Appendix 2. ISP Development Opportunities

December 2021

Appendix to Draft 2022 ISP for the National Electricity Market

Important notice

Purpose

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

AEMO publishes this Draft 2022 ISP under the National Electricity Rules. This publication has been prepared by AEMO using information available at 15 October 2021. Information made available after this date may have been included in this publication where practical.

Disclaimer

This document or the information in it may be subsequently updated or amended. This document does not constitute legal or business advice, and should not be relied on as a substitute for obtaining detailed advice about the National Electricity Law, the National Electricity Rules, or any other applicable laws, procedures or policies. AEMO has made every effort to ensure the quality of the information in this document but cannot guarantee its accuracy or completeness.

Accordingly, to the maximum extent permitted by law, AEMO and its officers, employees and consultants involved in the preparation of this document:

- make no representation or warranty, express or implied, as to the currency, accuracy, reliability or completeness of the information in this document; and
- are not liable (whether by reason of negligence or otherwise) for any statements or representations in this document, or any omissions from it, or for any use or reliance on the information in it.

Version control

Version	Release date	Changes
1	10/12/2021	Initial release.

Draft ISP Appendices

Contents

Tables

Figures

A2.1 Introduction

Sections 3 and 4 of the Draft ISP set out the ISP development opportunities for electricity generation and storages to enable the NEM's ongoing transformation within each future ISP scenario.

This appendix supports the Draft ISP with additional detail on the electricity generation and storages needed for the least-cost development path of each of the four ISP scenarios, as well as detailing the impact to generation developments of various sensitivities examined in the ISP.

The 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.

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).

A2.2 A rapidly evolving NEM will transform energy supply

The Draft 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-powered generation, and DER. Development will far exceed the replacement of the existing generation fleet in most scenarios to meet additional load associated with economic growth and opportunities for 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 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 forecast as least cost for consumers (see Section A6.3 of Appendix 6 for more detail). The table demonstrates the significant scale of development opportunities forecast in this Draft ISP, with utility-scale VRE growing to approximately 140 GW from current levels of approximately 15 GW in the *Step Change* scenario, for example. All ISP scenarios present at least a trebling of VRE.

Newer technologies in offshore wind and hydrogen turbines feature in the *Progressive Change* and *Hydrogen Superpower* scenarios respectively.

Table 1 Installed capacity to 2029-30 and 2049-50 for the least-cost DP 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	1,665	0	1,120	0	3,385	0
Mid-merit gas	4,075	0	4,075	0	2,387	0	2,387	0
Peaking gas + liquids	8,305	13,546	8,305	9,318	8,305	11,687	8,619	4,876
Hydrogen gas turbine	0	0	0	0	0	8,919	0	0
Hydro	6,818	7,056	7,208	7,056	7,208	7,056	6,818	7,056
Utility-scale storage	5,989	19,961	5,985	14,560	10,771	68,565	7,634	16,498
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	3,666
Wind	19,216	73,573	30,491	69,239	51,424	256,057	18,421	36,025
Offshore wind	0	299	0	0	0	0	0	0
Solar	11,796	65,139	12,086	67,872	28,038	302,179	12,215	16,493
Distributed PV	31,394	60,844	35,131	68,593	39,671	81,161	31,073	46,133

A2.2.2 Energy storages: 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. A diversity of storage technologies is forecast to be 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 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 the *Step Change* scenario.

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.

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 the least-cost DP under Step Change scenario

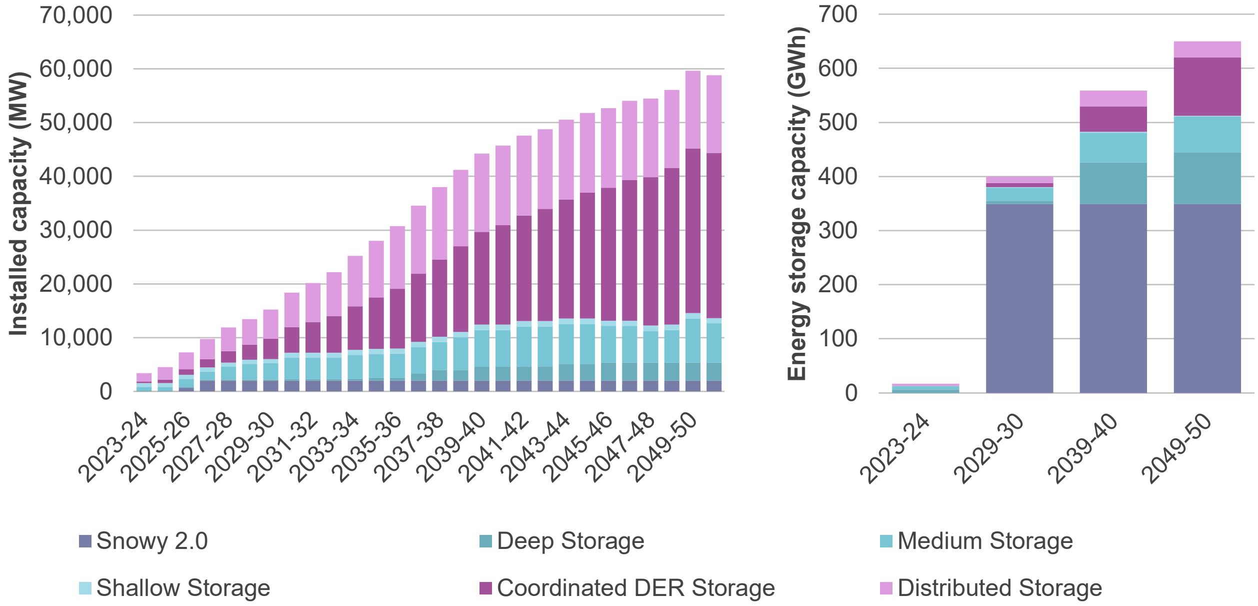
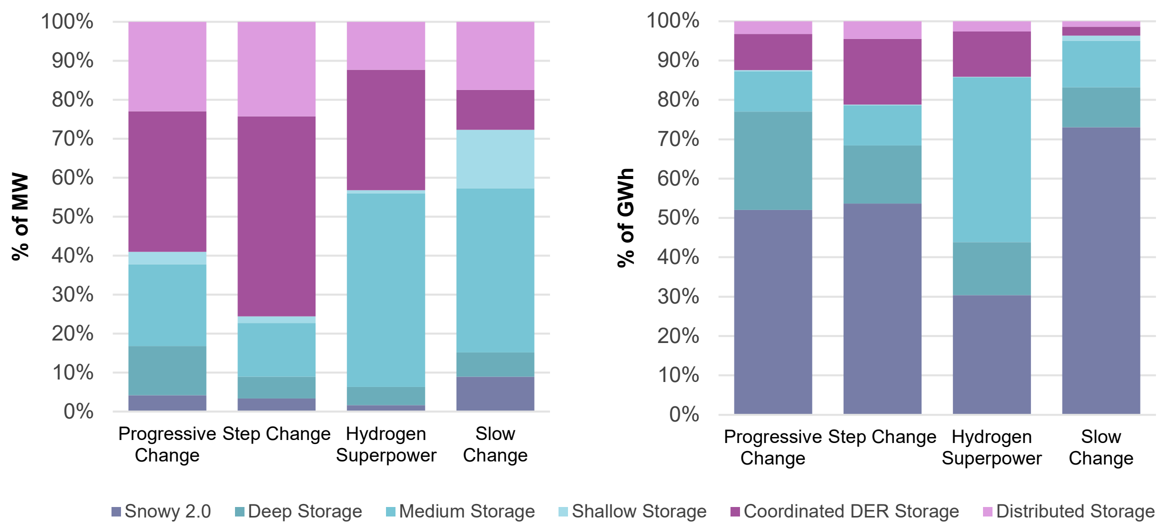


Figure 2 presents the mix of energy storage capacity that will be required to complement the new VRE developments. Deep storage is predominant across the scenarios in GWh terms, with lower participation in the *Hydrogen Superpower* scenario since it requires less long storage duration because of hydrogen flexible loads. Coordinated DER storage also plays a significant role in managing intra-day variability, particularly in the *Step Change* scenario.

Figure 2 Mix of energy storage type by scenario for each least-cost DP in 2050 – storage MW capacity (left) and energy storage depth (right)



A2.2.3 The low emissions-intensity NEM

The transformation of the NEM will continue with the strong projected uptake of VRE, driven by energy policies, economics of new entrant development options, and retirement of thermal generation. The emissions intensity of the NEM is forecast to reduce in all ISP scenarios, as shown in Figure 3.

The pace of decarbonisation is rapid in the *Step Change* and *Hydrogen Superpower* scenarios, with carbon budgets applying in the 2020s to deliver earlier NEM transformation. 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 the *Step Change* scenario, from 176 Mt CO_2-e in 2005 to 48 Mt CO_2-e, and 89% for the *Hydrogen Superpower* scenario, from 176 Mt CO_2-e in 2005 to 19 Mt CO_2-e. By 2049-50, emissions are forecast to be just 7 Mt CO_2-e for the *Step Change* scenario and 6 Mt CO_2-e for the *Hydrogen Superpower* scenario.

In the *Progressive Change* scenario, emissions reductions are forecast to occur more gradually, as a carbon budget does not apply until 2030-31. Up to this point, new VRE developed to meet state-based renewable energy targets is the key driver in the forecast emissions reduction by 2030 of 56% compared to 2005 levels.

Although the *Slow Change* scenario does not apply a carbon budget, VRE developments and economic retirements due to lower energy consumption contribute to a strong forecast emissions reduction of 67% by 2030, then slowing, before a more rapid reduction again in the 2040s as the last of the brown coal retires (to 93% by 2049-50).

Figure 3 Annual emissions by scenario for each least-cost DP

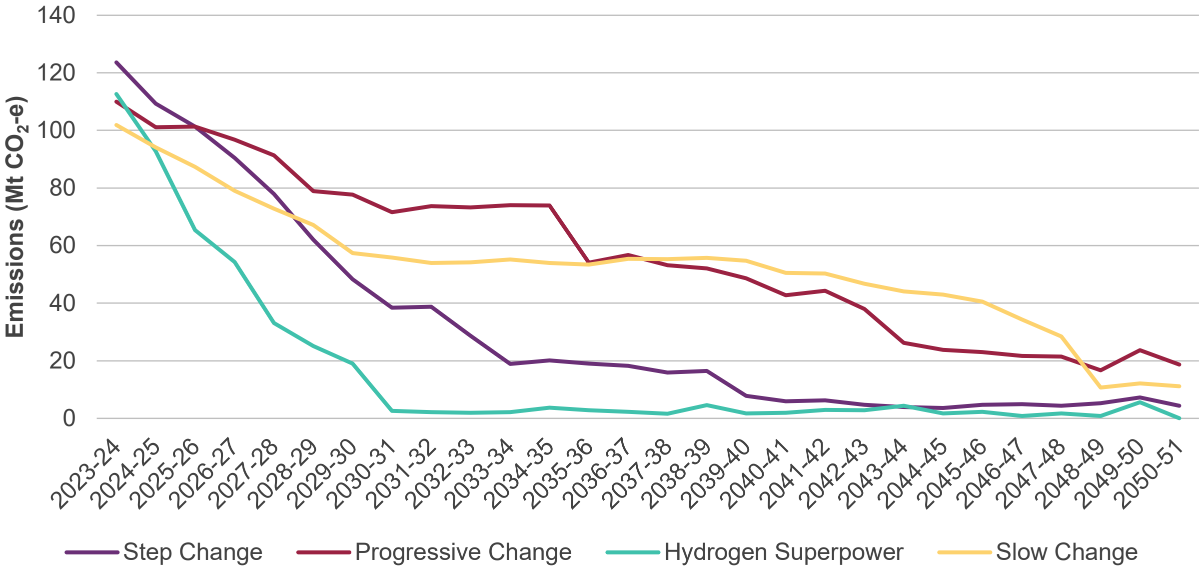
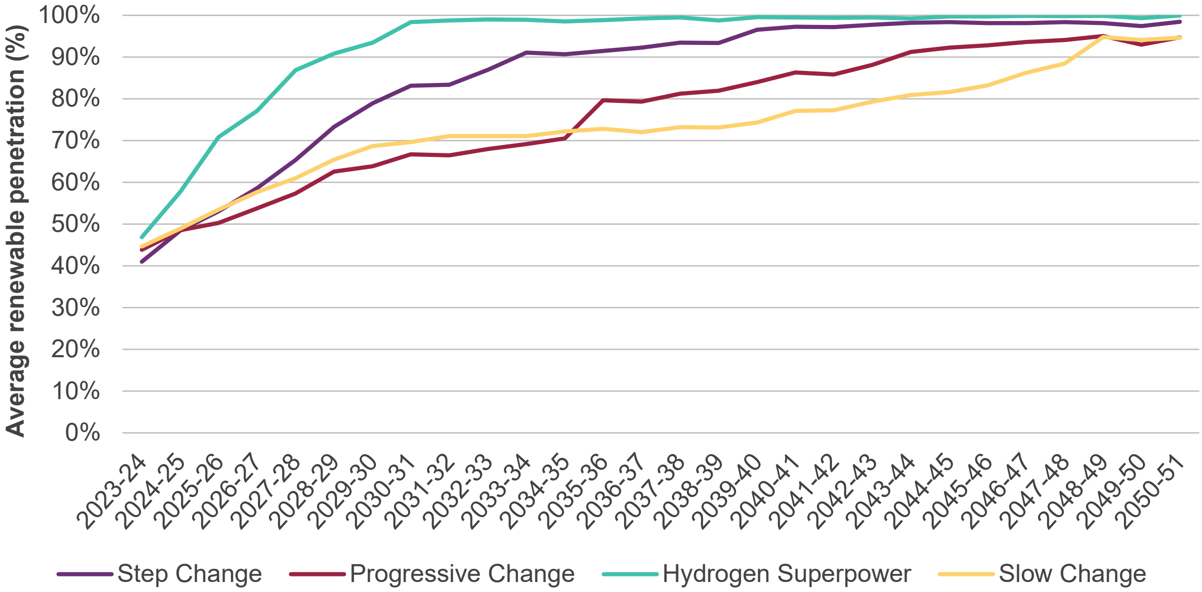


Figure 4 presents the level of renewable energy penetration by scenario to 2049-50, demonstrating how the grid can achieve the significant carbon reductions observed in the next 30 years. By 2049-50, 99% of generation is forecast to be generated from renewable sources in *Hydrogen Superpower* scenario. In *Step Change*, the share of generation from renewable sources increases to 97%, while the *Progressive Change* and *Slow Change* scenarios reach 93% and 94% respectively.

Figure 4 Evolution of the annual share of total generation from renewable sources for each least-cost DP – from capacity outlook model



A2.3 ISP development outlooks across scenarios

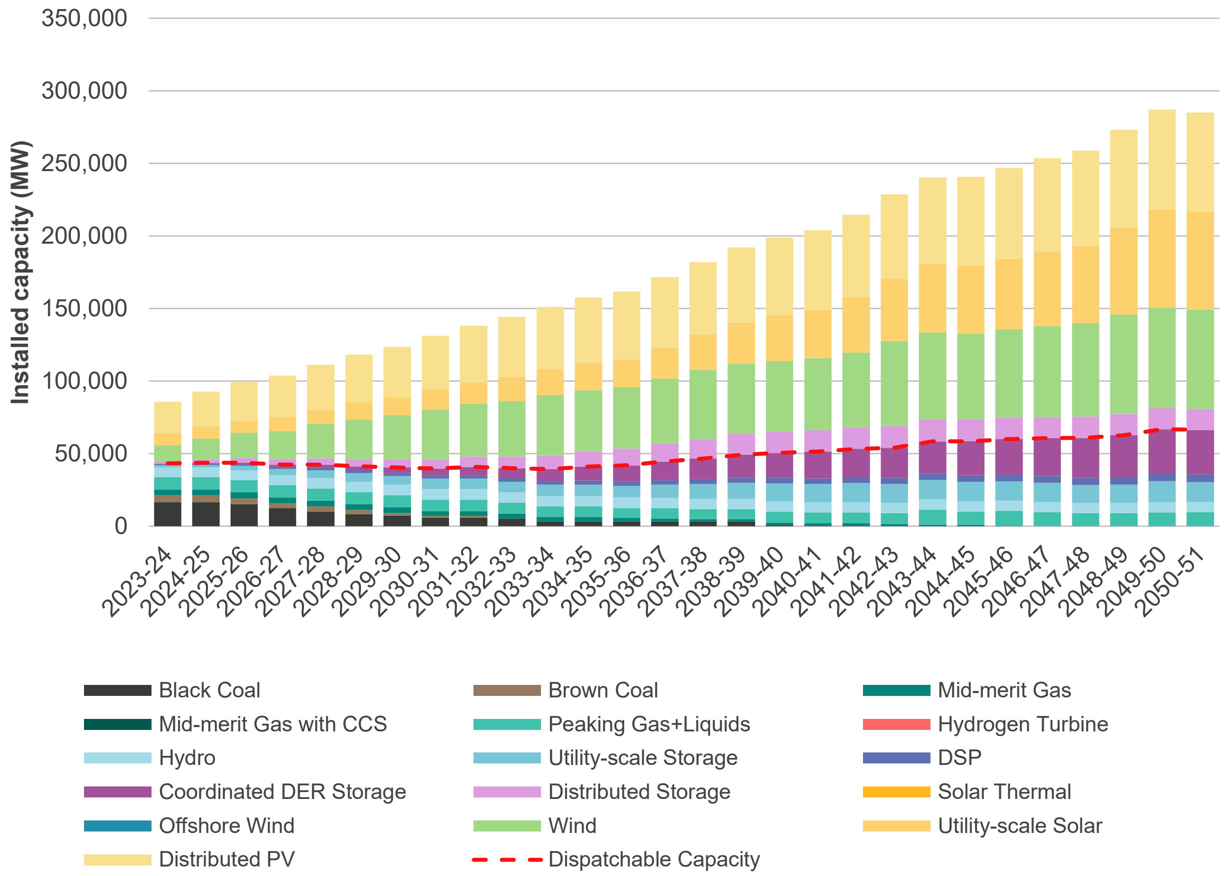
A2.3.1 Step Change

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 technological capability and cost provide a backdrop to faster net zero emission reduction ambitions, with greater adoption of energy efficiency measures and co-ordinated DER.

Details on the ISP Projects that are included in this least-cost development path are provided in Section A6.3.1 of Appendix 6.

Generation and storage development in the *Step Change* scenario

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



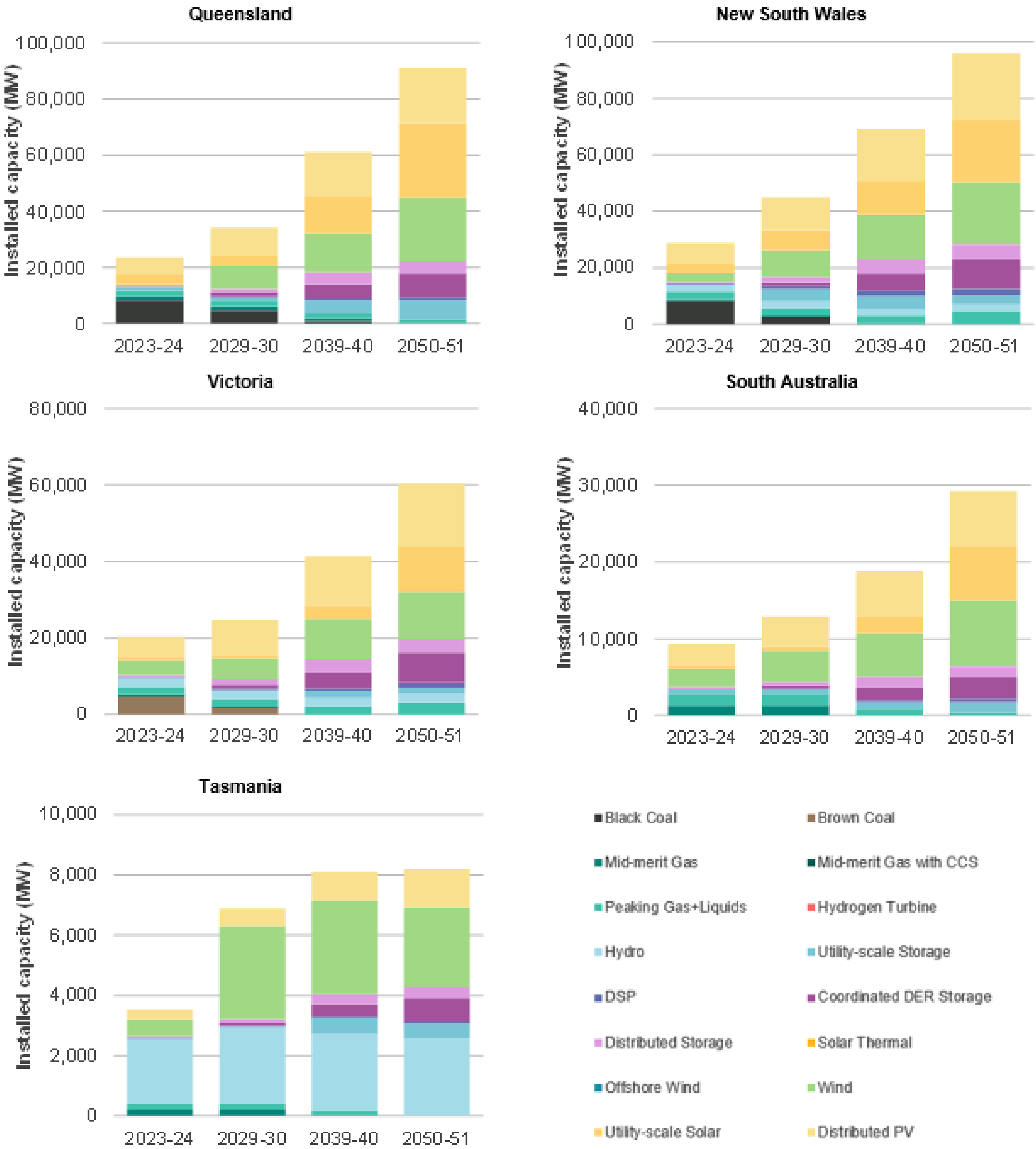
The generation capacity forecast (shown in Figure 5 above) projects that:

- To 2029-30:
  - VRE developments extend beyond the requirements of legislated state government policy, as the NEM provides a grid with low emission-intensity to 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, offsetting strong growth in VRE and DER. By 2049-50:
  - All coal and mid-merit gas 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 in the NEM, including co-ordinated DER storages but also expanded utility-scale developments that provide greater storage depth, as well as peaking gas developments to provide further resilience.

Figure 6 shows the capacity development at the regional level.

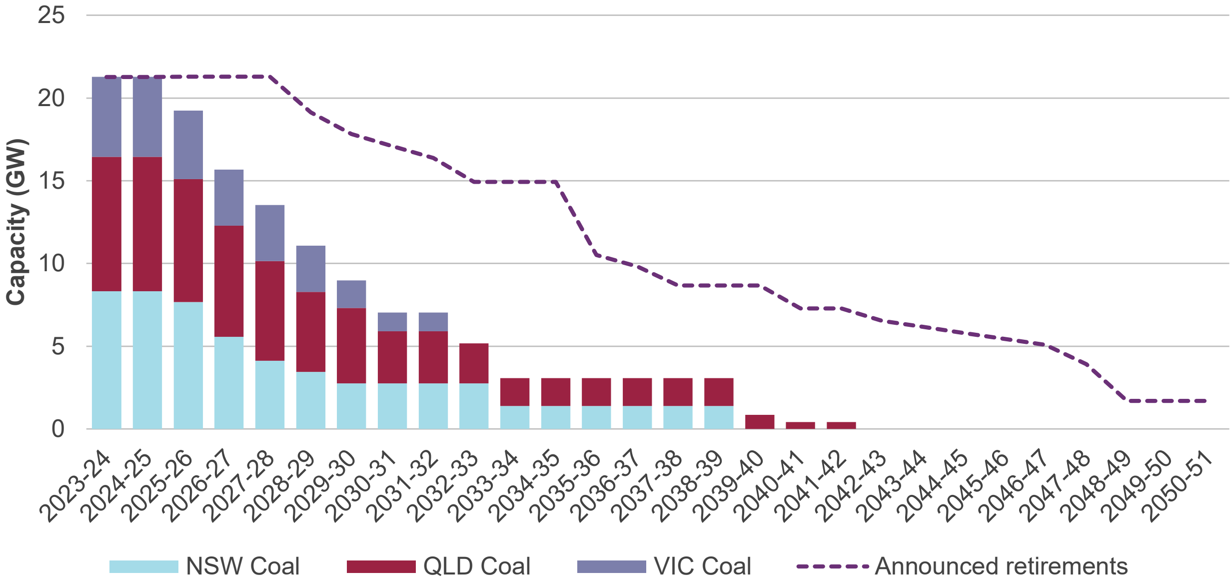
Figure 6 Forecast regional generation capacity to 2050-51, *Step Change*



Emission reduction requirements bring forward coal retirements

Rapid emission reduction is required in the *Step Change* scenario due to the application of economy-wide carbon budgets to limit global temperature rise to well below 2° compared to pre-industrial levels. With the carbon budget applying to all sectors, 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 two-thirds 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* scenario



The pace of transformation will be influenced by the availability of transmission to deliver VRE generation to consumers across the planning horizon. Figure 11 demonstrates the faster retirement schedule that would be required if transmission expansion was not part of AEMO's ODP.

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, while a negative value indicates a net deduction due to either an economic 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.
- Additional distributed energy storage increases the flexibility of the customer load. Additional utility-scale energy storages are 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* scenario

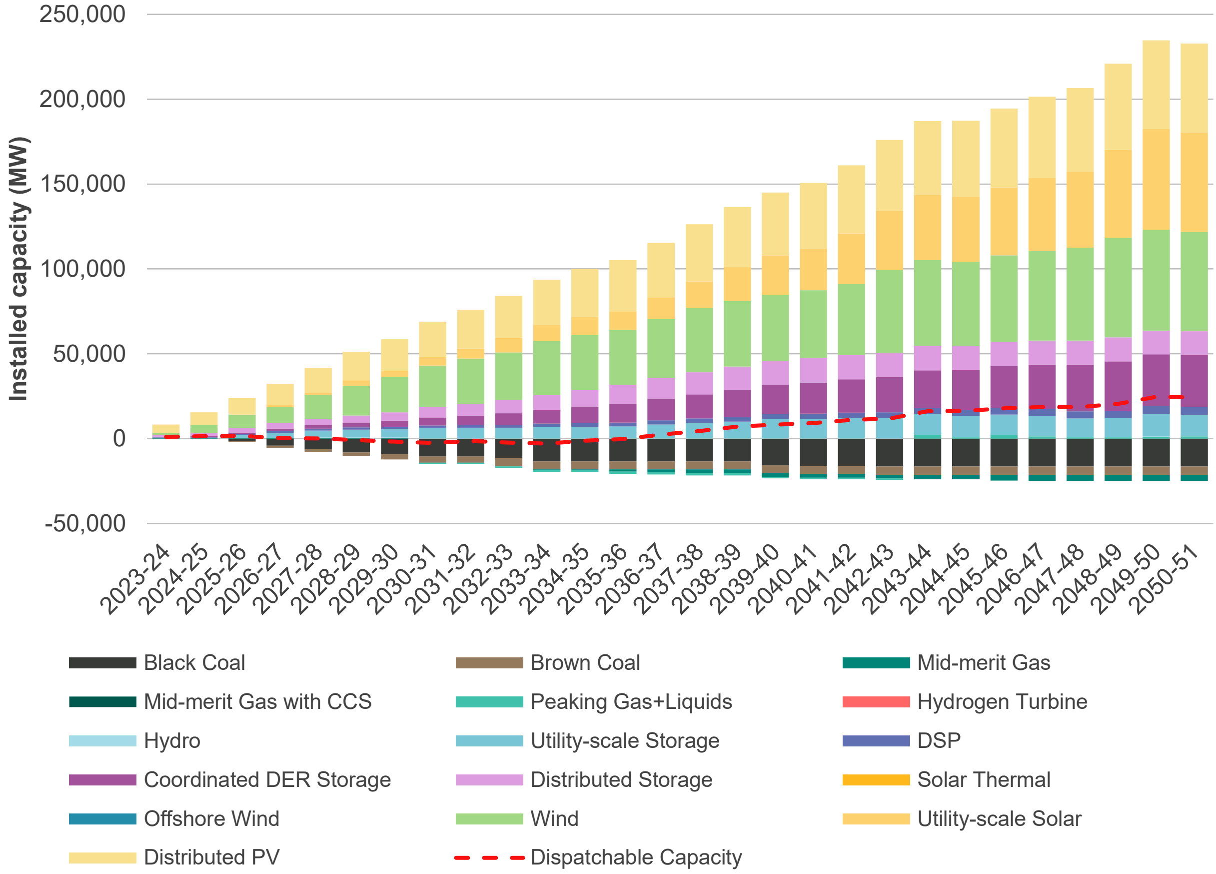
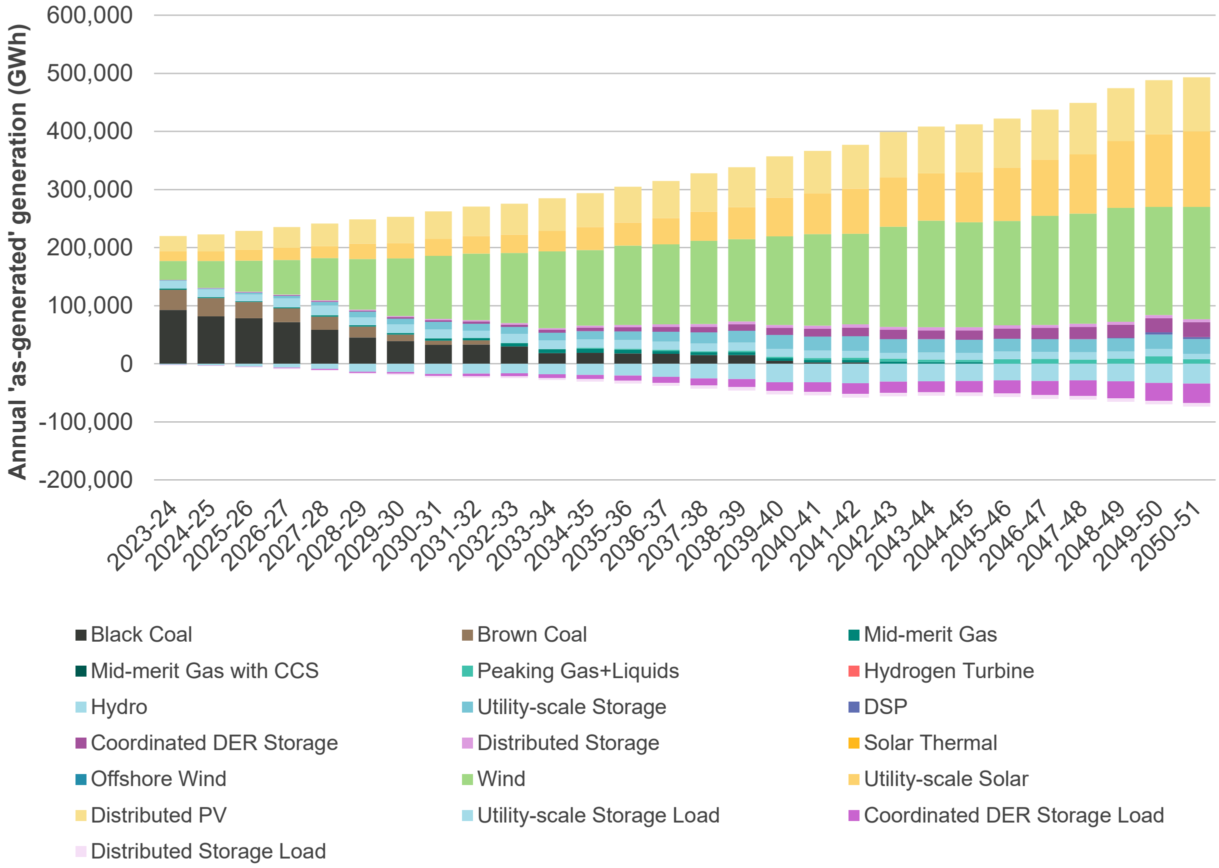


Figure 9 shows the forecast generation mix in the *Step Change* scenario, identifying that:

- A rapid shift from thermal generation to VRE is projected within the next decade. As described in section A4.2.2 of Appendix 4, frequent periods of 100% renewable generation are anticipated. By the mid-2040s the system is expected to operate 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 generation.
- By 2049-50, renewable energy sources are forecast to make up 97% 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 consumer load (given charging inefficiencies), but also enabling the efficient utilisation of surplus renewable energy generation.

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



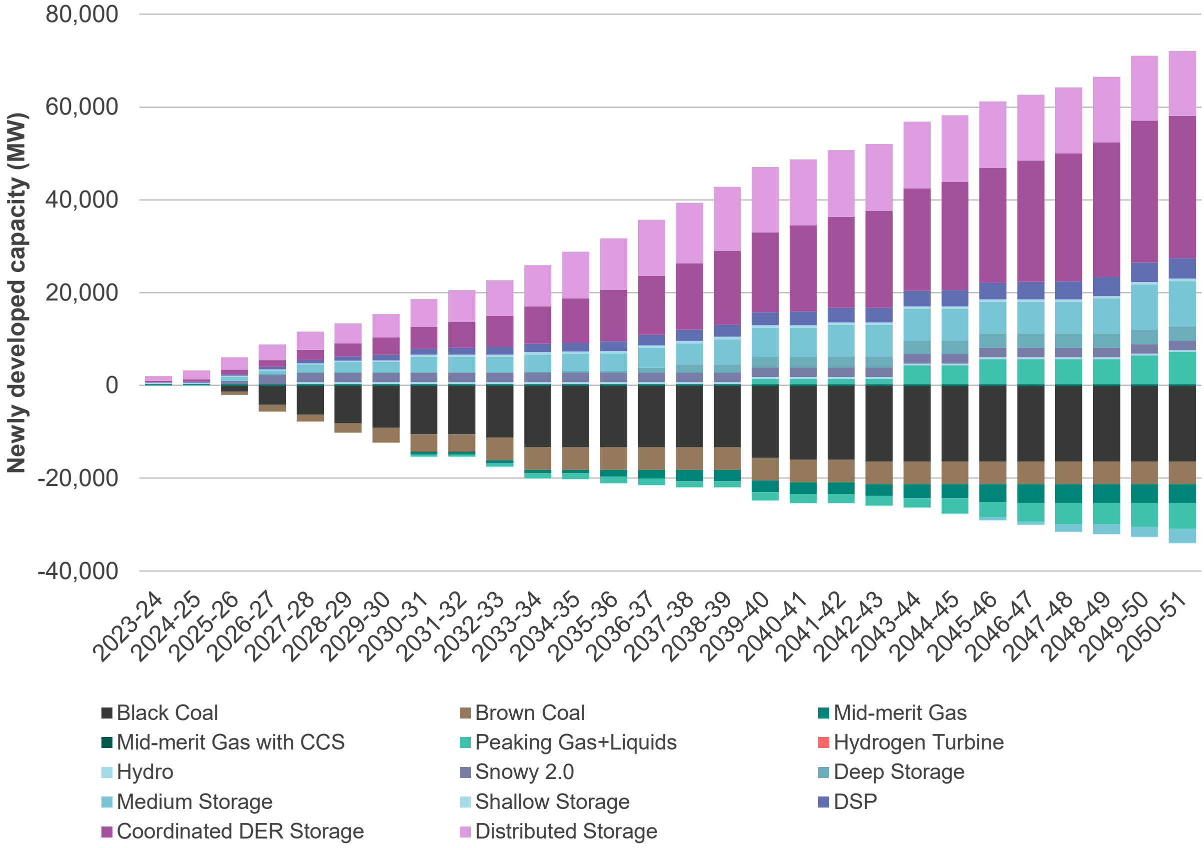
Storage complements VRE, but still a role for peaking capacity

The increased uptake of DER in the *Step Change* scenario means that relatively shallow distributed storage systems make up a large part of the new dispatchable capacity developments. These distributed storages primarily meet the need for shallow storages which manage intra-day variability. The shallow storages are complemented by a suite of deeper, utility-scale storage developments to replace accelerated thermal retirements. Approximately 6 GW of peaking gas is also developed later in the planning horizon, 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 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* scenario



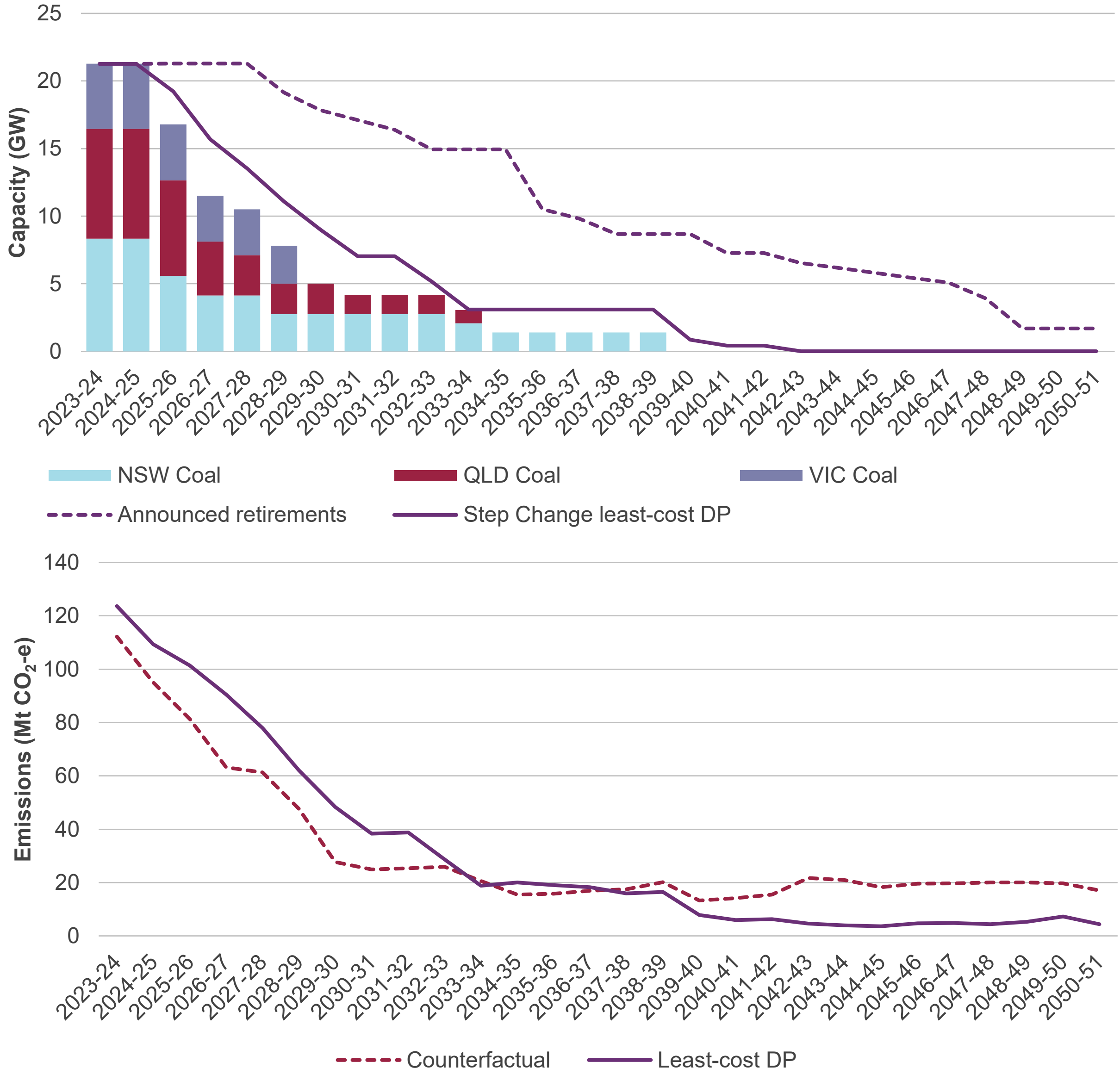
Future generation mix in the *Step Change* scenario without the ISP transmission developments

Impact of transmission development on coal retirements

AEMO's 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. 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 the least-cost development path without significant curtailment of those resources at times, and therefore relies on alternative generation sources such as mid-merit gas in the later years of the horizon. Figure 11 below shows a comparison between the coal retirements in the counterfactual and least-cost development paths, and below, the comparison in emissions trajectory.

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



Capacity development in the counterfactual development path

With transmission limitations restricting further VRE development, new mid-merit gas 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.

Limitations to REZ access require a more diverse mix of technologies to meet the needs of the future NEM. Approximately 10 GW of offshore wind would 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 Reinforcement project.

Investment in carbon sequestration technologies, for example gas generation with carbon capture and storage technology, is also required later in the horizon in Queensland and Victoria, as a relatively low emissions intensity means of providing dispatchable capacity and operating within the carbon budget.

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

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

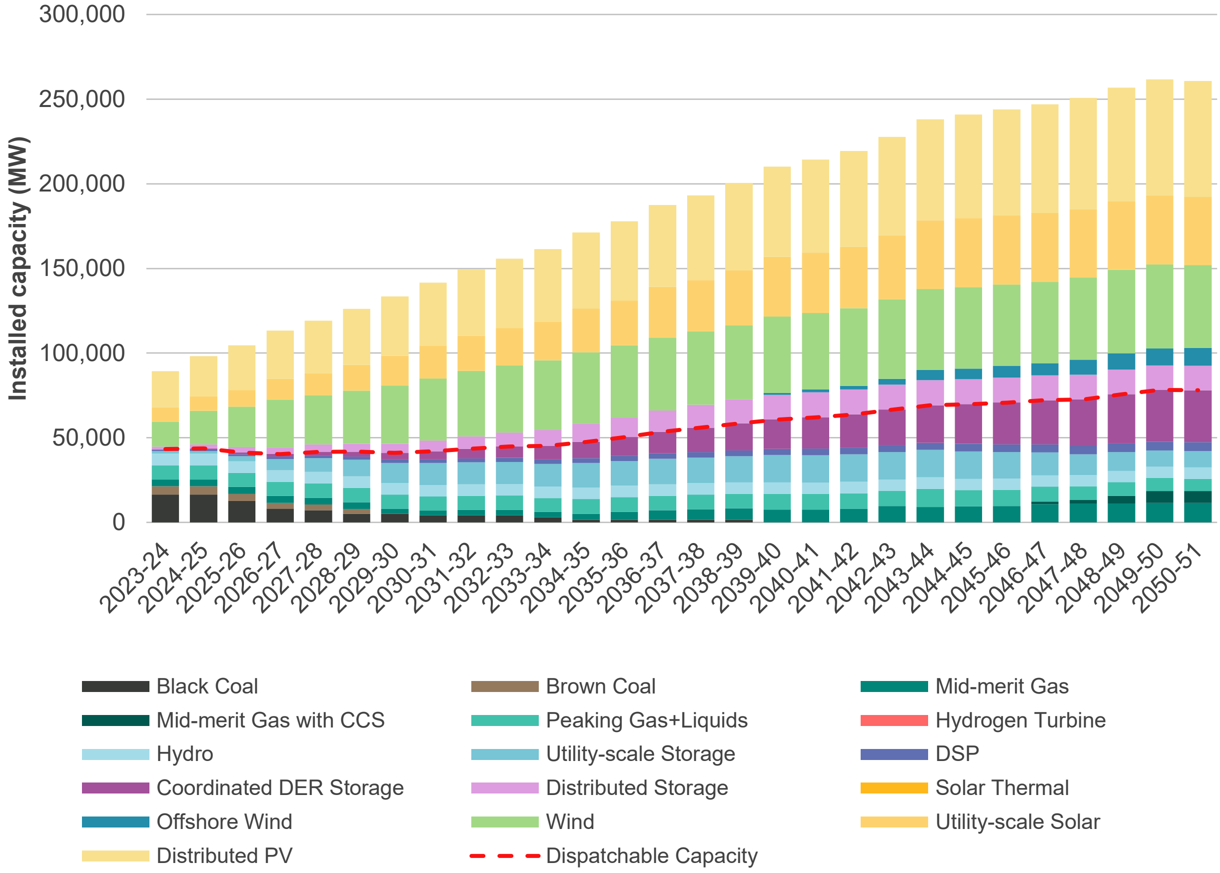
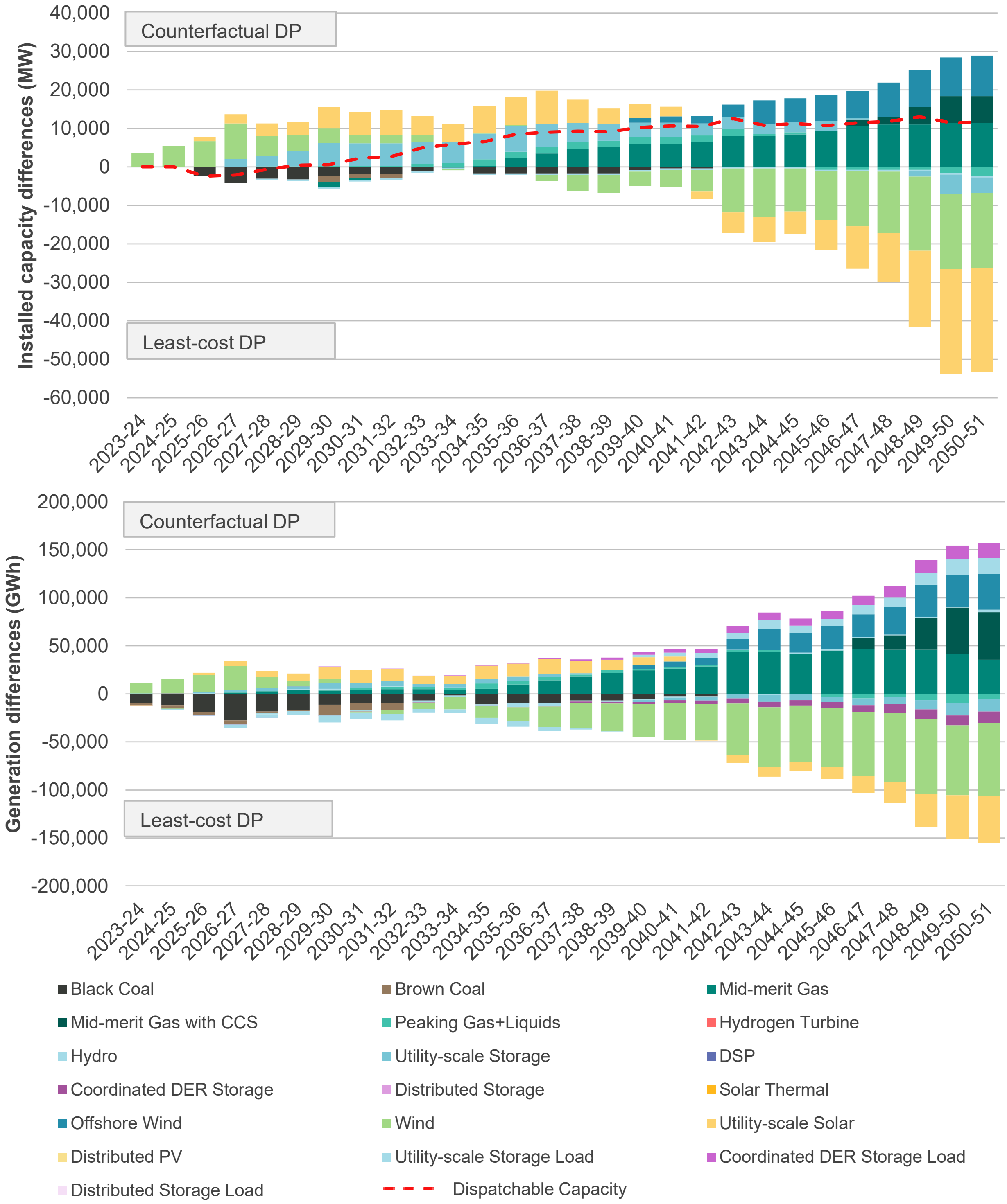


Figure 13 below shows the differences in ISP developments and generation with the benefit of the efficient transmission developments identified in the *Step Change's* least-cost DP, compared to the counterfactual. A positive value indicates higher total installed capacity in the counterfactual development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

Figure 13 Forecast capacity developments (top) and generation (bottom) to 2050 for least-cost development path compared to counterfactual, *Step Change* scenario



A2.3.2 *Progressive Change*

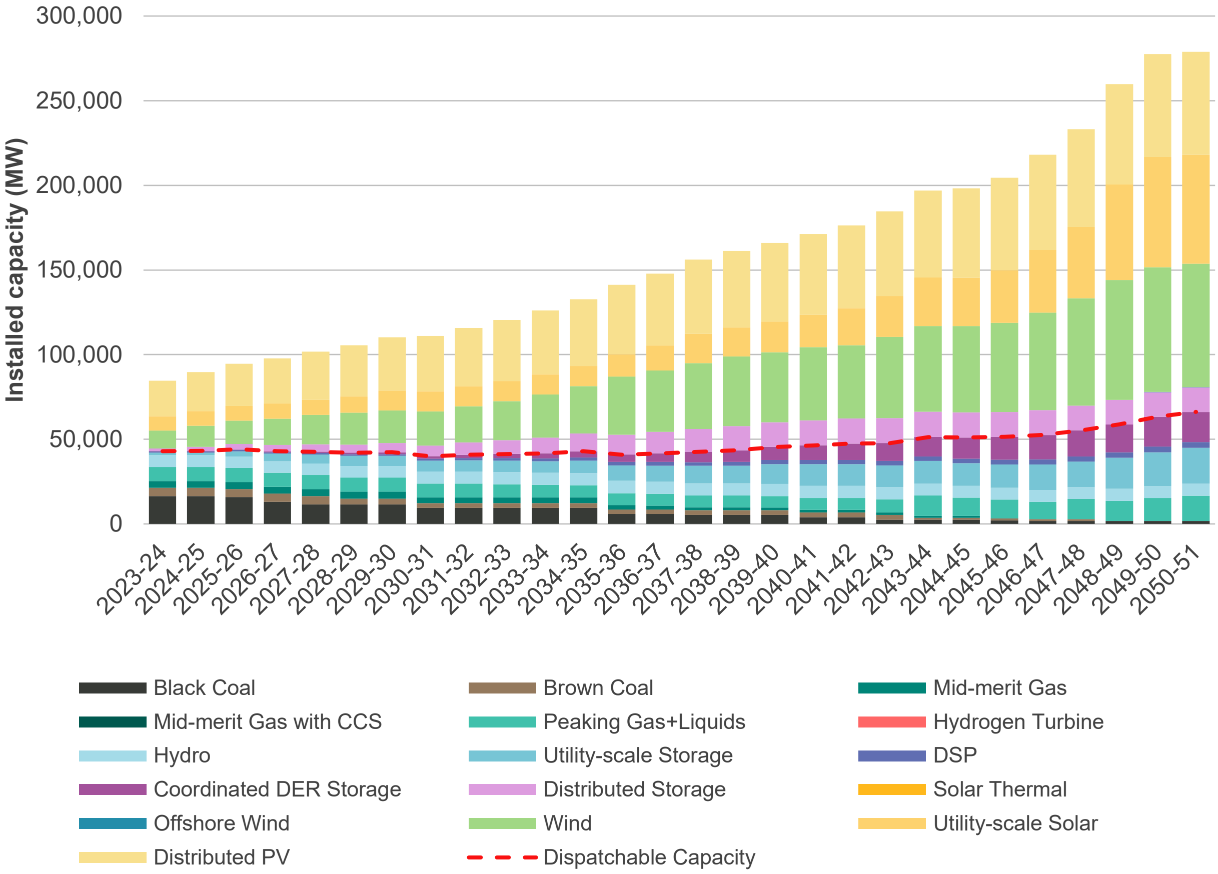
The *Progressive Change* scenario represents a future that delivers action towards an economy-wide net zero emissions objective by 2050, with initial focus on technology and cost advancements of low and zero emissions technologies. To achieve the net zero emissions outcomes, strong growth in electrification occurs as the 2050 deadline approaches.

This section describes the ISP developments that are forecast to maximise net market benefits in the *Progressive Change* scenario's least-cost optimal development path. Details on the ISP projects that are included in this least-cost development path are provided in Section A6.3.2 of Appendix 6.

Generation and storage development in the *Progressive Change* scenario

Figure 14 presents the forecast capacity mix for the NEM across the outlook period to 2049-50.

Figure 14 Forecast NEM generation capacity to 2050-51, *Progressive Change* scenario



The generation capacity forecast 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. Government policy in New South Wales will also drive the addition of 2 GW of long-duration storage.
  - Total installed capacity of coal will reduce to 15GW, 36% lower than existing capacity. Coal generation will reduce as new renewable energy developments increase, complemented by additional energy storage.

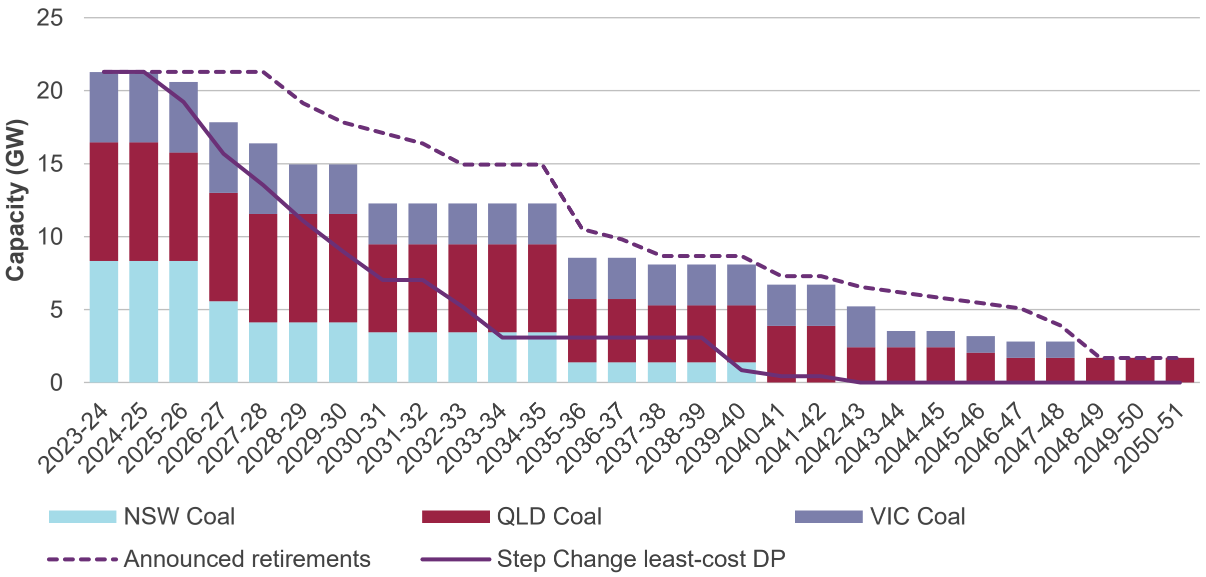
  - Network augmentation will reduce the need for new dispatchable investments beyond existing developments and policy commitments to meet the current reliability standard.
- By 2049-50:
  - Coal power stations continue to retire to meet carbon budget requirements, with less than 2 GW remaining by 2050. This demonstrates that while the scenario is 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 support increasing levels of demand response and distributed storage to maintain reliability as existing thermal generation retires.

Retiring gas 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 modelled coal retirements

The change in modelled coal closures in the *Progressive Change* scenario, relative to announced closure years and to the *Step Change* scenario, is shown in Figure 15.

Figure 15 Forecast coal retirements, *Progressive Change* scenario



Coal retirements in the *Progressive Change* scenario are accelerated compared to the expected closure years currently nominated by market participants. The key driver of these early retirements is the projection of new VRE and energy storage generation and the impact on wholesale prices and coal generation volumes.

Early coal closures before 2030 in New South Wales and Queensland are the result of declining revenue sufficiency (See section A4.2.7 of Appendix 4 for more information). By 2029-30, coal generation is projected to produce 38% of total electricity generated, compared to 65% in 2020-21.

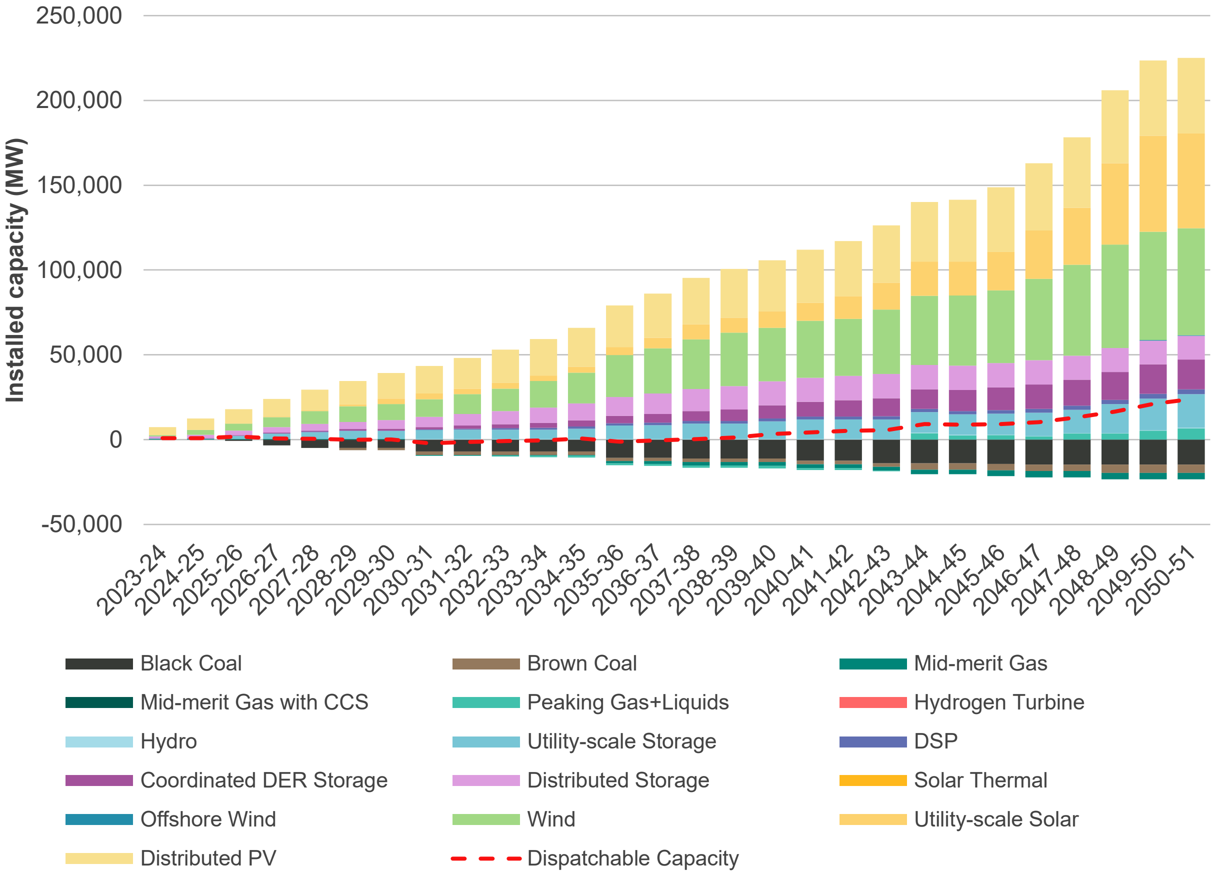
From 2030, further early retirement of black coal-fired generators is forecast. Unlike *Step Change*, the slower carbon budget reductions lead to earlier retirement of the more costly black coal generators rather than the more emissions-intensive brown coal generators. By 2050, coal capacity has decreased considerably to 1.7 GW, representing 1% of total capacity and producing approximately 2% of the total generation.

Strong growth in VRE uptake continues, and accelerates as electrification increases

Figure 16 shows the cumulative change in investment and withdrawal by fuel and technology type over time. Key highlights include:

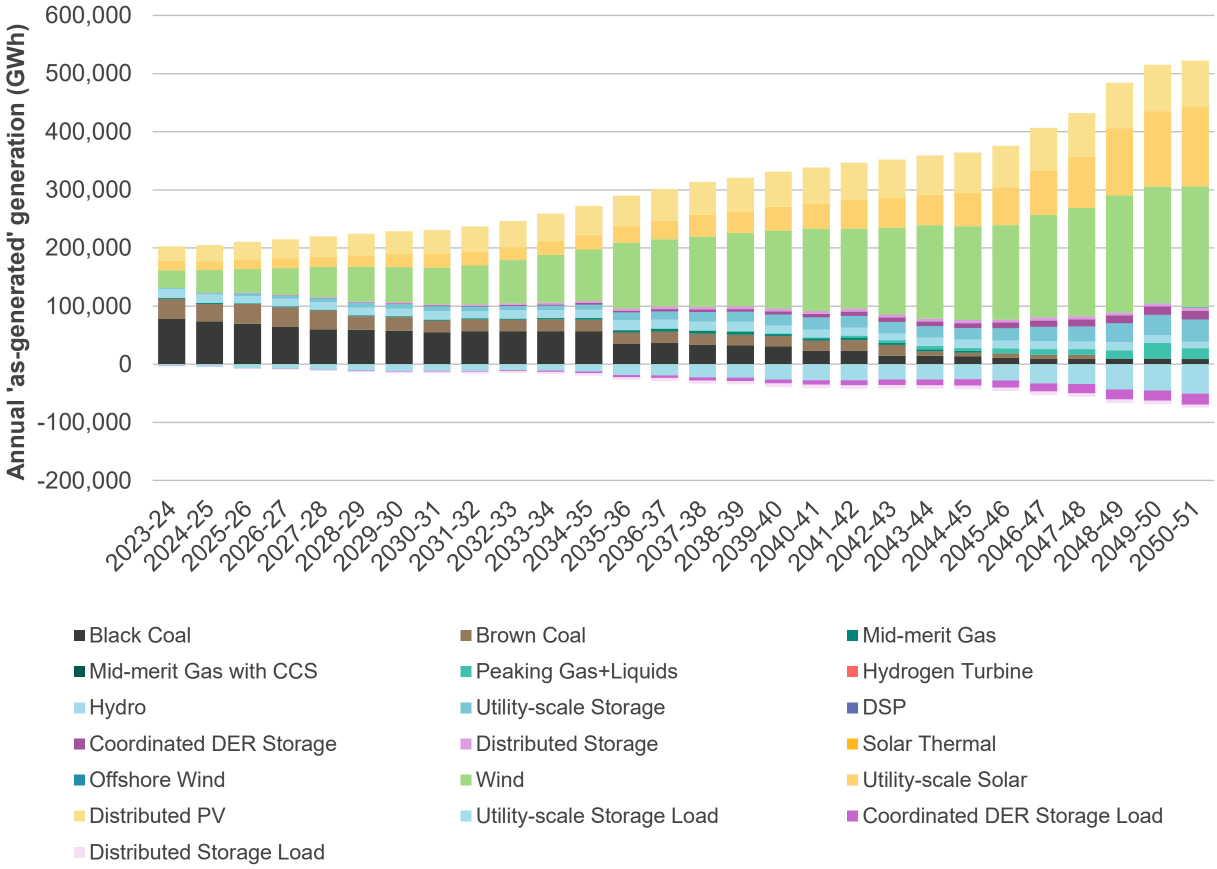
- Advanced thermal retirements are forecast to be offset by a combination of VRE, energy storage and DER. In the later decade of the horizon, gas generation retirements are generally replaced by new peaking gas developments. These developments provide firming support as more coal capacity retires from the system, and VRE developments start being limited by both transmission access and resource availability. Further discussions on these risks are outlined in Appendix 4.
- By 2049-50, in addition to over 60 GW of distributed PV, the NEM is forecast to need over 130 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 distributed storage from residential batteries and EVs.

Figure 16 Forecast relative change in installed capacity to 2050-51, *Progressive Change* scenario



In terms of energy production, Figure 17 demonstrates the forecast change in the energy mix that is very different 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 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 17 Forecast annual generation to 2050-51, *Progressive Change* scenario

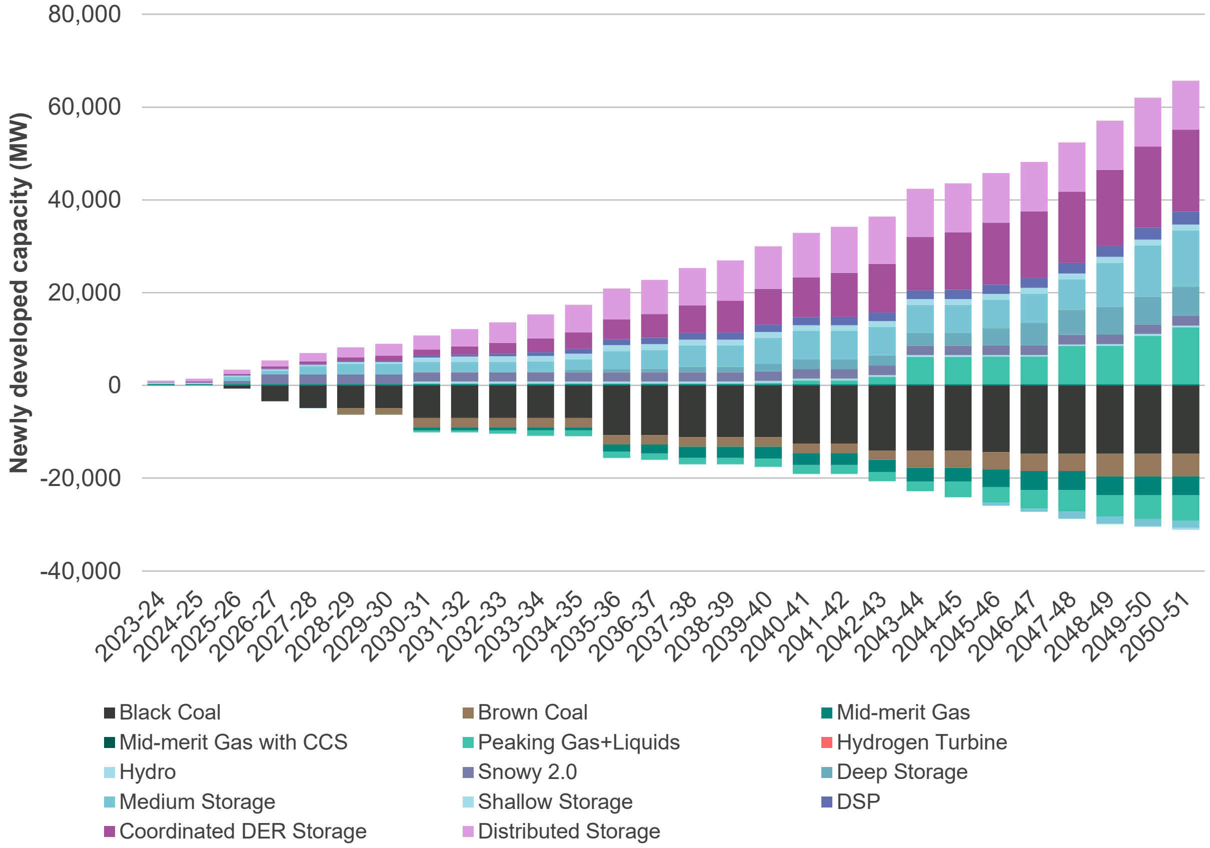


Storage complements VRE, but still a role for peaking capacity

New dispatchable capacity developments and transmission augmentations strengthen the capability of the network to operate and deliver renewable energy efficiently to consumers and maintain reliability. Energy storage developments before 2030 are mainly developed in New South Wales as a result of the New South Wales Electricity Infrastructure Roadmap's long-duration storage target and the Snowy 2.0 development. From 2035, the dispatchable capacity uptake is projected to increase considerably as more thermal generation retires and VRE is developed.

Peaking gas capacity is developed to provide support by generating at times of low wind and solar availability. Towards the end of the horizon, as existing peaking capacity reaches the end of its technical life and retires, new peaking capacity is generally built to replace it as shown in Figure 18.

Figure 18 Forecast firm capacity development to 2050-51, *Progressive Change* scenario



Contrasting the *Progressive Change* scenario with the *Step Change* scenario

Figure 19 below presents the capacity difference between the *Progressive Change* and *Step Change* scenarios. What is evident from this figure is that by the end of the horizon, the difference between the scenarios starts to narrow, as the scale of electrification in the *Progressive Change* scenario catches up with the earlier developments of *Step Change*.

The key differences from the *Step Change* scenario 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.
- The *Progressive Change* scenario is characterised by lower uptake of distributed storage technologies (less residential battery systems and less EVs that are capable of vehicle-to-grid operation) that increases the need for utility-scale firming developments in the long term.

Figure 19 Comparison of generation capacity developed between *Progressive Change* and *Step Change* scenarios

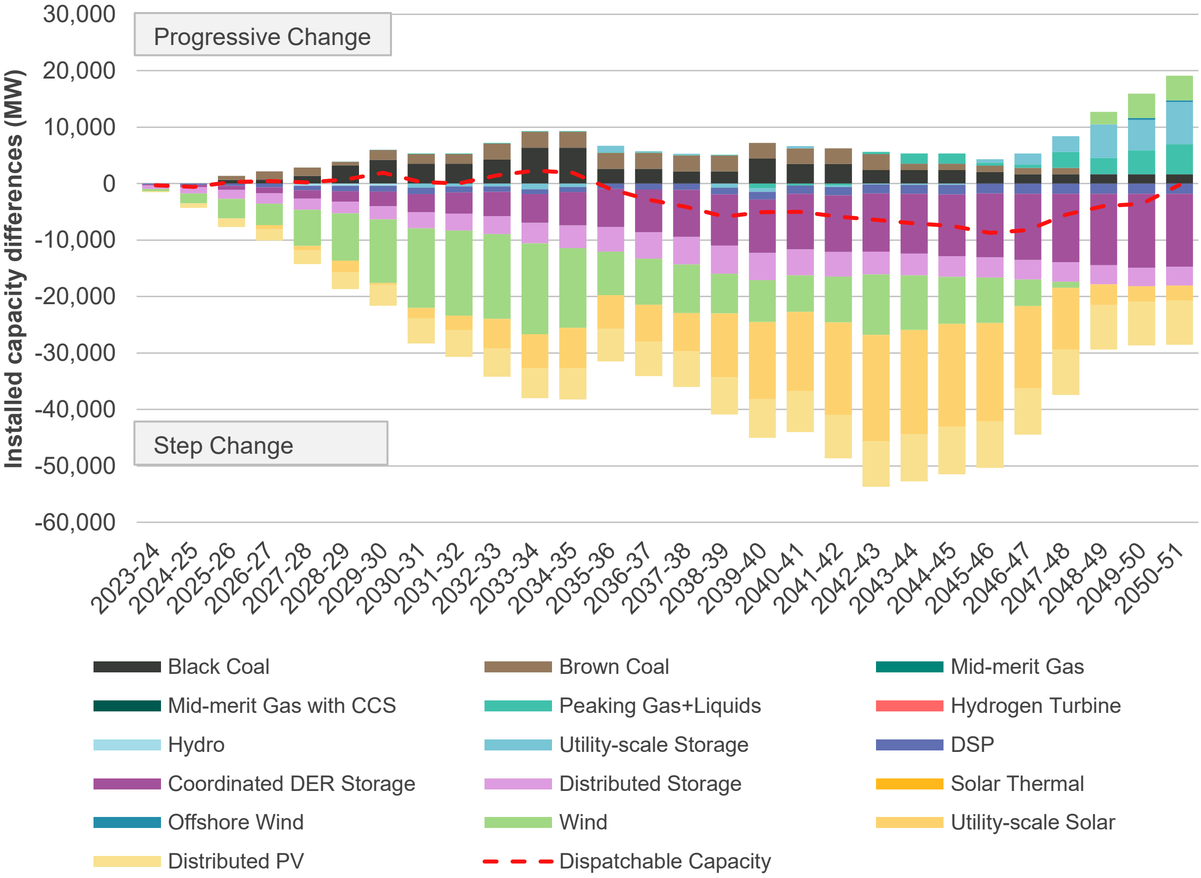


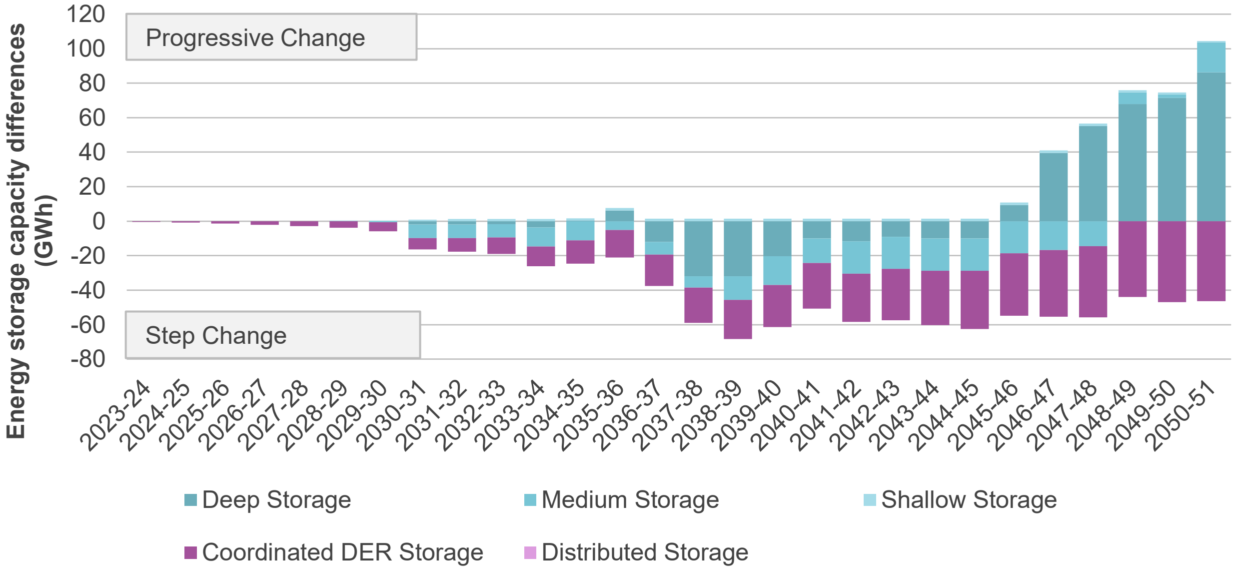
Figure 20 demonstrates the lower uptake of distributed storage technologies in the *Progressive Change* scenario compared to *Step Change*.

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 mid 2040s), as well as lower uptake of distributed 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 both a greater need for 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 2040's 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 20 Comparison of energy storage capacity between *Step change* and Net Zero scenarios



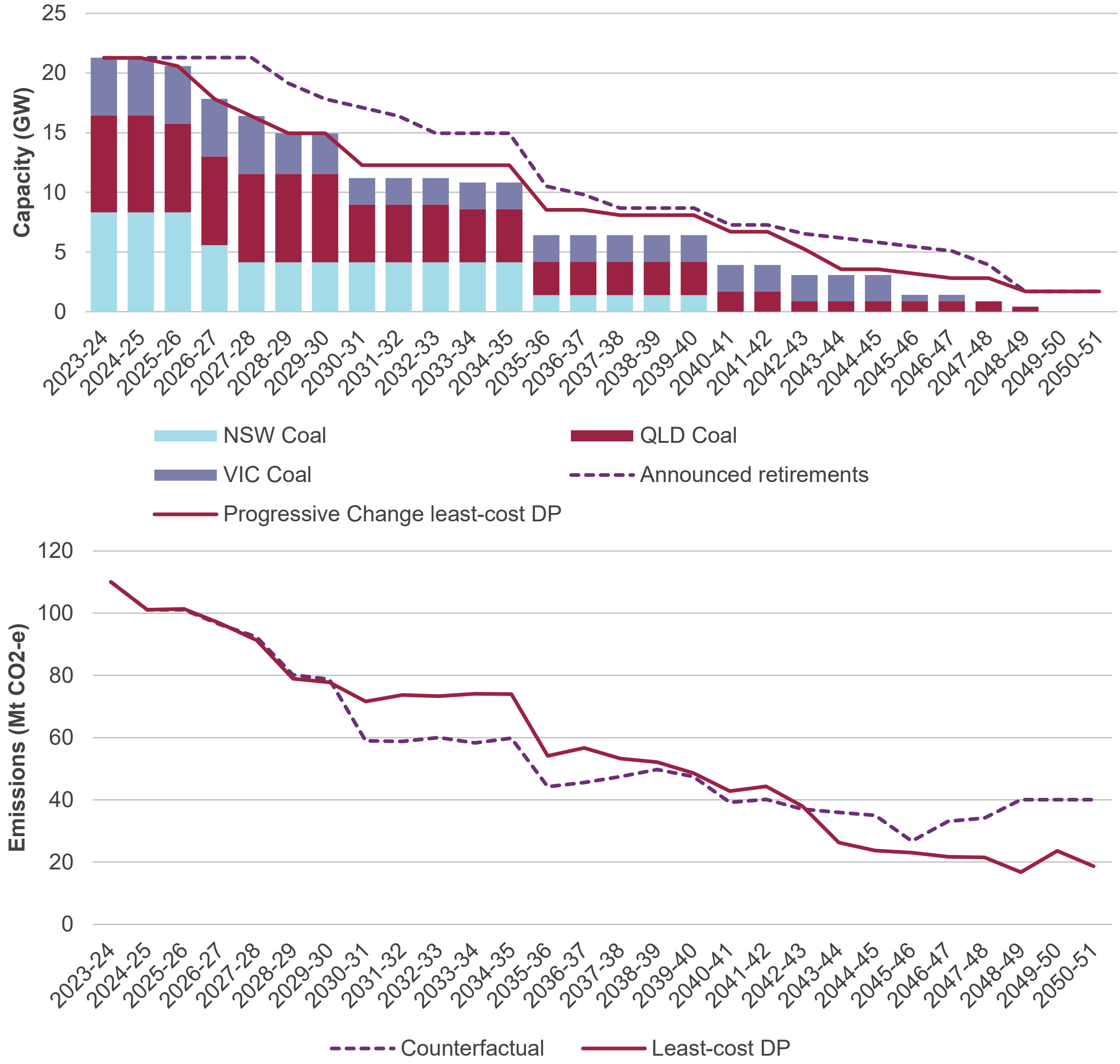
Future generation mix in the *Progressive Change* scenario without the benefit of transmission development

Impact of transmission development on coal retirements

As a result of the carbon budget, which is in place beyond 2030, coal is retired earlier in counterfactual than the least-cost *Progressive Change* retirements (described above). Without transmission augmentation there is a higher reliance on gas generation in the later part of the horizon as VRE operations are transmission curtailed. To accommodate this and meet the carbon budget which applies from 2030, earlier coal closures are forecast.

Figure 21 below contrasts the economic coal retirement schedule in the *Progressive Change* with and without transmission augmentation.

Figure 21 Forecast coal retirements (top) and emissions trajectory (bottom) to 2050, *Progressive Change* scenario counterfactual

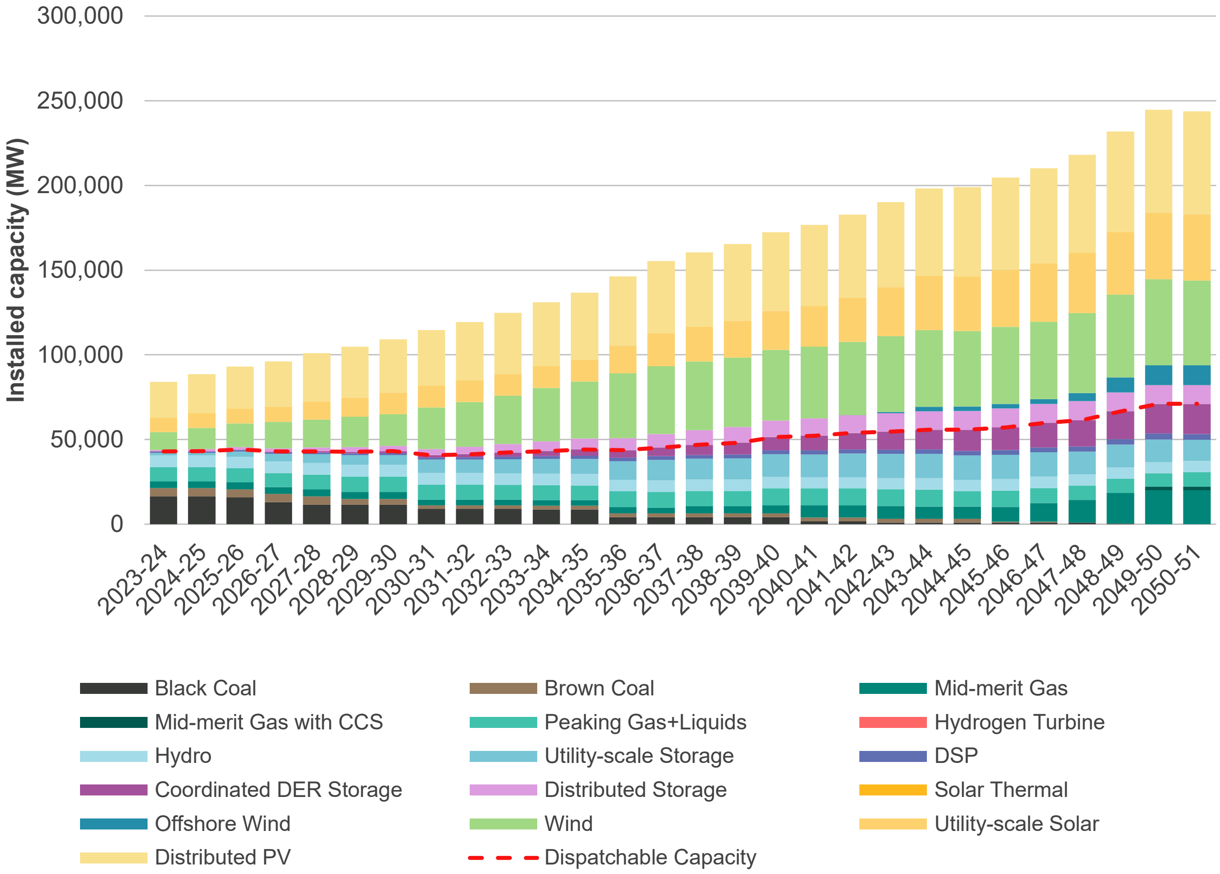


Capacity development in the counterfactual development path

Figure 22 below presents the capacity development outlook for the *Progressive Change* scenario in the absence of transmission developments and committed or anticipated network augmentations.

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 (with and without CCS) gas generation plays an increasing role in meeting consumer needs. 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 near the Sydney, Newcastle, and Wollongong sub-region.

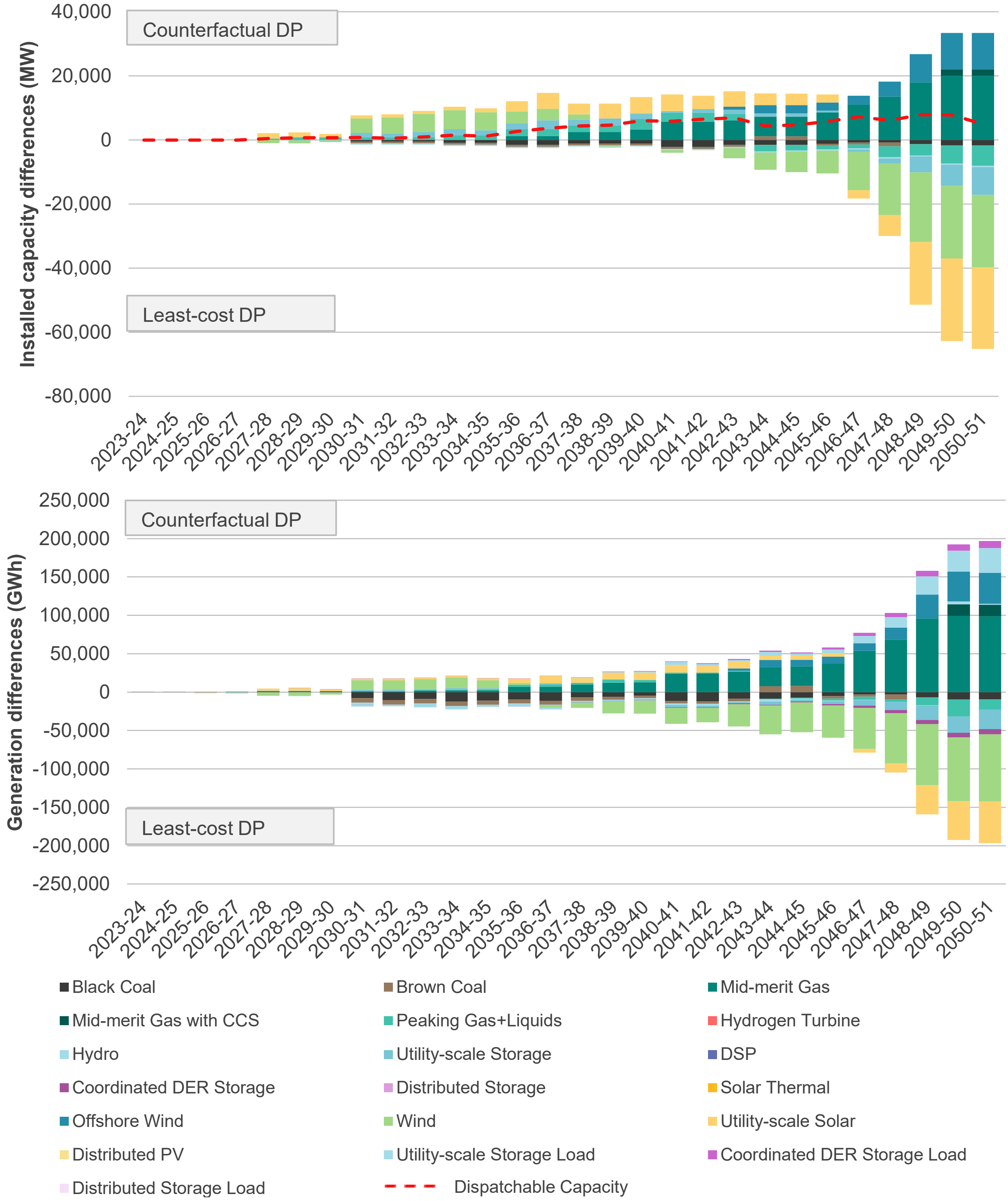
Figure 22 Forecast NEM generation capacity to 2050-51, *Progressive Change* scenario counterfactual



For comparison, Figure 23 presents the difference in installed capacity and dispatched generation between the least-cost development path 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 23 Forecast capacity developments (top) and generation (bottom) to 2050-51 for least-cost development path compared to counterfactual, *Progressive Change* scenario



A2.3.3 Hydrogen Superpower

The *Hydrogen Superpower* scenario represents a world with very high levels of electrification to meet strong decarbonisation targets, with hydrogen becoming a ubiquitous fuel supported by strong technology cost improvements. These technology cost reductions improve Australia's capacity to export renewable energy to global consumers, supporting stronger domestic economic outcomes relative to other scenarios.

The *Hydrogen Superpower* scenario is based on a number of assumptions, particularly related to the uptake of hydrogen for both domestic and export use. These assumptions are likely to be refined and enhanced as more information becomes available in future. The scale of development and the pace of change in this scenario presents a number of challenges in terms of the ability to deliver given supply chain constraints, and also the potential for other development barriers, such as social licence considerations. Development at this scale would further increase the need for additional operational tools to operate the system securely and efficiently. These enhancements and market reforms are currently being progressed through the post-2025 electricity market design process.

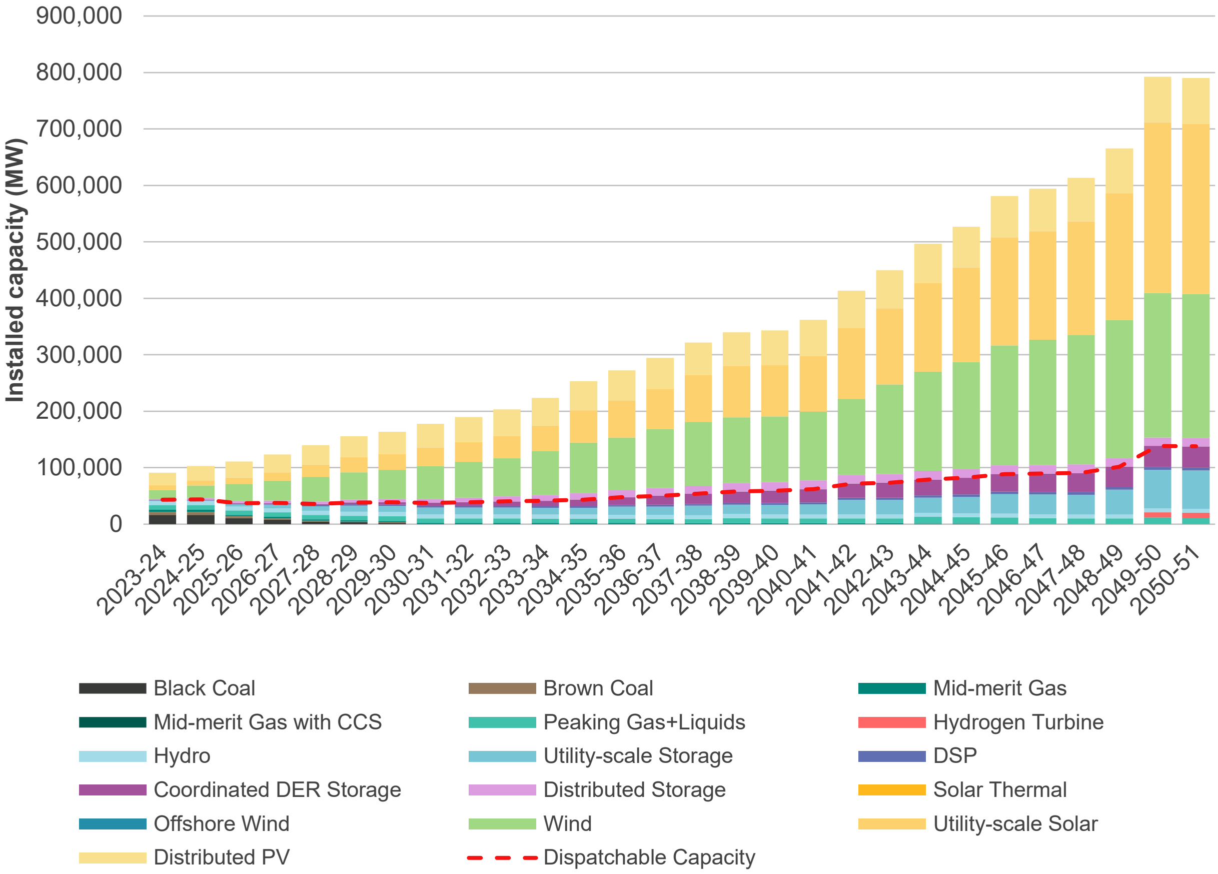
Generation and storage development in the *Hydrogen Superpower* scenario

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

- To 2029-30:
  - Total coal installed capacity reduces to only 3 GW, 84% lower than existing capacity, in response to the ambitious decarbonisation objectives, and the remainder retires the following year.
  - Development of VRE far exceeds the requirements of state government policies in all regions, primarily to replace the energy lost from retired coal generation.
  - VRE development exceeds the *Step Change* scenario at the same stage by approximately 35 GW. From the 15 GW installed today, a staggering 64 GW would need to be developed in a decade – twice the record rate observed recently. Supply chain constraints may make this challenging.
- By 2049-50:
  - All mid-merit gas generation has been retired.
  - Over 550 GW of large-scale VRE is forecast for development to meet almost 1,000 TWh of electricity load required for hydrogen export to the scale assumed in the scenario.
  - Approximately 130 GW of electrolyser capacity is needed to meet both export and domestic hydrogen demand.

Figure 24 illustrates the vast scale of generation development in this scenario.

Figure 24 Forecast NEM generation capacity to 2050-51, *Hydrogen Superpower* scenario

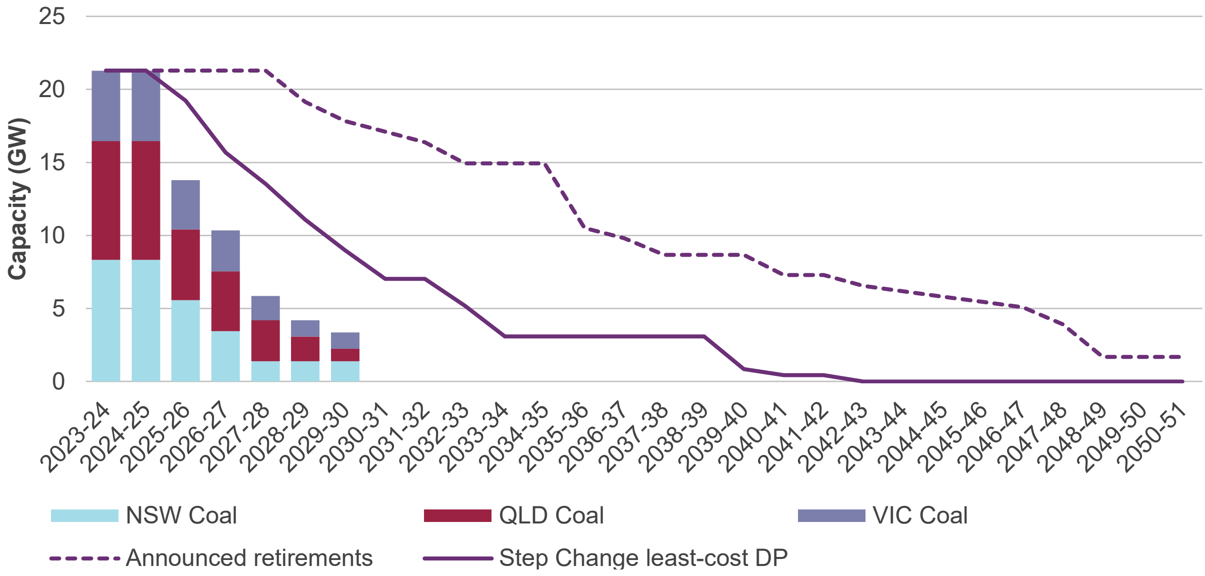


Impact of transmission development on coal retirements

The *Hydrogen Superpower* scenario 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 the *Step Change* scenario.

Figure 25 below illustrates the speed of the retirement schedule in the scenario for coal generation in comparison to the *Step Change* scenario.

Figure 25 Forecast coal retirements, *Hydrogen Superpower* scenario



Hydrogen developments

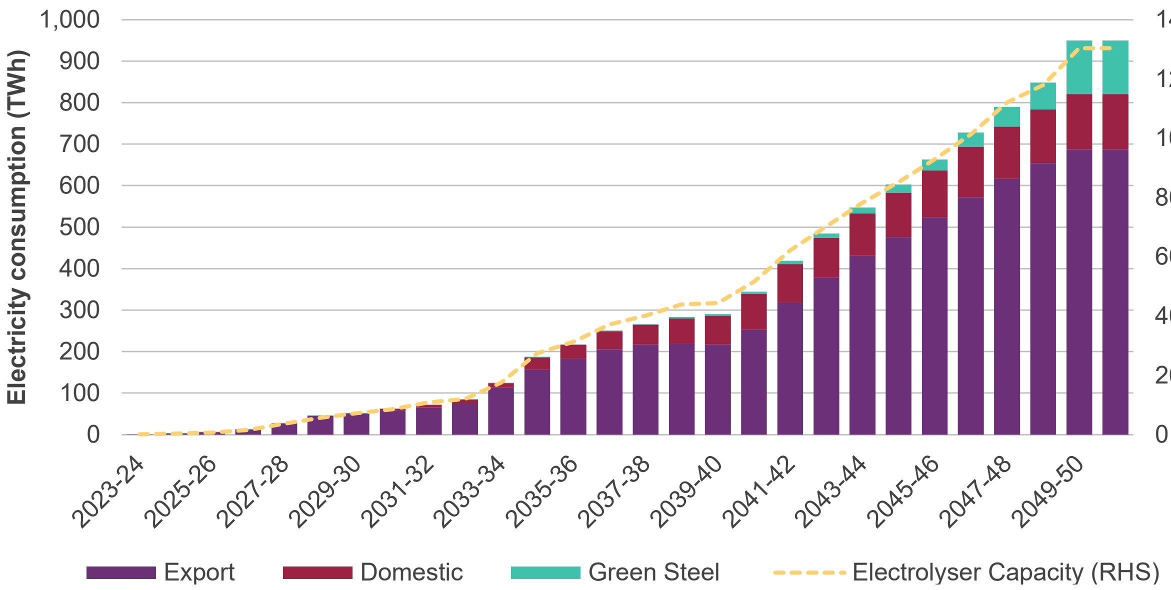
The ISP modelling considered grid-connected hydrogen developments for domestic use, for export (as ammonia), and for the production of green steel. The assumed domestic and export hydrogen demands were modelled as loads with sufficient flexibility to be optimised within a monthly timeframe. In addition 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.

Figure 26 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.

Figure 26 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 was developed to allow for utilisation rates of between 75-80% 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.

A spread of geographical diversity is expected to minimise costs, with Queensland and South Australia providing the greatest export opportunity (see Figure 27). 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 27 Regional allocation of hydrogen developments by 2050

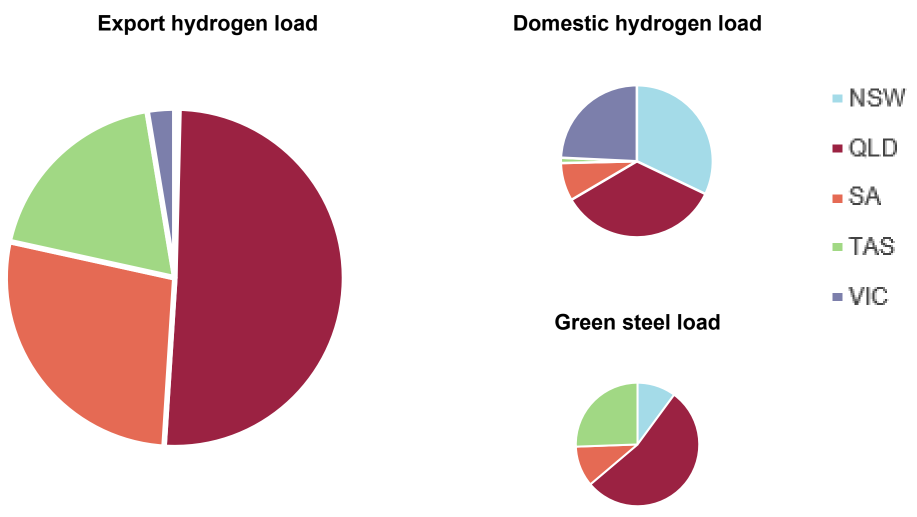
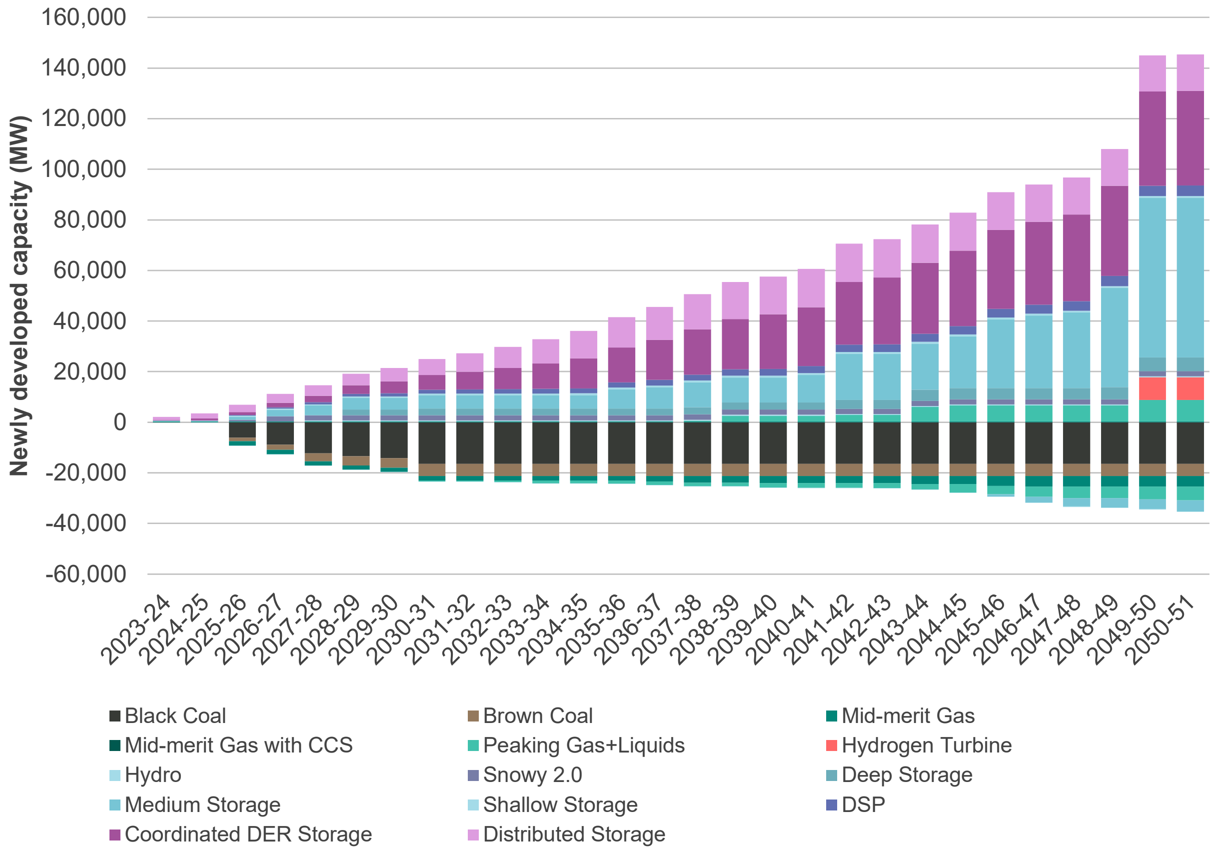


Figure 28 shows the development of new dispatchable capacity required in the *Hydrogen Superpower* scenario to service the growing demand of consumers and new industry. The high uptake of distributed storage in the *Hydrogen Superpower* scenario is complemented by medium and deep utility-scale storage development to firm the additional renewable energy developments particularly after coal generation retires.

While hydrogen production provides an inherent capacity to operate flexibly and flex to avoid exacerbating extreme demand conditions, additional loads associated with hydrogen are expected to need more firm supply. Approximately 8.5 GW of peaking gas and 9 GW hydrogen turbines are developed later in the horizon in part to meet this additional hydrogen load, including ammonia production facilities for export, and electric-arc furnaces for green-steel manufacturing. The degree to which these loads can operate flexibly to avoid the need for significant additional firm electricity supplies will remain an uncertainty while the technology is immature.

Figure 28 Forecast firm capacity development to 2050, *Hydrogen Superpower* scenario



Future generation mix in the *Hydrogen Superpower* scenario without the benefit of transmission development

Capacity development in the counterfactual development path

As shown in the previous sections, the *Hydrogen Superpower* scenario results in a very large increase in NEM demand, and as such a much larger investment need for new capacity in the NEM than other scenarios. This scale of expansion will require at least 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 demand for electricity to produce hydrogen would not be able to be met which would be inconsistent with the scenario narrative. For that reason, for this scenario, this targeted transmission development has been allowed to occur in the counterfactual development path.

The forecast capacity mix in the counterfactual development path is shown in Figure 29.

Figure 29 Forecast NEM generation capacity to 2050-51, *Hydrogen Superpower* counterfactual

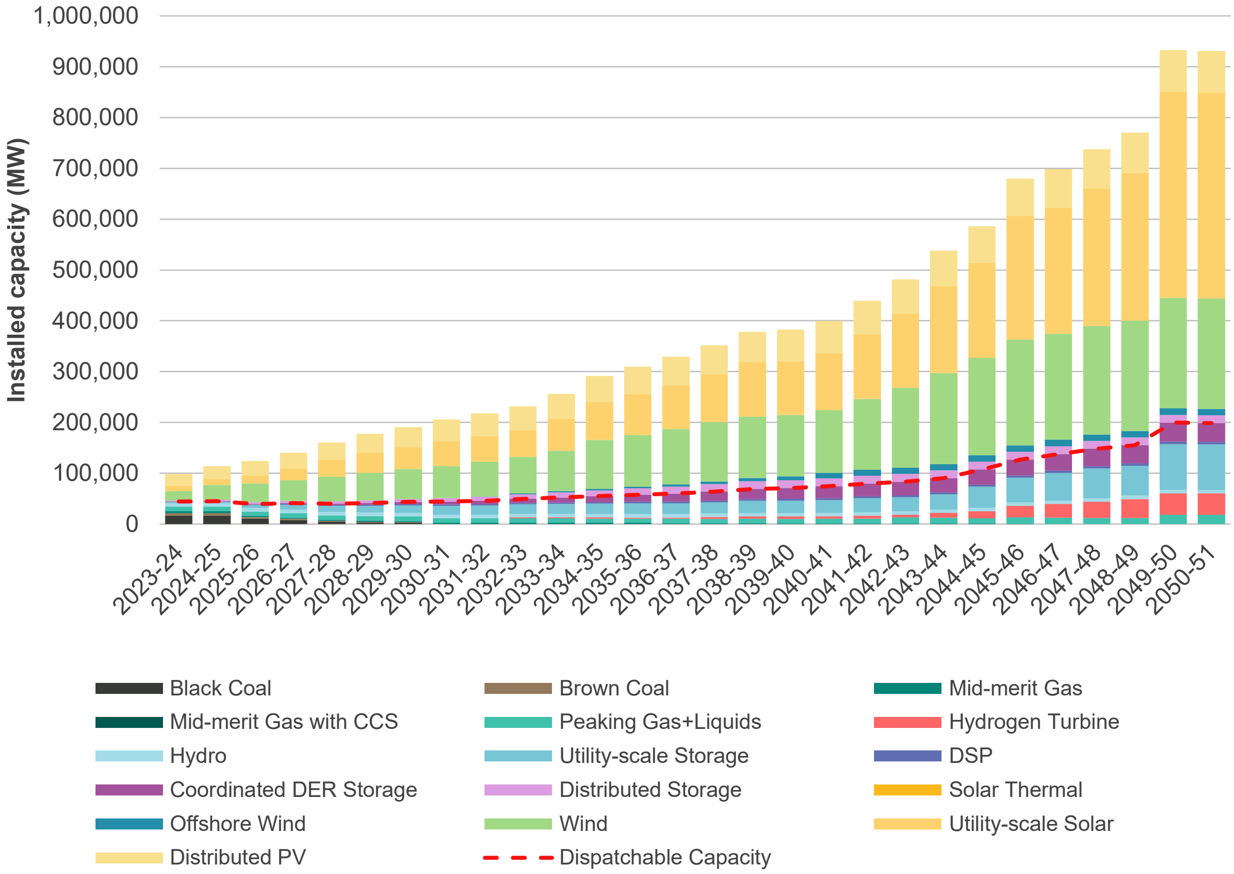
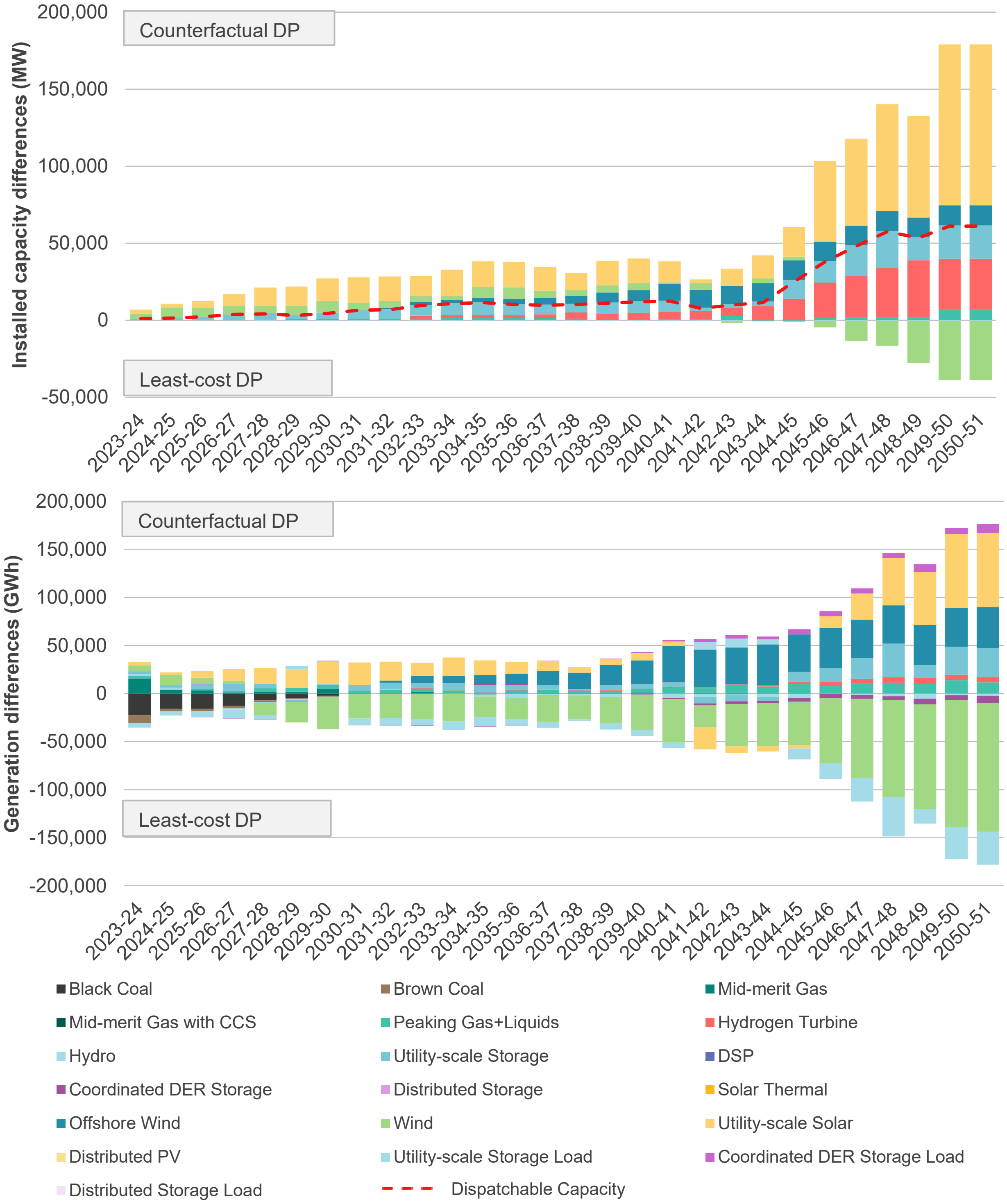


Figure 30 demonstrates the differences in ISP developments and generation between the least-cost and the counterfactual development paths. Without broad transmission expansion, further onshore wind development would be too heavily curtailed, so a greater development of solar (to complement wind development in highly developed REZs) and offshore wind is forecast, with storages, to meet the energy needs that cannot be delivered efficiently through wind (without transmission).

Figure 30 Forecast capacity developments (top) and generation (bottom) to 2050-51 for least-cost development path compared to counterfactual, *Hydrogen Superpower* scenario



A2.3.4 Slow Change

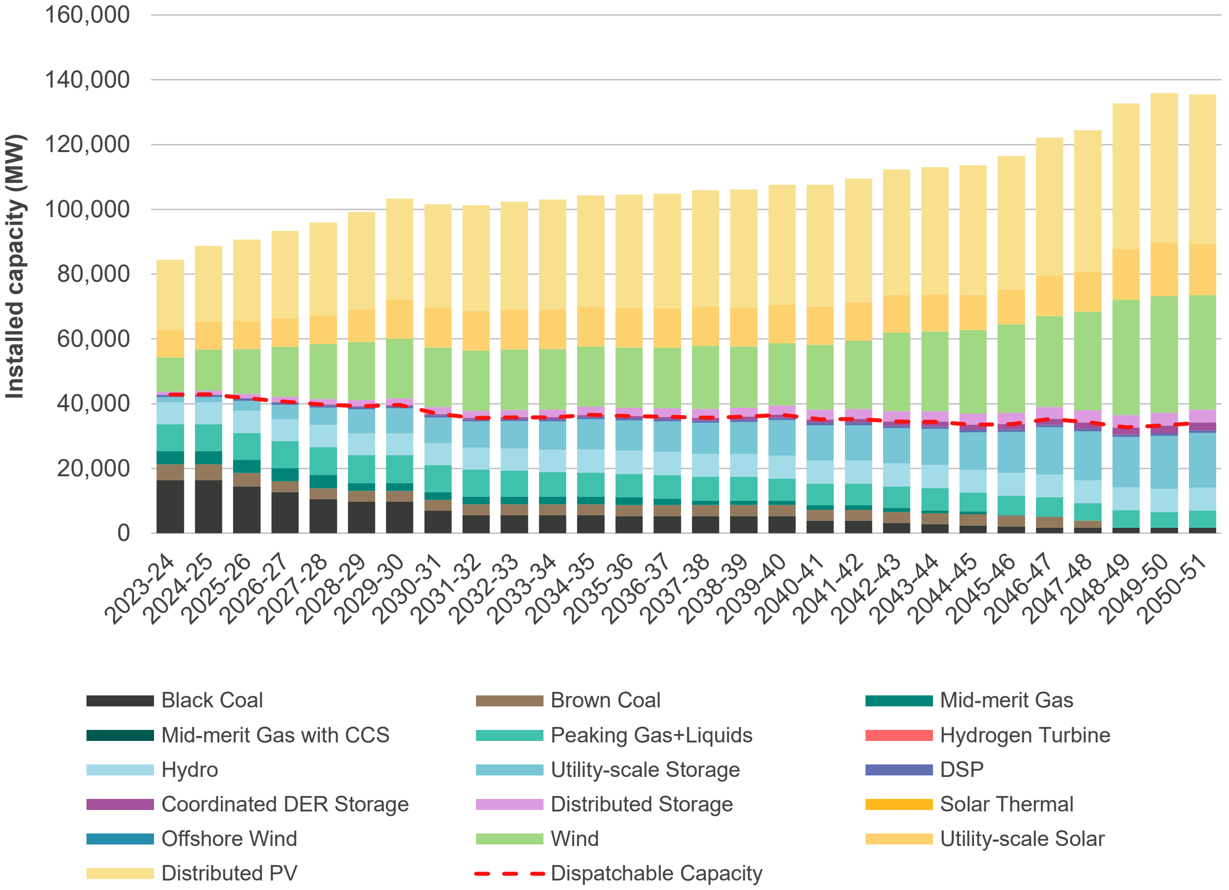
The *Slow Change* scenario reflects a challenging economic environment following the COVID-19 pandemic, leading to a greater risk of industrial load closures. Technology advancements are slower, the economy-wide net zero emission target is pushed out beyond 2050, and there are few policy drivers beyond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

Generation and storage development in the *Slow Change* scenario

The generation capacity forecast (shown in Figure 31) projects that:

- To 2029-30:
  - New VRE developments are driven by 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, particularly of black coal generation in Queensland and New South Wales, as declining operational demand and additional VRE result 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 31 Forecast NEM generation capacity to 2050-51, *Slow Change* scenario



Coal retirements in response to challenging conditions

As with the other scenarios, retirements of most coal generators are forecast to be brought forward. 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 the *Progressive Change* scenario. Despite no explicit carbon budget applying in this scenario, challenging conditions are forecast for baseload coal capacity that is competing with growing renewable energy generation at both utility and distributed scale.

The key driver of the earlier coal retirements in the *Slow Change* scenario is the combined impact of decreasing operational demand at the same time that additional VRE is being developed to achieve policy objectives.

Figure 32 compares coal retirements in the *Slow Change* scenario with the *Progressive Change* scenario, and to expected closure years.

Figure 32 Forecast coal retirements, *Slow Change* scenario

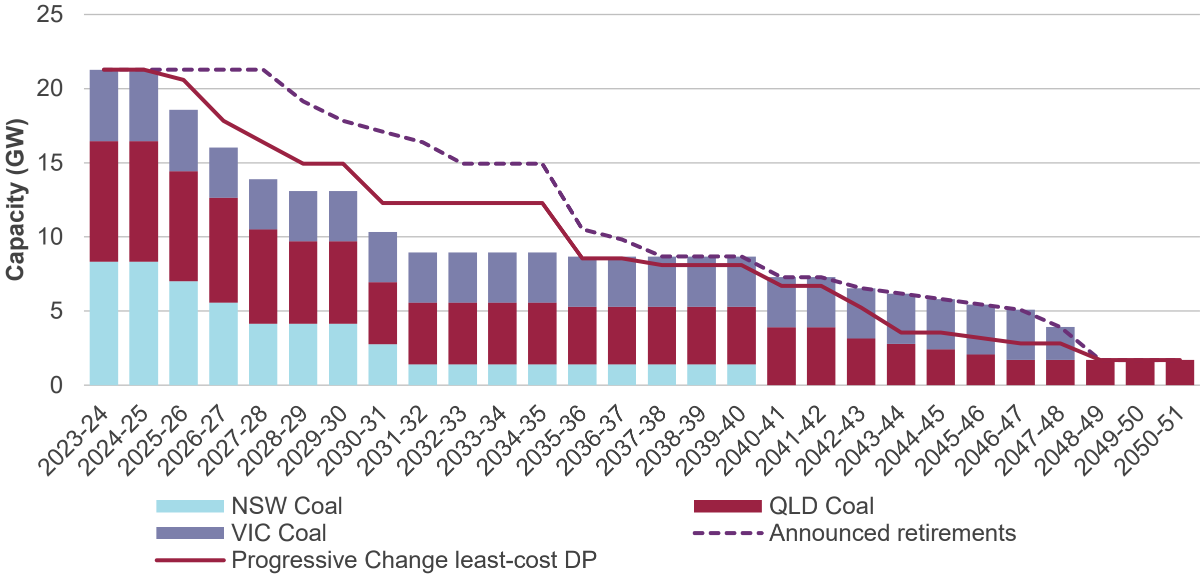
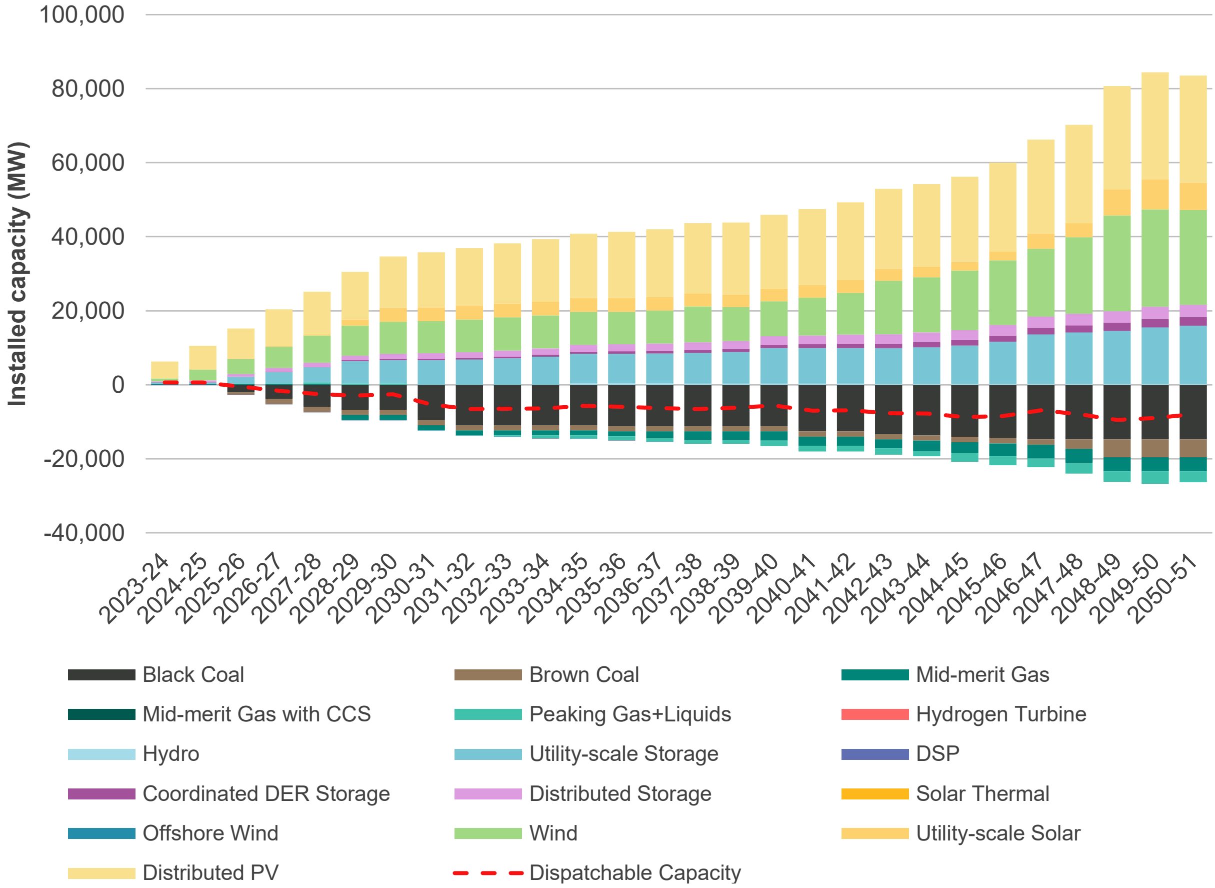


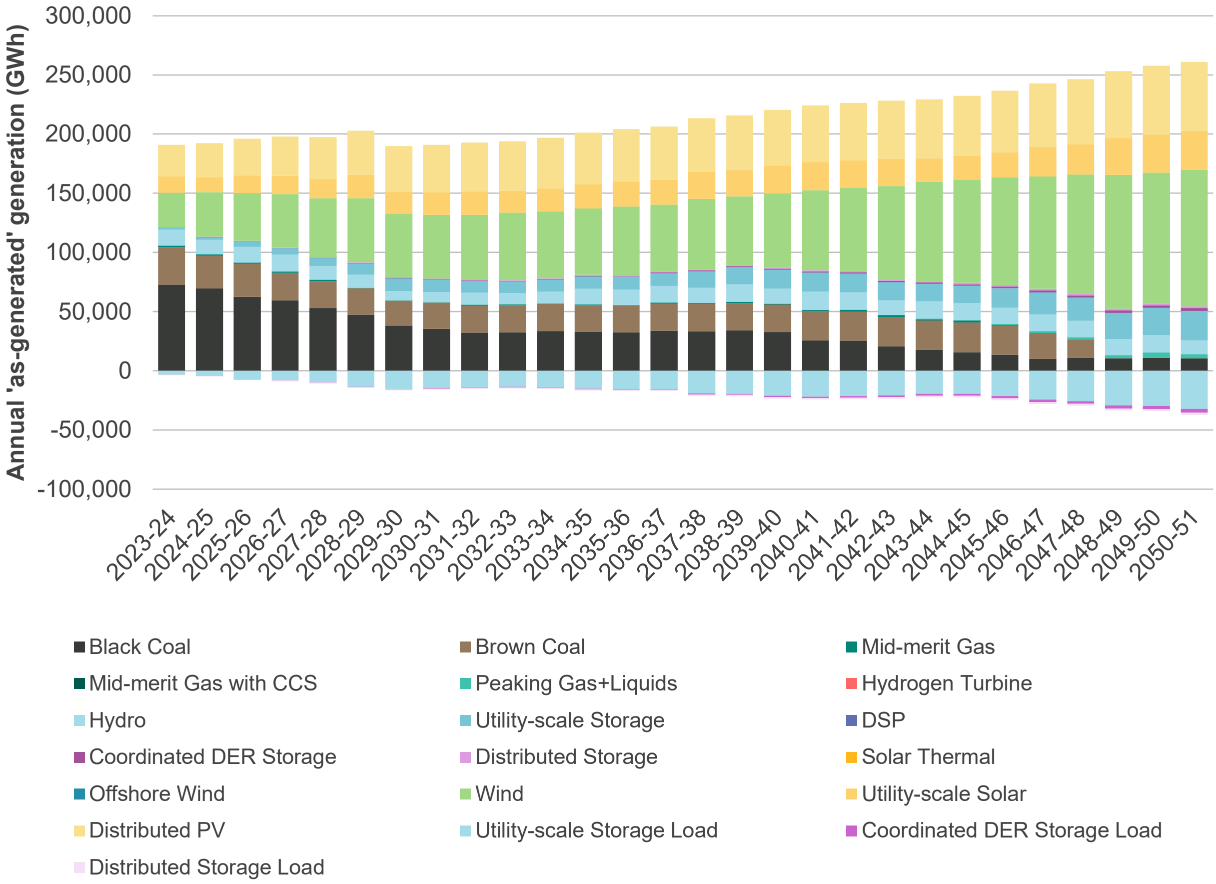
Figure 33 below shows the development of capacity in the *Slow Change* scenario. Policy-driven developments and earlier coal closures slow in the 2030s, as the policies are met. In the longer term, less electrification of other sectors leads to more muted generation investment, although additional VRE development, complemented by energy storage, is developed to replace end of life coal retirements.

Figure 33 Forecast relative change in installed capacity to 2050-51, *Slow Change* scenario



Despite the lack of any explicit decarbonisation objective, Figure 34 below shows that even in the *Slow Change* scenario, the energy mix is dominated by VRE, with over 94% of generation being from renewable sources by 2049-50. By then, the projected mix of VRE generation is 55% wind, 16% utility-scale solar and 29% distributed PV.

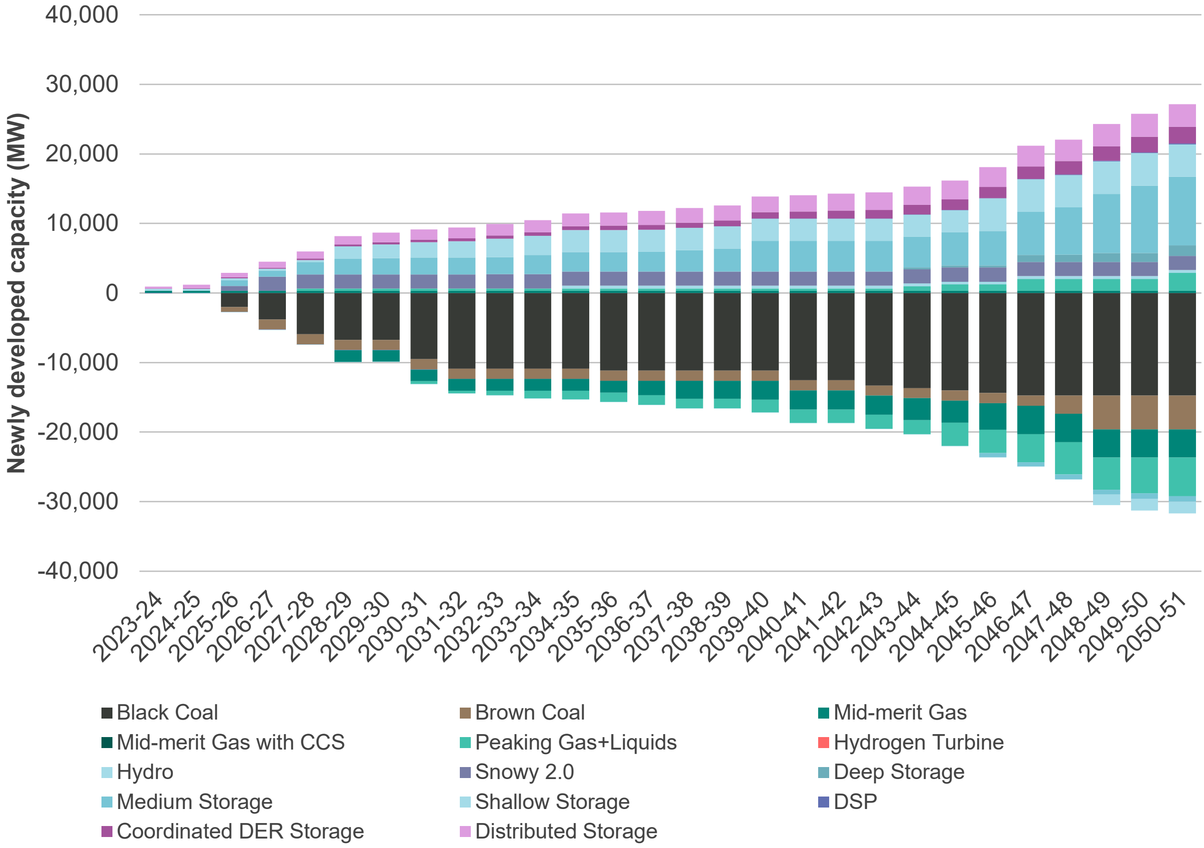
Figure 34 Forecast annual generation to 2050-51, *Slow Change* scenario



Firm capacity developments largely to replace retiring coal and gas generation

The relatively slow uptake of distributed storage in the *Slow Change* scenario 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 35.

Figure 35 Forecast firm capacity development to 2049-50, *Slow Change* scenario

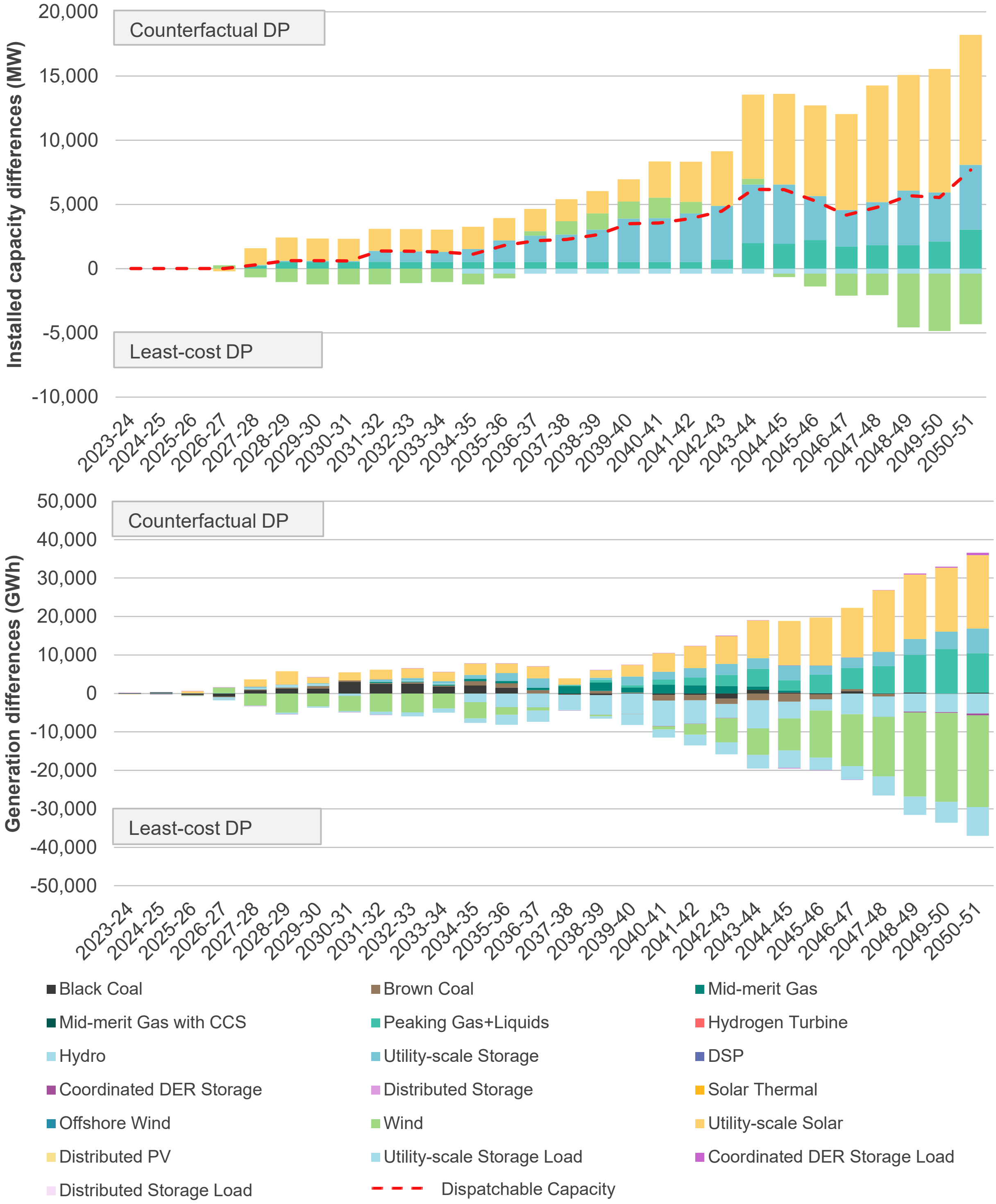


Future generation mix in the *Slow Change* scenario without the ISP transmission developments

The differences in capacity development between the counterfactual and least-cost development paths in the *Slow Change* scenario are shown in Figure 36, 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.
- Without increased access to the diverse resources across the NEM, greater investments in dispatchable technology such as peaking gas and large-scale energy storage will be required, particularly nearer load centres in New South Wales and Victoria.
- This scenario does not require expansion of new technologies (such as offshore wind or generation with CCS), as slower transformation and lesser demand growth leads to less development, and there is forecast to be spare transmission capacity in some REZs allowing further development in the counterfactual.

Figure 36 Forecast capacity developments (top) and generation (bottom) to 2050-51 for least-cost development path compared to counterfactual, *Slow Change* scenario



A2.4 The influence of sensitivities on ISP Developments

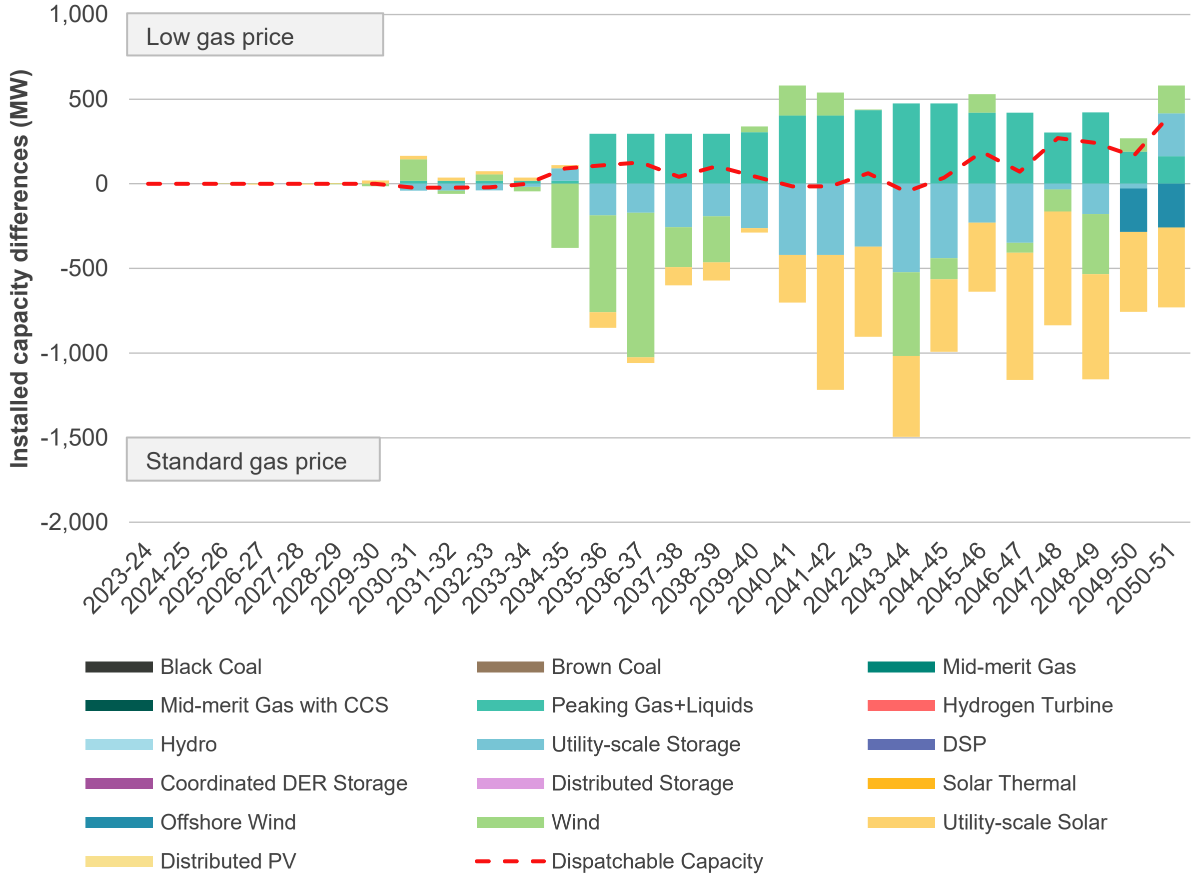
This section outlines the capacity differences in some of the key sensitivities that have been performed to understand the resilience of various candidate development paths. The impact of these sensitivities on net market benefits is explored in depth in Section A6.7 of Appendix 6.

Low gas prices

The *Low Gas Price* sensitivity explores the impact of lower gas price forecasts on development opportunities. For this sensitivity, the *Progressive Change* and *Step Change* scenarios have been focused on to draw conclusions.

Figure 37 below compares capacity developments in the NEM with lower gas prices than the base assumptions, shown for the *Progressive Change* scenario. With lower gas prices leading to lower operating costs for gas generators, there is a slight shift in preferences to build additional peaking gas generators instead of large-scale energy storage as a means for meeting dispatchable capacity requirements following the retirement of thermal generators. The figure demonstrates the relatively small impact given the overall scale of energy storage development using the base assumptions (when compared with Figure 18).

Figure 37 Forecast NEM generation capacity to 2050-51 for the least-cost DP in the *Progressive Change* scenario, *low gas price* sensitivity compared to standard gas price assumptions



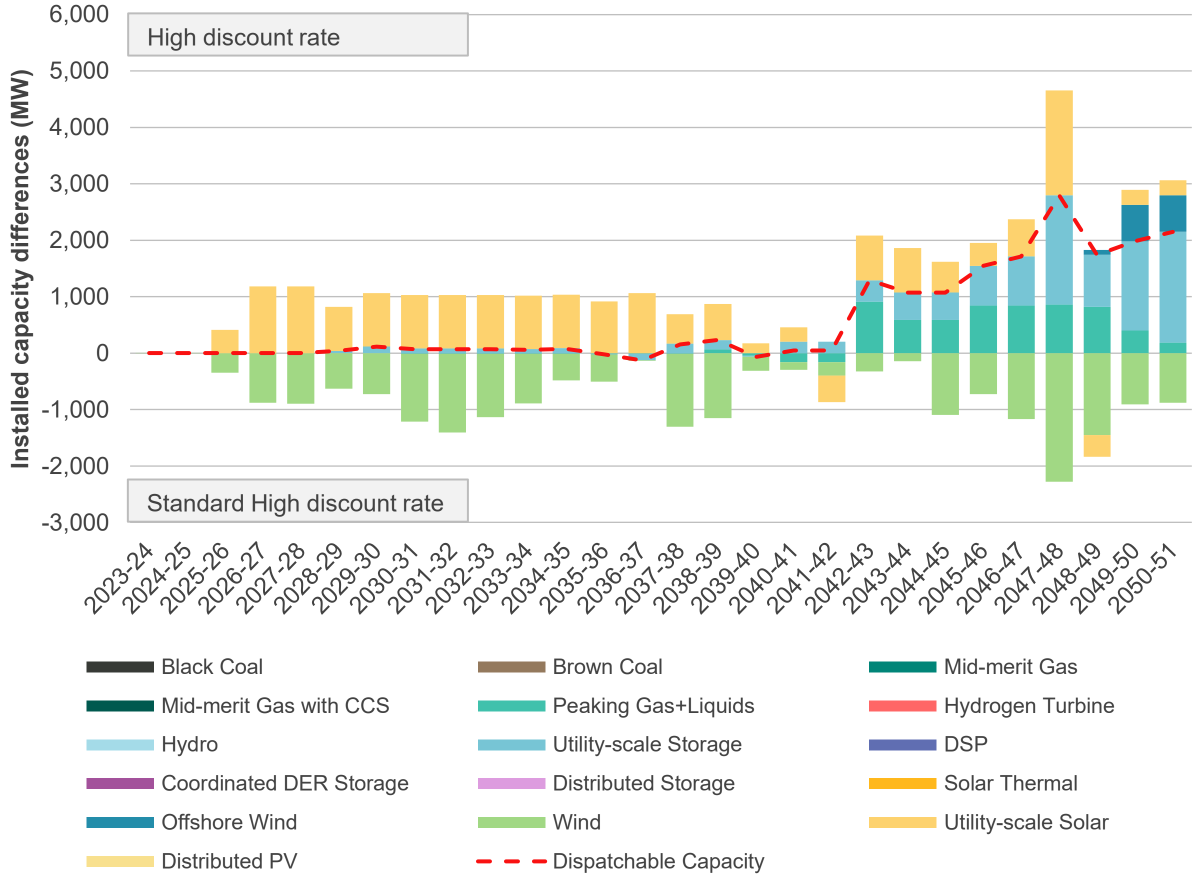
Financial investment costs – the impact of higher funding costs

The *Higher Discount Rate* sensitivity tests the robustness of the candidate development paths to an increase in the discount rate and explores variations in least-cost generation investments resulting from a higher weighted average cost of capital.

With a higher discount rate and cost of capital, there is a preference for investing in 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. For similar reasons, additional large-scale solar (which has a lower capital cost) is preferred to wind. These differences are shown in Figure 38.

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.

Figure 38 Forecast NEM generation capacity to 2050-51 for the least-cost DP in the *Progressive Change* scenario, *higher discount rate* sensitivity compared to central discount rate assumption



Strong electrification – strong abatement without significant hydrogen production

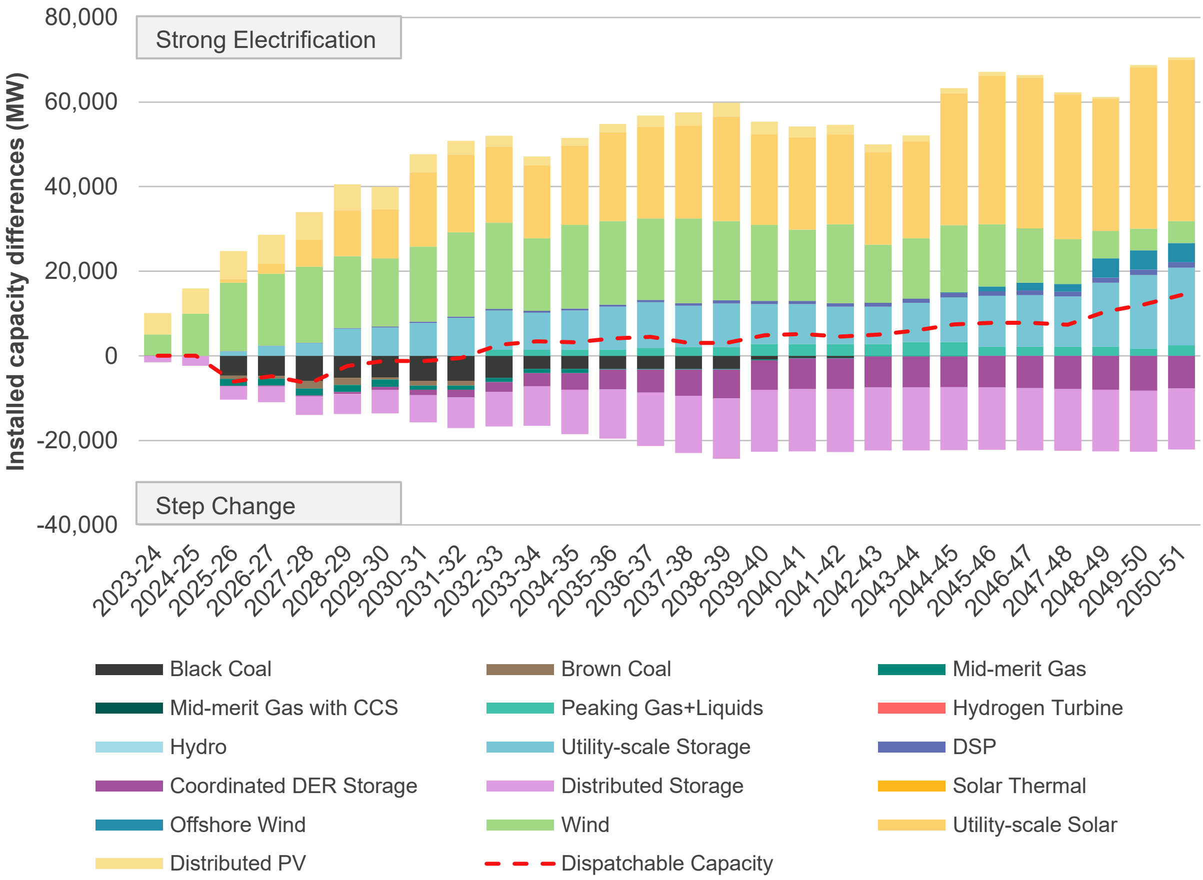
The *Strong Electrification* sensitivity represents a future aligned with the decarbonisation objectives of the *Hydrogen Superpower* scenario, but with limited hydrogen technology deployment and more muted energy efficiency. This leaves the majority of the emissions reductions to be achieved through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

This section describes how the NEM developments change in this sensitivity, comparing it to the *Hydrogen Superpower* scenario (comparing the impact of stronger hydrogen deployment), and comparing it to the *Step Change* scenario (comparing the impact of faster and stronger decarbonisation objectives).

Capacity development compared to the *Step Change* Scenario

As shown in Figure 39, 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 advanced thermal retirements are forecast to be replaced by a combination of VRE and utility-scale, then the additional investment in these technologies continue to increase, mainly due to the increase in electrification. By 2049-50, compared to the *Step Change* scenario, about 60 GW of additional VRE and utility-scale storage is installed. The sensitivity does not incorporate the degree of consumer-led storage investments, replacing these with utility-scale storages with greater depth. As such, particularly by 2040, approximately half of the storage capacity that was distributed in *Step Change* is developed at utility scale, but by 2050 a similar scale of energy storage (at utility scale) is forecast.

Figure 39 Forecast capacity developments to 2050-51 for least-cost DP of *Strong Electrification* sensitivity compared to *Step Change* scenario



Capacity development compared to the *Hydrogen Superpower* Scenario

The additional demand for electricity in the *Hydrogen Superpower* scenario 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 the scenario is approximately 200% larger than this sensitivity.

Despite the substantial difference in energy consumption, the requirement for firm generation capacity is similar. By 2049-50, firm capacity technologies such as hydro generation, gas generation and storage make up 17% of the total capacity mix in the *Hydrogen Superpower* scenario, 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 demand which helps manage VRE intermittency without the need for as much complementary firming generation.