of consumers to reduce their demand during periods of high wholesale electricity prices or when reliability issues emerge. This can occur through voluntarily reducing demand, or generating electricity.

Term	Acronym	Explanation
Development path	DP	A set of projects (actionable projects, future projects and ISP development opportunities) in an ISP that together address power system needs.
Dispatchable capacity	-	The total amount of generation that can be turned on or off, without being dependent on the weather. Dispatchable capacity is required to provide firming during periods of low variable renewable energy output in the NEM.
Distributed solar/ distributed PV	-	Solar photovoltaic (PV) generation assets that are not centrally controlled by AEMO dispatch. Examples include residential and business rooftop PV as well as larger commercial or industrial “non-scheduled” PV systems.
Firming	-	Grid-connected assets that can provide dispatchable capacity when variable renewable energy generation is limited by weather, for example storage (pumped-hydro and batteries) and gas-powered generation.
Future ISP project	-	A transmission project (or non-network option) that addresses an identified need in the ISP, that is part of the ODP, and is forecast to be actionable in the future.
Identified need	-	The objective a TNSP seeks to achieve by investing in the network in accordance with the NER or an ISP. In the context of the ISP, the identified need is the reason an investment in the network is required, and may be met by either a network or a non-network option.
ISP development opportunity	-	A development identified in the ISP that does not relate to a transmission project (or non-network option) and may include generation, storage, demand-side participation, or other developments such as distribution network projects.
Net market benefits	-	The present value of total market benefits associated with a project (or a group of projects), less its total cost, calculated in accordance with the AER’s Cost Benefit Analysis Guidelines.
Non-network option	-	A means by which an identified need can be fully or partly addressed, that is not a network option. A network option means a solution such as transmission lines or substations which are undertaken by a Network Service Provider using regulated expenditure.
Optimal development path	ODP	The development path identified in the ISP as optimal and robust to future states of the world. The ODP contains actionable projects, future ISP projects and ISP development opportunities, and optimises costs and benefits of various options across a range of future ISP scenarios.
Regulatory Investment Test for Transmission	RIT-T	The RIT-T is a cost benefit analysis test that TNSPs must apply to prescribed regulated investments in their network. The purpose of the RIT-T is to identify the credible network or non-network options to address the identified network need that maximise net market benefits to the NEM. RIT-Ts are required for some but not all transmission investments.
Reliable (power system)	-	The ability of the power system to supply adequate power to satisfy consumer demand, allowing for credible generation and transmission network contingencies.
Renewable energy	-	For the purposes of the ISP, the following technologies are referred to under the grouping of renewable energy: “solar, wind, biomass, hydro, and hydrogen turbines”. Variable renewable energy is a subset of this group, explained below.
Renewable energy zone	REZ	An area identified in the ISP as high-quality resource areas where clusters of large-scale renewable energy projects can be developed using economies of scale.
Renewable drought	-	A prolonged period of very low levels of variable renewable output, typically associated with dark and still conditions that limit production from both solar and wind generators.
Scenario	-	A possible future of how the NEM may develop to meet a set of conditions that influence consumer demand, economic activity, decarbonisation, and other parameters. For the 2024 ISP, AEMO has considered three scenarios: *Progressive Change*, *Step Change* and *Green Energy Exports*.
Secure (power system)	-	The system is secure if it is operating within defined technical limits and is able to be returned to within those limits after a major power system element is disconnected (such as a generator or a major transmission network element).
Sensitivity analysis	-	Analysis undertaken to determine how modelling outcomes change if an input assumption (or a collection of related input assumptions) is changed.
Spilled energy	-	Energy from variable renewable energy resources that could be generated but is unable to be delivered. Transmission curtailment results in spilled energy when generation is constrained due to operational limits, and economic spill occurs when generation reduces output due to market price.

Term	Acronym	Explanation
Transmission network service provider	TNSP	A business responsible for owning, controlling or operating a transmission network.
Utility-scale or utility		For the purposes of the ISP, 'utility-scale' and 'utility' refers to technologies connected to the high-voltage power system rather than behind the meter at a business or residence.
Value of greenhouse gas emissions reduction	VER	The VER estimates the value (dollar per tonne) of avoided greenhouse gas emissions. The VER is calculated consistent with the method agreed to by Australia's Energy Ministers in February 2024.
Virtual power plant	VPP	An aggregation of resources coordinated to deliver services for power system operations and electricity markets. For the ISP, VPPs enable coordinated control of CER, including batteries and electric vehicles.
Variable renewable energy	VRE	Renewable resources whose generation output can vary greatly in short time periods due to changing weather conditions, such as solar and wind.