Appendix 2. ISP Development Opportunities

June 2022

Appendix to Final 2022 ISP for the National Electricity Market

Important notice

Purpose

This is Appendix 2 to the 2022 *Integrated System Plan* (ISP), available at https://aemo.com.au/energy-systems/major-publications/integrated-system-plan-isp.

AEMO publishes the 2022 ISP under the National Electricity Rules. This publication has been prepared by AEMO using information available at 15 October 2021 (for Draft 2022 ISP modelling) and 19 May 2022 (for 2022 ISP modelling). AEMO has acknowledged throughout the document where modelling has been updated to reflect the latest inputs and assumptions. Information made available after these dates has been included in this publication where practical.

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Version control

Version	Release date	Changes
1.0	30/6/2022	Initial release.

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ISP Appendices

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A2.1 Introduction

Sections 3 and 4 of the 2022 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 within each future ISP scenario.

This appendix supports the 2022 ISP with additional detail on the electricity generation and storages needed in each of the four ISP scenarios[1], as well as detailing the impact to generation developments of the various sensitivities examined in the ISP.

This appendix presents a predominantly NEM-wide view of these ISP developments, with regional breakdowns where most appropriate. In this appendix:

- A2.2 summarises the evolution of the energy system across the ISP scenarios.
- A2.3, for each scenario, provides a more detailed examination of generation and storage development, illustrating the impact of transmission augmentation, and an overview of relevant impacts from the sensitivity analysis.
- A2.4 details the impact of the sensitivity analysis on generation and storage development.

The content here is complemented by:

- Appendix 3, which provides more granular reporting on the development opportunities (and broader 'scorecards') for individual REZs.
- Appendix 4, which provides greater detail on the operability of the future NEM with the various ISP developments outlined for each scenario in this appendix.
- Appendix 6, which provides the cost benefit assessment of the candidate development paths (CDPs).

In this appendix all dates are on a financial year basis. For example, 2023-24 represents the financial year ending June 2024.

This appendix is supported by the **Generation Outlook files** which provide details of the capacity developments, energy generated, and retirement outlook for regions and generation technologies. This data is coupled with emissions outcomes, and comparisons to alternative CDPs (including comparisons of system costs).

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

A2.2 A rapidly evolving NEM will transform energy supply

The 2022 ISP forecasts that the supply of electricity in the NEM will transform from a generation mix dominated by coal-fired generation, to a grid with very high renewable energy penetration, supported by energy storage, transmission, hydropower, gas-fired generation, and DER. This NEM transition will support an emerging net zero emissions economy, and therefore NEM development will need to exceed the replacement of the existing generation fleet to meet additional load associated with electrifying other sectors that utilise a low-emissions electricity system to decarbonise.

The future NEM is projected to be a combination of technologically and geographically diverse resources, including:

- Renewable energy – a mixture of diversely located VRE generators (solar and wind farms) and DER.
- Energy storages – to provide operational support to manage intermittency and periods of high and low renewable energy generation. Critically these storages can also firm the renewable energy generators, providing backup supply and peaking support, as well as a range of essential power system security services if designed appropriately and market mechanisms provide sufficient incentives to operate as such.
- Gas-fired generation – to provide peaking support particularly during long periods of low VRE output, as well as a range of essential power system security services including fast frequency response and FCAS.
- Increased transmission, including interconnection – to support the integration of significant quantities of dispersed VRE across the grid, and facilitate the efficient sharing of renewable energy, storage, and backup and firming services.

A2.2.1 A changing generation mix to service consumers

Across all ISP scenarios, significant capacity of new VRE generation is expected to transform the NEM and reduce the emissions intensity of Australia's power system.

Table 1 presents the generation mix for all scenarios, presented in terms of capacity, where each scenario develops the level of transmission investments that are in CDP11 which features actionable timings for Marinus Link and HumeLink, as well as a staged delivery of VNI West (see Section 5 of the 2022 ISP for more detail). CDP11 was chosen because it represents a likely path of development for the NEM, it presents a consistent transmission investment path for all scenarios in the near-term, and the long-term development outcomes for generation investments are similar to those that would result from the ODP. The accompanying Generation Outlook data files contain ISP development opportunity information for other CDPs.

The table demonstrates the significant scale of development opportunities forecast in this ISP, with utility-scale VRE growing to approximately 140 GW in *Step* Change, from current levels of approximately 20 GW, for example. All ISP scenarios present at least about a trebling of VRE by 2050.

Newer technologies in offshore wind and hydrogen gas turbines feature in *Progressive Change* and *Hydrogen Superpower* respectively. As emerging technologies, these may be developed to achieve policy objectives, improve social licence, and/or address broader economic and technological considerations than has been assumed in AEMO's inputs. AEMO has further explored the influence of expanded offshore wind developments in the sensitivity analysis described in A2.4.

Table 1 Installed capacity to 2029-30 and 2049-50 by scenario (MW)

Technology	*Progressive Change*		*Step Change*		*Hydrogen Superpower*		*Slow Change*	
	2029-30	**2049-50**	**2029-30**	**2049-50**	**2029-30**	**2049-50**	**2029-30**	**2049-50**
Black coal	11,556	1,692	7,312	0	2,242	0	9,706	1,692
Brown coal	3,385	0	1,720	0	1,160	0	3,385	0
Mid-merit gas	4,075	0	4,075	0	2,387	0	2,387	0
Peaking gas + liquids	8,284	13,153	8,255	9,637	8,696	13,936	8,433	5,405
Hydrogen gas turbine	0	0	0	0	0	4,954	0	0
Hydro	7,208	7,056	7,208	7,056	7,208	7,056	7,208	7,056
Utility-scale storage	5,847	20,967	5,936	15,780	10,646	27,061	6,220	16,331
Coordinated DER storage	1,208	17,535	3,819	30,637	4,696	37,313	391	2,338
Distributed storage	3,174	11,136	5,453	14,447	5,870	14,832	2,015	3,966
Wind	19,189	76,093	31,283	70,472	49,578	269,498	18,450	35,857
Offshore wind	0	337	0	0	0	0	0	0
Solar	11,844	66,740	12,222	70,249	28,884	278,436	12,176	16,360
Distributed PV	31,394	60,844	35,131	68,593	39,671	81,161	31,073	46,133

A2.2.2 Energy storages needed to complement renewable generation

Additional storage capacity will be needed to complement the large amount of VRE developments and to provide a dispatchable and firm source of supply. Diverse storage technologies are needed, distributed across the NEM. AEMO has defined the following storage classes:

- Coordinated DER storage – includes behind-the-meter battery installations that are enabled and coordinated via VPP arrangements. This category also includes VPP coordinated EVs with V2G capabilities.
- Distributed storage – includes non-aggregated behind-the-meter battery installations designed to support the customer's own load.
- Shallow storage – includes grid-connected 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 value.
- 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 "droughts" (long periods of lower-than-expected VRE availability) and seasonal smoothing of energy over weeks or months.

Figure 1 presents the NEM-wide storage capacity by depth to 2049-50 under *Step Change*.

On the left-hand side, it shows the scale of distributed storage assumed, with additional utility-scale developments required to complement VRE penetration. Deep developments (beyond the committed Snowy 2.0 development) occur from the mid-2030s, particularly to complement ISP developments replacing retiring coal generation. The right-hand side of the chart presents the energy storage capacity (GWh) in selected years. The figure shows the significant depth that the Snowy 2.0 development provides, being the key driver for the increase in depth before 2029-30. From 2030, a balance of medium and deeper storages complements shallower developments at both utility- and distributed-scale.

Figure 1 NEM storage MW capacity (left) and energy storage capacity (right) in *Step Change*

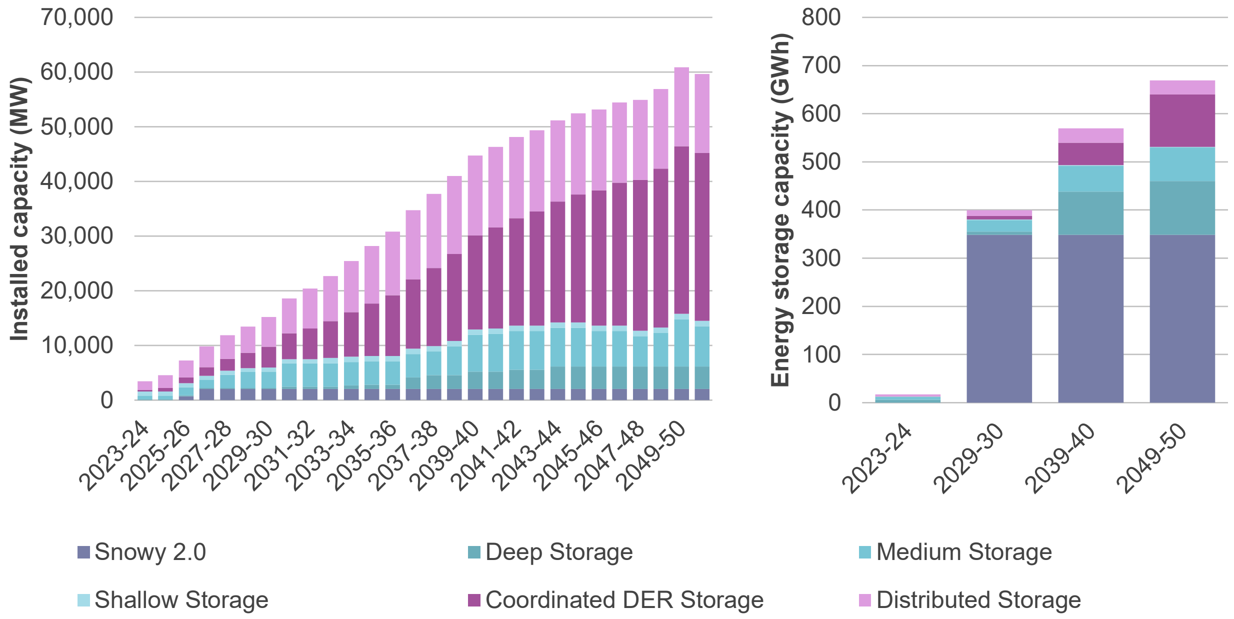
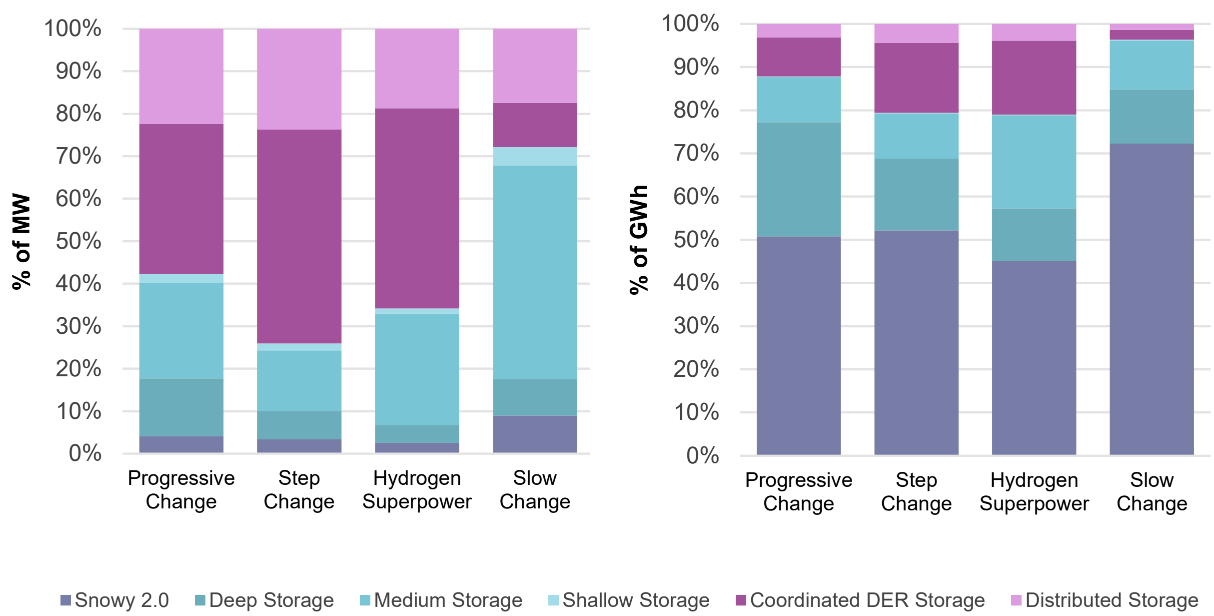


Figure 2 presents the mix of energy storage capacity that will be required to complement the new VRE developments. Deep storage is predominant across the scenarios in GWh terms. Coordinated DER storage also plays a significant role in managing intra-day variability, particularly in *Step Change*.

Figure 2 Mix of energy storage type by scenario in 2050 – storage MW capacity (left) and energy storage depth (right)



A2.2.3 The low emissions-intensity NEM

The transformation of the NEM to support Australia's transition to a net zero emissions economy by 2050 will require strong projected uptake of VRE, driven by energy policies, economics of new entrant development options, and retirement of thermal generation. This significant transformation of the NEM will reduce the electricity sector's emissions intensity in all ISP scenarios, as shown in Figure 3.

The *Step Change* and *Hydrogen Superpower* scenarios require a significant and rapid change to the NEM's generation mix to achieve each scenario's emissions reduction objectives. This leads to most thermal retirements occurring in the 2020s (see Section A2.3.1 and A2.3.3). By 2029-30, NEM emissions are forecast to reduce by 73% for *Step Change*, from 176 Mt CO_2-e in 2005 to 48 Mt CO_2-e, and by 88% for *Hydrogen Superpower*, from 176 Mt CO_2-e in 2005 to 21 Mt CO_2-e. By 2049-50, emissions are forecast to be just 7 Mt CO_2-e for *Step Change* and *Hydrogen Superpower*.

In *Progressive Change*, emissions reductions are forecast to occur more gradually, as a carbon budget to reflect coordinated action does not apply until 2030-31. Up to this point, various renewable energy targets across jurisdictions provide the key driver for sufficient VRE developments to reduce forecast 2030 emissions by 57% compared to 2005 levels.

Although *Slow Change* does not apply a carbon budget, VRE developments and economic coal retirements due to lower energy consumption contribute to a strong forecast emissions reduction of 70% by 2030. Eventually all brown coal will retire, with VRE providing the replacement energy in this scenario also, leading to a significant 93% reduction in electricity emissions by 2049-50, relative to 2005 levels. However, without as much electrification in this scenario, the economy-wide reductions are not delivered as strongly as other scenarios.

Figure 3 Annual NEM emissions by scenario

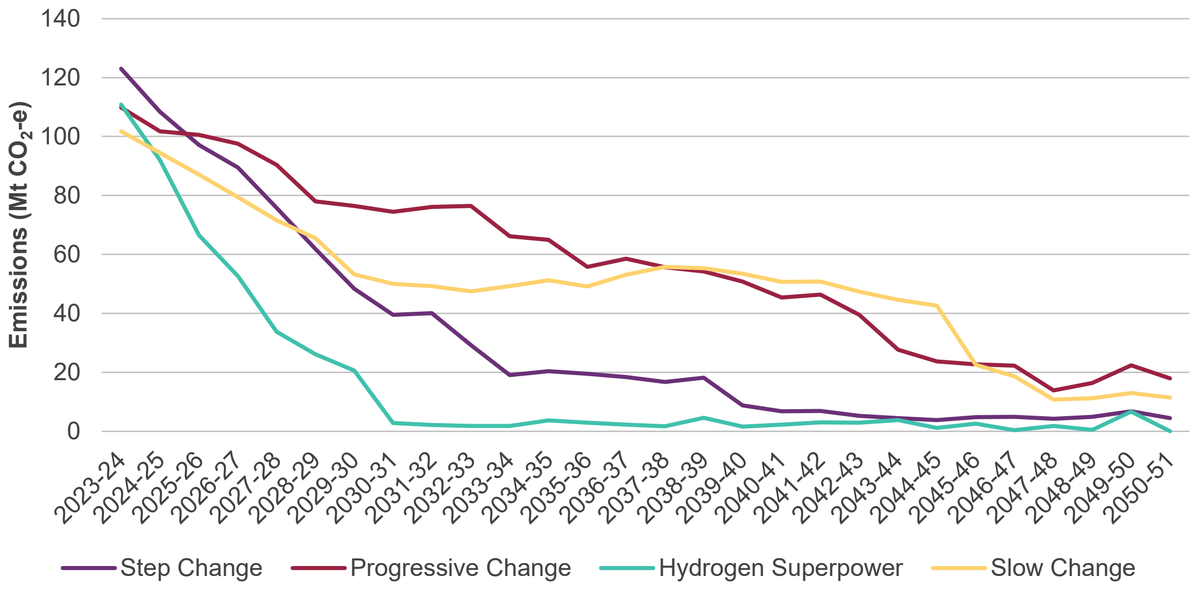
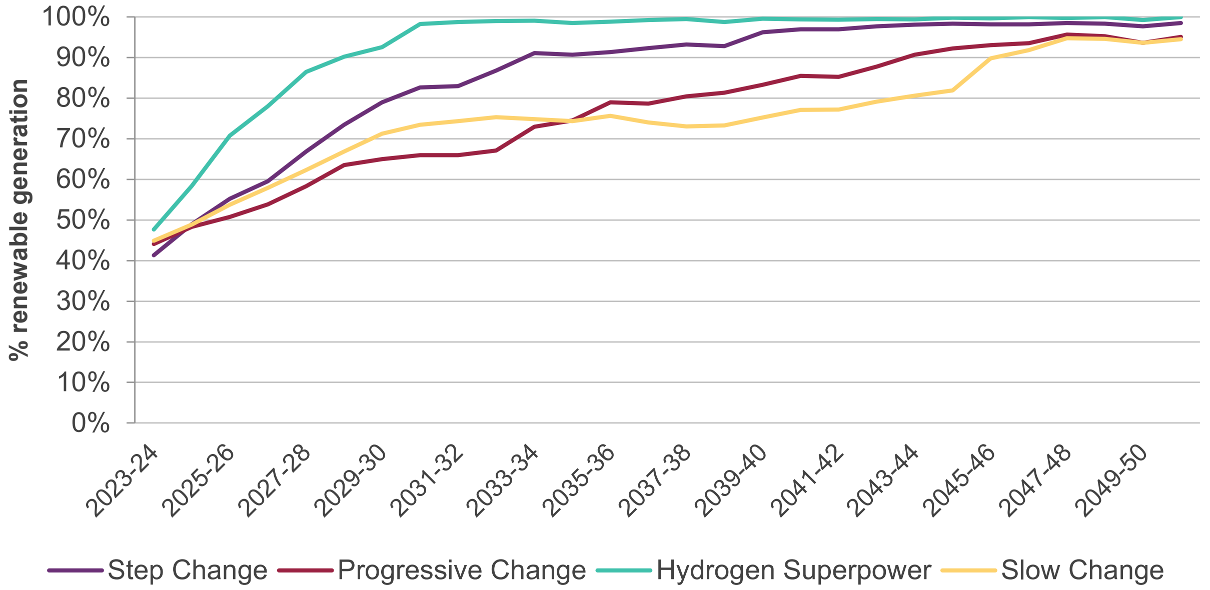


Figure 4 presents the level of renewable energy penetration by scenario to 2049-50, demonstrating how the grid can achieve the significant carbon reductions observed in the next 30 years. By 2049-50, 99% of generation is forecast to be generated from renewable sources in *Hydrogen Superpower*. In *Step Change*, the share of generation from renewable sources increases to 98%, while both *Progressive Change* and *Slow Change* reach 95%.

Figure 4 Evolution of the annual share of total generation from renewable sources – from capacity outlook model (CDP11)



A2.3 ISP development outlooks across scenarios

Change in capacity development since the Draft 2022 ISP

AEMO has added targeted refinements to inputs and assumptions since the Draft 2022 ISP was published in December 2021. These updates consider recent announcements and developments in the NEM, and the insights accumulated from the consultation of the Draft ISP (described in detail in the ISP Consultation Summary Report).

Key changes include:

- The early closure of Eraring, Bayswater and Loy Yang A power stations.
- The delay in the earliest entry date of Marinus Link.
- The inclusion of additional committed and anticipated projects reported in AEMO's February 2022 Generation Information release.

In response to feedback received in the consultation on the Draft ISP, AEMO has also made some minor improvements in modelling assumptions:

- Several minor adjustments and improvements in the assumptions relating to transmission and REZ limits.
- Enhancement in the determination of electrolyser capacity development, which produces a more cost-effective solution with lower levels of storage development towards the end of modelling horizon.

Finally, AEMO has increased the granularity of the modelling underpinning some of the scenarios to be aligned across all scenarios. In these scenarios, the granularity had been slightly lower in the Draft ISP modelling for practical computational reasons.

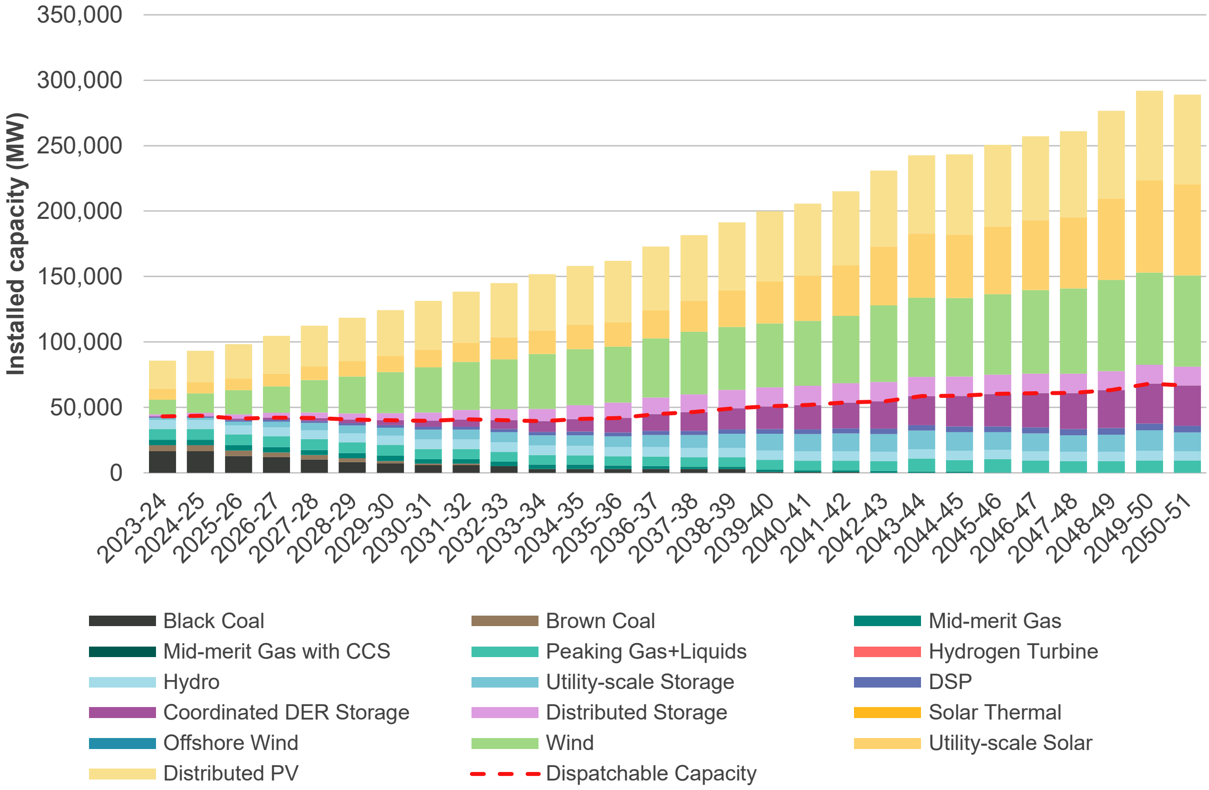
The following sections highlight the impact of these improvements in *Step Change* and *Hydrogen Superpower* where the impacts of the changes are most evident.

A2.3.1 *Step Change*

The *Step Change* scenario represents a future with a rapid, consumer-led transformation of the energy sector and a coordinated economy-wide approach to efficiently lower emissions. Technology improvements in capability and cost provide a backdrop to faster net zero emission reduction ambitions, with greater adoption of energy efficiency measures and co-ordinated DER.

Generation and storage development in *Step Change*

Figure 5 Forecast NEM generation capacity to 2050-51, *Step Change*



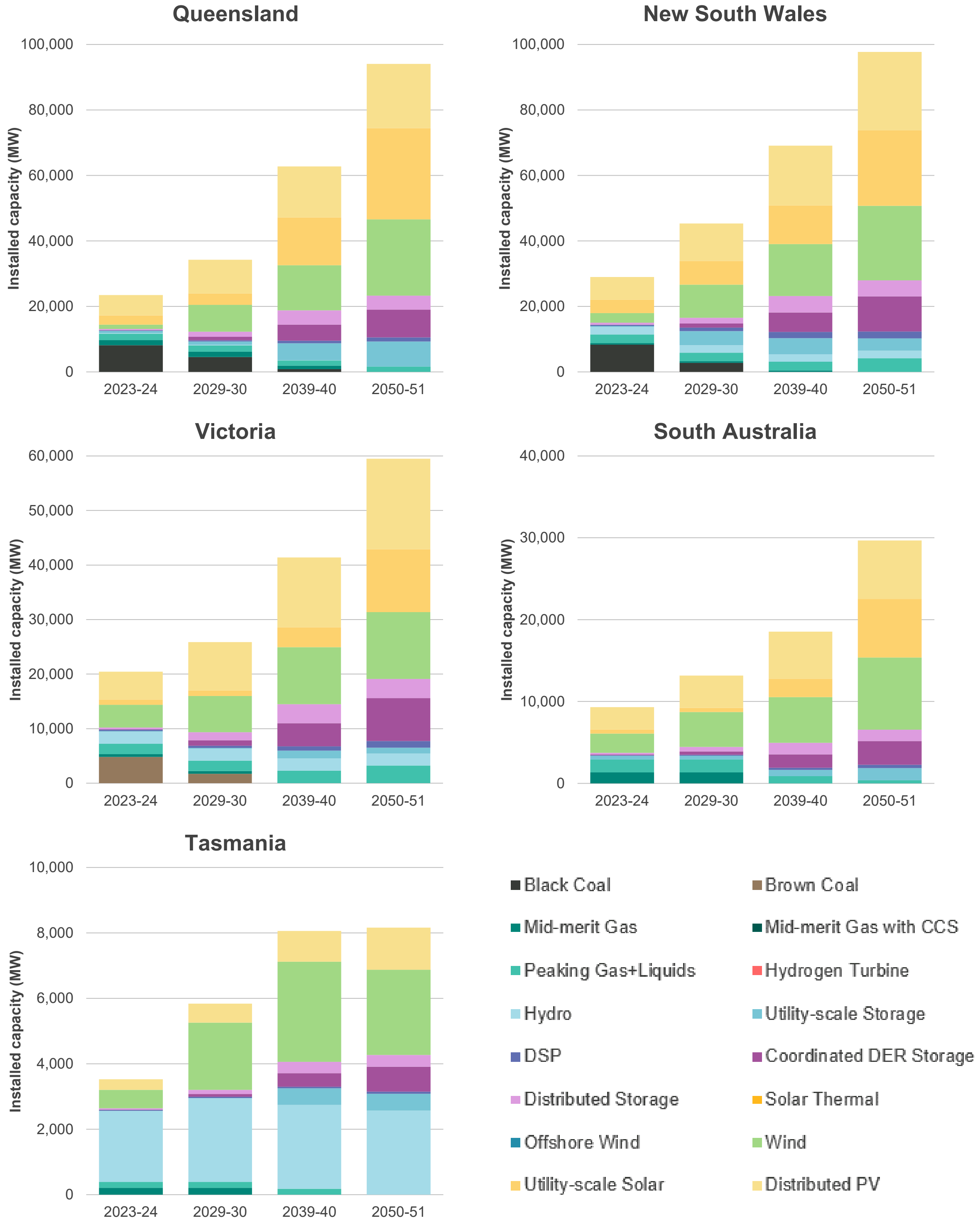
The generation capacity forecast (shown in Figure 5 above) projects that:

- To 2029-30:
  - VRE developments extend beyond the requirements of legislated government policy, as the NEM provides a grid with low emission-intensity to allow other sectors to electrify.
  - This renewable energy development is complemented by utility-scale storage and distributed storage (including coordinated storage).
- The broad retirement of coal generation accelerates across the NEM to meet a strong carbon budget, reducing the surplus energy that would be available with strong growth in VRE and DER. By 2050-51:
  - All coal and mid-merit gas-fired generation has been retired.
  - The development of VRE continues to accelerate as the existing thermal generation fleet retires, and demand further increases as more loads electrify to decarbonise. New firming developments are

> required to support a high VRE penetration, including co-ordinated DER storages but also expanded utility-scale developments that provide greater storage depth. Peaking gas developments provide further resilience, complementing VRE and storage developments and providing flexible, firm capacity to support the operational requirements of the grid.

Figure 6 shows the capacity development at the regional level.

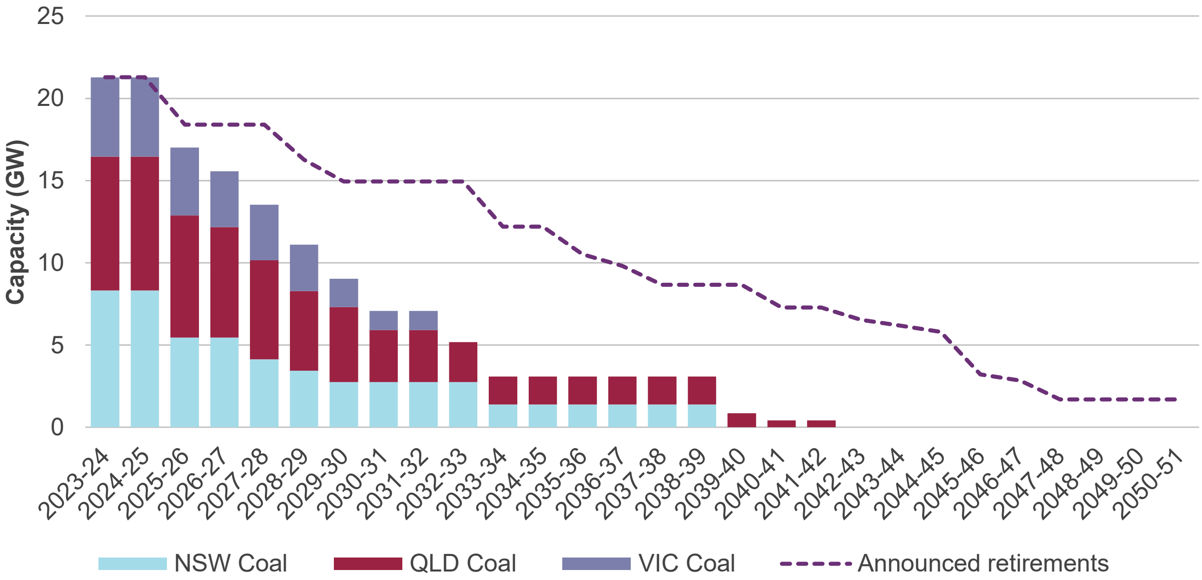
Figure 6 Forecast regional generation capacity to 2050-51, *Step Change*



Emission reduction requirements bring forward coal retirements

Rapid emission reduction is required in *Step Change* due to the application of economy-wide carbon budgets to limit global temperature rise to well below 2°C compared to pre-industrial levels. With a carbon budget applying to all sectors in *Step Change*, electricity emissions are identified as efficient early savings, and in particular higher emitting Victorian brown coal generators are retired sooner than the black coal fleet in New South Wales and Queensland. Over three-quarters of current coal capacity is retired in this scenario within the next 10 years, with all coal withdrawn by the early 2040s, as shown in Figure 7.

Figure 7 Forecast coal retirements, *Step Change*[2]



The pace of transformation will be influenced by the availability of transmission to deliver VRE generation to consumers across the planning horizon.

New VRE capacity outpaces coal retirements due to increasing electrification

Figure 8 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 end of technical life. Key highlights include:

- Significant development in new VRE generation is forecast throughout the planning horizon, offsetting accelerated coal retirements. The growth in renewable energy penetration leads to much lower NEM emissions (as outlined in Section A2.2.3). By 2049-50, the NEM will require approximately 140 GW of large-scale VRE capacity to replace retiring thermal generation and meet increasing energy demand despite strong adoption of energy efficiency measures.
- Coordinated DER storage and distributed energy storage increase the flexibility of the customer load, helping to smooth the customer load profile and manage shorter periods of capacity shortage. Utility-

[2] The *Step Change* coal capacity trajectory forecasts early coal withdrawals, including some forecast withdrawals from 2025-26 beyond current announced retirement dates. These withdrawals could be announced retirements, or some units being mothballed or otherwise unavailable in the lead up to a retirement.

scale energy storage is required to additionally manage more extended periods of high demand and/or low VRE output and provide storage depth to shift surplus renewable energy over longer durations, particularly 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).

Figure 8 Forecast relative change in installed capacity to 2050-51, *Step Change*

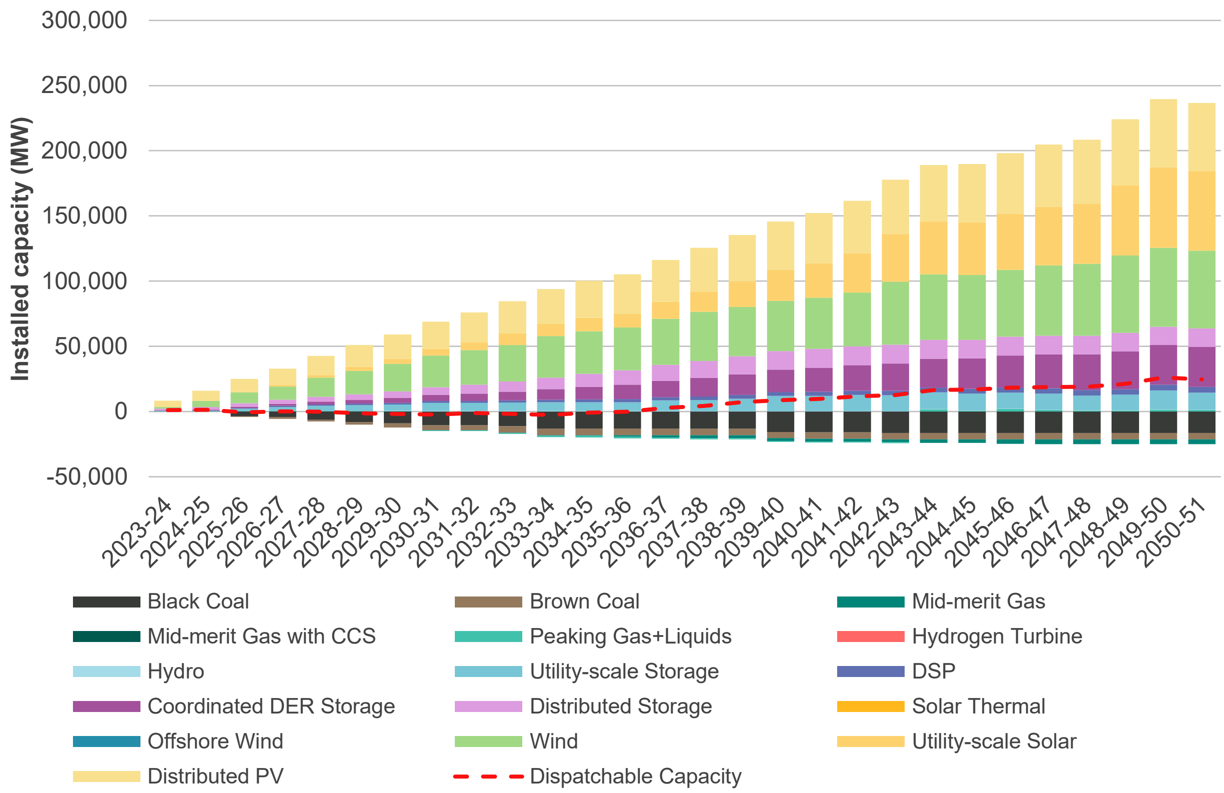
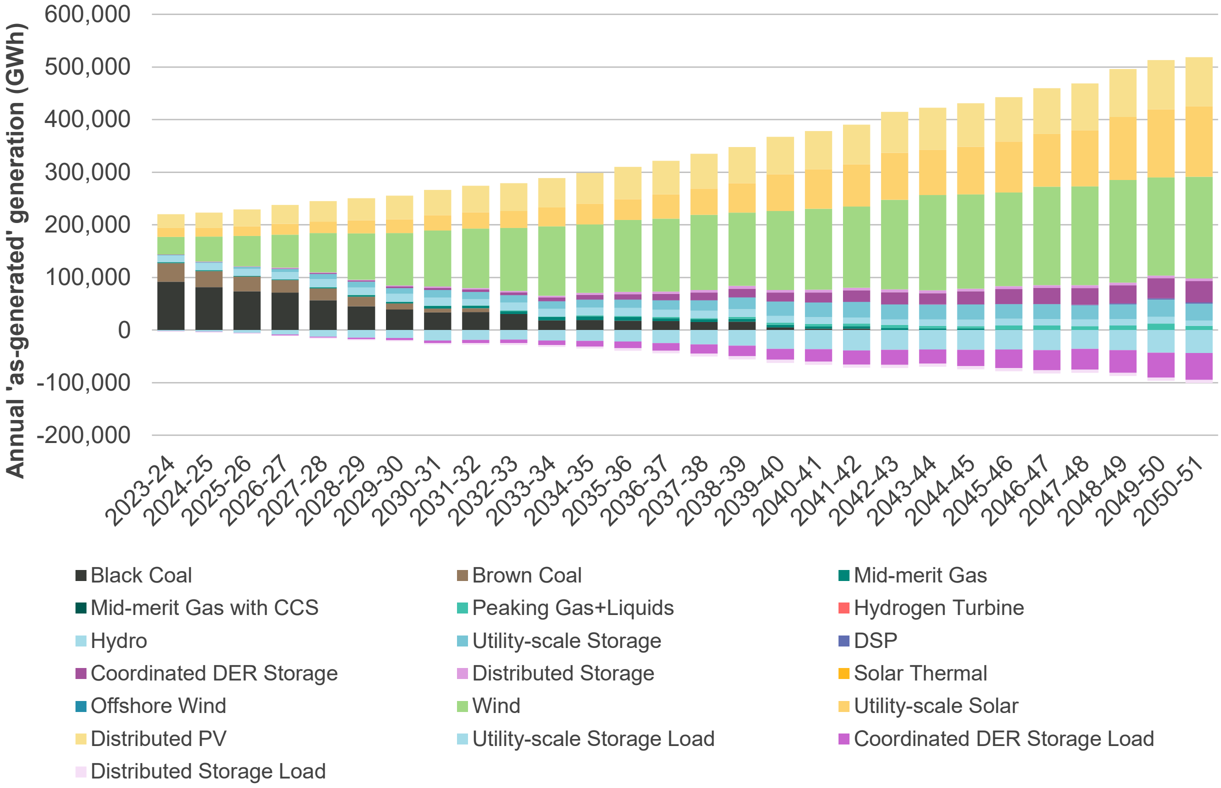


Figure 9 shows the forecast generation mix in *Step Change*, identifying that:

- A rapid shift from thermal generation to VRE is projected within the next decade. As described in Section A4.2.2 of Appendix 4, this capacity will provide periods where there is sufficient renewable energy to supply 100% of consumer demand as early as 2025, and more frequently by 2030. By the mid-2040s the system is expected to have sufficient renewable energy generation potential to meet the needs of consumers almost exclusively on renewable generation across the year, with utilisation of energy storages to manage renewable energy seasonality and intermittency, and with firming support via peaking gas-fired generation. The share of potential resource that is actually dispatched depends on a range of market factors.
- By 2049-50, renewable energy sources are forecast to make up 99% of all generation in the NEM. By then, the projected mix of VRE generation is 46% wind, 31% utility-scale solar and 23% distributed PV.
- Energy storages are heavily utilised to manage variability in the power system, leading to a net increase in overall load (given charging inefficiencies), but also enabling the efficient utilisation of surplus renewable energy generation.

- As the power system transitions, with synchronous generation being displaced by inverter-based resources, the provision of essential power system security services will need to evolve – see Appendix 7 for more information.

Figure 9 Forecast annual generation to 2050-51, *Step Change*



Storage complements VRE, but still a role for peaking capacity

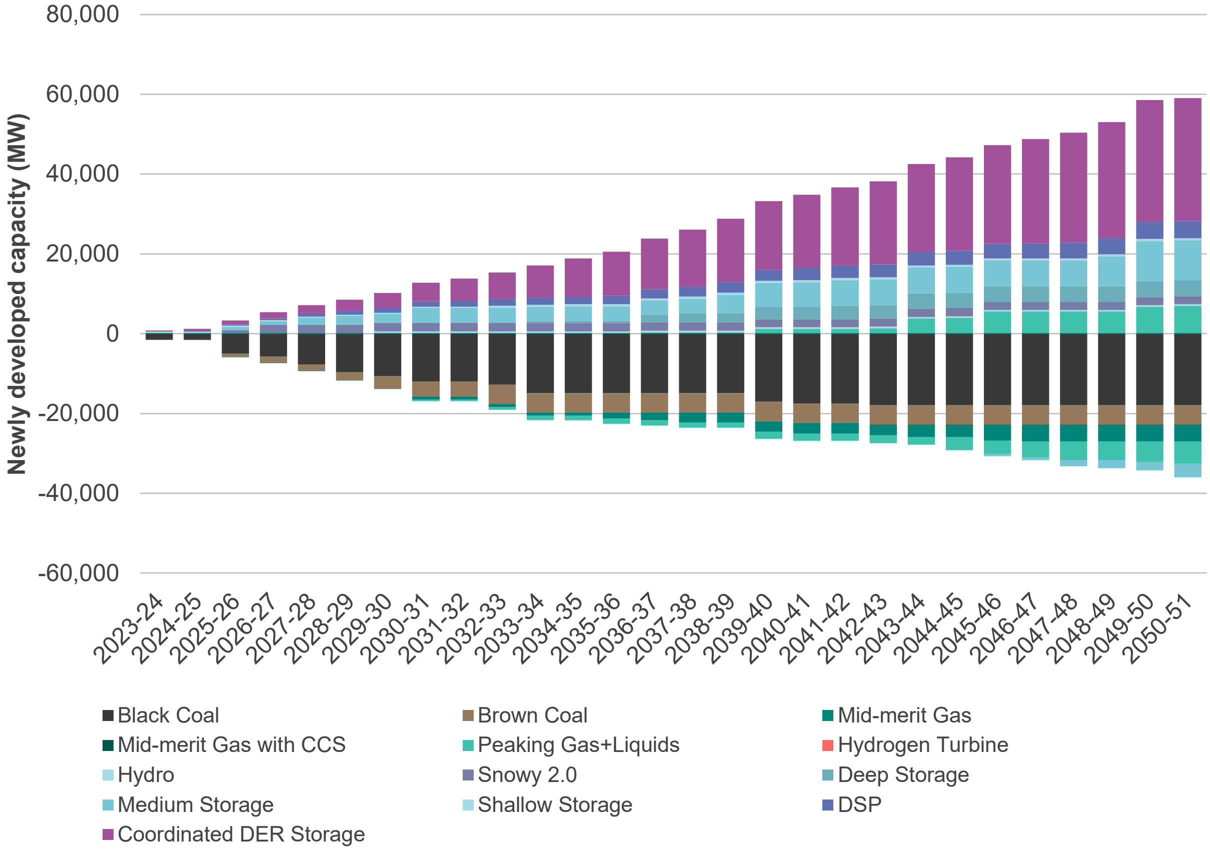
The increased uptake of DER in *Step Change* means that relatively shallow coordinated DER storage systems make up a large part of the new dispatchable capacity developments. These storages primarily meet the need to manage intra-day load variability in VRE and demand.

The shallow storages are complemented by a suite of deeper, utility-scale storage developments to replace accelerated thermal retirements.

Approximately 7 GW of peaking gas is also developed later in the planning horizon, complementing existing peaking capacity and supporting firming requirements as well as providing dispatchable capacity to assist in meeting a growing peak demand.

Figure 10 shows the development of dispatchable technologies. While gas-fired generation capacity is important for firming and dispatchable generation requirements, the operation of higher efficiency mid-merit gas plants is forecast to be low, leading to retirement of these technologies. Peaking gas (and/or storages) are developed to replace this capacity in the longer term after coal has (or has almost) exited the market.

Figure 10 Forecast firm capacity development to 2050, *Step Change*



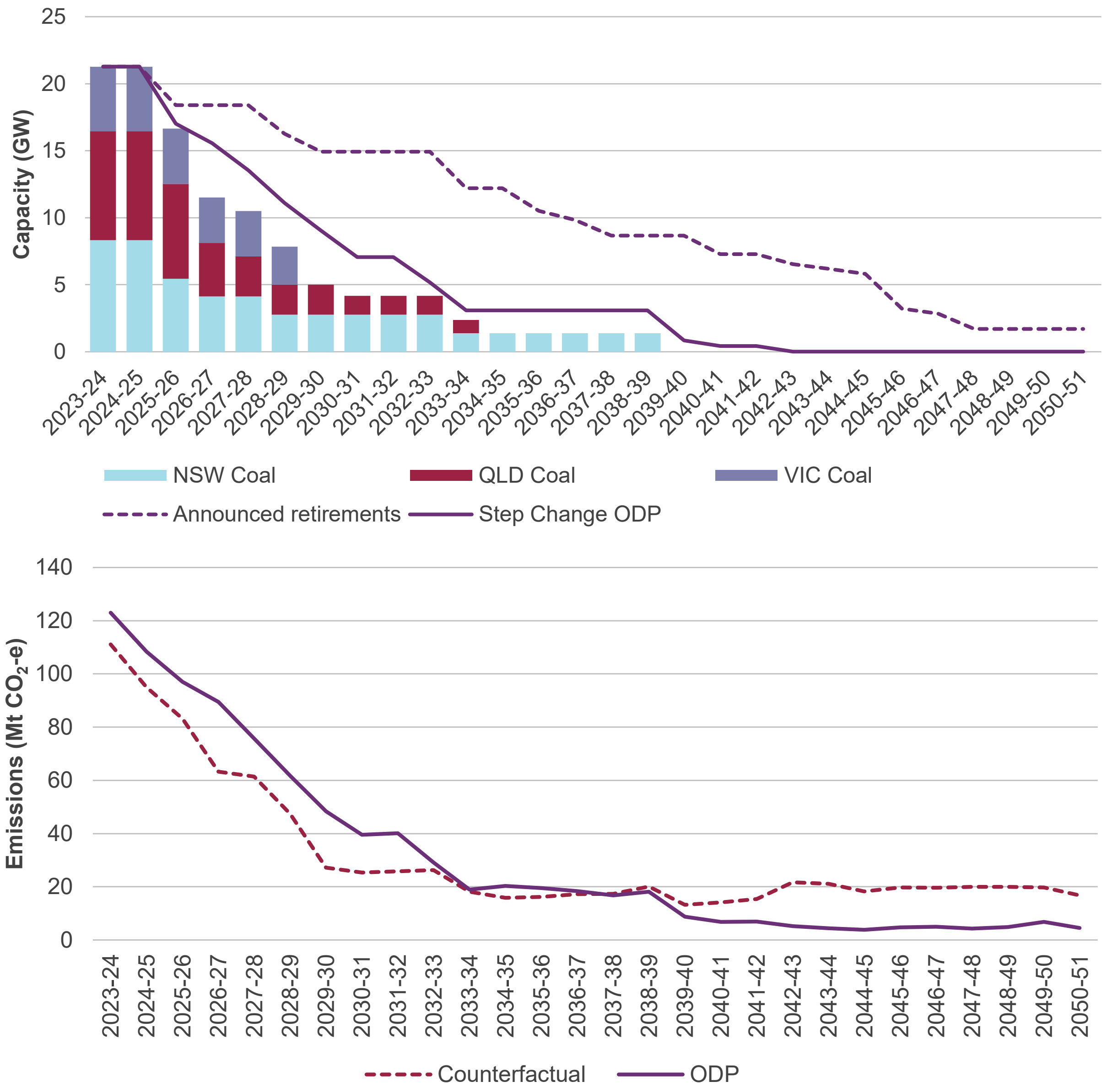
Future generation mix in *Step Change* without the ISP transmission developments

Impact of transmission development on coal retirements

The 2022 ISP identifies material savings to consumers through the expansion of transmission investments (see Section A6.3.1 of Appendix 6). These investments not only deliver positive economic benefits for consumers, but also assist in the transition to a lower carbon energy system. To adhere to the specified carbon budget, coal retirements would be required to be earlier in the counterfactual scenario, whereby VRE operation and capacity expansion is more frequently constrained within the existing transmission system. The more rapid reduction in emissions in the early years provides additional headroom in the carbon budget for more emissions in later years; that is, transmission expansion allows for a more flexible achievement of the required carbon budget, enabling coal operation to operate longer than in the counterfactual while still delivering equivalent cumulative emissions to 2050, but lowering costs to consumers.

The counterfactual development path cannot develop VRE to the same extent as those alternative development paths that have transmission development without significant curtailment of those resources. The counterfactual development path therefore relies on alternative generation sources such as mid-merit gas in the later years of the horizon, and a more rapid development of wind generation in the early years (but less capacity in total in later years). Figure 11 below shows a comparison between the coal retirements in the counterfactual (bars) and ODP (full line), contrasted with the announced closure dates (dashed line). Below the figure is a comparison in the emissions trajectory between the counterfactual and ODP.

Figure 11 Forecast coal retirements (top) and emissions trajectory (bottom) to 2050-51, *Step Change* counterfactual



Capacity development in the counterfactual development path

Limitations to REZ access require a more diverse mix of technologies to meet the needs of the future NEM. New mid-merit gas-fired generation is developed in the counterfactual to help meet demand particularly in the later years of the horizon, with lower emissions relative to the emissions intensity of the current fleet. Approximately 10 GW of offshore wind would also be developed by 2049-50, particularly to service loads in the Sydney, Newcastle, Wollongong area which otherwise would have limited local development options without the deployment of the Sydney Ring project.

Investment in carbon sequestration technologies is also required later in the horizon in Queensland and Victoria to couple with mid-merit gas-fired generation and provide a near-zero emissions intensity means of providing dispatchable capacity and operating within the carbon budget.

Figure 12 shows the evolution of the generation mix in *Step Change's* counterfactual development path.

Figure 12 Forecast NEM generation capacity to 2050-51, *Step Change* counterfactual

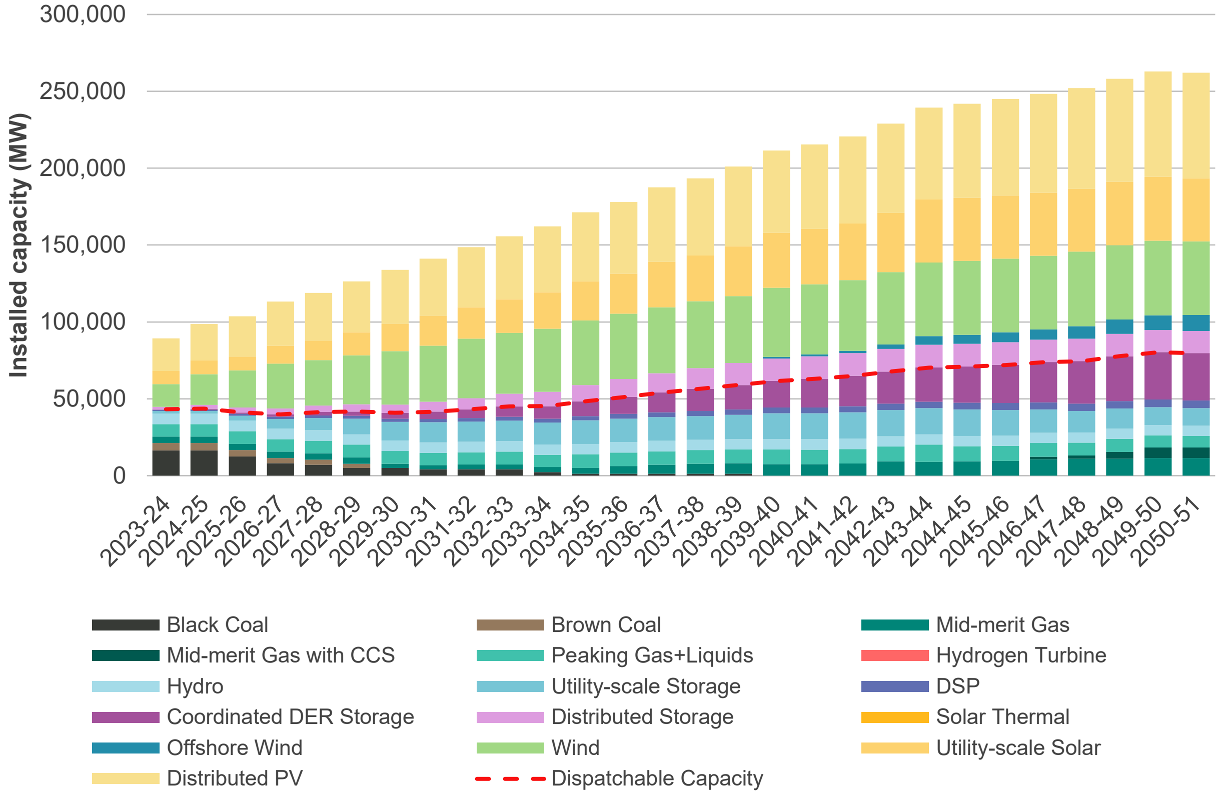
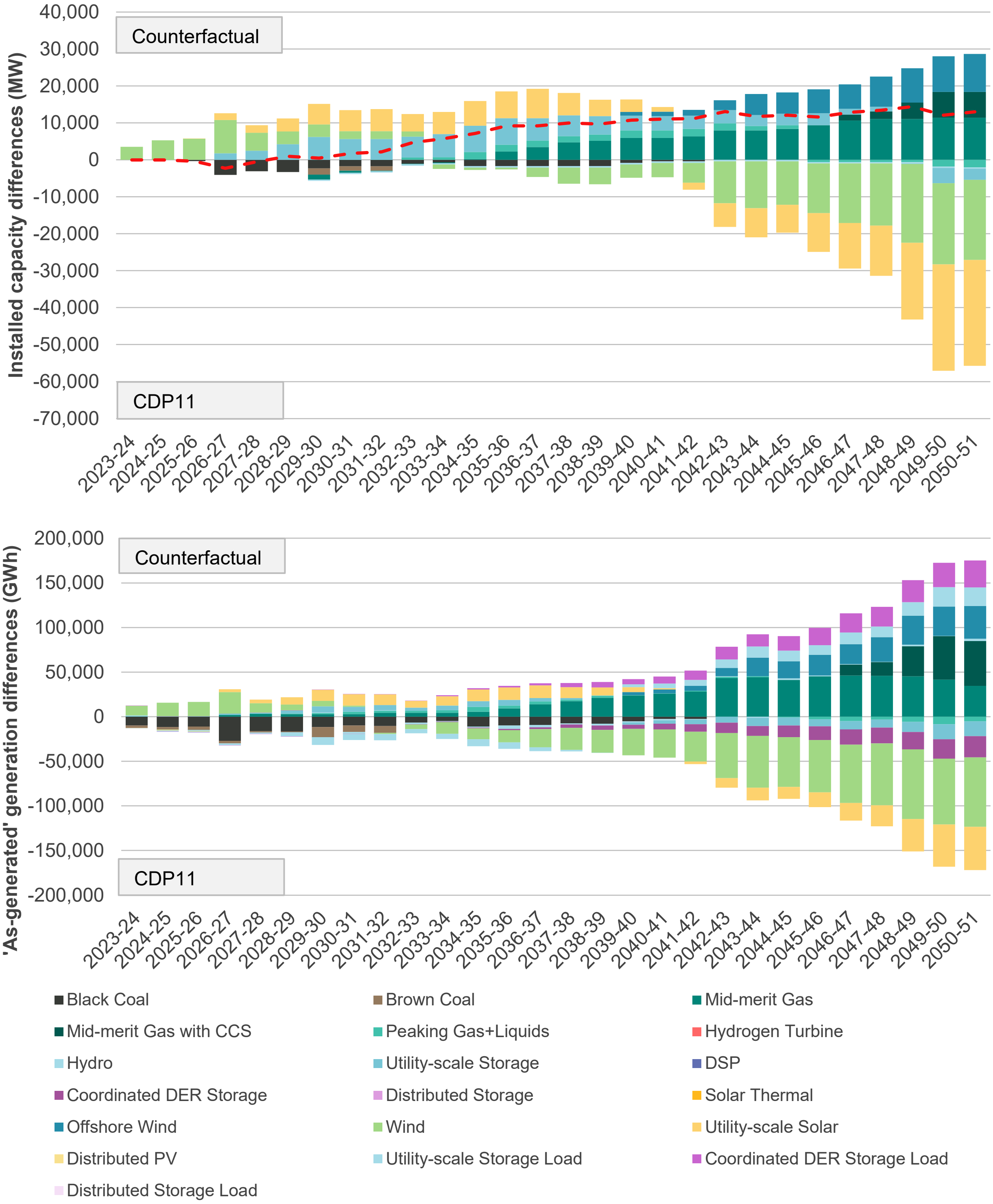


Figure 13 below shows the differences in ISP developments and generation with the benefit of the efficient transmission developments identified in *Step Change's* CDP11, compared to the counterfactual. A positive value indicates higher total installed capacity in the counterfactual development path.

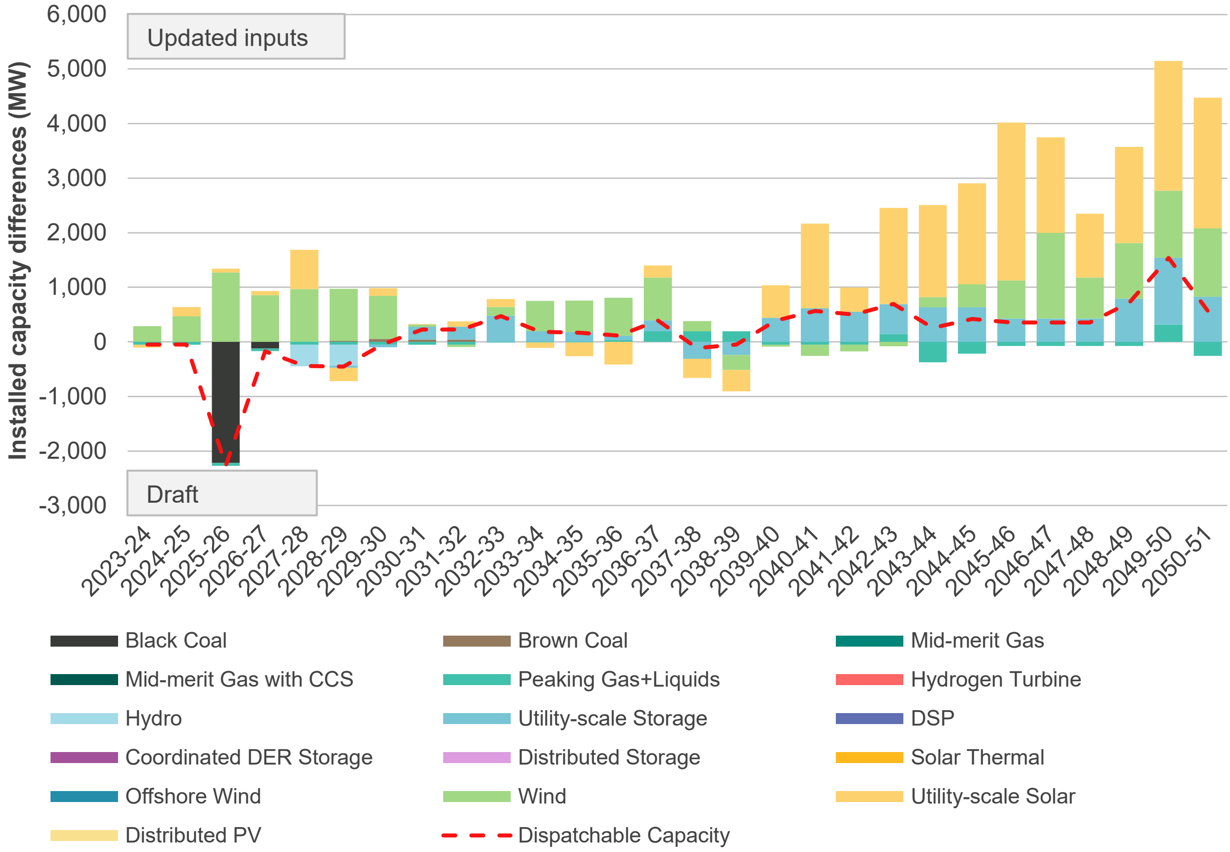
Figure 13 Forecast capacity developments (top) and generation (bottom) to 2050 compared to counterfactual, *Step Change*



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

As shown in Figure 14, the updated assumptions result in more wind development in early years compared to the Draft ISP, primarily as a result of the early withdrawal of Eraring Power Station. The announced early closures of Bayswater and Loy Yang A have minimal impact on the capacity developments of *Step Change*. In the long term, increased VRE with deeper storage are forecast due to an increase in the granularity of the capacity expansion models.

Figure 14 Forecast NEM generation capacity to 2050-51 in Step Change, final assumptions compared to Draft ISP assumptions



A2.3.2 *Progressive Change*

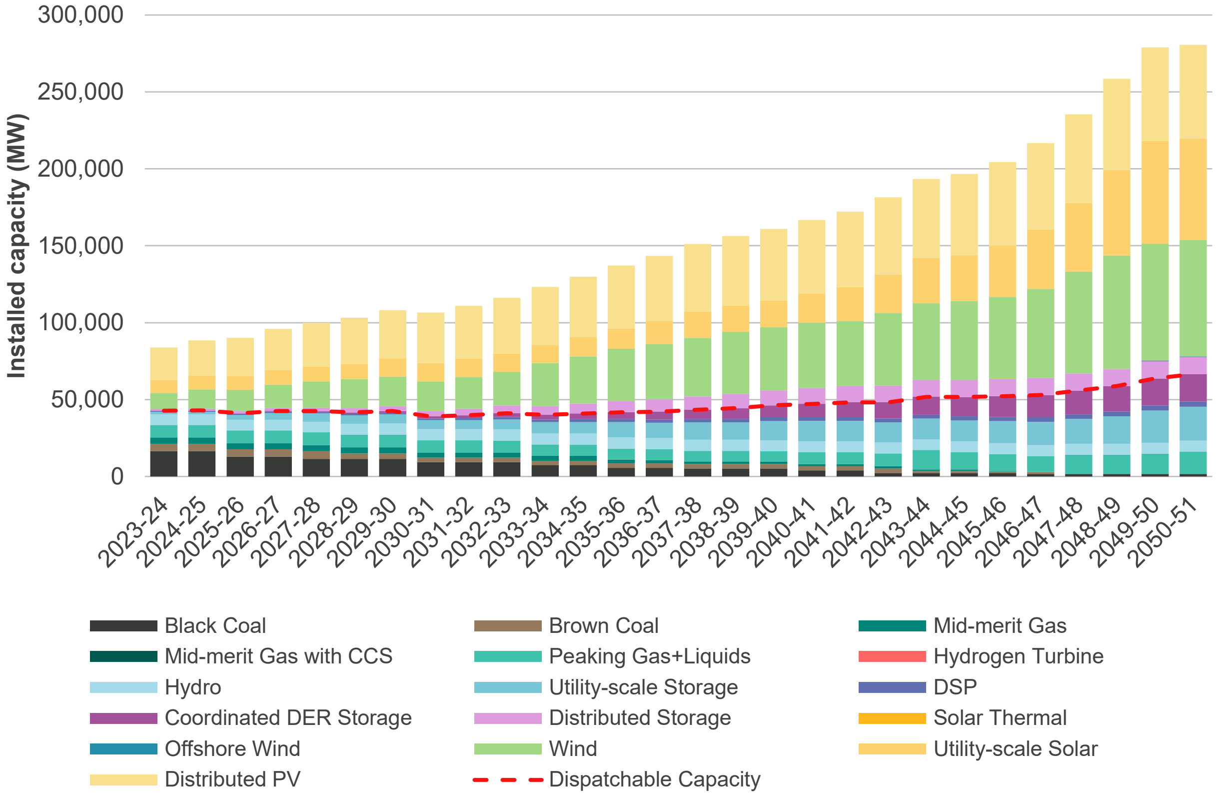
The *Progressive Change* scenario represents a future that delivers action towards an economy-wide net zero emissions objective by 2050, with a slower initial transition than *Step Change* before deploying low and zero emissions technologies. To achieve the net zero emissions outcomes, electrification of other sectors across Australia's economy occurs as the 2050 deadline approaches.

This section describes the ISP developments that are forecast to maximise net market benefits in *Progressive Change*.

Generation and storage development in *Progressive Change*

Figure 15 presents the forecast capacity mix for the NEM across the outlook period to 2049-50.

Figure 15 Forecast NEM generation capacity to 2050-51, *Progressive Change*



The generation capacity forecast (shown in Figure 15 above) projects that:

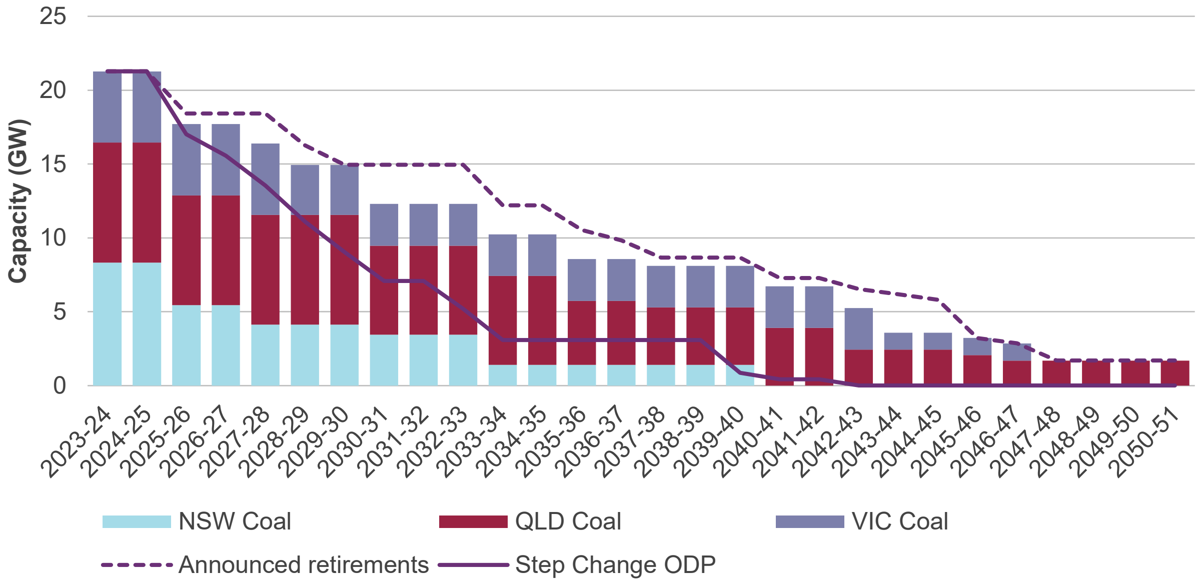
- To 2029-30:
  - Renewable energy policies in Queensland, New South Wales, Victoria, and Tasmania will drive the vast majority of VRE developments in those regions.
  - Total installed capacity of coal will reduce by 36% to 15GW. Coal generation will reduce as new renewable energy developments increase, complemented by additional energy storage.
- By 2049-50:

- Coal power stations continue to retire to meet carbon budget requirements, with less than 2 GW remaining by 2050. This demonstrates that while the scenario achieves net zero, it retains an economic level of emissions that would require offsetting through carbon sequestration in other sectors (such as the land-use sector).
- Development of VRE continues in all regions.
- New large-scale storages of various depths, supported by increasing levels of demand response, coordinated DER storage, and distributed energy storage help to maintain reliability as existing thermal generation retires.
- Retiring gas-fired generation is generally replaced with new peaking thermal generation that helps meet demand during extended periods of low wind and solar output.

Economic drivers bring forward coal retirements

The change in modelled coal closures in *Progressive Change*, relative to announced closure years and to *Step Change* (for comparison), is shown in Figure 16.

Figure 16 Forecast coal retirements, *Progressive Change*



Coal retirements in *Progressive Change* are accelerated compared to the expected closure years currently nominated by market participants. The key driver of these early retirements is the development of new VRE and energy storage and the impact this has on wholesale prices and coal generation volumes. By 2029-30, coal generation is projected to produce 37% of total electricity generated, compared to 65% in 2020-21.

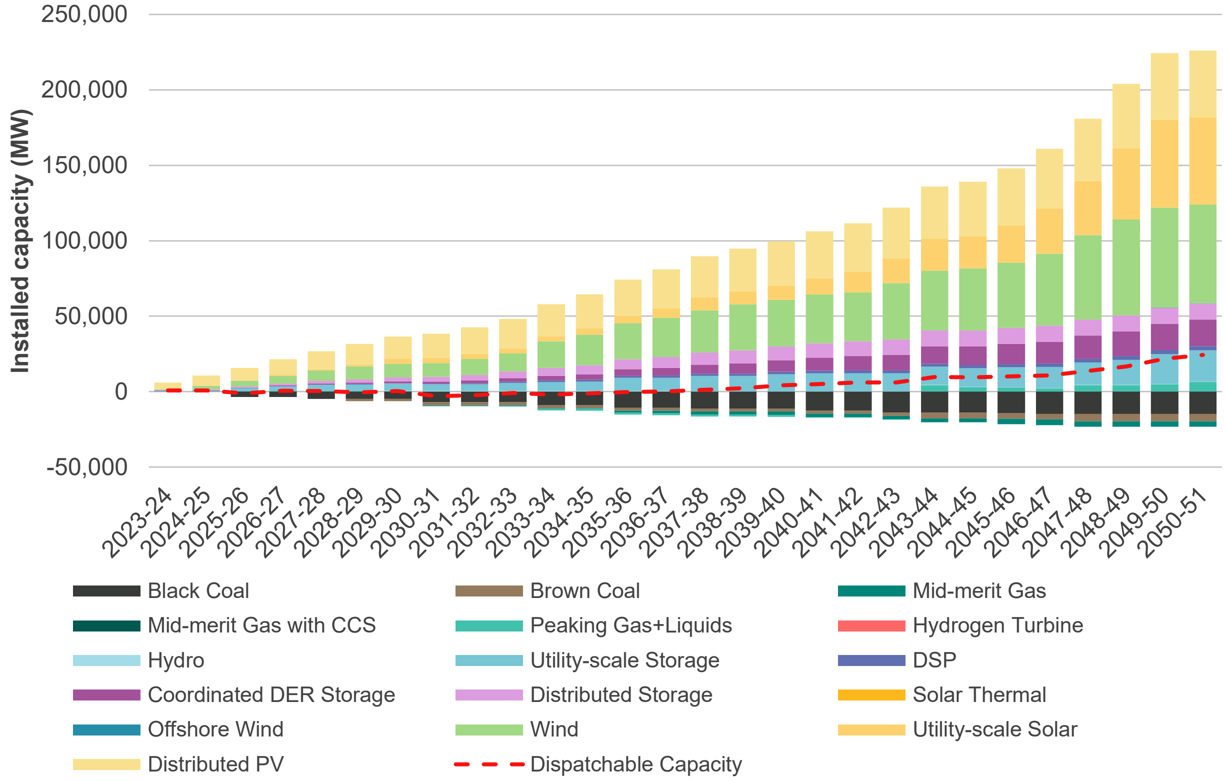
From 2030, coal-fired generators are forecast to continue to retire earlier than their current closure timings. Unlike *Step Change*, the more generous carbon budget available allows earlier retirement of the more costly black coal generators rather than the more emissions-intensive brown coal generators. By 2050, coal capacity has decreased considerably to 1.7 GW, representing 1% of total capacity and producing approximately 2% of the total generation.

VRE development accelerates as new loads electrify

Figure 17 shows the cumulative change in investment and withdrawal by fuel and technology type over time. Key highlights include:

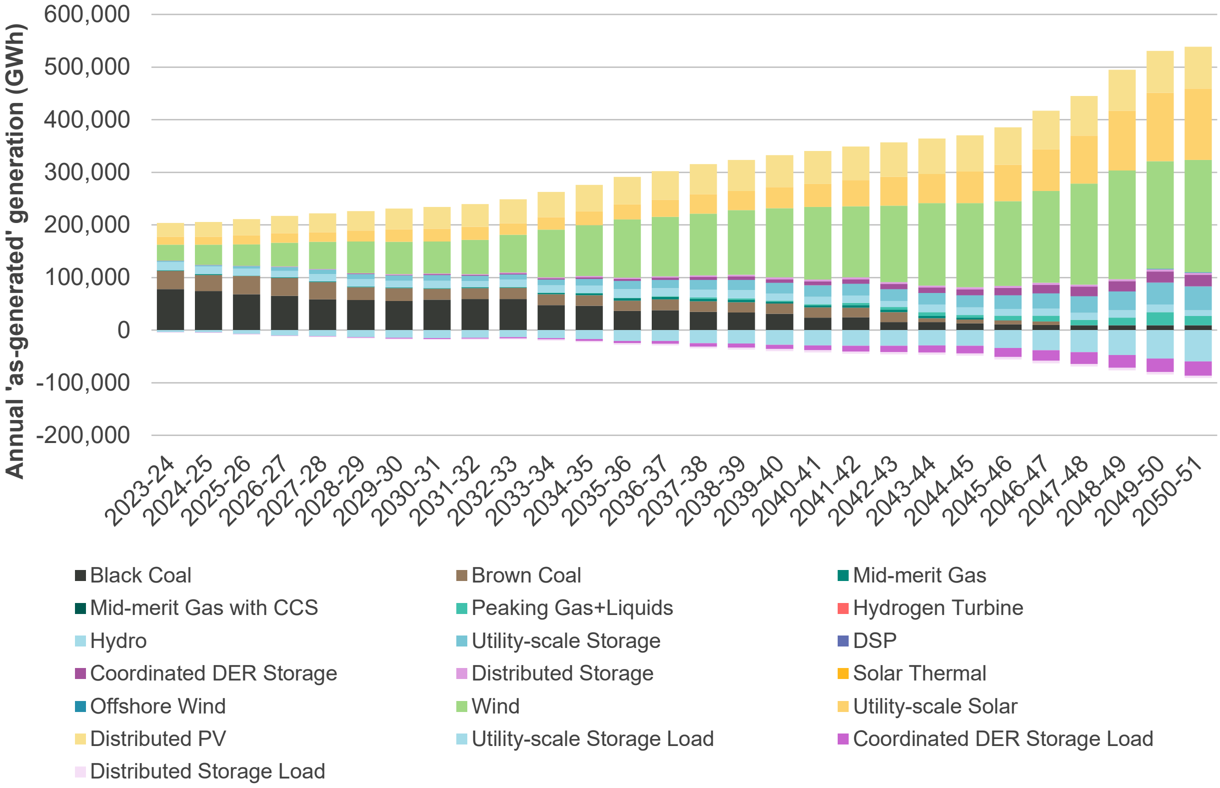
- Early thermal retirements are forecast to be offset by a combination of VRE, energy storage and DER. Gas generator retirements are generally replaced by new peaking gas developments. These developments provide firming support to offset coal retirements.
- By 2049-50, in addition to over 60 GW of distributed PV, the NEM is forecast to need over 140 GW of large-scale VRE to replace existing capacity and to meet increasing energy consumption due to electrification. This is complemented by over 20 GW of new large-scale energy storage, in addition to coordinated DER storage and distributed energy storage from residential batteries and EVs.

Figure 17 Forecast relative change in installed capacity to 2050-51, *Progressive Change*



In terms of energy production, Figure 18 demonstrates the change in the energy mix that leads to a very different energy mix to today's energy system, both technologically and geographically. Renewable energy is forecast to expand to approximately 93% of energy generated by 2049-50. The projected mix of VRE by 2049-50 is approximately evenly split between wind (49%) and solar generation (51%), with 62% of the solar generation being utility-scale and 38% of the solar generation being distributed PV.

Figure 18 Forecast annual generation to 2050-51, *Progressive Change*

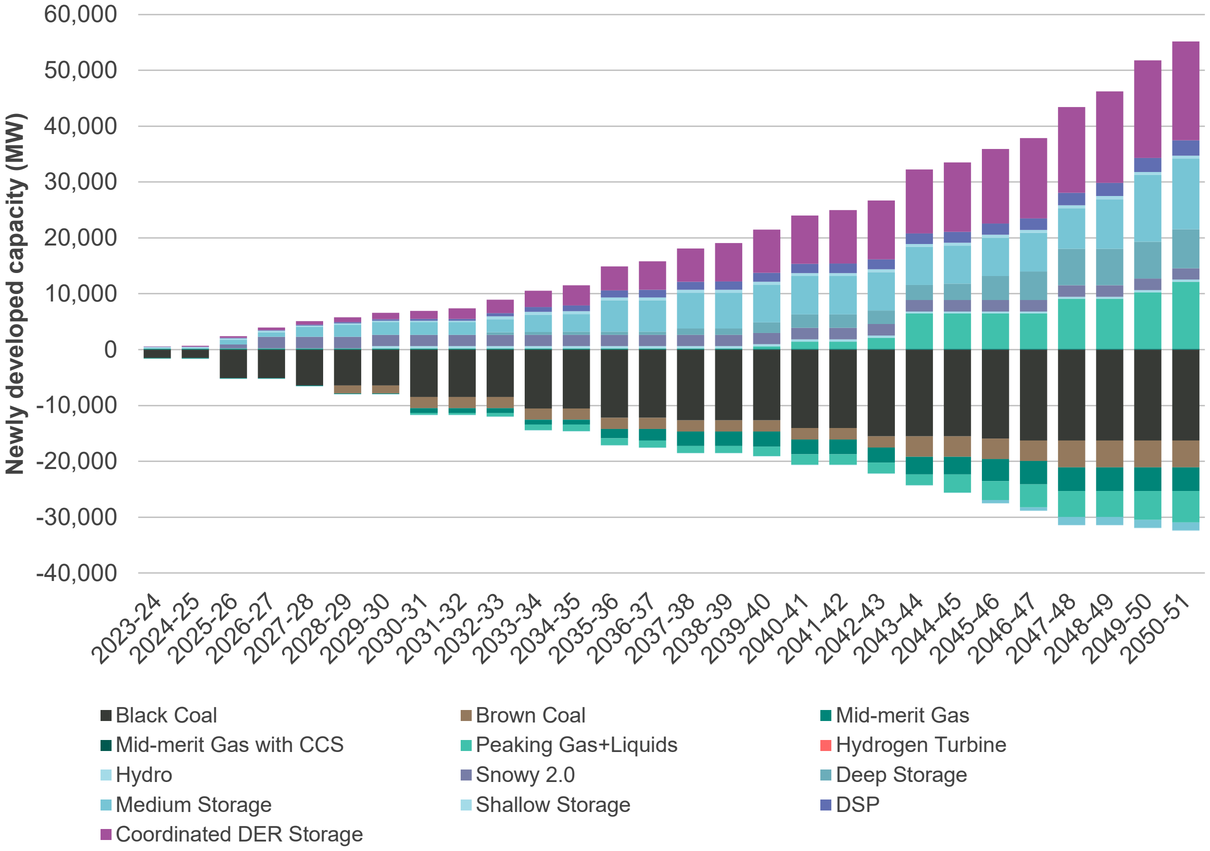


Storage complements VRE, but still a role for peaking capacity

Consistent with *Step Change*, significant expansion of various energy storage technologies are forecast, complemented by peaking gas capacity providing new dispatchable capacity and complement the energy generated by VRE developments.

Figure 19 demonstrates the change in firm capacity across the forecast horizon. By the 2040s, when coal capacity has almost entirely retired, new peaking gas capacity replaces retiring mid-merit and peaking gas plant.

Figure 19 Forecast firm capacity development to 2050-51, *Progressive Change*



Contrasting *Progressive Change* with *Step Change*

Figure 20 below presents the capacity difference between *Progressive Change* and *Step Change*. It is evident from this figure that by the end of the horizon, the difference between the scenarios starts to narrow as the scale of electrification in *Progressive Change* catches up with the earlier developments of *Step Change*.

The key differences from *Step Change* are:

- The slower emission reduction objectives of Progressive Change decrease the speed at which VRE is developed, slowing the retirement of existing coal capacity. By the end of the horizon the difference in VRE capacity between scenarios is more muted.
- Progressive Change is characterised by lower uptake of distributed storage technologies (fewer residential battery systems and fewer EVs that are capable of vehicle-to-grid operation), which increases the need for utility-scale firming developments in the long term, relative to Step Change.

Figure 20 Comparison of generation capacity developed between *Progressive Change* and *Step Change*

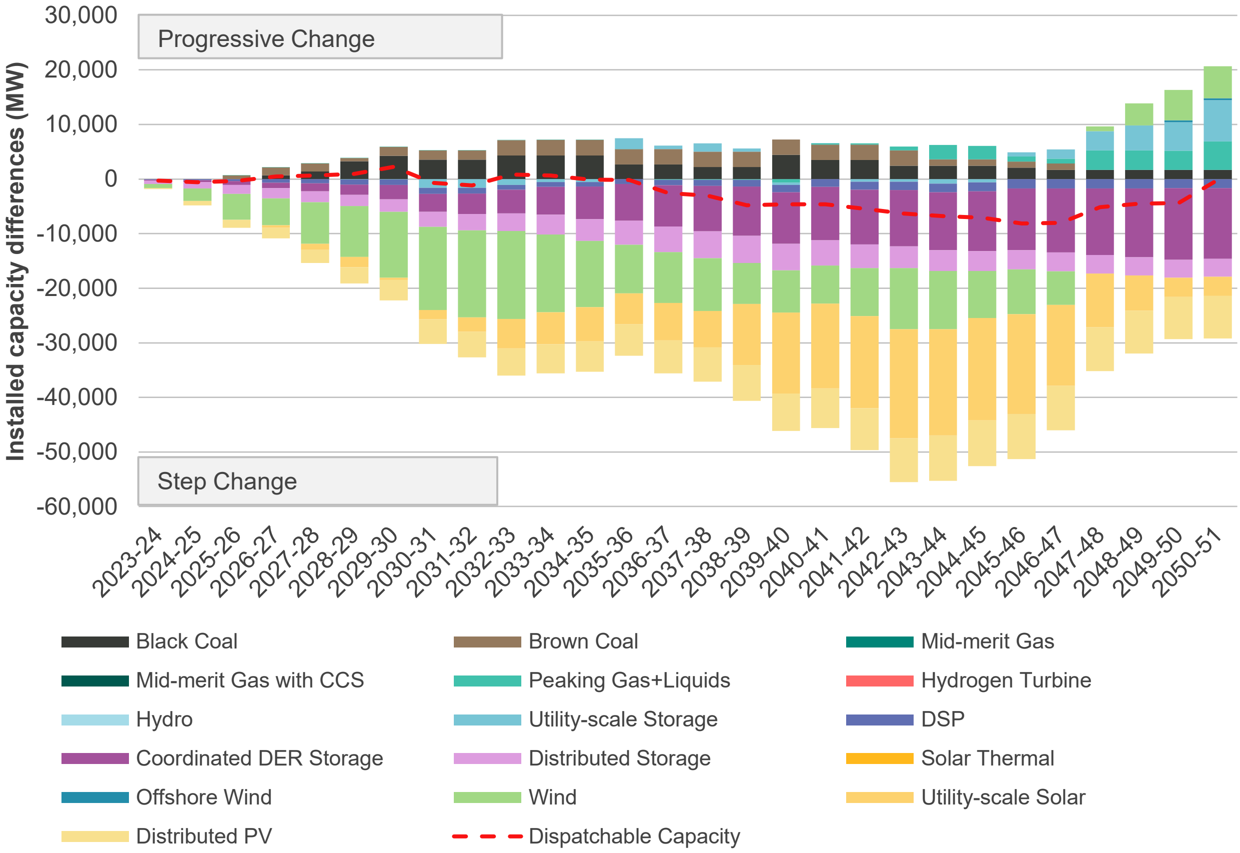


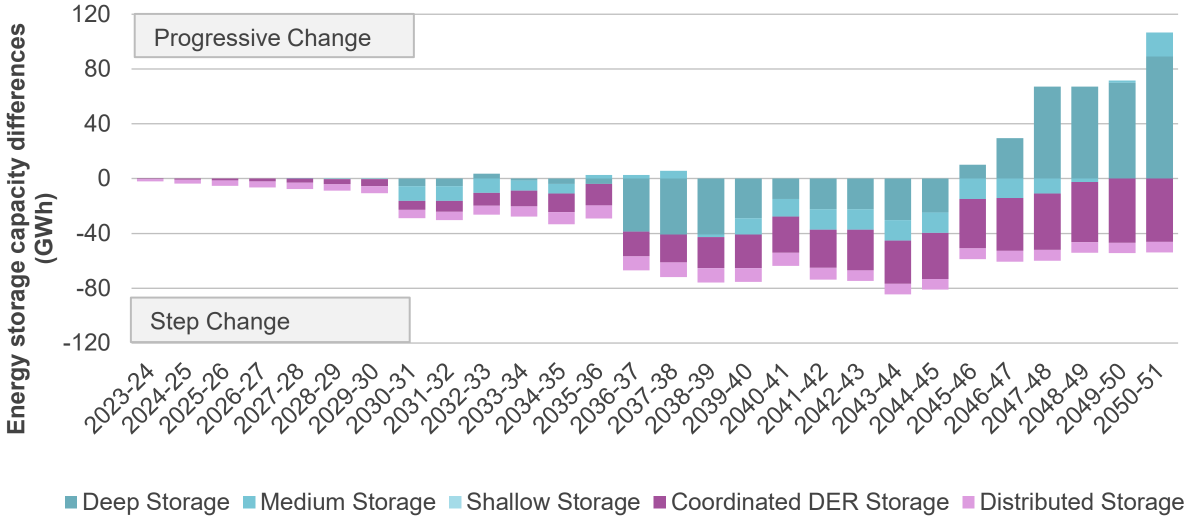
Figure 21 demonstrates the lower uptake of coordinated DER storage and distributed energy storage in *Progressive Change* compared to *Step Change*.

Towards the end of the horizon, there is a greater need for deep energy storage and gas developments in *Progressive Change* compared to *Step Change,* driven by higher peak demand and energy forecasts (from the mid-2040s), as well as lower uptake of coordinated DER storage and distributed energy storage.

These differences mean that compared to *Step Change, Progressive Change* has both higher and more variable demands due to the reduced smoothing effect of distributed storage. This leads to a greater need for both firming technologies and utility-scale storage. Furthermore, with less demand flexibility, the seasonal variability in energy consumption may increase the value provided by deeper storages that can provide longer energy shifting capability, relative to *Step Change*, particularly in the late 2040s when greater electrification influences the demand for electricity.

Further discussions on energy storage operability are outlined in Section A.4.2.5 of Appendix 4.

Figure 21 Comparison of energy storage capacity between *Step Change* and *Progressive Change* scenarios



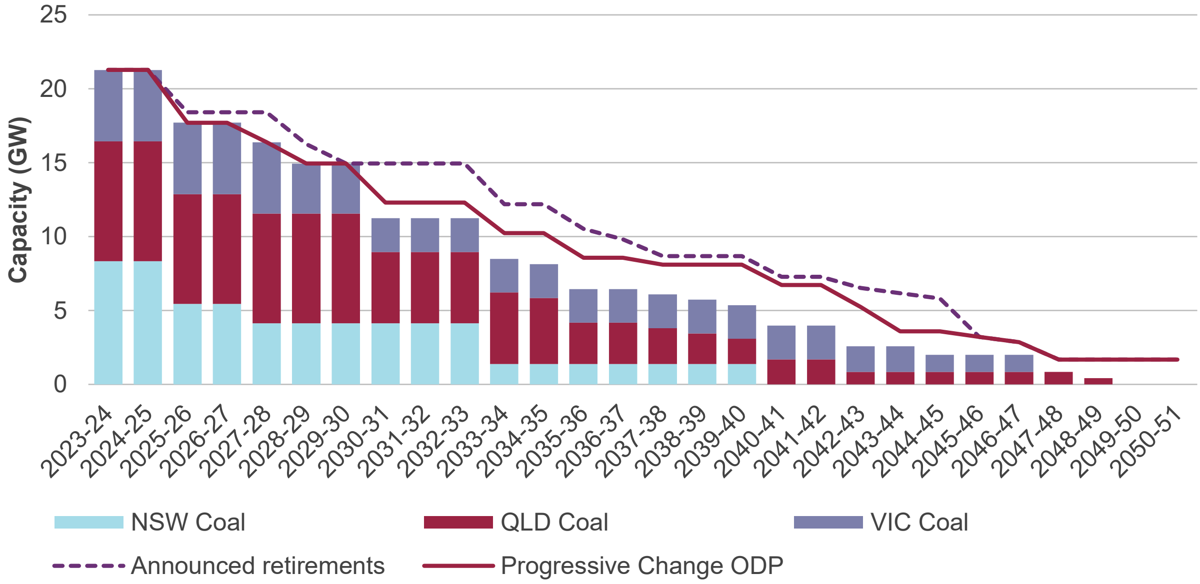
Future generation mix in *Progressive Change* without the ISP transmission developments

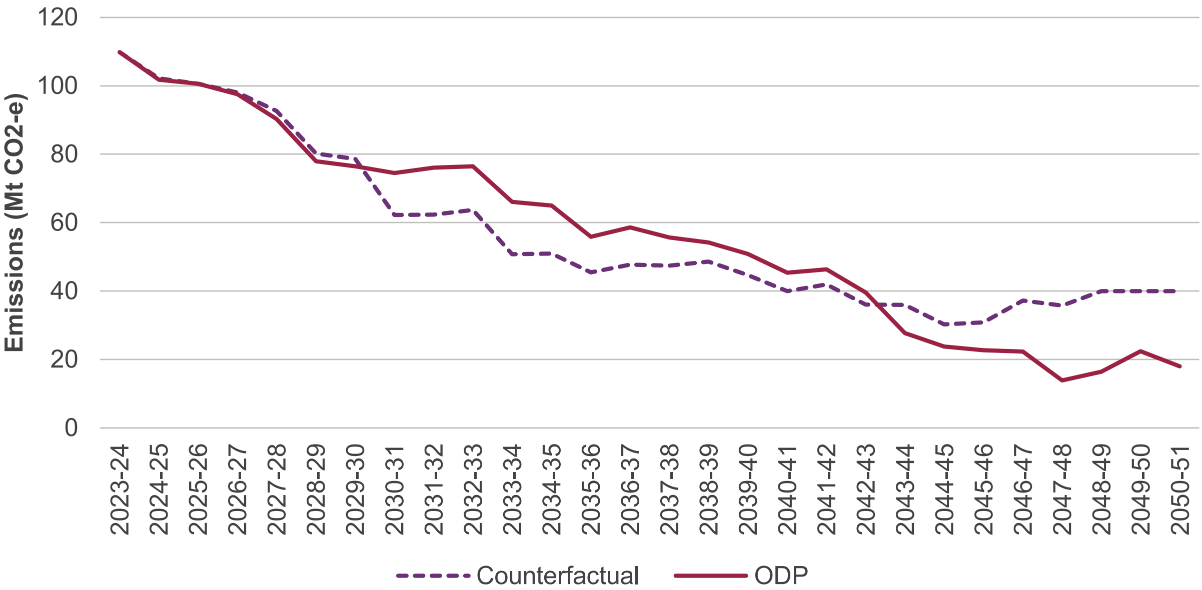
Impact of transmission development on coal retirements

As a result of the carbon budget, which is in place beyond 2030 in *Progressive Change*, coal is retired earlier in the counterfactual development path than the retirements in the ODP. As with *Step Change*, without transmission augmentation there is a higher reliance on gas-fired generation in the later part of the horizon as VRE generation is curtailed due to transmission congestion, leading to earlier coal closures to enable greater headroom in the carbon budget.

Figure 22 below contrasts the coal retirement schedule in *Progressive Change* with and without transmission augmentation.

Figure 22 Forecast coal retirements (top) and emissions trajectory (bottom) to 2050, *Progressive Change* counterfactual



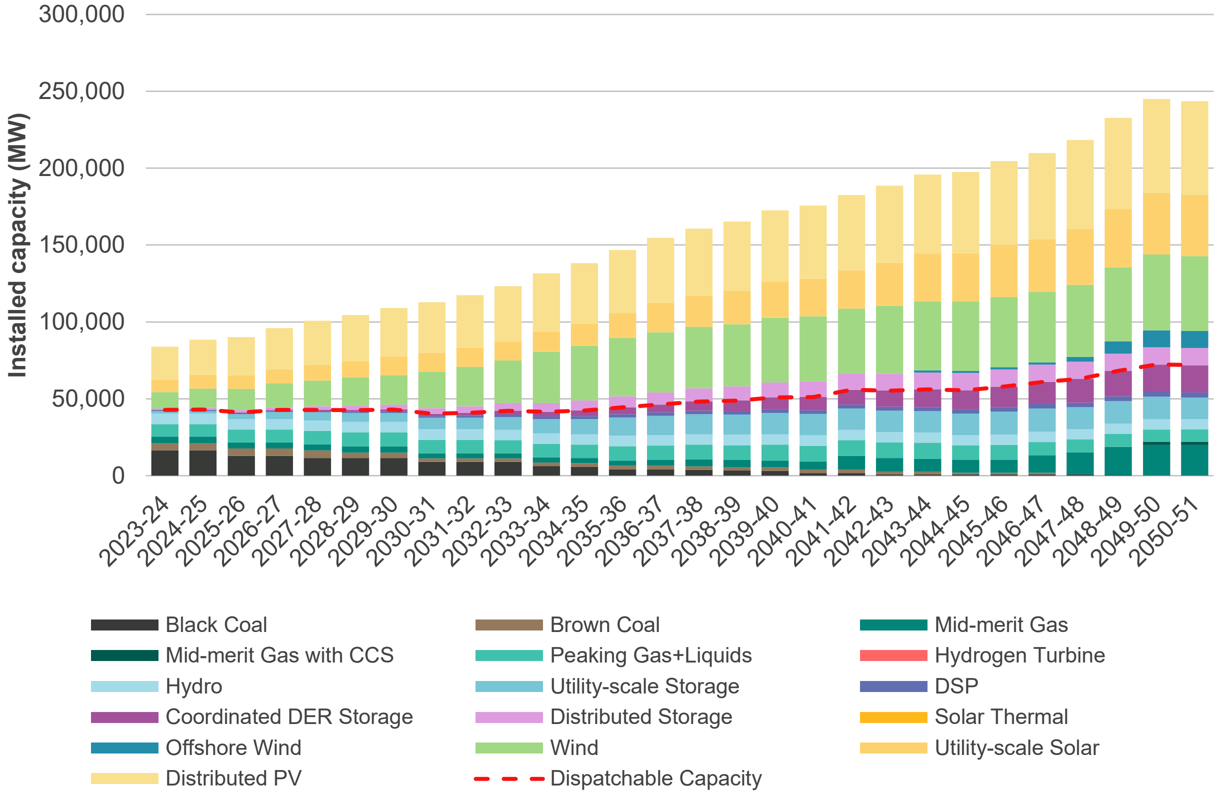


Capacity development in the counterfactual development path

Figure 23 below presents the capacity development outlook for *Progressive Change* in the absence of further transmission developments.

The development outlook for the counterfactual incorporates a faster development of VRE as well as the previously described earlier coal retirements. From the mid-2030s, both peaking and mid-merit gas-fired generation (with and without CCS) plays 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 load, such as offshore wind development.

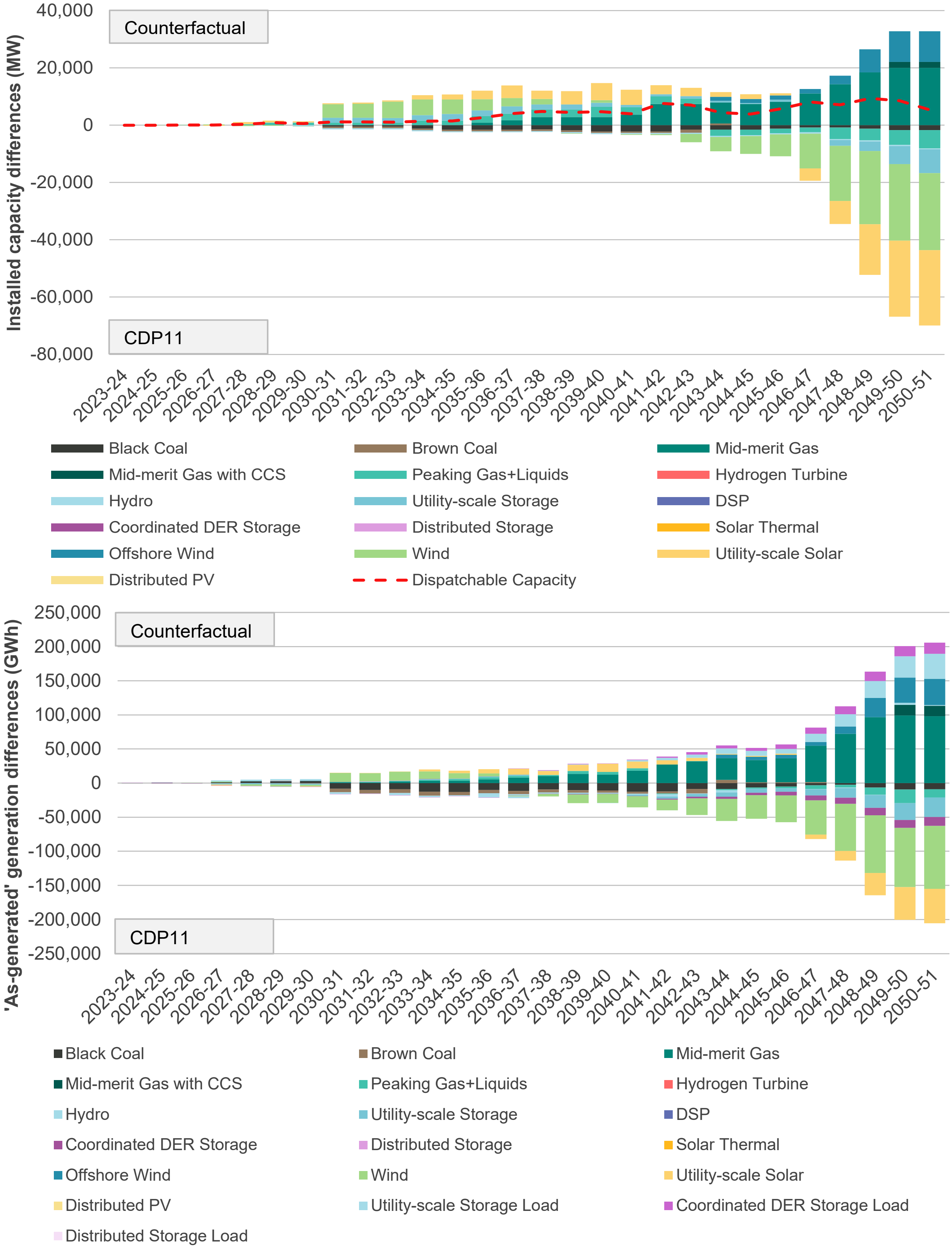
Figure 23 Forecast NEM generation capacity to 2050-51, *Progressive Change* counterfactual



For comparison, Figure 24 presents the difference in installed capacity and dispatched generation between CDP11 and the counterfactual.

Without the ability to augment the transmission access for REZs to reduce curtailment and with more rapid coal retirements, there are earlier VRE developments in the counterfactual, complemented by additional energy storage.

Figure 24 Forecast capacity developments (top) and generation (bottom) to 2050-51 compared to counterfactual, *Progressive Change*



A2.3.3 *Hydrogen Superpower*

The *Hydrogen Superpower* scenario represents a world with strong emission reduction targets, leading to even faster electrification of Australia's economy. It also features increasing availability of hydrogen production, supported by strong technology cost improvements, and the emergence of significant hydrogen exports to global consumers. As hydrogen becomes ubiquitous, development of new domestic industry (such as green steel) is forecast. In this scenario, Australia's economic outcomes are stronger relative to other scenarios.

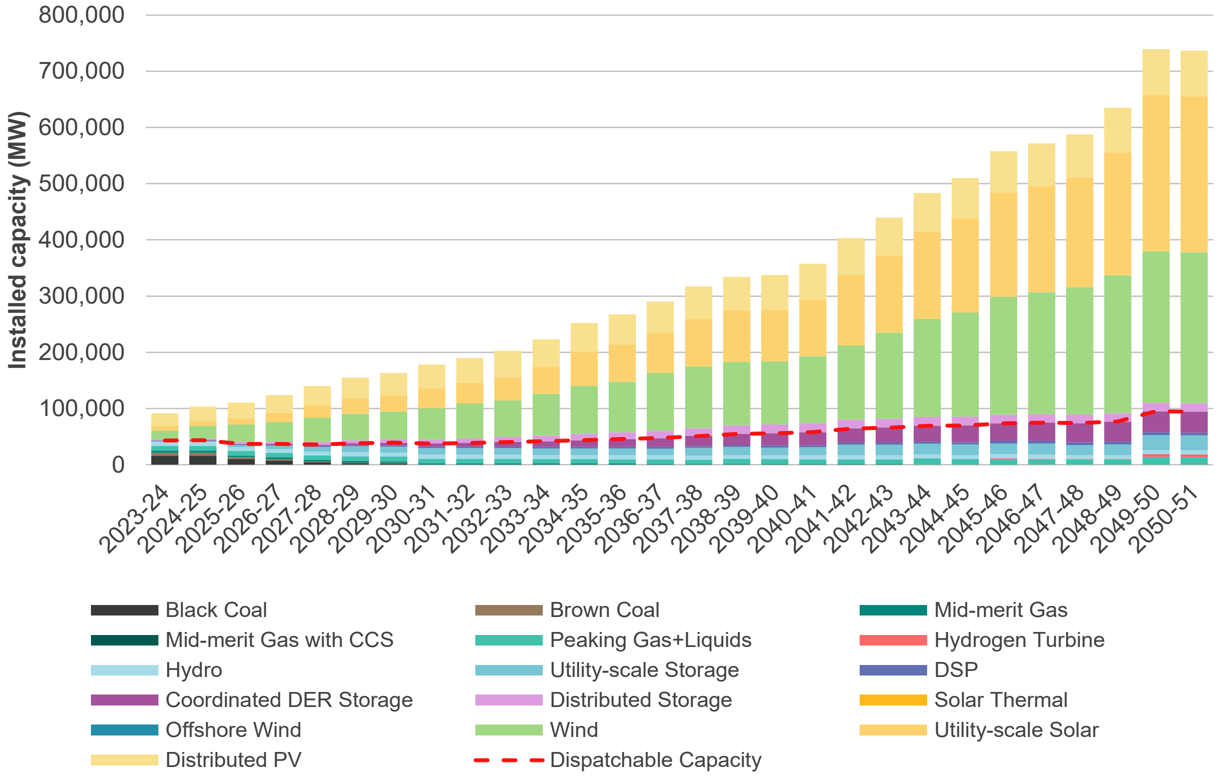
Generation and storage development in *Hydrogen Superpower*

In *Hydrogen Superpower*, the outlook for generation developments includes:

- To 2029-30:
  - Significant coal retirements result in only 3 GW of operating coal capacity by the end of the decade, 85% lower than existing capacity, in response to the ambitious decarbonisation objectives. The remaining coal capacity retires the following year.
  - To offset the coal retirements, significant VRE developments are forecast, far greater than that required by government policies in all regions. From the 20 GW installed today, a staggering 60 GW would need to be developed by the end of the decade – twice the record annual rate observed recently and 35 GW more than *Step Change*.
- By 2049-50:
  - All mid-merit gas-fired generation has retired.
  - Over 540 GW of large-scale VRE is developed, primarily to meet almost 1,000 TWh of electricity load required for hydrogen export to the scale assumed in the scenario.
  - Approximately 150 GW of electrolyser capacity is needed to meet both export and domestic hydrogen demand.

Figure 25 illustrates the vast scale of generation development in this scenario.

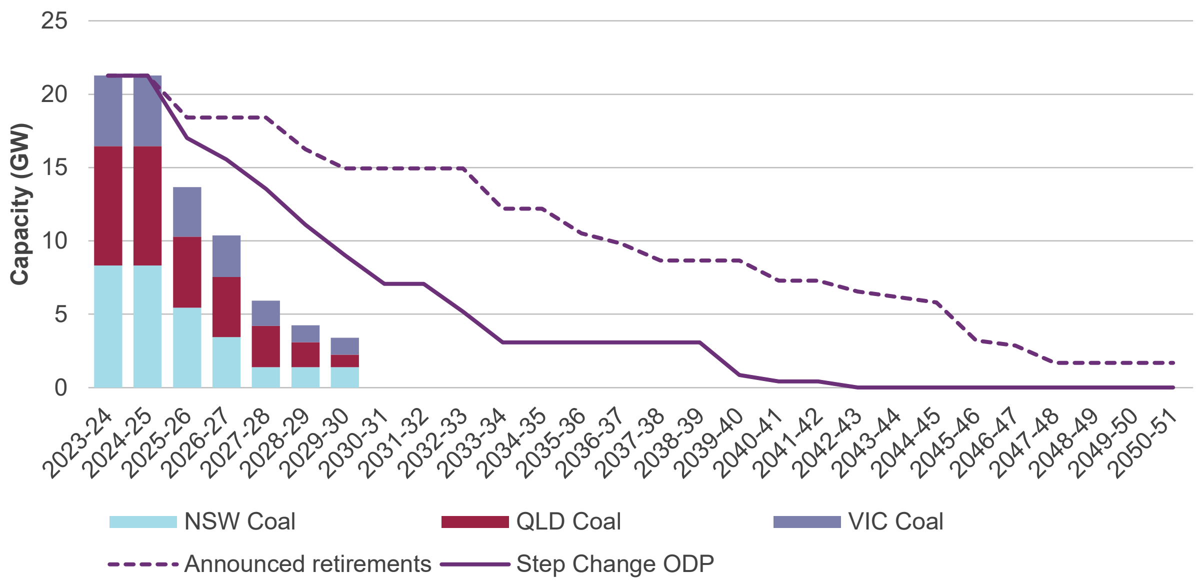
Figure 25 Forecast NEM generation capacity to 2050-51, *Hydrogen Superpower*



Impact of transmission development on coal retirements

Hydrogen Superpower applies a carbon budget associated with action to limit temperature rises to 1.5° by 2100 over pre-industrial levels. This requires an even more rapid retirement of coal generation than *Step Change*. Figure 26 below illustrates the speed of the retirement schedule in the scenario for coal generation in comparison to *Step Change* and current announcements.

Figure 26 Forecast coal retirements, *Hydrogen Superpower*



Hydrogen developments

- The ISP modelling considered grid-connected 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 be optimised within a monthly timeframe. In addition to the flexible electricity demand for hydrogen production, additional electricity demands used in electric arc furnaces associated with green steel production and ammonia conversion facilities were also included.
- Using AEMO's capacity outlook models, AEMO determined:
- The location and size of electrolysers, ammonia production facilities and green steel production facilities to meet export hydrogen demand and green steel production, which are specified at a NEM level.
- The size of electrolysers to meet domestic hydrogen demand which is specified for each region.

In the Draft ISP, there was a significant amount of storage capacity built towards the end of the modelling horizon. Following the publication of the Draft ISP, AEMO identified that much of the later year storage development was being developed to cater for renewable energy intermittency that was greater than should be anticipated if additional electrolyser capacity was developed to provide improved operational flexibility for hydrogen production. The final ISP electrolyser developments included an uplift, identifying a reduction in system costs in the process, and leading to reduced capacity development, as shown in Figure 27. As the figure demonstrates, with approximately 20% greater electrolyser capacity, the increased load flexibility reduces the need for storage investments materially, by over 40 GW by 2050.

Figure 27 Forecast NEM generation capacity to 2050-51 in *Hydrogen Superpower*, updated assumptions compared to Draft ISP assumptions

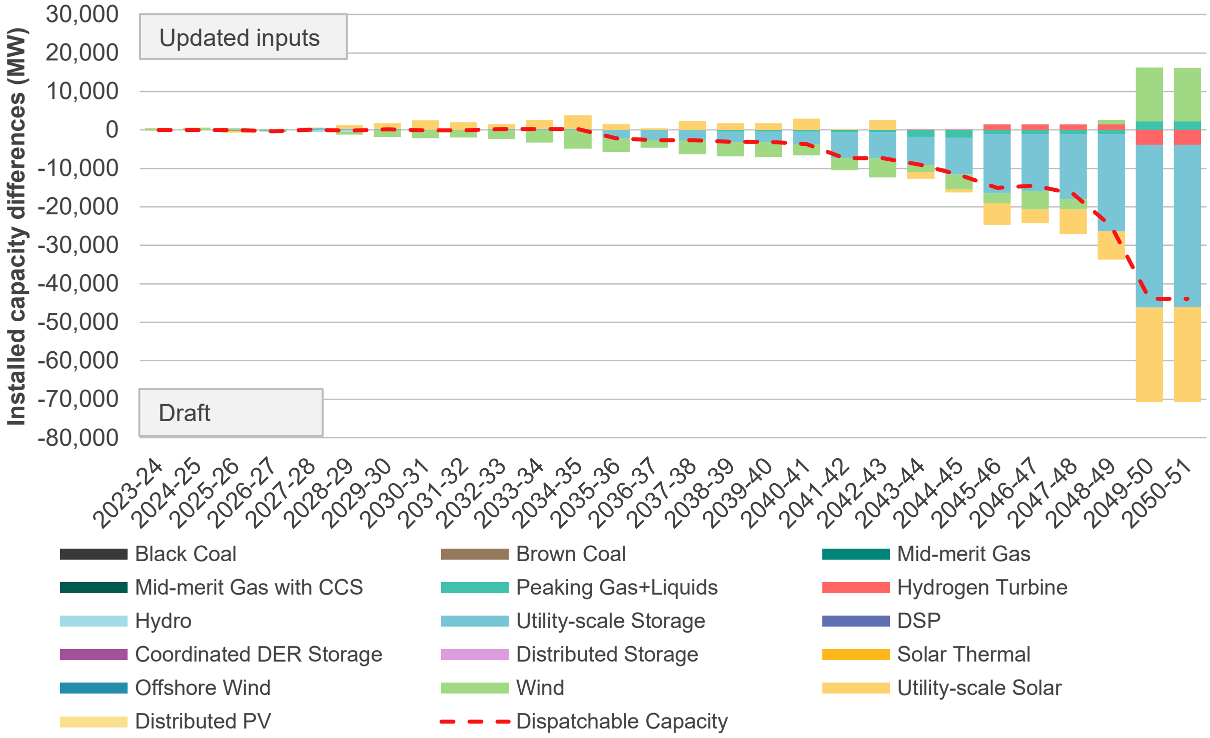
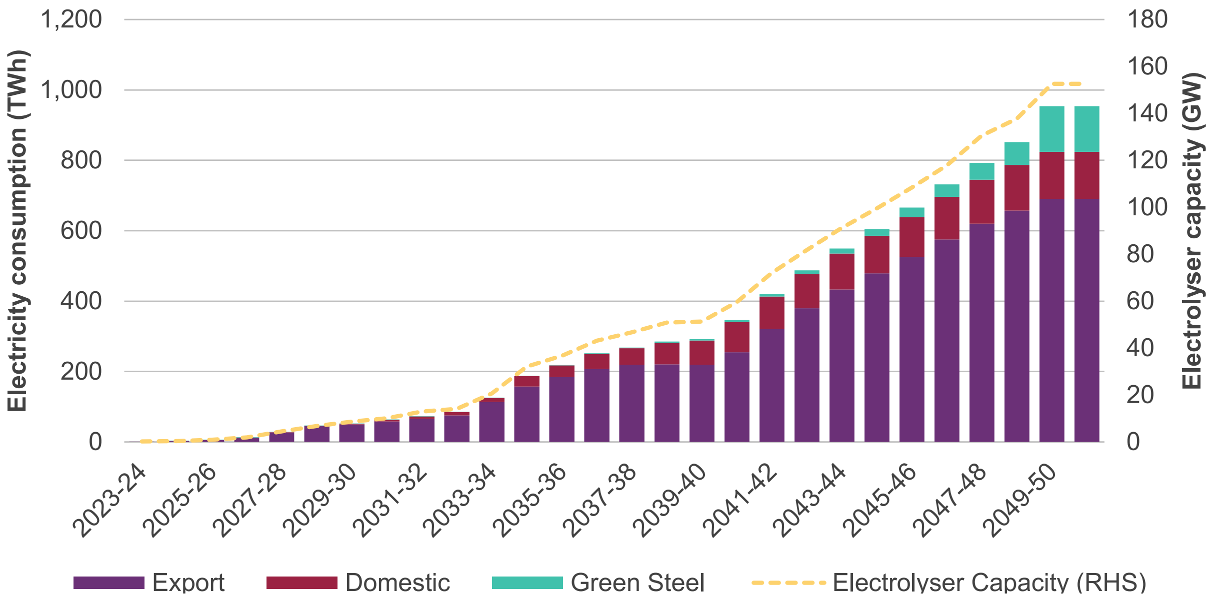


Figure 28 presents the assumed total electricity consumption to 2049-50 for hydrogen production (used for domestic use, export, and green steel production), and for ammonia conversion and green steel production in the final ISP.

Figure 28 Electricity demand associated with hydrogen



The model selects the optimal location for electrolysers to meet this demand at lowest cost, taking account of the necessary generation and transmission development needed to energise this level of new consumer demand. Sufficient electrolyser capacity is developed to enable flexible utilisation of between 65-70% on average, balancing the costs of additional capital investment in electrolyser capacity against additional energy costs through further VRE and utility-scale storage development and transmission augmentation.

Geographical diversity of electrolyser investments is found to minimise system costs, with Queensland and South Australia providing the greatest export opportunity (see Figure 29). Domestic electrolyser development is based on the assumed demand for hydrogen for domestic use, with existing industrial and transportation activity across regions providing a proxy for potential growth for domestic consumption.

Figure 30 shows the development of new dispatchable capacity required in *Hydrogen Superpower* to service the growing demand of consumers and new industry. The high uptake of coordinated DER storage and distributed energy storage in *Hydrogen Superpower* is complemented by medium and deep utility-scale storage development to firm the additional renewable energy developments particularly as coal retires.

While hydrogen production provides an inherent capacity to operate flexibly, additional firm supply is forecast. Approximately 10.5 GW of peaking gas and 9 GW of hydrogen turbines are developed later in the horizon 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[3].

[3] 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 29 Regional allocation of hydrogen developments by 2050

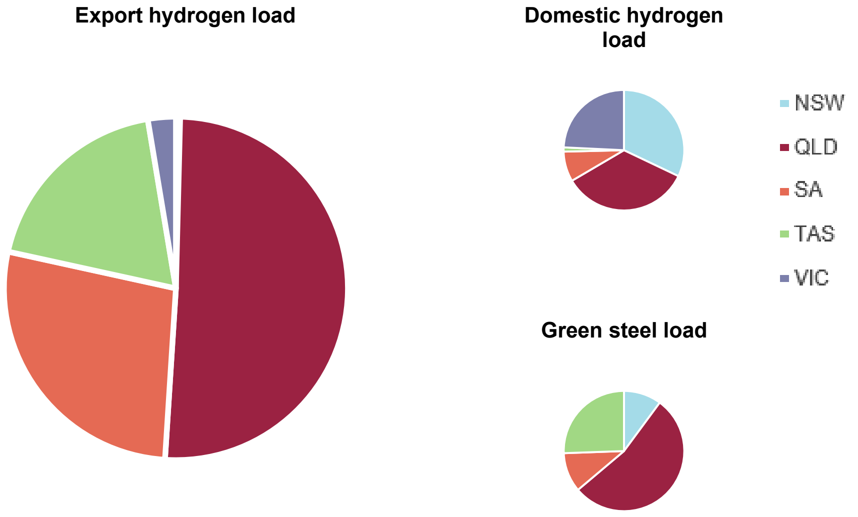
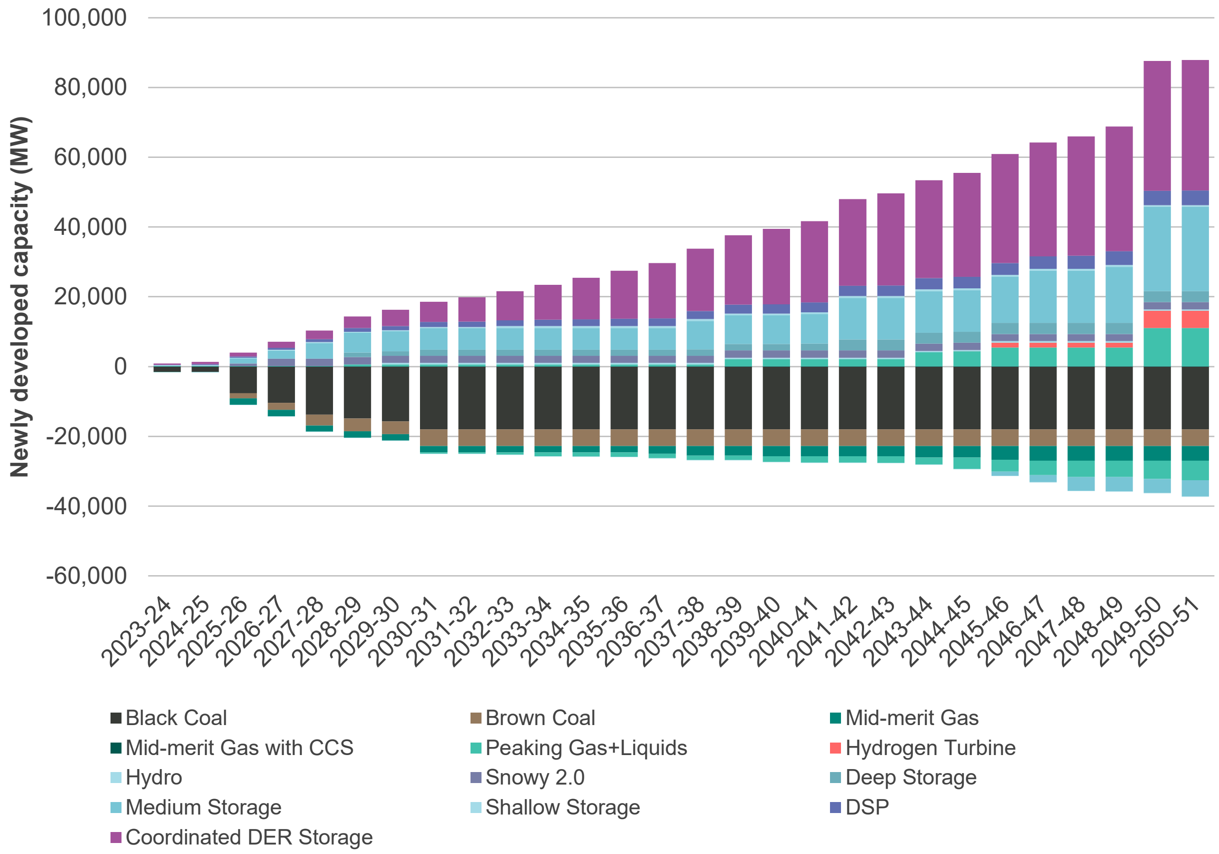


Figure 30 Forecast firm capacity development to 2050, *Hydrogen Superpower*



Future generation mix in *Hydrogen Superpower* without the ISP transmission developments

Capacity development in the counterfactual development path

As shown in the previous sections, *Hydrogen Superpower* results in a very large increase in NEM demand, and as such a much larger investment need for new capacity than other scenarios. This scale of expansion will require targeted transmission investment to enable energy to flow from REZs to export ports, as well as greater use of technology diversity, including offshore wind and hydrogen turbines. Without this access, the scale of hydrogen production would not be achievable (within the carbon budget). This counterfactual therefore allows targeted transmission development to support energy supply between REZ and export port only; broader transmission development to support domestic consumers is not available consistent with the counterfactual approach in other scenarios.

The forecast capacity mix in the counterfactual development path is shown in Figure 31.

Figure 31 Forecast NEM generation capacity to 2050-51, *Hydrogen Superpower* counterfactual

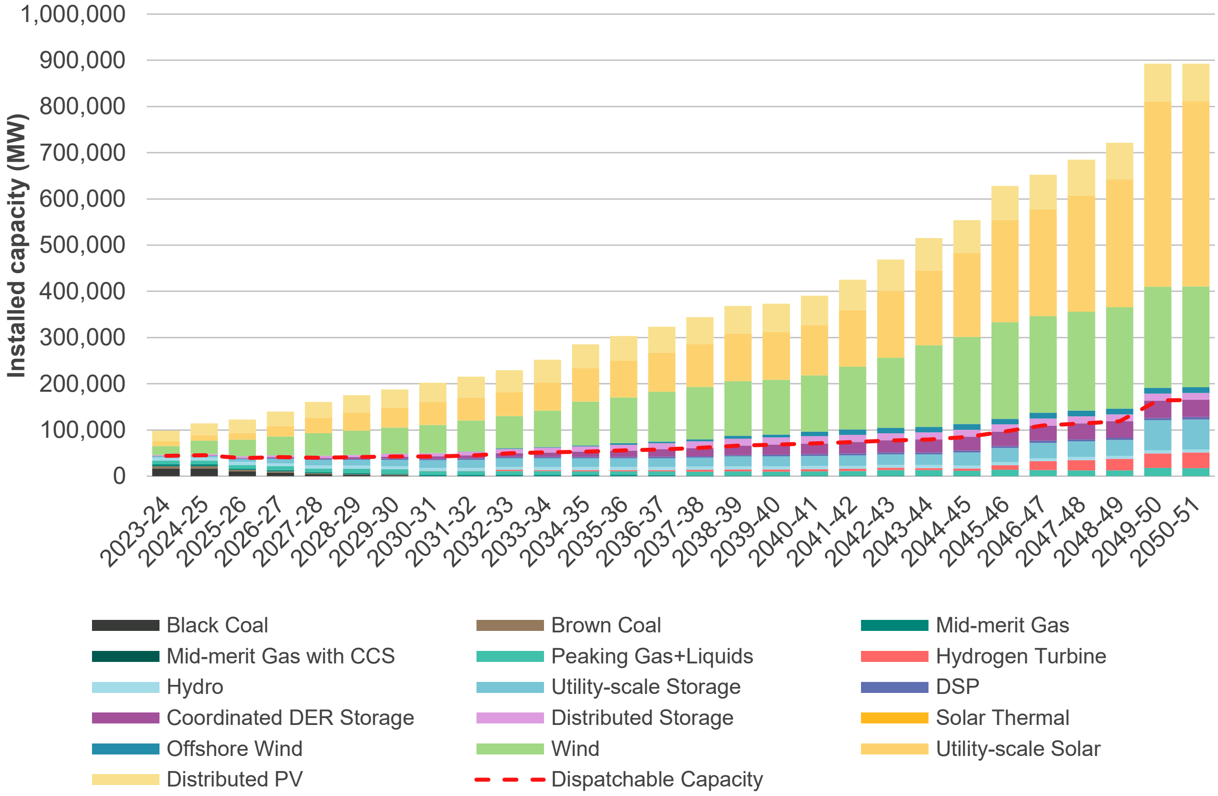
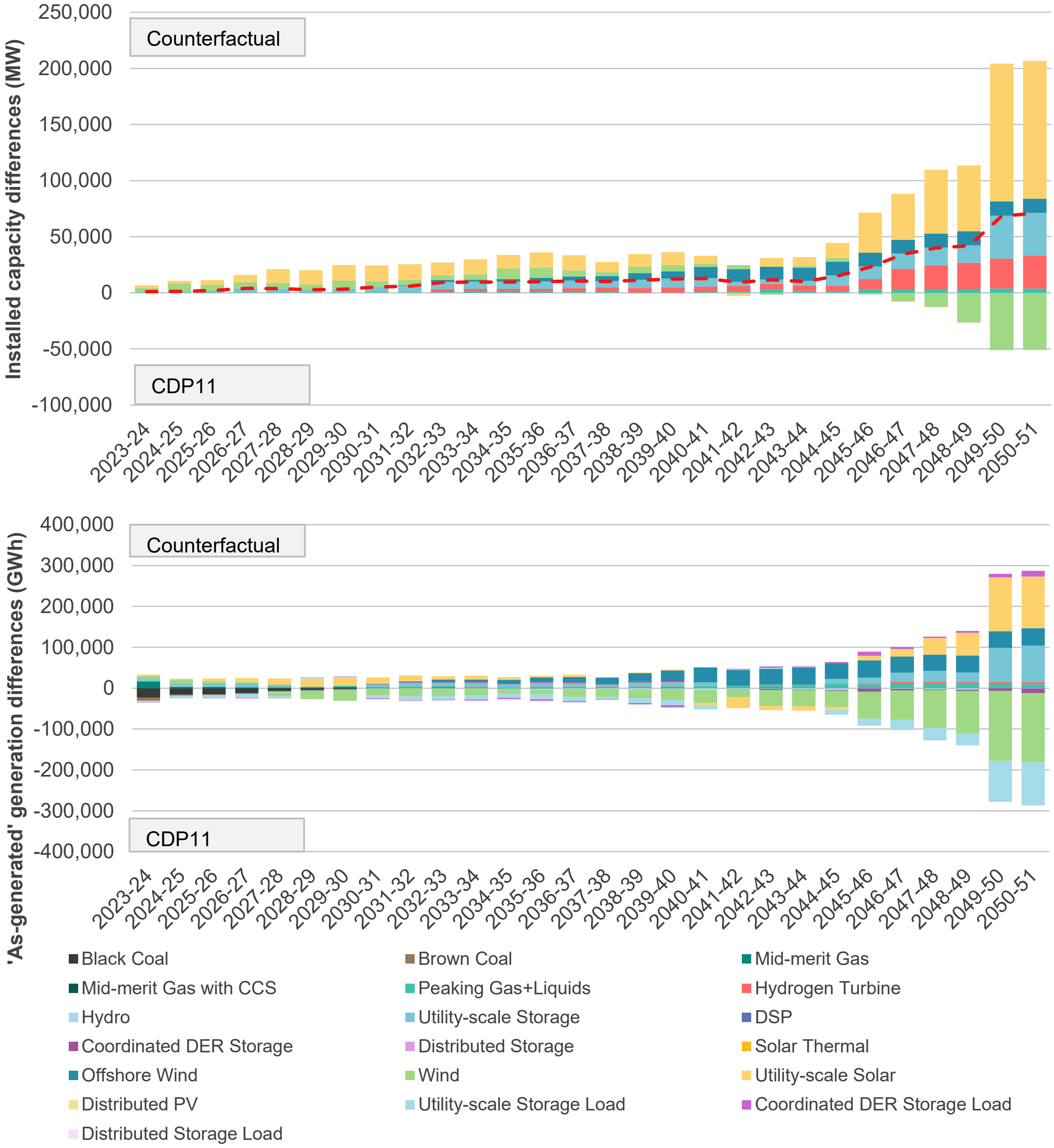


Figure 32 demonstrates the differences in ISP development capacity and generation between CDP11 and the counterfactual development path. Without transmission expansion to support domestic consumers, further onshore wind development would be too heavily curtailed, so a greater development of solar (to complement wind development in highly developed REZs) and offshore wind is forecast. Increased storage development is also required without the expansion of the transmission system to reduce potential congestion.

Figure 32 Forecast capacity developments (top) and generation (bottom) to 2050-51 compared to counterfactual, *Hydrogen Superpower*



Challenges in implementing *Hydrogen Superpower*

The scale and pace of change in this scenario will result in the greatest implementation challenge relative to other scenarios. Supply chain and social licence limitations may provide development impediments, and additional operational tools may be needed to operate the system securely and efficiently. These enhancements and market reforms are currently being progressed through the ESB's post-2025 electricity market design process. Section 7 of the ISP discusses the risk and challenges in the implementation of the ISP.

A2.3.4 *Slow Change*

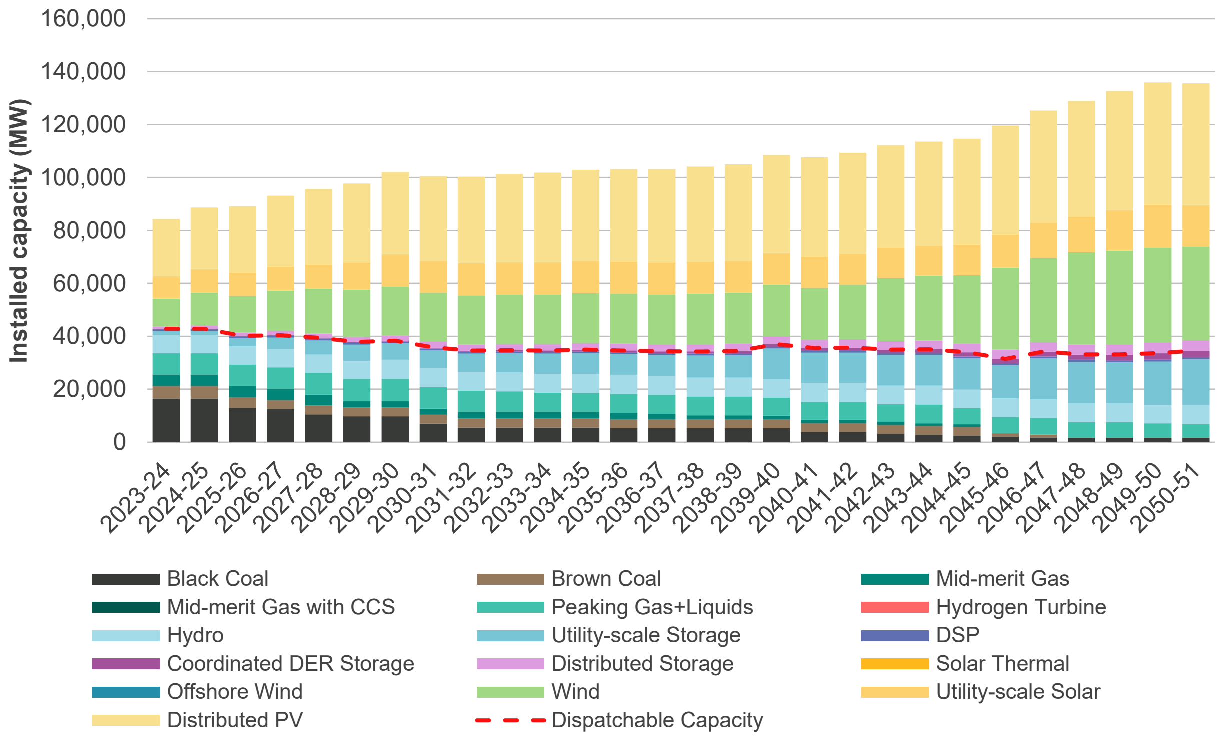
The *Slow Change* scenario reflects a challenging economic environment following the COVID-19 pandemic, with greater risk of industrial load closures. Technology advancements are slower, the economy-wide net zero emission target is pushed out beyond 2050, and there are few policy drivers apart from what is already legislated.

Generation and storage development in *Slow Change*

The generation capacity forecast (shown in Figure 33) projects that:

- To 2029-30:
  - New VRE developments are deployed to meet existing renewable energy policies in Queensland, New South Wales, Victoria, and Tasmania, with no additional developments above legislated ambitions.
  - Early retirement of coal generation is forecast relative to announced closure dates, particularly of black coal generation in Queensland and New South Wales, as declining operational demand and the additional VRE results in a relative oversupply of energy.
- By 2049-50:
  - Retiring thermal generation is replaced by a combination of large-scale VRE, primarily wind, and utility-scale storage. Distributed PV capacity continues to grow at pace and makes up most of the installed solar capacity.

Figure 33 Forecast NEM generation capacity to 2050-51, *Slow Change*



Coal retirements in response to challenging conditions

As with the other scenarios, retirements of most coal generators are forecast to be brought forward relative to current announcements, despite no explicit carbon budget providing a catalyst for retirements. This is driven by a combination of lower operational demand and policy-driven uptake of VRE resulting in lower levels of residual demand across the NEM compared to *Progressive Change*.

Figure 34 compares coal retirements in *Slow Change* with *Progressive Change*, and to expected closure years, demonstrating the earlier closure timings than currently announced over the next 10-15 years.

Figure 34 Forecast coal retirements, *Slow Change*

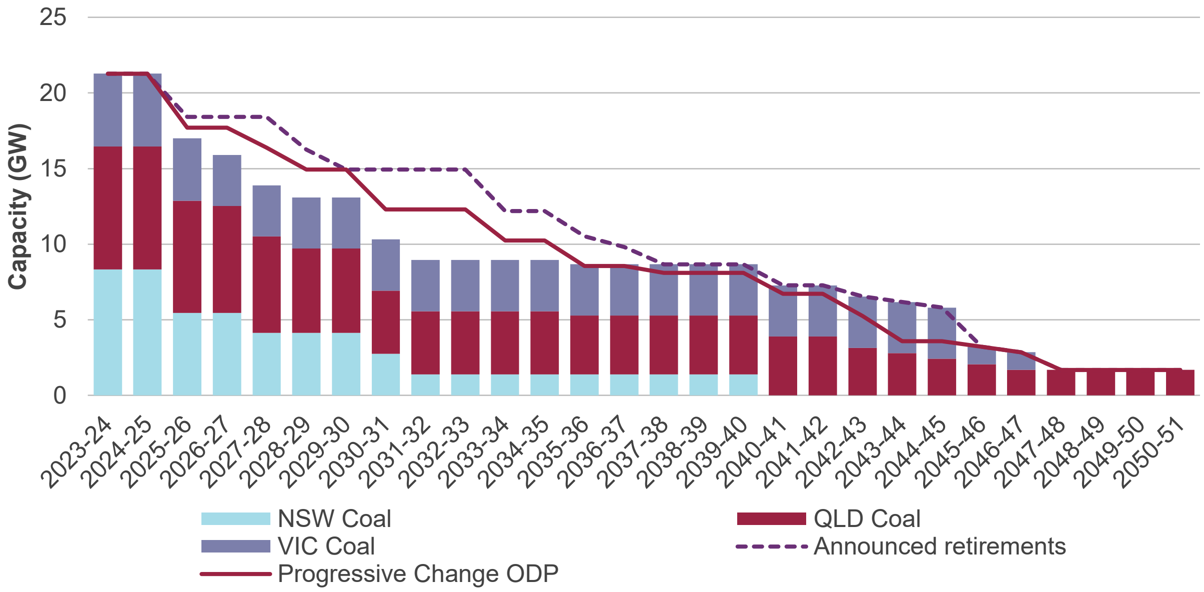
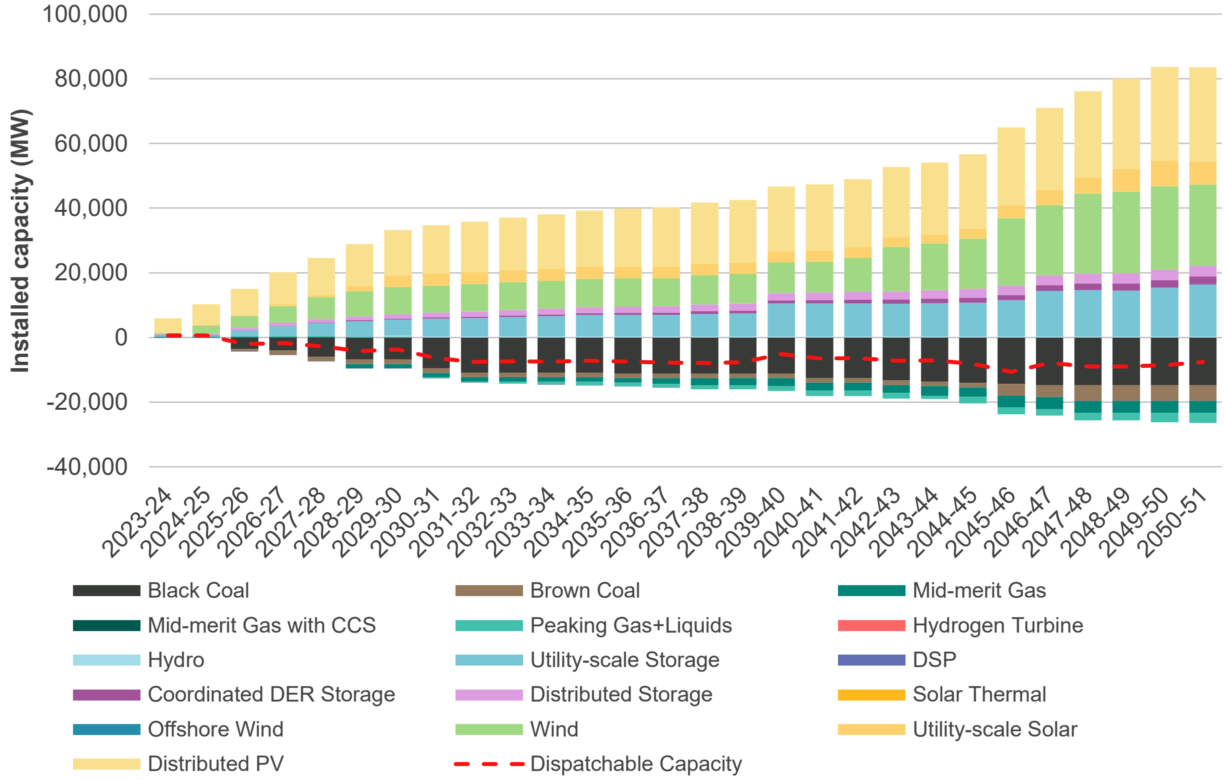


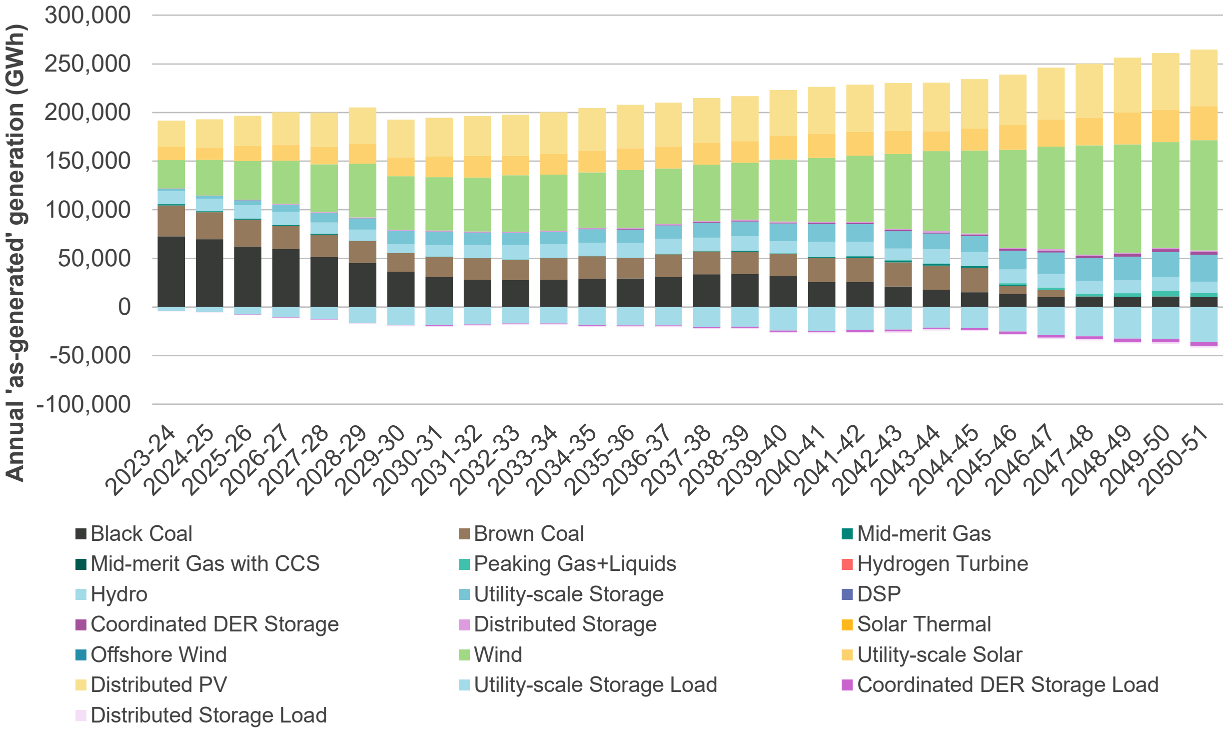
Figure 35 below shows the development of capacity in *Slow Change*. While developments in the near term are forecast with reasonable pace, as coal retirements slow and existing renewable energy policies are met, the pace of investment also slows. Less electrification of other sectors leads to more muted generation investment in the longer term, although additional VRE development, complemented by energy storage, is developed to replace end of life coal retirements.

Figure 35 Forecast relative change in installed capacity to 2050-51, *Slow Change*



Despite the lack of coordinated economy-wide decarbonisation action in this scenario, Figure 36 below shows that the energy mix is dominated by VRE, with 93% of generation being from renewable sources by 2049-50. By then, the projected mix of VRE generation is 54% wind, 17% utility-scale solar and 29% distributed PV.

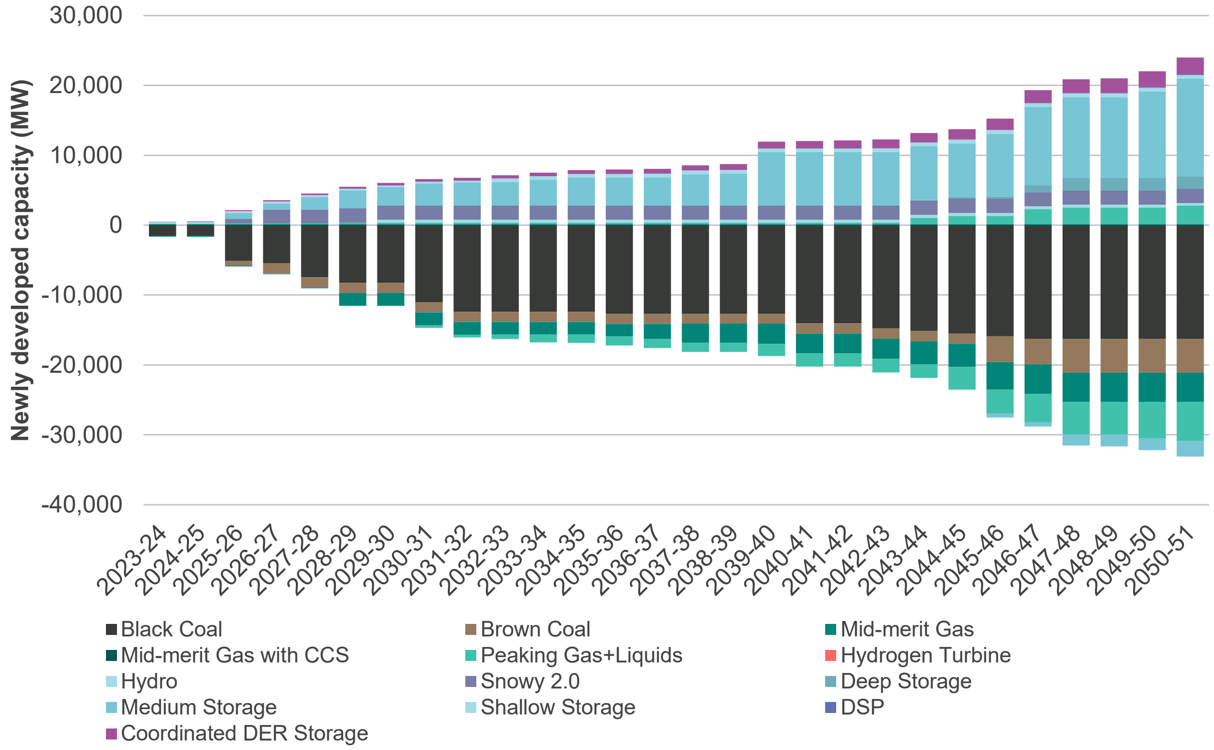
Figure 36 Forecast annual generation to 2050-51, *Slow Change*



Firm capacity developments largely to replace retiring coal-fired and gas-fired generation

The rather slow uptake of distributed storage in *Slow Change* creates greater relative opportunity for utility-scale storages to provide the emerging dispatchable capacity requirements of the grid. As in other scenarios, a range of storage depths are necessary to complement remaining dispatchable and VRE capacity, as shown below in Figure 37.

Figure 37 Forecast firm capacity development to 2049-50, *Slow Change*

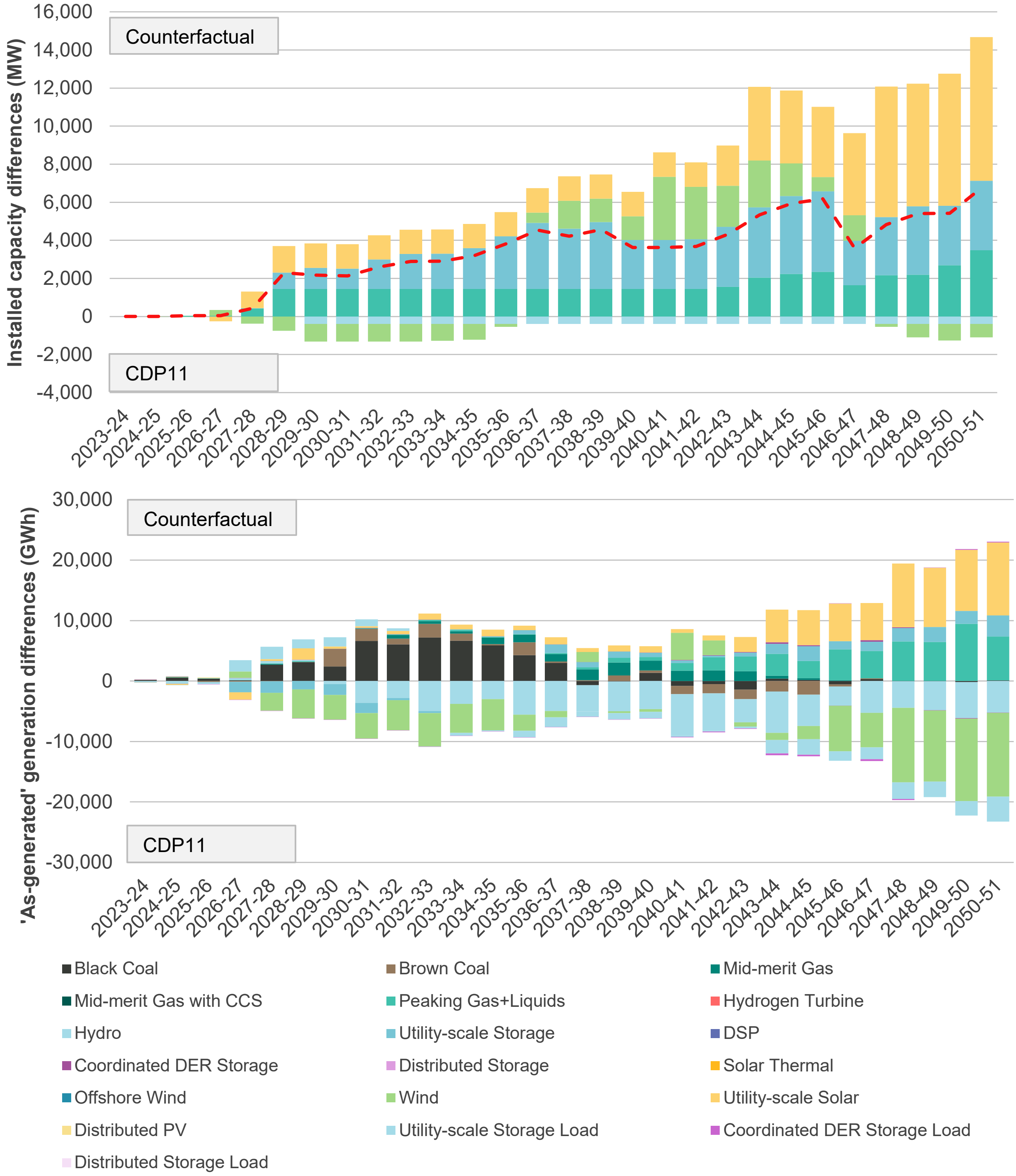


Future generation mix in *Slow Change* without the ISP transmission developments

The differences in capacity development between the counterfactual and CDP11 in *Slow Change* are shown in Figure 38, with the key highlights including:

- Without further investments in transmission infrastructure, significantly more generation capacity is required to be developed in the counterfactual to ensure sufficient supply in each region, including greater investments in dispatchable technology such as peaking gas and large-scale energy storage particularly near the load centres in New South Wales and Victoria.
- Lower demand growth means this scenario does not require expansion of new technologies (such as offshore wind or generation with CCS). Furthermore, with less overall VRE development, there are more REZs available with spare transmission capacity or cost-effective augmentation options.

Figure 38 Forecast capacity developments (top) and generation (bottom) to 2050-51 compared to counterfactual, *Slow Change*



A2.4 The influence of sensitivities on ISP Developments

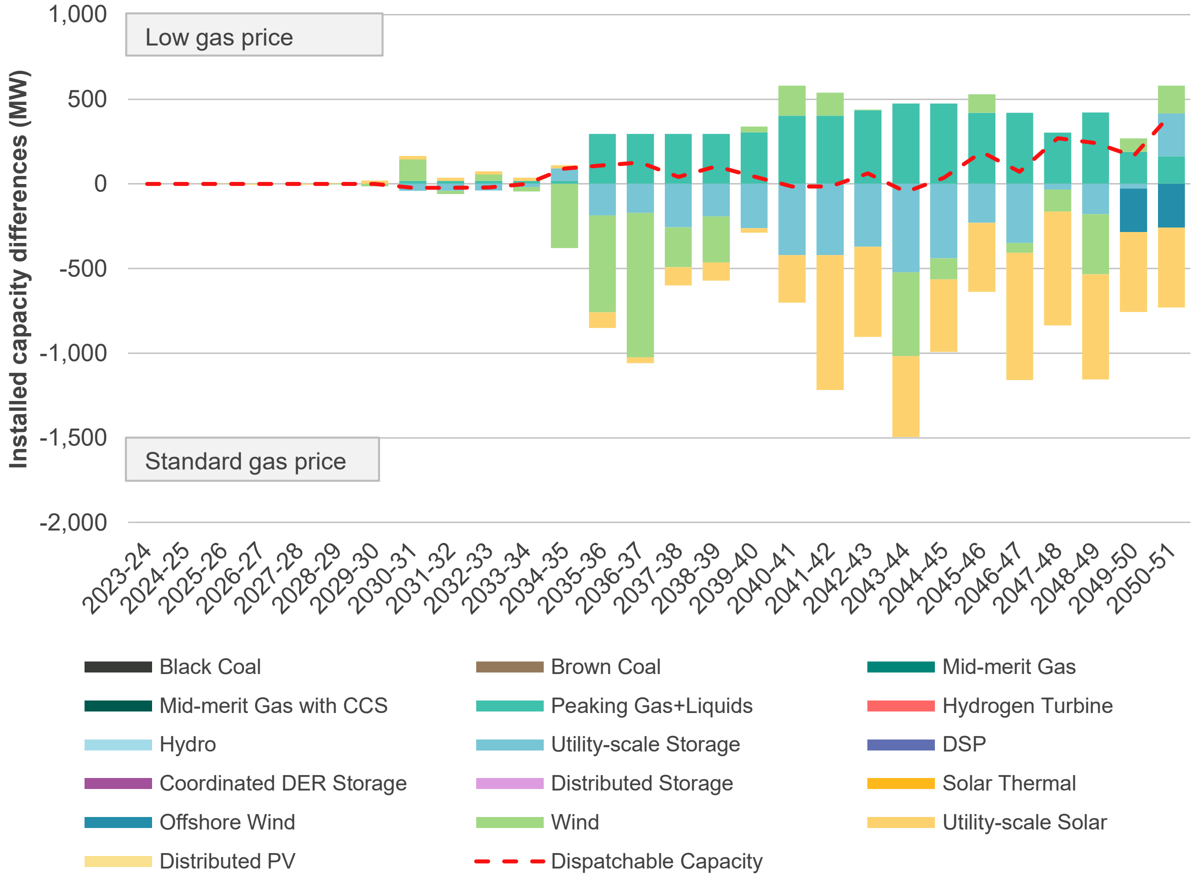
This section outlines the capacity differences in some of the key sensitivities that have been performed to understand the resilience of various candidate development paths. The impact of these sensitivities on net market benefits is explored in depth in Section A6.8 of Appendix 6. Unless otherwise specified, the sensitivities presented in this section are applied to the Draft ISP assumptions. As such, the comparisons in generation and storage development are compared against modelling outcomes from the Draft ISP.

Low gas prices

The *Low Gas Price* sensitivity explores the impact of lower long-term gas price forecasts on development opportunities. For this sensitivity, *Progressive Change* and *Step Change* have been simulated for the purpose of the cost benefit analysis (see Appendix 6). This section focuses on *Progressive Change*, but similar trends are also seen in *Step Change*, although to a much lesser extent.

Figure 39 below compares capacity developments in this sensitivity for *Progressive Change* compared with the core assumptions of the scenario, focusing on the least-cost DP for that scenario (CDP2).

Figure 39 Forecast NEM generation capacity to 2050-51 in *Progressive Change*, *Low Gas Price* sensitivity compared to standard gas price assumptions



With certainty of lower operating costs for gas generators, some additional peaking gas generators may be preferred to investment in large-scale energy storage to provide the dispatchable capacity requirements following the retirement of thermal generators. The impact, however, is small – the figure demonstrates that the development difference of dispatchable capacity is approximately 500 MW of additional peaking gas-fired generation capacity and a similar reduction in utility-scale storage. In contrast, the overall scale of dispatchable capacity development using the base assumptions leads to 36 GW of gas fired generation and new energy storage combined.

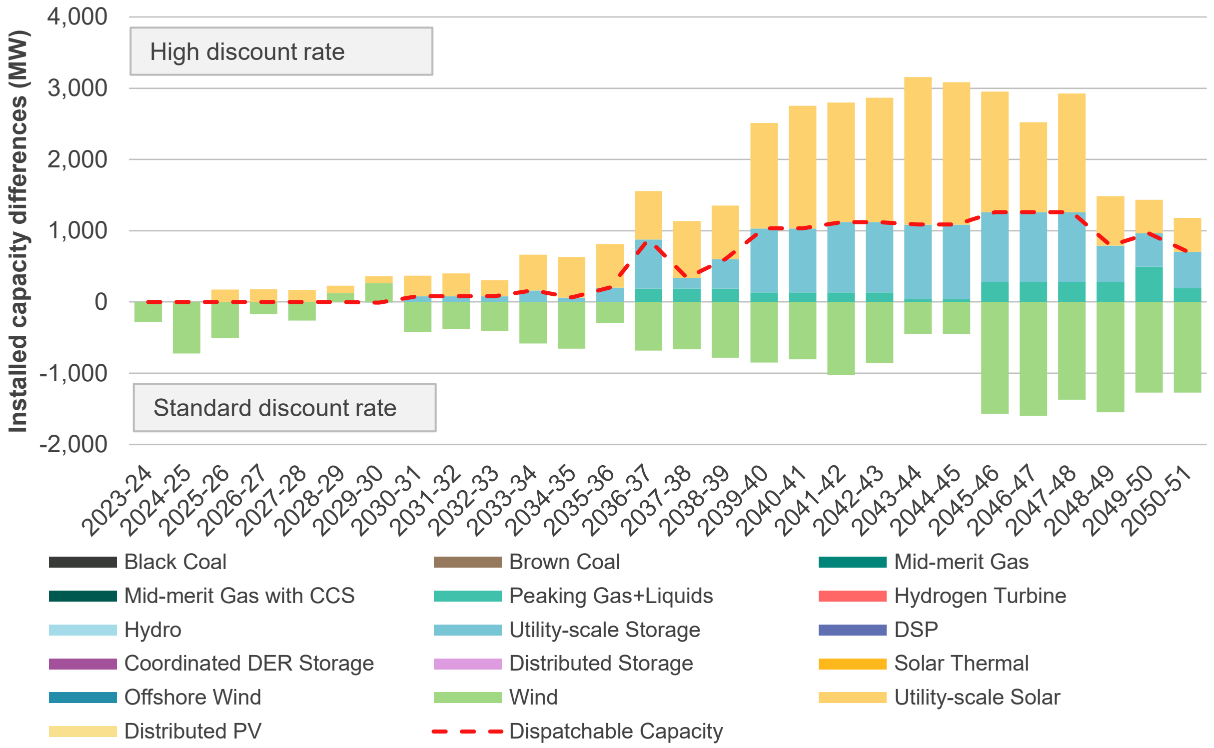
Financial investment costs – the impact of higher funding costs

The *Higher Discount Rate* sensitivity tests the robustness of the CDPs to an increase in the cost of capital (represented by the discount rate) and explores variations in least-cost generation investments resulting from a higher weighted average cost of capital (WACC).

With a higher discount rate and cost of capital, there is a preference for new generation technologies with shorter economic lives and/or lower upfront costs. Utility-scale batteries, for example, are preferred for providing storage services over pumped hydro storage, which has a higher upfront cost and a longer economic life. These investment choices trade off the capital investment costs with the operating costs of each technology; a higher discount rate favours technologies with a lower equivalent capital outlay, even if this leads to slightly higher operating costs. For similar reasons, additional large-scale solar (which has a lower capital cost) is preferred to wind. These differences are shown in Figure 40.

The impact of a higher discount rate in the consideration of CDPs is therefore predominantly related to the approach for discounting costs in the various development paths, rather than the impact it has on generation and storage development, which as seen below is relatively small given nearly 150 GW of new capacity is developed by 2050 in *Step Change* (for CDP 11).

Figure 40 Forecast NEM generation capacity to 2050-51 in *Step Change*, *Higher Discount Rate* sensitivity compared to central discount rate assumption



Strong electrification without significant hydrogen production

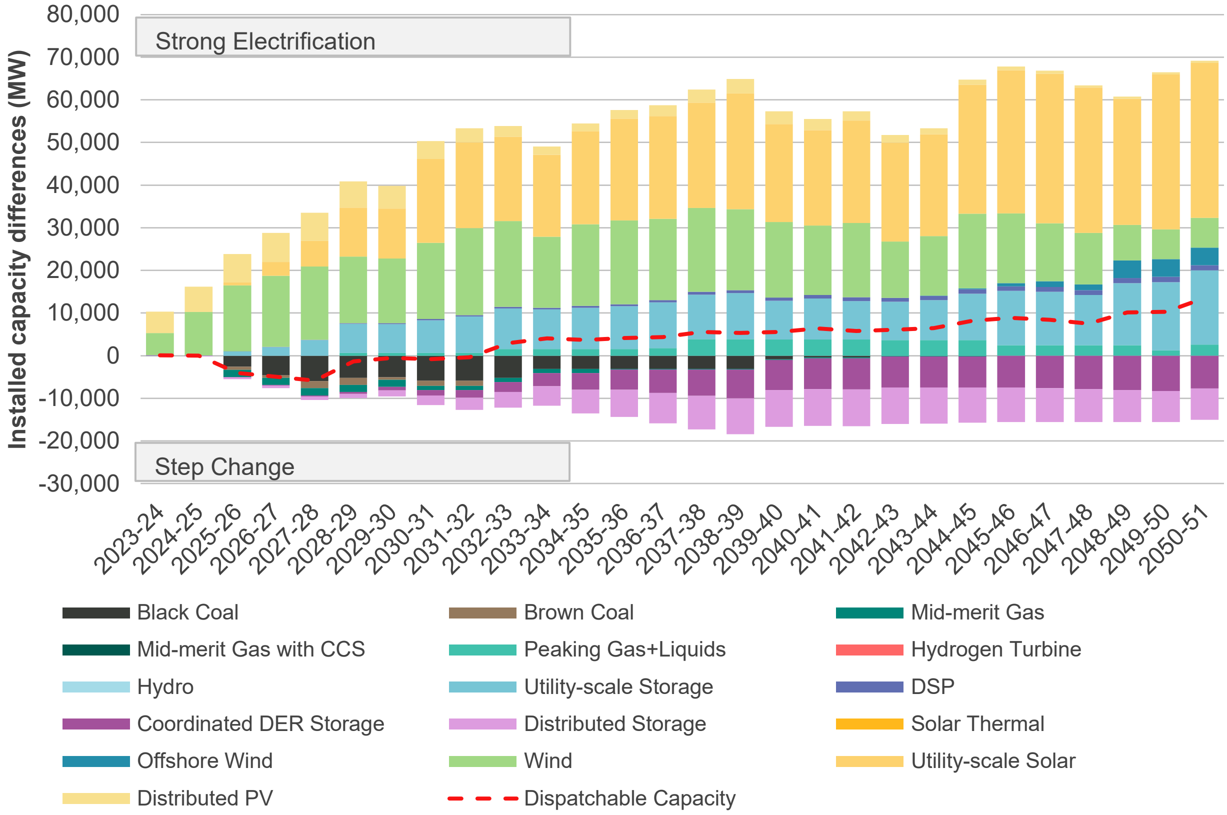
The *Strong Electrification* sensitivity represents a future aligned with the decarbonisation objectives of *Hydrogen Superpower*, but with limited hydrogen technology deployment and more muted energy efficiency. This leaves the majority of the emissions reductions to be achieved through electrification, testing the outer bounds of the existing system.

This section describes how the NEM developments change in this sensitivity, comparing it to *Hydrogen Superpower* (comparing the impact of stronger hydrogen deployment), and to *Step Change* (comparing the impact of faster and stronger decarbonisation objectives within a higher economic and population growth environment). These outcomes incorporate updated modelling assumptions since the Draft ISP.

Capacity development compared to *Step Change*

As shown in Figure 41, thermal retirements are accelerated compared to *Step Change* due to the need to meet more aggressive decarbonisation requirements, with all coal to be retired by 2030-31 (12 years earlier than *Step Change*). The early thermal retirements are offset by a combination of VRE and utility-scale storage developments. Beyond this, additional investment in these technologies continues to increase, mainly due to the increase in electrification, and as an outcome of stronger economic circumstances and population levels affecting commercial and residential consumption in addition to electrification. By 2049-50, compared to *Step Change*, about 60 GW of additional VRE and utility-scale storage is installed. The sensitivity does not incorporate the degree of consumer-led storage investments in *Step Change*, and develops more utility-scale storages with greater depth instead.

Figure 41 Forecast capacity developments to 2050-51 of *Strong Electrification* sensitivity compared to *Step Change*



Capacity development compared to *Hydrogen Superpower*

The additional demand for electricity in *Hydrogen Superpower* for hydrogen production, particularly for export, far exceeds the demand growth due to electrification in the *Strong Electrification* sensitivity. As such, the level of VRE investment required in *Hydrogen Superpower* is approximately 200% larger than in this sensitivity.

By 2049-50, firm capacity technologies such as hydro generation, gas-fired generation and storage make up 14% of the total capacity mix in *Hydrogen Superpower*, whereas this proportion increases to over 22% in the *Strong Electrification* sensitivity. This is due to the flexibility of the majority of the load associated with hydrogen production which helps manage VRE intermittency without the need for as much complementary firming generation.

Offshore wind – the impact of the Victorian offshore wind policy

In March 2022, the Victorian Government released a Directions Paper with a vision to build 9 GW of offshore wind by 2040. AEMO has conducted an *Offshore Wind* sensitivity on *Step Change* to explore the potential impact of this policy on renewable resource developments (particularly across Victoria, Tasmania and New South Wales) and the development of interconnectors. This sensitivity includes:

- Offshore wind ramping up to 2 GW by 2032, 4 GW by 2035, and 9 GW by 2040 (with gradual developments between these years). To meet the early developments from 2028 to 2032, the lead time for Gippsland developments has been reduced, reflecting the growing maturity of announced projects in that offshore wind zone.
- Updated offshore wind build cost projections based on updated capital costs from the Draft GenCost 2021-22 report. The Global NZE post 2050 scenario has been applied to reflect this lower anticipated cost.

While offshore wind developments (according to the Draft GenCost 2021-22 report) remain higher cost relative to onshore options, the updated forecast costs have reduced by a relatively large amount, reflecting the learnings from international deployment of offshore technologies. Stakeholders also recognised in the Draft 2022 ISP submissions that offshore wind projects may reduce the social licence barriers that may exist in developing onshore alternatives, and therefore developments in a relatively higher-cost option may still deliver improved social outcomes. The sensitivity aims to provide insights into the impact of greater development of offshore wind, in terms of onshore generation and storage developments and also on the benefits provided by transmission augmentations (see Section A6.8.5 of Appendix 6).

Figure 42 compares capacity developments in the NEM with and without offshore wind targets and revised offshore wind costs. It shows around 10 GW of offshore wind capacity by 2050 primarily displacing approximately 20 GW of onshore wind and solar capacity by 2050. The large reduction in the need to develop a significant scale of onshore VRE may help to reduce social licence challenges and potentially reduce onshore VRE congestion risks[4]. This displaced capacity is predominantly in Victoria, but also to a lesser extent in New South Wales, South Australia, and Queensland. However, additional Victorian offshore wind was found to have a minimal impact on VRE developments in Tasmania due to the quality of those resources relative to the mainland. Despite offshore wind displacing onshore VRE investment in Victoria, onshore VRE

[4] AEMO has not quantified if this potential for reduced congestion is realised in the sensitivity.

developments exceed Victoria's committed and anticipated projects, but to a lesser extent than when the offshore wind target is not in place.

Figure 42 Forecast NEM generation capacity to 2050-51 in *Step Change*, *Offshore Wind* sensitivity compared to base case assumptions

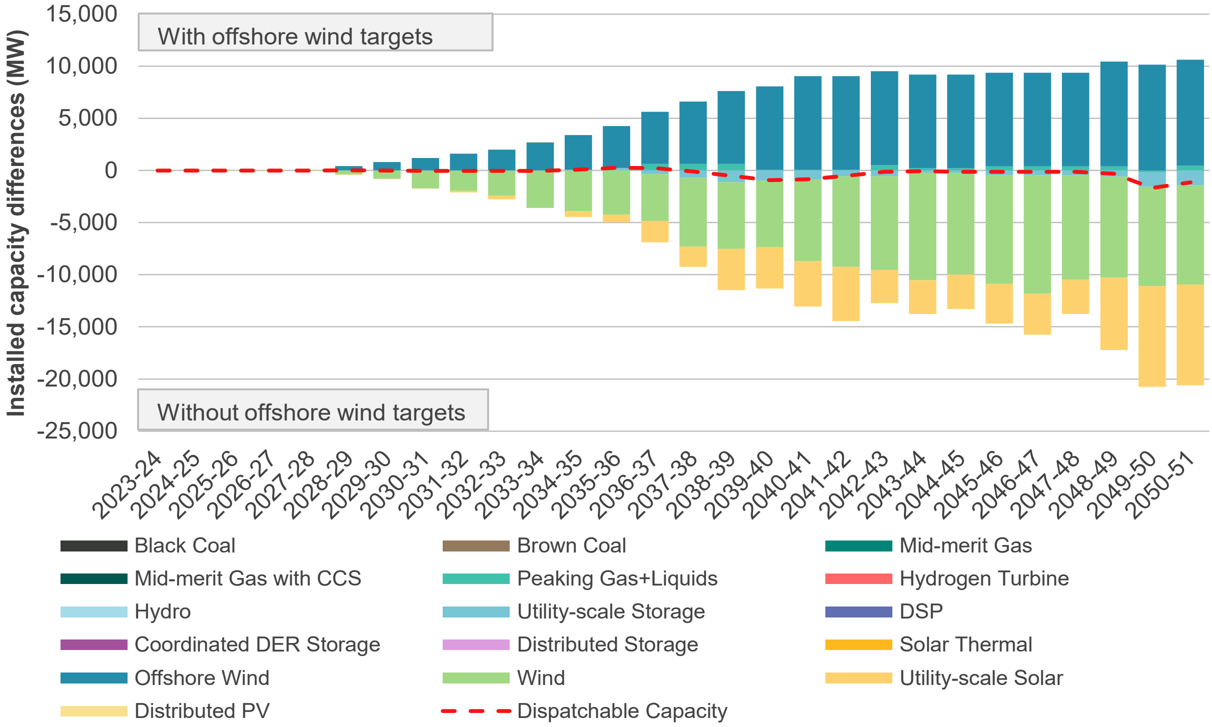
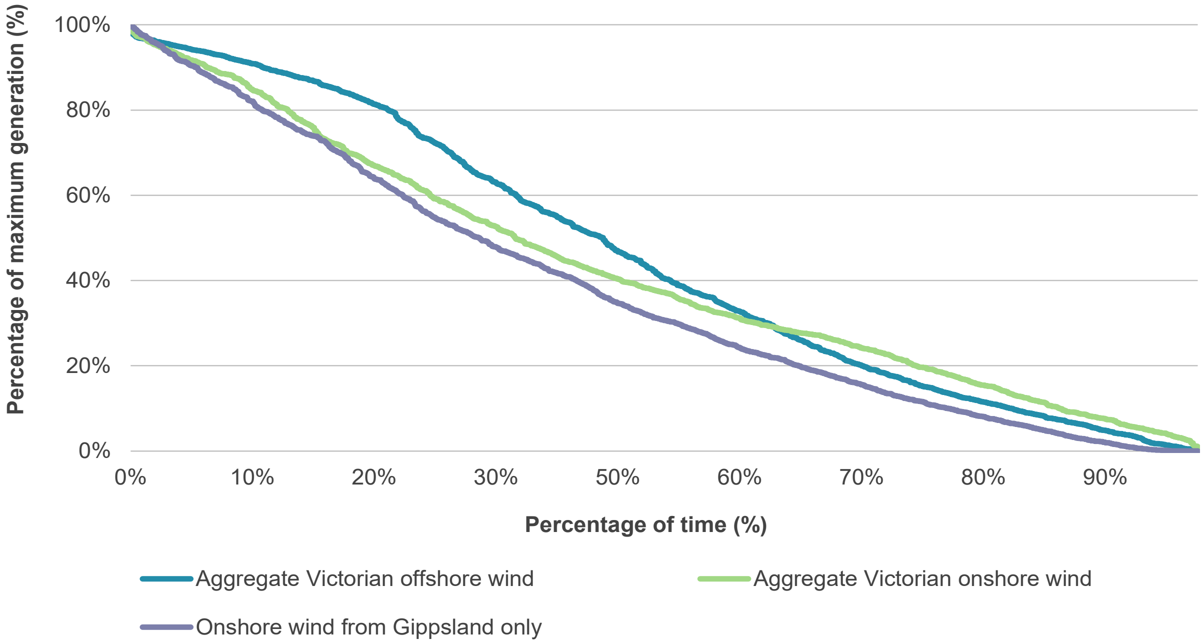


Figure 43 shows a normalised generation duration comparison for the year 2032-33 between the aggregate Victorian offshore wind (which by this point is almost entirely at Gippsland), aggregate Victorian onshore wind, and onshore wind from Gippsland only. The comparison shows that the aggregate offshore wind does have a greater percentage of time at higher production levels compared to either aggregate onshore wind or onshore wind in Gippsland. This explains the ability of offshore wind to displace approximately twice onshore VRE as much as its installed capacity.

However, compared to aggregate onshore wind, which benefits from greater geographical diversity, offshore wind has more periods of low production. The normalised generation duration curve of Gippsland onshore wind exhibits greater frequency of low output than offshore wind, which confirms the importance of geographical diversity supported by expanded transmission access in reducing firming requirements. Because the generation profiles of aggregate onshore wind and the offshore wind locations selected for development to some extent complement each other, the *Offshore Wind* sensitivity has not resulted in a material reduction in the development of firming capacity requirements, as Figure 42 also demonstrates.

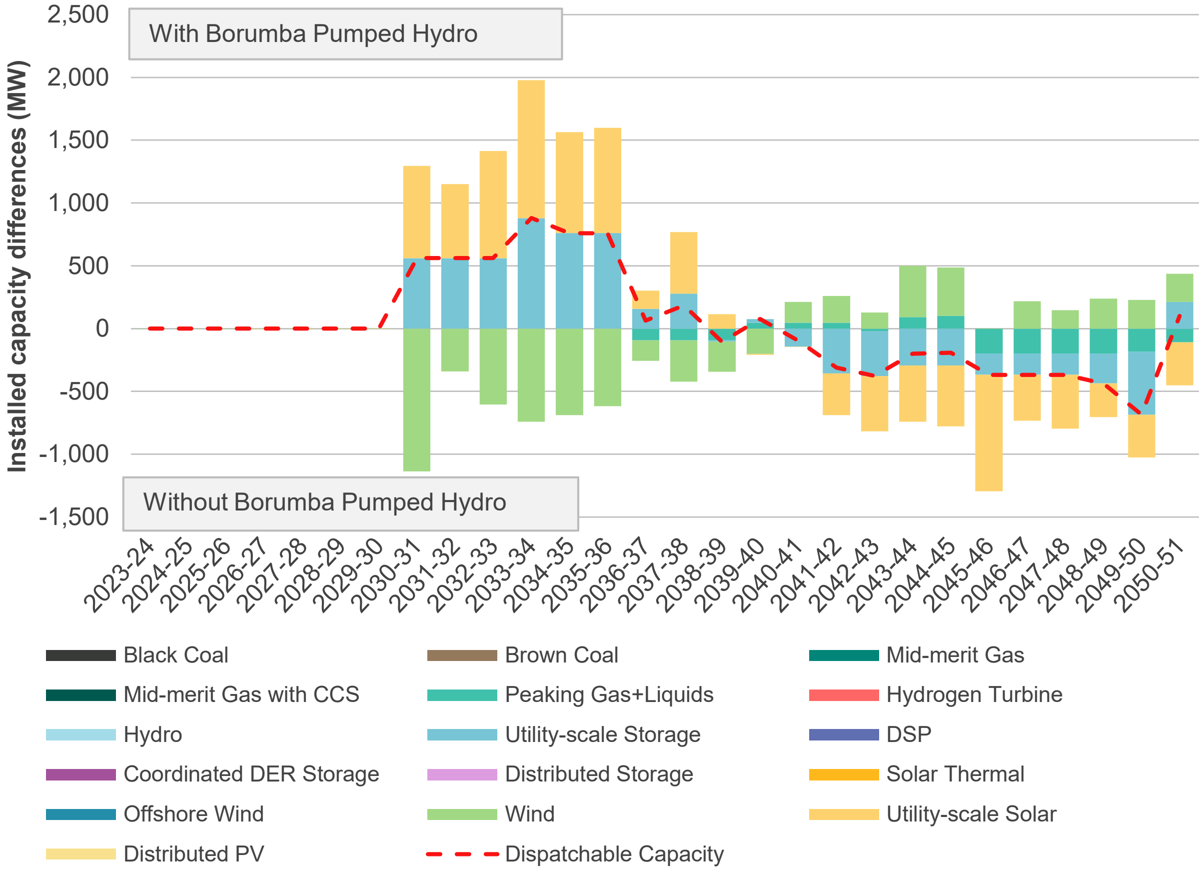
Figure 43 Normalised generation duration comparison between Victorian offshore wind and wind



Impact of Borumba Pumped Hydro project

The Queensland Government has announced additional storage development plans to support the transition to renewable generation. A key project being considered is the 1,500 MW Borumba Pumped Hydro project, which has a storage capacity in excess of 24 hours. To explore the potential impact of such a development, AEMO conducted a sensitivity on *Step Change* which includes the development of Borumba from 2030. This sensitivity has been based on updated inputs since the Draft ISP. Figure 44 below shows the projected impact of the project on NEM capacity developments.

Figure 44 Forecast NEM generation capacity to 2050-51 in *Step Change*, *Borumba* sensitivity compared to base assumptions



The commissioning of Borumba initially increases storage capacity in Queensland, although this is partly offset by a reduction in battery storage development. Early on, the additional storage also enables a greater investment in solar generation, given the greater availability of storage capacity, but with less wind development. By the late 2030s this technology trend reverses, with greater storage depth from a similar level of storage capacity enabling increased wind generation development and operational management of stored energy, marginally reducing the need for peaking gas capacity and solar generation.

With greater storage available in southern Queensland the sensitivity also develops lesser central and northern Queensland renewable developments.