Appendix 2. Generation and Storage Development Opportunities

December 2023

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

Important notice

Purpose

This is Appendix 2 to the Draft 2024 *Integrated System Plan* (ISP) which is available at https://aemo.com.au/energy-systems/major-publications/integrated-system-plan-isp.

AEMO publishes the Draft 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 30 October 2023 unless otherwise indicated.

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Version control

Version	Release date	Changes
1.0	15/12/2023	Initial release.

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ISP Appendices

Appendix 1. Stakeholder Engagement

- Preliminary engagement
- Major engagements
- Draft 2024 ISP Consultation

Appendix 2. Generation and Storage Opportunities

- A rapidly evolving NEM will transform energy supply
- Generation and storage development opportunities across scenarios
- The influence of sensitivities on generation and storage development opportunities

Appendix 3. Renewable Energy Zones

- REZ candidates
- REZ development overview
- Regional outlook and REZ scorecards

Appendix 4. System Operability

- The NEM's demand profiles will continue to evolve
- VRE penetration and curtailment
- System flexibility manages increased variability
- Operating the power system during long, dark, and still conditions
- Storage technologies will firm VRE
- Implications for coal operation during the transition
- Impacts of gas system adequacy on system operability
- Maintaining reliability during the transition

Appendix 5. Network Investments

- Transmission development overview
- Committed and anticipated projects
- Actionable projects
- Future ISP projects

Appendix 6. Cost-Benefit Analysis

- Approach to the cost-benefit analysis
- Determining the least-cost development path for each scenario
- Determining the set of candidate development paths to identify the ODP
- Assessing the candidate development paths
- Selecting the optimal development path
- Testing the resilience of the candidate development paths
- The impact of consumer risk preferences on transmission timings
- The optimal development path

Appendix 7. System Security

- Recent reforms to the security planning frameworks
- AEMO's approach to system security planning
- System security concepts and requirements
- Projected outlook and opportunities

Appendix 8. Social Licence

- Social licence overview
- Social licence for infrastructure development
- Consumer mobilisation, adoption, and orchestration
- Social licence and the energy transition

Contents

Tables

Figures

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 to meet future energy needs. The ISP's optimal development path sets out the needed generation, firming and transmission, which would deliver significant net market benefits for consumers and economic opportunities in Australia's regions.

This appendix presents the ISP development opportunities for electricity generation and storages in the optimal development path (ODP) for three ISP core 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 NER requirements and the 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 backed-up by gas-powered generation is the lowest 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 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 targets.
- Utility-scale VRE and consumer energy resources are forecast to grow throughout the outlook period. NEM-wide utility- scale VRE development reaches 48 GW, 57 GW, and 98 GW in *Progressive Change*, *Step Change*, and *Green Energy Exports*, respectively. This scale of development is currently supported by various renewable energy targets.
- To firm the variable renewable generation, 14-21 GW of new dispatchable resources are forecast to be needed.

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 complement renewable generation and storage technologies by operating when renewable resources are low, more likely in winter periods as solar resources reduce with the 'shorter' days.

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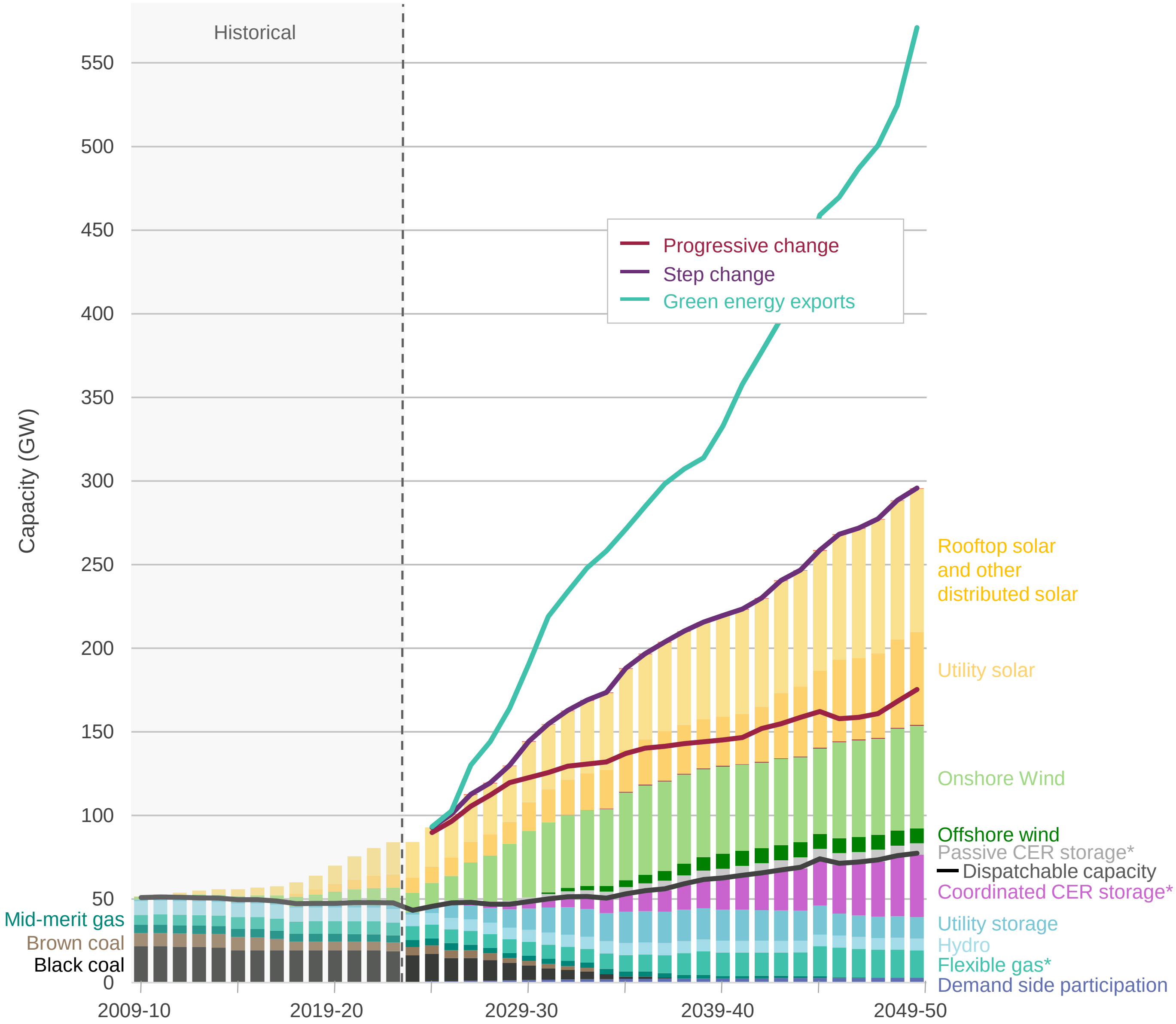
[1] Australian Energy Market Commission (AEMC), *Emissions Target Statement under the National Energy Laws*, September 2023. At https://www.aemc.gov.au/sites/default/files/2023-09/AEMC%20Emissions%20targets%20statement%20-%20final%20guide%20September%202023.pdf.

- Significant dispatchable storages at various storage depths will be needed to complement the renewable generation mix and the level of consumer battery sources assumed. Up to 50 GW / 654 GWh in *Step Change,* 21 GW / 581 GWh in *Progressive Change* and 67 GW / 817 GWh in *Green Energy Exports* of utility-scale storage and Coordinated CER storage capacity will help to firm renewables and respond to dispatch signals.

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

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 and biomass capacity.
"CER storage" are consumer energy resources such as batteries and electric vehicles.

Appendix 6 of the Draft 2024 ISP contains the cost-benefit analysis (CBA) of these scenarios and sensitivities, outlining the relative market benefits derived from different transmission development pathways.

A2.1 Introduction

Sections 3, 4, and 6 of the Draft 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 Draft 2024 ISP with additional detail on these development opportunities, in particular:

- A2.2 summarises the generation and storage development aspects of the energy system across the three core ISP scenarios[2].
- A2.3 provides more detailed examination of generation and storage development for each scenario and illustrates the impact of transmission augmentations on those developments.
- A2.4 details the impact of the various sensitivities to key assumptions to those development opportunities.

The content in this appendix is complemented by:

- Appendix 3, which provides more granular reporting on the renewable energy development opportunities and broader 'scorecards' for individual renewable energy zones (REZs),
- Appendix 4, which provides greater detail on the operability of the NEM under the various developments outlined in this appendix,
- Appendix 6, which provides the cost-benefit assessment of the candidate development paths (CDPs) considered in this Draft 2024 ISP, and
- Appendix 7, which quantifies NEM system security requirements and provides insights into the nature, timing, and geography of the services needed to address them.

This appendix presents a NEM-wide view, and regional breakdowns where appropriate, of these developments.

This appendix is also complemented by the **Generation and Storage Outlook Workbooks**[3], which provide details of the capacity developments, energy generated, and retirement outlook for all relevant NEM regions. The workbook also presents emissions outcomes and comparisons of costs between alternative CDPs.

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[2] The outcomes presented in this appendix are based on CDP11 (see Appendix 6 for further details).

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

Key changes from the 2022 ISP

The 2023 *Inputs, Assumptions and Scenarios Report* (IASR) publication provides details of the inputs and assumptions for each of the core scenarios considered in the Draft 2024 ISP. Several significant changes affecting the inputs and assumptions for this Draft 2024 ISP, relative to the 2022 ISP, have material impacts on the outcomes presented within the Draft 2024 ISP, such as:

- Inclusion of federal and state policies in all scenarios,
- Updated demand forecasts, including consumer energy resources (CER), electrification, energy efficiency and business consumption, and the emergence of hydrogen loads,
- Varying increases in transmission, generation, and storage costs,
- Reduction in the gas price forecast,
- Inclusion of new renewable energy zones (REZs), and updates on REZ resource limits and transmission limits, and
- Improvements on the wind and solar site-selection process, resulting in changes to REZ capacity factors.

For detailed information on the inputs and assumptions used for the Draft 2024 ISP, please refer to 2023 IASR.

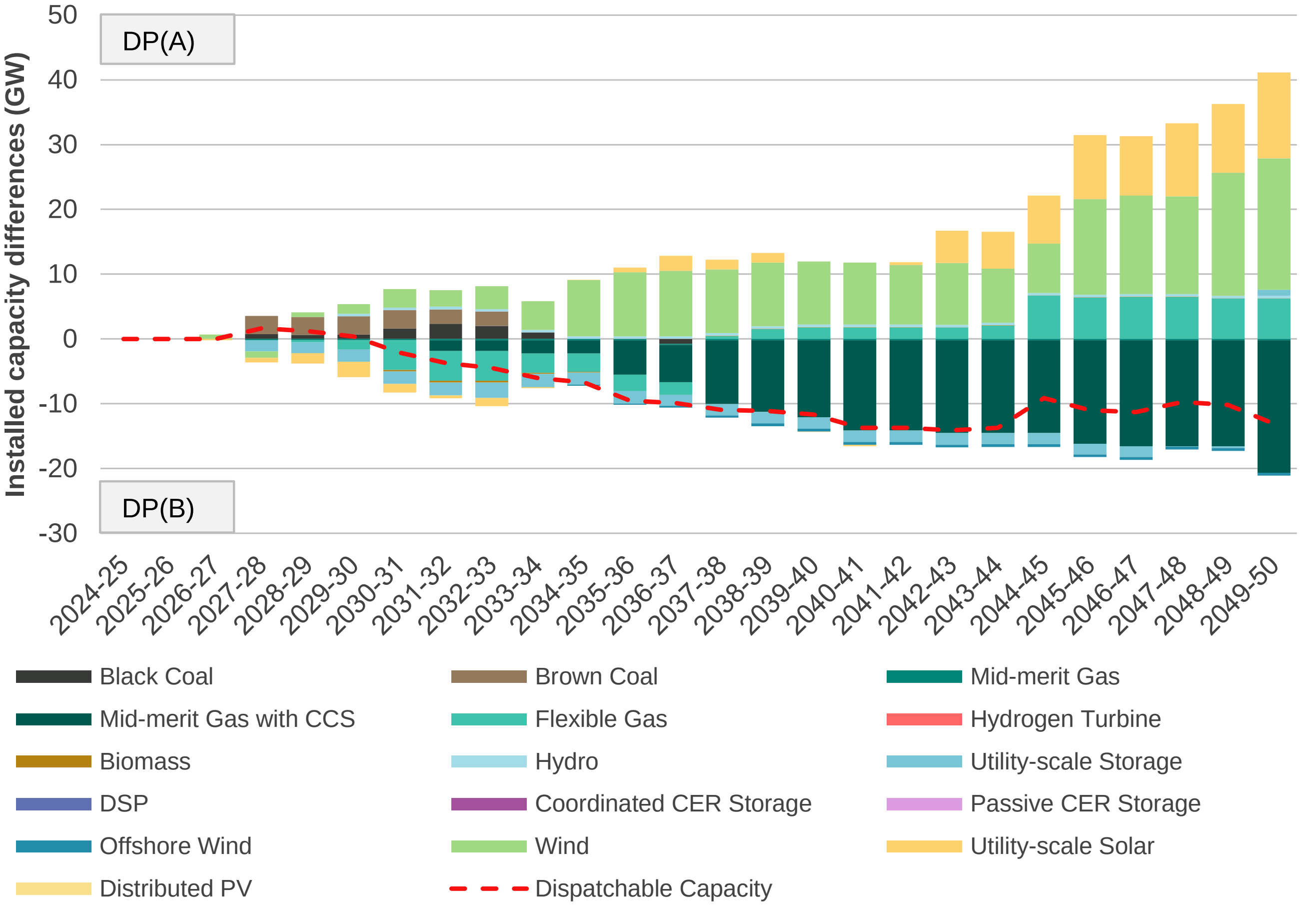
A2.1.1 Interpreting the graphics in this appendix

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

When interpreting the sample chart in Figure 2:

- 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 utility-scale solar 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 (which is used as the equivalent descriptor in the primary Draft 2024 ISP report).

Figure 2 Example interpretation of forecast capacity differences used in this appendix



A2.2 A rapidly evolving NEM will transform energy supply

Similar to the 2022 ISP, the Draft 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 storage, transmission developments, hydro power, gas-powered generation, and CER. As this transition supports a net-zero emissions economy, NEM development will need to replace, and add to, the existing generation fleet to meet growing demand and 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).
- Gas-powered generation – to firm renewable energy and provide flexible operation, particularly during periods of low VRE output.
- Consumer energy resources, including Distributed PV, battery systems and electric vehicles. These will connect to the distribution system, and if appropriately orchestrated (for battery and vehicle devices) then the scale of utility-scale development opportunities will likely be impacted.

A2.2.1 The development of the NEM is influenced by policy targets

Several of the policies included in the Draft 2024 ISP target specific aspects of NEM development. That includes:

- Powering Australia Plan – the 82% renewable energy target by 2030, and the recent announcement for the Capacity Investment Scheme[4] to support 32 GW of renewable and/or firming technology. The 82% target will be influenced by the level of forecast electricity consumption.
- Emissions budgets and targets in NEM jurisdictions – this includes several state commitments to emissions reduction and the Climate Change Act’s (Cwlth) 43% emissions reduction target. The Draft 2024 ISP includes an overall carbon budget to meet these targets, and to reach net-zero by 2050 (see the 2023 IASR Assumptions Workbook[5] and Section 3.2 of AEMO’s 2023 IASR[6] 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 Draft 2024 ISP.

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

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

[6] 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.

A2.2.2 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 optimal development path (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 (Hunter Transmission Project and investigation of southern network options),
- New England REZ Transmission Link,
- Victoria New South Wales Interconnector West (VNI West),
- Project Marinus (Stage 1 and 2),
- Gladstone Grid Reinforcement,
- Queensland SuperGrid South.

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 126 GW in *Step Change* by 2049-50, and to 86 GW and 367 GW respectively in *Progressive Change* and *Green Energy Exports.* This is 43%, 50%, and 65% of the total installed capacity for 2049-50for *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 are developed to achieve at least the objectives of government policies, such as the Victorian Offshore Wind Target[7], South Australian Hydrogen and Jobs Plan[8], and Queensland Energy and Jobs Plan [9]. These policies are detailed in the 2023 IASR[10].

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

[8] At Hydrogen Jobs Plan | Office of Hydrogen Power South Australia (ohpsa.sa.gov.au).

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

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

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	7.3	3.1	1.7	4.6	0	0
Brown coal	4.8	2.8	0	0	3.4	0.6	0	1.1	0	0
Mid-merit gas	4.3	3.1	1.5	0.2	2.6	1.5	0.2	3.1	1.5	0.2
Mid-merit gas with carbon capture and storage	0	0	0	0	0	0	0	0	0	0
Flexible gas	7.2	8.7	14.8	17.1	8.7	9.3	10.9	8.8	15.1	17
Hydro	6.8	7.2	7.1	7.1	7.2	7.1	7.1	7.2	7.1	7.1
Utility-scale storage	2.2	12.7	18.6	12.9	14.2	20.2	17.0	17.3	25.5	22.9
Coordinated CER storage	0.1	3.7	18.1	37.3	0.2	1.4	4.1	4.5	22.9	44.4
Passive CER storage	0.6	2.8	6.4	6.8	1.5	2.8	4.0	3.7	8.0	8.8
Offshore wind	0	0	9.0	9.0	0	9.0	9.0	0	9.0	9.1
Onshore wind	10.4	39.6	52.0	61.4	32.0	33.3	43.6	66.5	101.2	145.0
Utility-scale solar	8.4	17.4	29.4	55.5	16.4	18.8	33.5	31.2	68.7	212.6
Distributed PV	21.3	36.1	60.2	85.7	27.7	36.3	42.3	40.8	70.1	98.6
DSP	0.9	1.6	2.5	2.9	1.4	1.8	1.9	2.0	3.7	5.0

A. Based on October 2023 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 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[11] 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 decarbonisation and renewable energy targets at federal and state levels. Figure 3, demonstrates the historical and forecast coal closure outlook in *Step Change* for the NEM's coal generation fleet in comparison with other projections considered in 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. 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.

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

Figure 3 Historical and forecast coal retirements, 2009-10 to 2049-50 (GW)

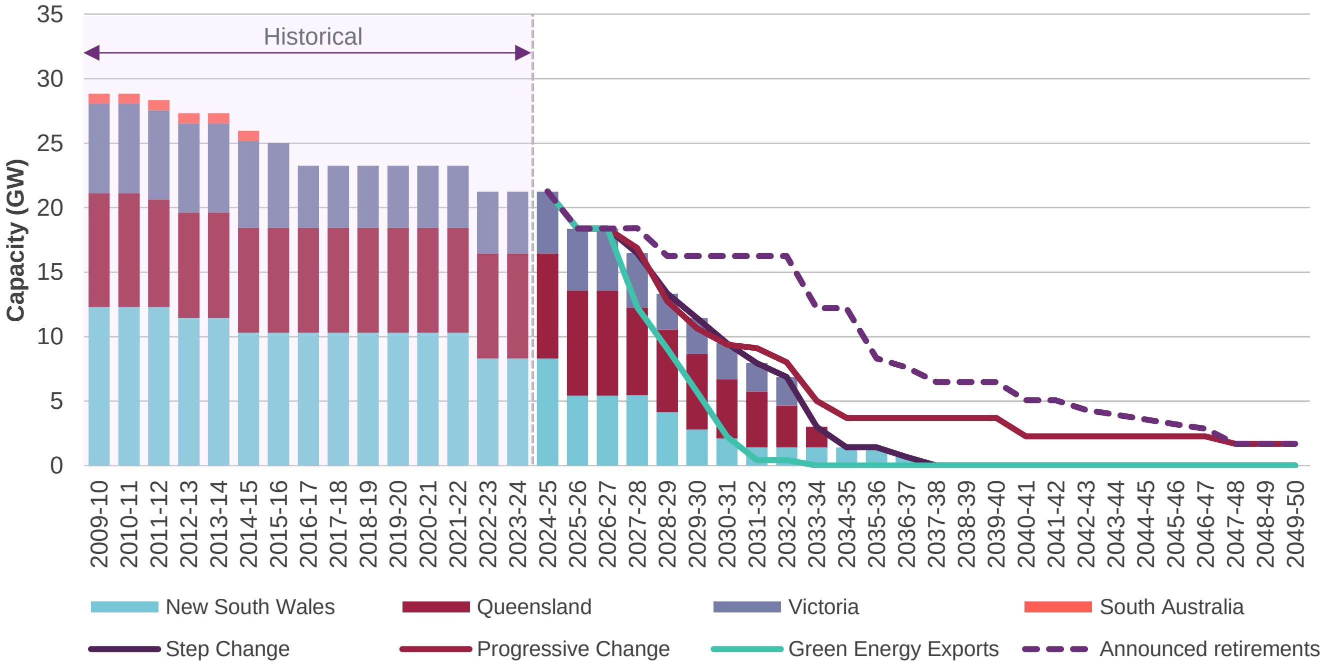
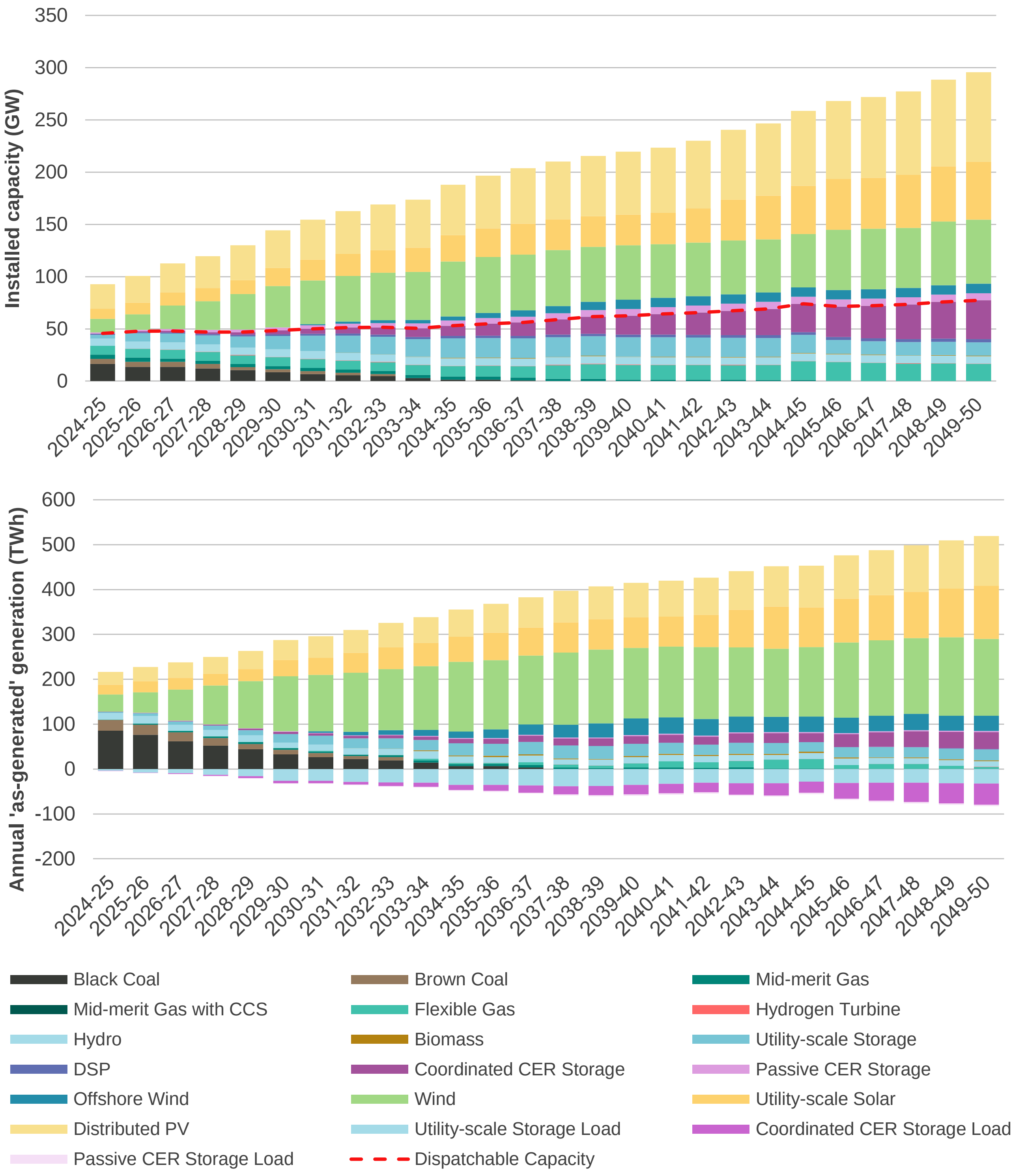


Figure 4 below (showing *Step Change*) shows that new VRE, storage, gas-power generation development is forecast to meet consumer's energy, security and reliability needs. In terms of generation capacity, utility-scale VRE and distributed PV capacities are forecast to ramp up to replace retiring coal-fired 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 4 also shows than renewable generation is expected to increase. In 2029-30, projected total generation from solar capacity (utility-scale and distributed PV) is 31% (81.2 TWh) of the NEM’s total generation, while wind generation makes up 47% (122.4 TWh). By 2034-35 – five years later – these are forecast to grow to 37% (116.5 TWh) and 54% (169.9 TWh) respectively.

Figure 4 NEM-wide installed capacity (top) and energy generation (bottom), *Step Change*, 2024-25 to 2049-50 (GW and TWh)



Generation from flexible gas generation 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. Depending on power system investments, there may also be a role for gas generation to continue to provide power system services.

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.

A2.2.3 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 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 FCAS (not included in AEMO’s modelling) than for its energy management capability.
- **Medium 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 5 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 developments to complement VRE penetration.
- The chart on the right presents the energy storage capacity (in GWh) for selected years. The figure 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 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 VRE system.

Deep storage developments (beyond the committed Snowy 2.0 and anticipated Borumba Dam Pumped Hydro) occur from the 2030s to complement and firm VRE developments and to provide sufficient dispatchable capacity to maintain reliability as coal capacity retires. 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 if the scale of CER and CER orchestration is achieved. 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 Draft 2024 ISP develops more flexible gas in later years to service these gaps, however, deeper storages would be another alternative.

Figure 5 NEM-wide storage installed capacity (left) and energy storage capacity (right), *Step Change*, 2024-25 to 2049-50 (GW and GWh)

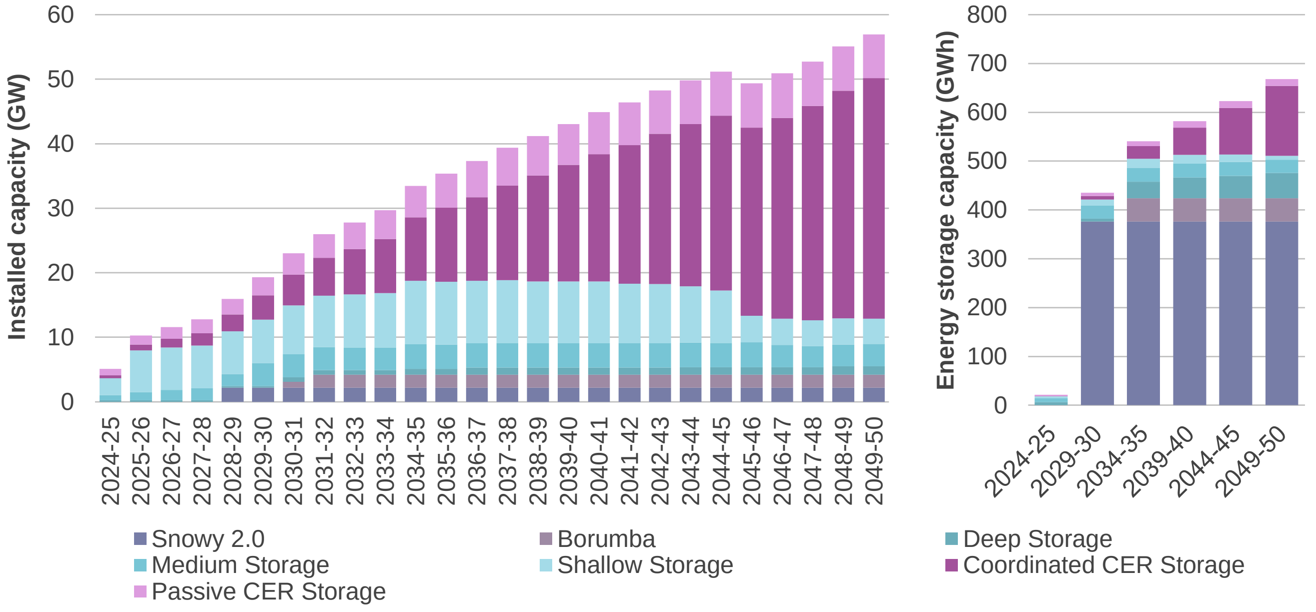
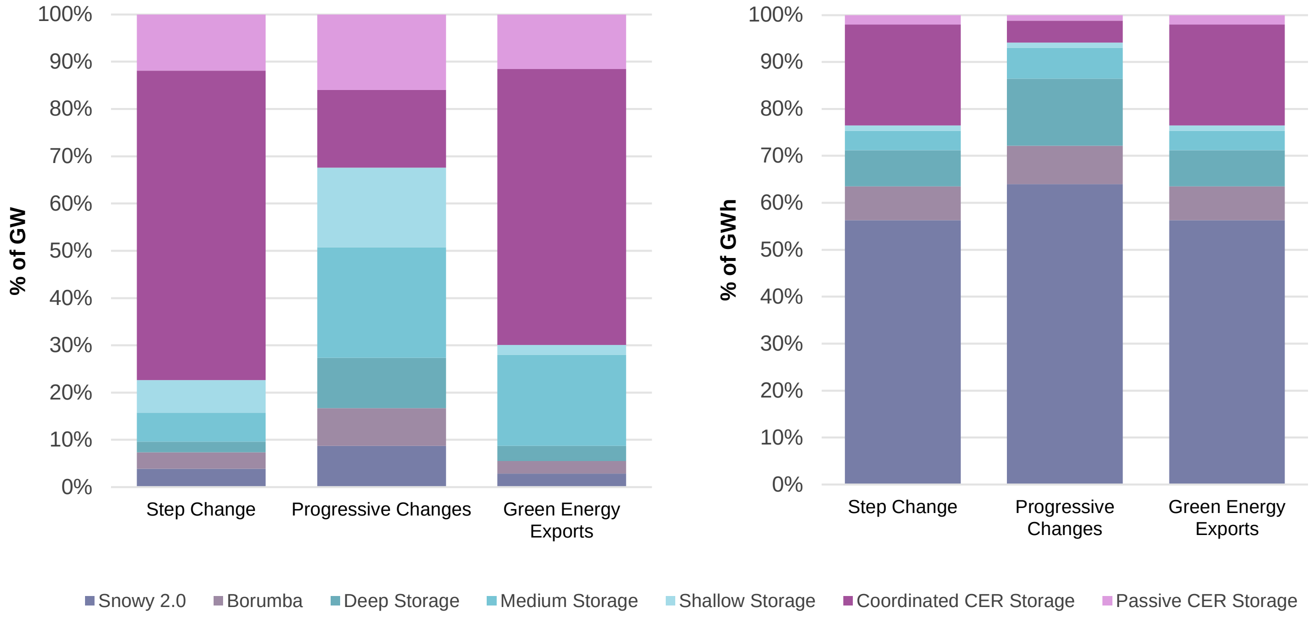


Figure 6 presents the mix of energy storage capacity forecast to be required to complement and firm VRE developments across the three core scenarios. As shown in the figure, the scale of CER uptake is significant as it will offset the need for more shallow and medium-depth utility-scale storage – as 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.

Figure 6 Mix of energy storage type by scenario in 2049-50 – storage installed capacity (left) and energy storage depth (right) (%GW and %GWh)



A2.2.4 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 upon strong VRE uptake, reducing the electricity sector's emissions intensity under all ISP scenarios, as shown in Figure 7 and Figure 8. The current set of decarbonisation policies to 2030, which are similar in all scenarios, drive the emissions pathways, with divergence emerging as the scenarios navigate alternative paths to net-zero by 2050.

Figure 7 shows forecast emissions trajectories to 2049-50 across all scenarios. 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 according to the level of VRE developments in each scenario supporting the electrification of the economy and providing additional relative emissions savings economy-wide.

In *Step Change* and *Green Energy Exports*, significant and rapid change to the NEM's generation mix to achieve the scenarios' emissions reduction objectives are required. This leads to the forecast retirement of most thermal generation in the late 2020s and early 2030s (see Sections A2.3.1 and A2.3.3). By 2029-30, NEM emissions are forecast to reduce by 76% in *Step Change* (from 176 Mt CO_2-e in 2005 to 42 Mt CO_2-e in 2029-30), and by 90% in *Green Energy Exports* (from 176 Mt CO_2-e in 2005 to 18 Mt CO_2-e in 2029-30). By 2049-50, emissions are forecast to be just 3 Mt CO_2-e and 1 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. Up to this point, various renewable energy targets provide the key driver for sufficient VRE developments to reduce emissions which results in 78% fall in emissions between 2004-05 and 2029-30.

Figure 7 Actual and forecast annual NEM-wide emissions by scenario, 2004-05 to 2049-50 (Mt CO_2-e)

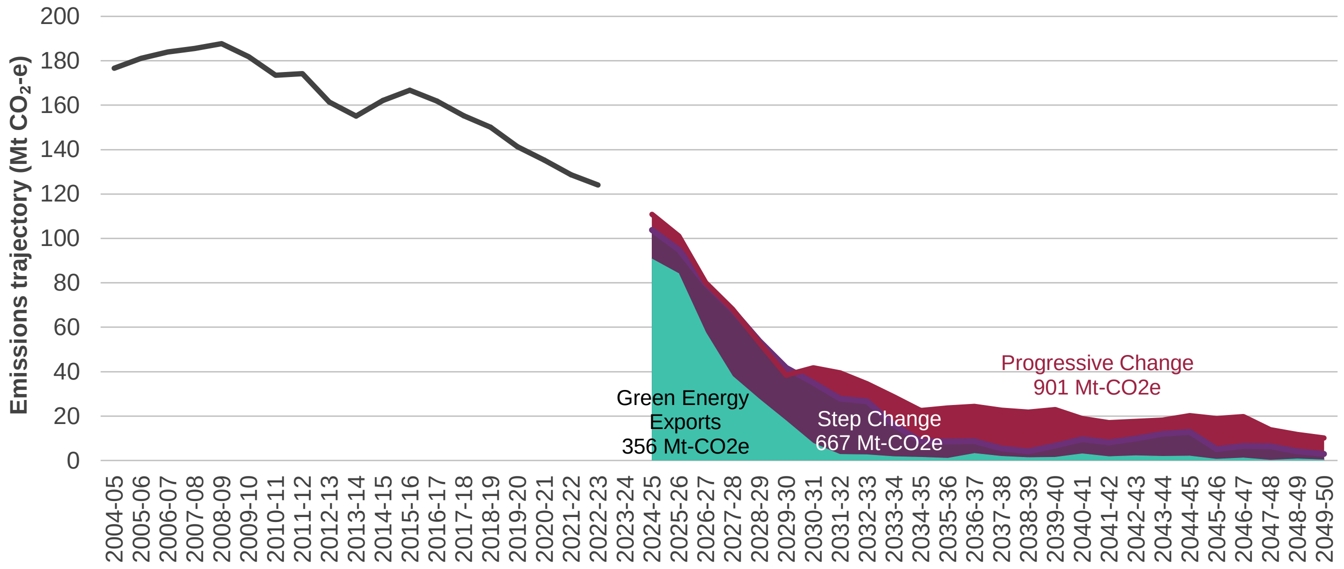
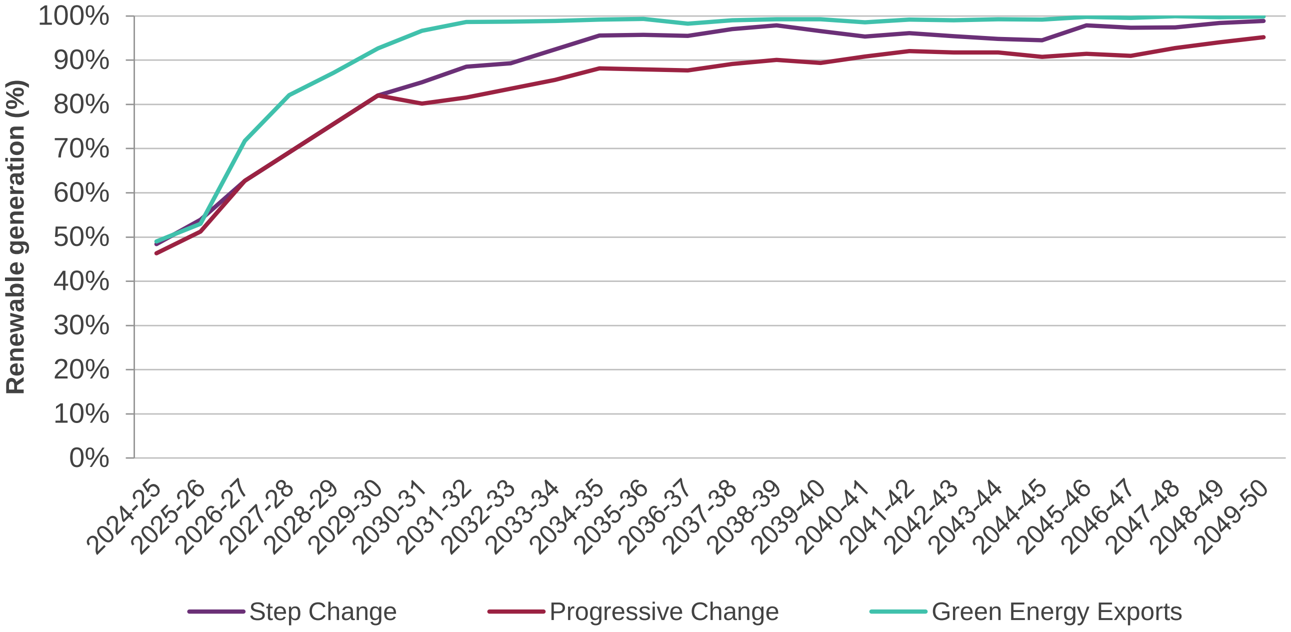


Figure 8 presents the forecast level of renewable energy penetration to 2049-50 by scenario. Complementing Figure 7, it demonstrates the increasing role of VRE to reduce emissions over the next 25 years. In *Step Change*, the share of generation from renewable sources is forecast to reach 99% by 2049-50.

Figure 8 Evolution of the annual share of total generation from renewable sources, from capacity outlook model, by scenario, 2024-25 to 2049-50



A2.3 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 emission reduction, coal retirements and energy consumption forecast. The magnitude of utility-scale VRE development is supported by various renewable energy targets, and it reaches 48 GW, 57 GW, and 98 GW in *Progressive Change*, *Step Change*, *Green Energy Exports*, respectively by 2029-30. By 2049-50, utility-scale VRE developments diverge across scenarios more significantly, as 86 GW, 126 GW and 367 GW in *Progressive Change*, *Step Change*, and *Green Energy Exports* are developed respectively.

A2.3.1 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 orchestrated 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 9) projects that:

- To 2029-30:
  - VRE developments are driven by renewable energy and decarbonisation policies such as the Powering Australia Plan 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 9 **Forecast NEM installed capacity, *Step Change*, 2024-25 to 2049-50 (GW)**

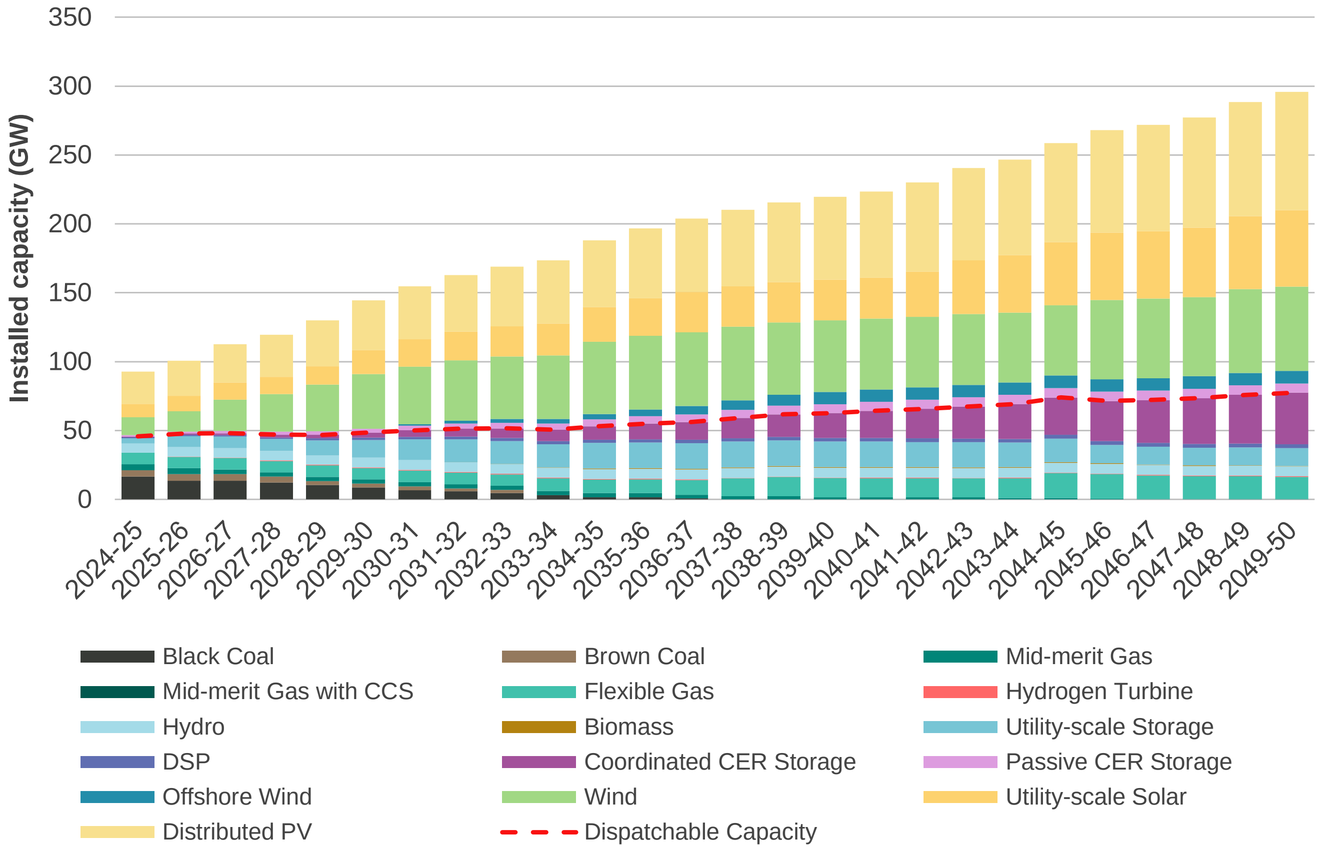
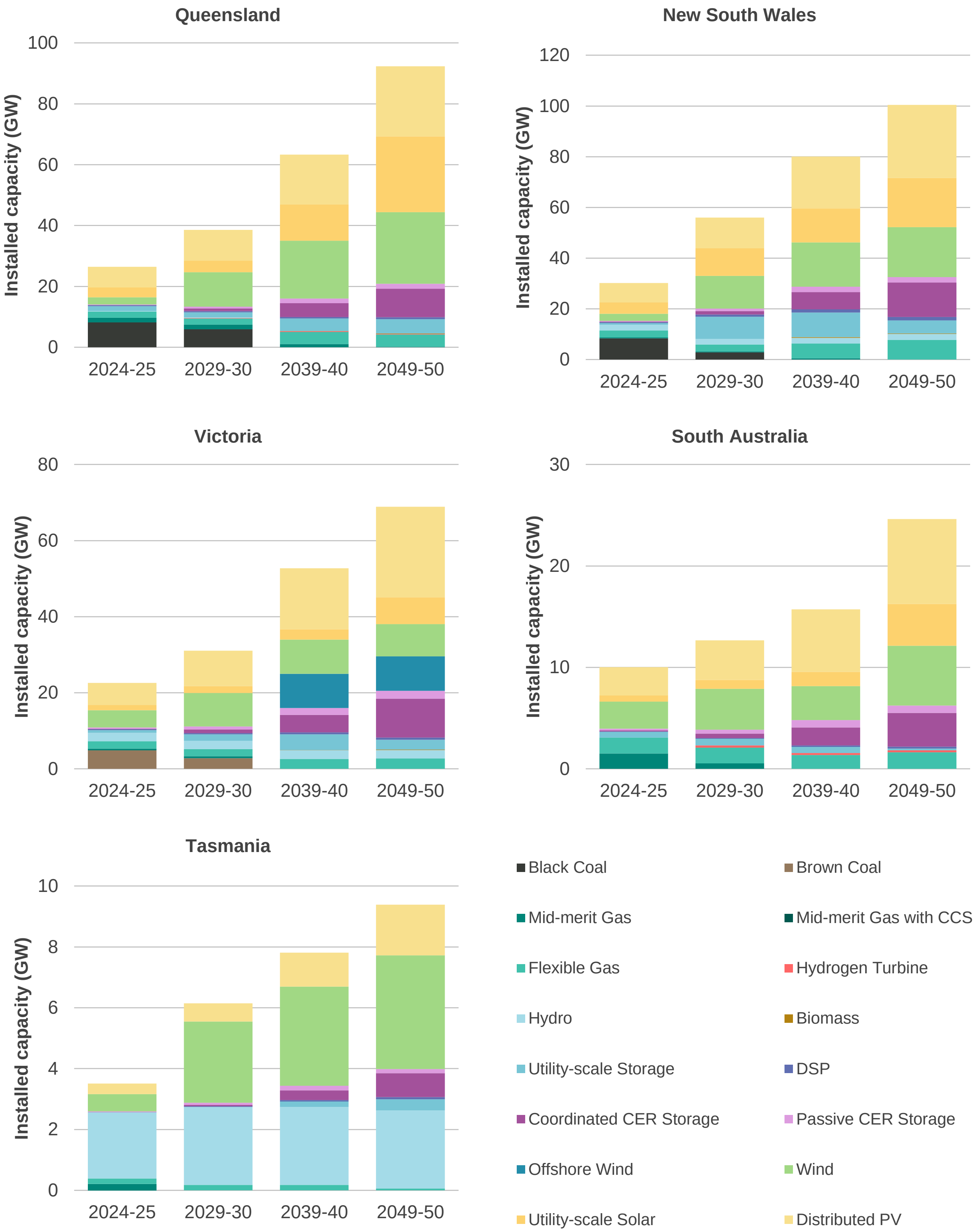


Figure 10 below shows capacity development in *Step Change* at the regional level in the outlook period.

Figure 10 Forecast regional generation capacity for selected years to 2049-50, *Step Change* (GW)



New VRE capacity replaces coal to serve growing demand

Figure 11 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. 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 119 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 to smooth the customer load profile and manage shorter periods of generation availability shortage, particularly if these assets are orchestrated and 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 11 Forecast relative change compared to 2023-24 in installed capacity, *Step Change*, 2024-25 to 2049-50 (GW)

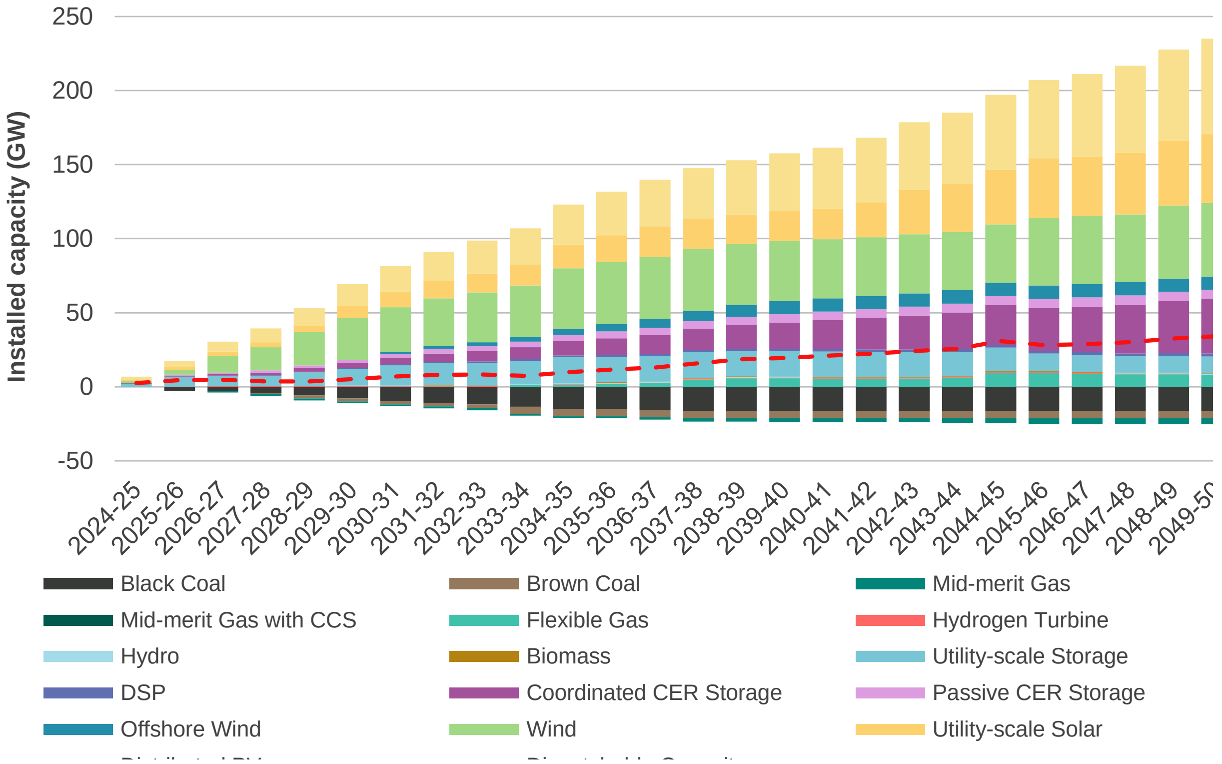
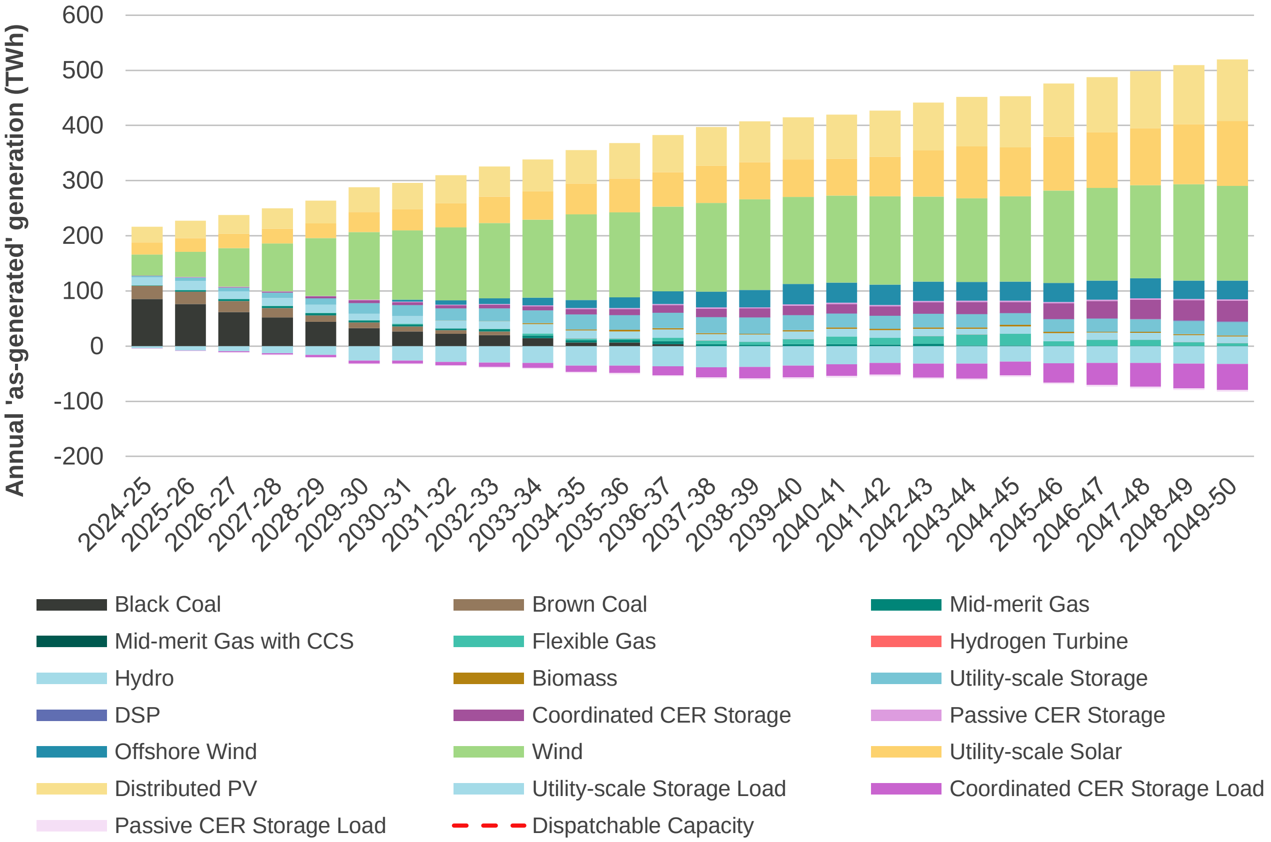


Figure 12 shows the forecast generation mix in *Step Change*. The following are additional insights on the changing capacity mix discussed above:

- As described in Section A4.3 of Appendix 4, it is projected that periods of over 100% VRE potential[12] (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.
- As the power system transitions and as synchronous generation is displaced by inverter-based resources, the provision of essential power system security services will need to evolve – see Appendix 7 for more information.

Figure 12 Forecast annual generation, *Step Change*, 2024-25 to 2049-50 (TWh)



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[12] The share of potential resource that is dispatched depends on a range of market factors including bidding behaviours, maintenance and forced outages.

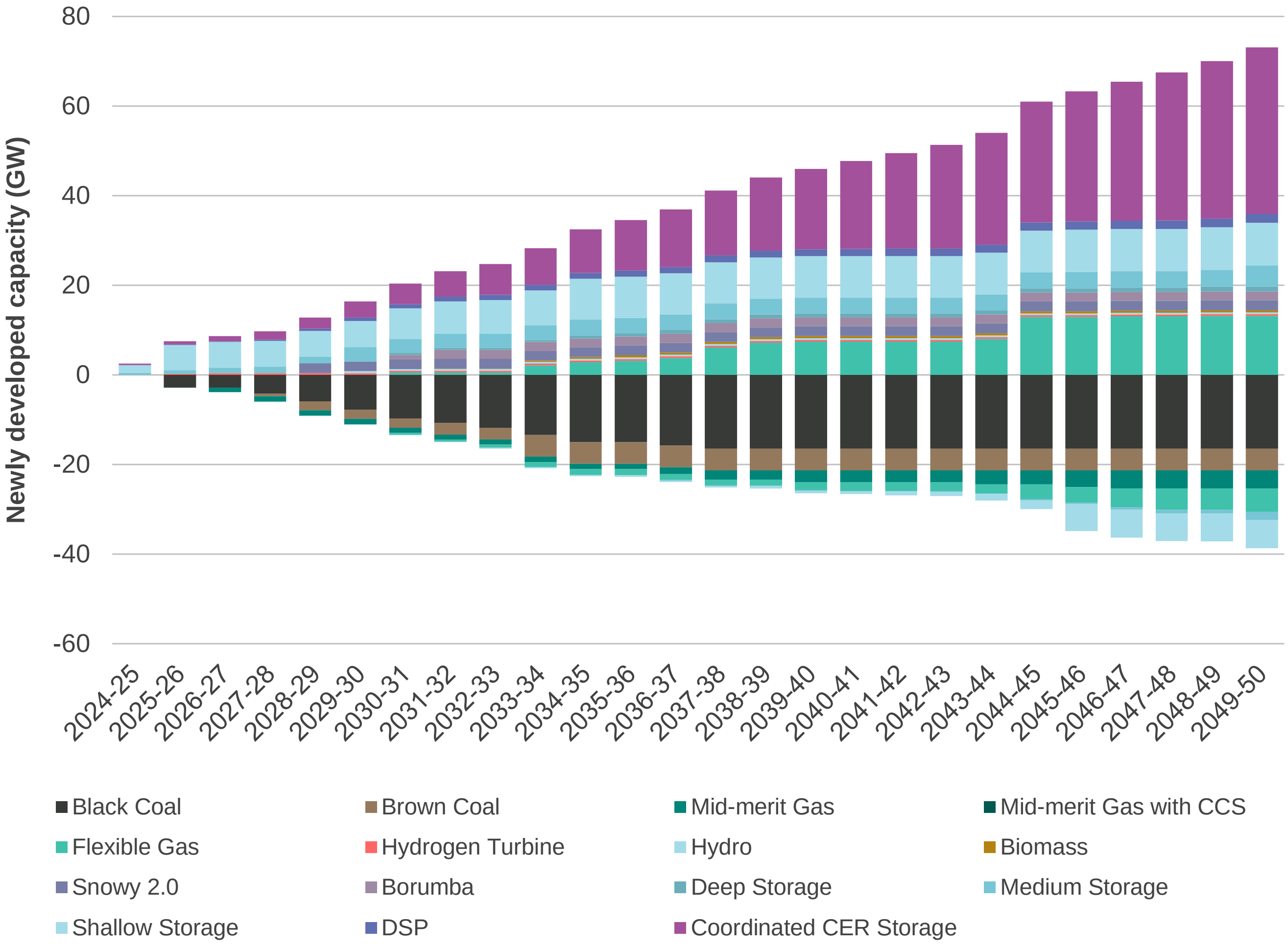
Firming the NEM will require a mixture of technologies and storage durations

The increasing uptake of orchestrated 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 13 GW of flexible gas generation is also developed by 2049-50. This complements existing peaking capacity, supports firming requirements, and provides additional dispatchable capacity to assist in meeting growing peak demand.

Figure 13 shows the forecast development of dispatchable technologies, reinforcing the important role for new flexible gas, as well as storages (shallow and medium depth in particular, to complement the committed and anticipated Snowy 2.0 and Borumba Dam Pumped Hydro).

Figure 13 Forecast relative change compared to 2023-24 in dispatchable capacity, Step Change, 2024-25 to 2049-50 (GW)

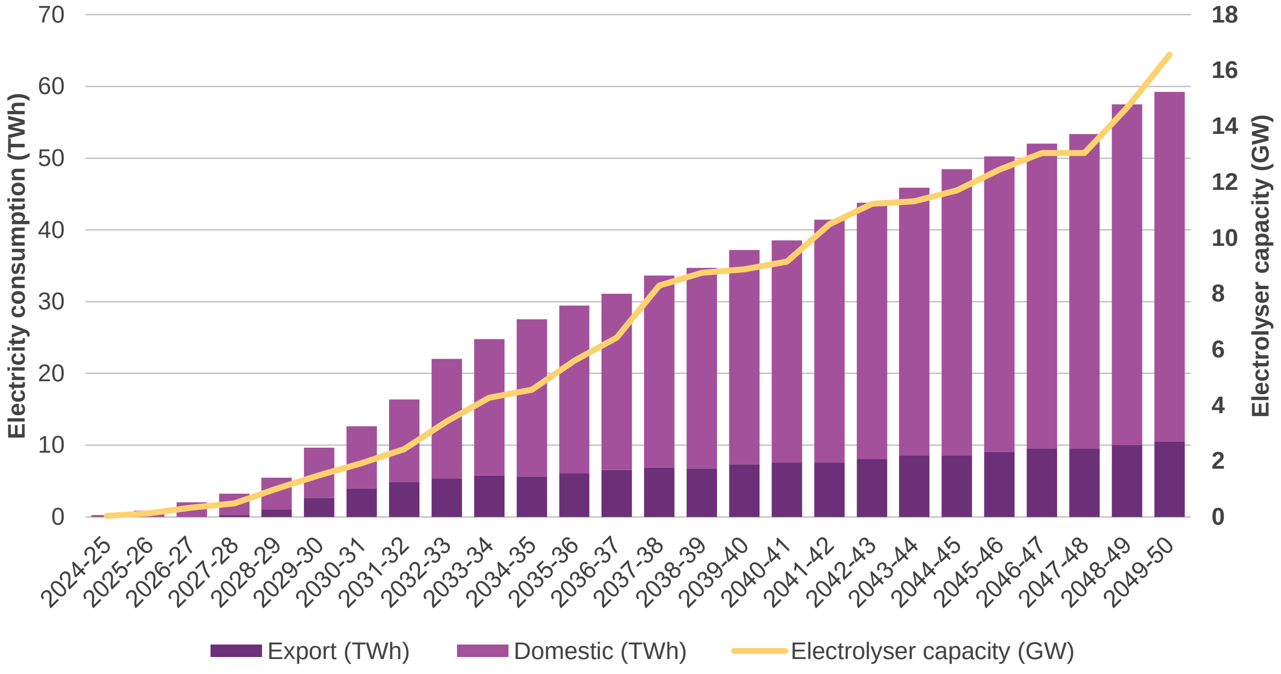


Hydrogen developments

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 14 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, over 15 GW 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 though 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).

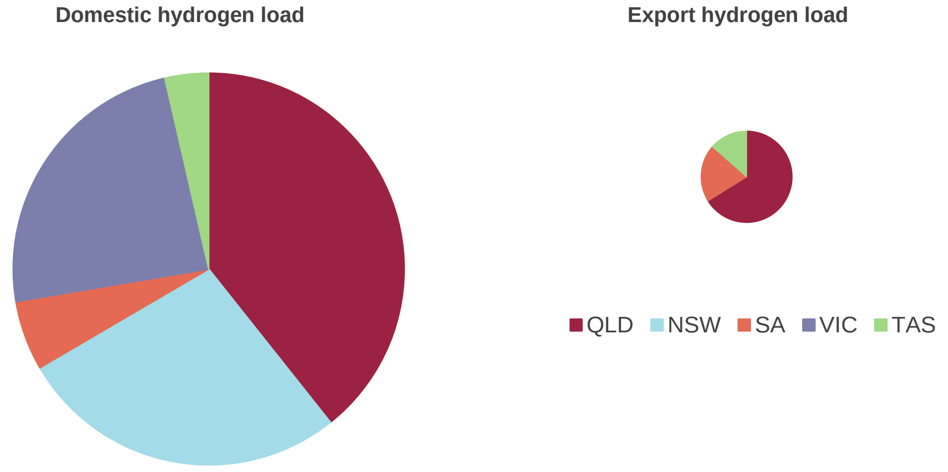
Figure 14 Electricity consumption associated with hydrogen production and ammonia conversion, *Step Change*, 2024-25 to 2049-50 (TWh and GW)



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 15.

Figure 15 Regional allocation of hydrogen developments by 2049-50, *Step Change*



The scale of the circles represents the relative size of the domestic and export load respectively

Future generation mix in *Step Change* without transmission developments

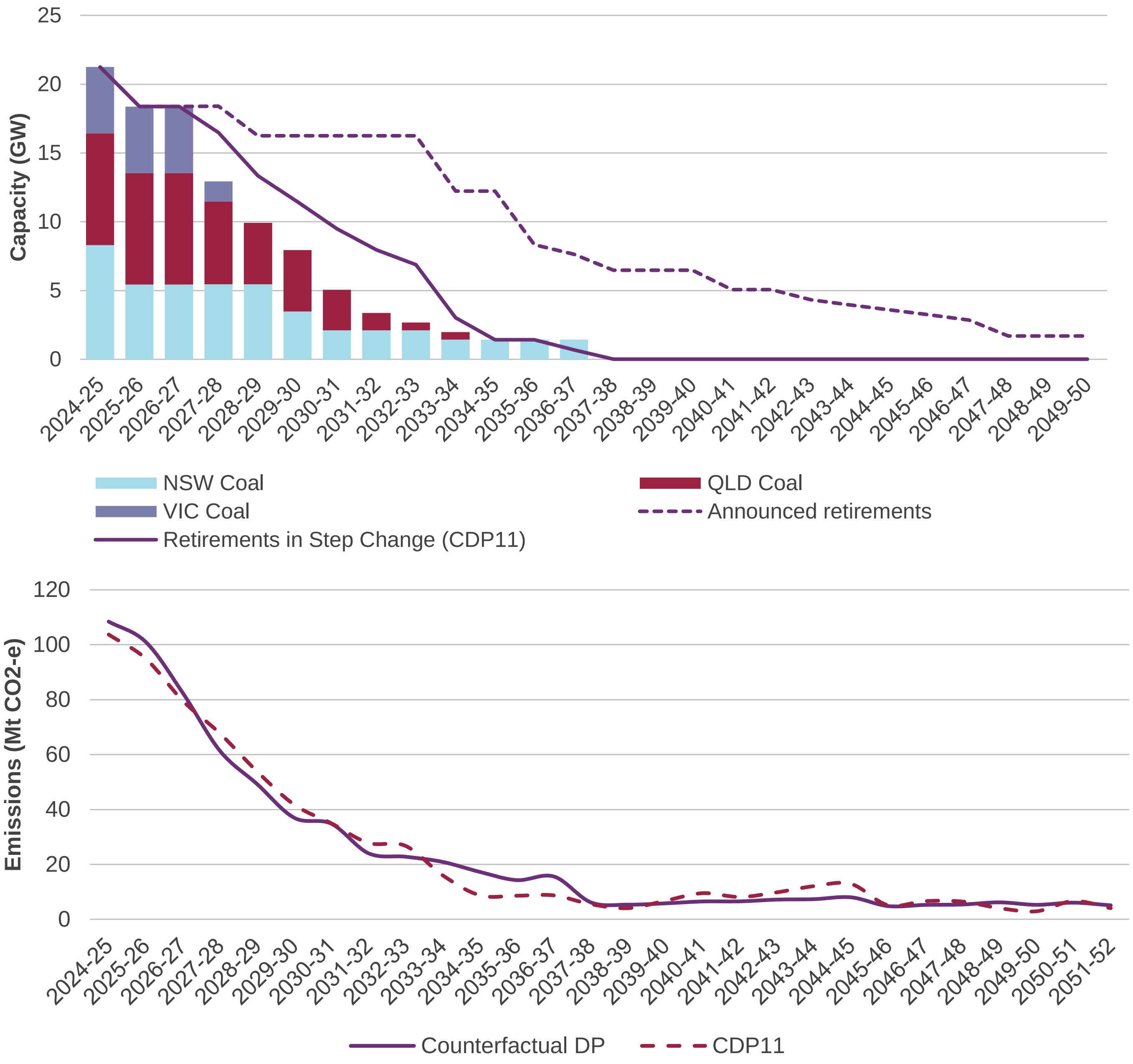
Impact of transmission development on coal retirements

The Draft 2024 ISP identifies material savings to consumers through the expansion of the transmission network (see Section A6.3 of Appendix 6). Transmission investments help to 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.

Figure 16 below shows a comparison between coal retirements in the counterfactual DP which does not expand transmission (bars) and CDP11 (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 CDP11 (the Draft 2024 ISP's ODP).

Figure 16 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. Approximately 5 GW of flexible gas is developed in the early 2030s to service load centres in Victoria, New South Wales, and Queensland. Later in the outlook period, 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 17 shows the evolution of this generation mix in *Step Change's* counterfactual DP.

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

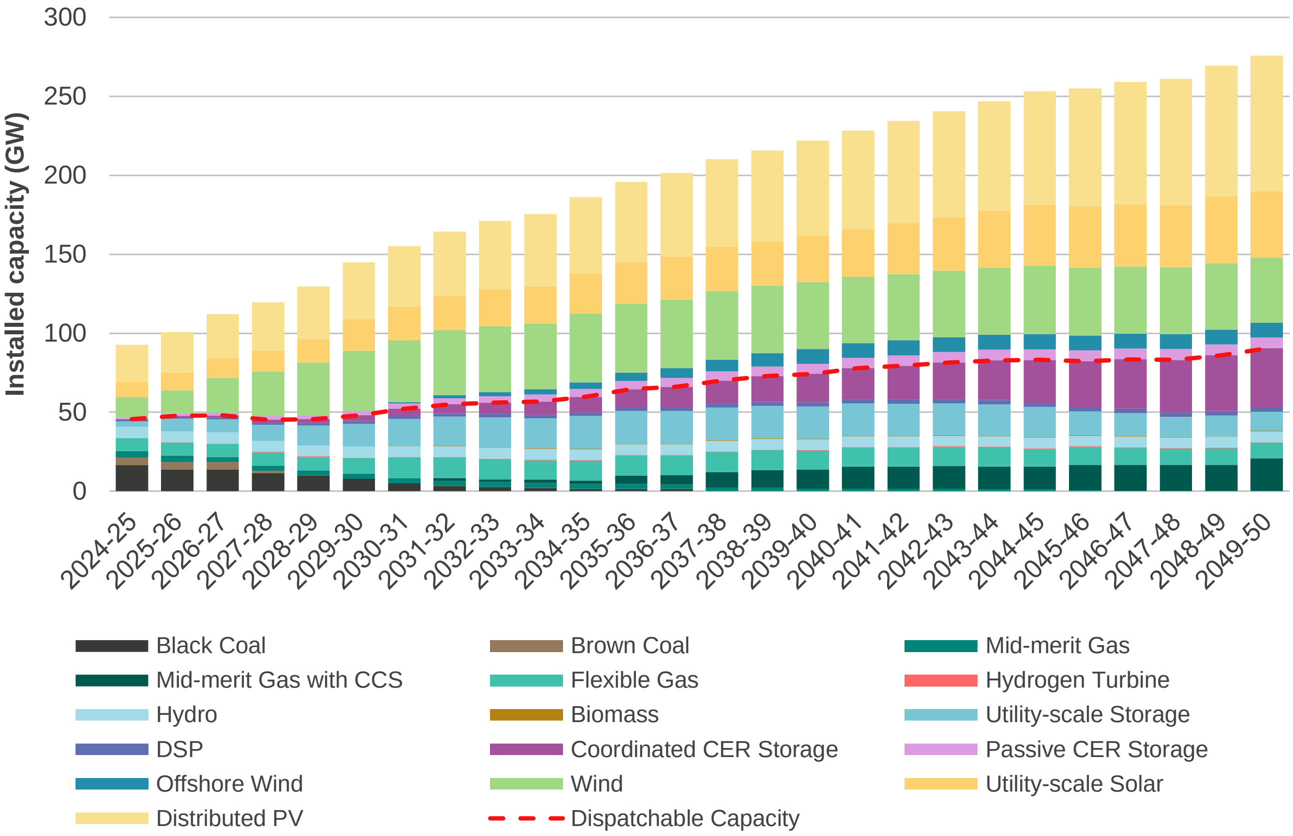
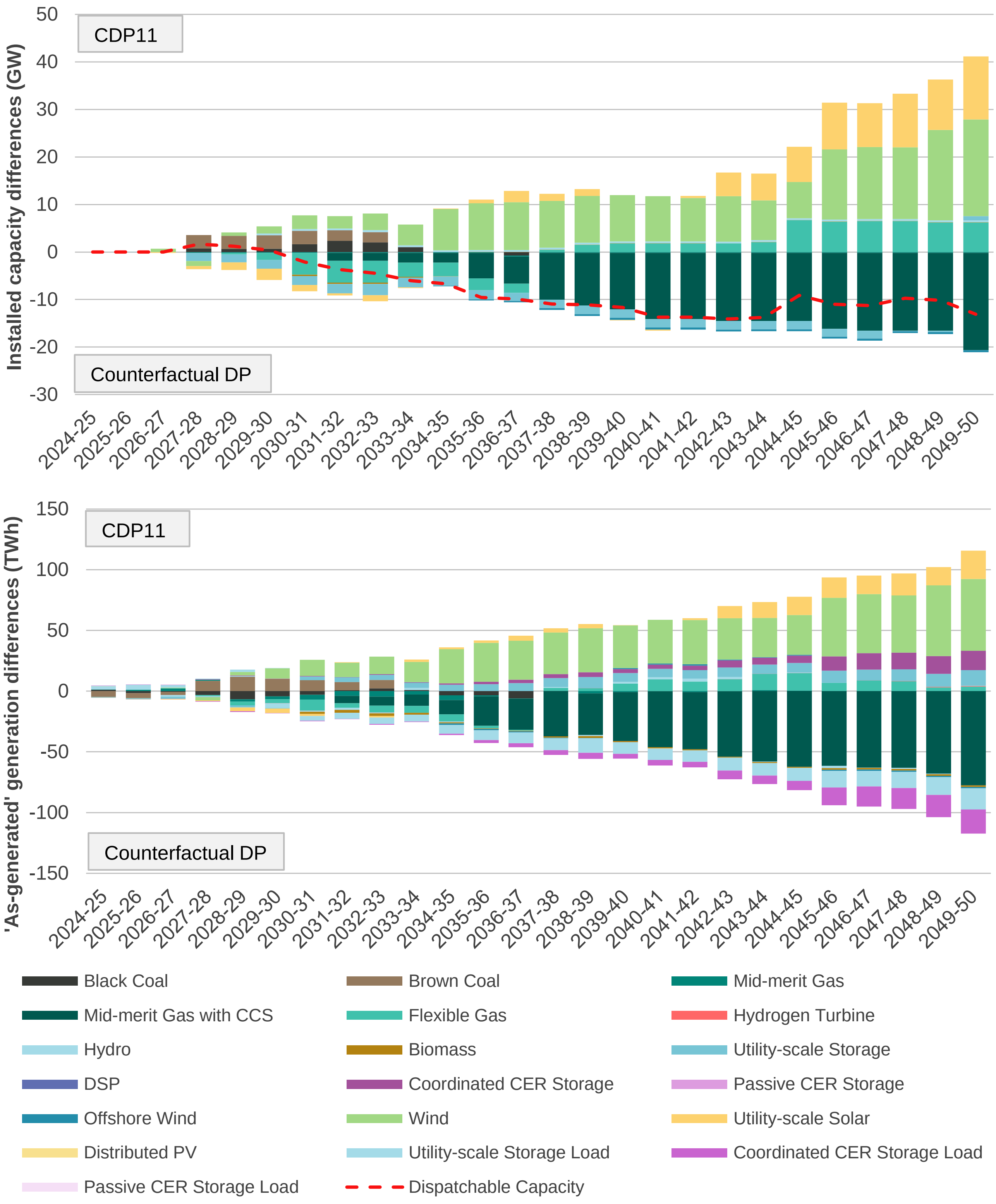


Figure 18 below shows the differences in capacity and generation developments in *Step Change* between CDP11 and the counterfactual DP. A positive value indicates higher total installed capacity in the CDP11.

Figure 18 Forecast capacity developments (top) and generation (bottom) to 2049-50 under counterfactual DP compared to *Step Change* (GW and TWh)



A2.3.2 *Progressive Change*

The *Progressive Change* scenario 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*.

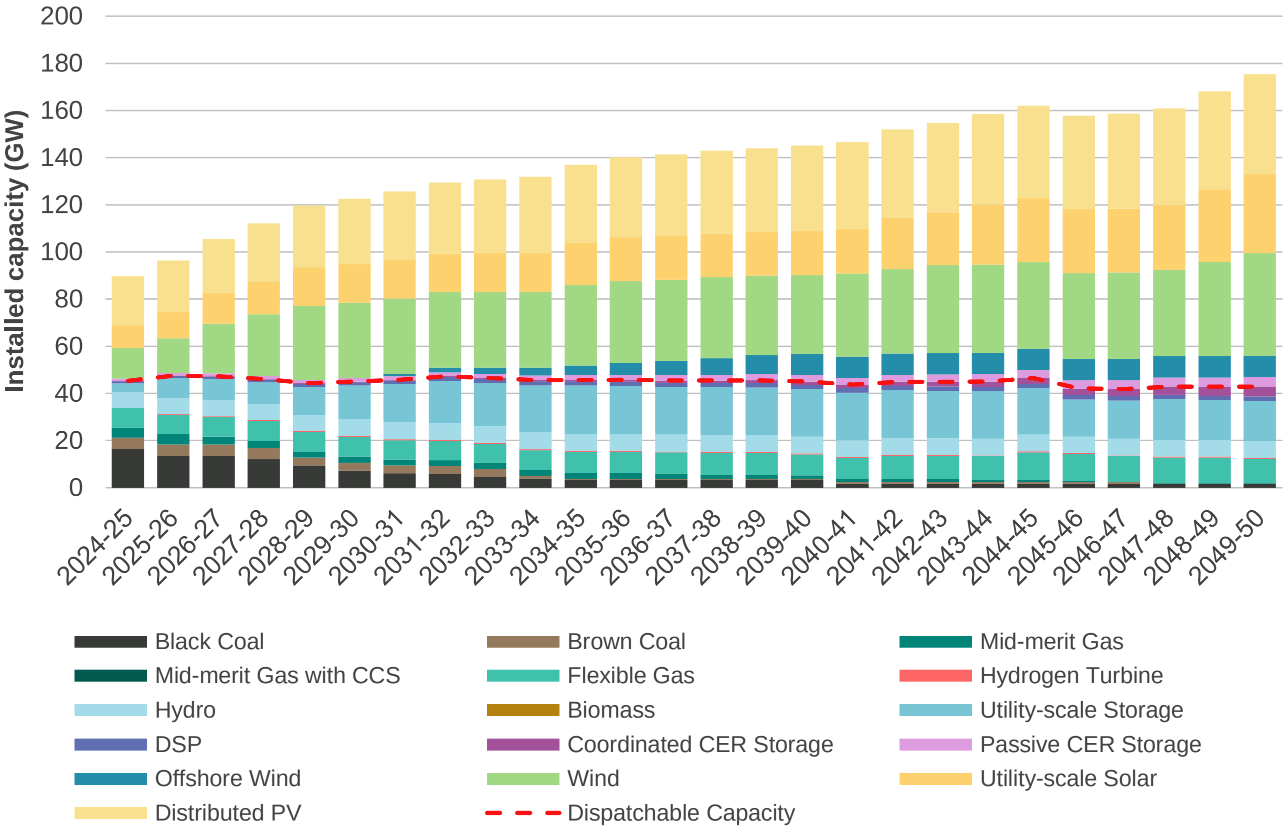
In this scenario, transformational energy sector investments to meet policy objectives continue but economic and international factors place industrial loads at greater risk, and lesser consumer investments are anticipated.

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

Generation and storage development in *Progressive Change*

Figure 19 presents the forecast capacity mix for the NEM across the outlook period to 2049-50.

Figure 19 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.

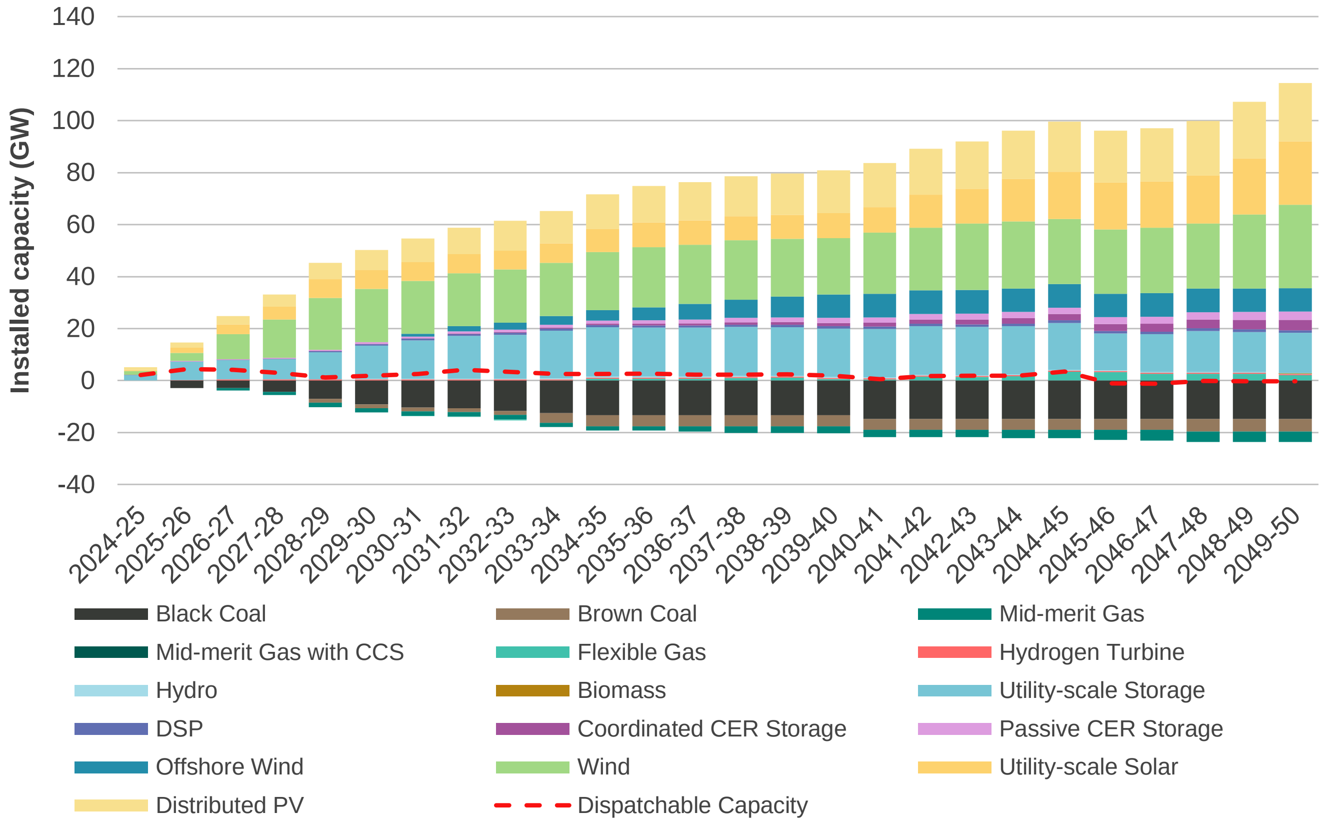
  - Coal-fired capacity is forecast to reduce more slowly than in *Step Change* but is still forecast to approximately halve from current levels as new renewable energy developments and additional energy storage increase.
- By 2049-50:
  - Less than 2 GW of coal capacity is forecast to be operational as a result of achieving the scenario's carbon budgets. For the economy to be net zero with some retained coal capacity, other solutions such 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 20 shows the cumulative change in investment and withdrawal by technology type forecast over the outlook period. Key highlights include:

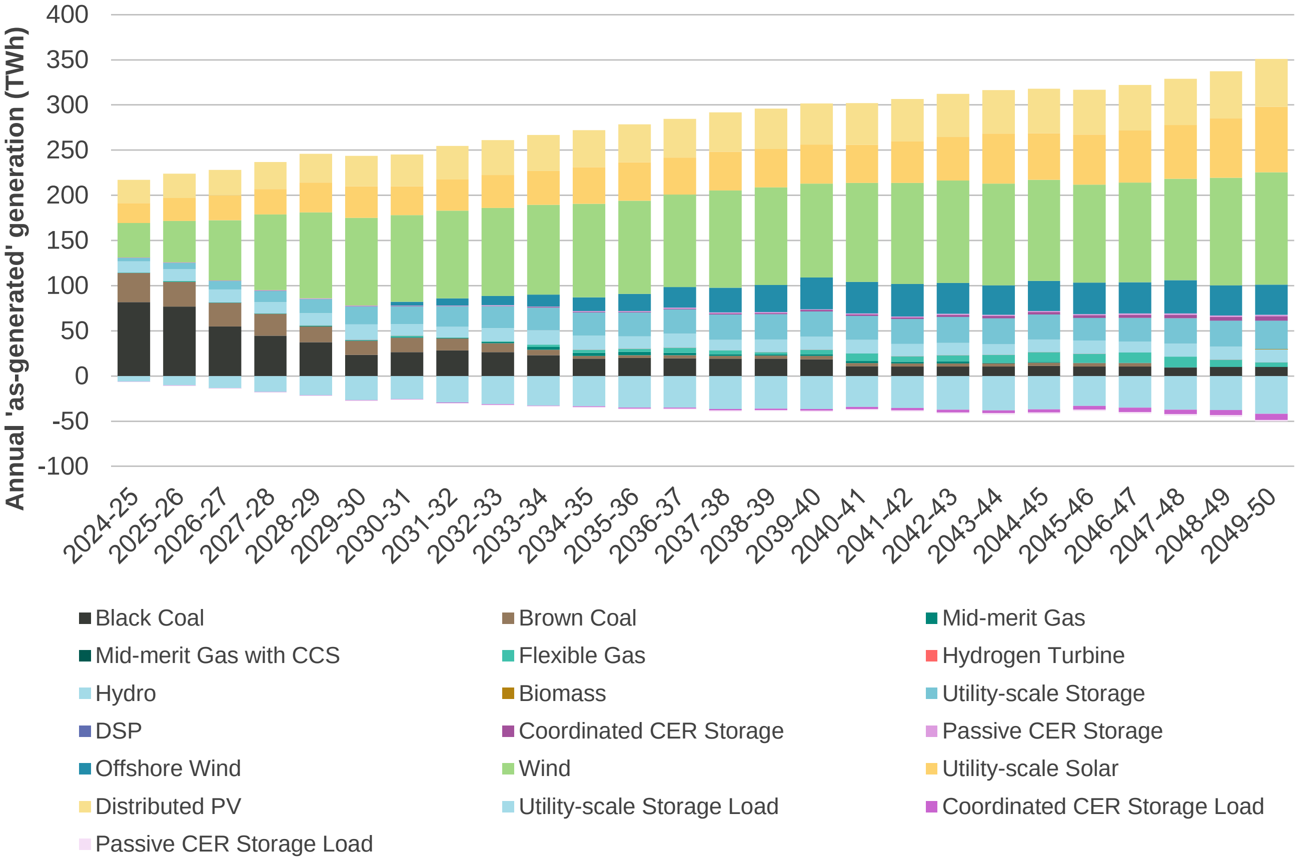
- Coal retirements are forecast to be replaced by a combination of VRE, utility-scale storage and CER. Retiring gas-powered generators are generally replaced by new flexible gas developments to provide firming support.
- By 2049-50, in addition to over 40 GW of distributed PV, the NEM is forecast to need over 70 GW of new utility-scale VRE to replace existing capacity and to meet increasing energy consumption. This is complemented by 15 GW of new utility-scale energy storage in addition to CER storages.

Figure 20 Forecast relative change compared to 2023-24 in installed capacity, *Progressive Change*, 2024-25 to 2049-50 (GW)



In terms of energy production, Figure 21 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 56% wind, 26% utility-scale solar and the remainder from distributed PV.

Figure 21 Forecast annual generation, *Progressive Change*, 2024-25 to 2049-50 (TWh)

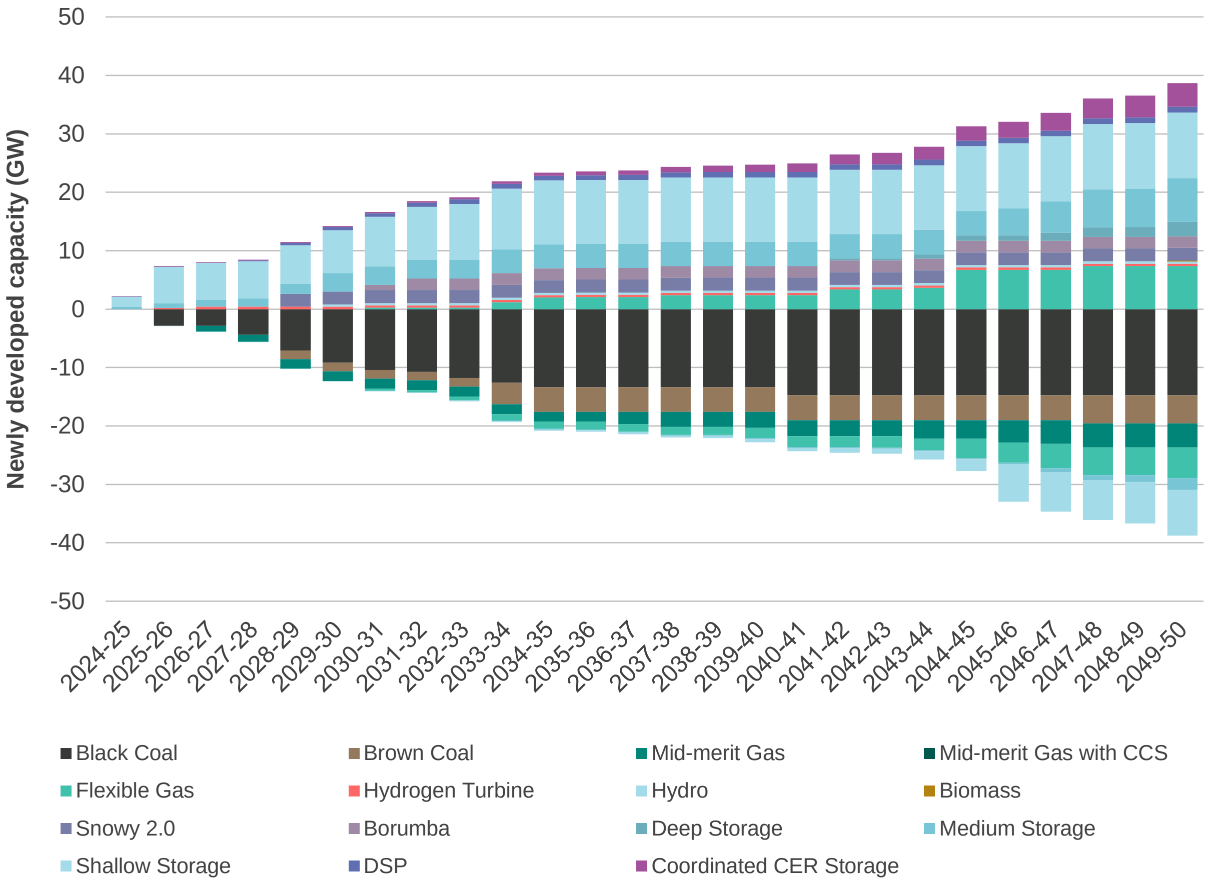


Firming the NEM will require a mixture of technologies and storage durations

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

Figure 22 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 22 Forecast relative change compared to 2023-24 in dispatchable capacity, *Progressive Change*, 2024-25 to 2049-50 (GW)



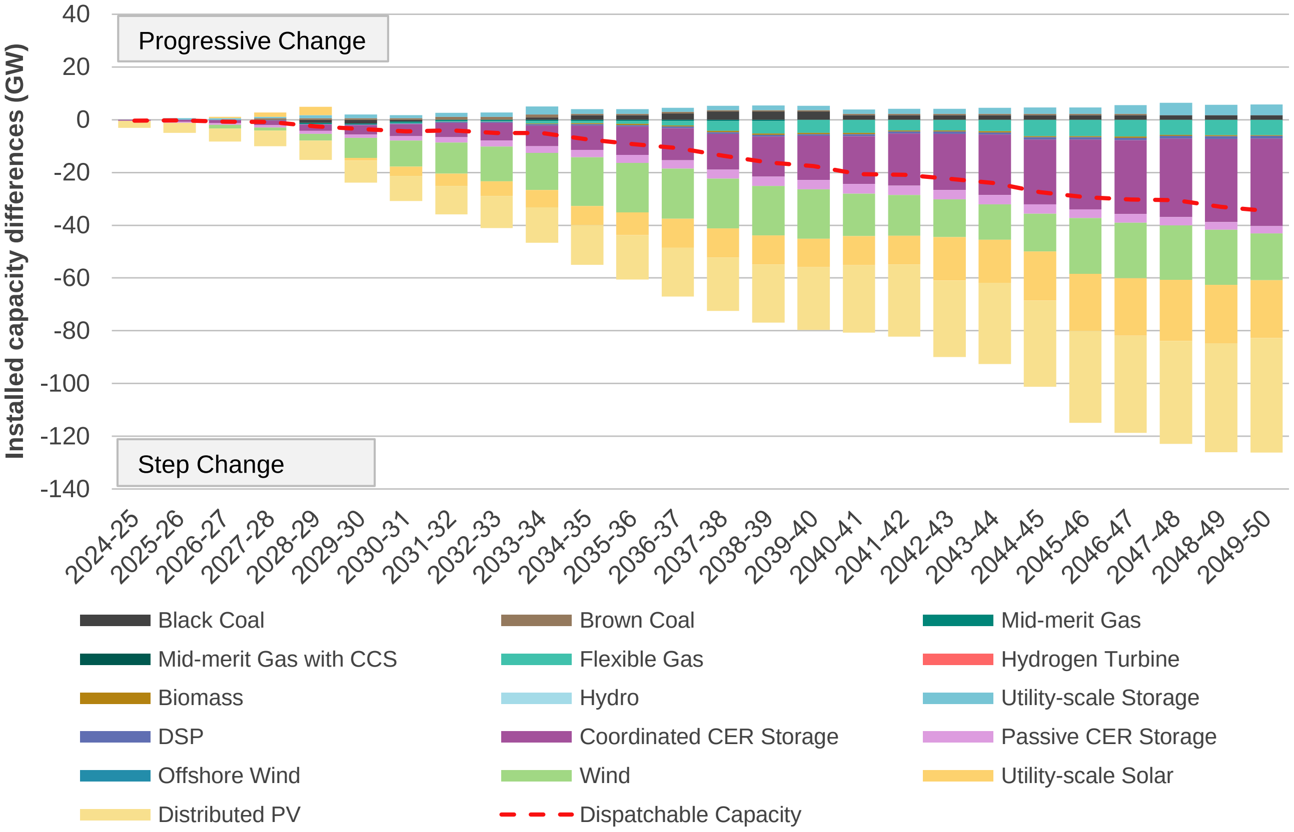
Contrasting *Progressive Change* with *Step Change*

Figure 23 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 orchestrated 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 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 lesser orchestration of the 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 23 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 CDP11. Figure 24 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 gas-powered generation 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 24 Forecast coal retirements (top) and emissions trajectory (bottom) to 2049-50, *Progressive Change* counterfactual DP (GW and Mt CO_2-e)

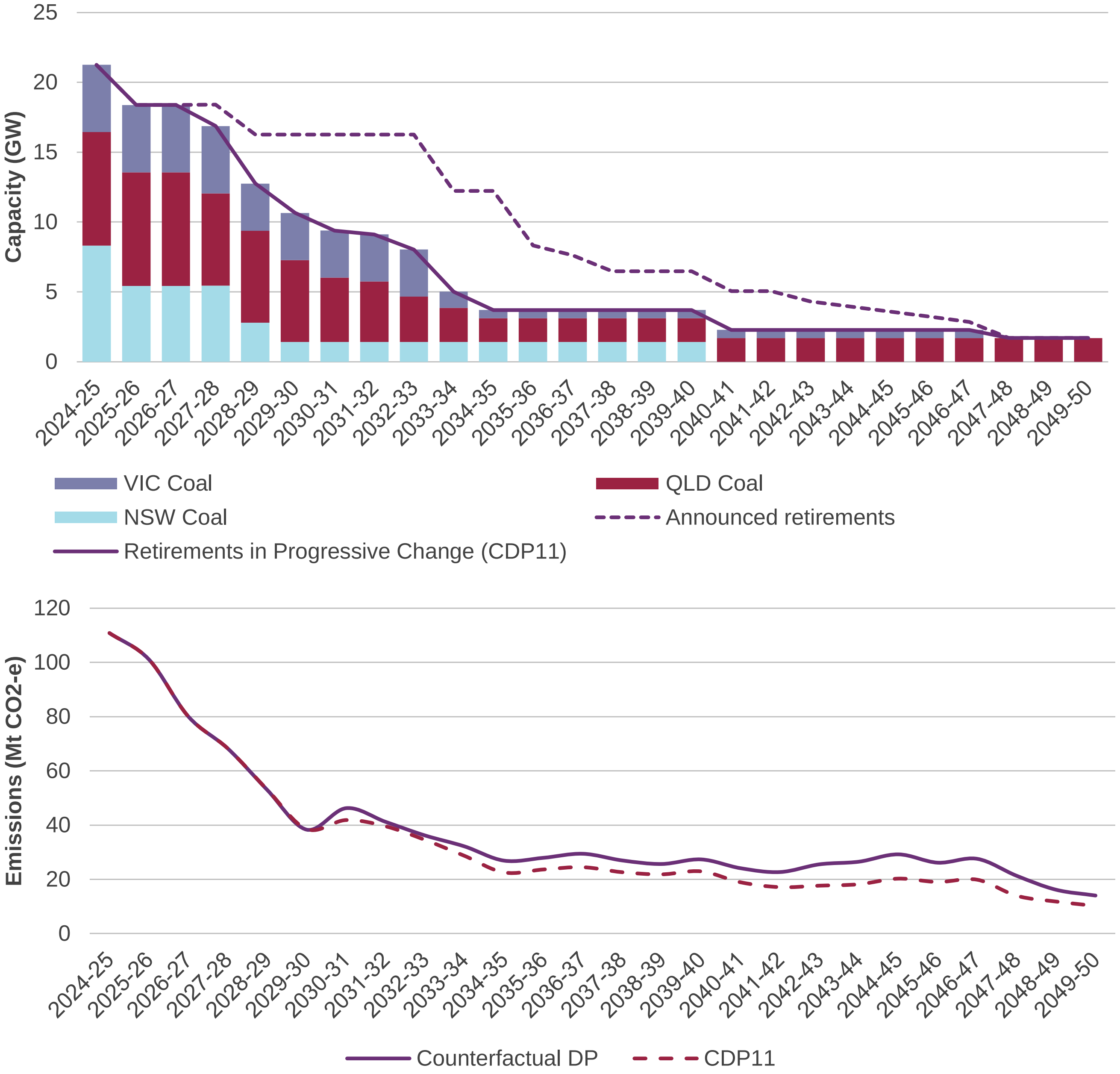
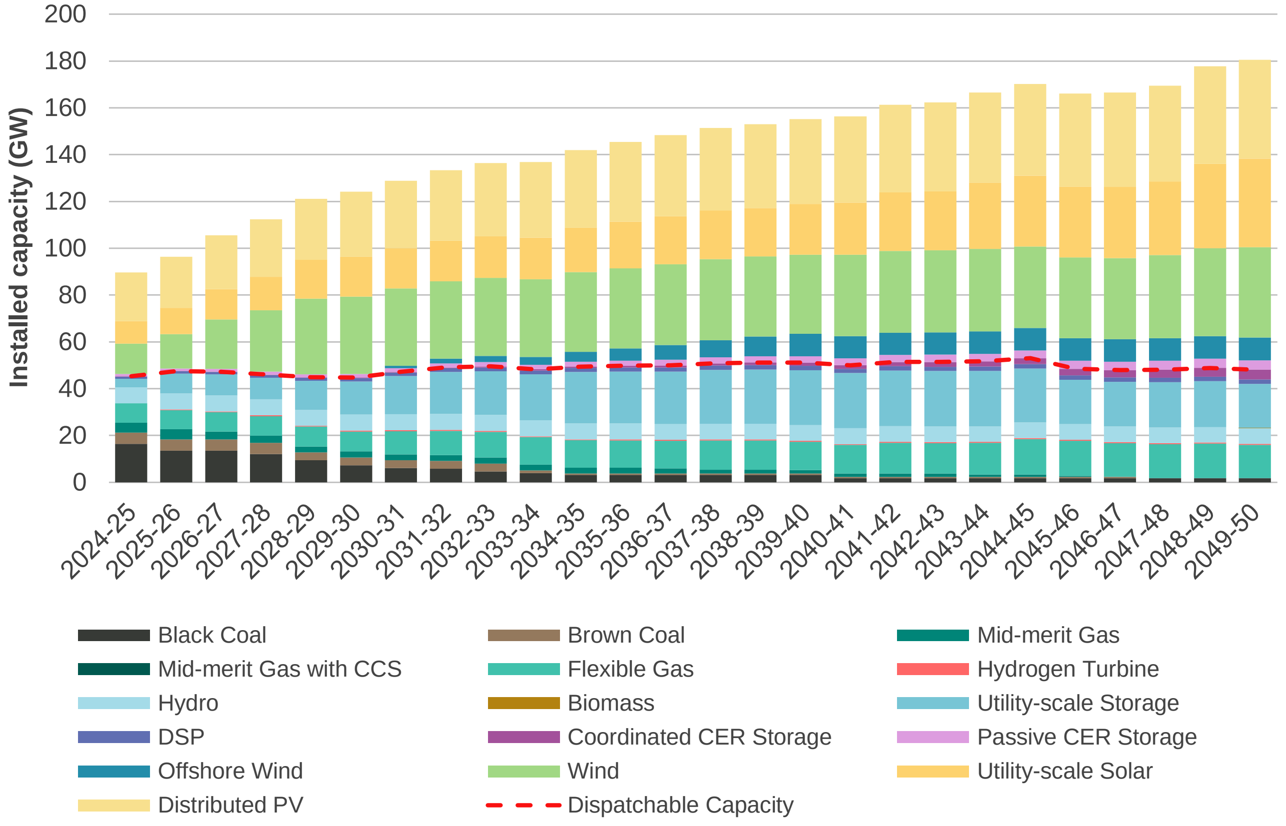


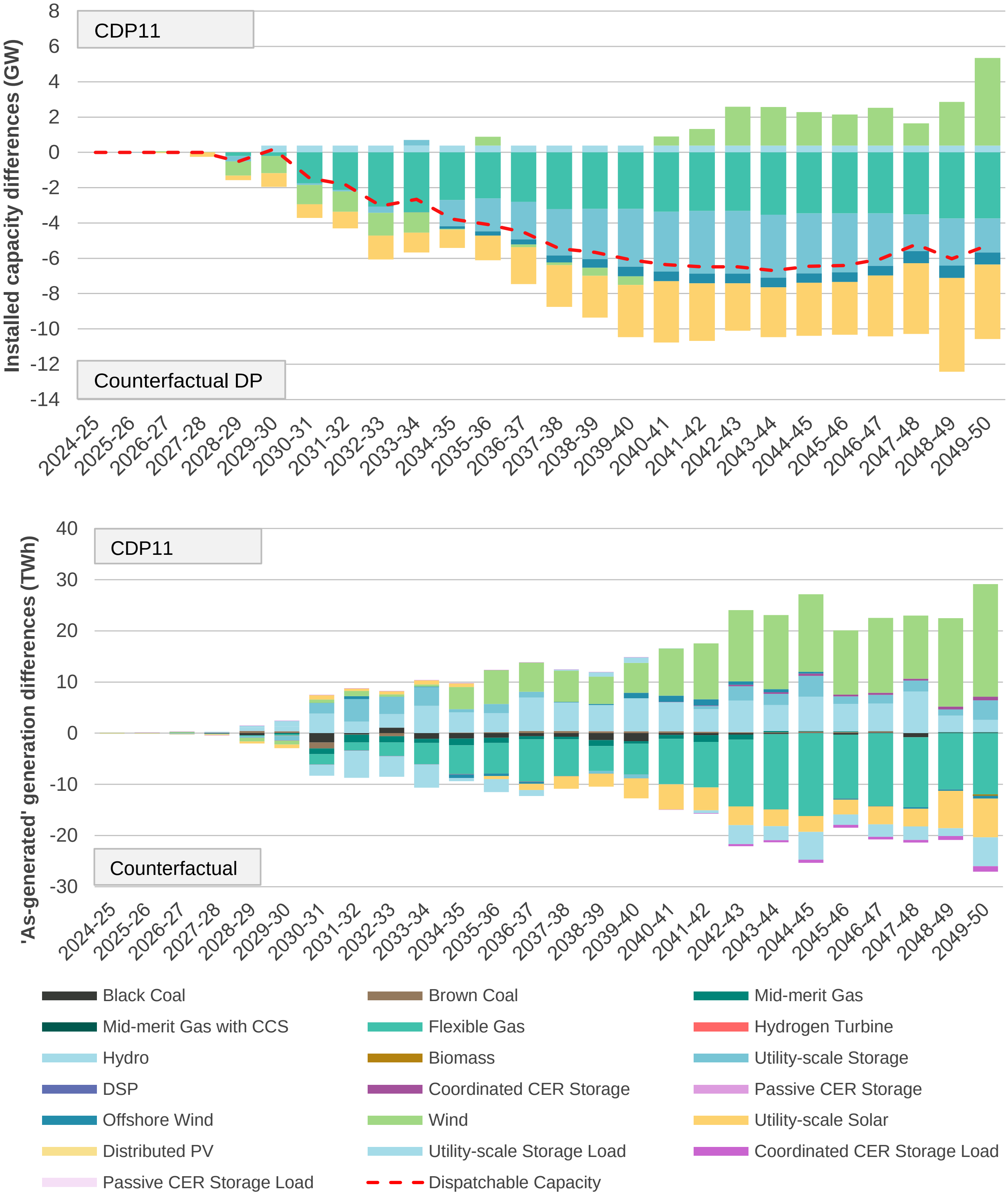
Figure 25 below shows that the counterfactual DP incorporates slightly higher development of VRE until 2029-30 as the lack of transmission development forces development in locations with lower resource quality. From the early 2030s, gas-powered generation and storage play an increasing role in meeting 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 25 Forecast NEM installed capacity, *Progressive Change* counterfactual DP, 2024-25 to 2049-50 (GW)



For comparison, Figure 26 presents the difference in installed capacity and dispatched generation between CDP11 and the counterfactual DP, demonstrating a greater role for gas and storage.

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



A2.3.3 *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.

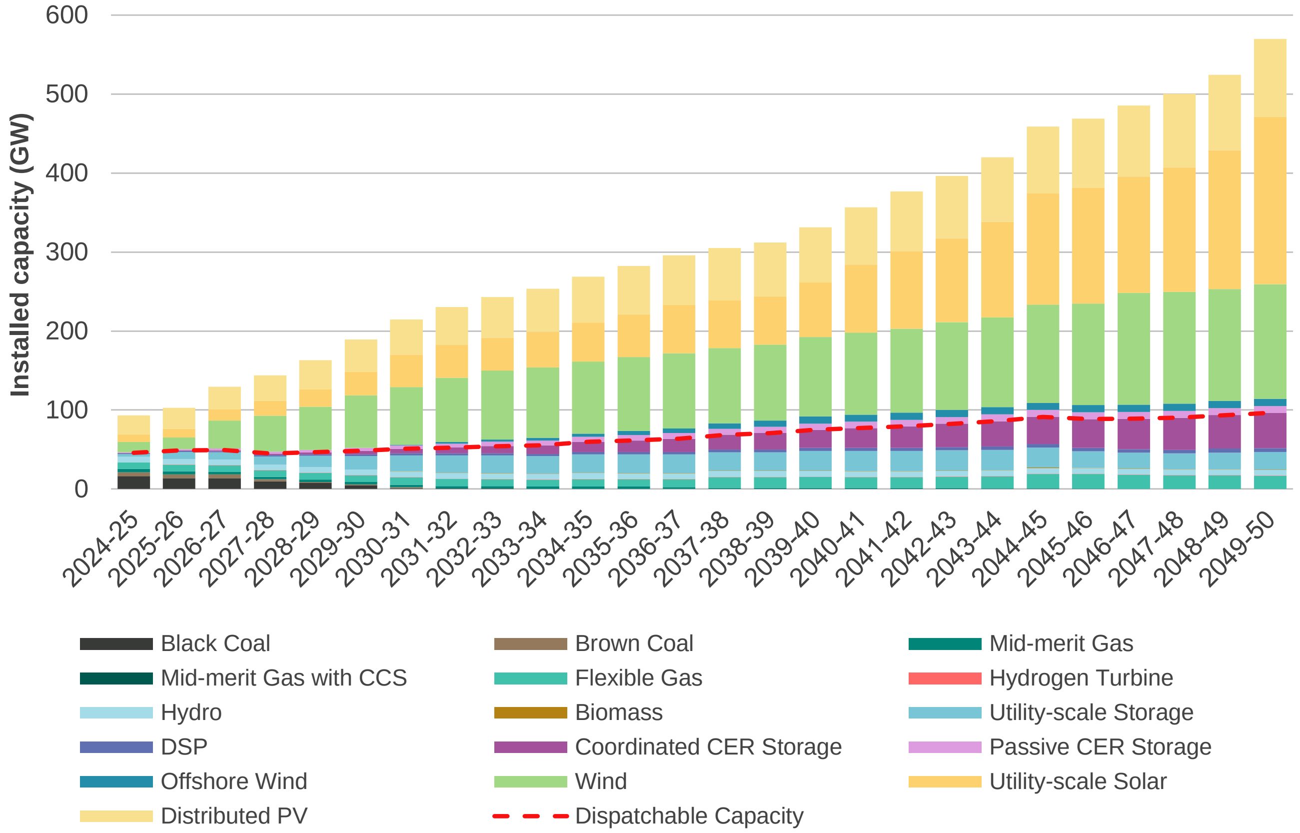
Generation and storage development in *Green Energy Exports*

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

- 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 360 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 27 illustrates the scale of generation development under this scenario.

Figure 27 Forecast NEM installed capacity, *Green Energy Exports*, 2024-25 to 2049-50 (GW)



VRE development accelerates due to significantly higher consumption forecast.

Figure 28 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 gas-powered generators 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 350 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 over 30 GW of new utility-scale energy storage and around 13 GW of new flexible gas, in addition to CER storage.

Figure 29 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 43% wind, 44% utility-scale solar and 13% distributed PV.

Figure 28 Forecast relative change compared to 2023-24 in installed capacity, *Green Energy Exports*, 2024-25 to 2049-50 (GW)

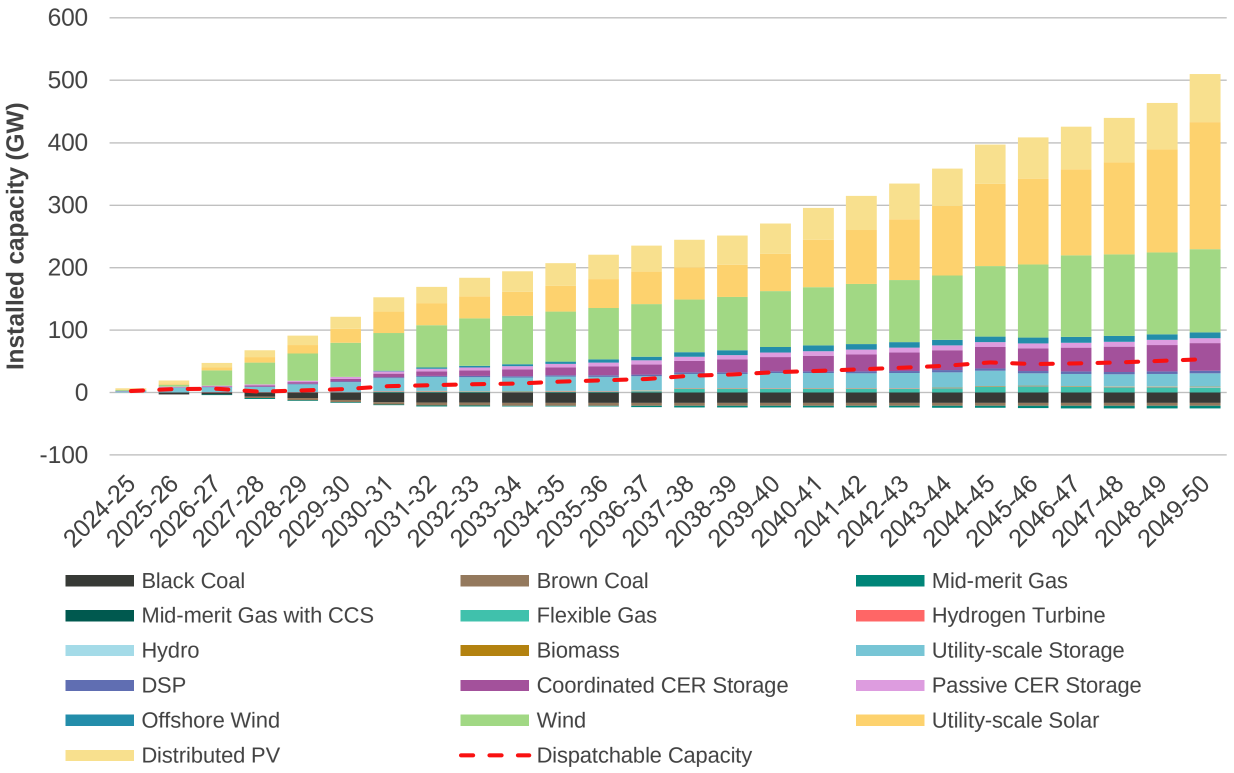
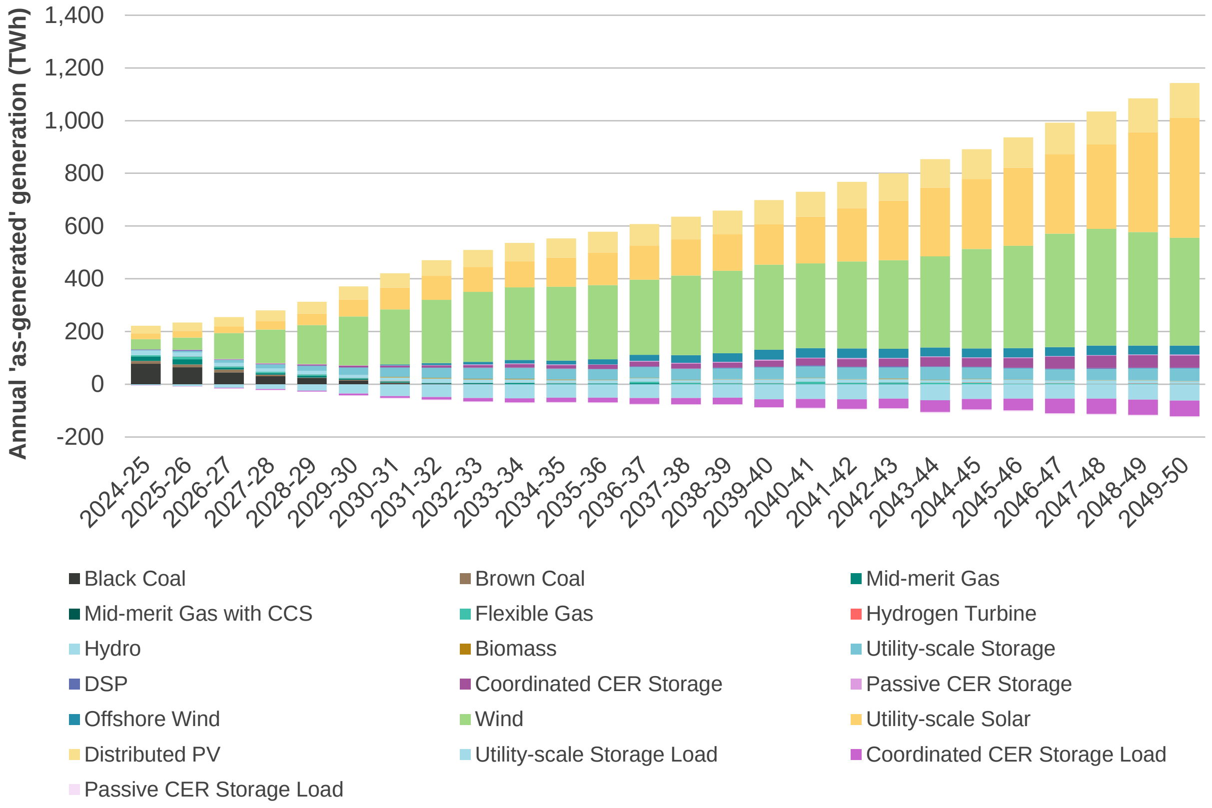


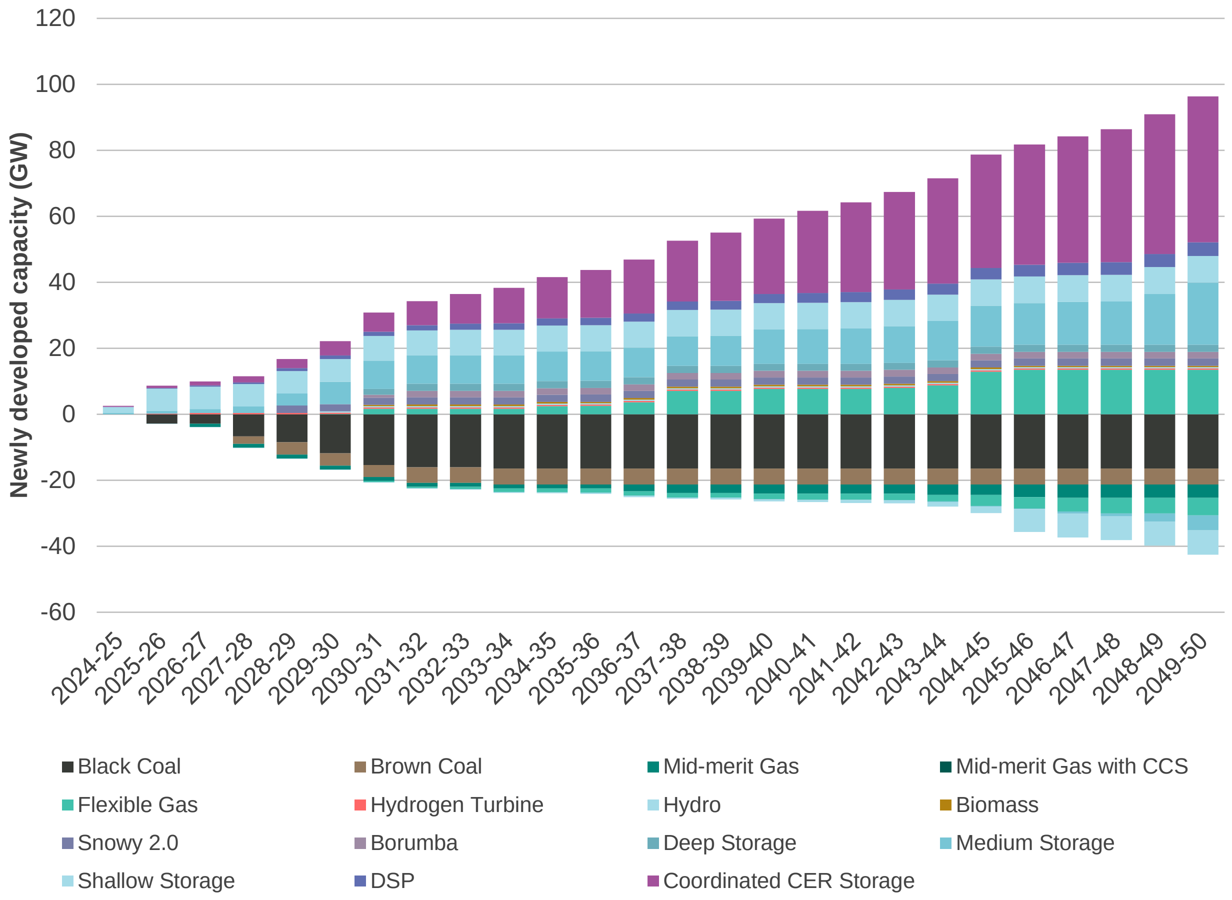
Figure 29 Forecast annual generation, *Green Energy Exports*, 2024-25 to 2049-50 (TWh)



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

Figure 30 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 and deep utility-scale storages to firm the additional renewable energy developments. Gas generator retirements are generally replaced by new flexible gas-powered generation. With significant electrolyser developments, the scenario features a material capacity of potentially flexible load.

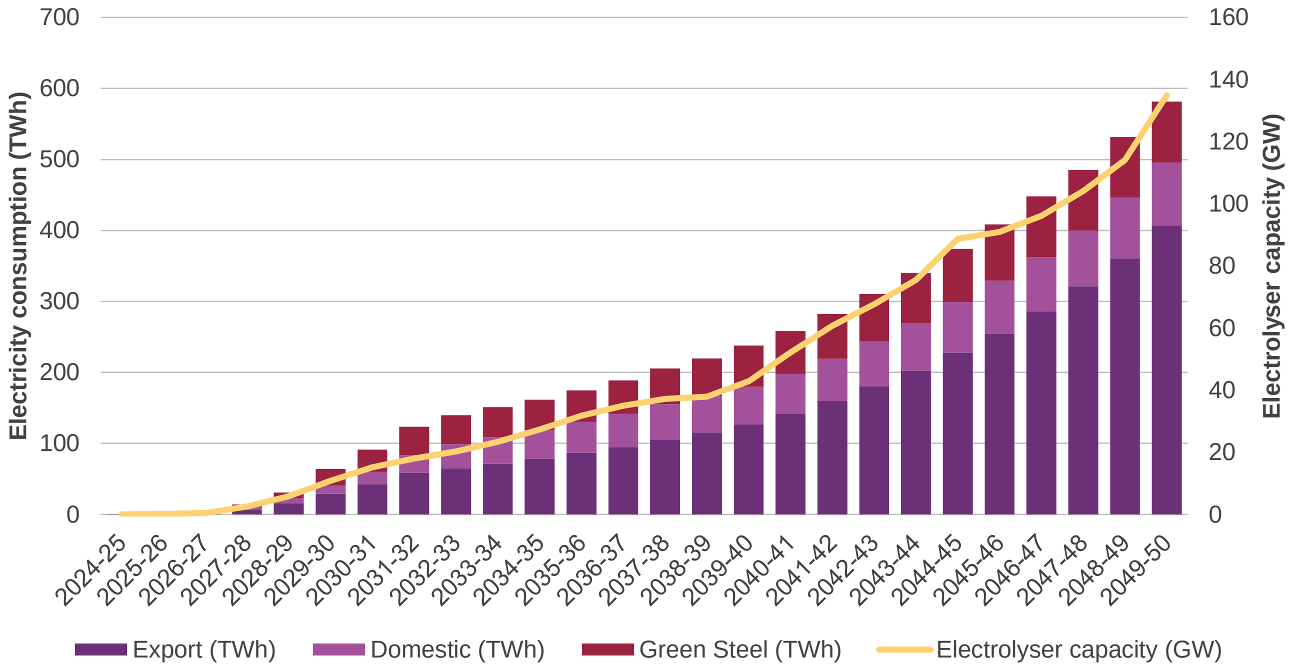
Figure 30 Forecast relative change compared to 2023-24 in dispatchable capacity, *Green Energy Exports*, 2024-25 to 2049-50 (GW)



Hydrogen developments

Green Energy Exports is characterised by significant forecast hydrogen production. Figure 31 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 31 **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 135 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%).

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 (78%), followed by Tasmania (12%) and South Australia (8%) (see Figure 32).

While hydrogen production may potentially provide a flexible operational profile, additional firm supply is still needed. Approximately 13 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[13]. 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. Figure 33 shows an example electrolyser consumption profile for a facility in Queensland, demonstrating that if operated with appropriate flexibility, with a load factor of between 40-60%, then it can generally follow the average generation profile of solar in Queensland, with wind generation used to fill any overnight or daytime gaps.

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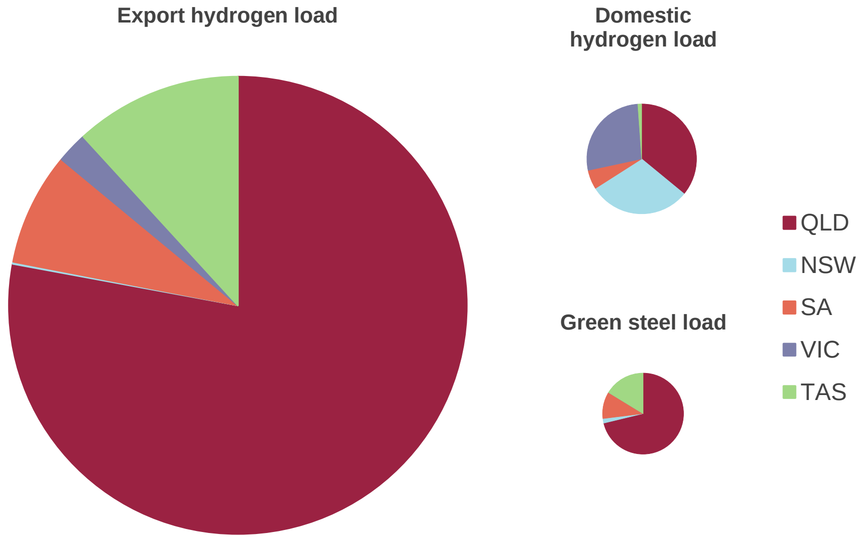
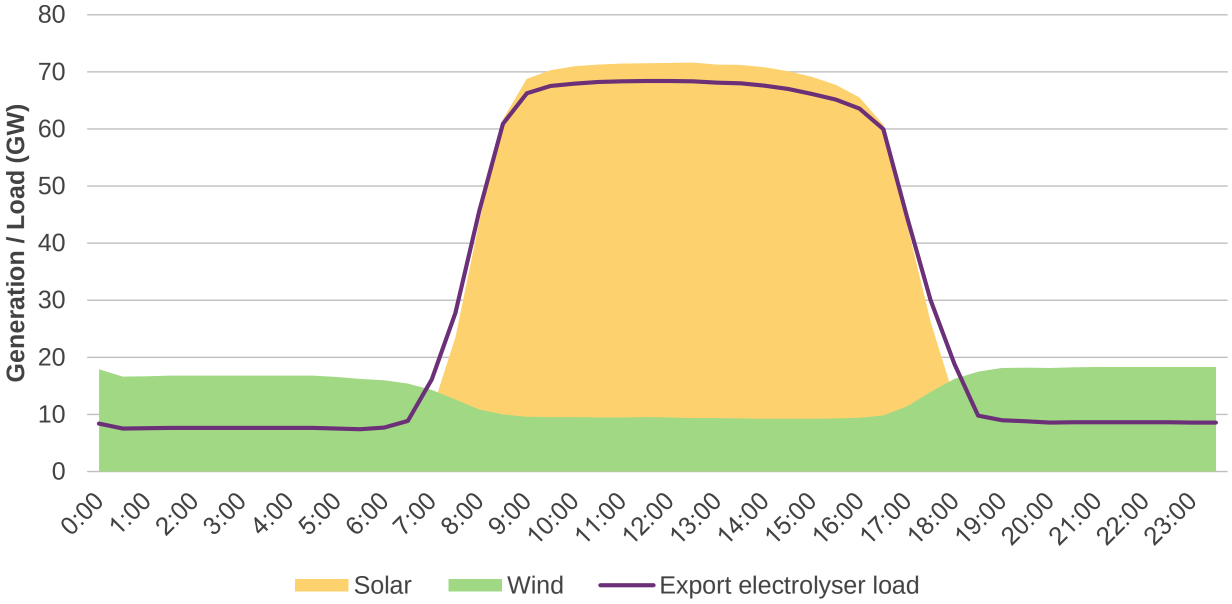
[13] The degree to which these loads can operate flexibly to avoid the need for significant additional firm electricity supplies will remain an uncertainty until the technologies mature.

Figure 32 Regional allocation of hydrogen developments by 2049-50, *Green Energy Exports*



The scale of the circles represents the relative size of the domestic, export and green steel load

Figure 33 Average annual diurnal consumption profile of export electrolyser in North Queensland in 2049-50, *Green Energy Exports* (GW)



Contrasting *Green Energy Exports* with *Step Change*

Figure 34 below presents the capacity difference between the results 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, gas-powered generation and storage make up a slightly lower proportion of the total capacity mix in *Green Energy Exports*, due to the flexibility of the majority of the load associated with hydrogen demand.

Figure 34 Forecast capacity development to 2049-50 under *Green Energy Exports* compared to *Step Change* (GW)

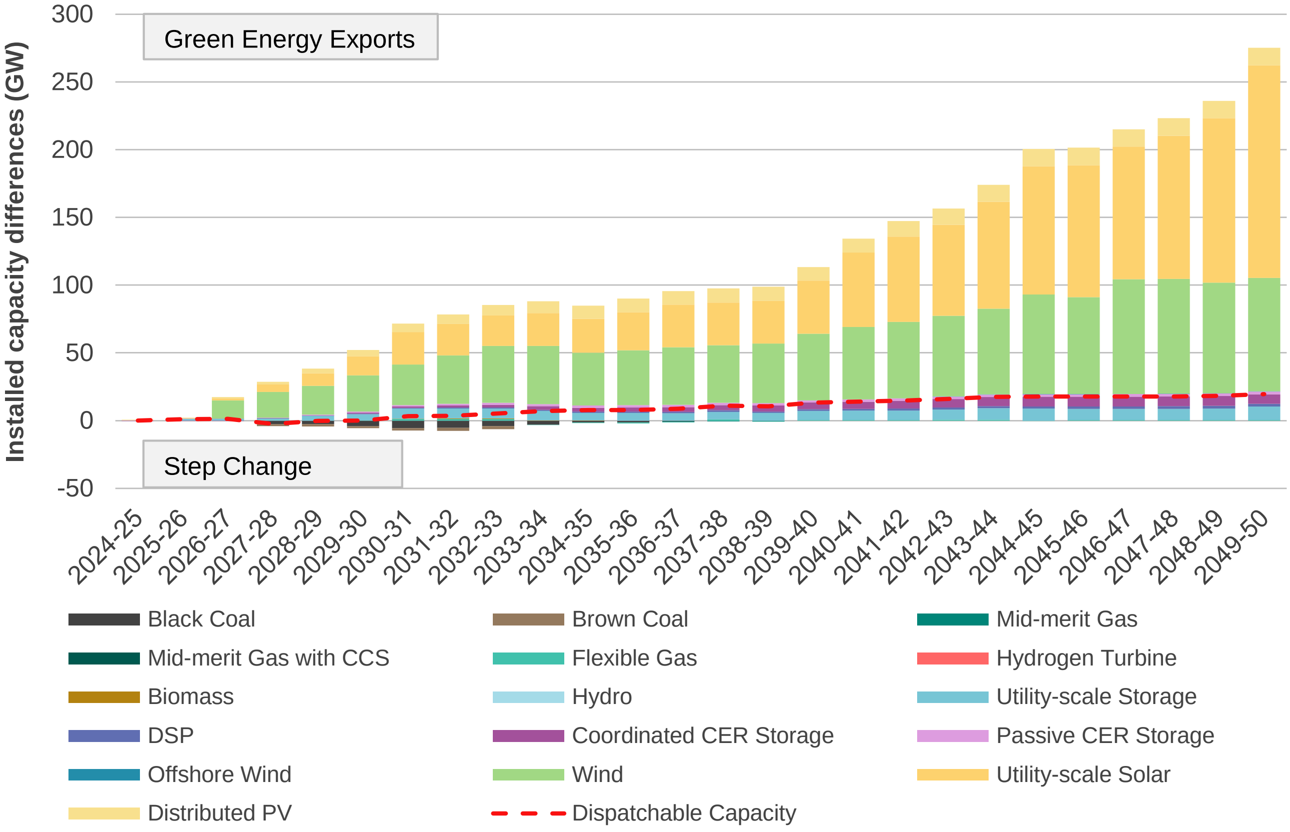
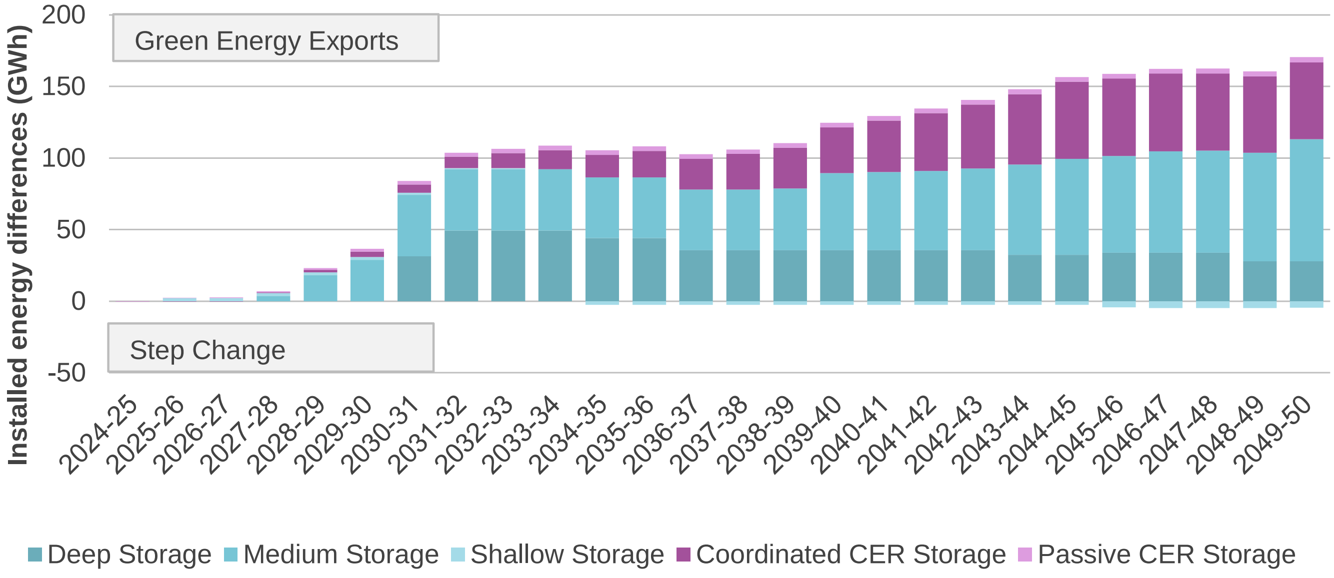


Figure 35 shows energy storge development in *Green Energy Exports* compared to *Step Change*.

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



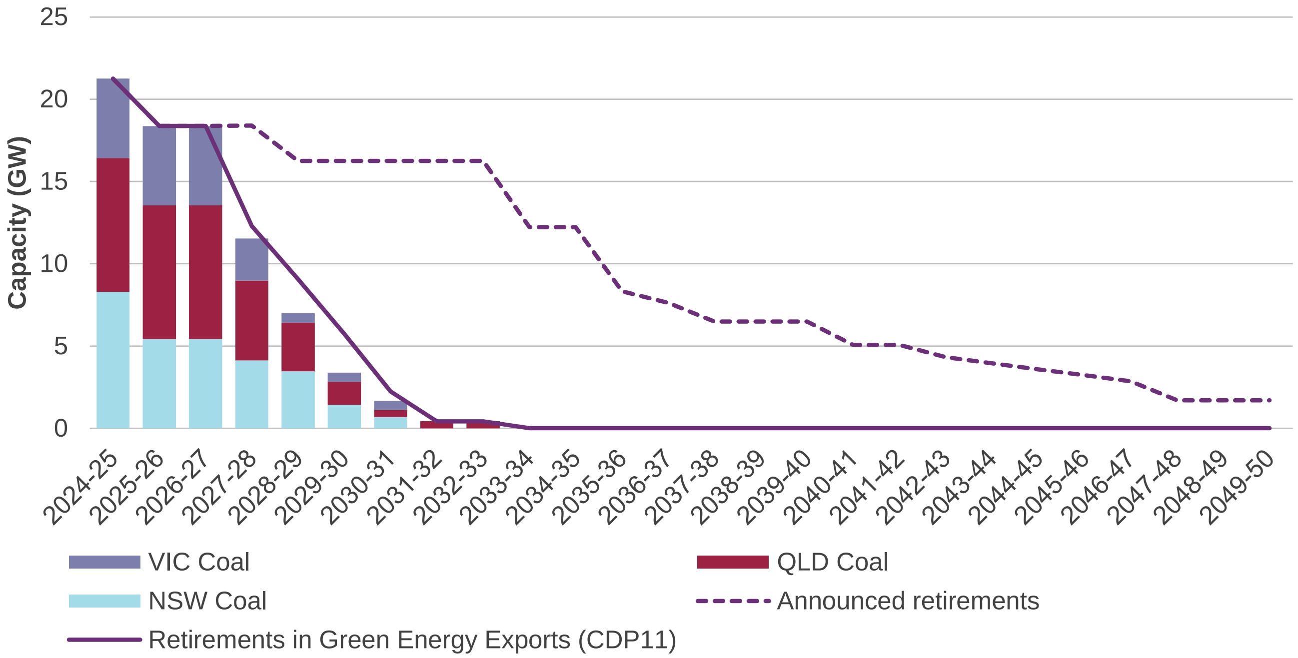
Future generation mix in *Green Energy Exports* without transmission developments

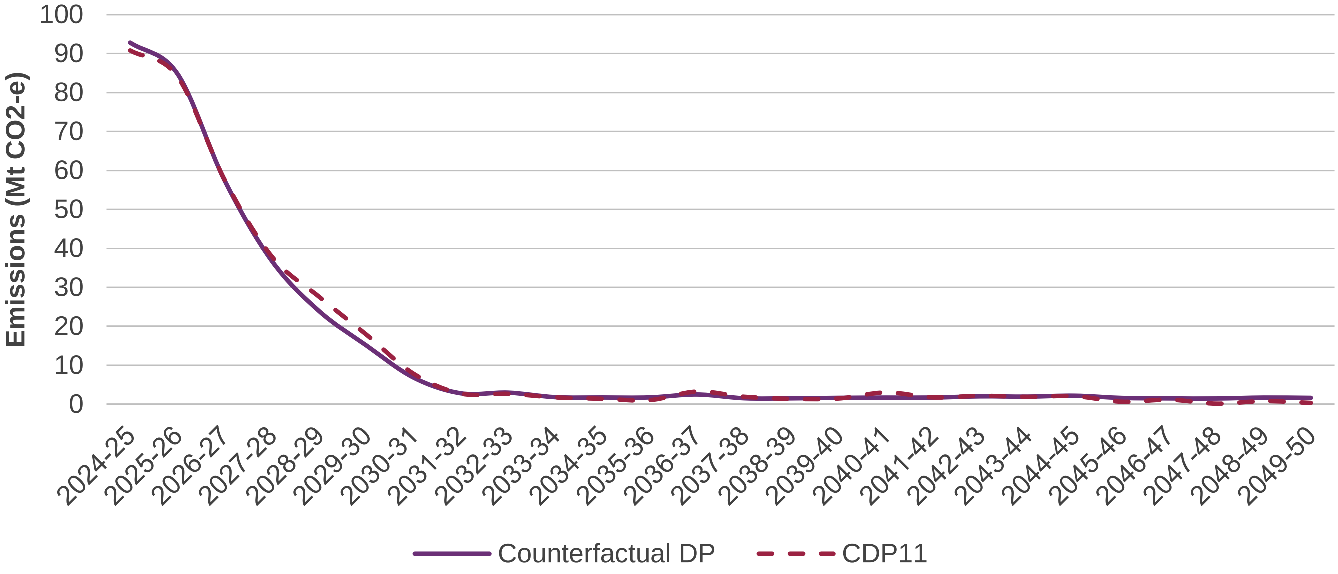
Impact of transmission development on coal retirements

As a result of the emissions budgets, coal is retired earlier in the counterfactual DP than in CDP11. 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 36 below contrasts the coal retirement schedule forecast under *Green Energy Exports* with, and without, transmission augmentation.

Figure 36 **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 port 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 37.

Figure 37 Forecast NEM installed capacity, *Green Energy Exports* counterfactual DP, 2024-25 to 2049-50 (GW)

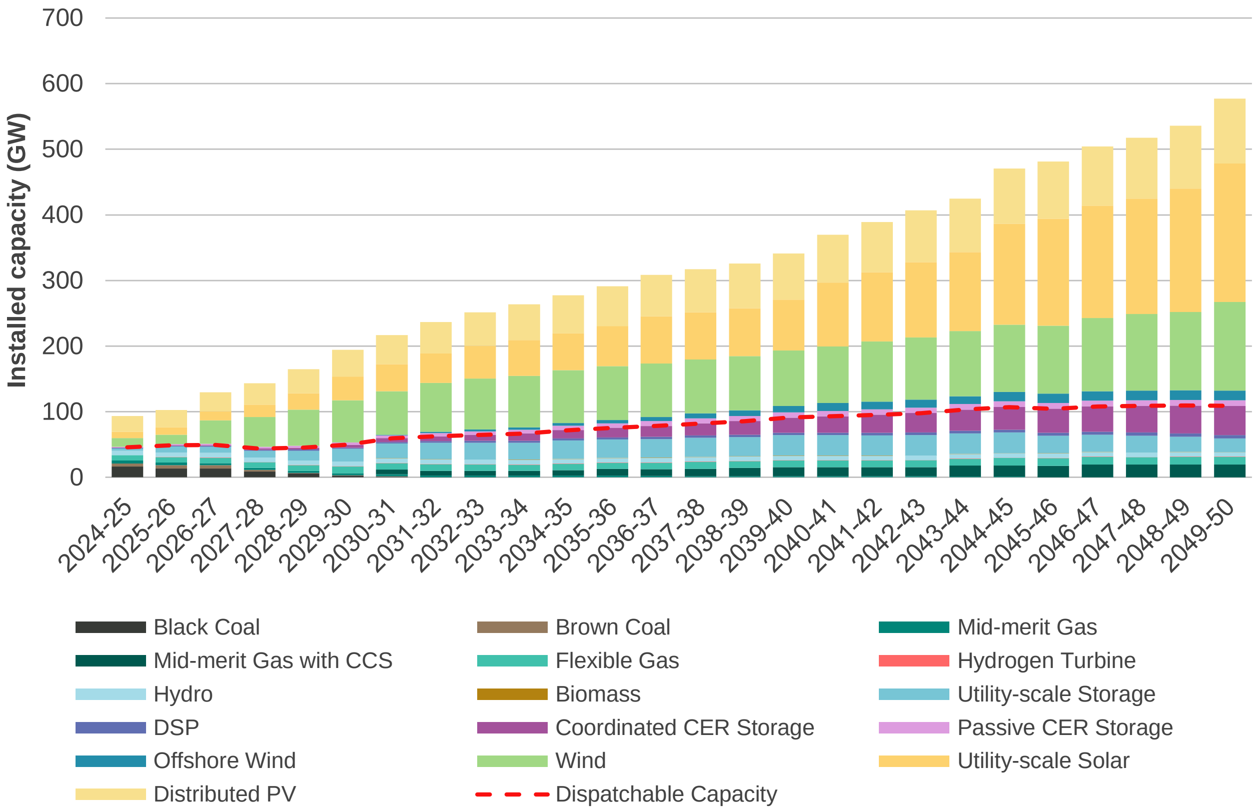
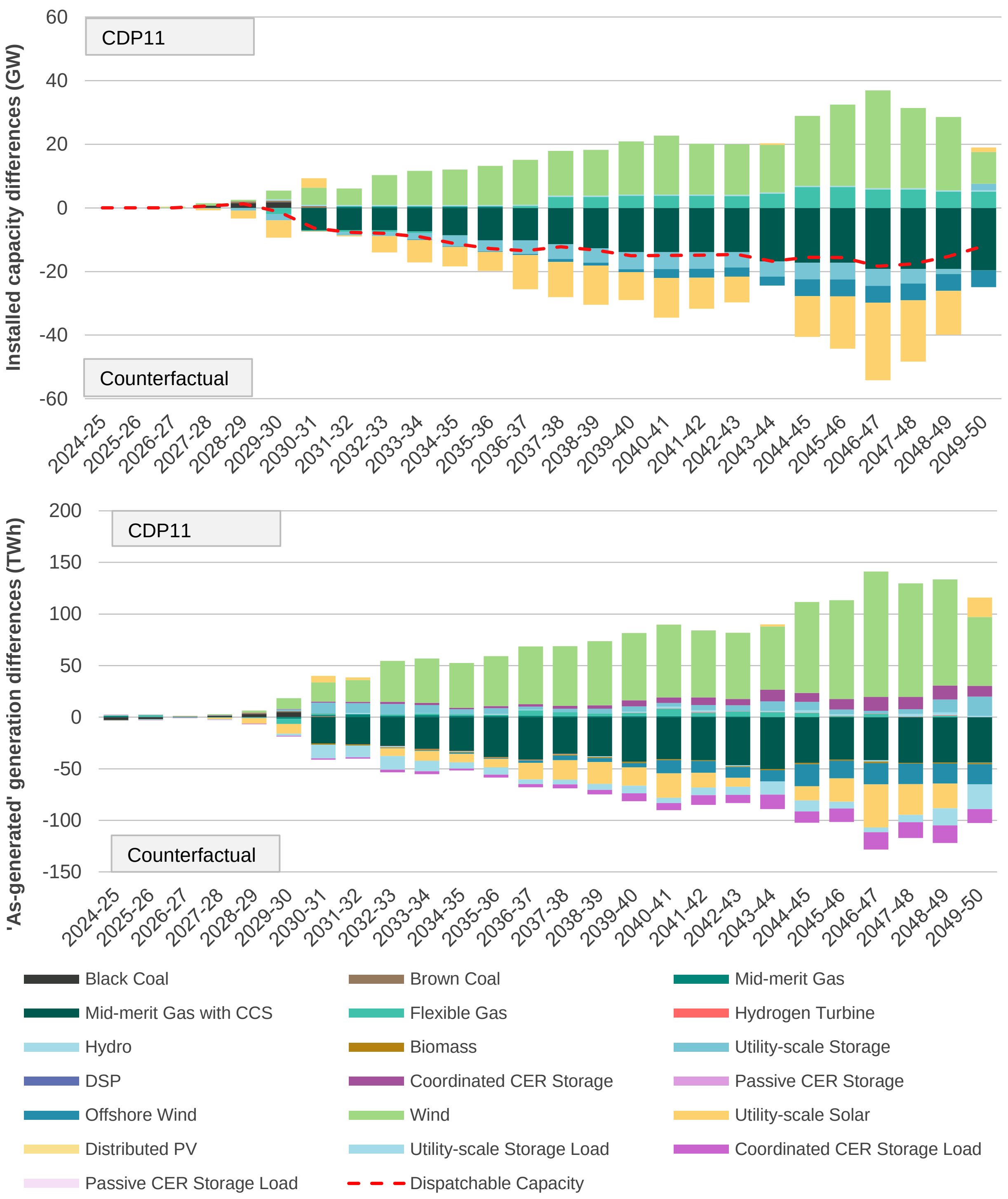


Figure 38 demonstrates the differences in capacity and generation development between CDP11 and the counterfactual DP. Without transmission expansion to support domestic consumers, further onshore wind development would be heavily curtailed and greater development of gas with CCS, utility-scale solar, and offshore wind is forecast. From the start of the outlook period, storage development is also required without the expansion of the transmission system to reduce potential congestion.

Figure 38 **Forecast capacity developments (top) and generation (bottom) to 2049-50 under counterfactual DP compared to *Green Energy Exports* (GW)**



A2.4 The influence of sensitivities on generation and storage development opportunities

This section outlines the differences between the generation and storage developments after applying alternative assumptions to the *Step Change* forecast through sensitivity analysis. These sensitivity analyses test the resilience of the development outlook and CBA analysis. The impact of these sensitivities on net market benefits is explored in depth in the cost-benefit analysis (see Section A6.7 of Appendix 6).

The sensitivities are also included in the **Generation and Storage Outlook Workbooks**[14], providing additional detail of the capacity developments, energy generated, retirement outlook and emissions outcomes for the sensitivities.

A2.4.1 *Alternative Discount Rates*

The *Higher Discount Rate* and *Lower Discount Rate* sensitivities demonstrate the impact of valuing future costs and benefits at higher or lower levels than assumed in the core assumptions of *Step Change*.

As outlined in the 2023 IASR, the cost of capital for all projects and the present value of all costs are both discounted using a rate of 7%. These sensitivities apply:

- Higher discount rate of 10.5%.
- Lower discount rate of 3%.

Applying a higher 10.5% discount rate

With a higher discount rate and cost of capital, the forecast reduces the value derived from future cost savings and prefers assets that incur relatively lower capital costs. Utility-scale batteries, for example, are preferred for providing storage services over pumped hydro storage which has a higher upfront cost but a longer economic life to recoup that cost. A higher discount rate favours technologies with a lower equivalent capital outlay, even if it has slightly higher operating costs. In general, assumed higher discount rates favour delaying larger capital expenditures.

Figure 39 shows a forecast reduction in capacity developments given the higher cost of new developments with a higher discount rate. Compared to the central discount rate for *Step Change*, by 2034-35, there is around 1.7 GW less installed capacity (with a reduction of wind, solar, and deep storage), and a slight increase in shallower utility storage. By 2049-50, there is 1.1 GW less VRE capacity and net reduction of 0.5 GW total energy storage. With less new investments, greater utilisation of existing mid-merit gas is forecast in this sensitivity.

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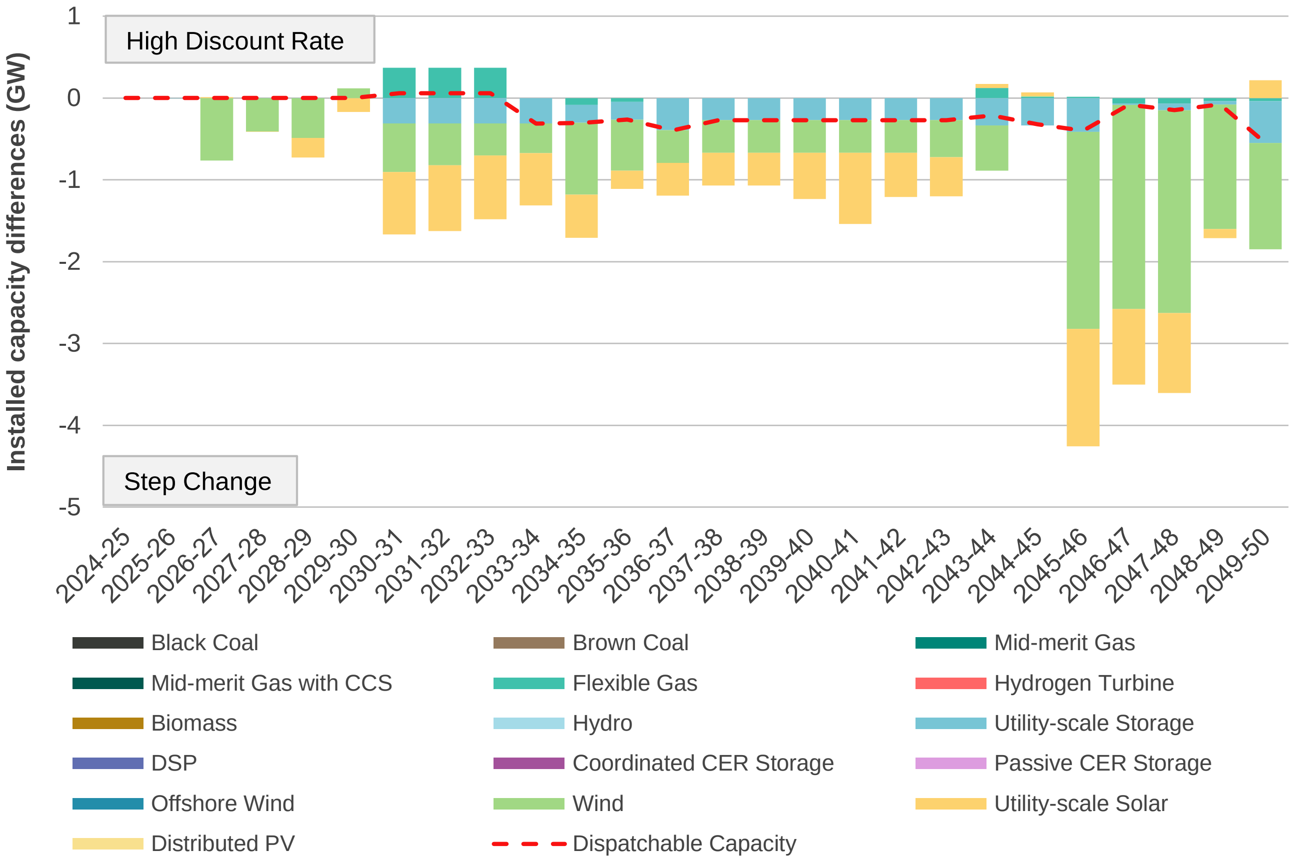
[14] At https://aemo.com.au/consultations/current-and-closed-consultations/draft-2024-isp-consultation.

Figure 39 Forecast capacity developments to 2049-50 under the *Higher Discount Rate* sensitivity compared to *Step Change* (GW)

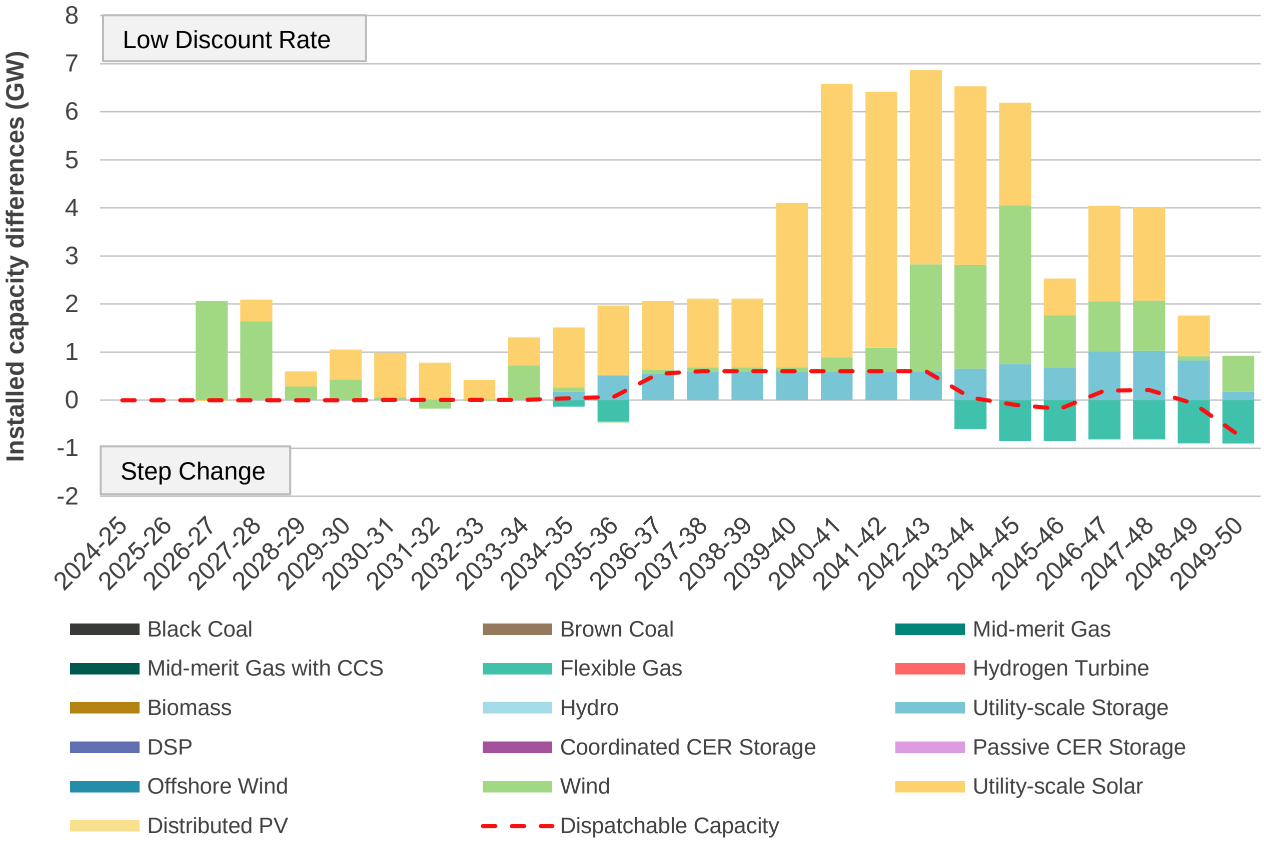


Applying a lower 3% discount rate

In contrast to the higher discount rate, a lower discount rate and cost of capital leads to projected higher investments in new generation technologies from the beginning of the outlook period, with future savings valued relatively more. Due to the lower cost of capital, solar, wind and energy storage with longer duration are built earlier in the period, reducing the need for flexible gas capacity that would have been developed under a higher discount rate assumption to provide firming support later in the horizon. These differences are shown in Figure 40.

Compared to *Step Change*, this sensitivity has a higher impact on capacity development from the mid-2030s. There is a combined 1 GW of solar and wind generation added by 2029-30, and during the 2040s, there are more VRE developments compared to *Step Change*, yet the differences minimise by 2049-50, reaching similar levels of installed capacity to *Step Change*.

Figure 40 Forecast capacity developments to 2049-50 under the *Lower Discount Rate* sensitivity compared to *Step Change* (GW)

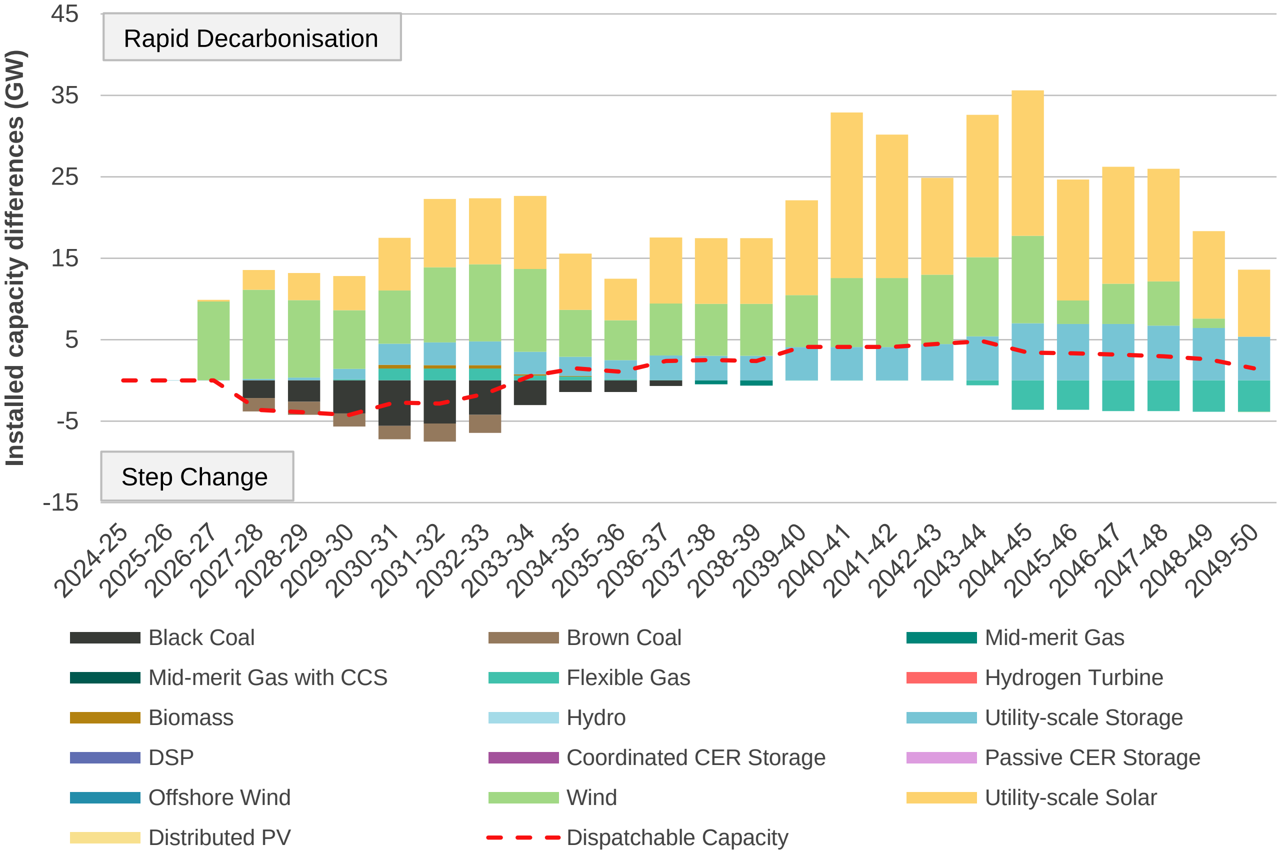


A2.4.2 *Rapid Decarbonisation*

The *Rapid Decarbonisation* sensitivity examines the impact of accelerated decarbonisation on the investment needs of the NEM by applying a tighter emissions budget that is consistent with the pace of transition in *Green Energy Exports* aimed at limiting temperature rise to 1.5°C by the end of the century. That is, by applying a carbon budget that is almost half that of *Step Change*, without the scale of growth of the green energy sector associated with *Green Energy Exports*. No other input was adjusted for this sensitivity to *Step Change*.

Figure 41 below compares capacity developments in this sensitivity to *Step Change*. It demonstrates that faster coal retirement as well as faster VRE and storage build-out would be needed to meet the tighter emissions budget under the same energy consumption forecast. By 2029-30, there is 5.7 GW less coal capacity, 11 GW more VRE, and 1.2 GW more storage in the system than in *Step Change*. Flexible gas capacity is also 1.4 GW higher in the 2030s to provide firming and energy security services under this sensitivity. Towards the end of the outlook period, the generation and storage developments under this sensitivity are greater than *Step Change*. By 2047-48 there is about 19 GW more VRE and 6.7 GW more (mostly deep) utility-scale storage.

Figure 41 Forecast capacity developments to 2049-50 under the *Rapid Decarbonisation* sensitivity compared to *Step Change* (GW)



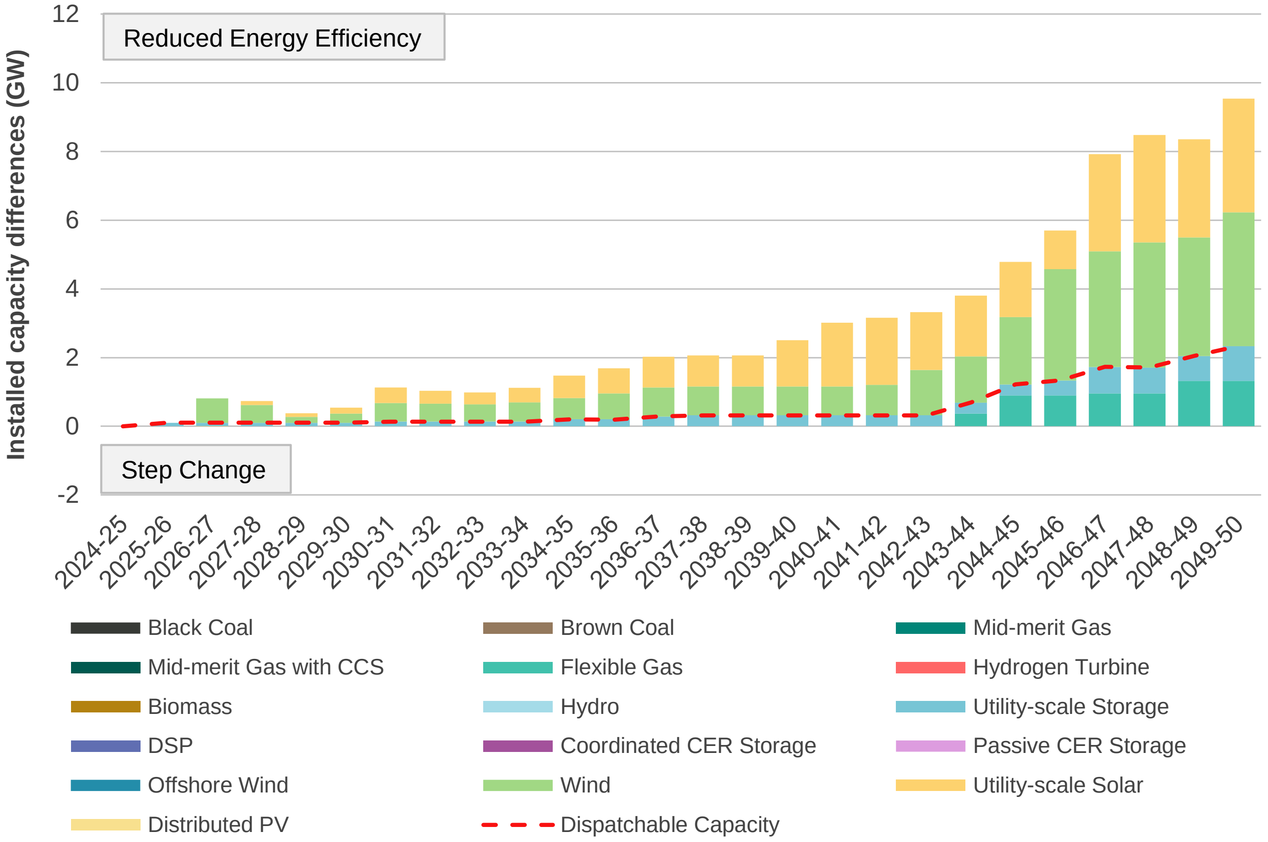
A2.4.3 Reduced Energy Efficiency

The *Reduced Energy Efficiency* sensitivity explores the effect of reducing the avoided energy consumption that is forecast through energy efficiency investments, relative to *Step Change*. Much of the energy efficiency investments made by consumers (residential, business and industry) are anticipated through technology improvements, building improvements, and other economic choices supported by policy. This sensitivity limits expanded energy efficiency investments to only those that AEMO has estimated are supported by existing and committed policies, which by 2050 represents an almost 40% reduction in energy efficiency savings relative to *Step Change*, more similar to the *Progressive Change* outlook. The 2023 IASR provides a comparison of the various savings trajectories applied.

By 2029-30, the consumption is 0.9 TWh higher than in *Step Change*, and 14.5 TWh higher in 2049-50, with the savings primarily spread across New South Wales (5.4 TWh), Victoria (4.8 TWh) and Queensland (2.8 TWh).

With higher electricity consumption, there is a need for more VRE and storage to be built. As Figure 42 shows, 7 GW more VRE and storage developments would be needed in this sensitivity relative to *Step Change*.

Figure 42 Forecast capacity developments to 2049-50 under the *Reduced Energy Efficiency* sensitivity compared to *Step Change* (GW)

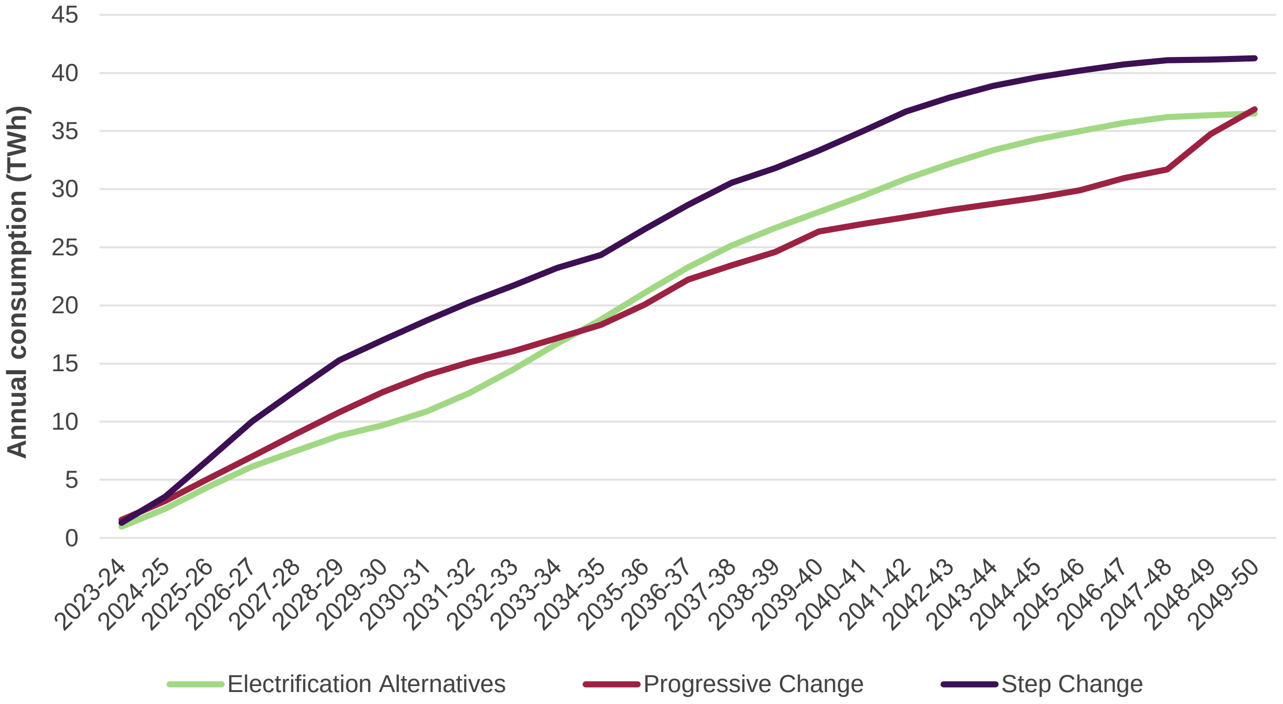


A2.4.4 *Electrification Alternatives*

The *Electrification Alternatives* sensitivity examines the role of alternatives to electrification, such as biomethane, that may delay industrial switching to electricity relative to *Step Change*. It examines this by reducing the pace and breadth of electrification across industrial energy use, retaining a more diverse mix of fossil and renewable molecular energy forms in the primary energy mix, including a growing role for biomethane in decarbonising industry.

This sensitivity applies a lower electrification forecast than *Step Change*, as shown in Figure 43.

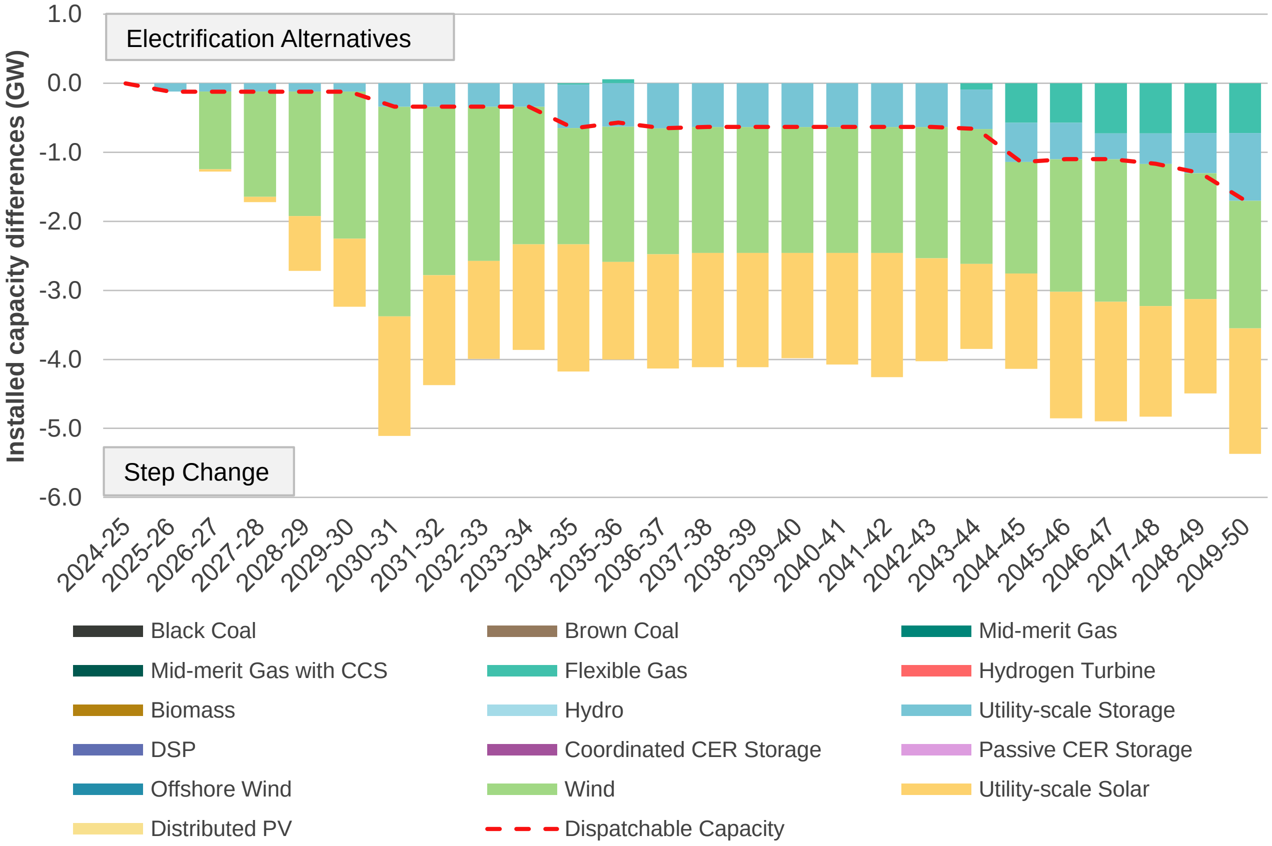
Figure 43 **Electrification forecast across *Step Change*, *Progressive Change*, and *Electrification Alternatives*, 2023-24 to 2049-50 (TWh)**



The lower share of industrial electrification impacts each region considering the scale of mining, minerals and broad industry decarbonisation required in each region. By 2029-30, consumption is 8.5 TWh lower than *Step Change* across the NEM, with Queensland (4.4 TWh), New South Wales (3.1 TWh) and South Australia (0.8 TWh) most affected.

Reduced consumption leads to lower generation development requirements throughout the outlook period, as shown in Figure 44. Across the horizon there is a greater reduction in VRE developments than there is in reducing storage compared to *Step Change*, demonstrating that the reduction in industrial demand is not lowering the needs for energy storage to support all consumers during low VRE conditions.

Figure 44 Forecast capacity developments to 2049-50 under the *Electrification Alternatives* sensitivity compared to *Step Change* (GW)



A2.4.5 *Constrained Supply Chains*

The *Constrained Supply Chains* sensitivity explores how limitations in infrastructure delivery speed will impact the development and economic efficiency of generation, storage, and transmission in *Step Change*. This is to reflect potential constraints in supply chain capacity and workforce availability affecting the transition to a net zero economy by 2050.

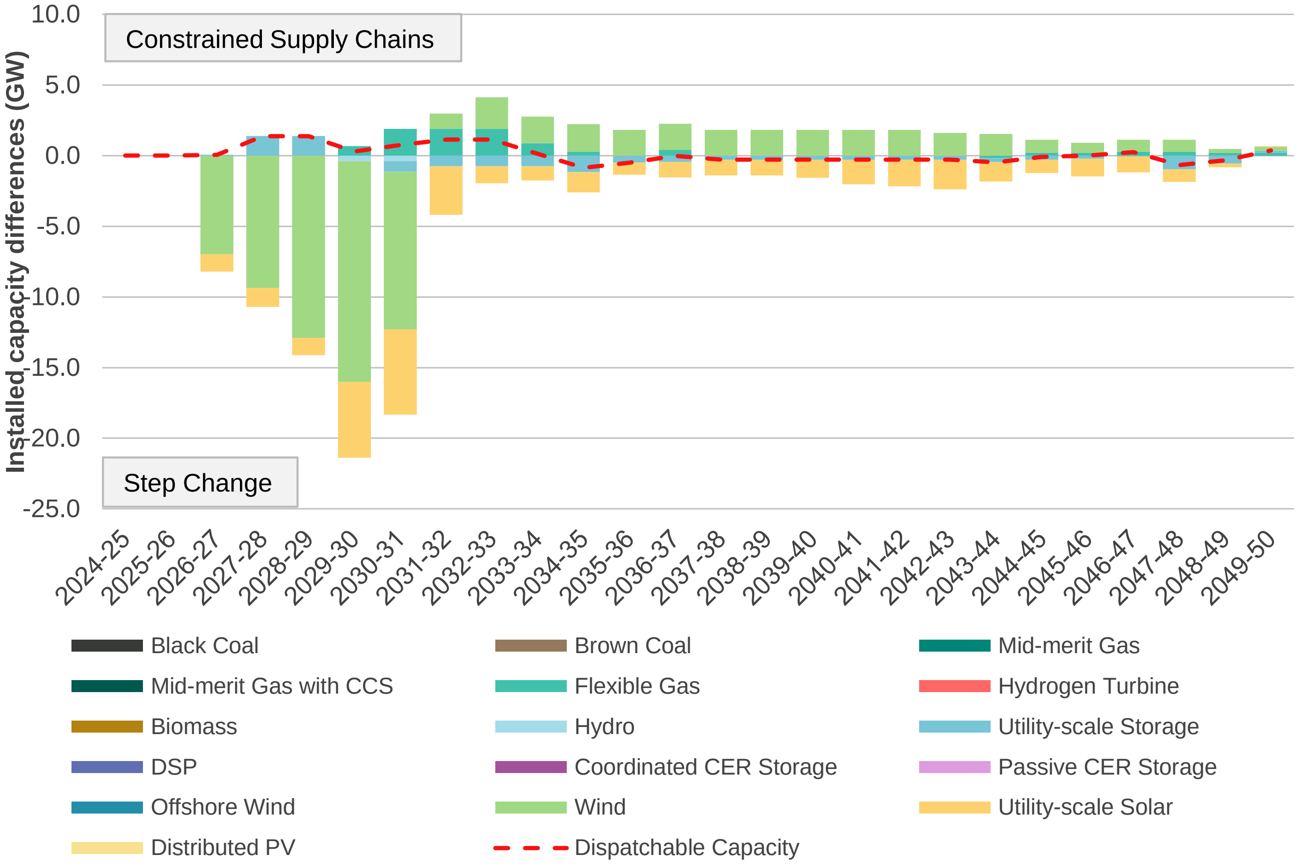
These limitations have been reflected through the following adjustments in inputs:

- NEM-wide annual build of additional generation and storage developments is limited to 4 GW until 2029-30.
- Two-year delay to the earliest in-service date (EISD) for transmission augmentation options and REZ augmentations (excluding committed and anticipated projects).

Figure 45 shows that there is projected to be 16 GW less wind and 5 GW less utility-scale solar by 2029-30 compared to *Step Change,* and 0.7 GW of flexible gas will need to be developed instead. The development of new gas provides more potential generation per MW than renewable generation, if required. The use of incumbent coal is also higher compared to *Step Change* to meet forecast growing demand to 2029-30.

If supply chains are limited, to meet policy settings the developments will concentrate within those regions with explicit renewable energy development targets within the policy collection. This impacts the ability to achieve the 82% renewable energy target by 2030, instead achieving only approximately 62%. That is, if a limited supply chain constrains renewable generation development, the achievement of the renewable generation targets may be delayed to slightly later than policy intends (leading also to higher emissions above the emissions budget for a short duration). Figure 45 shows the NEM-wide development impact, showing the slower renewable energy developments before then ‘catching up’ once the supply chain is assumed to have expanded.

Figure 45 Forecast capacity developments to 2049-50 under the *Constrained Supply Chains* sensitivity compared to *Step Change* (GW)



A2.4.6 *Reduced Social Licence*

The *Reduced Social Licence* sensitivity explores the influence that limited community acceptance for new infrastructure development (generation, pumped hydro, and transmission) may have on the developments forecast to be needed to transition the energy sector. Social licence needs to be earned and maintained throughout the transition, and if not forthcoming then may slow the overall transition.

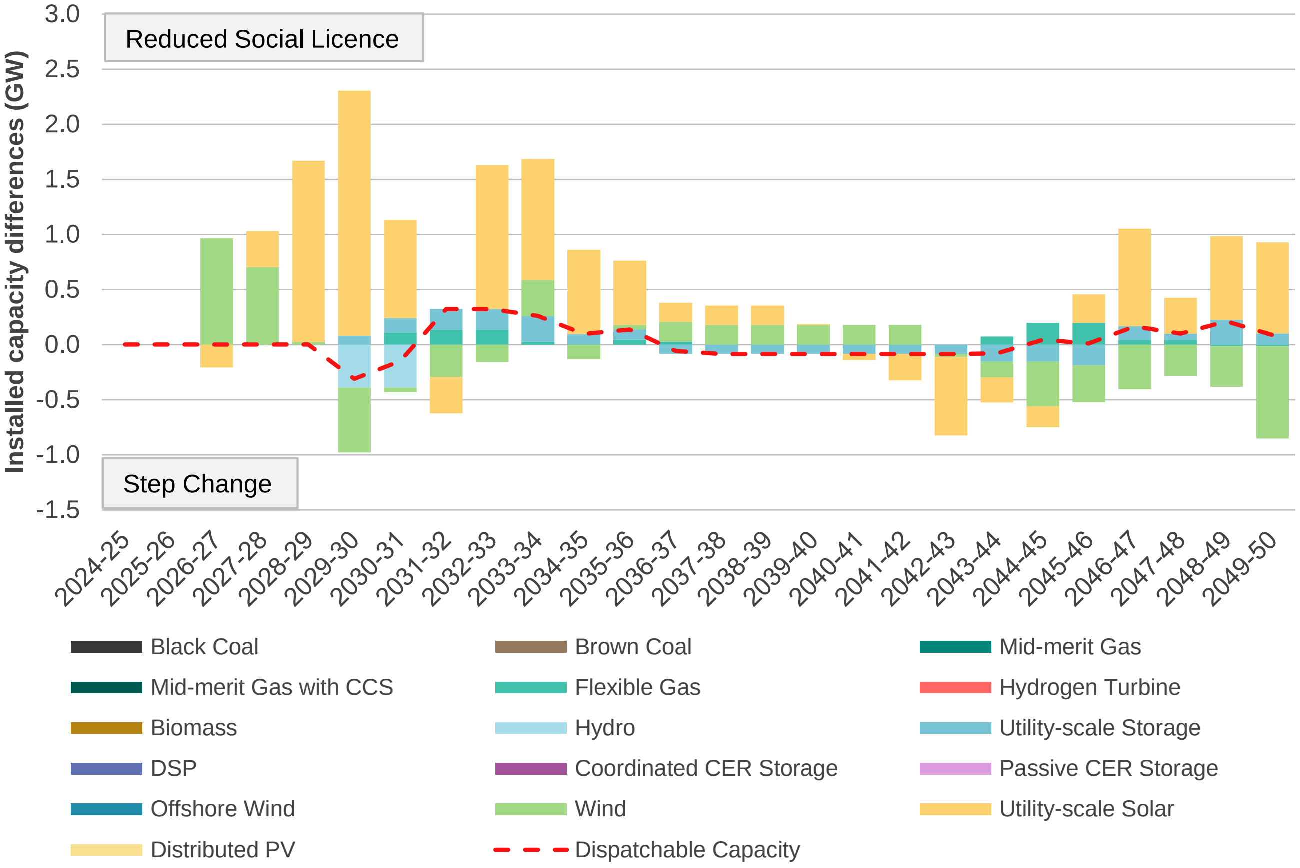
The *Reduced Social Licence* sensitivity was implemented by reflecting greater limitations and higher costs on key infrastructure developments, compared to *Step Change*, as shown in Table 2.

Table 2 Draft 2024 ISP social licence sensitivity parameters

Sensitivity	Details
Transmission timing Extending project lead times for all transmission augmentation options by two years.	• Reflects delay impacts from low social licence for transmission. The delay does not include committed and anticipated projects, as these projects are already progressed to be delivered and there is more certainty surrounding the completion date. • This reflects the impact of low social licence on extended lead times in obtaining transmission easements and property rights.
Transmission costs Project costs observed to increase by approximately 15%. Reflects changes in work scope due to low social licence.	• Add a cost impost to transmission augmentations to reflect scope changes to routes and designs. • Designed to capture small re-routings, re-design of towers, easement adjustments. • Also captures associated materials and labour. • Additional to existing cost estimates that already include scope changes and risks. • Reflects more adjustments and engagements will be needed for transmission projects. • This parameter has also been applied to pumped hydro projects. • Committed and anticipated projects included smaller adjustments, as they are progressed actionable projects that have already undertaken some measures.
REZ generation costs REZ generation costs observed to increase by approximately +5% to +60% based on private land parcel density, and applied to specific REZ generation costs by technology type (such as wind or solar).	• Applied to onshore solar and wind generation build costs within each REZ. • Add a cost impost to REZ generation to reflect increased social licence costs within a REZ such as scope changes and additional community engagement and benefit sharing. • Additional to existing cost estimates that already include community engagement and benefit sharing programs. • Reflects more dense REZs that may have more stakeholders and pose higher social licence risks. • Use a generalised approach towards all NEM REZs.

Figure 46 shows the impact of these adjusted assumptions on the forecast capacity developments. Delayed investments in transmission leads to slightly more VRE developments in the next ten years compared with *Step Change*, but these are temporary as by the mid 2030's the overall scale of VRE and storage developments are similar. By 2049-50, there is 0.8 GW more utility-scale solar; the difference in capacity is due to the higher REZ development cost, where developments are moved from REZs with higher private land parcel density that are more costly in this sensitivity, to locations with lower development cost.

Figure 46 **Forecast capacity developments to 2049-50 under the *Reduced Social Licence* sensitivity compared to *Step Change* (GW)**



A2.4.7 *Development of Pioneer-Burdekin Pumped Hydro Project*

The Queensland Government has announced plans to support the transition to renewable generation as part of its *Queensland Energy and Jobs Plan*, including key deep pumped hydro projects at Borumba Dam (2 GW/24 GWh), and the larger Pioneer-Burdekin (5 GW/120 GWh). For the Draft 2024 ISP, Borumba Dam Pumped Hydro has been classified as ‘anticipated’, whereas Pioneer-Burdekin Pumped Hydro Project is yet to reach sufficient development milestones for that classification. As such, the Draft 2024 ISP does not assume its development. This sensitivity explores the potential impact on broader capacity developments of having Pioneer-Burdekin as an anticipated project.

In this sensitivity, the project was assumed to be delivered in two stages – 2.5 GW/60 GWh to commence operation in 2032-33, and a further 2.5 GW/60 GWh in 2035-36[15], and complemented with the Queensland SuperGrid North transmission project to allow for higher flows from North Queensland.

With the additional storage developed, the need for flexible gas is reduced, and greater development of lower cost solar is more effective and efficient than wind generation, as shown in Figure 47. By 2049-50, there is 3.4 GW more utility-scale storage, and 4.7 GW more utility-scale solar developments, than in *Step Change*.

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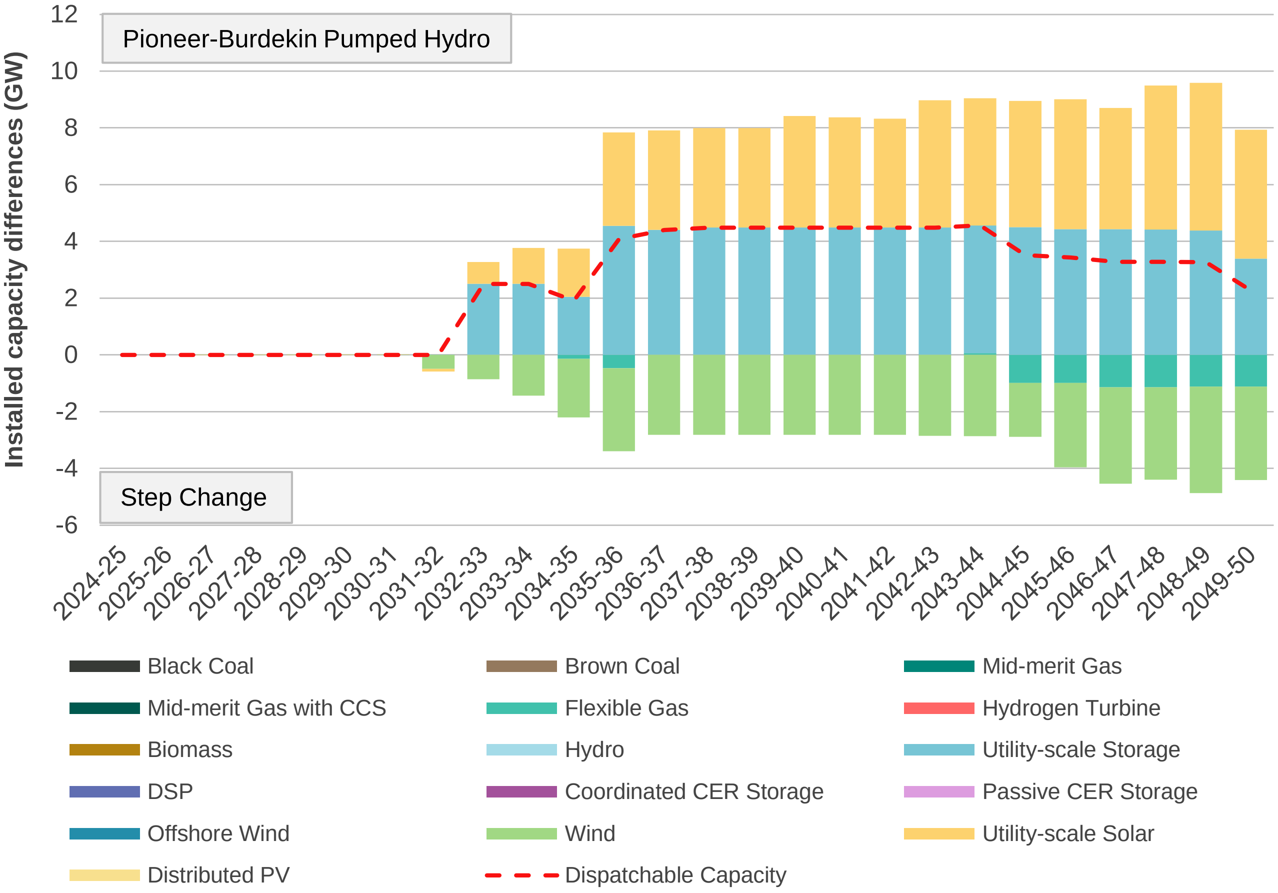
[15] Queensland Government, *Queensland SuperGrid Infrastructure Blueprint*, September 2022. Page 37. At https://www.epw.qld.gov.au/__data/assets/pdf_file/0030/32988/queensland-supergrid-infrastructure-blueprint.pdf.

The effect of installing storage in North Queensland affects the distribution of VRE across Queensland, with less development in central and southern Queensland.

Figure 47 Forecast capacity developments to 2049-50 under the *Pioneer-Burdekin Pumped Hydro Project* sensitivity compared to *Step Change* (GW)

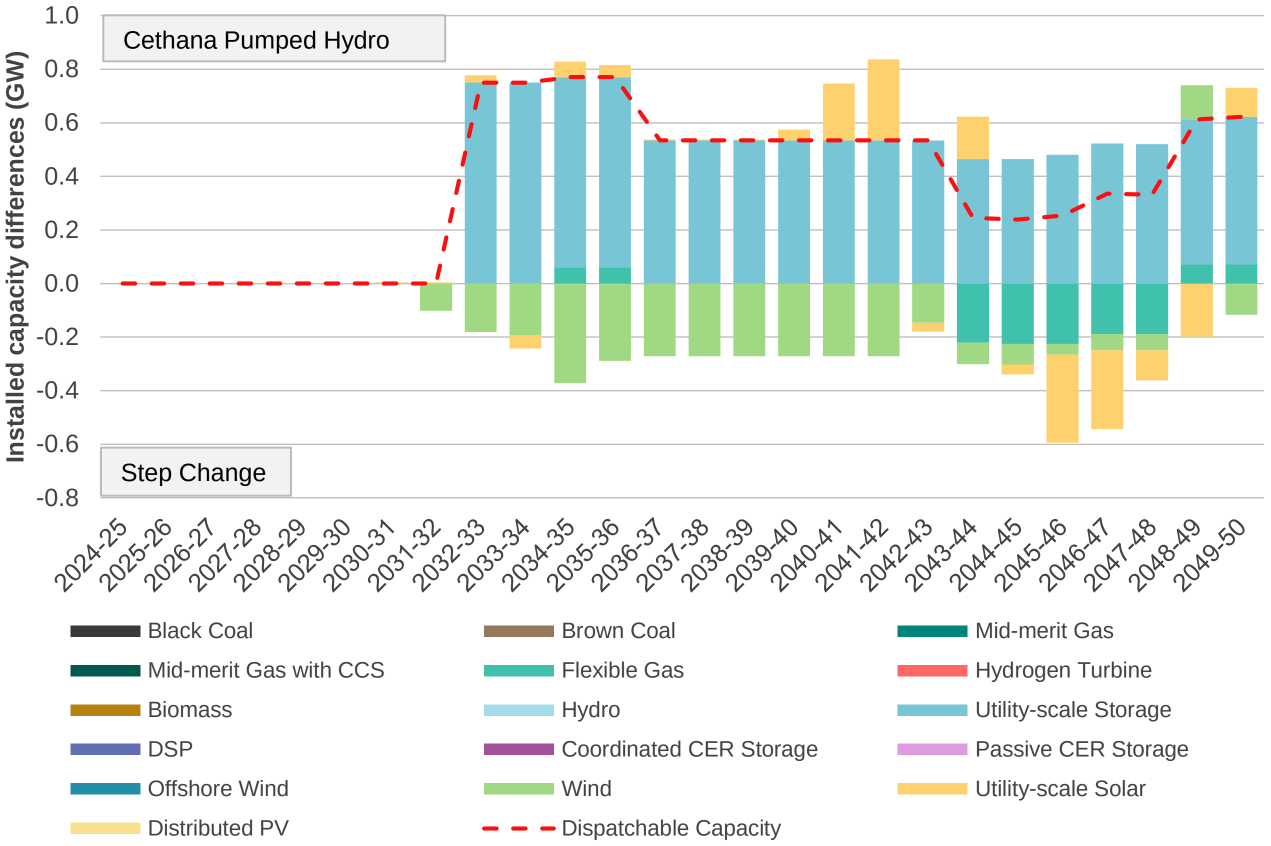


A2.4.8 *Development of Cethana Pumped Hydro Energy Storage*

The Federal Government has announced it will use its *Rewiring the Nation* fund to provide low-cost financial support for the Battery of the Nation project in Tasmania, but the Draft 2024 ISP does not apply either a committed or anticipated commitment classification to Tasmania's storage projects. This sensitivity has been included to investigate the impact on broader development opportunities of assuming the Cethana pumped hydro energy storage as an anticipated project, commencing operation from 2032-33. The project has an expected capacity of 750 MW / 15 GWh.

Figure 48 shows that the addition of the Cethana project is expected to generally reduce the need for wind and flexible gas developments relative to *Step Change*, without the need for additional VRE generation, suggesting increased effectiveness to store and shift available energy from the VRE developments most accessible to the Tasmanian storages to enable some developments to be deferred.

Figure 48 **Forecast capacity developments to 2049-50 under the *Cethana Pumped Hydro Energy Storage* sensitivity compared to *Step Change* (GW)**



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. 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

Term	Acronym	Explanation
		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.
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.

Term	Acronym	Explanation
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.
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.
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.