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What AEMO'S Integrated System Plan Report implies about the National Energy Guarantee

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Summary

AEMO has undertaken very detailed engineering cost modelling of the operation of the electricity supply system of the NEM, assuming the shares of renewable generation implied by government policies now in place. These policies include the Victorian and Queensland government renewable energy targets, but do not include the NEG, as it is not yet policy.

The objective of the modelling is to determine the least cost mix of new transmission connections, energy storage, and other new approaches and technologies, which will ensure that the system remains at all times secure and reliable, despite a large increase it its dependence on variable renewable generation from wind and solar farms. It does this by recognising, from the outset, that reliability and security are properties of the system as a whole, not of individual generators supplying the system.

The NEG, by contrast, identifies just a single problem to be addressed as new renewable generation enters the NEM, lack of reliability, and chooses a single approach, generator dispatchability, to address the problem. This cannot be an optimal approach. There is no consideration of whether other options, most obviously transmission upgrades, could provide the same level of reliability at lower cost (while also providing other services, such as system strength). Irrespective of how efficient the proposed market in reliability services may be, it cannot be economically optimal or least cost overall, because it is using a single, narrow, predetermined approach, rather than a whole of system optimisation approach.

A large electricity supply system, like the NEM grid, has often been likened to a gigantic machine, with a great many different moving parts. In order to get the best outcome and the cheapest price we need to look at the whole system and not just focus on individual parts. The NEG is only concerned with one narrow solution, dispatchable power, and by doing this it is failing to give electricity consumers and all Australians the best solution that is going to be of the most benefit. The NEG's narrow solution is not only going to be more

expensive it is also does not take proper account of the long term change that the electricity sector is undergoing. At best, the NEG can be seen as an expensive Band-Aid that will eventually have to be ripped off.

Under AEMO’s base case (Neutral) scenario the total renewable share of NEM grid generation reaches 41% in 2030. If rooftop PV is included, the renewable share reaches 48%. The modelling approach means that these levels of renewable supply are perfectly consistent with a secure and reliable supply system, provided that investments have been directed in a timely manner to the required mix of new transmission and other grid service augmentations. Under some other approaches the renewable share reaches nearly 70%, again without compromising security and reliability.

A case study of the effectiveness of the system optimisation approach is provided by the South Australian part of the NEM system. After completion of a new high capacity synchronous interconnector, called RiverLink, between South Australia and New South Wales, during the early 2020s, AEMO concludes that this will be sufficient, in combination with the other new types of grid services described in the report, to eliminate the need for local, continuously operating synchronous, dispatchable generation. Consequently, the model closes all four “baseload” gas generators in the state in 2025, while also, by definition, delivering lower cost bulk electricity than would have been the case had gas generators remained open.

AEMO does not report the emissions arising from the different levels and mixes of generation under the various scenarios. Our report converts AEMO’s generation figures to emissions, using a model based on all of AEMO’s own generator performance parameters. The conclusion is that the proposed NEG emissions reduction target is meaningless, because it will be exceeded well before 2025 in all of AEMO’s scenarios. By 2030 emissions reduction could reach nearly 40%, and more under some scenarios.

Overall conclusion

AEMO’s modelling results show that, with efficient planning of and investment in the most efficient mix of network services, it will be quite possible to ensure that the electricity supply system of the NEM remains secure and reliable, with much larger emission reductions, and much higher shares of renewable generation in the supply mix, than envisaged in the design of the NEG, and do so at lower total cost.

AEMO’s modelling framework, including as it does a complete array of system augmentation options to deliver security and reliability, also ensures that, for any given level of renewable generation, total system costs will be lower than those of an approach, such as the NEG, which restricts augmentation to a limited choice of augmentation options. Hence AEMO’s system optimisation approach will deliver lower wholesale prices than the NEG.

Introduction

In June 2017, the Chief Scientist, Dr Alan Finkel, delivered to the government his *Independent Review into the Future Security of the National Electricity Market: Blueprint for the Future*. In July, Commonwealth, state and territory energy ministers, meeting as the COAG Energy Council, agreed to adopt 49 of the 50 recommendations contained in Dr Finkel's report, the sole exception being the recommendation to adopt an emissions reduction trajectory and Clean Energy Target for the National Electricity Market (NEM). On 25 August, the Ministers delivered a report to COAG Leaders on how the 49 recommendations should be implemented.

Recommendation 5.1 of the Finkel reports was that:

> "By mid-2018, the Australian Energy Market Operator, supported by transmission network service providers and relevant stakeholders, should develop an integrated grid plan to facilitate the efficient development and connection of renewable energy zones across the National Electricity Market." (p. 128)

The Ministers proposed implementation in the following terms:

> "By mid-2018, AEMO, supported by transmission network service providers and relevant stakeholders, will develop an integrated grid plan to facilitate the efficient development and connection of renewable energy zones across the NEM. AEMO will extend its planning work in this year's National Transmission Network Development Plan to be published in December 2017. The first integrated grid plan will be developed in July 2018."

More broadly, the Finkel report defines four key outcomes required for the future of the NEM: increased security, future reliability, rewarding consumers (with lower prices and better information), and lower emissions (p. 8). The report then goes on to state that these outcomes will be enabled by what it calls three key pillars: orderly transition, system planning, and stronger governance (p. 9).

On July 17 2018, AEMO (the Australian Energy Market Operator) released a report entitled *Integrated System Plan for the National Energy Market*. The Executive Summary of the report draws attention to second of these three key pillars, in the following words:

> "The Blueprint highlighted the need for better system planning as one of the three pillars required to achieve the following:
>
> > 'Enhanced system planning will ensure that security is preserved, and costs managed, in each region as the generation mix evolves. Network planning will ensure that new renewable energy resource regions can be economically accessed.' Independent Review of the National Electricity Market (Finkel Review)"

(p. 4)

AEMO's report goes on to observe:

> "The Finkel Review's planning recommendations were agreed to by COAG energy ministers and this, as the first ISP, is an important step in enhancing system planning and fulfils specific recommendations in the Blueprint." (p. 4)

What AEMO has done, very sensibly, is replace the phrase "Integrated grid plan" by "integrated system plan". In doing so it has gone considerably beyond the narrow terms of the Finkel report's recommendation 5.1. In the words of the report:

> "This ISP is the initial implementation of the second pillar, improved system planning, as well as a specific recommendation (5.1) in the Finkel Review." (p. 16)

The result is a report which brings a ray of light to the currently gloomy landscape of electricity policy, illuminating the limitations of what seems to be accepted opinion about the proposed National Energy Guarantee.

Achieving secure and reliable power system operation

To understand why this is so, the starting point is to understand what security and reliability mean in relation to an electricity supply system. The following definitions from the glossary attached to the ISP report are helpful. Power system reliability is defined as:

> "The ability of the power system to supply adequate power to satisfy customer demand, allowing for credible generation and transmission network contingencies."

Power system security is defined as:

> "The safe scheduling, operation, and control of the power system on a continuous basis in accordance with the principles set out in clause 4.2.6 (of the N[ational] E[lectricity] R[ules])."

What that means in more understandable language is spelled out under the definition of system security, as the ability of the system

> ".... to continue operating within defined technical limits even in the event of the disconnection of a major power system element such as an interconnector or large generator."

The word power system have been underlined, because the definitions make a most fundamental point: reliability and security are properties of the system as a whole, not of individual generators.

In the current NEM system the services needed to make the system both reliable and secure are provided almost exclusively by conventional generators. Ever since the first electricity supply systems were built, in the closing decade of the 19th century, that has been the case. Generator rotors, driven by either coal fuelled steam or falling water, all spin synchronously at 50 cycles per second. The 50 cycle alternations of voltage and current are exactly aligned across the whole interconnected grid, stretching from north of Cairns to west of Port Lincoln.

System security is provided by the intrinsic characteristics of this type of generator. When, as happens quite regularly, a large generator suddenly disconnects from grid, the frequency across the whole system will instantaneously drop below 50 cycles. If the fall in frequency is too fast for too long, it could cause catastrophic damage to some of the remaining generators, which are therefore programmed to disconnect should frequency fall below a specified level, triggering a system collapse. When the system is operating as planned, such a collapse is averted within a few tenths of a second by the rotational inertia of all the other generators still connected, slowing the fall in frequency. However, this effect can only work for a second or so, as valves open to allow more steam into turbines. Within a few more seconds, and if the disconnection remains, larger injections of additional energy will be required, and some of the connected generators will start to increase their output to make up for lost supply. This service is mainly provided hydro and gas turbine generators, which have the particular ability of being able to increase output very rapidly. Within a few minutes, steam generators, unless they are already operating at full capacity, will also be able to increase their output more substantially, thus restoring stability to the system.

More or less a mirror image sequence of processes occurs if a sudden increase in frequency is triggered by the abrupt disconnection of a major load, either by disconnection of the load itself (not a common event) or, more commonly, by loss of supply to a major load caused by a transmission line failure. The very fast rotational inertia response is a service provided at no monetary cost to the system or to electricity consumers by all the conventional generators operating at the time of an incident. At present in the NEM, this means that the service is mainly being provided by coal fired generators, since they are always the largest source of electricity supply. However, the responses over longer time frames, from 6 seconds to 5 minutes, are provided for a fee by a sub-set of generators which have chosen to provide what are called frequency control ancillary services (FCAS). The NEM Rules specify eight separate FCAS products, four to increase frequency over different time periods, and four to lower frequency; each of the eight products has its own spot market price.

Synchronous generators also support another important attribute of a secure electricity supply system, which is called system strength, which, in AEMO's words, is "a measure of the stability of a power system under all reasonably possible operating conditions"[1]. A strong system is better able to "maintain stable voltage control in response to small and large system disturbances"[2]. Good system strength ensures that all system protection equipment (the equipment which automatically isolates, for example, the part of a transmission system which has short circuited to earth, so as to prevent damage to the rest of the system) will operate correctly. Operation of the protection equipment is triggered by a sudden increase in current, caused by the short circuit fault, in just the same way as a short circuit in household wiring will cause a sudden increase in current, which then causes the circuit breaker (formerly a fuse) to go off. If system strength is not large enough, the fault current may not be large enough to trigger substation protection equipment, meaning that the fault will then not be isolated and system damage could cascade.

The performance of the power electronic converters, the equipment which wind and solar generators use to output synchronised power to the grid, can also be adversely affected by low system strength. System strength is currently assured by having synchronous generators distributed across the grid; unlike frequency stability, it cannot be provided so readily by very distantly located generators. In the aftermath of the collapse, in September 2016, of the South Australian part of the NEM system, triggered by destruction of several major transmission lines by tornadoes and the inability of an important gas generator to operate as expected, AEMO introduced emergency grid management procedures, now relaxed, which required at least two gas generators to be operating in the state at all times, to provide system strength, as well as reliability.

System reliability is provided by a requirement in the Rules that there must at all times be more generation available than is expected to be required. If there is an unexpected increase in demand, the system operator (AEMO) will dispatch the additional available generation capacity, meaning that the generator is instructed when and by how much to increase output. Generators which are able to respond as instructed in this way are termed dispatchable. To be dispatchable, a generator must have energy stored, in a form other than electricity, available for immediate use. Depending on the type of generator, the stored energy may be a coal stockpile next to the boiler, gas at high pressure (termed line pack) in the pipeline supplying the generator, or water stored in a reservoir.

Until now most of the services needed to ensure system reliability and security have been provided for most of the time by conventional generators in the ways described. There are, however, other ways of making the electricity supply system both secure and reliable.

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[1] AEMO (n.d.) *Fact sheet: System strength,* https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Reports/2016/AEMO-Fact-Sheet-System-Strength-Final-20.pdf

[2] AEMO (n.d.) *Fact sheet: System strength,* https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Reports/2016/AEMO-Fact-Sheet-System-Strength-Final-20.pdf

Pumped hydro storage has been used for many decades to provide system reliability in systems all around the world. Australia has three such systems, all built before the inauguration of the NEM in 1999: Talbingo or T3 (part of the Snowy scheme) and Shoalhaven, in New South Wales, and Wivenhoe, in Queensland. The combined capacity of these schemes is about 2.3 GW, which is about 10% of average demand across the NEM as a whole during the past year. It is also equal to just under half the current installed capacity of wind generators in the NEM, and more than the capacity of the proposed Snowy 2.0. During the first decade very considerable use was made of each of these three schemes, but since around 2010 they have hardly been used at all.

A well-established way of providing of providing system security, particularly inertia, and also system strength, is use of synchronous condensers. These are effectively a synchronous generator which is electrically connected to the grid but operates without connection to a turbine, and so does not generate electricity. Three were installed in Victoria in the 1960s and used regularly until their retirement a couple of years ago[3]. Synchronous condensers can also contribute to enhanced system strength, and AEMO is currently working with ElectraNet, the transmission service provider in South Australia, on plans for the installation of synchronous condensers at three, or possibly more, locations in the South Australian part of the NEM grid. ElectraNet states that it has compared the cost of installing synchronous condensers with the cost of contracting with one or more synchronous generators in the state to stay on line at all times, and has concluded that installation of synchronous condensers are the lower cost option.[4] The reason that ElectraNet is undertaking this work is that in September 2017 the Australian Energy Markets Commission (AEMC) brought in a new Rule, requiring transmission service providers to maintain minimum levels of system strength to keep the system stable[5], but not mandating how they should do so.

As noted, both pumped hydro storage and synchronous condensers are well established and widely used technologies. They are two examples of how there are other ways of providing the supply system services that, until now, have been provided by synchronous generators operating in continuous mode (so-called baseload). AEMO is currently in the midst of a

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[3] Bones (2017) *RE: ElectraNet synchronous condenser asset life review,* https://www.aer.gov.au/system/files/ElectraNet%20%E2%80%93%20ENET062%20%E2%80%93%20ElectraNet%20%E2%80%93%20GHD%20%E2%80%93%20Synchronous%20Condenser%20Asset%20Life%20Review%20%E2%80%93%20March%202017.pdf

[4] Bones (2017) *RE: ElectraNet synchronous condenser asset life review,* https://www.aer.gov.au/system/files/ElectraNet%20%E2%80%93%20ENET062%20%E2%80%93%20ElectraNet%20%E2%80%93%20GHD%20%E2%80%93%20Synchronous%20Condenser%20Asset%20Life%20Review%20%E2%80%93%20March%202017.pdf

[5] AEMC (2017) *Final rule: Managing power system fault levels,* https://www.aemc.gov.au/news-centre/media-releases/final-rule-managing-power-system-fault-levels

major work program called ‘Power system security and reliability’[6], which is intended to determine how AEMO can best fulfil its obligation to

> “continually meet the needs of the power system, in the face of major structural changes and the resulting uncertainty across investment and operational timeframes.” (p. 4)

Its *Power System Requirements Reference Paper* reviews the range of these needs, of which the examples given above are just a sample, and goes on to briefly describe the range of different technologies, some established, others new and emerging, by which these needs might be met.

Some of these new technologies are currently being trialled. For example, the widely publicised Tesla “big battery”, adjacent to the Hornsdale wind farm in South Australia is currently successfully using stored energy to provide both short term bulk energy supply and frequency and voltage control services. At the same location, a trial using special power electronics, often called synthetic inertia, linked to one part of the wind farm (Hornsdale 2) is providing frequency control services in a different way, using energy as it is being generated by the wind farm. Yet another technology is demand response, which is a contractual relationship between an electrical energy consumer and the electricity system operator or a network service provider, under which the customer agrees to have part of its supply interrupted for a short period, in exchange for an agreed payment. The additional energy made available for a short period in this way can be used, in the event of a system emergency, to avoid cutting off supply to other consumers with essential needs, and also to support voltage and frequency control.

AEMO’s *Reference Paper* includes a very useful summary table, reproduced in the Appendix to this paper, in the form of a matrix, setting out the full range of electricity supply system services against the range of technologies by which the services can be provided. There is only one technology which is able, by itself, to provide all the required services. That technology is centralised, synchronous generation, that is, conventional, established thermal (coal or gas) and hydro generation.

It would appear that the design of the National Energy Guarantee has been based on the simplistic assumption that, because only one technology can provide all of the services, in a single package, as it were, continued choice of that technology must be the most effective, and least cost way of providing those services. A useful metaphor is to think of the electricity system as a house which the occupants wish to keep warm in winter. The AEMO report is like a home energy audit that lists out all the improvements which could be undertaken to keep the house warm: how well the heater works, how insulated is the

[6] AEMO (2018) *Power system requirements reference paper,* http://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Power-system-requirements.pdf

house, are there gaps that are letting warmth escape to the outside. The ISP report considers all the different options, how much they cost and how effective they will be. It then lists out what is the best option available to keep the house warm at the lowest cost. The NEG by comparison only focuses on one part of the problem. The NEG is effectively obsessed with the home heater without considering all the other parts. But while it is cranking up the heater it is ignoring that fact that the windows are being left open.

There is nothing in the supporting documentation for the NEG which justifies the assumption that continuing for the indefinite future to rely on synchronous generators to supply all the essential grid services is the lowest cost or most effective option. The ElectraNet synchronous condenser example, described above, suggests that alternative approaches may be better.

What is the Integrated System Plan report?

Turning to the detailed content of AEMO's *Integrated System Plan Report*, it is evident that AEMO concludes that alternative approaches may be more effective and less costly. In the words of the plan report:

> "... the ISP has modelled and outlined targeted investment portfolios that can minimise total resource costs, support consumer value, and provide system access to the least-cost supply resources over the next 20 years to facilitate the smooth transition of Australia's evolving power system.
>
> "The result of this modelling and engineering analysis is the identification of those investments in the power grid that can best unlock the value of existing and new resources in the system, at the lowest cost, while also delivering energy reliably to consumers." (p. 3)

Foundational assumptions, common, unless otherwise noted, to all the scenarios which were modelled for the ISP include the following:

- All "policy directives current at the time of modelling" are assumed. This means principally the Large Renewable Energy Target (LRET), the Small Renewable Energy Scheme (SRES), the Victorian Renewable Energy Target (VRET), and the Queensland Renewable Energy Target (QRET).
- All coal fired power stations will be retired when they reach the age of 50 years (except Liddell, which will be 51 when it is retired in 2022, as planned by its owner, AGL).
- Annual consumption of electrical energy will grow more slowly than either GDP or population, moderated by continuing steady improvements in energy use efficiency (as has been the case for the past decade).

- Annual consumption of grid supplied electrical energy will remain relatively flat, as most of the growth in consumption will be matched by continuing growth in localised supply (termed distributed energy resources – DER), particularly rooftop PV.
- Snowy 2.0 and Tasmanian Battery of the Nation projects are not modelled in the main scenarios, because they are not yet committed, but are explicitly modelled in a separate scenario.
- "Inherent in the planning is the assumption that policy certainty will allow efficient, technology-neutral investment decisions to be made, and that the appropriate framework will be in place to deliver the reliability outcomes and sustainability policy context built into the pln."

A total of seven scenarios were modelled. This paper concentrates mainly on three scenarios: Neutral, Fast change and Slow change. Change, in this context, refers to change of the electricity supply system of the NEM, but Fast and Slow are broader in that they incorporate, respectively, faster and slower rates of economic and population growth, and other key parameters. The modelling covers a period of 20 years, out to 2040. During this period the majority of Australia's existing coal fired power stations will reach 50 years of age and, as noted above, are assumed to close, and will have to be replaced with other sources of generation. The report states:

> "ISP analysis demonstrates that, based on projected cost, the least-cost transition plan is to retain existing resources for as long as they can be economically relied on. When these resources retire, the modelling shows that retiring coal plants can be most economically replaced with a portfolio of utility-scale renewable generation, storage, DER, flexible thermal capacity, and transmission. ....
> ...." The investment costs associated with replacing old and retiring infrastructure with new plant, in one of the most capital-intensive industries, are significant and unavoidable. AEMO's modelling shows that the total investment required to replace the retiring generation capacity and meet consumer demand has an NPV cost of between $8 billion and $27 billion, depending on assumptions made around economic growth and rate of industry transformation. This level of capital investment is going to be needed, irrespective of this plan.
> "However, modelling shows that by spending 8% to 15% of this total capital investment on transmission rather than generation, efficiency gains are achievable. The ISP conservatively projects total system cost savings ranging between $1.2 billion and $2.0 billion with the integrated approach and new transmission investment in the ISP." (p. 5)

The economic results presented in the report are the net benefits, in terms of total resource cost in the National Electricity Market, of this spending on transmission investment, compared with, effectively, investing all the capital into new supply capacity only.

The report provides the explicit estimated savings, covered by the $1.2 to $2.0 billion range as quoted above, for each of the scenarios. It does not, however, provide any more detailed information about the make-up of the $8 billion to $27 billion cost range quoted in the preceding paragraph. However, that is not where the value and importance of this report is to be found. Its key value lies in the outcomes of each scenario in terms of the mix of generation, year by year, in each NEM region (state). This is because each generation mix examined, when combined with the optimal mix of transmission and other grid support investments, is able, according to AEMO's expert judgment, to provide a completely secure and reliable supply of electricity across the NEM.

To be more explicit, the various scenarios include different shares of renewable generation year by year, but in each year in each case, low or high, the resultant electricity supply system is reliable and secure.

Key results from the Integrated System Plan modelling

In the remainder of this paper we first summarise, in graph form, the modelled year by year mix of generation by technology type reported by AEMO for the various scenarios modelled. We then go on to examine the emission outcomes associated with the various scenarios. AEMO's ISP report provides no quantitative emissions outcome results. We have used a spreadsheet model, which incorporates AEMO's published emissions parameter values (as-generated emissions intensity and auxiliary factor) for every NEM power station. The results of this modelling have been set against the announced emissions target for the proposed National Energy Guarantee (NEG). We calculate this target to equate to 129.0 Mt CO_2-e, which is 26% below the 175 Mt level of NEM emissions in 2005.[7] Although the ISP modelling extended to 2040, all graphs in this paper go only as far as 2030-31. The reason for this restriction is to maximise the light which this modelling throws on both the share of renewable generation and total emissions in 2030, because both are the focus of the current political debate about electricity industry policy. Most of the graphs show results for the NEM as a whole, but some individual state data are shown also shown.

Starting with future annual electricity consumption, Figure 1 shows the two sets of consumption levels used in the modelling. It shows both consumption of electrical energy supplied through the grid, and consumption inclusive of distributed energy resources (DER) which, as previously noted, are mainly rooftop PV. The Slow scenario used the Slow level of future consumption; all other scenarios use the Neutral level. It can be seen that DER are assumed to make very large contributions to total consumption under all scenarios.

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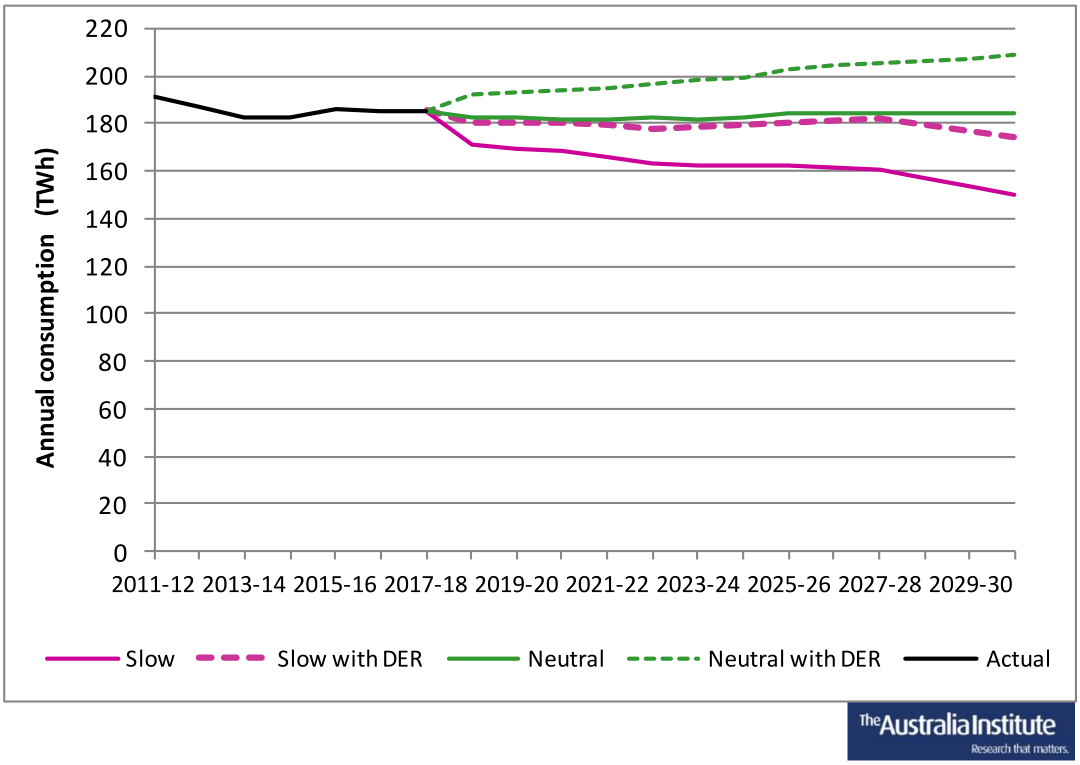
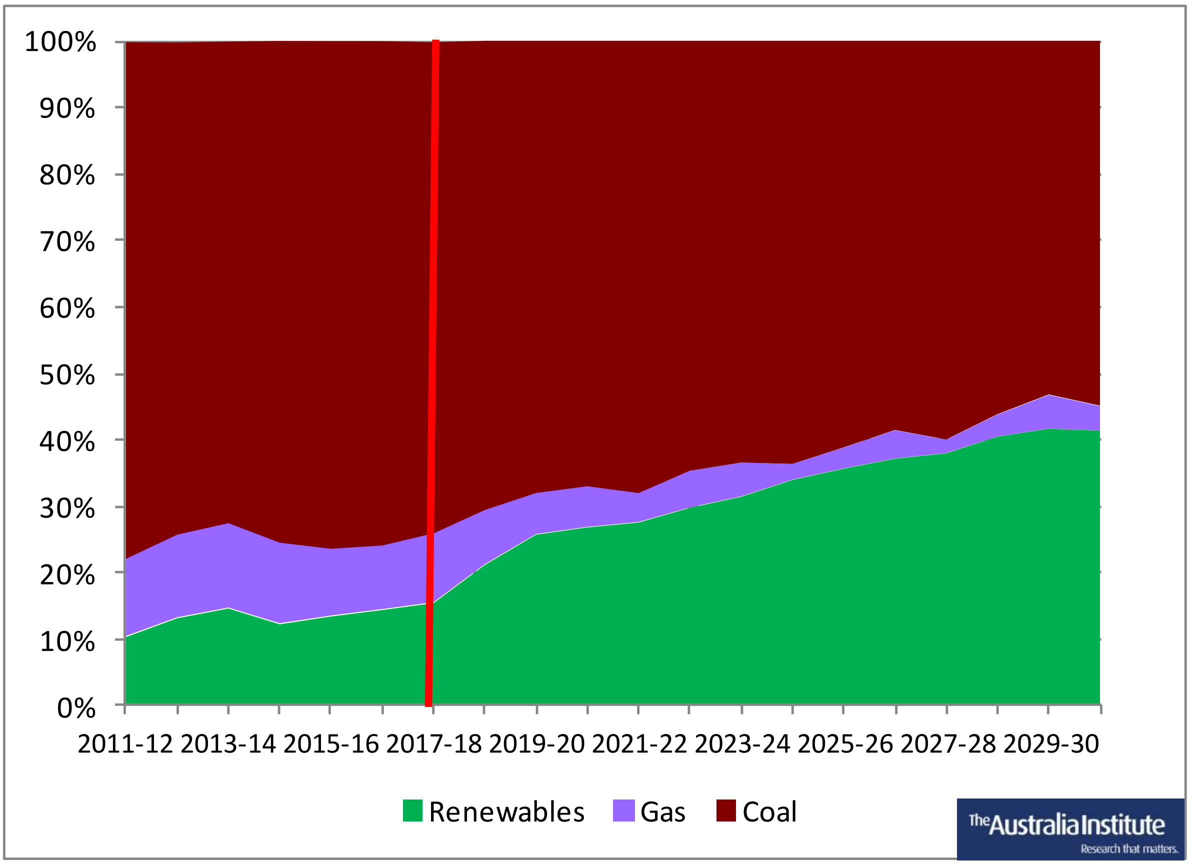
[7] Note there are different estimates of 2005 emissions from different models. NEEA's estimate is 175.7, while earlier work by Frontier Economics is based on 174.3.

+ Figure 1: Future annual energy consumption: Neutral and Slow settings

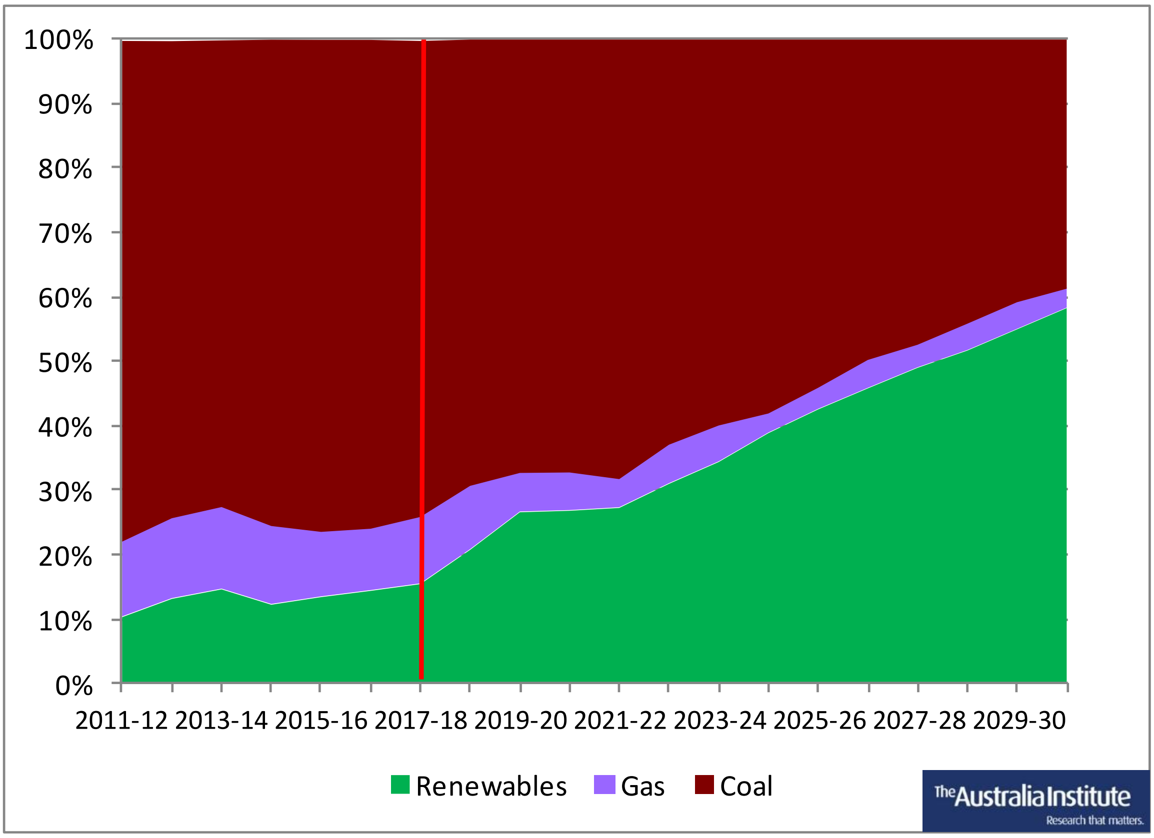


Figures 2 and 3 show the changing mix of all three major generation types, coal, gas, and renewable, under the Neutral and Fast scenarios respectively. Gas generation losses market share at about the same rate under both scenarios. Under the Fast scenario, coal generation loses out to renewable twice over. Not only do renewables supply all the additional consumption required under this scenario, but they also take a larger share of the "baseline" Neutral scenario consumption.

+ Figure 2: Changes in the mix of grid generation sources: Neutral scenario

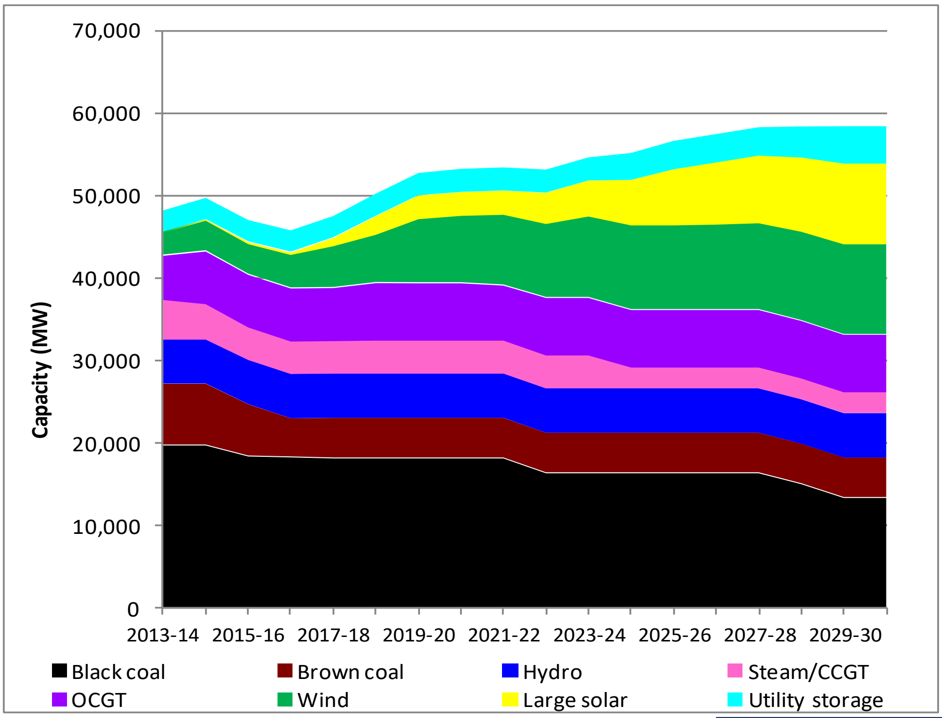


+ Figure 3: Changes in the mix of grid generation sources: Fast scenario

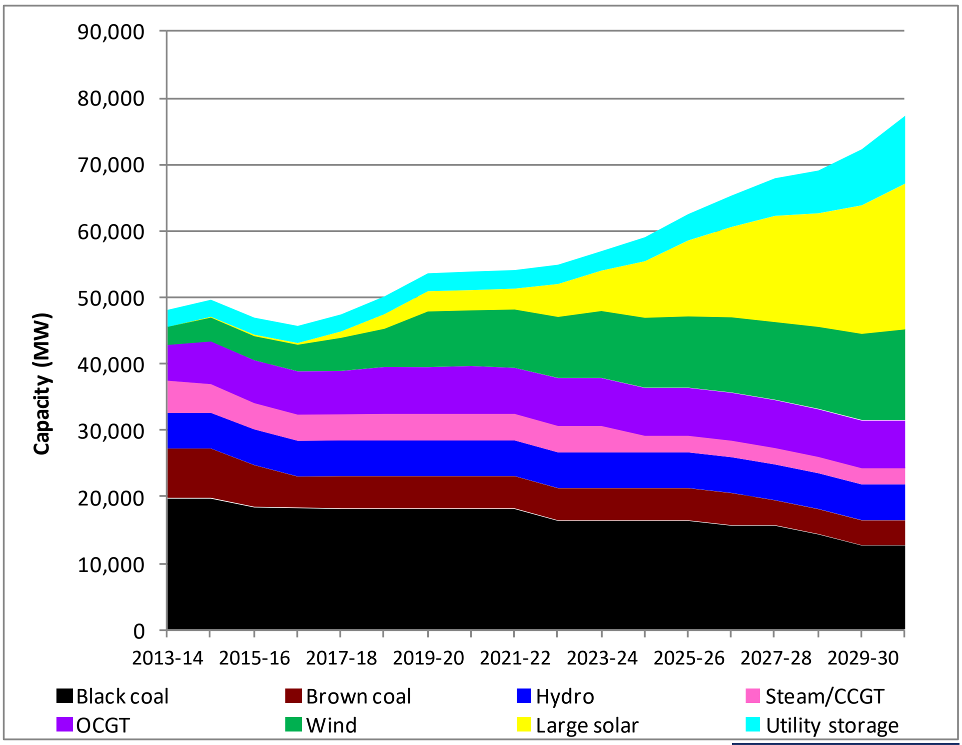


As previously noted, a key modelling assumption is that coal fired power stations stay open until they reach the age of fifty years. Under this assumption, only three stations close during the 1920s: Liddell in 2022 and Vales Point if 2028, both in New South Wales, and Gladstone in 2029, in Queensland. These reductions in black coal generating capacity can be seen in Figure 4, for the Neutral scenario, and Figure 5, for the Fast scenario. A reduction in steam and combined cycle gas generation capacity can also be seen in the mid-2020s. Most of this occurs in South Australia, where the four existing power stations of this type are all shut down (see below).

+ Figure 4: Changes in the mix of generator capacity installed: Neutral scenario



+ Figure 5: Changes in the mix of generator capacity installed: Fast scenario

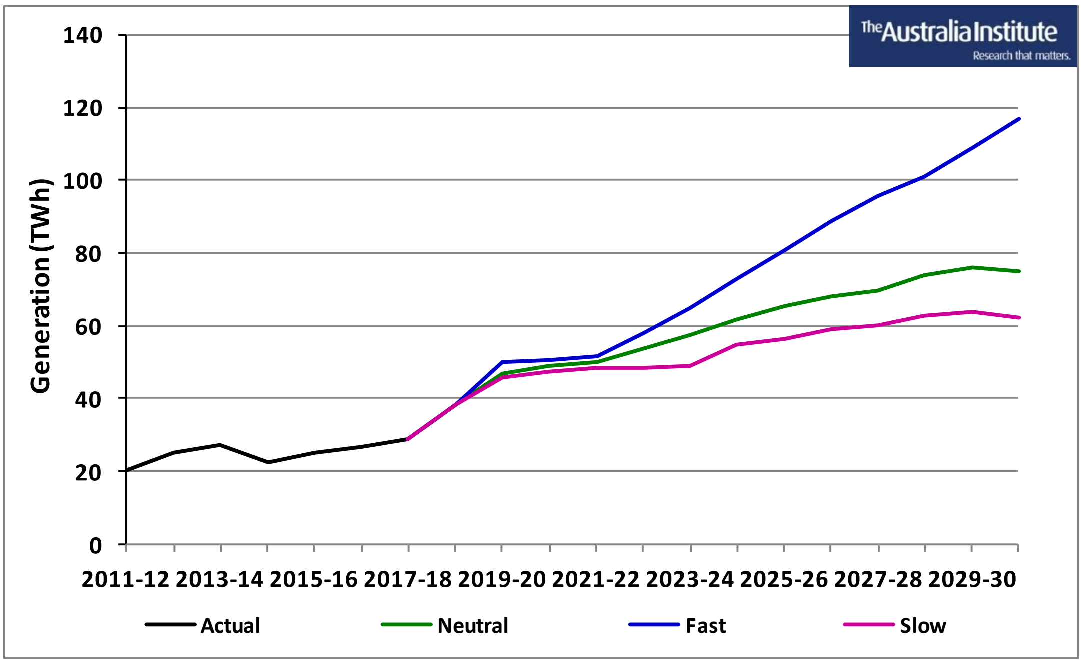


When interpreting these graphs it is important to understand that open cycle gas, wind and solar generators are all designed and expected to operate at relatively low capacity factors, typically in the range 20% to 30% for solar and 30% to over 40% for wind. (The Snowy and other mainland hydro generators are also designed to operate at low capacity factors, whereas most of the Tasmanian hydro system is designed to operate with high capacity factors.) A low capacity factor means that the installed capacity of this type of generator is much larger, relative to their annual output, than is the case for coal and combined cycle gas turbine generators. This is, of course, an inherent feature of these various technologies, fully allowed for in all calculations of comparative generation costs. But it does mean that, when wind and solar capacity reaches the sorts of levels achieved by 2030, there will often be times when wind and/or solar can supply almost all demand.

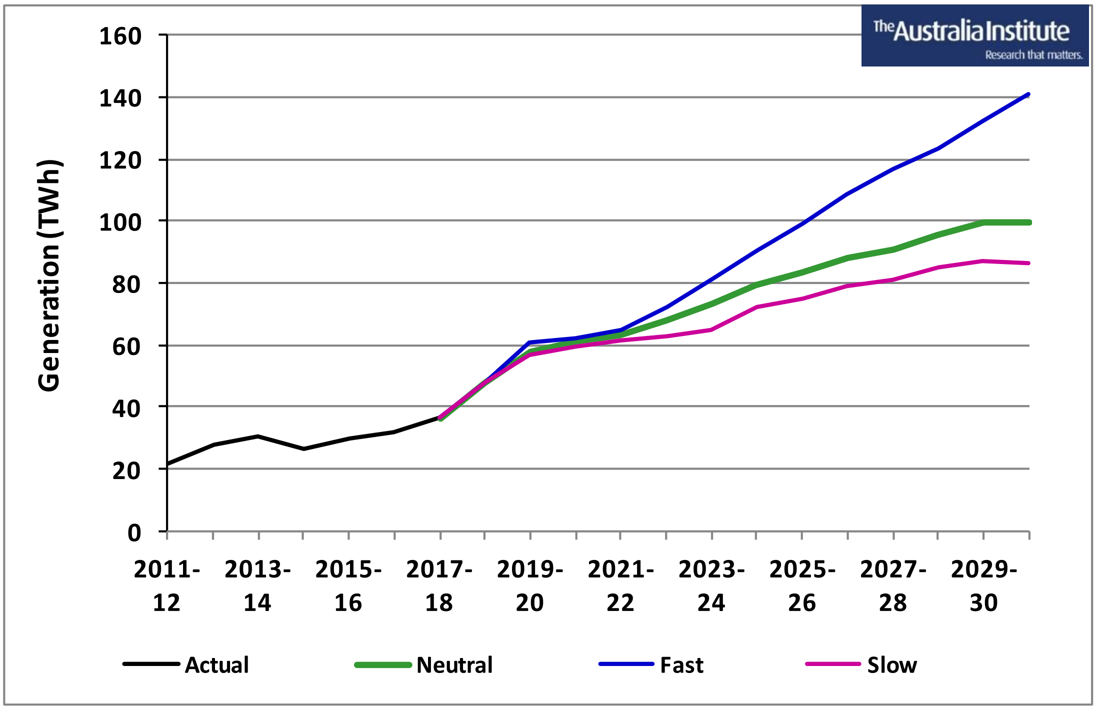
This has important implications for the economics of coal and combined cycle gas generators, because it means that they will be displaced at times of high wind and solar generation. On the basis of both economics and technical characteristics, these types of generator were designed and built to operate with relatively high capacity factors, typically in the range 70% to 85%.   The modelling results show that, with only three closures during the 2020s, most existing coal capacity is still open in 2030, whereas total coal generation has fallen dramatically, particularly in the Fast scenario. The modelling results indicate that almost all of the coal generator output reduction occurs at black coal generators in New South Wales and Queensland. The lower fuel costs of Victorian brown coal generators will, during the 2020s, enable them to be more competitive than black coal generators in New South Wales and Queensland, just as they were in the over-supplied NEM wholesale energy market prior to the closure of Hazelwood in March 2017.

The next few graphs focus on the renewable component of figures 2 and 3. Figure 6 shows the total supply of grid scale renewable generation, including hydro, and Figure 7 shows grid plus DER generation. The Slow scenario uses the same level of DER as the Neutral, meaning that grid renewable generation is less in the Slow scenario.

+ Figure 6: Total grid level renewable generation supplied

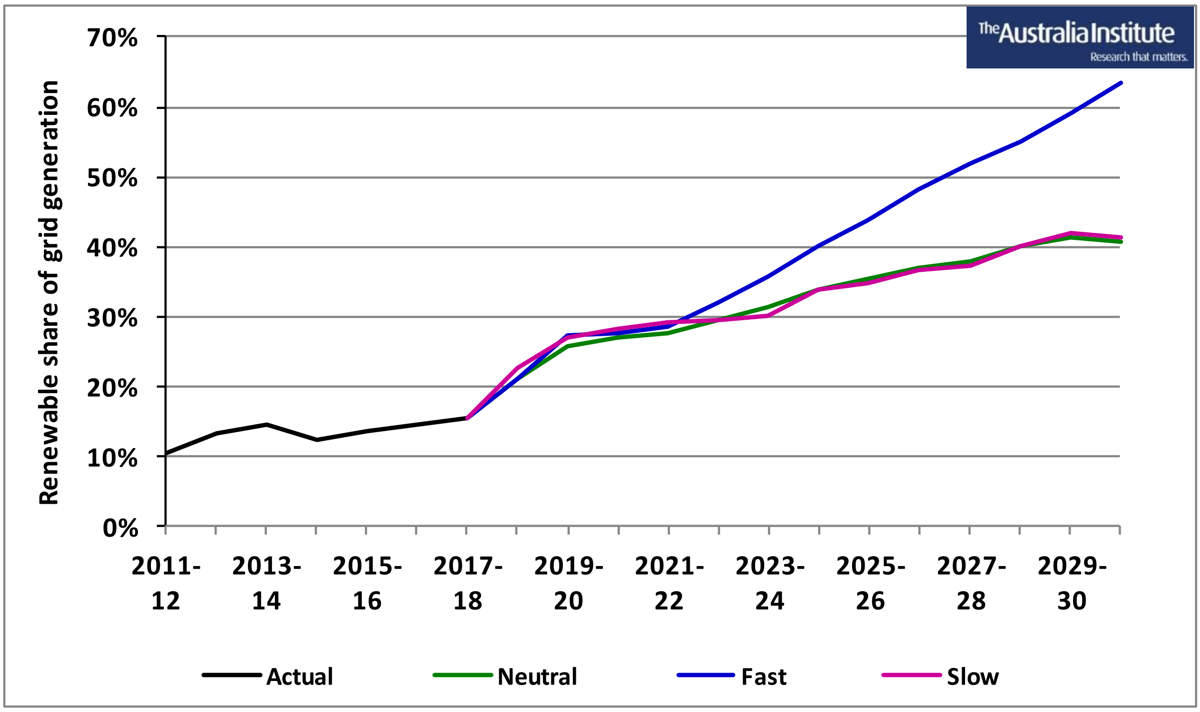


+ Figure 7: Total grid plus distributed (rooftop PV) renewable generation supplied



Figures 8 and 9 show the same numbers as Figures 6 and 7, but expressed as shares of total generation – total grid generation in Figure 8 and total grid plus distributed in Figure 9.

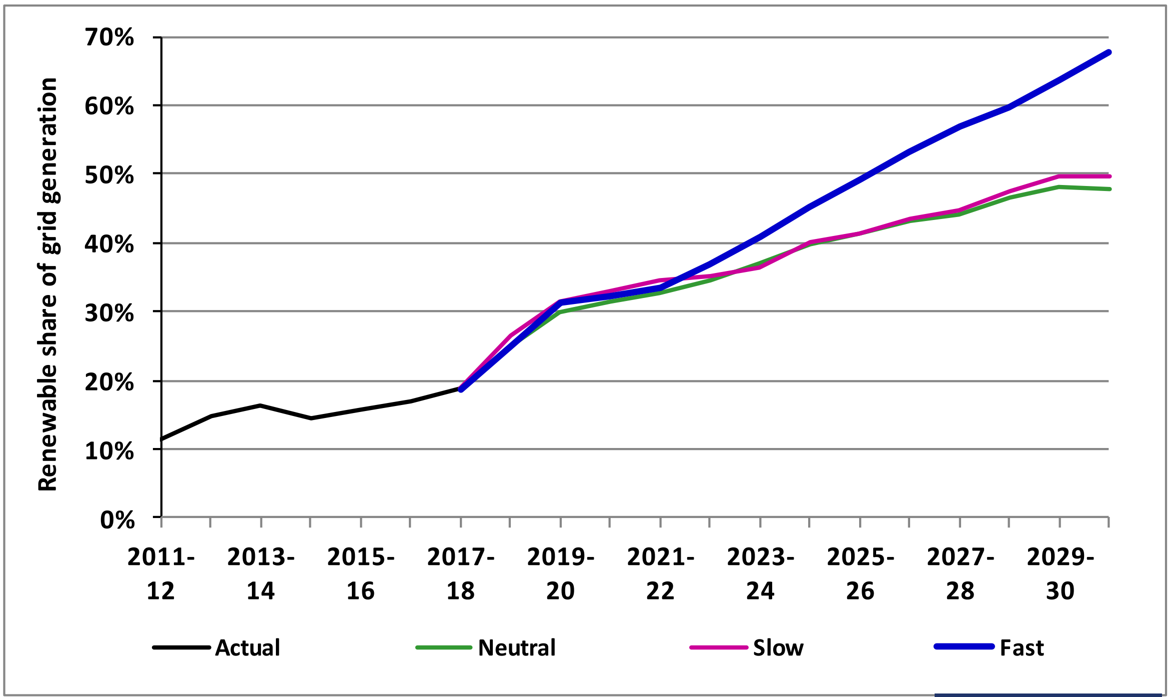
+ Figure 8: Grid level renewable generation as a share of total grid generation



What these two graphs show is that AEMO is confident that it is entirely feasible to maintain levels of reliability and security of the NEM electricity supply system, consistent with current National Electricity Rule settings, with the share of grid renewables reaching just over 40% by 2030. If account is also taken of rooftop PV generation, the overall renewable share reaches just under 50%. Under the Fast scenario, which has consumption growing at a faster rate, all the additional generation capacity required is provided by new wind and grid scale solar projects. As a result, the total renewable share in 2030 reaches over 60%; if rooftop solar is added the renewable share rises to almost 70%.

Wind and solar supply all the additional generation required under the Fast scenario because they are less costly than either coal or gas generation. These results demonstrate that AEMO is confident that supply system security and reliability can be maintained, provided that investments are directed in a timely manner to the required mix of new transmission and other grid service augmentations.

+ Figure 9: Grid plus distributed renewable generation as a share of total grid plus distributed generation from all sources



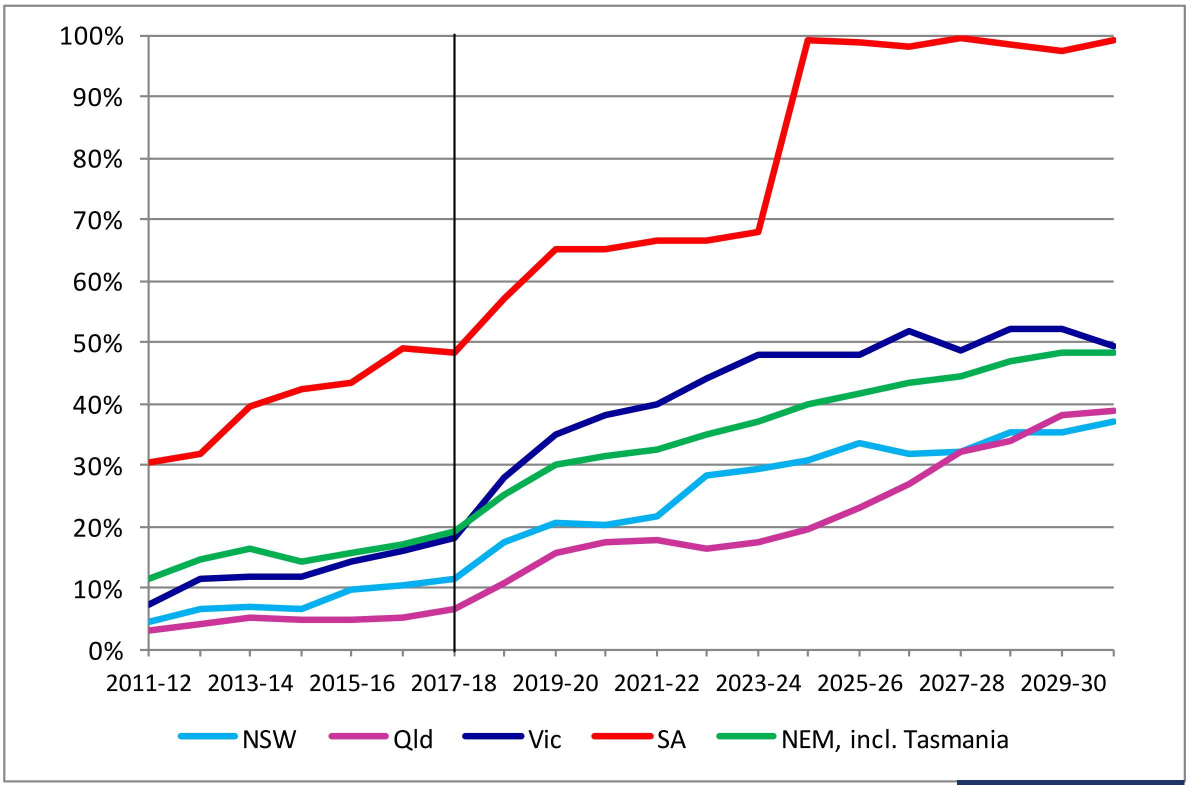
The main drivers of the overall growth in renewable generation in the NEM are the three main policies in place: LRET nationally, which reaches its final target in 2020, VRET, which reaches its 40% target in 2025, and QRET, which does not reach its 50% target until 2030.

The very large increase in renewable generation between now and 2020 reflects the very large amount of capacity about to come on line to meet the LRET target. This capacity is spread across all mainland states, as can be deduced from Figure 10, showing how renewable generation shares grow over time in each state. Tasmania is not shown, because it is already almost 100% renewable. In both Victoria and Queensland, the new LRET renewable generation in their respective states contributes to the achievement of their final renewable generation targets.

During the four years after 2020, the renewable share grows faster in Victoria than elsewhere, as the state moves towards and, as it appears, exceeds its 2025 target. In Queensland there is a lull in renewables growth, followed by a steady climb towards the 2030 target.

In South Australia there is a sudden jump to almost 100% in 2025, as the modelling completely shuts down both the two more than 50 years old Torrens Island gas fired steam power stations, but also the two more modern combined cycle gas turbine (CCGT) stations, Pelican Point and Osborne. This is a particularly striking outcome. Following the system black event in September 2016, AEMO introduce a requirement for a minimum level of synchronous generation to remain online in South Australia at all times. This requirement remains in force, though it has been somewhat relaxed since then. The key reason for the requirement is that during windy conditions, when the state's entire electrical energy demand can be met by wind generators, the Heywood interconnector to south west Victoria is the only source of system strength and security services if the local gas generators shut down. One of the key components of the first five years of AEMO's integrated system plan is a new high capacity synchronous interconnector, called RiverLink, to run from the mid north of South Australia to southern New South Wales and be completed by 2025. By implication, AEMO has concluded that, when RiverLink is completed it will be sufficient, in combination with the other new types of grid services mentioned previously, to eliminate the need for local synchronous generation. This is the clearest possible example of how a well-planned combination of grid level services can obviate the need for synchronous generation, and do so at lower cost.

+ Figure 10: Renewable shares of total state generation, including PV, by state



+ Figure 11: Renewable generation, including PV, shares of total state operational consumption, by state

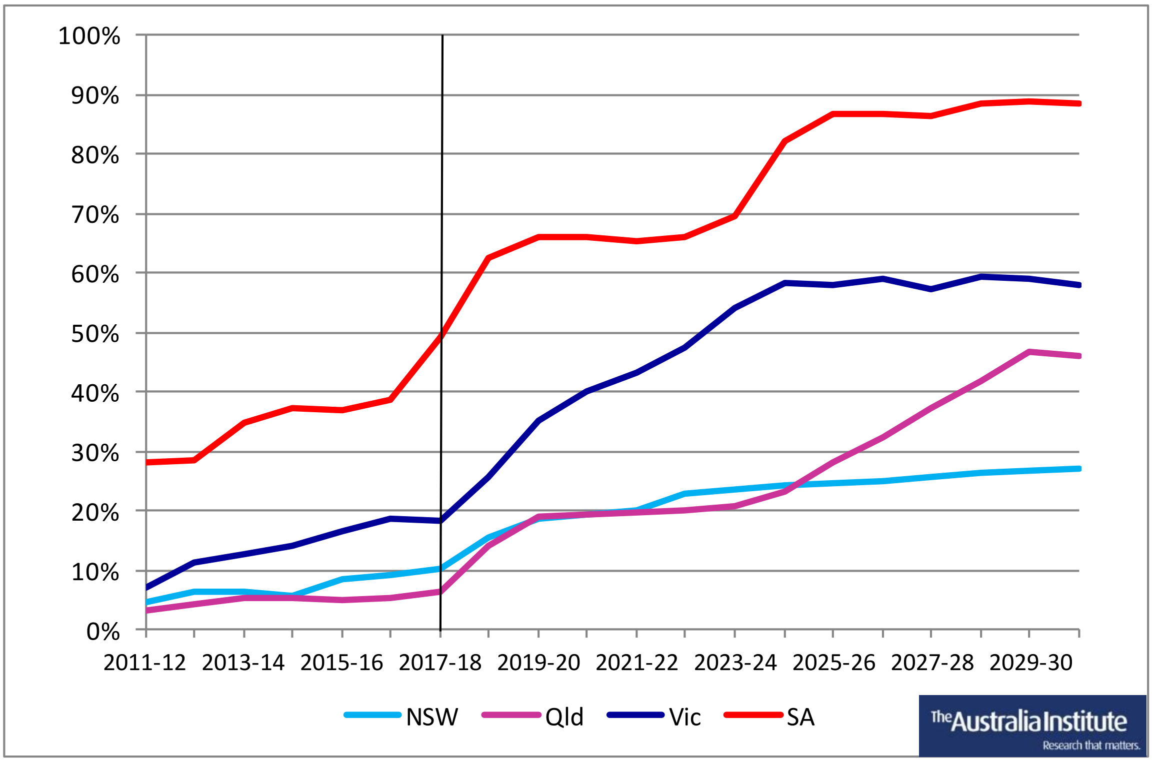


Figure 11 uses the same generation data as Figure 10, but relates it not to state generation but to state operational consumption. If a state is a net exporter of energy, the renewable shares in Figure 9 will be higher than those in Figure 8. Victoria and Queensland are in that situation for most of the 2020s. New South Wales and South Australia, by contrast, are net importers of energy, particular in the latter years of the decade, so that the shares in Figure 11 are lower than those in Figure 10.

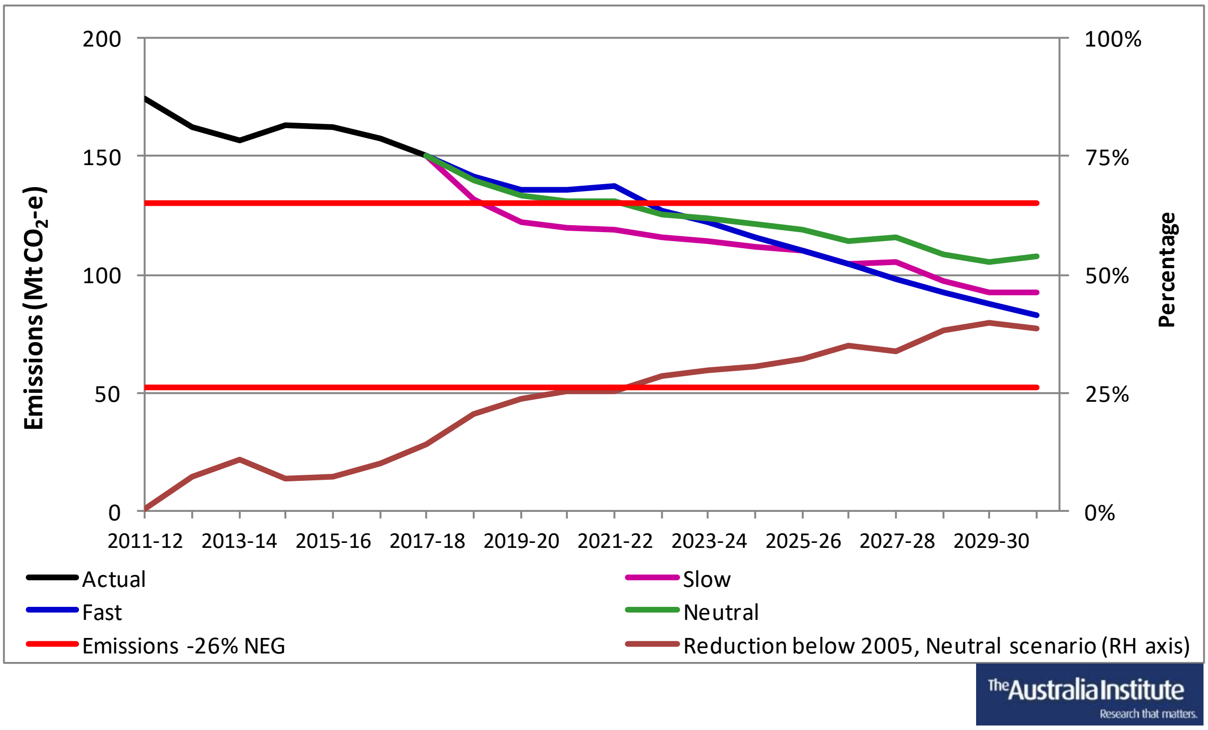
We now turn to examine what AEMO's ISP implies about NEM emissions. Figure 12 shows the implication for total NEM emissions of the Neutral, Fast and Slow scenarios. The top half of the graph shows total annual emissions under all three scenarios, in absolute terms, while the bottom half shows the reduction, in the Neutral scenario, relative to the 2005 reference level. As it happens, total emissions in 2011-12 were almost identical with the total in 2004-05, which is the reference for Australia's Paris Agreement 2030 commitment and for the government's proposed 2030 emissions reduction target for the NEG. It can be seen that, under the Neutral scenario, emissions almost reach the target level in less than two years from now, and decisively exceed it in 2022-23. By 2030 the reduction reaches 39%.

The very rapid fall in emissions over the next two years is undoubtedly based on AEMO's estimation of likely new wind and solar capacity to be commissioned over the next two years. AEMO can be expected to have a very well informed view on both the size and location of the capacity likely to be connected to the grid over the next two years, simply because having a such well-informed view is essential for the discharge of its core system planning and management responsibilities. The further sharp reduction in 2022 follows the closure of Liddell power station.

Emissions fall even faster under the two other scenarios. Under the Slow scenario, the fall in grid consumption outweighs the slower growth of new renewable capacity, so that some of the reduced demand, relative to the Neutral scenario, contributes to reduced demand for coal generation, with consequent emissions reductions. Conversely, under the Fast scenario, acceleration of renewable generation construction outweighs the acceleration in electricity consumption, meaning that coal consumption supplied by coal generators is again reduced. Under the Slow scenario, the reduction in emissions relative to 2005 reaches 49%; under the Fast scenario the reduction in emissions by 2030 reaches nearly 53%.

According to media reports, the Energy Security Board, which is responsible for developing the NEG, agrees that NEM emissions will fall to 26% below 2005 levels by 2020-21, in a business as usual context, a finding consistent with the results shown in Table 12. However, the NEG expects no further emission reduction over the subsequent ten years, because it excludes both the VRET and the QRET from its modelling.

+ Figure 12: NEM emissions outcomes under the three scenarios



Conclusions

One of AEMO's most important projects currently underway is its Future Power System Security program, of which the previously referenced *Power System Requirements Reference Paper* is a key document.[8] The opening words of the Paper are

> Modern power systems are giant, multi-faceted machines. To operate the complex 'system of systems' in Australia's National Electricity Market (NEM), AEMO oversees in aggregate millions of separate electricity supply and demand decisions in real time, all day, every day." (p. 4)

Describing a grid electricity supply system as a gigantic machine is now, justifiably, well established[9]. Extending this metaphor, the *Power System Requirements Reference Paper* can be likened to a comprehensive catalogue of the many different new and replacement parts which will be needed to ensure that the machine continues to function well for the next thirty years. Many of the existing components will need to be replaced over the next few years, and the most cost effective replacements will operate in different ways. In addition, the machine is being asked to, as it were, produce an important new product, emissions reduction.

While the *Power System Requirements* paper may be likened to a catalogue, the *ISP Report*, which is the first one of its kind that AEMO has produced, can be likened to a first comprehensive maintenance and upgrade plan for the NEM machine. Being comprehensive, takes account of the diversity of upgrade and replacement requirements for the machine, and it incorporates a diverse range of components and approaches to upgrade and replacement, within an overall cost-based engineering optimisation framework.

The NEG, by contrast, identifies a single problem to be addressed, lack of reliability, and chooses a single approach, generator dispatchability, to address the problem. Annual requirements for dispatchability will be set without, as far as can be determined from the published documentation, considering whether other options, most obviously transmission upgrades, could provide the same level of reliability at lower cost (while also providing other services, such as system strength). The NEG then proposes to institute a complex new market framework, which is intended to use competition between suppliers of dispatchability to achieve and deliver an economically efficient quantity of dispatchability within the previously defined, narrow, dispatchability-only framework.

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[8] AEMO (2018) *Power system requirements reference paper,* http://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Power-system-requirements.pdf

[9] Smithsonian.com (n.d.) *The largest machine ever built,* https://www.smithsonianmag.com/videos/category/history/the-largest-machine-ever-built/

Needless to say, such a narrow approach can provide no assurance at all that this will be the most efficient way to upgrade the machine as a whole.

It is of course well recognised that the government's proposed 26% emissions reduction target for the NEM is hopelessly inadequate. Our analysis of the results of AEMO's modelling for the ISP shows that the target is in fact meaningless, because within a few years it will be exceeded. Emission reductions will be driven by the large numbers of new wind and solar generation projects now in train, particularly in Victoria and Queensland. Further large emission reductions will flow providing that, as AEMO's modelling framework assumes, the QRET policy remains in place.

AEMO's modelling results show that, with efficient planning of and investment in the most efficient mix of network services, it will be quite possible to ensure that the electricity supply system of the NEM remains secure and reliable, with much larger emission reductions, and much higher shares of renewable generation in the supply mix, than envisaged in the design of the NEG.

Reducing emissions sooner, by more, is likely to be more costly than the approach of building new renewable generation capacity only as old capacity retires, simply because investment is being brought forward in time. However, it is most important to understand that any such additional cost is not the cost of changing the electricity supply system. It is the additional cost of achieving greater emission reductions. Any such additional cost must be compared, not with the cost of doing less within the electricity supply sector, but with the cost of achieving similar emission reductions from other sectors, such as transport or agriculture.

+ Summary of required system services, and capability of technologies to provide them

Source: AEMO, Power system requirements

Service description				Supply side		Network						Demand side		
				Centralised generation		Transfer between regions		Transfer within regions	Stabilising devices			Load	Decentralised resources	
System Attribute	Requirement	Service	Spatial level of need	Synchronous generator	Non-synchronous generator	DC interconnection	AC interconnection	Transmission and distribution networks	Grid reactor, grid capacitor, static VAR compensator	Static synchronous compensator	Synchronous condenser [1]	Large industrial, residential, commercial	Solar PV	Battery storage
Resource adequacy	Provision of sufficient supply to match demand from customers	Bulk energy	System wide	●	●	→	→	→	○	○	○	●	●	●
		Strategic reserves	System wide	● [2a]	◐ [3a]	→	→	→	○	○	○	●	◐ [3b]	◐ [3b]
	Capability to respond to large continuing changes in energy requirements	Operating reserves	System wide	● [2b]	◐ [3a]	→	→	→	○	○	○	●	◐ [3b]	◐ [3b]
	Services to transport energy generated to customers	Transmission & distribution services	Local	● [4]	● [4]	●	●	●	●	●	●	● [4]	◐	◐
Frequency management	Ability to set frequency	Grid formation	Regional	●	◐ [5]	⇨ [5]	●	●	○	○	○	○	○	◐ [5]
	Maintain frequency within limits	Inertial response	Regional	●	◐ [6]	◐ [6]	→	→	○	◐ [7]	●	○ [8]	○	◐ [6]
		Primary frequency control	Regional	●	● [9]	→	→	→	○	○	○	●	●	● [9]
		Secondary frequency control	Regional	●	● [9]	→	→	→	○	○	○	●	●	● [9]
		Tertiary frequency control	Regional	●	● [9]	→	→	→	○	○	○	●	●	● [9]
Voltage management	Maintain voltages within limits	Fast response voltage control	Local	●	●	●	○	○	●	●	●	●	◐	●
		Slow response voltage control	Local	●	●	●	○	○	●	●	●	●	◐	●
		System strength	Local	●	○	○	⇨	→	○	○	●	○	○	○
System restoration	Ability to restore the system	System restart services	Local	●	◐ [10]	◐ [10]	●	→	○	○	○	○	○	◐ [10]
		Load restoration	Local	●	●	●	●	⇨	●	●	●	●	◐	◐

1 This includes generators with ability to operate in synchronous condenser mode.
2a While many synchronous generators can provide energy reserves, some less firm technologies (solar thermal or pumped hydro storage) will be limited by the amount of energy storage they include.
2b While many synchronous generators can provide flexibility services, coal generators are limited in their ability to provide such services.
3a Limited by duration for which service can be delivered.
3b Limited by duration for which service can be delivered; existing controllability is limited.
4 The provision of local voltage support from generators and loads can improve the network transport capability near their respective connection points.
5 Grid forming power electronic converters are available and have been proven on small power systems. Development of grid forming converters for large power systems is an emerging area of international research.
6 Some fast frequency response capabilities can provide emulated inertia response, but are not yet proven as a total replacement for synchronous inertia.
7 Static synchronous compensators with energy storage devices are being trialled as an emerging provider of inertial response.
8 Except for load relief.
9 Includes fast frequency response capabilities.
10 System restoration services from variable non-synchronous generators is an emerging area of international research. If they are grid scale, batteries are likely to provide some system restoration support.

Ability to provide service		
●	◐	○
Fully capable	Partial or emerging	Unable
→	⇨	
Enables delivery	Partial or limited delivery	

Note: Classifications are indicative of the general ability of each technology type. The extent to which technologies can provide each service must be assessed on the specifics of each individual system.