Hydro Tasmania

Battery of the Nation

Analysis of the future National Electricity Market

Exploring a vision where Tasmania plays a significantly expanded role in the NEM

April 2018

Prepared by

Hydro Tasmania

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Authors
Cameron Potter (lead), Pippa Williams, Stuart Allie, Marian Piekutowksi, James Butler, Carolyn Maxwell

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Email

batteryofthenation@hydro.com.au


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Foreword

Stage 1 analysis of the future energy investment opportunities identified by the *Battery of the Nation* concept shows Tasmania can make a significant contribution to the transformation of the National Electricity Market (NEM) over the next two decades.

The national market has the opportunity to invest in a combination of more interconnection, wind development and new hydropower assets in Tasmania, offering a future energy solution that is clean, reliable and affordable. The opportunity offers economies of scale, diversity and high quality new renewable energy resources combined with large scale storage that is able to be built with economic and timing optionality.

Key findings from the Stage 1 analysis

Significant hydropower potential at competitive cost

- Existing Tasmanian hydropower assets can be repurposed to provide more valuable services in the future market; targeted investment in pumped hydro energy storage in the system strengthens this proposition. When the obligation of Tasmanian energy security is shared with wind generation, the hydropower system can provide new system support services at very low cost to construct and operate. Adding pumped hydro capability to existing hydropower schemes would also increase the value of existing schemes through increased controllability.
- The cost to develop Tasmania's pumped hydro opportunities is very competitive, with over 4800 MW and 140 GWh of opportunity at a cost to construct from $1.05-$1.5m/MW.

Significant wind potential

- Tasmania's undeveloped wind resource is high quality and diverse. This is due to a high quality natural resource and lower correlation with wind resources on mainland Australia. Further development of this resource could bring substantial and valuable diversity to the NEM over the next 10 years.

A cost competitive coordinated solution

- The coordinated development opportunity of Tasmanian pumped hydro, wind and interconnection is cost competitive against all other realistic options for the future energy system.

National planning alignment

- The opportunity aligns with AEMO's current integrated system planning (ISP) and delivers on all identified benefits required of a renewable energy zone (REZ) in that plan. In particular, it introduces more generation diversity (by location) and market investment optionality.
- As significant investment will be required across the whole NEM, Tasmanian development can be adapted to work within nationally coordinated market planning to manage the risk of asset stranding.
- Investment decisions on new interconnection can be timed to align with retirement of coal-fired generation, which in turn will trigger further Tasmanian wind and hydropower investment.

Addressing the energy trilemma

- The concept strongly supports all three requirements of the energy trilemma - sustainability, security and equity (affordability) - in one coordinated system solution. It can bring new generation firming services to the market and put downward pressure on Tasmanian and mainland prices.
- Initial modelling shows these opportunities can reduce national reliance on open cycle gas generation (OCGT) for capacity. This is because flexible hydropower can be used more for system capacity support. This could translate to a 20% reduction in energy costs and an additional reduction of up to nine million tonnes of greenhouse gas emissions per year.

Through these attributes, *Battery of the Nation* has shown that Tasmanian development options can deliver reliable and secure energy supply at least cost to consumers both in Tasmania and the mainland states.

The formal assessment for the second Bass Strait interconnector has already commenced: a critical step on this journey. Hydro Tasmania will continue to support this effort.

This report is only the first stage of this investigation. We welcome feedback on its content.

We will continue to further investigate the longer term market opportunity to better understand the opportunities and challenges to the concept.

Stephen Davy
Chief Executive Officer, Hydro Tasmania

Battery of the Nation offers a future energy solution that is clean, reliable and affordable.

1.0 Executive Summary

The national challenge

Australia's energy fleet is ageing. Approximately 65% of Australia's energy fleet is already at or beyond the mid-point of its technical life. It is forecast that from 2028 to 2037 about 35% of Australia's existing generation capacity will retire simply due to age-related deterioration. This represents the loss of around 15 000 MW over a 10-year period.

This scale of retirement of major infrastructure is significant. Replacing this infrastructure will require a substantial response on a national scale.

Figure 1 shows a conservative retirement schedule for generation assets in Australia based *purely* on age – primarily retirement of coal-fired generation. As older plant retires, new plant will need to be built. The late 2020s is forecast to be the precipice of a rapid change.

The retirement of the Hazelwood coal-fired plant in 2017 increased energy security risks and caused a substantial rise in energy prices. This highlighted the thin reserve margins in the NEM and indicates a need for significant proactive investment in new generation infrastructure.

The scale of the challenge facing the NEM is an order of magnitude larger and will require a combined response from a variety of technologies and proponents across the NEM.

Replacement generation sources are likely to be variable – notably wind and solar. The interactions of these variable energy sources will change the nature of the power system and power system planning and modelling.

Energy services that help manage the reliability and security of the system will become critical to the market. New services that can store large quantities of energy during times of energy surplus and supply back to the grid during times of relative energy scarcity will be part of a solution to produce the lowest cost supply for customers.

Changes in the physical power system are prompting reconsideration of market design. A market design based on dependable floor prices underpinned by short run marginal cost of energy may not support the transformation of the electricity sector away from fossil fuel-based technologies. The new system services that work alongside variable energy sources to provide a steady output to meet demand will need to be properly assessed and valued. Any change to the market design will need to solve the energy trilemma of energy equity (affordability), security and sustainability.

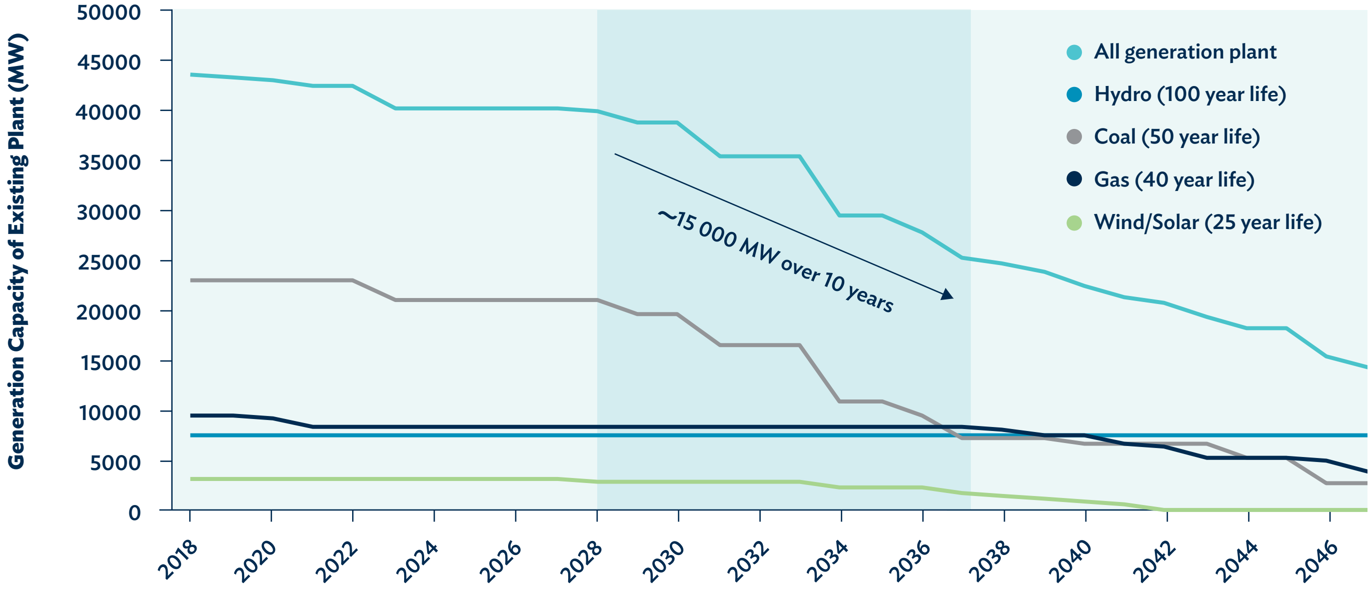
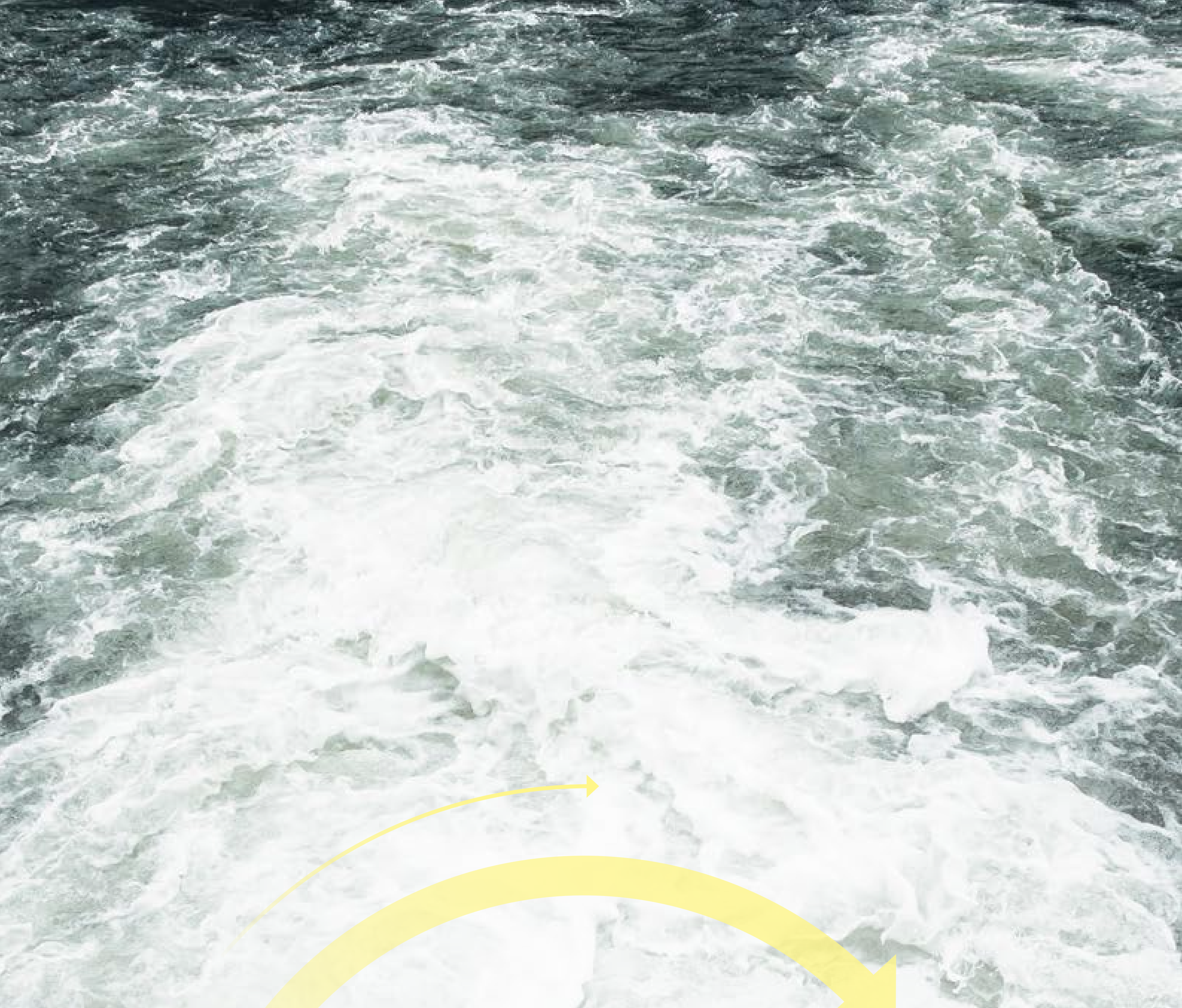


Figure 1. Expected retirement profile of existing generation assets in the NEM (based on life expectancy)



Key challenges

Australia's energy fleet is ageing. The late 2020s will see the start of an unprecedented rapid and sustained retirement schedule.

No single solution will be able to meet the size of the challenge. A coordinated response is needed. There will be no 'business as usual'.

Wind and solar are likely to be cost competitive energy sources of the future and the power system will need new services to support their variability and integration.

Can Tasmania deliver on this opportunity?

Tasmania has a strong opportunity to contribute competitive large scale energy storage and high quality wind resources to the future energy mix of the NEM.

Tasmania’s existing valuable and flexible hydropower assets can play a system balancing role, maximising the value of new variable renewable energy developments while providing a new supply of secure and firm energy to mainland Australia. This value could be amplified by targeted investment in pumped hydro technology increasing system controllability – a critical asset in a national market with substantial variable wind and solar generation.

Tasmania’s wind resource is relatively untapped, plentiful, high quality and could bring substantial diversity to the national market.

With further interconnection and a sound development plan, Tasmania could produce significantly more renewable energy for the nation and fully realise the value of its current hydropower system.

With further interconnection and a sound development plan, Tasmania could produce significantly more renewable energy for the nation and fully realise the value of its current hydropower system.

The full report presents the findings of the first stage of analysis. The Executive Summary presents key outcomes. The supporting evidence underpinning the views, assertions and outcomes in the Executive Summary is contained in the full report.

The Tasmanian perspective

Critical to the success of this proposal is active engagement and participation from the broader Tasmanian community. This vision for their energy future must deliver the best possible outcomes for Tasmanians. This opportunity could:

1. **Ensure the lowest possible power prices for Tasmanians**

   The modelling so far supports this view. In simple terms, Tasmania will need to have comparably low prices to be able to export its excess energy.

2. **Ensure long term energy supply security for Tasmania**

   Thousands of MWs of new wind generation on island and more interconnection to the mainland would mean secure long term energy supply for Tasmania. It would diversify Tasmania's energy options and reduce direct exposure to climate change variability, particularly relating to rainfall.

3. **Provide a long term economic stimulus to regional areas of Tasmania**

   The investment in pumped hydro, wind generation and the transmission system will be incremental over decades and is focussed on areas of the state outside major city centres. This will generate significant, ongoing economic stimulus in regional areas of Tasmania.

At this stage, the identified social and environmental impacts are also relatively low. It is possible to create and sustain broad community support for this opportunity.

The national perspective

The *Battery of the Nation* opportunity offers economies of scale, diversity and high quality new renewable energy resources combined with large scale storage that is able to be built with economic and timing optionality. This will bring national benefits including:

1. **Ensure the lowest possible power prices for the NEM**

   The modelling so far supports this view. Compared with credible alternatives, the developments modelled under *Battery of the Nation* would reduce cost across the NEM.

2. **Provide stable, secure and reliable energy supply**

   The ability to leverage existing assets and storages will enable Tasmania to provide critical system balancing and firming services to ensure reliable energy provision in the NEM.

3. **Meet Australia's energy sustainability targets**

   Investing in Tasmania's world class and nationally diverse wind resources will deliver towards Australia's energy sustainability targets and international carbon abatement commitments.

Approach to the analysis

To understand the opportunity presented by *Battery of the Nation*, a consistent and plausible view was formed for the future NEM. Stage 1 of the project has:

1. Assessed **technologies** that make up the Tasmanian opportunity against other known credible future technology options.
2. Assessed the specific **application** of these technologies in the Tasmanian context and compared them against other known credible future application across the NEM.
3. Constructed an integrated 'system solution' cost model for the Tasmanian option, and
4. Tested this model for competitiveness against credible future NEM **scenarios.**

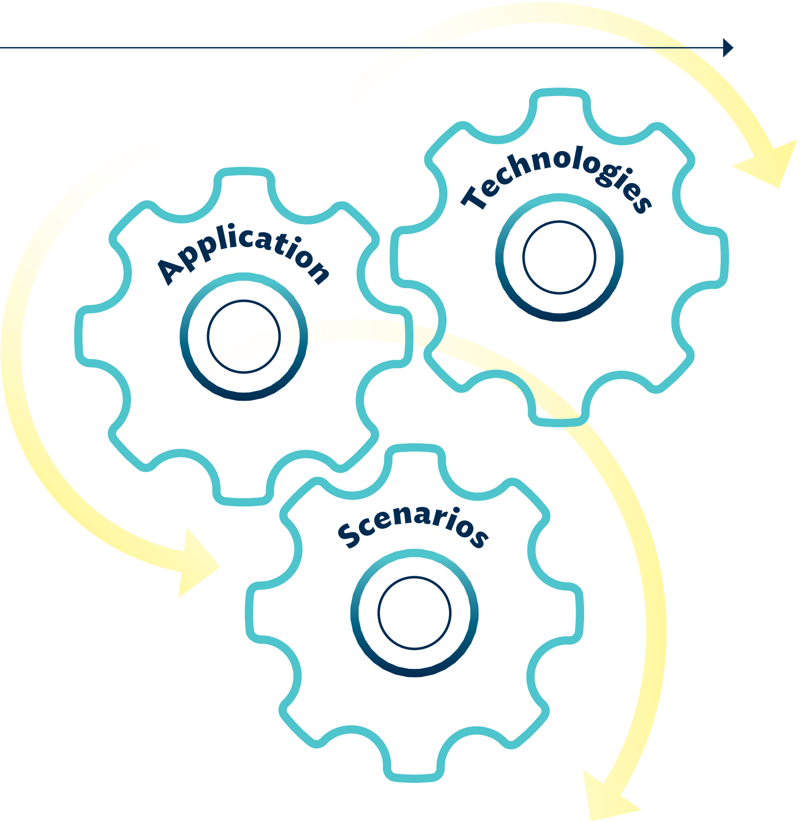
In this process, third party system modelling consultants have been utilised for the modelling (EY) and review (Oakley Greenwood).

A 'systems thinking' approach was taken for the scenario modelling to account for the fact that in the future, time-variable renewable energy sources will begin to dominate the energy mix. This also allows for synergy of new assets. A conventional resource allocation approach was considered inadequate. The chosen approach led to a range of planned 'build out scenarios' that considered the complementary development of wind farms and pumped hydro projects in Tasmania.

Dispatch modelling of the NEM was undertaken for four scaled scenarios, six sensitivities and a 'NoTasDev' situation (no further energy developments in Tasmania beyond Cattle Hill and Granville Harbour wind farms). These scenarios translated to modelling scenarios with three to five interconnectors, 2000 MW to 6500 MW of wind generation, and 1500 MW to 3500 MW of pumped hydro. Figure 2 shows the range of modelled scenarios. Figure 3 shows the scenario with five interconnectors and strong wind development.

The *Battery of the Nation* concept is not intended to meet all the future needs of the NEM. The largest scenario explored shown in Figure 3 only meets 20% of the total need for dispatchable capacity through to 2040.

The first phase of analysis explored substantial change in the broader market in response to retirement of coal-fired generation and typically chose conservative market assumptions. This resulted in the modelling showing substantial utilisation of open cycle gas generation (OCGT) to provide the marginal capacity required to fill, potentially extended, periods of scarcity.



This results in a conservative position for the *Battery of the Nation* concept; a high level of gas generation decreases the requirement for (and value of) long term storage. This is consistent with the initial findings of AEMO's Integrated System Plan [ISP 2017] and also with any more aggressive carbon abatement targets for the electricity sector.

A key hypothesis for this analysis is that storage of 12 – 24 hours will be required to support the system for (southern) states where the variability is driven primarily by wind energy. This is supported by the analysis; across the entire NEM, there will be a two day period of low wind generation every fortnight on average, see Section 5.2.2 in the full report for more detail.

Chemical batteries are not considered economic for storages beyond four hours duration, even by 2050, see Section 5.2.5.2 in the full report for more detail. Flexible generation will be required to help manage generation variability. OCGT has traditionally provided this service to the market. Due to the cost competitive nature of Tasmanian pumped hydro options (see section 5.2.5 in the full report for more detail), it will outcompete other options for dispatchable energy supply.

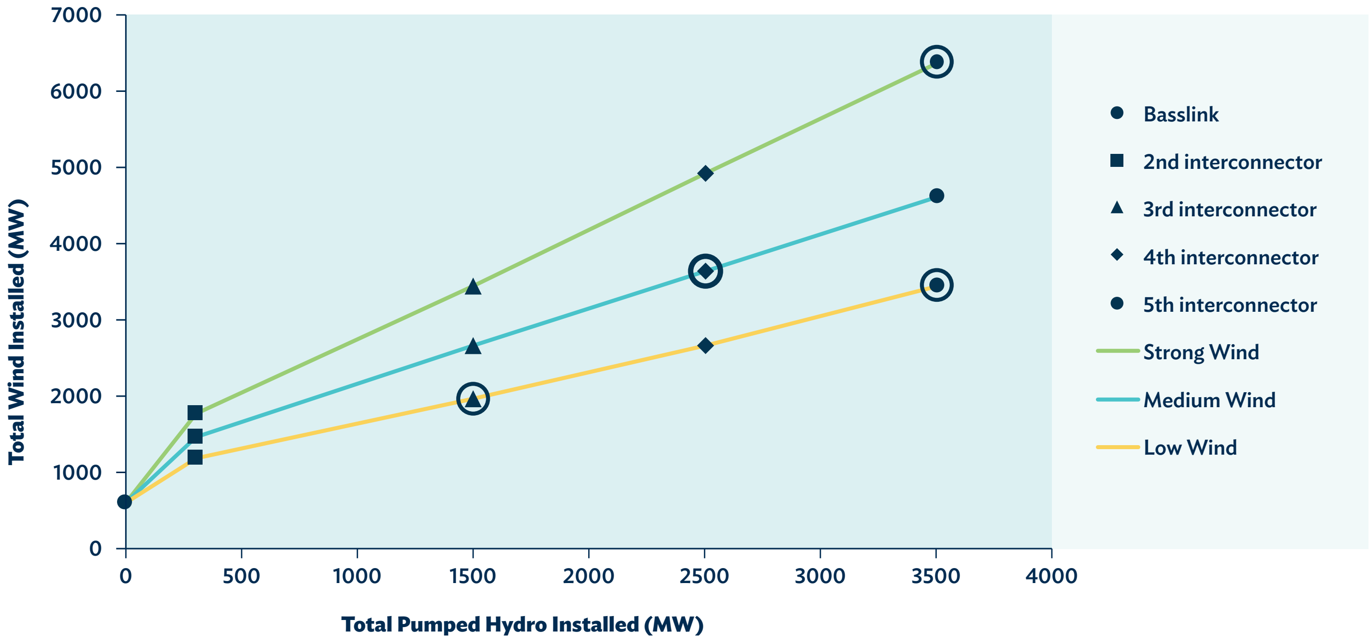


Figure 2. Range of modelled scenarios

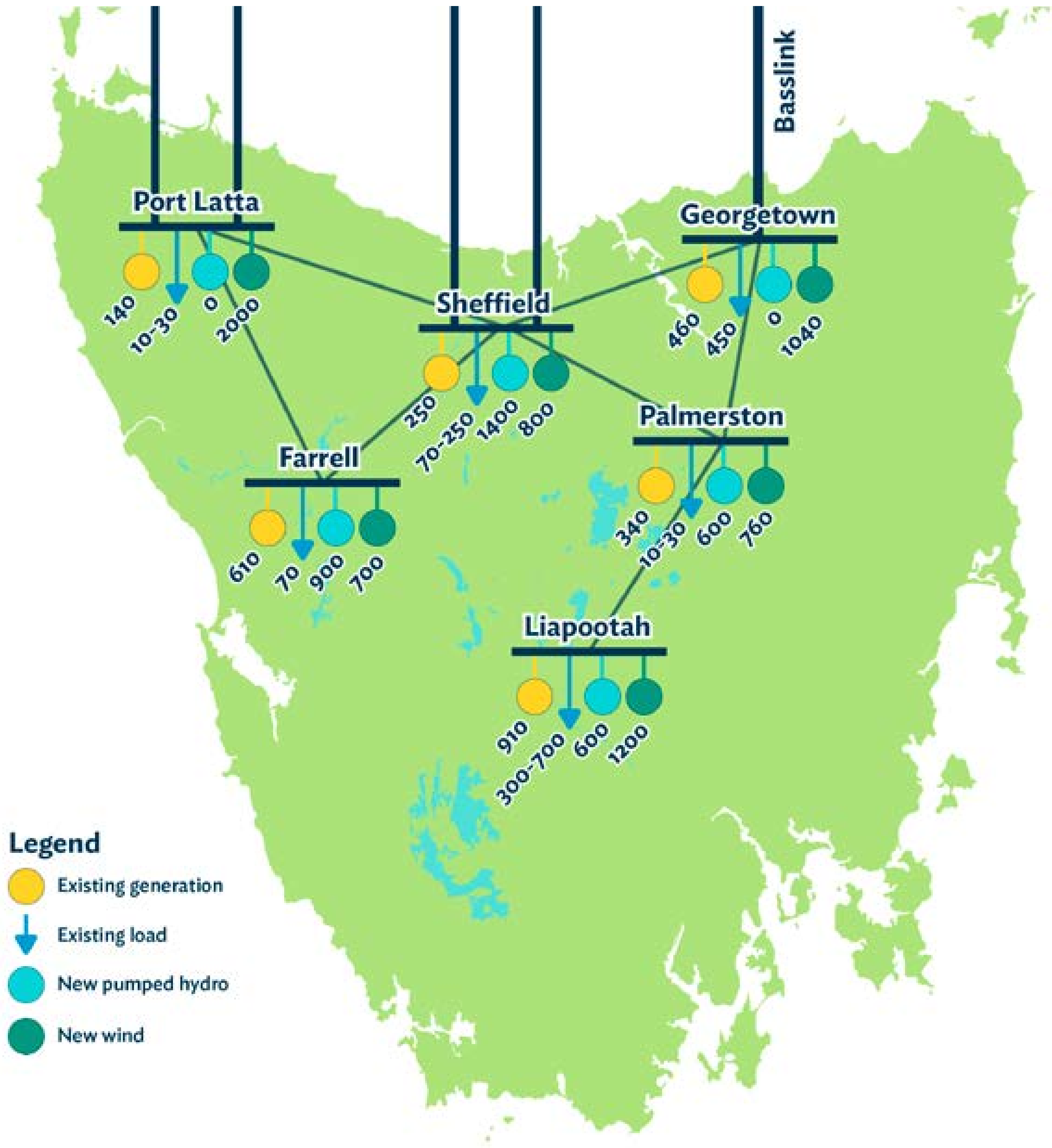


Figure 3. Five interconnector, strong development scenario

Key *Battery of the Nation* findings

Key finding – significant hydropower potential

Existing Tasmanian hydropower assets can be repurposed to provide more valuable services in the future market; targeted pumped hydro investment in the system strengthens this proposition.

When the obligation of Tasmanian energy security is shared with wind generation and more substantial interconnection, the hydropower system can provide new system support services at very low cost to construct and operate. Adding pumped hydro capability to existing hydropower schemes would also increase the value of existing schemes through increased controllability.

Tasmania's extensive and established hydropower system is well-placed to contribute to the challenges facing the energy system with proven, reliable, dispatchable renewable energy backed by Hydro Tasmania's extensive experience developed over 100 years.

Tasmania's hydropower assets are currently primarily focussed on long term energy security for the state and most plant are optimised to provide baseload power to Tasmania. However, with the right investment Tasmania can repurpose existing elements of the hydropower system to store energy when sun and wind energy are abundant, and draw on this storage to deliver power to the nation when weather conditions limit wind and solar generation, demonstrated in Figure 4.

Increasing the flexibility of a greater proportion of hydropower assets in Tasmania would result in more cost-effective energy dispatch and lower prices for consumers.

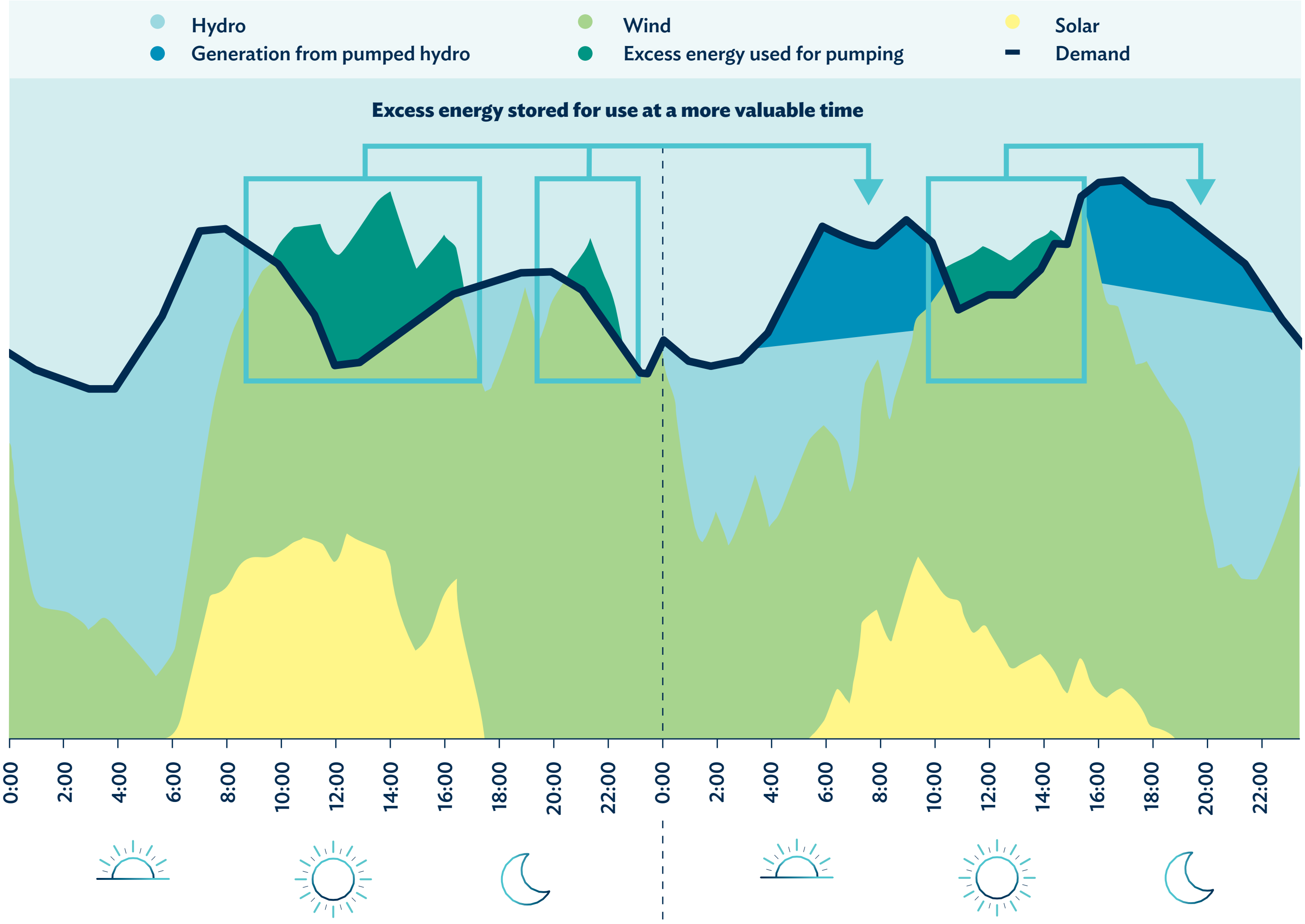


Figure 4. The role of energy storage

Tasmania has strategic advantages which should make pumped hydro investment a national priority.

The suite of pumped hydro energy storage projects under *Battery of the Nation* is large, mostly being able to support 24 hours of continuous supply, and cost-effective with construction costs that range from $1.05 to $1.5 million per MW. Note the actual energy storage for each pumped hydro station is largely dictated by geography and has little correlation to construction costs, resulting in economically scalable duration of supply.

Modelling of existing hydropower in Tasmania has shown that under a likely future energy mix the schemes with more storage (which are more flexible and controllable) are substantially more valuable than those that have smaller storages. The value of existing run-of-river hydropower assets could increase by as much as 25% with selective development of pumped hydro energy storage.

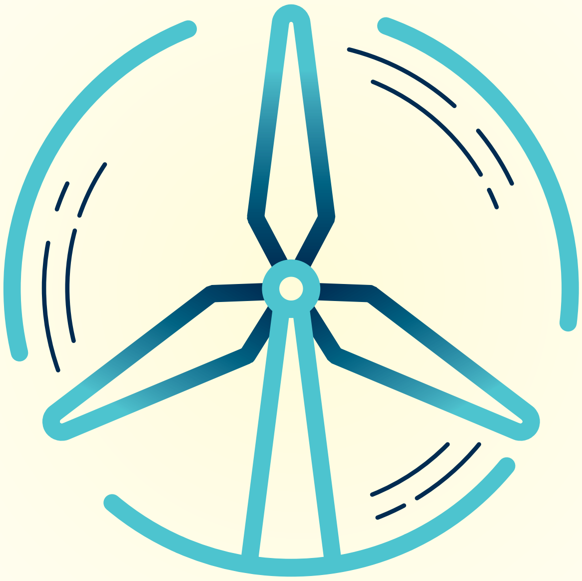
A major advantage for the suite of projects being considered in Tasmania is that a pumped hydro installation towards the top of a series of cascaded hydropower stations amplifies the contribution of the pumped hydro asset as released water from the station can pass through all downstream power stations.

Tasmania has natural topographical advantages and existing infrastructure that position the state as a very attractive location to develop large-scale pumped hydro necessary to meet all elements of the energy trilemma (security, affordability and sustainability).

Investment in pumped hydro will help ensure Tasmania can deliver valuable system security services to the market when they are most needed.

Key finding – significant wind potential

Tasmania's wind resource is high quality and diverse. This is due to a high quality natural resource and lower correlation with wind resources on mainland Australia. Further development of this resource could bring substantial diversity to the NEM over the next ten years.



This diversity will become more and more valuable as the penetration of variable renewables increases and is a key benefit of the nationally planned renewable energy zones. Tasmania's typical diurnal cycle has also been found to have a low correlation with mainland wind energy and also a notably different daily pattern of generation, see Figure 5. This difference in wind patterns provides diversity benefit to the NEM. It is also coupled with the highest capacity factor for wind energy generation in the NEM.

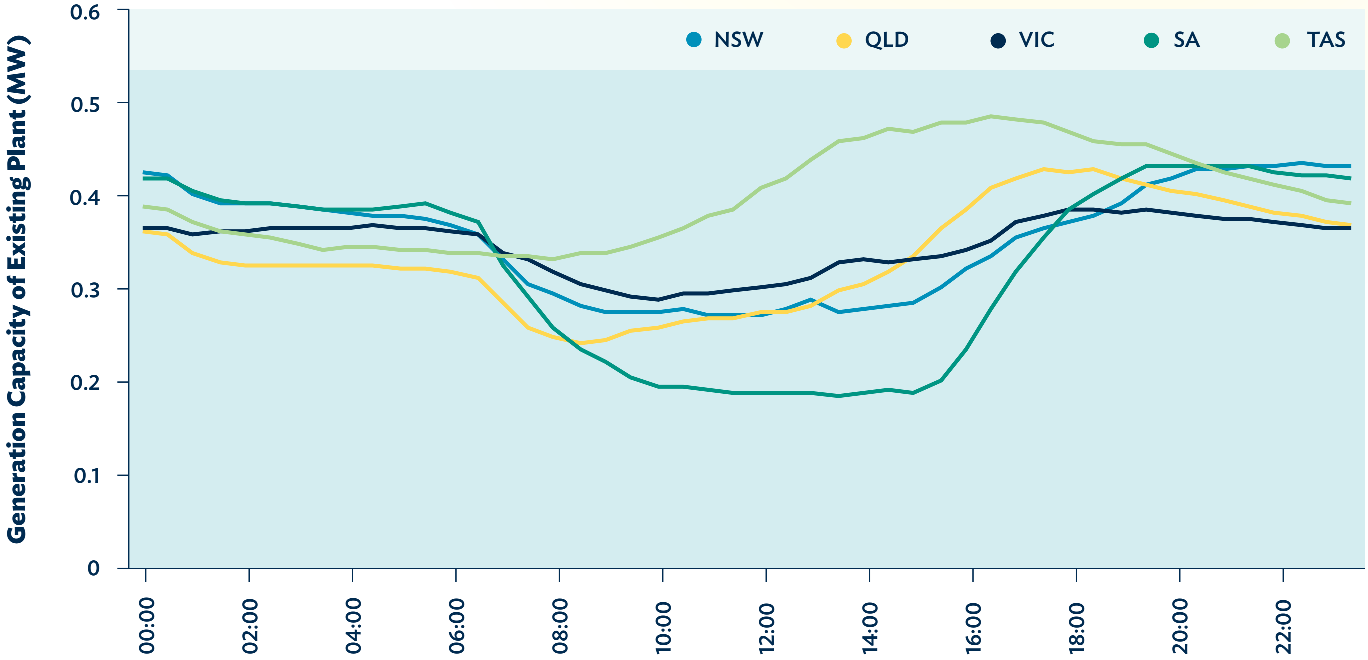


Figure 5. State wide wind energy diurnal capacity factor comparison based on modelled data in 2050

The benefit of Tasmania's wind energy diversity can be visually demonstrated to change the NEM-wide characteristics of wind energy production, see Figure 6. The figure shows that with substantial contribution from Tasmania, the national wind profile spends far more time in the most useful range and less time generating low amounts of energy. The need for storage will be reduced nationally by careful expansion of diverse variable renewable energy opportunities. This characteristic increases the value of Tasmanian renewable energy development to the entire system.

The proximity of strong wind resources in Tasmania to long term storage options, shown in Figure 7, increases the relative value of both resources. This is further amplified when combined with existing transmission corridors and reservoirs to reduce cost and minimise environmental impact. Preliminary investigations have shown that these developments are economically attractive and have relatively low social and environmental challenges (to be confirmed in the future with more detailed site specific assessments).

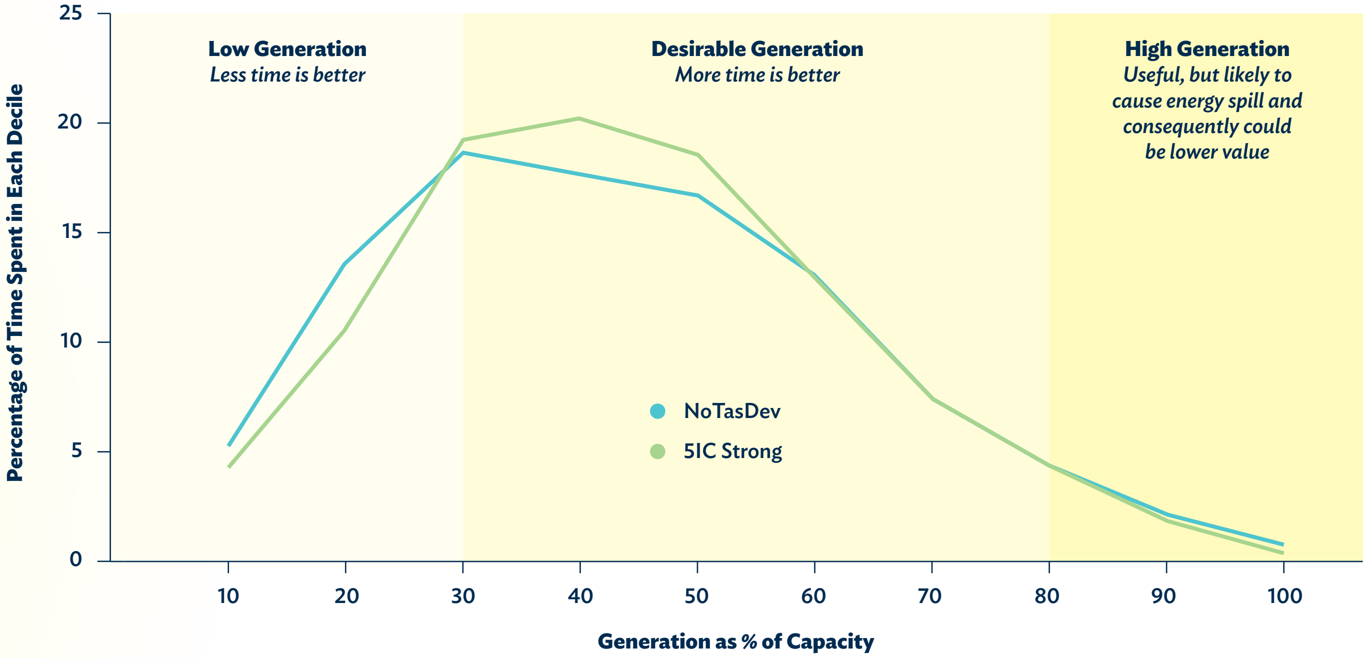


Figure 6. National wind generation profile – with and without Tasmanian development

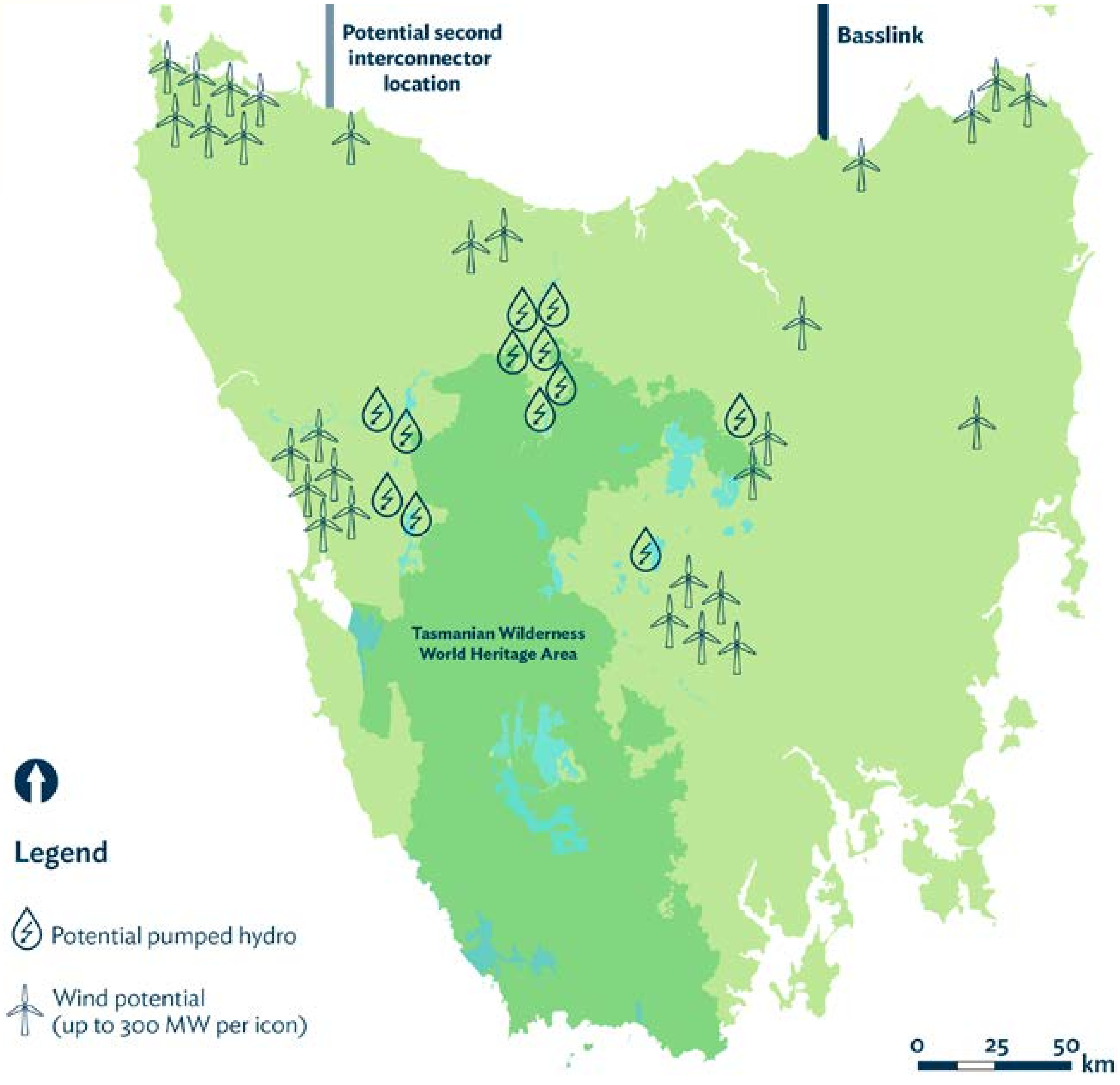


Figure 7. Wind and pumped hydro opportunities in Tasmania

Key finding – cost competitive coordinated solution

The coordinated development opportunity of Tasmanian pumped hydro, wind and interconnection is cost competitive against all other realistic options for the future energy system.

Figure 8 and Figure 9 show the cost stack of the coordinated development opportunity in Tasmania compared to other credible options for delivering a large amount of new, reliable energy to the market. For the purposes of this comparison the stream of energy was scaled to deliver 600 MW to Victoria's load centre, representing a possible size for the second interconnector. In the future, this assessment will need to be regularly validated as other credible options are developed in the market.

In Figure 9, the "gas only" option is the reference case. The size of the missing pieces in each pie chart reflect the relative competitiveness – the bigger the missing piece, the better the option. The two major cost contributors are variable gas costs (fuel) and the wind energy. This analysis shows the transmission and interconnection costs are only a minor contributor to the overall investment required.

Battery of the Nation also presents a staged infrastructure development pathway that can be a key component in meeting the future NEM requirements through scalable large scale and long duration (12+ hours) storage and high quality, regionally-diverse wind energy.

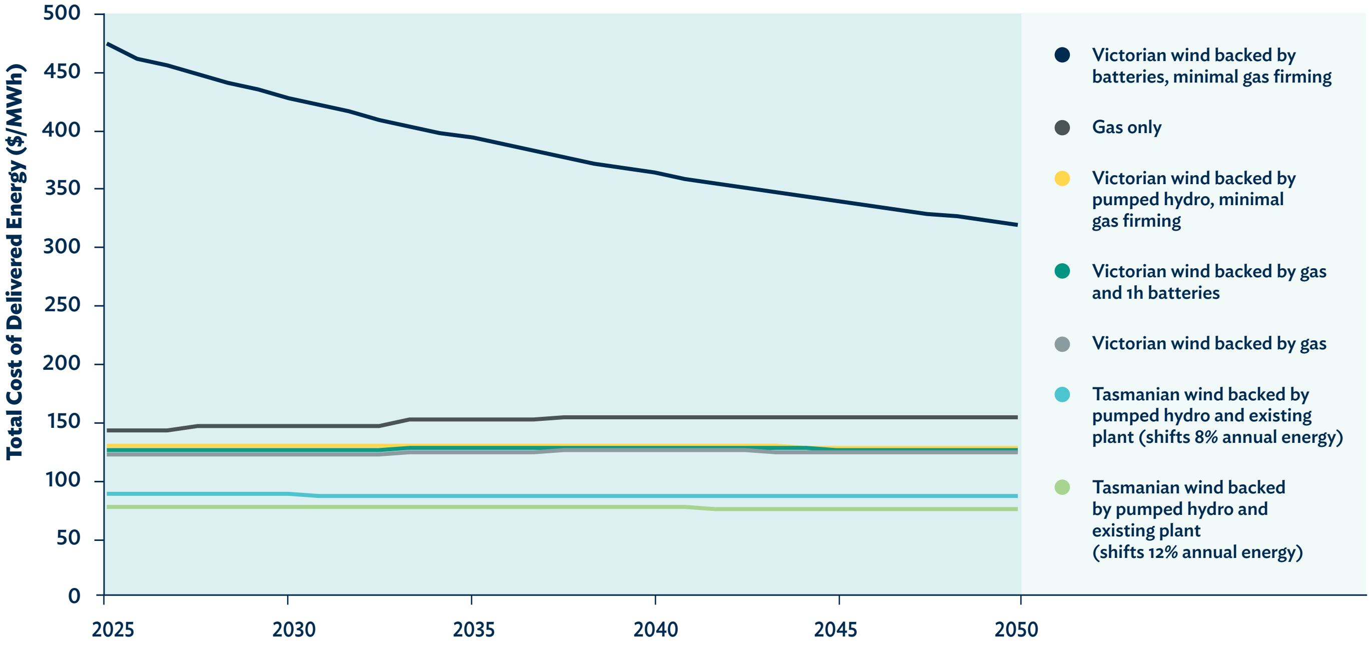


Figure 8. Comparison of options to deliver 600 MW from a new energy zone to the Victorian load centre

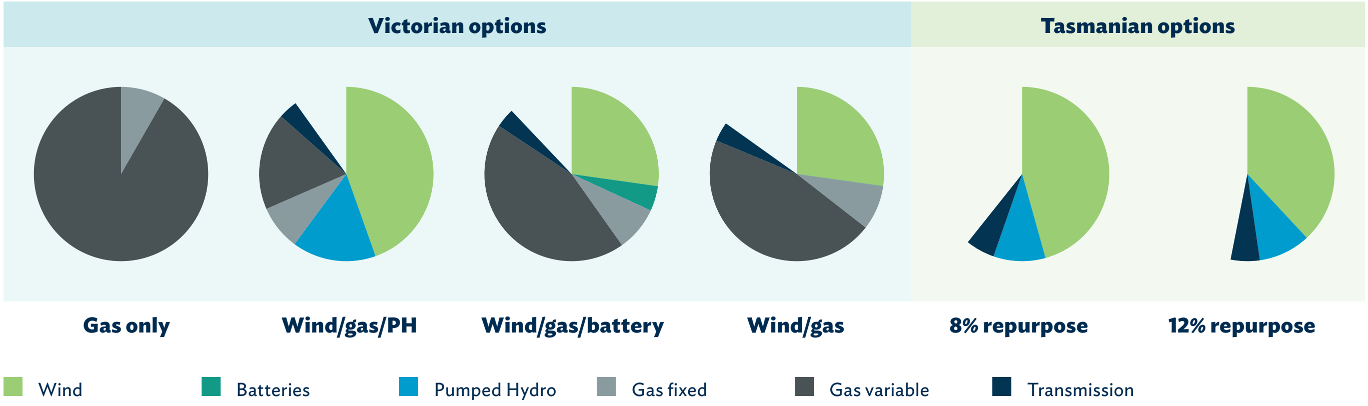


Figure 9. Comparison of options based on cost stack

There is optionality in both scalability and timing for pumped hydro, wind development and interconnection options that could occur in Tasmania. This makes Tasmanian infrastructure choices robust to a range of potential futures, bringing benefits to both Tasmanian and mainland customers.

Tasmania can further leverage existing hydropower assets by investing in a number of new pumped hydro storages to optimise the Tasmanian hydropower system to provide critical system balancing services to the NEM. The discrete nature of these opportunities, shown in Figure 10, also means that the program can be structured to provide substantial optionality around timing and scale of construction.

Development of pumped hydro and wind farms in Tasmania could be strategically sequenced to align with development of additional interconnection; yet, given the scale of the vision, the actual 'building blocks' allow careful management of investment risk.

As significant investment will be required across the whole NEM, Tasmanian development can be adapted to work within nationally coordinated market planning to manage the risk of asset stranding. Investment decisions on new interconnection can be timed to align with retirement of coal-fired generation, which in turn will trigger further Tasmanian wind and hydropower investment.

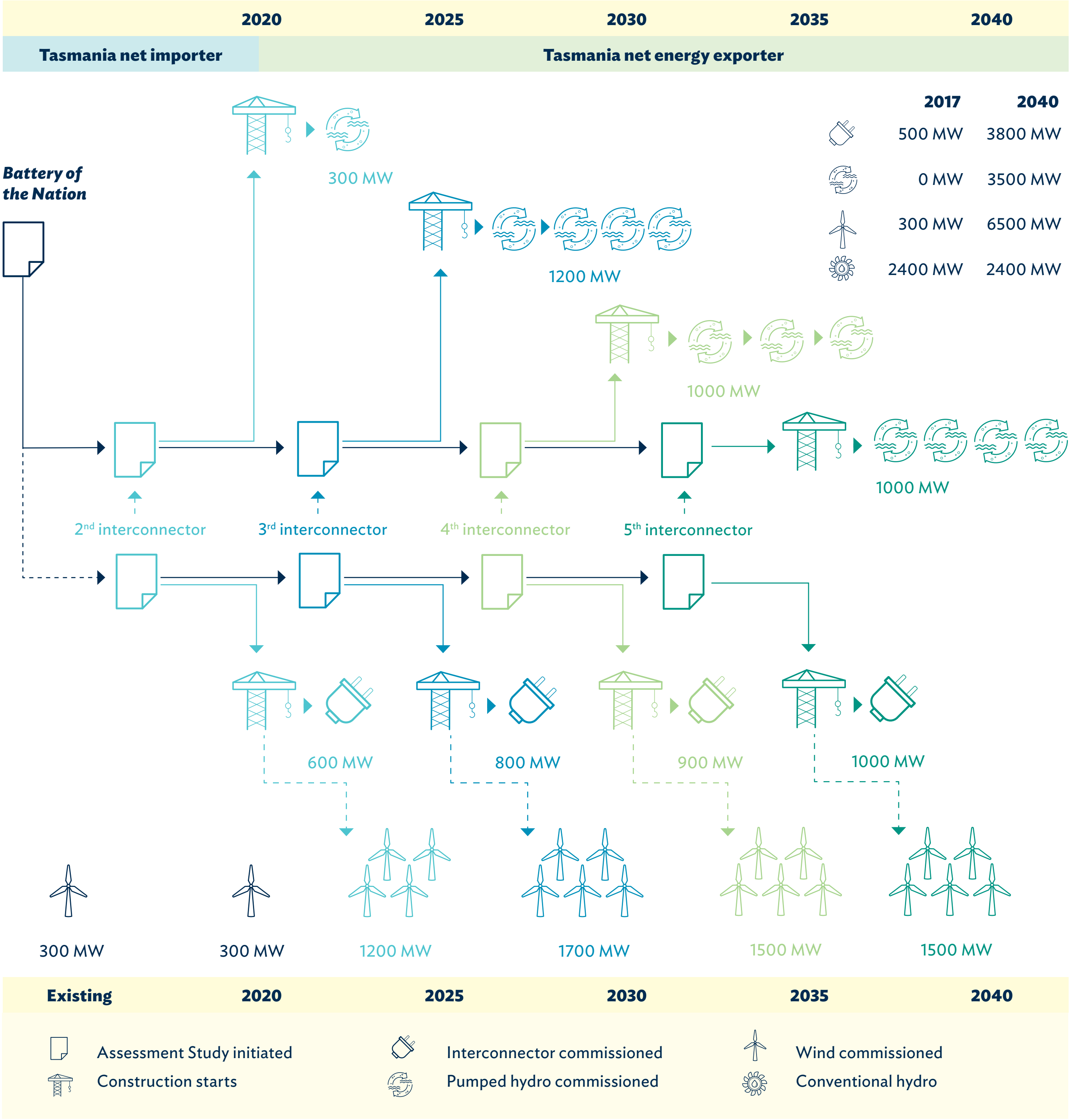


Figure 10. Demonstrative timeline of the optionality of future Tasmanian energy system investment

Key finding – national planning alignment

The opportunity aligns with AEMO's current integrated system planning (ISP) and delivers on all identified benefits of a renewable energy zone (REZ) in that plan.

The Tasmanian power system has the potential to unlock greater value from existing hydropower assets to deliver a new source of low-cost reliable energy supply to the NEM. During the course of this Future State NEM analysis, the concepts of renewable energy zones and AEMO's Integrated System Plan have emerged. It is possible that the analysis in this report could act as the first step in identifying Tasmania as an opportunity to develop a significant REZ.

The Tasmanian development opportunity strongly supports all three requirements of the energy trilemma in one coordinated system solution. The mix of technologies is environmentally sustainable and has substantial flexibility that will work towards meeting system security needs.

Developments proposed by *Battery of the Nation* deliver on all identified benefits of a REZ:

- Achievement of reliable and secure energy supply at least cost to consumers by:
  - Leveraging economies of scale for generation, storage and efficient use of both new and existing transmission using synergistic technologies.
  - Improving the national diversity of variable renewable energy through the addition of Tasmanian wind energy, reducing the need for storage.
  - Delivering substantial access to the highest quality wind resource in the NEM.
- An opportunity that is modular in nature and can be scaled to the size of the economic opportunity enabling progressive investment.
- The ability to adapt timing and build outs to work within nationally coordinated planning to manage the risk of asset stranding through flexible optionality.

To extract the potential value from Tasmania's natural advantages, substantial and timely interconnection to mainland Australia will be required. The Australian Renewable Energy Agency (ARENA) and the Tasmanian Government announced support for a business case study of a second interconnector in late 2017, a critical milestone for *Battery of the Nation*.

The CSIRO Low Emissions Technology Roadmap [CSIRO 2017a] found that electricity sector emissions may need to reduce by 52–70% by 2030 and 90% by 2050 to meet the national target of 26–28% by 2030 and 70% by 2050. In the recent Integrated System Plan produced by AEMO a 'fast change' scenario is proposed based on the low end of these targets. While this analysis has not modelled a fast change scenario, *Battery of the Nation* would be consistent with achieving more ambitious reduction targets.

Tasmania has scalable options which provide optionality to fit a range of scenarios based on different levels of interconnection.

Tasmania has scalable options which provide optionality to fit a range of scenarios based on different levels of interconnection.

Key finding – addressing the energy trilemma

The modelling is showing positive impacts on the sustainability and equity (affordability) elements of the energy trilemma.

The modelling is based on comparison of multiple scenarios using consistent assumptions to explore the value of the Tasmanian development options. The 'NoTasDev' (no further energy developments in Tasmania beyond Cattle Hill and Granville Harbour wind farms) situation provides a basis for comparison in which substantial variable renewable energy is largely firmed and balanced by open cycle gas turbines generation.

The largest scale scenario for *Battery of the Nation* was compared against 'NoTasDev' and found to substantially reduce the reliance on open cycle gas turbine generation. This resulted in potential reductions to generation weighted NEM-wide resource cost of energy (analogous to spot price) by 20%, Victorian resource costs by 30% and Tasmanian resource costs by 50%, see Figure 11. Concurrent with the savings, CO_2-equivalent emissions reduced by up to nine million tonnes per year during the later stages of the development.

More diverse generation combined with system balancing solutions, such as those offered by *Battery of the Nation*, will also continue to add value beyond the end of the period modelled.

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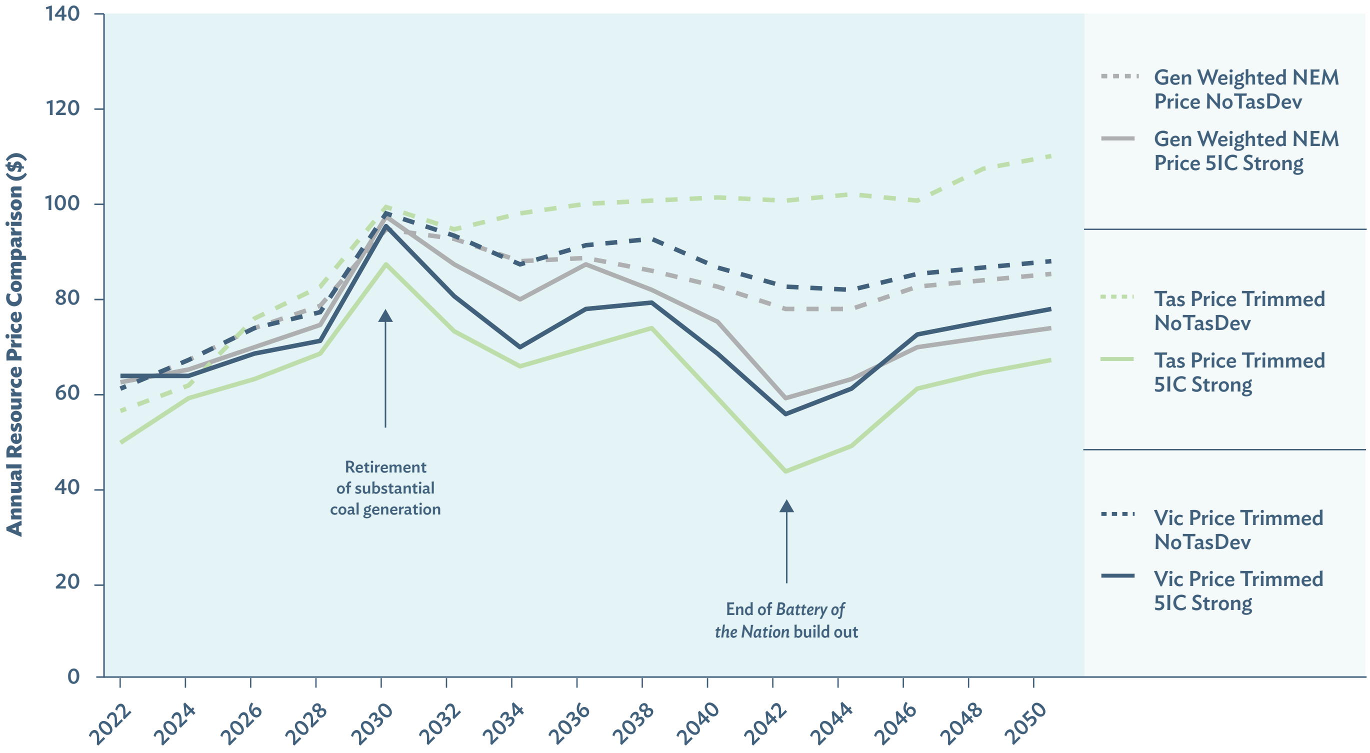


Figure 11. Comparison of NEM annual resource costs translated to market price

A future market design will need to value a variety of system services that will recognise the value of inertia, flexibility and ability to rapidly change output, alongside the existing energy and ancillary services.

Broader market findings

In the future NEM, the definition of 'peak' and 'off-peak' will change.

The modelling shows that the familiar peak versus off-peak paradigm will shift, and even invert, on a national scale. The new 'peak value' and 'off-peak value' times will be defined by generation scarcity or abundance (rather than the level of demand).

The modelling shows that by 2035 there may be sufficient residential solar that the daily average minimum net national demand will occur at midday (and this will be even more pronounced in certain regions). Wind energy will also have a substantial impact on the system resulting in extended periods of surplus or scarce energy generation. This will likely erode the relevance of baseload generation as responsiveness becomes valued more than efficiency.

The modelling is underpinned by the operation of the existing market (based on the concept of short run marginal cost) and what would be considered feasible within that paradigm. The future market will need to provide market signals for new system management services, such as storage and rapid response generation, to make best use of the available energy and manage a system that has redefined concepts of peak and off-peak.

Realising the full value of energy storage is difficult in the context of the current NEM.

A study by the Rocky Mountain Institute [RMI 2015] collated a series of results from earlier studies showing up to 13 different value streams. Attempts to assign direct value to storage in Australia typically only recognise energy arbitrage value (since frequency control ancillary services (FCAS) markets are not presently considered bankable).

The Future State NEM analysis modelling has found that storage reduces the cost of energy in the NEM and is qualitatively understood to provide critical system reliability services.

A future market design will need to value a variety of system services that will recognise the value of inertia, flexibility and the ability to rapidly change output, alongside the existing energy and ancillary services.

Storage is not simply a generator that buys its 'fuel' from the same market it sells into; acknowledging the value of its other services, including dispatchable load to help manage excess generation, will better optimise the potential benefits of this technology for the broader operations of the NEM.

Storage provides a variety of services, all of which have value, and should not be simply seen as a 'generator' within the system. This oversimplifies the value proposition of storage, which should be treated as a provider of system services.

> *The future market will need to provide market signals for new system management services, such as storage and rapid response generation, to make best use of the available energy and manage a system that has redefined concepts of peak and off-peak.*

Not all storage is equal.

Storage is typically priced on a $/kWh or $/MWh basis, with the implicit assumption of one-hour duration. Figure 12 shows a cost comparison of the two main storage technologies being considered in the Australian market, over a lifespan of 40 years based on Electricity Generation Technology Cost Projections [CSIRO 2017b], the same source that AEMO is using for the Integrated System Plan.

The figure shows that batteries are already cost competitive for single-hour storage, and will be roughly competitive for four-hour storage by 2050. Longer duration batteries are not cost competitive against identified pumped hydro energy storage opportunities. For longer storage requirements, pumped hydro will be the main viable option.

It is important to note that the cost and storage size of the pumped hydro opportunities are influenced more by geography and hydrology than electrical or mechanical plant costs.

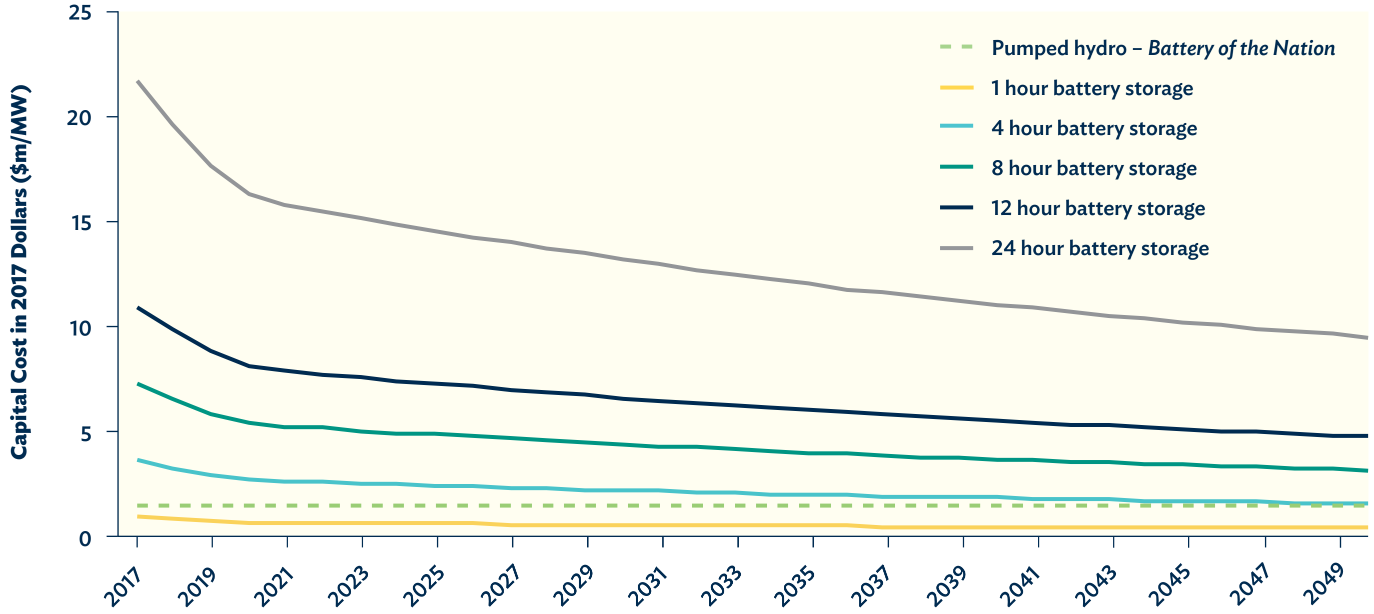


Figure 12. Capital costs for 40-year storage assets (future expenditure recognised, discounted at 7.5%)

The modelling showed that longer duration storages will be effective for system reliability. Even the largest storages were found to be fully operated and have value in the extremes of their operating range. Figure 13 shows a snapshot of the modelled operations for storages of different sizes. Each storage contributes to system reliability across different timescales.

Figure 13 highlights that solar-dominant states are likely to be well-served by storages that can capture energy over a six-to-eight hour period: storing energy during the daylight hours, and supplying energy during the night hours. States with substantial wind penetration (such as Tasmania, Victoria and South Australia) will need storage capable of storing days of excess generation and supplying energy to support the system during days of relatively low wind generation. The larger storages can (and do) store for longer and supply for longer – showing very different operational characteristics.

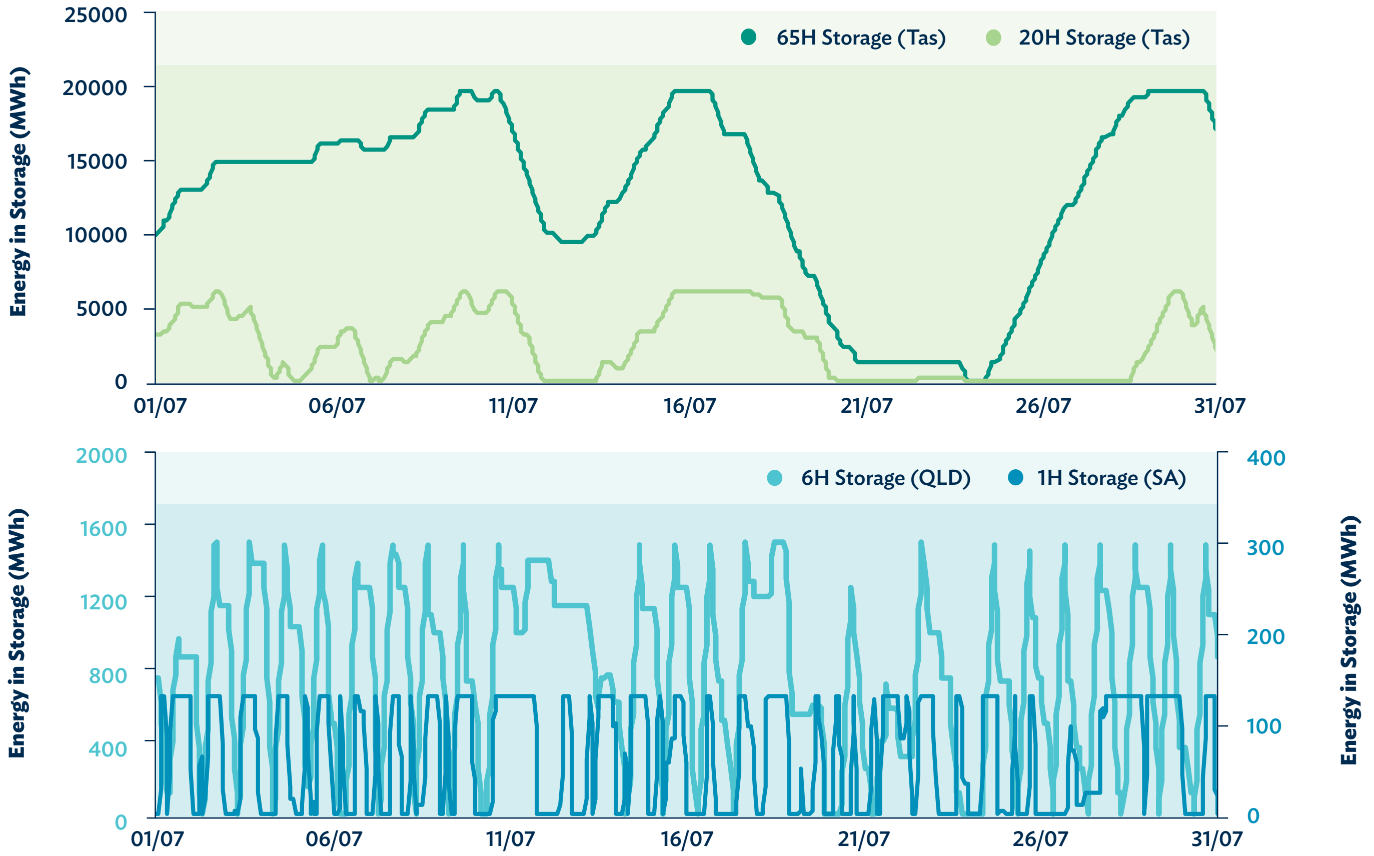
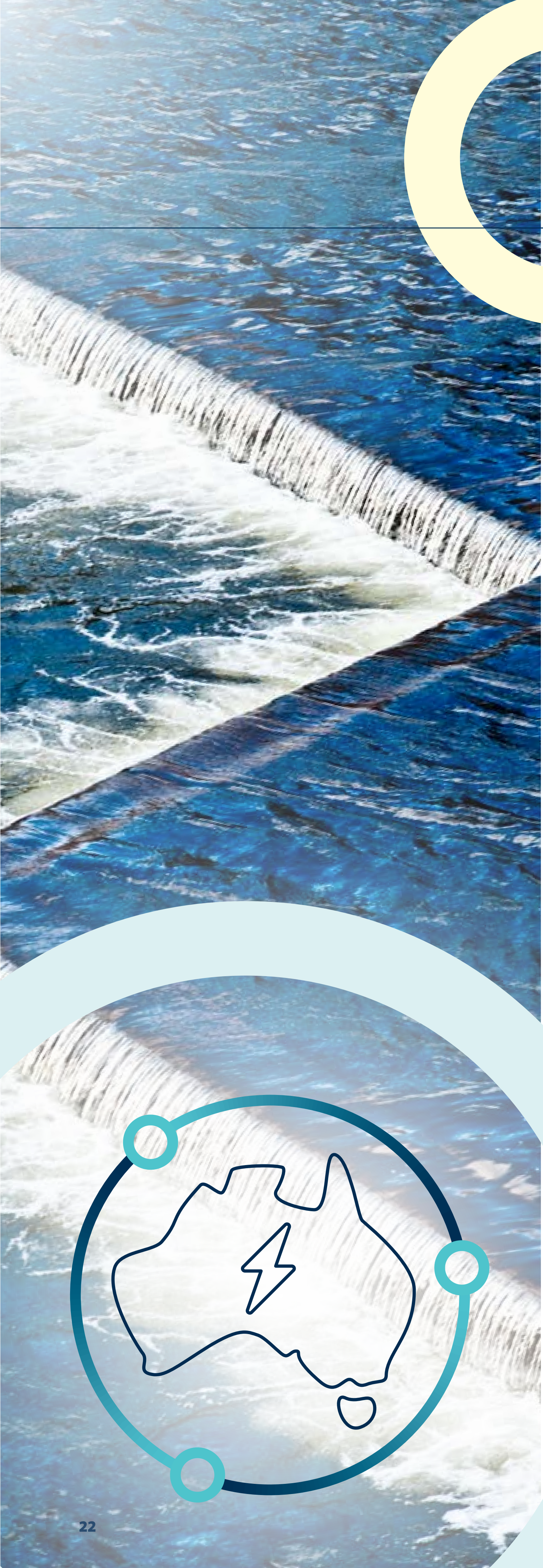


Figure 13. Sample month showing the contrast between storages of different duration


CO2



Next steps

Timing is critical.

The *Battery of the Nation* development options provide a clear pathway to better system security, improved affordability and increased sustainability. While Tasmania has a number of substantial advantages, this opportunity is bound by time due to the long term nature of the investment planning and construction cycle. Retiring coal generation will need to be replaced over the next two decades and without careful and proactive planning, it will become difficult to displace operators and technologies that opportunistically fill the gap at greater long term cost to the market.

No single solution can meet the scale of the challenge facing the NEM.

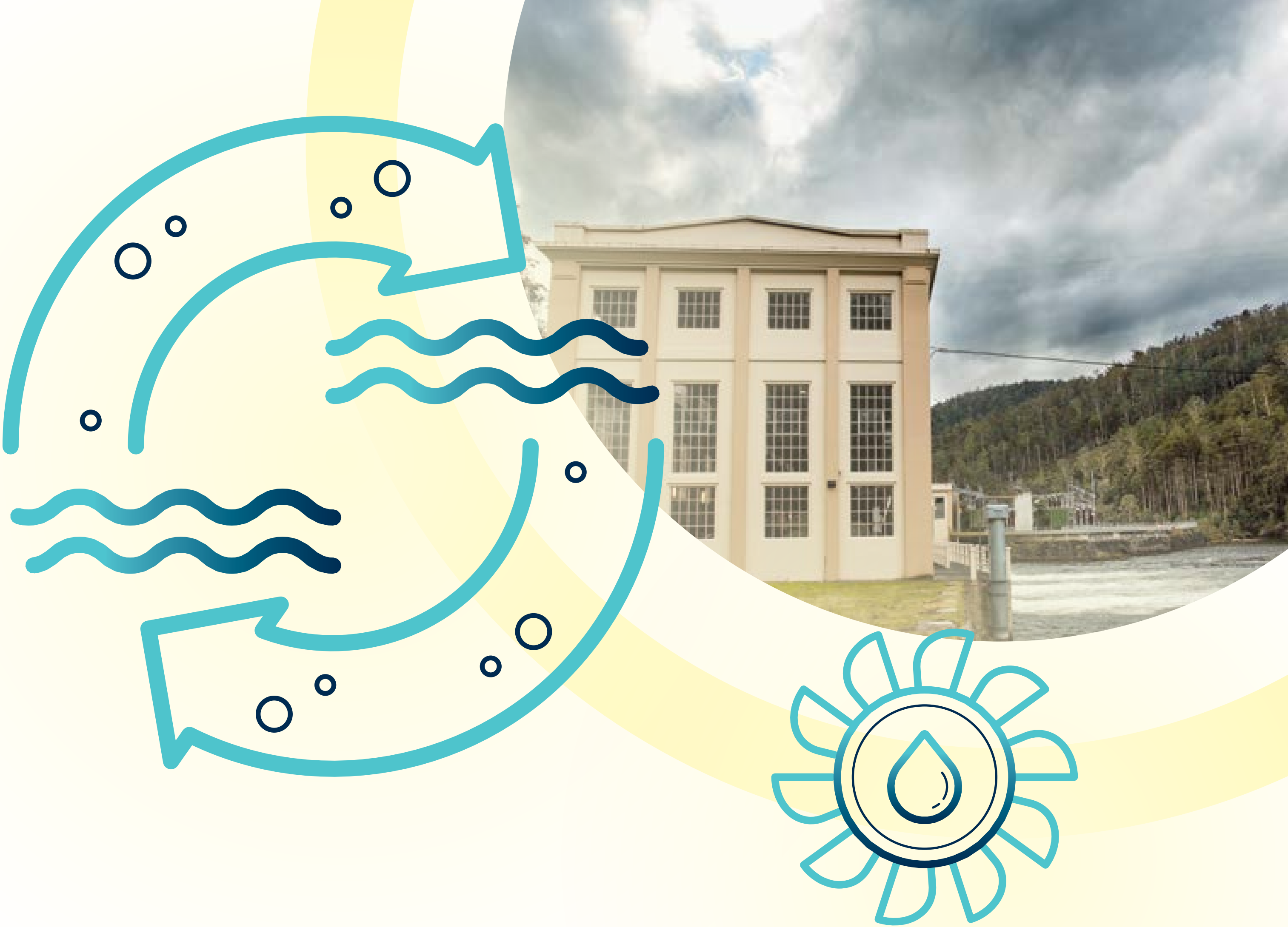
A range of technologies have a variety of strengths, and, if judiciously planned and incentivised, these strengths can be coordinated to best solve the energy trilemma in the national interest. The use of a combination of options is likely to result in an efficient outcome, with the ability to ramp-up investment in a strategically managed transition.

Reacting only to short term investment triggers will likely lead to suboptimal solutions driven by first-mover advantage. This could result in missed system opportunities and ultimately mean that Australia's energy economy is uncompetitive.

Similarly, investment without both economic and timing optionality can be ineffective as well. The ability to plan, bundle and fast-track efficient options for long term outcomes will better optimise Australia's national electricity system.

Energy security is a national issue built on a legacy of state-based assets and jurisdictions.

The accountability for energy security at a jurisdictional level is a strong influence in decision making. Controlling individual accountabilities is understandable, yet this will reduce the cross-regional optimisation from leveraging Australia's national resources and diversity of energy sources. All state jurisdictions have a major role to play to drive the new required development – collaboration and cooperation will be key to national success.



Next stage of the analysis

This report is the first stage of this investigation. During this first phase, a number of simplifications and assumptions were made due to the complex nature of the work. Further work is required to refine this analysis and understand the interplay between the Tasmanian development opportunities and likely mainland developments. Additional modelling will be required to further test sensitivities and assumptions and to improve optimisation against future market constructs. This will include supporting further assessment of the Tasmanian pumped hydro and existing hydropower opportunities.

The following themes will be further examined as part of the second phase of the Future State NEM analysis. Some elements may be undertaken as part of a coordinated national effort.

- ***Requirements for storage***

  In the modelling to date, the size of storage required is not yet optimised. Two characteristics need to be balanced in terms of storage – capacity and duration. Capacity is frequently discussed and understood in order to make storage work like generation – but duration is critical for system reliability and reserves. Industry reports suggest an extremely wide variety of answers to these questions, highlighting the uncertainty of the optimisation.

  To date, *Battery of the Nation* has established that its cost-effective pumped hydro energy storage will be competitive as part of a value-stacked renewable energy zone, but the national need for storage (and even the best size for individual projects) needs further analysis.

- ***Impacts on individual hydropower storages***

  The first stage of this analysis undertook high-level investigations of the impacts to Hydro Tasmania's existing hydropower schemes. Further study will be required by Hydro Tasmania to better understand site-specific interactions.

- ***Greater understanding of the required services and markets in the future electricity system***

  Better understanding of the physical services that the market requires, and the markets that will support the delivery of those services, is necessary. The interdependency of the underlying time series (demand, price, wind, solar, water/rain, storage etc.) makes this a complex issue to address. The services must support the physical operations of the system and the markets must allow for both price signals and risk management/hedging. The introduction of five minute settlements may further affect the services or the availability of those services.

- ***Management of an energy system with a high proportion of generation with $0 fuel costs***

  As the penetration increases of technologies with near-zero 'fuel' costs, new challenges arise in terms of capital investment planning since the 'floor-setting' short run marginal cost is essentially $0.

- ***Imperfect foresight***

  Most power system market models assume participants have perfect foresight over a certain time period. This assumption allows optimisation of the use of plant – storing energy at the lowest possible prices and supplying energy at the highest possible prices to maximise system value. However, with imperfect foresight, longer duration storages will have additional value, demonstrated in Figure 14. This element needs further examination.

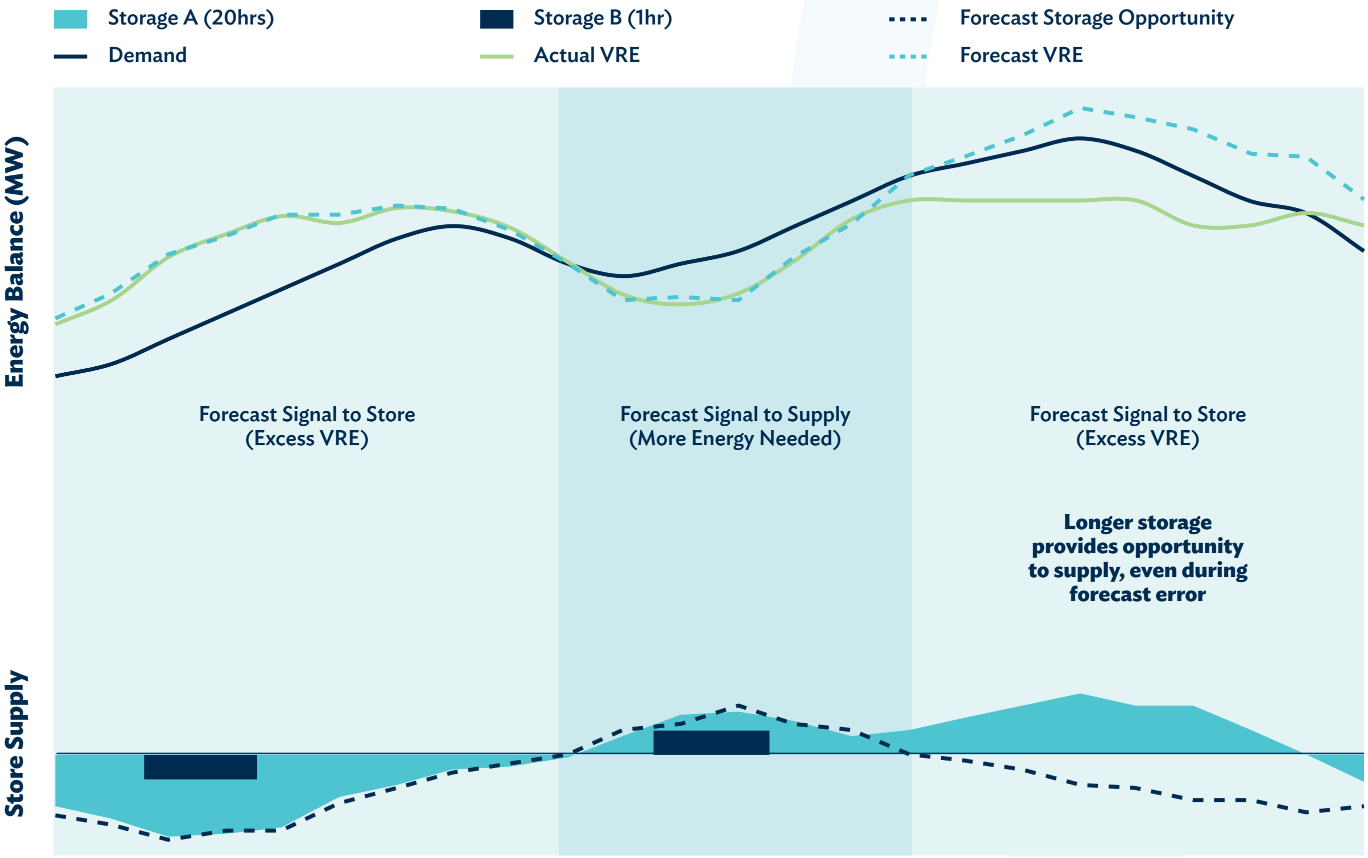


Figure 14. The impact of imperfect forecasts on storages of different size

- ***Valuation of the full set of services from High Voltage Direct Current (HVDC)***

  The full capabilities of latest HVDC transmission technology needs to be understood in the context of the services it can enable in the future market. This will impact the cost benefit analysis for studies of further interconnection between Victoria and Tasmania.

This report is only the first stage of the investigation. To better understand the case for a larger Tasmanian role in a future NEM, the analysis will continue to be developed from stage 1 (model, assumptions and scenarios) to define a clear case for Tasmania as a high priority renewable energy zone.

The formal assessment for the second Bass Strait interconnector has already commenced, which is a critical step on this journey and one that will continue to be supported by Hydro Tasmania.

Hydro Tasmania will continue to collaborate with the industry in working through some of the challenges that face the industry more broadly in this market transformation.

Contents – Body of Report

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2.0

Analysing the future National Electricity Market (NEM)

Australia's NEM is facing a period of significant change and the future NEM is expected to bear little resemblance to the past. Thermal generation will be progressively replaced by variable renewable energy from wind and solar, the low cost energy sources of the future, and new services will be required to help manage the system.

2.1 Mapping a way forward

Australia's NEM is facing a period of significant change and the future NEM is expected to bear little resemblance to the past.

Ageing coal generation will retire due to age-related deterioration and competitive pressures. The thermal generation will be progressively replaced by variable renewable energy from wind and solar, the low cost energy sources of the future. With increasing penetration of variable energy sources, the market will change.

Energy services that help manage the reliability and security of the system will become far more valuable and new services that can recover excess generation and shift bulk energy to times of relative energy scarcity will become critical.

In April 2017, the Federal and State Governments announced support for Hydro Tasmania to conduct studies into boosting Tasmania's clean energy capacity within the context of the future NEM.

The *Battery of the Nation* initiative is now investigating and mapping out future development opportunities for Tasmania to make a bigger contribution to a future NEM.

The initiative is creating a blueprint for how Tasmania's renewable resources could be developed over coming decades to deliver reliable energy supply at least cost, benefitting Tasmania and the mainland states.

The streams of work are:

- identification of pumped hydro opportunities
- detailed development of specific augmentations to existing Tasmanian hydropower schemes
- undertaking a NEM system-wide analysis, known as Future State NEM analysis.

This report covers the Future State NEM analysis stream of work. Separate reports will be available detailing the specific findings of the other streams of work.

The *Battery of the Nation* initiative consists of four competitive fundamentals:

- repurposing existing hydropower plant,
- high quality and diverse wind,
- short-distance transmission, and
- cost-effective pumped hydro energy storage.

More interconnection, wind development and investment in new hydropower assets in Tasmania, offers economies of scale, diversity and quality of new renewable energy resources combined with large scale storage that is able to be built with economic and timing optionality.

The Future State NEM analysis models a number of scenarios which are a subset from the range of possible futures. The underlying fundamentals of the *Battery of the Nation* scenarios are based on the reality of the physical change occurring in the Australian energy system. The physical changes indicate that the market must undergo a transformation and trying to maintain a static business-as-usual posture is unlikely to be optimal, and potentially not even possible.

There is an opportunity for Tasmania to play a major role in this energy transformation, take advantage of the changing market and leverage the state's natural advantages.

2.2 Report structure

The Executive Summary is intended to present the outcomes and provide a contextual understanding of the analysis. The bulk of the evidence behind the views, assertions and outcomes are held in the body of the report.

The body of the report is structured to commence with the problem statement, highlighting the challenges facing Australia’s NEM in Section 3.0. It provides context of the present state of the NEM, focussing on the generation assets, followed by historical context on how this developed to better understand how these challenges may be addressed.

Some of the relevant studies are commented upon, including reference to similar international initiatives. Some of the challenges with policy uncertainty are briefly discussed before concluding with a case for action.

Section 4.0 provides a description of the approach to the analysis. This is intended to provide perspective on the methodology adopted, including the necessary assumptions and simplifications, to manage the scale and complexity of this work.

The outcomes and findings are presented in Section 5.0, *Battery of the Nation provides a credible opportunity*; this section makes up the bulk of the content in the report. This includes outcomes from dispatch modelling, wind modelling, pumped hydro studies, system-wide environmental reviews, transmission analysis and the interplay and costing of the various components. It is structured to answer the three aspects of the energy trilemma.

The report is then concluded with a summary of opportunities, risks and sensitivities including the next steps to be able to progress this initiative and undertake the work to develop this keystone initiative in the transformation of Australia’s National Electricity Market.

The appendices include a glossary, references and some other detailed technical information that was used as inputs to the rest of the analysis.

3.0

Challenges facing Australia’s National Electricity Market

Australia is facing a mass retirement of major energy infrastructure. This scale of retirement is unlike anything that Australia has faced before. Replacing this infrastructure will require a substantial response on a national scale.

Australia is facing a mass retirement of major energy infrastructure.

During the 1970s and 1980s, the various state governments undertook substantial infrastructure building initiatives and fundamentally built the energy system that we benefit from today, see Figure 15. This legacy of large and valuable infrastructure has also created a problem due to a large number of similarly aged assets that are all approaching technical end of life.

3.1 Current market context

The NEM is facing a period of significant change as ageing coal generation infrastructure retires and is replaced by variable renewable energy generation sources with completely different operating characteristics. The new variable generation will then need to be firmed by dispatchable (i.e. controllable) storage and generation.

Energy services that help manage the reliability and security of the system will become far more valuable and new markets for new or undervalued services will need to be defined to incentivise the necessary investments. New services that can capture excess generation and shift bulk energy to times of relative energy scarcity will become critical in terms of both system reliability and affordability.

The future NEM is expected to bear little resemblance to the historic operations of the NEM and work is required to understand Australia’s future options.

Since joining the NEM in 2006, Tasmania has played a relatively minor role. In the changing landscape of the energy market, there is scope for Tasmania to make a much more substantial contribution to the energy security, cost-effectiveness and sustainability of the NEM.

Battery of the Nation explores the viability of leveraging Tasmania’s natural advantages to produce more reliable and cost effective national energy in a rapidly changing market.

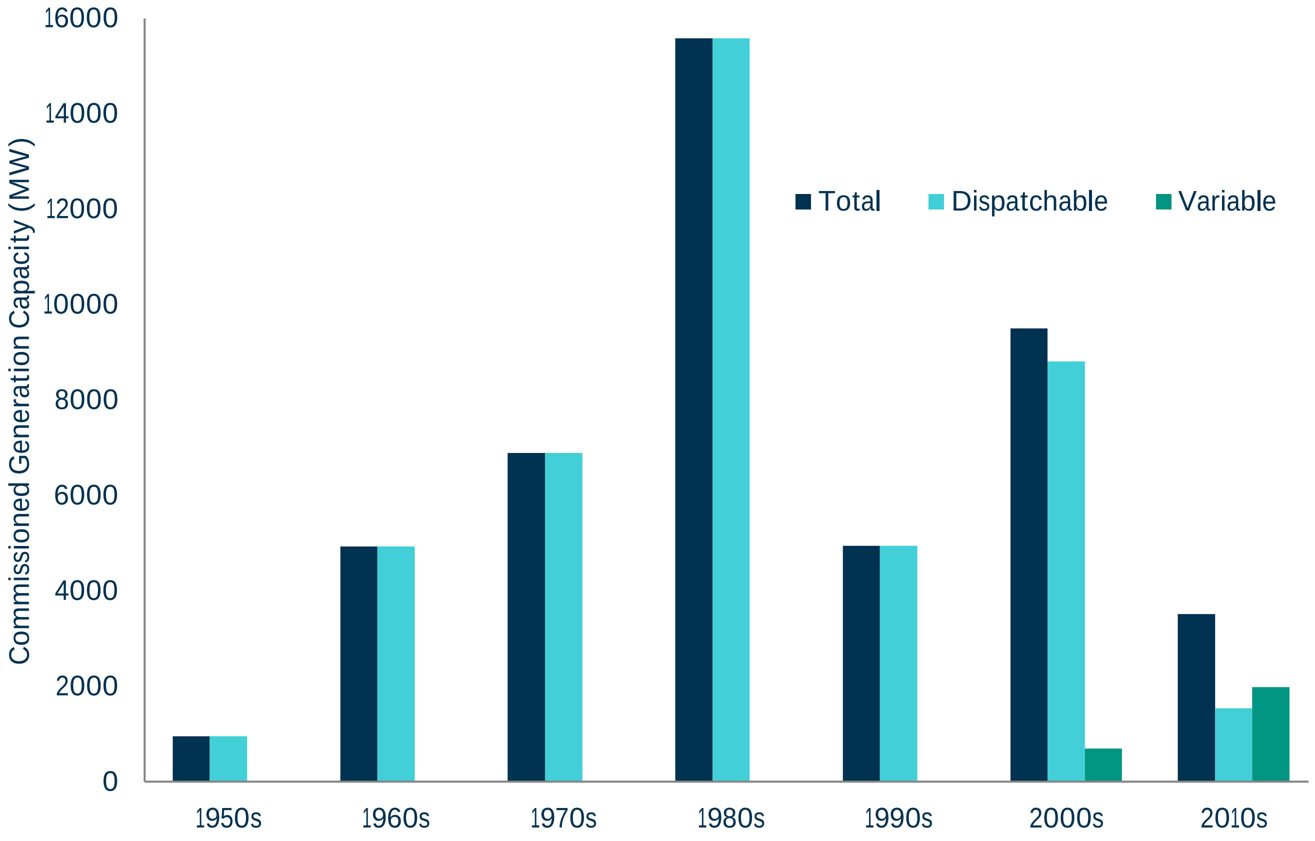

Figure 15. Newly commissioned generation plant by decade

	Coal	CCGT	OCGT	Gas Other	Solar*	Wind	Water	Biomass	Storage	Other
■ Withdrawn	-1600	-62								
■ Proposed		500	2950		12735	16956	4784	214	110	1758
■ Announced Withdrawal	2000	208	34	30						
■ Committed	78		4		1812	1867	4	31	2	29
■ Existing Less Announced Withdrawal	20916	2805	6400	2129	323	4462	7941	579	100	142

** Excluding rooftop PV*

Figure 16. Existing NEM installed capacity – data sourced from AEMO's "Generation Information Page" [AEMO 2017]

3.1.1 Ageing assets across the nation

Approximately 65% of Australia's energy fleet is already at or beyond its half-life, and may even be forced to retire earlier.

Moreover, by 2040 approximately half of the existing generation infrastructure in the NEM is expected to have been decommissioned, more if considering the relative percentage of energy generated by these assets.

> *Approximately 65% of Australia's energy fleet is already at or beyond its half-life, and may even be forced to retire earlier.*

The NEM is dominated by coal fired generation as shown in Figure 16. The comparison on the basis of capacity understates the dominance of coal; in terms of total energy over 70% of all electricity in NEM is generated from coal. Figure 16 also shows that large thermal generation (coal and combined cycle gas turbines) are exiting the market while wind and solar are both signalling substantial growth.

From Figure 16 it can be seen that the flexible generation sources, hydropower and open cycle gas turbines, are actively proposing further developments although have made no actual commitments to date.

It is relevant to note that these trends are also reflected in the modelling presented in the "Independent Review into the Future Security of the National Electricity Market" [Finkel 2017].

The coal plant built in the late 1970s and early 1980s are approaching retirement. It is forecast that in the ten years from 2028 to 2037 about 35% of our existing generation capacity will retire simply due to age-related deterioration. This would be equivalent to last year's Hazelwood Power Station retirement occurring every year for a decade.

Figure 17 shows a conservative retirement schedule for in generation assets in Australia based purely on age.

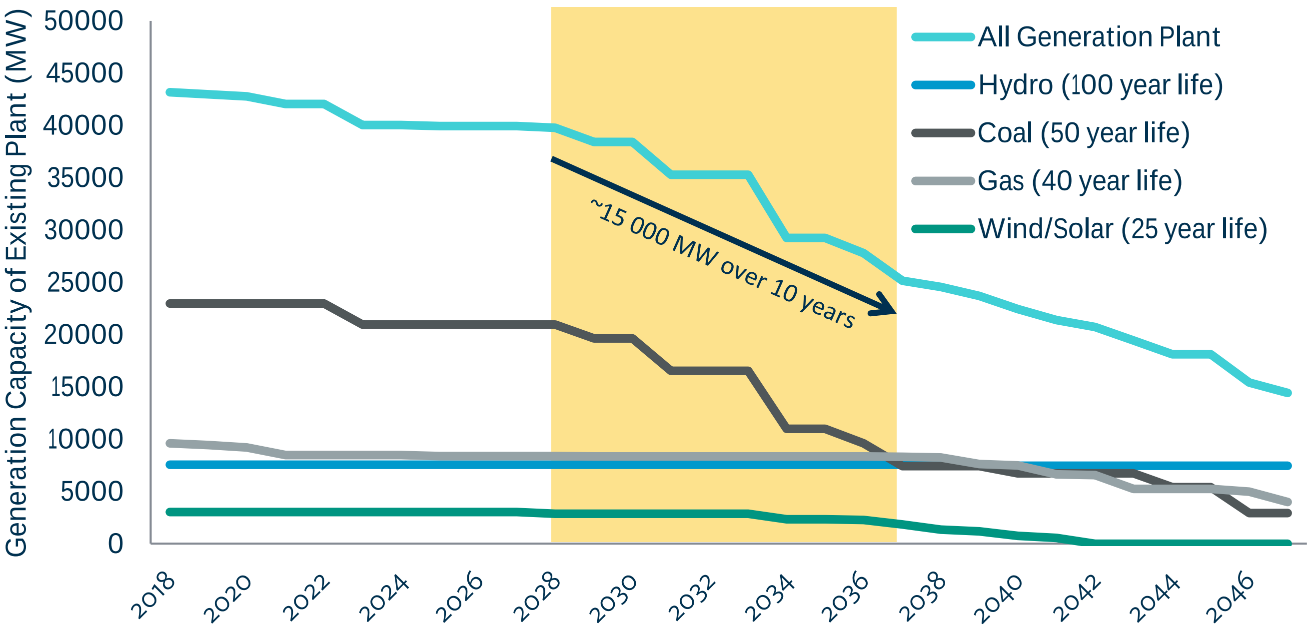

Figure 17. Expected retirement profile of existing generation assets in the NEM (based on life expectancy). As older plant retire, new generation capacity will be required

Examining Figure 17 more closely highlights that there is relatively little change until approximately 2030. This adds particular context to the graphic since the Liddell coal-fired power station is substantially larger than Hazelwood and is due to retire in the early 2020s.

However, as the start of a decade, 2030 is frequently used as a milestone for assessment. Unfortunately, the relative composition of the NEM at this time is likely to be misleading; 2030 is at the precipice of a rapid change in the supply mix.

When Hazelwood power station announced in late 2016 that it would close at the end of quarter one in 2017, there was an immediate increase in the forward contract market.

It is difficult to estimate the size of the impact as it occurred during a time of rising policy uncertainty, increasing gas prices, and other real and potential market changes, yet there is no doubt that Hazelwood alone had a significant and ongoing impact on wholesale prices, particularly in Victoria.

Using 2030 to understand the mix of generation is likely to be misleading as it is the start of a rapid change.

The nature of the resource scarcity also means that the second withdrawal has more impact than the first and third more again, etcetera. As far as the overall market is concerned, the impacts can be much more widely felt than just the owner of the withdrawn plant.

If the energy required to replace the withdrawn plant is not available in the same region, there may be large changes to interconnector flows.

Regions that had been net exporters of energy can become net importers. There can also be large impacts to transmission network utilisation, ancillary services, and system stability.

It should be noted that with different assumptions it is possible to arrive at substantially different retirement forecasts; some show reinvestment in existing plant to extend their operating lives and others show faster retirements based on economic viability and relative wear and tear in addition to age.

For a portfolio of generation plant, the closure of individual stations can actually result in a net increase in overall revenue to the controlling entity.

If the revenue gained from the increase in wholesale prices exceeds the revenue lost from closing the plant (and no longer being paid for that plant's output) then the economically rational decision is to close the plant. This could drive a faster retirement schedule.

Regardless of the approach used, there will be a need for major investment in the energy sector over the foreseeable horizon and this is likely to transform the energy sector.

This is truly a national challenge. Tasmania and Queensland are likely to be least affected due to the life expectancy of their existing generation assets. While these regions are at the edges of the NEM, they are also the most secure in the future NEM. Australia would benefit from more interconnection to these regions to achieve a stronger national energy platform.

This is a national challenge. There will be a need for major investment in the energy sector and this is likely to transform the energy sector.

By contrast, the two most central regions, New South Wales and Victoria, are also the two states most heavily affected by coal retirements in coming decades.

Insufficient dispatchable energy capacity and storage options may result in unserved energy. The estimated national cost of unserved energy (known as the Value of Customer Reliability) has been estimated at $26 000 MW/h in 2015 [AEMO 2015]. The cost of energy supply failure is simply too high to accept.

Regular coal withdrawals, and potentially more pressure on gas supplies, necessitates that significant proactive investment in new generation infrastructure will be needed for the foreseeable future.

The scale of this change will require a combined response from a variety of technologies and proponents.

3.1.2 Historical legacies

Today's power system has evolved over time and is built on the historical legacies of prior investments. Early generation assets were developed based on close proximity to fuel sources (coal or water) and local load centres.

Originally the generators were really dedicated to serving single populations or industrial loads. However, each of these isolated systems needed to supply its own reserves to guarantee security and reliability of supply. This was expensive and inefficient.

These early generators and load centres were then connected to share resources and reserves, and to develop economies of scale.

This in turn opened possibilities for generation or loads to develop more broadly to utilise the transmission and matured into the regions that comprise the NEM today.

Each state had the clear jurisdictional accountability for security of supply and consequently most regions invested in their own generation to be able to be self-sufficient.

The core generation assets in these systems were proactively built through government investment[1] to create utilities for public good and the economy. The regions were interconnected to share reserves and reduce supply costs.

Since the first interconnection between Victoria and NSW via the Snowy scheme, all states in the NEM are now interconnected allowing sharing of the market benefits based on differences in capital costs, fuel costs, fixed and variable operations and maintenance costs, emission costs and costs of unreliability.

However the reliability and scale of the interconnection arrangement varies; even today the regions are fairly lightly connected – much like the early isolated generators and load centres.

The state-aligned accountabilities strongly influence current behaviour and under the present system each state must first look to meet their obligations before sharing any surplus resources or saving by importing cheaper energy.

The earlier days of the Australia power system have created a legacy that needs to be considered. National optimisation and state-based planning can be in conflict.

The Regulated Investment Test - Transmission (RIT-T) struggles to fully assess the benefits of large and high cost projects, especially with regard to opening new energy options and also introduces delays while the test is thoroughly undertaken.

This is especially notable for the modelled benefits of interconnectors that are often identified in regions that are not directly coupled to the physical link; however, the interconnector cost allocation is mostly limited to interconnecting regions only.

Historically, these costs have also been split evenly between the two states, which rarely reflect the assigned benefits. It should be noted that there are also other benefits in building major infrastructure, such as local employment, that influences location of new resources according to benefits that are external to the operations of the power system.

As retirements occur in the existing fleet and the generation mix changes, other factors may become critical in the decision on location of new development. With the increasing dominance of weather-driven renewables, there will be increasing benefit to the maximisation of diversity between resources. This will in turn drive the development of cost-effective renewable energy zones to unlock new opportunities.

More broadly, there will be an ongoing need to utilise the cheapest resources, including gas options with associated pipeline networks. Frequently, the cheapest resource may in fact be simply sharing reserves; increased resource sharing will better protect against failures and unforeseen circumstances, especially as the average age of dispatchable generation continues to rise and the individual reliability of the plant reduces.

Similarly, there will also be an ongoing need for deployment of flexible technologies which are able to respond quickly to rapidly changing imbalance in the NEM.

There is a legacy from the early days of the development of the Australian power system, yet there is also an opportunity to address these issues and transform Australia's power system to suit future energy needs.

3.2 A changing market

The future NEM is expected to be vastly different to today. As the ageing assets retire, they are likely to be replaced by new energy sources with very different characteristics.

The low cost options for new energy generators are expected to be wind farms and solar photovoltaics, characterised as variable renewable energy sources. However, these are not necessarily available when needed which means that they need support from dispatchable generation or storage.

The low cost options for new energy generators are expected to be wind farms and solar photovoltaics.

Future projections, supported by *Battery of the Nation* modelling results, highlight that baseload generation will lose relevance as the market become driven by periods of generation excess and deficit.

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[1] Some of these utilities were later sold to free up capital for reinvestment. The key point is that the investments were made and the sales only occurred once the core infrastructure that underpins cost-effective economies and standards of living were established.

The NEM was designed to optimise the use of coal plant, the dominant technology in Australia providing well above 70% of the total energy demand. This produced efficient operations and low cost energy.

However, coal generation is not attracting new investment and will increasingly lose market share as these plant retire and get replaced by different technologies.

The design that suited the power system in past years will lose effectiveness in coming years and is already showing signs of stress. The Health of the NEM Report by the Energy Security Board [ESB 2017] stated that it was “not in the best of health”.

> *Efficient use of flexible energy supply, such as hydropower, will help the market minimise capacity overbuild to manage these system variations.*

The start of this transformation has been challenging. The resultant disruptions have made Australia’s electricity supply a hot topic in the media. The debate has been driven by incidences of high prices, and a shortage of reliable generation causing black-outs and brown-outs (i.e. restrictions in available electric power).

Efficient use of flexible energy supply such as hydropower (traditional or new pumped hydro) will help the market minimise capacity overbuild to manage these system variations.

Given appropriate market settings and suitable network interconnection, they will greatly assist the market in finding the “least cost” solution to reliable power.

3.2.1 Increasing price of gas

Retirement of assets has put more pressure on the remaining assets in the market and pressure on the resource utilisation.

One significant change in the energy market has been the rise of domestic gas prices, largely as the result of the development of LPG export facilities in Australia.

There are significant flow-on effects of higher gas prices on the wholesale electricity market.

In the past there has been an argument that retiring coal plant will be replaced by combined cycle gas turbines which will continue to provide baseload energy without a significant increase in the wholesale price of electricity.

This is no longer a credible scenario without substantial changes in the domestic gas prices.

Exposure to international gas prices is likely to continue and substantial increase in reliance on gas may put further pressure on existing resources.

The rise in gas prices has also meant that mechanisms for decarbonising the NEM are also impacted.

Previous modelling showed that a moderate carbon price could have caused gas-fired generation to be cheaper than black coal, thus achieving reduced emissions by substituting lower-emissions gas for coal.

However, at higher gas prices much of this modelling does not hold. Higher gas prices have thus driven gas away from baseload provision and towards a role as flexible, but less frequent, generation in the NEM.

3.2.2 Liquidity of the wholesale market

An issue which has surfaced in recent years is the lack of wholesale market liquidity for forward contracts. The lack of liquidity is almost certainly due to two key factors:

- market power becoming more concentrated in fewer hands, particularly under the "gentailer" model of vertical integration; and
- policy uncertainty making some market participants less willing to lock-in prices in a rapidly changing market.

For smaller market participants, the lack of liquidity can pose a significant risk, as the inability to effectively hedge their position makes them financially vulnerable to short-term market shocks. This has also been exhibited by market reluctance to build any assets that are not backed by long-term power purchase agreements or their own retail book.

Market liquidity is typically a sign of health and the only solution to increase liquidity is a combination of policy certainty giving clear investments signals and regulations that ensure adequate competition in the wholesale market.

3.2.3 The value of capacity

"Cap contracts" set a maximum price that the purchaser will pay for a given volume of energy. They are a standard contract product used to manage potential price volatility in the wholesale market.

The value of a cap contract depends on the probability of occurrence of spot prices above the cap strike price – usually $300/MWh in the current market.

In a sense, a cap contract is like an insurance product – you pay a premium to ensure that you won't pay more than the contract strike price.

The cap contracts have historically been an indicator of the narrowness of the reserve margin for a given period and therefore a signal to investors that additional generating capacity may be required.

With an abundance of supply there is little expectation of high spot prices and consequently the cap price is lower. Conversely, if supply is tight there is an expectation of high spot prices and therefore the cap price is higher.

For this reason, cap contracts are also considered to be a proxy for the value of additional capacity in the market. The reasoning is that any additional (generation) capacity in the market could choose to generate only during periods of high spot prices, and thus obtain the equivalent value of a cap contract.

This does sometimes lead to confusion where "cap" refers to both a maximum [i.e. "capped"] price and a "capacity" value.

Historically, the actual cap price outcomes (the average of spot prices above the $300/MWh strike price) have been lower than the expected outcomes indicated by forward contract prices. This indicates that the contract market implicitly includes some amount of premium in the cap price.

It has also been understood that construction of new generating capacity would ease the supply/demand balance and reduce the cap value past that point in time.

This has led to the view that a high cap price is generally considered to be unsustainable in the long term due to basic market dynamics – a price signal drives new investment which then removes the underlying cause of the price signal.

However, under a changing energy mix where the low cost energy is not dispatchable and the lack of generation from such sources may in fact be the cause of the imbalance causing the high spot price, this logic does not necessarily hold.

The technologies that provide capacity are expected to be different to the technologies that provide the low cost energy and so do not compete in the same way.

In a future NEM with much higher volumes of wind and solar (variable renewable energy) there will be a much greater need for flexible generation; under this situation cap contracts may not be sufficient and there may be a need for an explicit capacity market in some form to provide a more accurate and reliable value for capacity.

There are many forms a capacity market could take – the Finkel Report [Finkel 2017] mentions a "day ahead" capacity market as one option. Regardless of the form that a capacity market may take:

- Capacity has a value separate to energy and this is likely to strengthen over time;
- Current market mechanisms (cap contracts) provide only an indirect value for capacity[2];
- Increasing penetration of wind and solar and a reduction in baseload generation will drive greater need for flexible capacity;
- Flexible capacity will require some kind of reliable market price in order to provide investment signals.

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[2] It is also worth noting that from the perspective of a generator, a capacity market may have a similar effect to the concept of a "mandatory" cap contract in the system.

3.2.4 Hydropower in the wholesale market

Hydropower generation holds a unique place in the NEM. Many hydropower generators not only provide significant clean and renewable energy, but flexible generation capacity with the ability to respond rapidly to supply and demand changes.

Many hydropower stations are significant providers of ancillary services. In addition, prior to the development of utility-scale battery storage, hydropower provided the only reliable and widely-used means of energy storage.

Although it dominates Tasmania's electricity system, hydropower is a relatively small contributor to the NEM overall. The national contribution of hydropower is approximately 7.5% of the total NEM generation with around 60% of that coming from Tasmania's hydropower system.

The challenge arises from large upfront costs combined with finding suitable locations. However, while the assets have large up-front costs due to the extensive civil works, the assets generally have a very long life compared to other types of assets in the electricity market.

Refurbishment of hydropower stations can extend the use of other assets such as dams, canals, tunnels, etc. for decades.

If the full value of hydropower assets can be captured in financial modelling the assets can be attractive, particularly in a future NEM where responsive capacity has a higher value.

3.3 Commentary on previous works on related matters

This report builds on earlier information from both national and state related reports. There are many references throughout this report, although four merit specific attention due to their direct relevance to the outcomes presented.

3.3.1 Feasibility of a Second Tasmanian Interconnector - Final Study (Tamblyn Report)

The Tamblyn Report was established in April 2016 to produce a feasibility assessment of a second interconnector across Bass Strait (2IC). The review was established in response to the energy supply challenges in Tasmania during 2015/16 caused by a combination of very low inflows and an extended outage of the Basslink cable. The final report was released in April 2017.

From the final report:

"The Terms of Reference for this study call for a feasibility assessment of a 2IC and advice on whether it would; address energy security issues, facilitate development of Tasmania's large scale renewable energy resources and integrate with the Victorian electricity market and the wider National Electricity Market (NEM). The study was also to advise on implications for electricity consumers and related regulatory and financing issues."

The Tamblyn Report concluded that there were likely to be significant market benefits from a 2IC, including deferred new thermal generation on the mainland, and savings in variable generation costs due to more efficient use of the Tasmanian hydro system. However, these market benefits only exceeded the cost of the interconnector in some future market scenarios (i.e. if some specific market conditions were to be realised).

The report itself noted that the analysis it presented relied on many assumptions that were already out of date by the time the report was produced. The market was (and remains) in a state of rapid change and the report recommended that market conditions be continually monitored for emerging conditions that would strengthen the case for a 2IC.

The *Battery of the Nation* Future State NEM analysis essentially implements this idea by providing an updated view of possible benefits of significantly increased interconnection between Tasmania and Victoria. Thus the *Battery of the Nation* work can be seen to be continuing the work that commenced with the Tamblyn Report.

Whilst completing this present study, the commencement of further study of a second interconnector across Bass Strait has commenced with support from the Tasmanian Government and ARENA. As the next step, a business case study would examine and finalise the preferred route, optimum size, cost estimate, regulatory investment test and financial model for a second interconnector between Tasmania and Victoria.

Further interconnection will tap into the potential of Tasmania to expand its substantial renewable energy base and provide more affordable, reliable energy to the national grid.

3.3.2 Independent Review into the Future Security of the National Electricity Market - Blueprint for the Future (Finkel Report)

In June 2017 Australia's Chief Scientist Dr Alan Finkel provided an independent report [Finkel 2017] into the future security of the National Electricity Market.

The Finkel Report has clearly identified that Australia is facing an energy transition period. It describes the need for Australia to approach the transition by being well prepared to ensure a secure, reliable and affordable electricity system that produces lower emissions.

The report identified that if the required transition is managed well, Australia will benefit from a secure and reliable energy future. Managed poorly, our energy future will be less secure, more unreliable and potentially very costly. The report recommends that key outcomes are underpinned by three pillars of an orderly transition, better system planning and stronger governance.

Within the report, Dr Finkel noted that the variable renewable energy generators were likely to be the low cost sources of energy, but would need firming from other supply options in the market.

The report found pumped hydro to be a low-risk, low-impact technology, generally cheaper than battery storage and certainly cheaper than keeping coal-fired power plants on stand-by to back up renewable generation.

The report highlighted pumped hydro to be a low-risk, low-impact technology, generally cheaper than battery storage and certainly cheaper than keeping coal-fired power plants on stand-by to back up renewable generation.

The *Battery of the Nation* Future State NEM analysis is fully compatible with the outcomes of the Finkel Report. This work explores the possibility of increasing Tasmania's contribution to the NEM in order to support precisely the outcomes sought by the Finkel Report, including the lowest-cost most reliable future electricity supply for the whole of the NEM.

3.3.3 Integrated System Plan Consultation

AEMO released an Integrated System Plan (ISP) Consultation paper in December 2017 [ISP 2017]. The paper provides information about – and invites feedback for – the proposed ISP to be published in June 2018.

The ISP will present a long term strategic development plan to deliver continued reliability and security at least long term cost for consumers, while meeting emission reduction targets. AEMO proposes to incorporate the National Transmission Development plan into the ISP.

There is a pressing need for a nationally integrated strategic plan, one of the findings from the Finkel Report. This plan must consider how these transformations affect the need for infrastructure development and how the essential technical requirements of the power grid will continue to be efficiently met, taking a perspective across the whole NEM.

The first ISP, to be delivered in 2018, will deliver a strategic infrastructure development plan, based on sound engineering and economics, which can facilitate an orderly energy system transition under a range of scenarios.

This ISP will particularly consider:

- What makes a successful renewable energy zone (REZ) and, if REZs are identified, how to develop them.
- Transmission development options.

The *Battery of the Nation* concept has been shared with AEMO and features prominently in the consultation paper on the Integrated System Plan [ISP 2017].

The *Battery of the Nation* team continues to liaise closely with AEMO to ensure they are fully aware of the work being undertaken, and that the work is compatible with, and a significant contribution to, the ongoing development of the ISP.

Key Points of Relevance

- There is strong alignment between many of the findings and direction within the Integrated System Plan Consultation paper and Future State NEM analysis presented in this report.
- In many ways this analysis proposes an integrated development plan for building Tasmania as either one or multiple renewable energy zones.

3.3.4 Comparable international initiatives

The *Battery of the Nation* concept plays a key role in contributing and re-shaping Australia's energy future requirements. While the approach has been designed to be modular in nature, it is a substantial change from the present operations of the Tasmanian power system in the NEM.

Similar projects are being undertaken across the world, integrating valuable existing hydropower assets with larger markets through the use of new interconnection as well as exploring options for large scale pumped hydro.

Similar examples to *Battery of the Nation* are occurring in both Europe and North America.

Hydro Quebec has recently announced its initiative of "Battery of North America" [HQ 2017], partnering with New York on projects that will make significant contributions to the state's clean energy future.

Norway is hoping to become the "Green Battery of Europe" [NTNU 2015] by using its hydropower plants to provide responsive electricity production to fill times when other generation sources are scarce. This initiative is building and planning substantial, high capacity and long high voltage direct current (HVDC) cables to further connect with other markets.

3.4 Policy uncertainty

There is a clear need for significant investment in Australia's electricity infrastructure and yet there is uncertainty in the market slowing investment and adding to costs. This particularly influences investment decisions in assets that require large up-front capital that is paid off over a long life of operation.

Transmission and hydro plant (pumped or otherwise) are both characterised by this cost profile with large upfront investment and asset lives well in excess of 50 years.

In the current political climate, there remains a risk that government intervention may force suboptimal outcomes. Even short-term uncertainty can delay investment to avoid years with poor return. The fact that energy has become a political topic does introduce uncertainty and challenges to the market.

The National Energy Guarantee (NEG) is an attempt to achieve a stable platform for investment and the NEG Design Paper is an important and welcome step towards an enduring policy. The final policy will have a strong bearing on the speed and stability of Australia's clean energy transition.

At this point it is difficult to assess in detail the impact of the NEG on the *Battery of the Nation* concept. Regardless of how this policy eventuates, debate will continue about how to incentivise and connect new renewable projects.

Policy uncertainty can be both a threat and an opportunity for the *Battery of the Nation*. The threat lies in the risk of making long term decisions in an uncertain environment (the current state of affairs).

Policy uncertainty also means that there is a significant opportunity to help shape the future by articulating feasible solutions that can deliver sustainable, secure and cost-effective energy solutions: the three targets in the "energy trilemma[3]", graphically demonstrated in Figure 18.

Figure 18. The energy trilemma

Modern electricity markets strive to achieve the energy trilemma and this requires careful consideration and design. Inefficiencies with excess reserves and the inability to call upon a variety of complementary resources means that isolated systems struggle to meet these three criteria.

Hydropower assets combined with new wind/ solar generation (essentially the Battery of the Nation concept) meets all three aspects of the energy trilemma.

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[3] https://trilemma.worldenergy.org/

According to current World Energy Council (WEC) assessments of the energy trilemma, Australia sits 33rd in the world, even with an abundance of renewable energy resources and a comparably strong economy both in terms of per capita and total Gross Domestic Product [WEC 2017]. With careful design and optimised resource sharing, Australia should be well positioned to achieve strong improvements in all criteria.

Energy policy can change rapidly, so long-term planning must be robust to a range of policy outcomes. Fortunately, there are also physical characteristics of the energy system some of which are largely independent of policy and these fixed realities can be used as the basis of longer-term planning.

3.4.1 Investment in uncertain times

Understanding what contributes to uncertainty, and identifying attributes of the future electricity system which are reasonably predictable, is vital to enabling the proactive investment required to minimise consumer disruptions as the electricity system transforms to the future state of the NEM.

At present the power system, particularly electricity prices and reliability of supply, is a politically charged topic. There is bipartisan support for the idea that this needs to be addressed, but the specifics of energy policy tend to be used to differentiate the political parties – especially with respect to carbon abatement strategies. This means that policy settings can be uncertain, adding risk, and therefore cost, to investments.

A planning horizon of several decades is required to enable coordinated investment decisions across a wide range of participants, including timely and appropriate network investment.

The Future State NEM analysis team has completed comprehensive energy modelling analysis of multiple scenarios ranging over a 30 year timeframe, determining plausible outcomes that reflect new energy market opportunities that not only stimulate Tasmania's economy but also benefits the NEM more broadly as it pursues a pathway towards decarbonisation.

Although it is clear that firming (dispatchable generation and/or storage) will be required, along with other grid support services, investment is difficult as the type, extent and distribution of services required is uncertain.

Requirements will be dependent on the balance of different types of renewable energy deployed, and the extent to which consumers are effectively incentivised to contribute to grid security. A separate but related source of uncertainty for investors in firming technologies is the lack of policy to indicate how these vital services will be rewarded in the wholesale market.

Typically there is a balance between trying to innovate and gain first mover advantage contrasted against managing risk by delaying investment and waiting for clear market signals.

However, this balance is not the same for all market participants, especially since different technologies have different construction lead times.

Reactive investment tends to reward the technologies with shorter construction periods – yet these are not necessarily the most efficient solutions in the longer-term. Moreover, in an uncertain environment, especially where the "fuel" cost is dependent on the market that you are selling into the risk is relatively high and long-life assets only have a small portion of their value realised through the practice of discount rate economics.

If investment is reactive, suboptimal solutions may gain the first-mover advantage which could lead to expensive and/or unreliable energy for all Australians into the future. Therefore this analysis has been designed to inform a holistic vision for the future of energy generation and storage in Tasmania, whilst reflecting the benefits/opportunities this brings to the wider NEM.

These insights will support stakeholders in both the government and private sectors to make prudent yet proactive investments in major energy infrastructure.

Expected changes in the NEM represent a unique opportunity for Hydro Tasmania to reconsider and repurpose its assets, including investment in expansion/addition to existing schemes – particularly in light of changing economics that may make previously unviable options attractive.

Moreover, the design of the *Battery of the Nation* provides optionality allowing for cost-effective investments at scales which are practical and beneficial for the time of commissioning.

3.5 The case for action

Recognising that there is a level of uncertainty in the power system is important – yet it is also important to reflect on the more certain aspects of the power system which help inform strategic directions.

Australia, in line with 168 of the 197 parties to the United Nations Convention on Climate Change, has ratified the Paris Agreement, committing to significant carbon emissions reductions. Coal generators are the highest producers of carbon emissions.

Even the most optimistic numbers for advanced ultra-super-critical high efficiency low emissions are approximately 30% higher than gas. In a world which is continuing to set (and surpass) increasingly ambitious targets for carbon emissions reductions, large coal investment is considered risky.

Within Australia, a market consensus has arisen among major electricity utilities that coal has a limited life and further investments are unlikely. This is reflected in a cost of capital twice as high as variable renewable energy, according to the Finkel Report. This increased investment risk has already shown up as withdrawals and announced withdrawals of coal.

In contrast, variable renewable energy sources, namely wind and solar generation, are the only committed projects and make up the bulk of the proposed projects. This also reflects the outcomes from the Finkel Report showing that relative levelised cost of energy favours the variable renewable energy sources (wind and solar). However, these sources of energy are not dispatchable and are not always available when required.

Gas powered generation can feasibly generate when variable renewable energy is not available. However the significant running costs, significant greenhouse gas emissions and increasing fuel price volatility undermine the suitability of gas as a standalone solution to Australia's energy challenges.

Historically, states have largely taken responsibility for jurisdictional energy system planning.

To unlock the value of geographic diversity of variable renewable energy sources, and to cost-effectively ensure system security in this context, national system planning and increased connectivity between states will be critical.

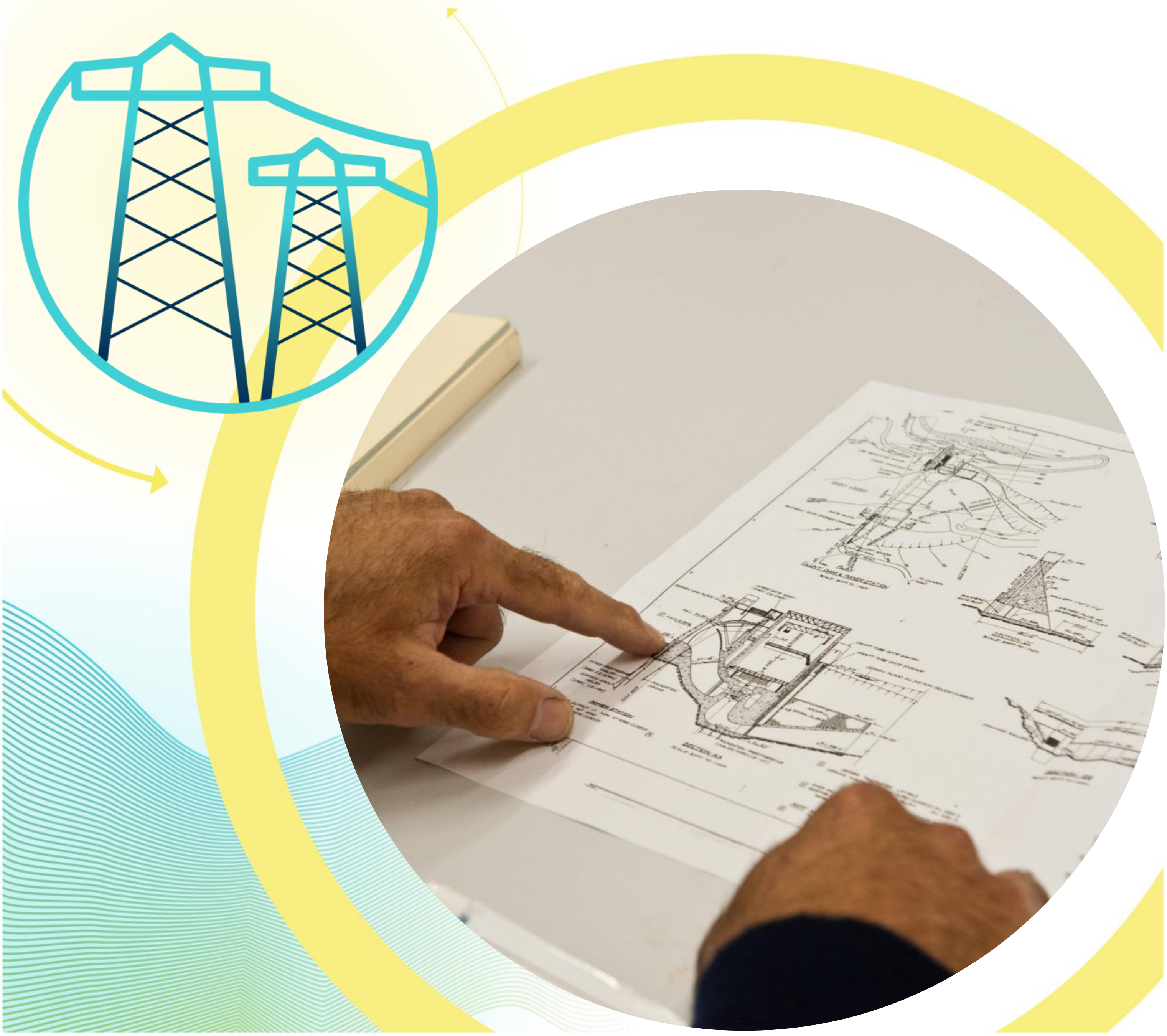
This has been recognised by the Council of Australian Governments Energy Security Board (COAG ESB) directing AEMO to develop an Integrated Grid Plan. AEMO has developed this concept further, and in 2018 will deliver an Integrated System Plan, which recognises the complexity and interdependent nature of the developments which will be required to address the challenges at hand.

4.0

Approach to the analysis

The aim of this analysis is to build a vision for Tasmania and the NEM which will support and underpin investment in a range of technologies by a range of stakeholders.

This is undertaken as a system-wide scale attempt to define relative benefits that will be robust to a range of possible changes in the market.



4.1 Context for the analysis

The *Battery of the Nation* initiative seeks to develop and clarify Tasmania's role in the future National Electricity Market in the context of this clear requirement for national action.

This report covers the Future State NEM analysis stream of work, consisting of phased analysis of Tasmania's potential future contribution to the NEM at the system-wide scale rather than focussing on any individual asset. It looks at the likely evolution of the characteristics of the NEM, focussing on the three decades to 2050. It then assesses the impact that a series of coordinated investments in Tasmania could have on reducing cost, reducing emissions and ensuring stability of this future NEM.

The aim of this analysis is to build a vision for Tasmania and the NEM which will support and underpin investment in a range of technologies by a range of stakeholders.

This report covers the first phase of the analysis and is focussed on developing the details of the *Battery of the Nation* vision and testing it against a set of scenarios. The degree of change being modelled introduces a large number of variables, meaning that the early work needed to focus on establishing credible scenarios and testing the potential behaviour of the *Battery of the Nation* vision.

It should be noted that there are aspects of this vision which would be difficult to test using modelling constructs built to suit today’s situation; revised approaches are required to model future markets or situations.

These factors meant that the focus for this phase was centred on exploring opportunities rather than risks and was not targeting the creation of a solid business case for major investment within a vastly changed NEM.

The following project phases will further explore the enablers and blockers for the vision before developing a roadmap or strategy for how the vision could be realised, as demonstrated in Figure 19.

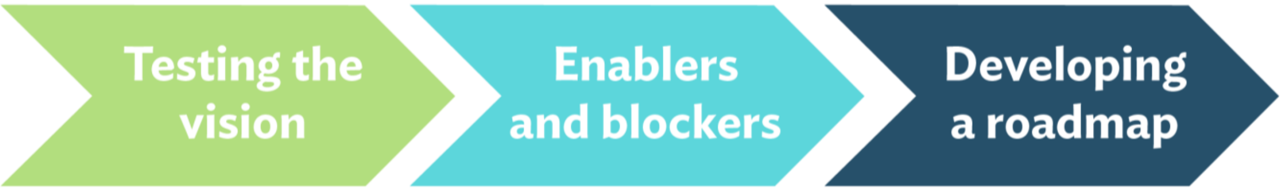


Figure 19. Future State NEM analysis staged pathway

4.2 Approach to modelling the power system

This analysis has built models of a future Tasmanian energy landscape including new renewable generation, storage and transmission and then tested their interaction in a nodal dispatch model of the NEM, built on the same engine as the dispatch model used by the Australian Energy Market Operator (AEMO)[4].

This has enabled investigation of the impact of substantial changes to Tasmania’s contribution to the NEM, and exploration of the scale of this opportunity for both Tasmania and mainland Australia.

The project team consisted representatives from Hydro Tasmania, TasNetworks and Entura. The project also sourced specialised industry expertise in terms of dispatch modelling from Ernst & Young (EY). EY brought the intellectual property in necessary system models to carry out system dispatch modelling and the expertise to provide insights in coming to terms with a rapidly changing energy mix.

Given the criticality of the assumptions underpinning the analysis and modelling Oakley Greenwood, a second independent specialist consultant, was engaged specifically to review and validate the assumptions.

An additional independent review of the key assumptions was also undertaken by representatives from AEMO as well as a range of industry participants in Tasmania. These assumptions are discussed in detail in Appendix B.

The analysis began with a high level view of likely future NEM trends and options for Tasmanian contribution. These

[4] Note that this is dispatch level modelling with a view to macro scale energy reliability rather than the detailed system security studies to study real time response to faults and other operational events.

options were then tested broadly on an individual basis, for example the scope and competitive advantages of Tasmanian wind, pumped hydro and repurposing of existing assets enabled by interconnection.

The key components of the *Battery of the Nation* initiative were found to feasibly be strong enough to achieve a lower levelised cost of energy than alternative options while absorbing the cost of interconnection. These insights were used to build a number of proposed scenarios for coordinated investment and modelled from 2021-22 to 2050-51.

A core decision was made to avoid the conventional resource allocation process for the modelling (piecewise addition to optimise the asset composition in the market). This is because the time synchronicity of the resources will become far more important in the future as the time-variable renewable energy sources begin to dominate the energy mix.

The simplifications required to undertake the conventional resource allocation prevents the valuation of interdependent or synergistic systems.

A "systems thinking" approach led to a range of build out scenarios where wind farms, pumped hydro projects and interconnection in Tasmania could be built coherently.

Equally, these packaged and planned developments are understood to be a "forced" input to the model. It is certainly possible that other, more optimal, packages exist.

For clarity, a simplified version of the modelling approach is provided in Figure 20. The inputs were essentially pre-determined data to create a variety of build-out scenarios that will be tested as part of the modelling. The assumptions are essentially configuring the model parameters and sensitivities to how changes in these parameters alter the outputs.

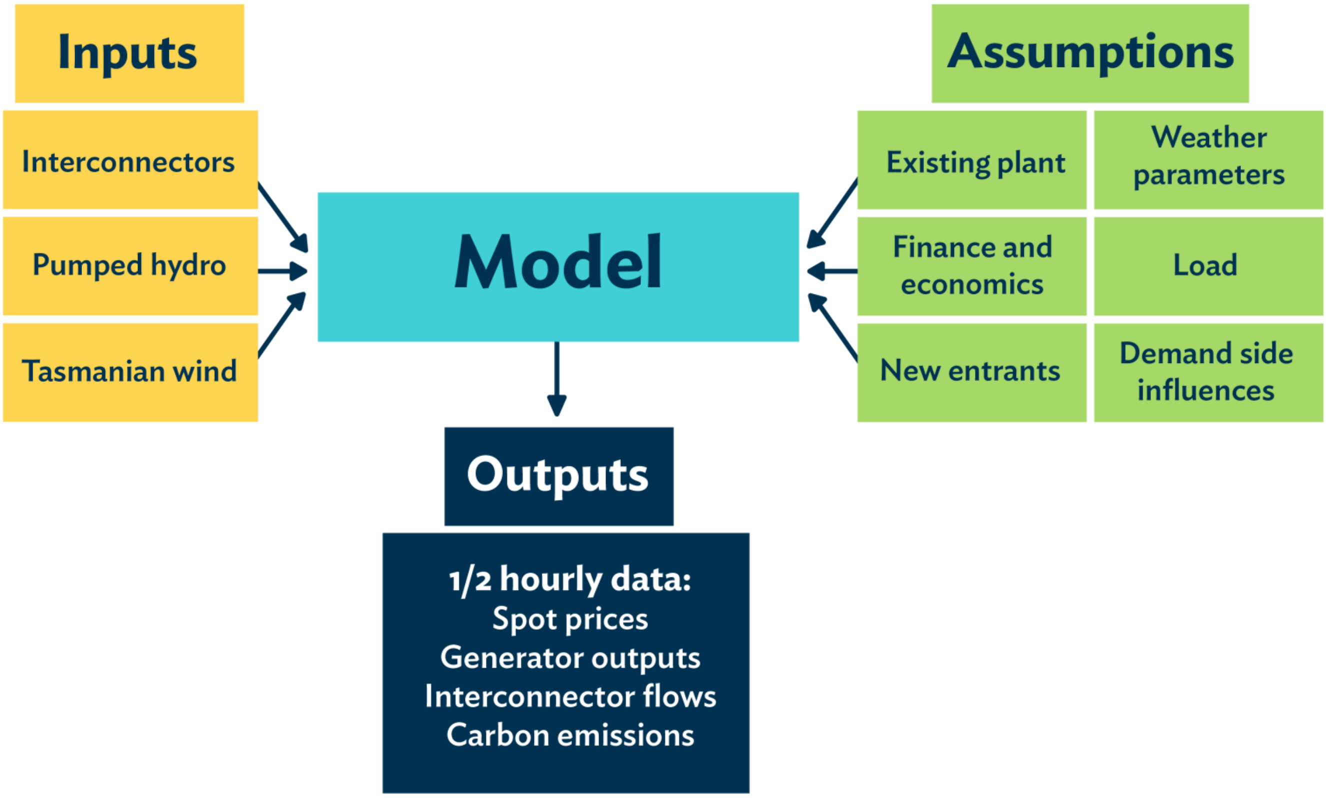


Figure 20. Simplified diagram of the modelling approach highlighting the different inputs to the model

Dispatch modelling was then undertaken to test these scenarios, which gave insight into the multifaceted outcomes of investment, including allowing existing Tasmanian hydropower assets to be better leveraged to meet the needs of the NEM, while maintaining secure and low-cost power supply locally.

A range of development scenarios were tested against a range of plausible future NEM contexts to inform the development of a strong and actionable vision for Tasmania. The impact of adding 3rd, 4th and 5th interconnectors together with additional pumped hydro and varying quantities of wind in Tasmania were examined as shown in Figure 21.

While this approach allows for the coherent build-out of synergistic systems it is more manual and labour-intensive than traditional resource allocation modelling.

The model included “micro” generation plant (0.1 MW) of each type that EY (the expert modelling consultants) deemed likely to be economic either through analysis or previous experience. When a micro generation plant proves to be economic, action is taken by the modeller and the plant is built at scale through an iterative process.

This does not reach optimal outcomes in the same way as the resource allocation modelling, but trades off the lack of optimality by being able to explore synergistic solutions that would be difficult to achieve using the more conventional approach.

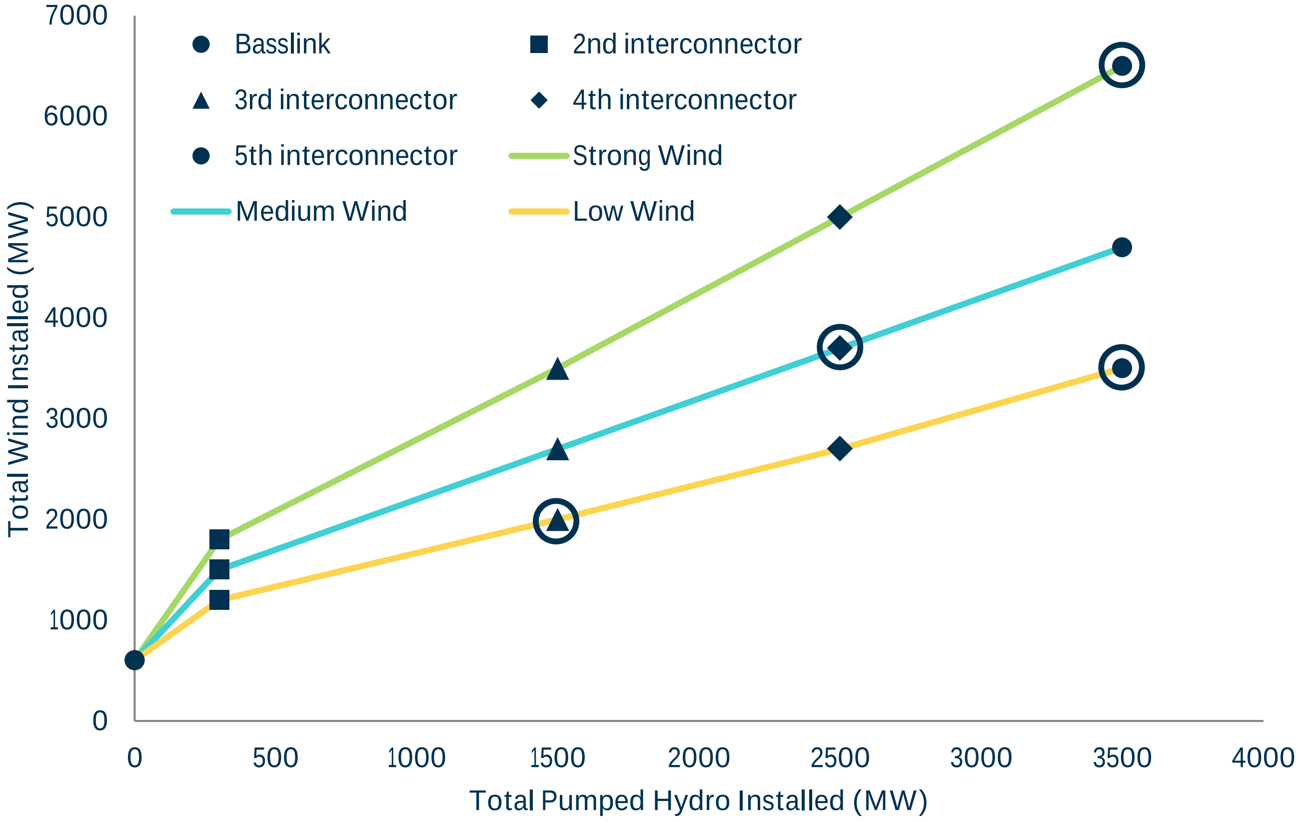


Figure 21. Build out scenarios with different levels of interconnection, pumped hydro and wind penetration. Selected scenarios for modelling are circled in black

4.2.1 Scenarios

The modelling focussed on developing ten broad scenarios based on different Tasmanian build-out rates, and sensitivities such as different mainland developments, the implementation of a carbon price etc. This range of scenarios and sensitivities enabled the identification of relative outcomes to inform future, more detailed, stages of analysis.

The 'NoTasDev' case (a counterfactual with no further energy developments in Tasmania beyond Cattle Hill and Granville Harbour wind farms) had a build out schedule determined by EY based on modelling experience and previous analyses consistent with the following core macroeconomic assumptions:

- Fixed thermal generation retirement schedule of 50 years for coal and 40 years for gas plant
- Capex and fuel costs from AEMO National Transmission Network Development Plan (NTNDP) 2016
- Demand data from AEMO Electricity Statement of Opportunities (ESOO) 2017
- No carbon price, although the targets set by the Paris Agreement would be met on a pro rata basis across the various energy sectors
  - It should be noted that *Battery of the Nation* has intentionally taken a conservative approach to carbon emissions. The modelling only targeted minimum emissions reductions targets to meet international obligations. If Australia is to meet its obligations from the Paris Agreement there is an increasing acceptance that the electricity sector will have to contribute above the pro rata reduction. The CSIRO Low Emissions Technology Roadmap [CSIRO 2017a] found that electricity sector emissions may need achieve above the pro rata rate to meet the national targets of 26-28% by 2030 and 70% by 2050. The more aggressive rates were identified to be reductions in the electricity sectors emissions profile of 52-70% by 2030 and 90% by 2050. These rates are consistent with the "fast change" scenario in AEMO's Integrated System Plan consultation paper. Although, the scenario still adopts the lower end of the 52-70% range.
  - While the Future State NEM analysis has not modelled a parallel to the "fast change" scenario, modelling results indicate that the developments proposed by *Battery of the Nation* would be consistent with achieving more ambitious reductions targets.
- The Large Renewable Energy Target (LRET) met by 2020
- The South Australia to New South Wales interconnector is commissioned prior to the modelling (2021)

Four of the Tasmanian build-out scenarios were selected from the range depicted in Figure 21 to best explore the potential and the boundaries of the modelling which could then be assessed with respect to sensitivities.

A summary of the key details of these scenarios is given in Table 1, with further details in Appendix D.

Scenario Name	Bass Strait interconnection (MW)	Tasmanian pumped hydro capacity (MW)	Tasmanian wind capacity (MW)
3IC Low (wind)	1900	1500	2000
4IC Medium (wind)	2800	2500	3700
5IC Low (wind)	3800	3500	3500
5IC Strong (wind)	3800	3500	6500

Table 1. Details of the build-out scenarios explored

4.2.2 Sensitivities

After preliminary modelling it was determined that further exploration of the 5IC Strong scenario would produce the most insights.

The scale of development magnified outcomes and lower levels of influence could be approximately assessed by considering earlier years in the modelling. Sensitivities were based on this core scenario.

The sensitivities were changes to the model to allow relative assessment of the impact of various alternative system and market conditions. These relative insights into the impact of each variable will inform the approach to future phases of analysis.

Each of these scenarios and sensitivities were carefully considered and compared. Throughout this report the meaningful outcomes have been used to highlight the modelled changes in the system behaviour and the impact on viability of certain outcomes.

Unless noted elsewhere in this report, these sensitivities did not have a material impact on the modelling outcomes specific to Battery of the Nation.

4.2.2.1 Interconnection (IC) Mainland

Description: QNI upgraded increasing northward capacity by 460 MW and southward by 190 MW.

Rationale: The *Battery of the Nation* vision for the future NEM is consistent with increased interconnection between all NEM regions. Additional SA-NSW interconnection was assumed as part of the base case. Initial modelling found that Queensland was frequently constrained off from other regions in the NEM causing notable price separation[5].

4.2.2.2 Snowy 2.0

Description: 2000 MW Snowy 2.0 pumped hydro scheme installed in 2024-25.

Rationale: Snowy 2.0 is a significant storage project and it is relevant to test the interplay of these initiatives. The *Battery of the Nation* analysis indicates that large-scale storage throughout the NEM can provide value and contribute to the energy trilemma. It was considered important to establish whether Snowy 2.0 substantially eroded benefits provided by the *Battery of the Nation* opportunities.

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[5] Modelling analysis found that this change had little overall impact from a NEM-wide perspective. Even with this change there were still substantial times of constraint between these regions and the sensitivity may not have been scaled enough to be notable compared with the other sensitivities.

4.2.2.3 Battery

Description: 30 GWh and 8000 MW of large-scale electrochemical storage installed across NSW, QLD, VIC and SA.

Rationale: As electrochemical battery costs reduce rapidly, batteries will likely have a strong role to play in short-term storage and network support. Batteries with 1, 2, 4 and 8 hours storage duration were planted throughout the NEM to assess the role of batteries and their interface with longer-term storage options.

4.2.2.4 CCGT

Description: 1000 MW of NSW OCGT and 600 MW of QLD OCGT reconfigured to CCGT.

Rationale: Closed Cycle Gas Turbines (CCGT) are more efficient but less suitable for peaking operation than Open Cycle Gas Turbines (OCGT). The ratio of these fossil fuel technologies built will strongly influence the storage requirements of the future National Electricity Market.

4.2.2.5 Carbon price

Description: Carbon price assumed from 2020-21 at \$25/tonne CO_2-e increasing to \$50 in 2030-31 and remaining at this value.

Rationale: While there is no federal policy to indicate the creation of a carbon price and it is not part of the base modelling assumptions, over the 30 year study period, a financial incentive for reduced carbon emissions is a plausible policy outcome. Therefore carbon price was modelled as a proxy for such policies.

4.2.2.6 Water control

Description: Tasmanian hydro schemes that are designated as run-of-river in the model (no storage, water is used as it becomes available or spilled) are modelled as being controllable across a week.

Rationale: Augmentation of existing schemes with pumped hydro can, in some cases, increase controllability and/or store water that otherwise would spill past power stations unused. This sensitivity sought to understand the value and system impacts of such augmentation.

4.2.3 Detailed example scenario

Initial work identified a range of plausible build out scenarios for further modelling covered in detail in Appendix D. To illustrate the degree of change being modelled in the Tasmanian power system, Figure 22 has been presented showing the 5th interconnector strong wind scenario.

This shows substantial further interconnection which supports up to 3500 MW of pumped hydro potential and 6500 MW of new wind potential. It should be noted that while this figure shows a geographic distribution, the modelling considers Tasmania as a single node and so the specifics have not changed the modelling results.

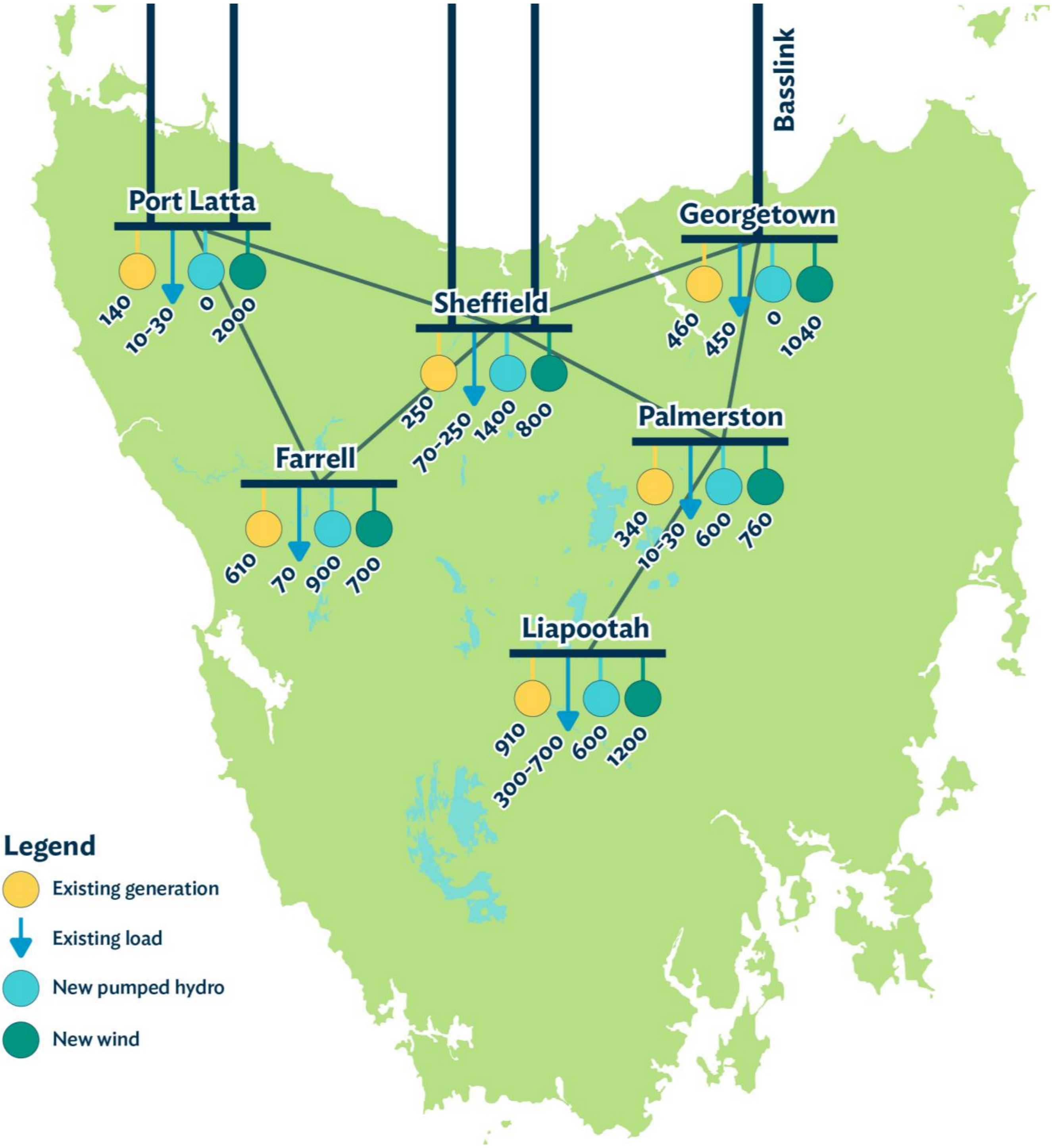


Figure 22. Potential 5IC Strong build-out scenario with indicative interconnection

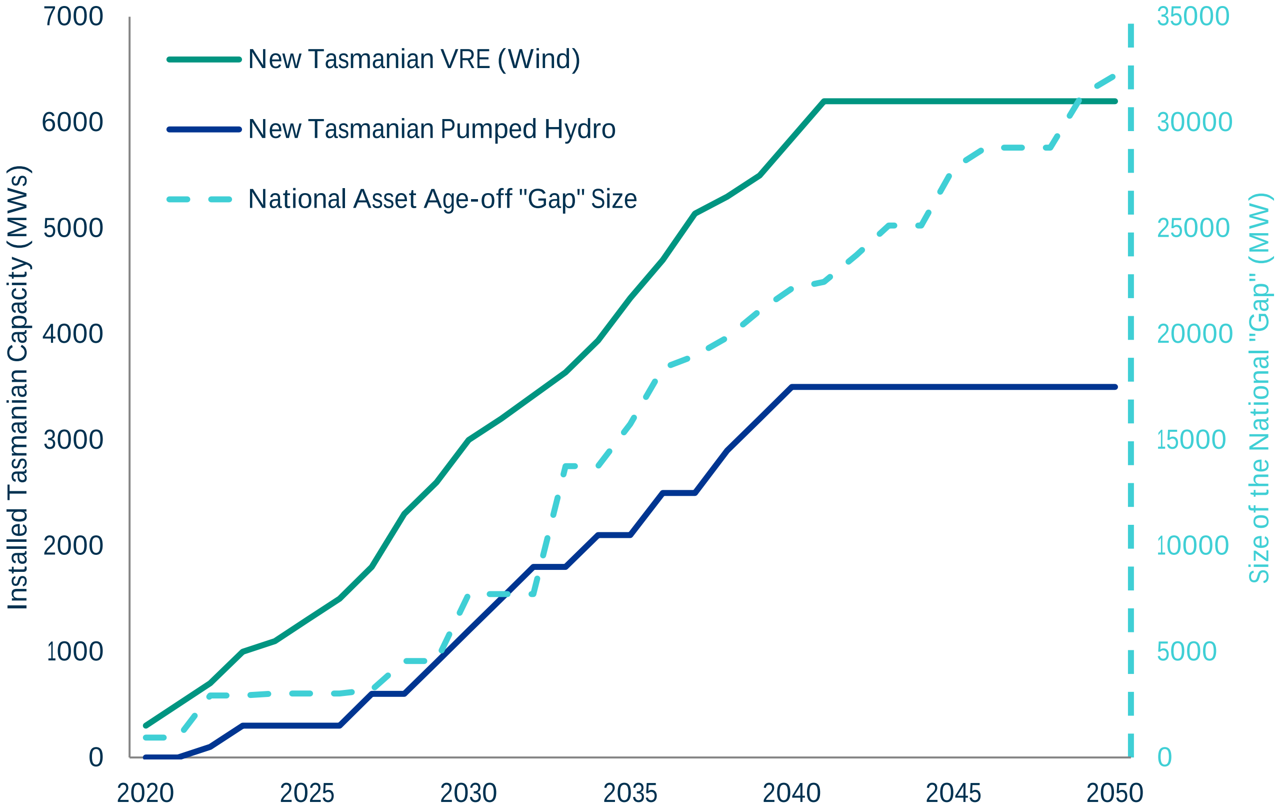


Figure 23. Example planting timelines for the 5IC Strong scenario plotted against national generation asset retirements

The timing of this build out has been scheduled to approximately align with the national age-based retirement schedule for the purposes of the modelling, shown in Figure 23. The green lines relate to Tasmanian capacity and the dotted blue line relates to the mainland “gap” – essentially the inverse of the retirements.

The national axis is five times larger than the Tasmanian axis, showing that even under this substantial scenario this additional capacity is still only replacing less than 20% of the retiring dispatchable capacity. This is a marked change in the role that Tasmania plays in the NEM, but by no means should be considered to be the only response required.

The *Battery of the Nation* initiative presents significant optionality by leveraging the decentralised nature of the Tasmanian hydroelectric system and the short interconnection pathways to allow a staged approach to development. This is currently being explored through a range of scenarios for different development options in Tasmania shown indicatively in Figure 23.

These scenarios are being tested using market dispatch modelling to test the impacts of different balances of wind, pumped hydro and interconnection investments.

4.2.4 Demand side response

The results from the modelling were found to be quite sensitive to very short periods of extremely high prices. This even showed up as substantial variance between annual average prices. The cause for these superpeaks of imbalance was determined to be caused more by the timing of randomised unplanned outages in the system, keeping in mind that this is purely modelling resource cost rather than market dynamics.

A post-processing approach was taken to simply limit the events of extreme prices with a cap of $1000 (still a very high price). This was determined to be a reasonable capability for demand side response to an unplanned outage sourced from large industrial customers, much like Tasmania’s System Protection Scheme, and the modelling showed that it was used less than 0.1% of the time. More storage would further reduce the need for this service.

4.2.5 Unserved energy (USE)

Unserved energy (USE) refers to the failure of the generation system to meet demand over some period of time. AEMO’s current reliability standard says that the system is considered reliable if the expected amount of USE in any given year is no greater than 0.002% of total energy demand.

Minimising USE, and ensuring that it is <0.002%, is a requirement of any proposed generation mix for the future NEM. It would be unacceptable to propose a future for the NEM when USE is significantly larger than 0.002%, and meeting this requirement was an input to the modelling work undertaken for *Battery of the Nation*.

4.3 Complementary analysis

While the first stage of analysis has been a high-level system view, it was important to establish that the concept is environmentally and socially feasible. Therefore, in addition to the power systems considerations, environmental and social sensitivities were explored.

Water management

Leveraging Hydro Tasmania's existing comprehensive aquatic risk management expertise, a preliminary system-level assessment was undertaken.

The assessment addressed how changes to water management in response to changes in hydropower operating regimes could impact environmental and social values, in comparison to business as usual.

Transmission

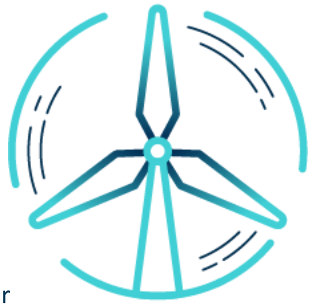
The technical feasibility of the regional and interregional transmission requirements of the project was also considered. TasNetworks collaborated with Hydro Tasmania to develop preliminary routes for required transmission augmentations.

The approach to developing transmission corridors capable of facilitating integration of renewable generation and pumped hydro energy storage considered:

- Efficiencies in fully developing renewable energy zones;
- Maximising the use of our existing transmission corridors – limiting environmental and community impacts;
- Development synergies with forecast transmission circuit renewal requirements;
- Interconnection including size, number, timing and termination points; and
- Transmission network development based on existing voltages and circuit capacities in Tasmania (i.e. 220 kV), whilst acknowledging higher voltages may be introduced (275 kV, 330 kV etc.).

This provided a considered approach to integration of new assets and provided the basis for an integrated cost stack of generation, storage and transmission.

Wind generation



Hydro Tasmania drew on internal and industry expertise to identify potential wind energy development zones. These zones focussed on areas which are technically and environmentally/socially feasible, and were assessed for average proximity to possible transmission hubs and potential wind generation capacity.

A variety of wind data sources were investigated, including current operating wind farm generation data, Bureau of Meteorology (BoM) ground stations, mesoscale data, and wind maps such as those provided by Australian Renewable Energy Mapping Infrastructure (AREMI) and the Global Wind Atlas, as well as internal data sets. None of the country wide wind maps provided sufficient high resolution and confidence in estimation of wind speed throughout the zones.

As a result, the zones were modelled using WAsP wind resource assessment software, initiated by either BoM ground station data or MERRA-2 satellite reanalysis data, a National Aeronautics and Space Administration (NASA) earth systems data resource. Comparison of these data sources with operating wind farm data showed moderate to good levels of correlation between wind speed and wind farm output on a 24 hour x 12 month basis. The WAsP modelling was then adjusted to align with knowledge about specific sites within the zones. Time series wind data was then used at a height of 130 m, estimated power curves for Class I/II/III wind resource turbine models and expected mean wind speeds at representative sites to produce total generation for each zone.

Pumped hydro energy storage

The pumped hydro energy storage stream of the *Battery of the Nation* initiative identified potential Tasmanian pumped hydro opportunities. These confirmed opportunities were used as inputs to the dispatch modelling process, ensuring that the magnitude and characteristics of pumped hydro projects modelled were a realistic representation of possible outcomes.

Alongside these analyses, national and international developments in power system planning and energy storage were used to test and inform the process.

4.4 Core hypotheses

The initial research led to a range of core hypotheses which were tested through the rest of the analysis.

These core hypotheses were:

- Additional value can be derived from the existing Tasmanian hydropower system through increased NEM interconnection and pumped hydro system augmentation.
- The cohesive investment options, presented by *Battery of the Nation*, provide value to the NEM when compared with plausible alternatives and can significantly reduce reliance on fossil fuels, while contributing to meeting the energy trilemma of price, emissions and security.
- Wind and solar power will be cost-competitive and will dominate future generation investment, opening up the requirement for firming services to support these options.
- That gas, particularly open cycle gas turbines (OCGTs), will be a viable firming option.
- That Tasmanian hydropower, including pumped hydro, will be at least competitive with gas.

These hypotheses were supported by the subsequent analysis, as discussed in Section 5.0 below.

5.0 *Battery of the Nation* provides a credible opportunity

Stage 1 analysis of the future energy investment opportunities identified by the *Battery of the Nation* concept shows Tasmania can make a significant contribution to the transformation of the NEM over the next two decades. The opportunity offers economies of scale, diversity and high quality new renewable energy resources combined with large scale storage that is able to be built with economic and timing optionality.

Battery of the Nation is designing a blueprint for how Tasmania can leverage its natural advantages for the benefit of both Tasmanians and mainland Australians.

The *Battery of the Nation* vision is for Tasmania to make a significant contribution to the transformation of the NEM over the next two decades. The opportunity offers economies of scale, diversity and high quality new renewable energy resources combined with large scale storage that is able to be built with economic and timing optionality.

Tasmania has a number of advantages that can support meeting all elements of the energy trilemma by cost-effectively improving system security and reliability while also reducing greenhouse gas emissions.

Tasmania's extensive and established hydropower system is well-placed to contribute to the challenges facing the energy system with proven, reliable, dispatchable renewable energy backed by over 100 years of experience in Hydro Tasmania.

This section of the report will explain how planned developments in the Tasmanian power system can meet each aspect of the energy trilemma.

5.1 Energy security

Battery of the Nation addresses all three aspects of the energy trilemma, and a key part of this is energy security and reliability.

While aspects of system security are discussed, this work is largely concerned with energy reliability – the ability to meet at least 99.998% of customer energy demand annually (as defined by the NEM reliability standards). Modelling carried out during the course of the studies has shown that the *Battery of the Nation* concept can make a significant contribution to system reliability across the NEM.

5.1.1 The changing shape of demand

The familiar peak versus off-peak paradigm will shift and even invert on a national scale. This is primarily driven by the consistent solar profile producing energy in the middle of the day. As covered in Appendix B, demand assumptions were primarily based on AEMO ESOO 2017 neutral case.

Historically, demand has followed one of two broad load shapes:

- Single-peak, where demand is driven by intense cooling loads and occurs towards the middle of the day, or
- Double-peak, where demand peaks early in the morning, when people are getting ready for school and work, and then again in the evening, when people prepare dinner, watch television etc.

However, this familiar paradigm is likely to be altered by factors such as household solar photovoltaics, household battery storage and electric vehicles, which may eventually dominate the demand profile.

Over the course of the study, the demand curves change such that midday demand becomes lower than any other time of day, as behind-the-meter solar photovoltaic generation dominates demand variability. This leads to a sharp load ramp in the late afternoon, when national demand increases by 20%.

Figure 24 shows the modelled annual average demand at a given time of day, illustrating that by 2035 there will be sufficient residential solar that the minimum net national demand will occur at midday. This will be even more pronounced in individual regions, and on any given day the variability is likely to be more acute.

In later years, the demand curve may be dominated by the charging patterns of electric vehicles and operational behaviour of behind-the-meter storage. If penetration is high and customers are successfully incentivised to charge in patterns which are supportive of system outcomes, the rate of change of this ramp may be significantly reduced.

However, if incentives are not successfully designed and implemented, the inrush of residential customers charging vehicles when they return home at the end of the day may exacerbate the situation significantly.

5.1.2 Generation type and services provided

0 below shows the broad categories of generation plant currently in the NEM and their ability to provide the range of services required to ensure both reliability and security. The table highlights that a variety of technologies are likely to be required to provide the necessary services. The optimal mix of plant will change over time and will reflect the changing relative costs and performance of the various plant types along with the changing needs of the market.

The contribution of different plant to the electricity system will also change over time. Older plant is typically less efficient, less reliable and has higher maintenance costs than equivalent newer plant, regardless of technology or fuel.

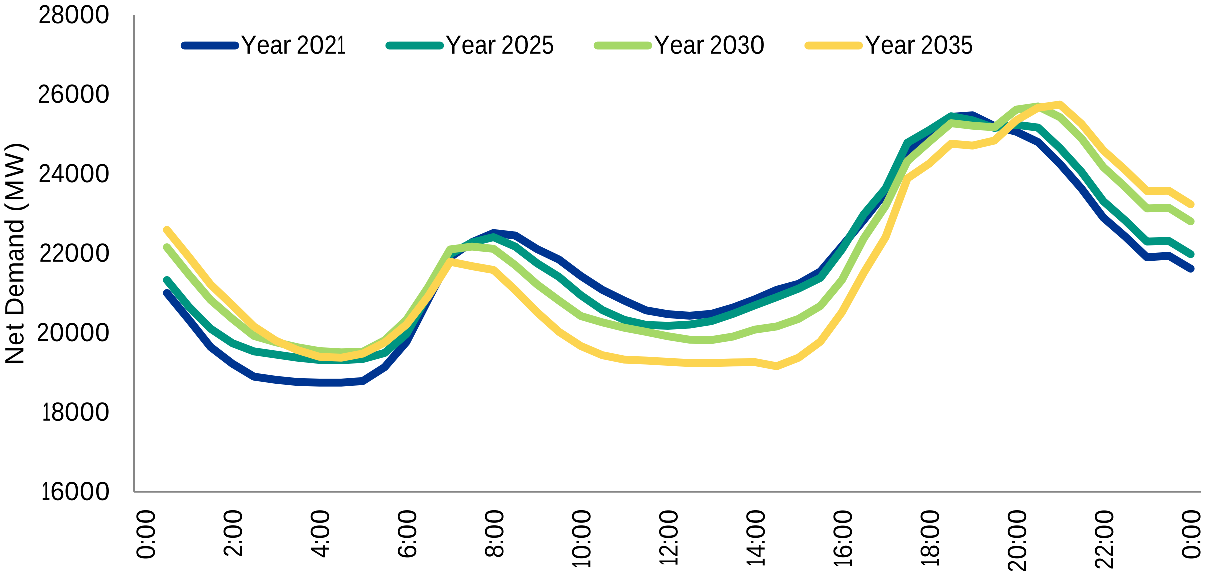


Figure 24. Modelled daily demand profile over a selection of years

Plant Type	Energy Generation	*Dispatchable Capacity*		*System Security Services*[a]		Low Emissions
		Sustained Capacity	Fast Rate of Change	Frequency Response	Inertia[b]	
Coal	✓	✓	-	✓	✓	-
CCGT	✓	✓	-	✓	✓	-
OCGT	*[c]	✓	✓	✓	*[d]	-
Wind	✓	-	-	✓	-	✓
Solar PV	✓	-	-	✓	-	✓
Hydro	✓	✓	✓	✓	✓	✓
Batteries	-	*[e]	✓	✓	-	✓
Pumped Hydro	-	✓[e]	✓	✓	*[f]	✓

Table 2. Prevalent plant options in Australia and the services they provide

Notes:

a For the purposes of this table system security services are split between response and inertia. Physical inertia is provided by rotating plant connected directly to the system, rather than via power electronics.

b Inertia is defined as pure physical inertia which does not require any control signals. Synthetic inertia can achieve rates of change close to this, but will always be limited by the communication signal speed and so is treated as fast frequency response (FFR) instead.

c While OCGT plant can run at high enough capacity factors to provide significant volumes of energy, it is considered both inefficient and expensive to operate them in this way in Australia.

d OCGT do provide small levels of inertia, but substantially less than the other plant listed as providing inertia in this table.

e While storage technologies can provide dispatchable capacity, it can only sustain the supply for the duration of the storage. Note that pumped hydro typically can sustain its capacity for a longer duration than an electrochemical battery storage system.

f Pumped hydro has different options (e.g. synchronous or variable speed) and some implementations can provide inertia.

Figure 25. Time requirements for energy supply, highlighting newer requirements. Fast frequency response (FFR), also sometimes called synthetic inertia, will provide some measure of resilience as many of the major inertia providing stations retire. Solar will need firming over several hours and wind will need firming for periods up to days

5.1.3 Generation firming

Generation firming refers to the ability of generation sources to respond to variation in supply. Historically, flexible generators have been required in the electricity system to respond to supply demand imbalances caused primarily by variable demand.

The services that were needed complemented the inflexible baseload generation. However with increasing variable renewable energy penetration the requirement for flexible generation and/or energy storage increases as both demand and energy sources are introducing variability to the energy balance.

The existing concepts of peak and off-peak times will likely be driven by times of relative abundance and scarcity of variable renewable energy rather than times of low and high demand.

A stylised display of the timeliness requirements is shown in Figure 25. A comparison of the requirements for wind firming and solar firming is shown in Figure 26.

The figure shows the modelled output from solar and wind generation over a single week in 2050. The dotted lines show the average outputs for that time of day (averaged over the whole year) while the solid lines show the actual output over the week shown.

Solar photovoltaic energy varies greatly over the course of each day, and, of course, is not generated at night time. However solar generation is reasonably predictable, usually follows the average output for that time of day. Note that the week illustrated in Figure 26 is during mid-winter, and therefore the days are shorter and the peak sunshine is typically less than the average for the whole year, sometimes significantly so. However, solar output also has days of low generation as shown by the final day in the figure.

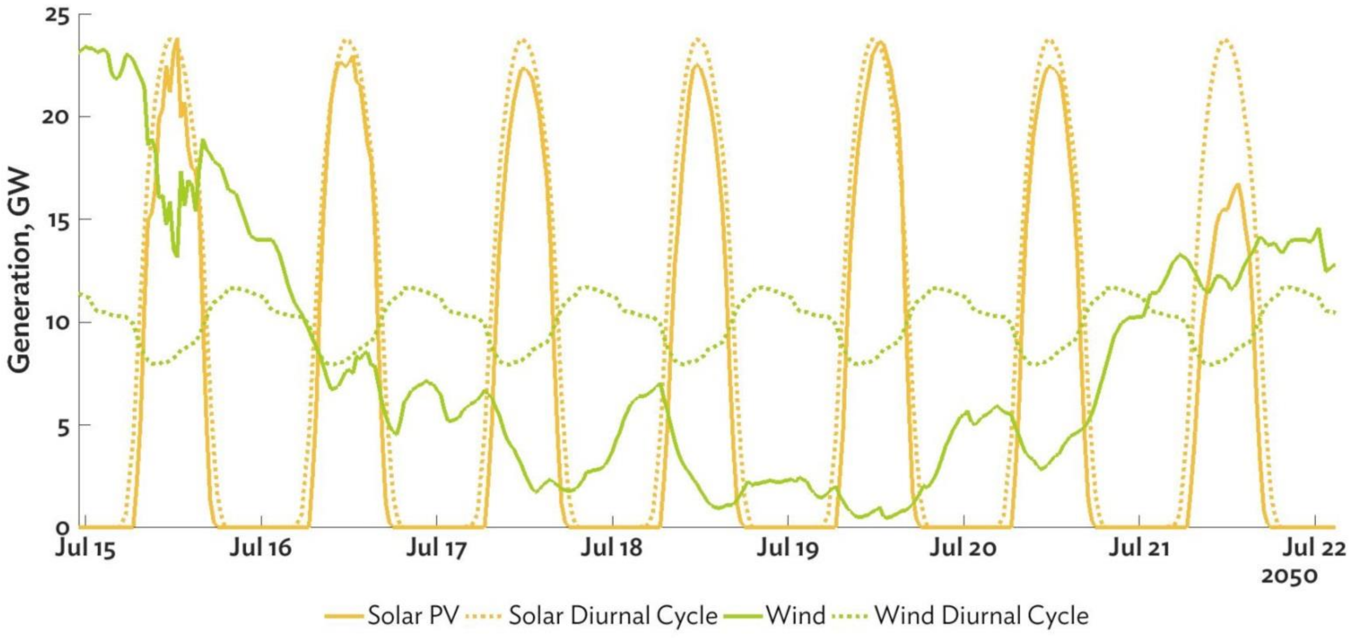


Figure 26. Example of modelled national variable renewable energy generation. This example shows a period of high wind, followed by an extended period of low wind and finally an example of a day of low solar generation

Solar photovoltaic energy varies greatly over the course of each day, although the variation is usually predictable.

Wind energy will also have a substantial impact on the system, but is less visible than solar in terms of average daily cycle since the daily pattern is not as consistent. The correspondence between the instantaneous solar output (in this case rooftop as well as utility-scale solar) and the annual diurnal cycle is much more pronounced than that between the instantaneous wind and its diurnal cycle. Wind also has a greater tendency to have extended periods at high generation and extended periods at low generation. Figure 26 also illustrates an example when total national wind production was significantly below average for four consecutive days.

Wind can have extended periods at high generation and extended periods at low generation.

In the current NEM, firming is provided by a number of generators that are able to flexibly alter their output on short time scales in response to both changing demand and changing variable renewable energy generation. Largely, this is done by various forms of gas-fired and hydropower generators. In the future, the need for these services will substantially increase and storage will also have a strong role to play in providing this firming.

5.1.4 The role of storage

Storage refers to the ability of a system to draw energy from the generation system and release that energy at a later time. Storage can be viewed as a combination of both dispatchable load and dispatchable generation. This means that storage provides ‘two-way’ firming services – it has the ability to adjust generation in order to meet demand, and it can adjust demand to match generation. This ‘two-way’ firming means that storage systems have inherently more value than the traditional pure firming generation sources.

Storage provides ‘two-way’ firming services – it can adjust generation in order to meet demand, and it can adjust demand to match generation.

As the amount of variable renewable energy in the NEM increases, there is going to be a need for storage in order to maximise the benefits of energy production from VRE. The ability of storage systems to absorb excess generation and release it later (probably at a time of low VRE output) increases the value of wind and solar and reduces the need for pure generation (one-way) firming.

Storage can also be seen as the complement of transmission. Transmission lines effectively move energy in space from one location (where it is produced) to another (where it is consumed). Storage effectively moves energy in time, from when it is produced (by non-dispatchable sources such as VRE) to when it is required. An optimal power system will maximise the effective use of both transmission and storage.

Storage systems are essentially defined by two key characteristics – the rate at which energy can be stored or released (usually expressed as a maximum output in MW) and the amount of energy that can be stored (in MWh).

Together, these numbers imply a maximum storage duration which is the length of time it takes to supply all the stored energy back to the grid. For example, a storage facility with 100 MW of capacity (maximum output) and 300 MWh of storage has a maximum storage duration of 3 hours (300 MWh ÷ 100 MW).

It is currently an open issue as to exactly how much capacity and how much energy in storage will be required in the future NEM, as it depends on a great many factors. Pumped hydro energy storage systems have significant flexibility in their design and construction that means it is possible to optimise them for a wide range of combinations of maximum output and energy storage capabilities.

The variety of pumped hydro energy storage opportunities being assessed as part of *Battery of the Nation*, when combined with a range of design options, provides substantial optionality in timing, cost, scale and services.

5.1.5 Tasmania's existing hydropower system

Tasmania's extensive and established hydropower system is well-placed to contribute to the challenges facing the energy system with proven, reliable, dispatchable renewable energy. At present, Tasmania's hydropower assets are primarily focussed on long-term energy security and are optimised to provide baseload power to Tasmania, augmented with bilateral electricity trade with mainland Australia.

However, with the right strategy and investments Tasmania can repurpose its existing reservoirs to save water at times of surplus and draw on this storage to deliver power when energy would be otherwise scarce.

Tasmania's hydropower system can support the energy system with proven, reliable, dispatchable renewable energy.

This new operating model would leverage the flexibility of hydropower to provide energy balancing services which are expected to become more valuable in the future NEM.

The changes that face Australia's electricity sector require a large and concerted response. Tasmania is well placed to respond to the needs and challenges and thereby contributes far more to our national energy requirements. Since joining the National Electricity Market, Tasmania has played a relatively minor role.

However, there is scope for Tasmania to make a much more substantial contribution to the security and cost-effectiveness of the NEM.

Tasmania is Australia's largest producer of renewable energy and produces 60% of Australia's annual hydropower generation with less than a third of the installed capacity; this is shown in Table 3.

Hydropower	Capacity (MW)	Annual Energy (GWh)
Tasmania	2400	9000
Mainland	5000	6000

Table 3. A comparison of existing hydropower characteristics in Australia

Tasmania has a series of energy-rich hydropower schemes combined with substantial storage. Tasmania's asset base is optimised, and largely operated, to provide secure baseload generation. This provides a greater opportunity to adapt to providing new services to the NEM.

Furthermore, the majority of mainland hydropower capacity can run at maximum output for 1-2 days before reservoirs or conveyances become constrained due to water availability or conveyance design, shown in Figure 27.

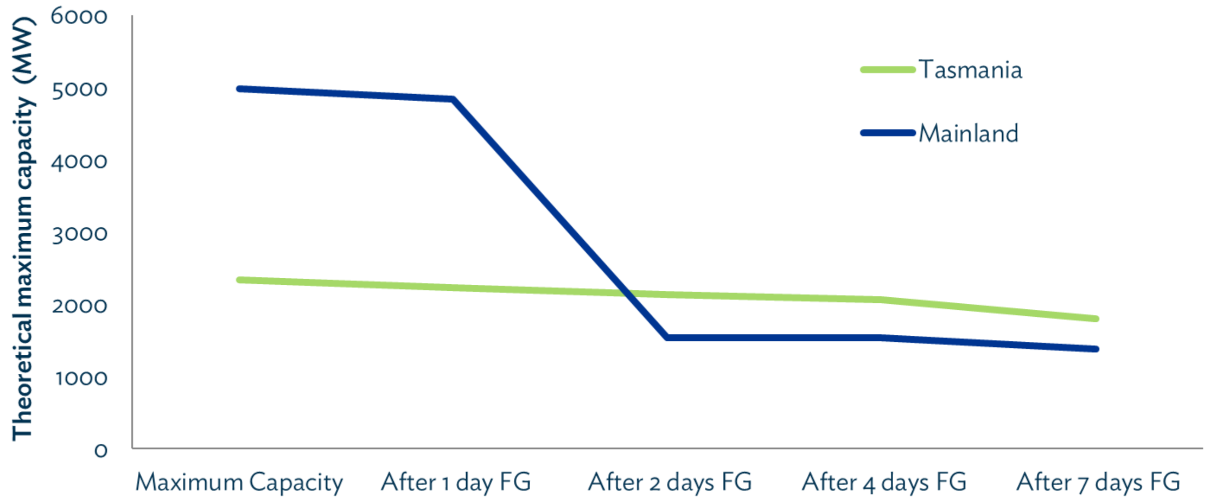


Figure 27. Theoretical maximum capacity of hydropower systems after days of full gate (FG) operation. Hydro Tasmania has greater capability to provide sustained capacity over a period of days

By contrast, Tasmania's hydropower system was designed to also accommodate baseload generation and needs to be able to provide a constant source of supply.

It should be noted that changes in the power system assets will continue to alter these ratios over time; Snowy 2.0 and the developments proposed by *Battery of the Nation* could substantially affect this situation.

Tasmania has strong potential to further maximise the benefit of its hydropower assets through the development of pumped hydro energy storage sites. Initial desktop studies [HT 2018a] identified a list of 30 sites in Tasmania totalling to greater than 9000 MW and 205 GWh of potential pumped hydro energy storage.

Of this potential, 4800 MW with approximately 140 GWh of total storage were found to be under $1.5 million per MW. Work continues to explore the feasibility of these opportunities and select those most likely to be prioritised for development.

The combination of existing hydro power assets and new pumped hydro energy storage projects provides a significant set of benefits over either traditional hydro systems or pumped hydro energy storage alone.

That is, there is considerable synergy between hydro generation and pumped hydro storage.

Combining conventional hydropower with pumped hydro:

- Provides sustained high output generation and/or flexible and responsive generation.
- Complements high amounts of variable renewable energy by being able to store and release energy – effectively shifting wind and solar output in time to meet demand.
- Provides system security services such as regulation, FCAS, rapid ramping, and other similar services.

Observed inflows to Tasmania's hydro-electric system declined through the 20th century. Tasmanian Climate Futures modelling predicts this decline to continue, especially on the Central Plateau, as well as changes to the spatial and temporal pattern of inflows [CFT 2010].

These changes are forecast to result in decreased power generation capacity within Hydro Tasmania's existing system by 2100. If these forecasts are proven accurate, the augmentation and changing operational profile of the Tasmanian hydropower system along with significant expansion of wind energy diversifies the energy system in Tasmania and has the potential to provide energy security benefits in terms of year-to-year climate resilience.

5.1.6 Storage options

Energy storage is attracting a lot of attention in Australia's energy market.

There is a growing recognition of the need to better understand storage options and characteristics in order to better plan for a system with high penetrations of variable renewable energy.

There are two major storage technologies highlighted in AEMO's Integrated System Plan: pumped hydro and electrochemical batteries.

The industry is working to understand the options and benefits that each of these technologies bring in terms of service provision in the future energy market. It is generally recognised that electrochemical batteries are flexible, fast to commission and becoming increasingly cost effective.

Equally, it is generally recognised that for longer storage options, pumped hydro will be more cost-effective.

However, a review of other works in the Australian energy market shows little active discussion on the interplay between the *duration* of storage and the capacity, and thereby does not properly assess the relative cost-effectiveness. This is demonstrated graphically in Figure 28.

There is a general desire to understand how much storage and how much capacity is required, yet considering these aspects separately does not address the core requirement. The work led by Professor Andrew Blakers at ANU found that Australia only needs 450 GWh (±30%) of storage from 15-25 GW of pumped hydro to achieve 100% renewable energy generation [Blakers 2017]. However, this work has been used out of context in other studies since.

Storage options must be able to deliver the energy required to meet the expected capacity over the time of the opportunity. The modelling undertaken for this work established that the peak net demand (after the influence of rooftop solar) across the NEM is approximately 34 GW and the peaks occur at approximately 9pm. Therefore 34 GW of dispatchable capacity is required to meet demand as it is also shown that during this peak there is no solar generation and there are also times of near zero wind generation.

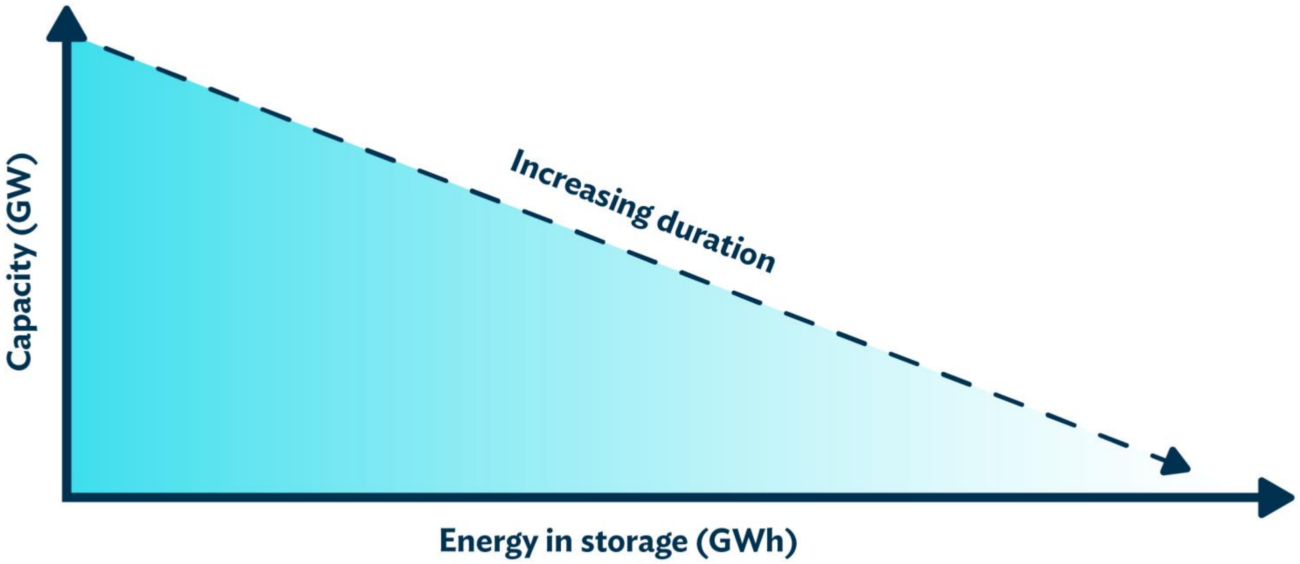


Figure 28. A demonstration of the relationship between capacity, storage and duration. Capacity is required to meet instantaneous demand, storage is required to meet the need for energy and duration is the ability to sustain the capacity over time. Considering energy storage or capacity separately does not address the entire issue

The main options to provide dispatchable capacity are existing hydropower, storage and gas, supplemented by a small amount of biomass and any coal generators that are still operating. The actual amount of capacity required is a relatively simple equation:

$$\textit{Max. Net Demand} - \textit{DSR} + \textit{RRM} = \textit{Hydropower} + \textit{Storage} + \textit{Gas} + \textit{Biomass} + \textit{Coal} + \textit{VRE}_{capacityvalue} - \textit{TX Losses}$$

Where:

DSR = Demand Side Response, including the option of unserved energy
RRM = Required Reserve Margin
$VRE_{capacityvalue}$ = Reliable minimum generation from all combined variable sources of generation
TX Losses = Transmission losses

Depending on assumptions of the energy mix, the need for capacity from storage can vary greatly. The requirement for energy in storage is essentially the same calculation as above, only integrated over time. This is where it is important to understand that each storage will also have a maximum duration; the capacity is only useful if it is available when needed.

There is substantial uncertainty about the future energy mix and there is work required to better define the necessary services to incentivise the development of the most valuable assets in the market and so estimates of required capacity or storage are fraught and must be heavily contextualised.

To further explore the limitations of separate definitions of capacity and storage, it may be useful to consider the numbers provided for a 100% renewables viewpoint from Blakers at ANU again. A misinterpretation of this data may indicate that a single large storage may be able to provide the entire energy storage requirement.

There has been commentary that Snowy 2.0 can provide (nearly) all the required storage since its energy in storage is 350 GWh. It would then be possible to add significant short duration storage with high capacity to meet the stated requirements.

However, once the short duration storage has expended its energy, there would only be 2 GW of dispatchable capacity and the energy balance above would not be able to be met.

A more market driven approach would be to identify the key technologies, particularly with reference to their costs and identify which solutions cost effectively provide the required services.

This approach is the preferred approach taken for *Battery of the Nation* and is covered in further detail in Section 5.2.5.

5.1.7 Potential Tasmanian pumped hydro energy storage projects

In parallel with the Future State NEM studies under the *Battery of the Nation* initiative, a study of pumped hydro energy storage project options in Tasmania has been completed [HT 2017]. Potential development of new pumped hydro projects in Tasmania could play an important role in supporting the NEM transition to variable low emissions sources of generation, demonstrated in Figure 29.

With the forecast increase of variable renewable energy penetration into the NEM, the system support and energy security provided by additional hydropower capacity and energy storage would assist in achieving a secure reliable future grid.

Figure 30 illustrates the basic principles of operation of a pumped hydro energy storage system. When electricity is plentiful and potentially even going to waste, water is pumped into an upper reservoir. When electricity supply is scarce compared to demand, this water is released through a turbine to generate electricity.

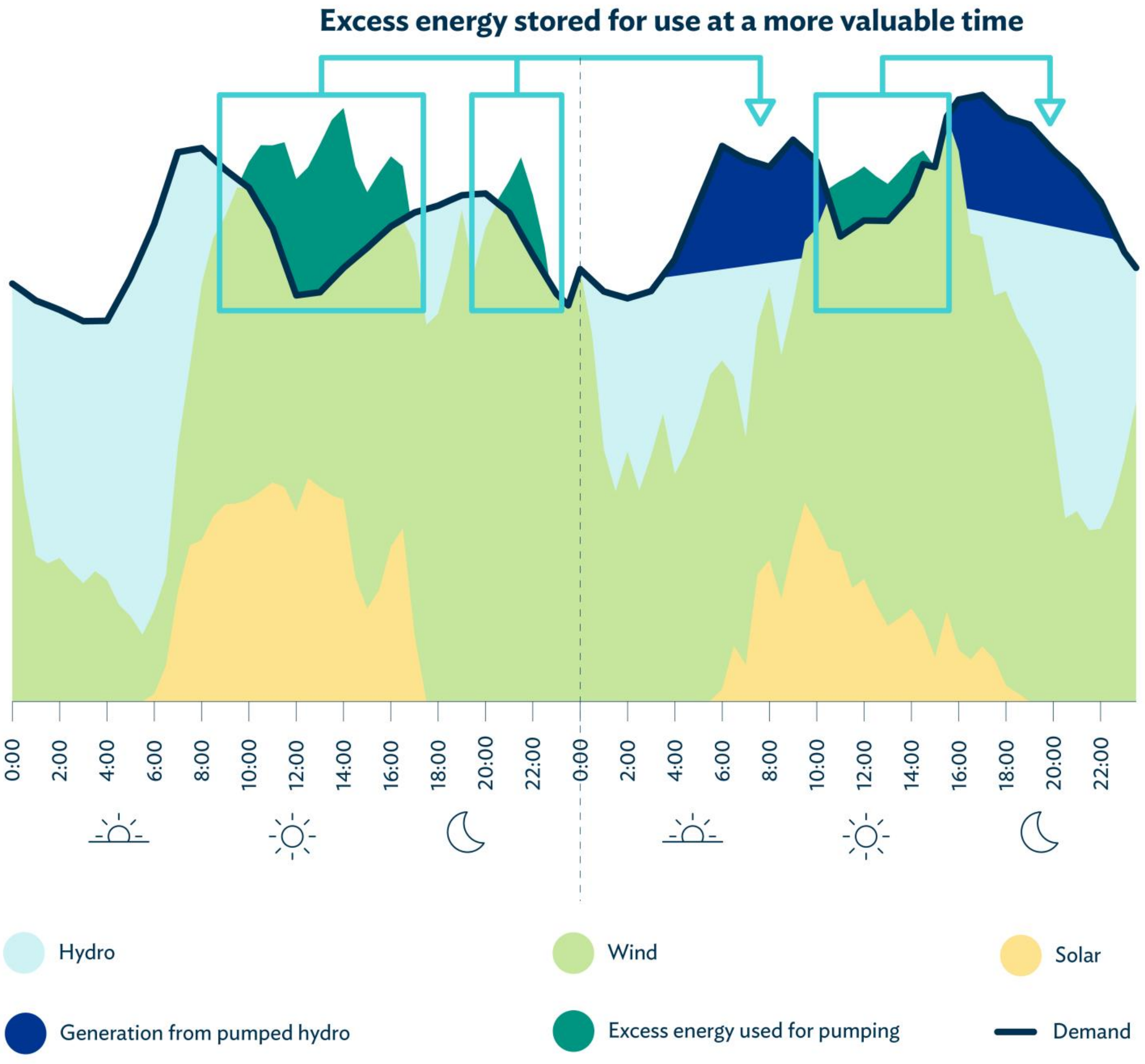


Figure 29. Illustrative demonstration of the role of storage in a potential future energy mix

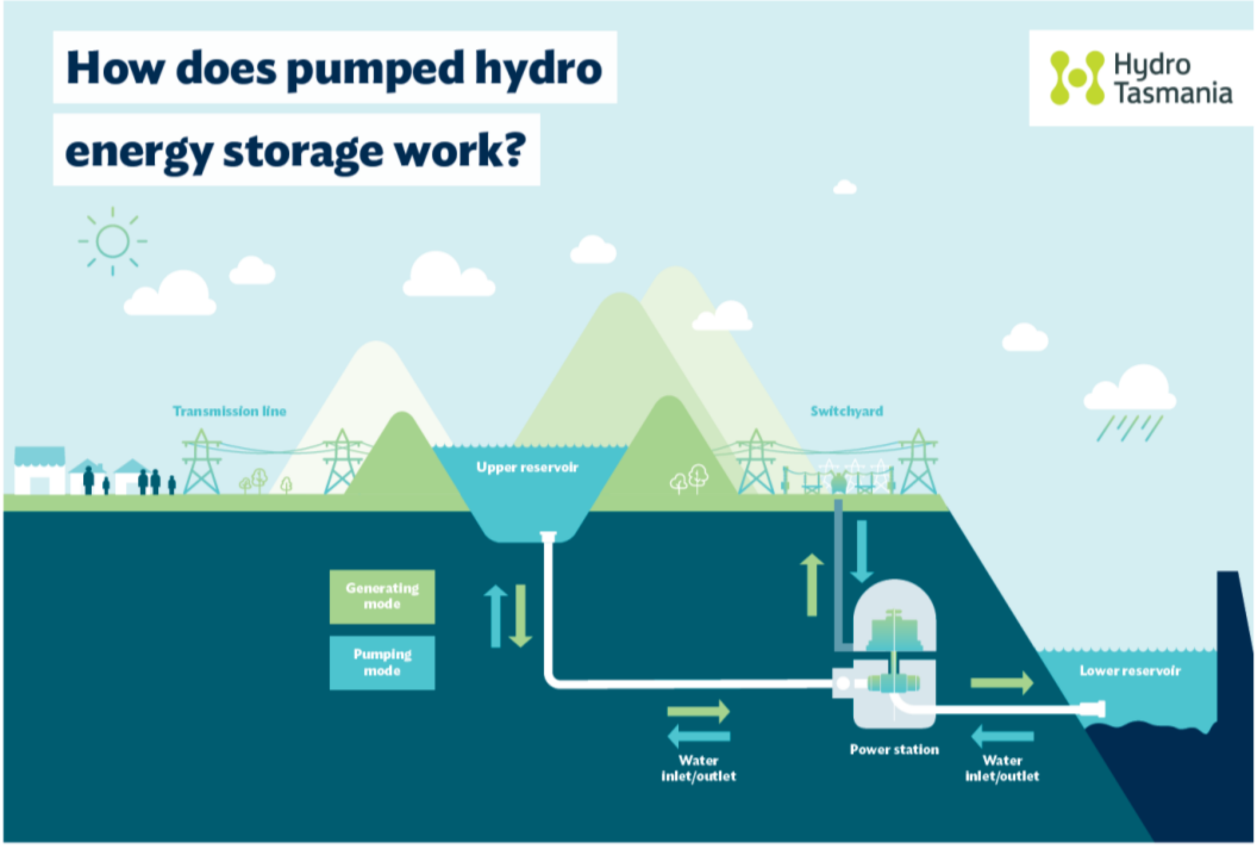


Figure 30. The operation of a pumped hydro energy storage scheme

The *Battery of the Nation – Tasmanian Pumped Hydro Options Study* identified high potential pumped hydro options in Tasmania for future prefeasibility studies.

This includes 14 options covering redevelopment of existing power stations, new links between existing Hydro Tasmania storages and utilising existing Hydro Tasmania storages linked to new off-stream storages.

The high potential sites have been produced from an initial list of about 2000 potential sites using a series of constraints and filters.

The options study has demonstrated that pumped hydro project opportunities exist in Tasmania, which are likely to be technically and economically viable given the right market conditions. Further study is required to identify project siting and design options and assess their technical, economic, social and environmental risks.

The high potential options represent up to about 4800 MW of cumulative installed capacity, with up to 140 000 MWh of energy in storage and high level capital cost estimated in the range of $1.05 to $1.5 million per MW installed.

5.1.8 Generation mix

Figure 31 and Figure 32 illustrate the national installed capacity and annual generation respectively, for each year of the study for the NoTasDev case (a counterfactual with no new plant in Tasmania for duration of the study) and the strongest *Battery of the Nation* scenario modelled.

EY provided expert advice that previous modelling showed that coal was not economic; a finding which is reflected in market behaviours and sentiment.

This was carried forward as an assumption in the *Battery of the Nation* analysis.

No new coal was built in either scenario, with coal capacity reducing from 23 GW in 2021 to 2 GW in 2050, and annual coal energy production reducing from 130 TWh in 2021 to 19

TWh in 2050. This is a reduction from supplying almost 70% of Australia's power to less than 10%, with or without the developments proposed by *Battery of the Nation*.

Previous economic modelling also showed that variable renewable energy (VRE) such as wind and solar will be built to provide low cost energy, and predicted that open cycle gas turbines (OCGT) will be the prevalent source of firming.

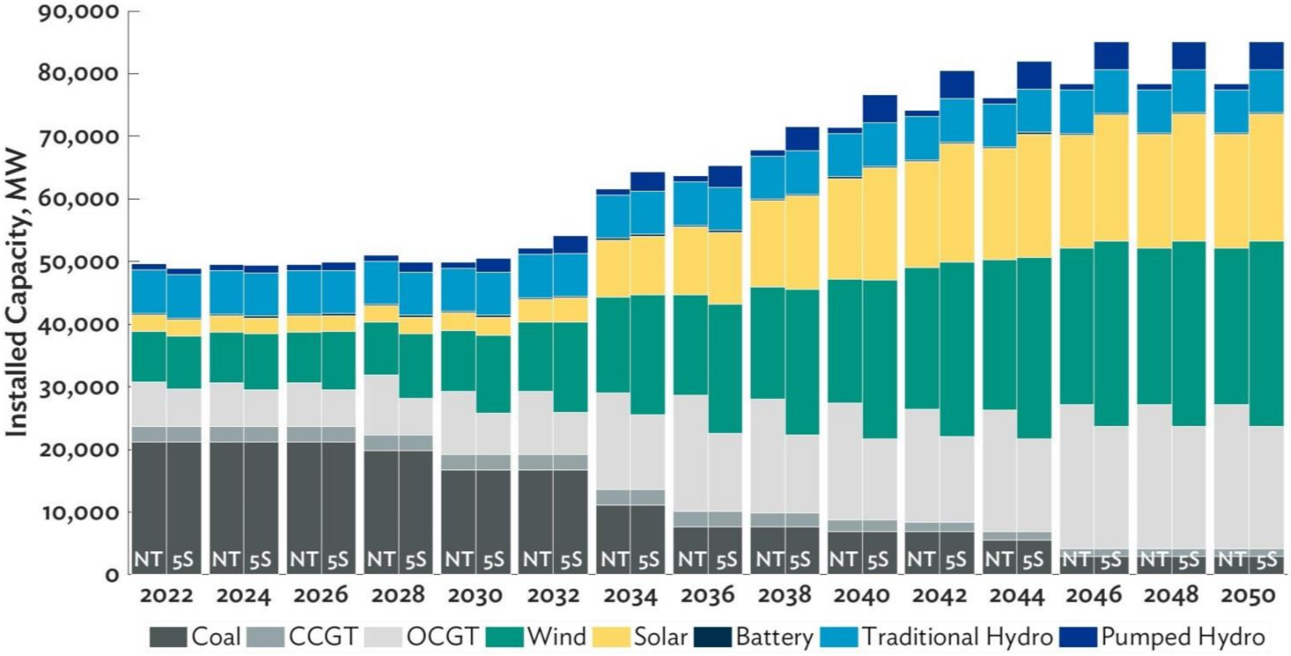


Figure 31. Modelled installed capacity projections. Comparison of the NoTasDev scenario (NT) and 5IC Strong scenario (5S)

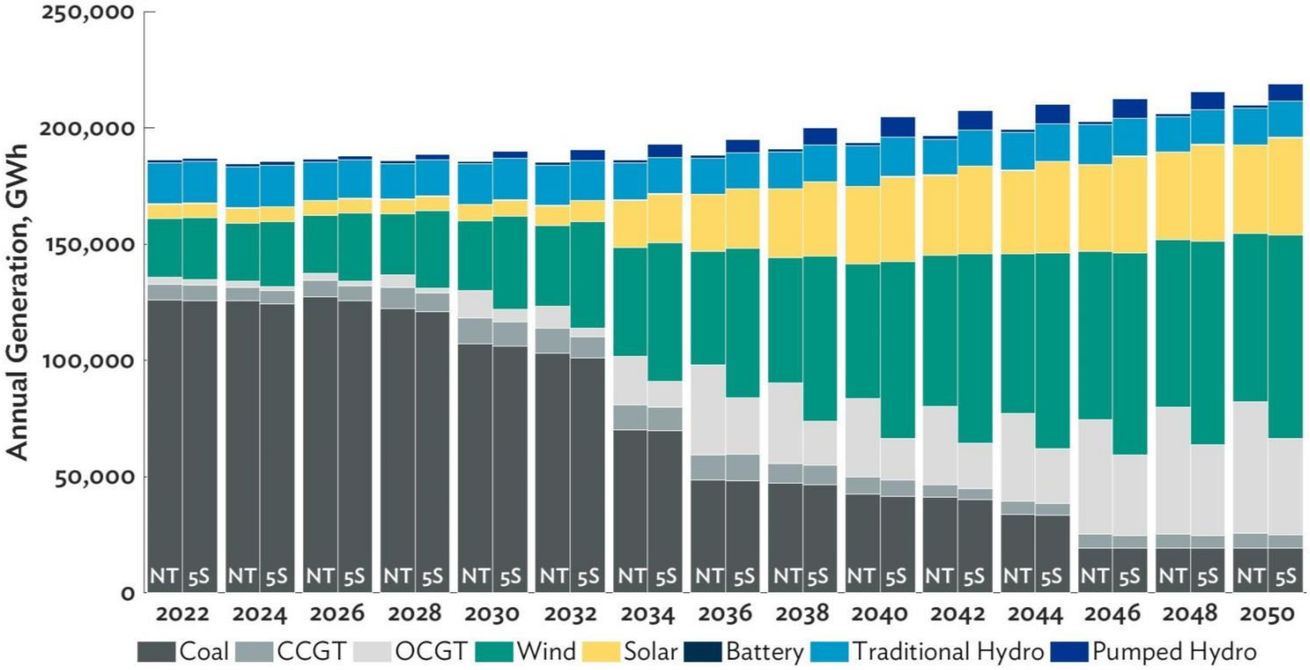


Figure 32. Modelled generation projections. Comparison of the NoTasDev counterfactual scenario (CF) and 5IC Strong scenario (5S)

One of the key points shown by the capacity and energy results in Figure 31 and Figure 32 is that the developments proposed by *Battery of the Nation* represent a modest yet significant change in the mix of generation sources in the NEM. It is not, nor does it attempt to be, a radical reshaping of the generation landscape through a single initiative.

There is a need for a concerted effort from a range of technologies and developers for the NEM to adapt to its changing future.

The most significant impact of *Battery of the Nation* modelling is that Tasmanian pumped hydro stores wind (and solar) energy and delivers this renewable energy back to the grid when required. For example in 2041, the year in which the modelling plants the last *Battery of the Nation* project, the modelling of the 5IC Strong scenario shows:

- Wind generation increases by 30% to 79 TWh
- Utility scale solar generation increases by 9% to 37 TWh
- OCGT generation decreases by 46% to 17 TWh.

Battery of the Nation contributes to an alternative option for the future of Australia's national electricity system, whereby reliance on fossil fuels is significantly reduced, or could possibly even be eliminated. With gas prices linked to global oil prices, and energy security an increasing global concern, shielding Australian electricity prices from these effects may be a prudent option to improve national energy security.

5.1.9 A case study of example of impacts

To visually demonstrate some of the system behaviours that support (and require) services for energy security, a two week period in 2050 has been used as a case study, shown in Figure 33. The plot compares combined Victorian and Tasmanian generation in the NoTasDev scenario (dotted lines) with the 5IC Strong scenario (solid lines).

This single example demonstrates that for the *Battery of the Nation* scenario:

- There is significantly less firming from OCGT generation despite the extended period of low wind output.
- The pumped storage is operated to store energy over the first few days shown and this energy is then released through the period of low wind output, highlighting the need for long-term storage.
- The existing hydro storages with large storage capability operate less in the high wind output initial period and then operate more consistently at high output through the low wind period.

Battery of the Nation developments have

- effectively reduced the requirement for gas-fired firming generation,
- improved the economic/system benefit utilisation of existing hydro assets, and
- made substantial use of the pumped storage ability to shift energy from a period of high variable renewable energy output to a period (several days in this case) of low variable renewable energy output.

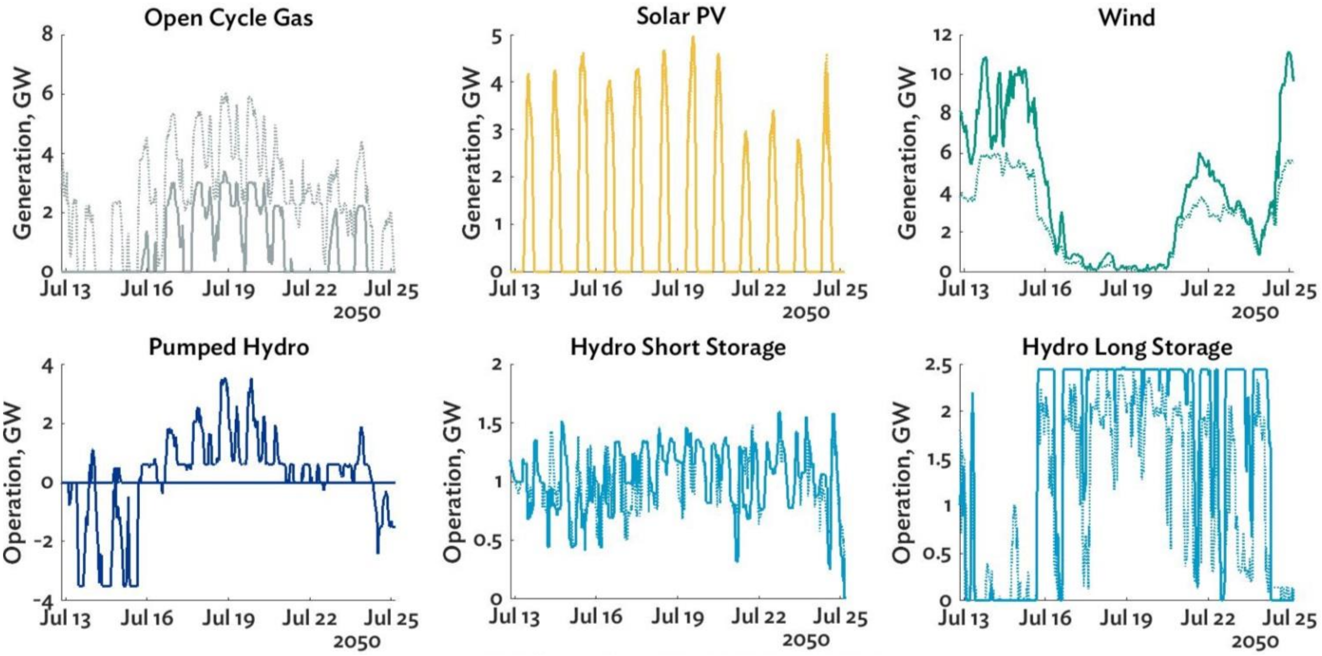


Figure 33. Victorian and Tasmanian variable renewable energy and flexible generation profiles for example days in 2050. The NoTasDev case is plotted as dotted lines and the 5IC Strong Scenario is plotted as solid lines

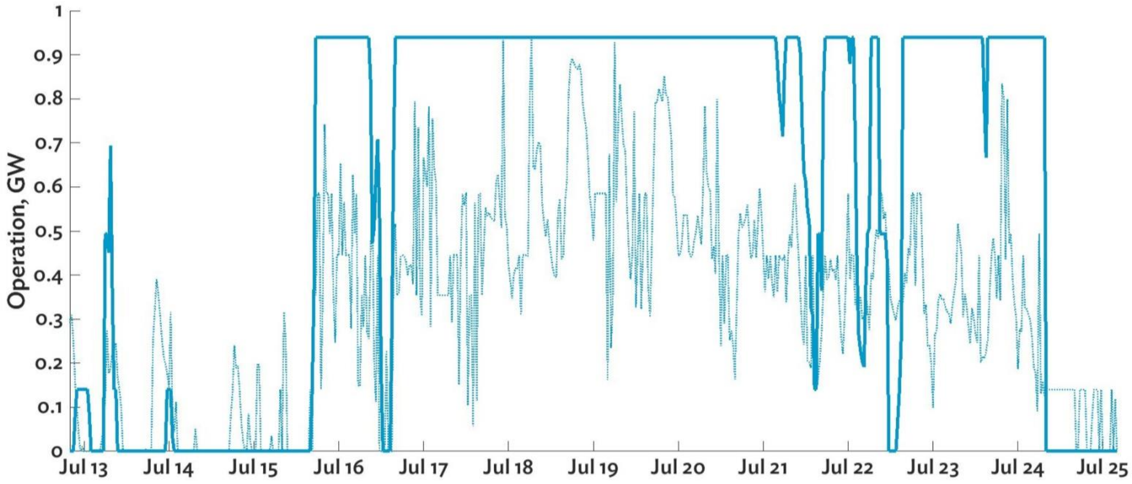


Figure 34. Existing Tasmanian long storage hydro for example days in 2050. The NoTasDev case is plotted as the paler dotted lines and the 5IC Strong Scenario is plotted as the stronger solid lines

5.1.10 Response of existing storages

Figure 34 focusses on output from the existing large storage Tasmanian hydro systems using the same data from Figure 33. The greater interconnection, alongside responsive pumped hydro storing energy from the increased Tasmanian wind power assets, leads to more optimised use of the long term hydro storages.

These generators operate at high output when the supply/demand balance is tight, and are not required to run when supply is plentiful.

Battery of the Nation analysis shows existing Tasmanian hydropower assets would provide more value to the NEM, magnifying the value of the new investments.

5.1.11 Storage operation

Figure 35 shows the operation of a selection of storage systems, ranging in duration from 1 hour to 65 hours, in the 5IC Strong scenario. The plot demonstrates that all the storages shown are operated over their full range (i.e. from empty to full), with the smaller storages cycling much more rapidly than the larger (longer duration) storages.

This illustrates a number of important points:

- The operation of storages is very strongly tied to the maximum duration of the storage, with smaller (shorter duration) storages operating on shorter time scales and larger (longer duration) storages operating over longer time scales.
  - – This may seem apparent, but it is a point that is often neglected in simplistic discussions of the necessity for, and value of, storage systems in the NEM.
- There is a need for both small and large storage systems in the NEM. While the optimal mix of storage maximum output and storage duration is very much an open question, the full utilisation of storage systems ranging from 1 hour to 65 hours in storage duration shows that there is value for storages systems of all sizes.
- There is no single storage solution that will meet all the requirements across all time scales. Considering only existing affordable technologies, it would be reasonable to interpret this as meaning that there is a place in the current and future NEM for both large-scale batteries and significant amounts of pumped hydro storage, with each technology supplying the services it is best suited to provide.

One advantage of energy storage, particularly longer-term storage such as pumped hydro, is the ability to reduce the curtailment of variable renewable energy generation at times when the generation exceeds demand. Curtailment of these near zero short run marginal cost generators is essentially lost value to the customer. Energy storage allows the system to absorb this excess energy, making it available at a later time.

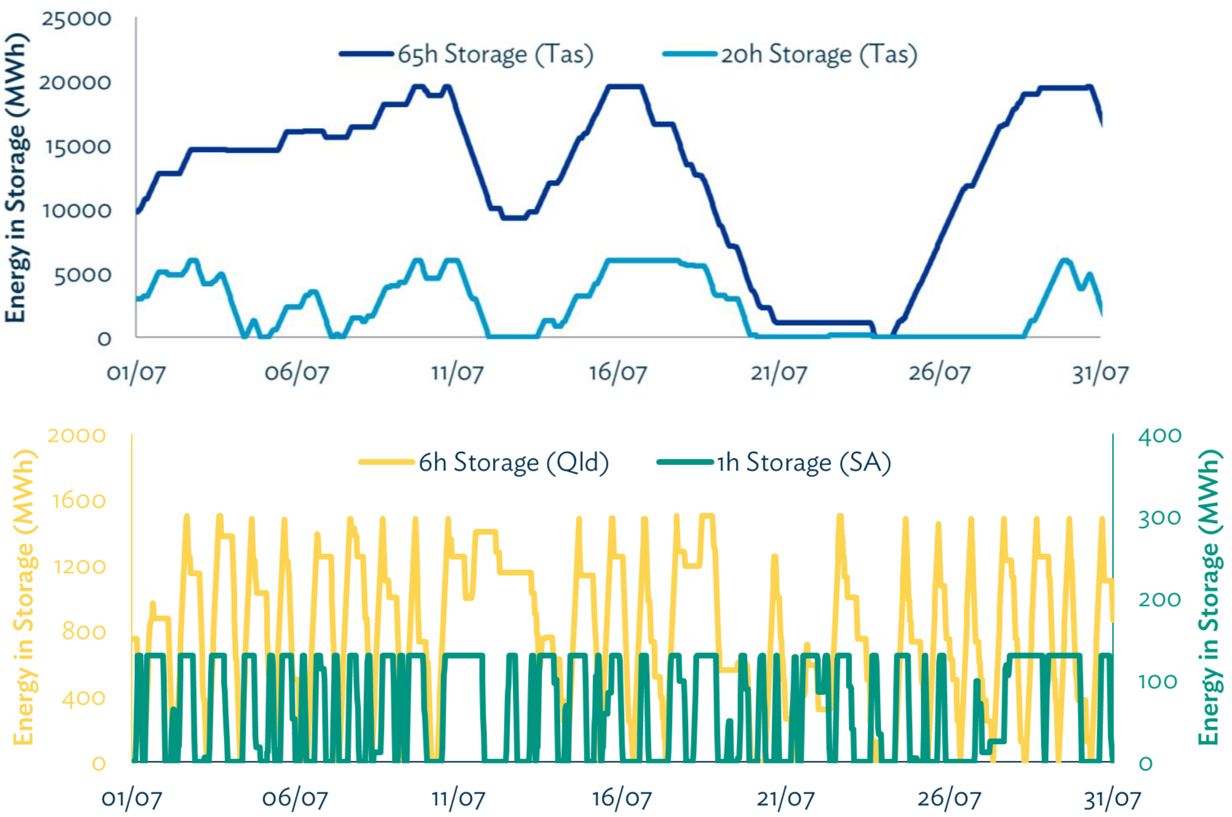


Figure 35. Sample month of modelled operation showing the contrast between storages of different duration. Each storage contributes to system reliability across different timescales

This is illustrated by comparing the capacity factors (actual average generation divided by maximum possible generation) of wind, see Table 4, and (non-rooftop) solar PV, see Table 5, for the 4IC Medium and 5 IC Low scenarios. The wind and solar PV capacities for the mainland states are close to identical between these two scenarios, but 5IC Low has considerably more pumped hydro energy storage in Tasmania, along with the necessary additional interconnection.

4IC Medium	NSW	QLD	SA	TAS	VIC	NEM
Average Generation (MW)	3919	589	1218	1417	1901	9043
Capacity (MW)	11 669	1842	3622	3708	5916	26 757
Capacity Factor (%)	33.6%	32.0%	33.6%	38.2%	32.1%	33.8%
5IC Low	**NSW**	**QLD**	**SA**	**TAS**	**VIC**	**NEM**
Average Generation (MW)	3938	590	1244	1383	1954	9109
Capacity (MW)	11 669	1842	3622	3508	5916	26 557
Capacity Factor (%)	33.7%	32.0%	34.4%	39.4%	33.0%	34.3%
Curtailment Saved						
Total (GWh)	**171**	**7**	**229**	**371**	**461**	**1240**

Table 4. Reduction in wind curtailment with the addition of substantial storage

4IC Medium	**NSW**	**QLD**	**SA**	**TAS**	**VIC**	**NEM**
Average Generation (MW)	1882	1634	320	-	966	4802
Capacity (MW)	8118	6100	1812	-	4212	20 242
Capacity Factor (%)	23.2%	26.8%	17.7%	-	22.9%	23.7%
5IC Low	**NSW**	**QLD**	**SA**	**TAS**	**VIC**	**NEM**
Average Generation (MW)	1895	1641	343	-	1006	4885
Capacity (MW)	8118	6100	1812	-	4212	20 242
Capacity Factor (%)	23.3%	26.9%	18.9%	-	23.9%	24.1%
Curtailment Saved						
Total (GWh)	119	64	199	-	348	730

Table 5. Reduction in industrial scale solar PV curtailment with the addition of substantial storage

The addition of 1000 MW of pumped hydro energy storage in Tasmania leads to a reduction in VRE curtailment of 2000 GWh per annum by 2050-51. Of this, most of the saving is in Victoria due to the proximity to the pumped hydro energy storage in Tasmania.

It is also worth noting that this calculation is for the differential of adding 1000 MW of pumped hydro on top of 2800 MW from an alternative scenario. The earlier storages will have a greater impact and therefore this is a conservative benefit compared with benefit of the first storages to be built.

Modelling shows an addition of 1000 MW of pumped hydro in Tasmania enables the recovery of enough 'spilled' variable renewable energy to serve ~1% of NEM demand.

5.1.12 Strong Tasmanian development would contribute to the energy security of the NEM

Supply and demand will continue to evolve over time and the modelling has shown a credible need for flexible solutions to provide the full range system services required to successfully operate the power system.

Developments proposed by *Battery of the Nation* can contribute strongly to meeting that need:

- Tasmania has strong potential for further variable renewable energy generation, interconnection, and large-scale pumped hydro energy storage.
- The combination of interconnection, wind generation, and pumped hydro energy storage means that the developments proposed by *Battery of the Nation* can contribute to the full range of system services.
  - It is not just a supplier of energy, capacity, storage, or system security services but can contribute to all of those aspects of the energy security puzzle.
- The flexibility in the precise mix and timing of generation, storage, and interconnection options means that the *Battery of the Nation* vision can be customised to provide the least cost outcome for the market under a wide range of future conditions.
  - The variety of pumped hydro energy storage options means that the *Battery of the Nation* vision can be adapted to complement other storage (e.g. batteries) in the power system to provide the optimal mix of capacity (maximum output) and storage duration.
- *Battery of the Nation* analysis indicates that planned developments in Tasmania can maximise the use of existing hydro generation assets, further increasing the synergistic benefits of the project and providing a unique benefit to pumped hydro in Tasmania.

5.2 Energy equity

Battery of the Nation addresses all three aspects of the energy trilemma, and a key part of this is energy equity. The options presented by *Battery of the Nation* are expected to be economic in its own right and therefore result in an affordable supply of electricity to the NEM. **Tasmania has natural advantages that underpin the value proposition of *Battery of the Nation*.**

- Mountainous topography combined with established hydropower storages produce ideal conditions for new pumped hydro energy storage developments.
- Rich wind resources that benefit from the value of diversity results in a strong economic opportunity for wind energy development.
- Short transmission distances and well-established corridors make for cost effective energy transfer.
- Short interconnection distances, lower losses and high utilisation rates results in cost effective interconnection, even accounting for the cost of HVDC transmission.

By combining these benefits, *Battery of the Nation* presents a cost-effective option.

5.2.1 Existing assets

Tasmania has a natural advantage through the ability to leverage and repurpose existing power station assets to provide more valuable services in the context of the future market. Hydro Tasmania has 30 hydropower stations grouped across six areas in Tasmania, shown in Figure 36.

Broadly speaking, Hydro Tasmania's assets were designed to meet energy security requirements for Tasmania, with some of the areas having substantial storage while others operating more as "run-of-river" hydropower and are optimised for energy production rather than capacity provision. In simple terms, run-of-river means water flows to power stations directly from a river, and cascades through a series of hydropower stations. In reality, most power stations have some level of storage, but the run-of-river-stations may only store several hours, as opposed to days or even years, of energy in storage.

Figure 36. Hydropower systems in Tasmania

Past experience has shown that each of the six schemes in Tasmania can be approximated in terms of grouped power stations with varying levels of controllability (i.e. storage).

- Gordon-Pedder, *yingina* / Great Lake - South Esk and King - Yolande are all typically represented as having large storages which can operate effectively on an annual/seasonal cycle.
- The Pieman scheme is represented as having seven days of storage.
- The Mersey - Forth and Derwent are typically represented as run-of-river.

With some minor re-allocation of capacities within different schemes, this has been found to represent Hydro Tasmania's historical operations reasonably well. It also highlights an opportunity to change operations to potentially better capture the value of these flexible assets in the context of a future market.

In order to explore the relative value of storage and controllability in Tasmania's hydropower system a sensitivity was explored which assessed the effect of changing the run-of-river schemes to be considered controllable over the period of one week. This would be achieved through careful selection of new pumped hydro construction or purposeful redevelopment of existing hydropower assets to optimise for controllability and capacity over energy efficiency – one such example would be the redevelopment of the Tarraleah hydropower scheme.

The redevelopment of the Tarraleah scheme is another stream of work undertaken as part of the *Battery of the Nation* initiative [HT 2018b].

It should be noted that this sensitivity does not take into account impacts at individual storages and the opportunity may be larger or smaller.

Figure 37 shows the relative increase in value for both Derwent and Mersey Forth by considering them to be more controllable. Note: *yingina* / Great Lake - South Esk has been left off this image since the addition of pumped hydro with a lower reservoir that is allowed to spill acts as both an addition of pumped hydro and conventional generation.

This means that the value of this scheme increases disproportionately over time as higher prices can be targeted with additional capacity. It has been left off the plot to avoid distraction.

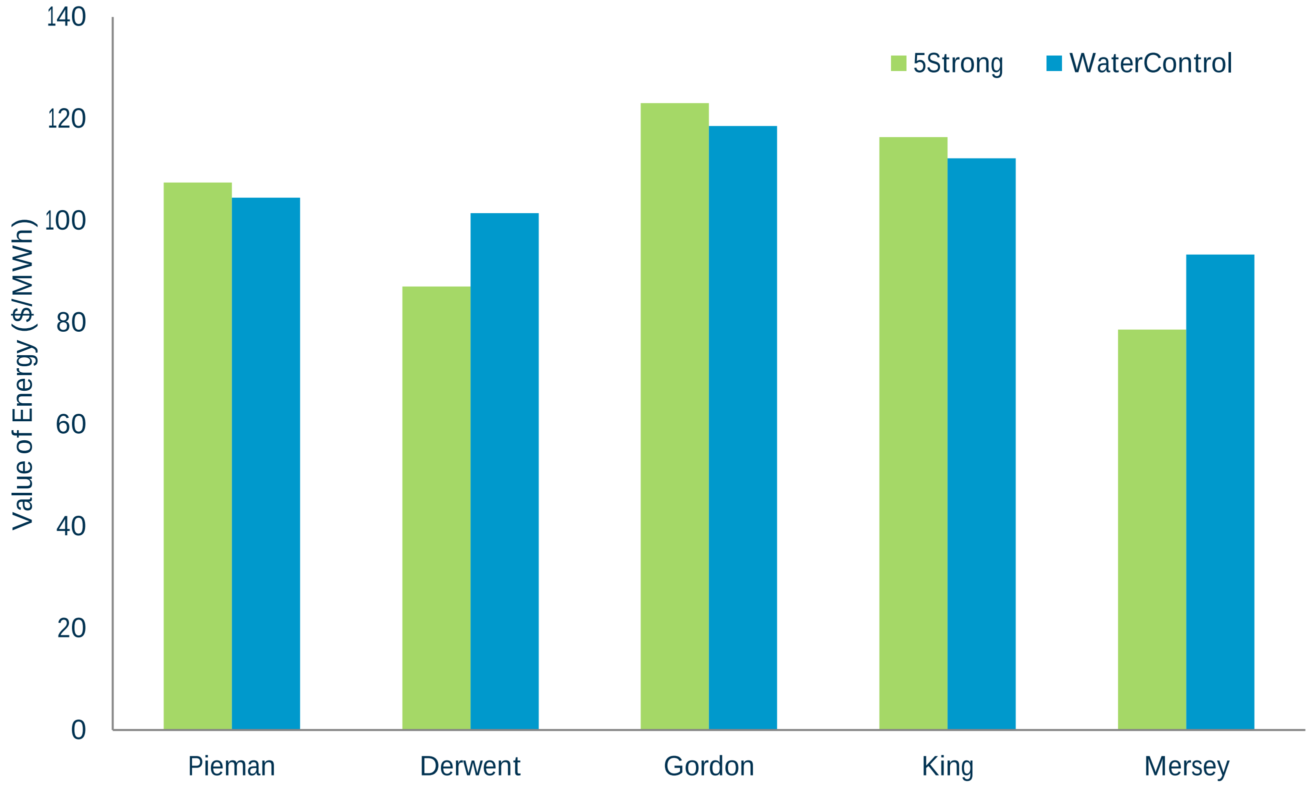


Figure 37. Increase in value of energy by increasing the controllability of a storage over the duration of the entire study period (2021-2050)

Analysis of the modelling showed that the value of the existing run-of-river hydropower assets could increase substantially through the selective construction of pumped hydro development or hydropower redevelopment that would increase the controllability of these schemes. Figure 37 also shows that the schemes that are already modelled as being controllable lose some value as a result of this change. This is because some of the increased value from Derwent and Mersey - Forth is taken from the other schemes. However, the net outcome for the portfolio is still positive and so it continues to be an investment with potential.

On a larger scale, the total resource cost of energy in Victoria reduces by 1.6% with South Australia reducing by 1.3% and New South Wales reducing by 1.1%. Even so, the net value of the energy produced by Tasmania's hydropower portfolio increases by 5.1% as the available energy is supplied at more valuable times.

> *Just by increasing the flexibility of Hydro Tasmania's run-of-river assets, the value of the energy produced increases while the spot prices fall across the NEM.*

It should also be noted that the benefit improves over time as the influence of variable renewable energy becomes greater and the need for controllability becomes more valuable; this is shown in Figure 38 for the Derwent system. The figure shows that in the later years, the benefit of controllability can be as much as a 25% improvement in the value of the energy produced.

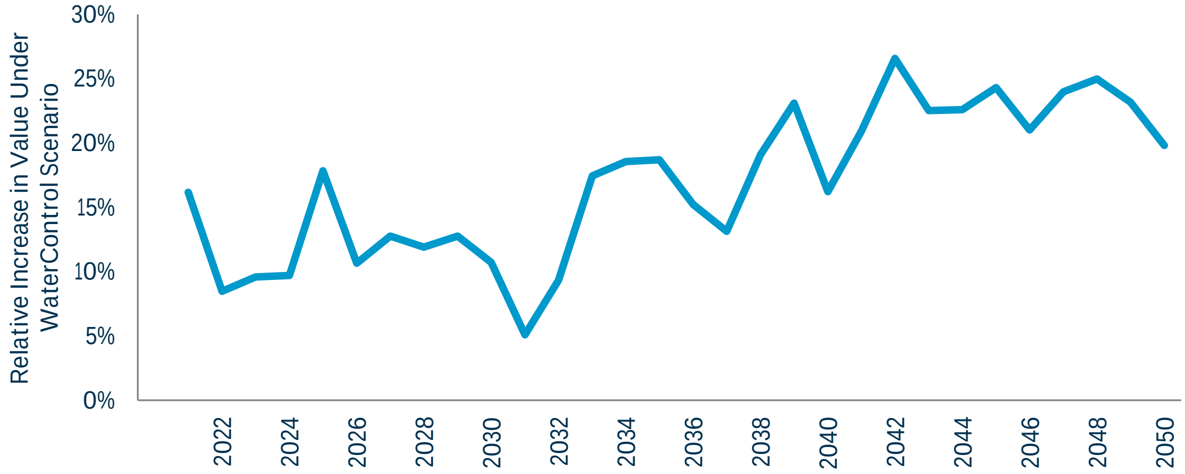


Figure 38. Modelled relative increase in value of energy through the increase in controllability of the Derwent. This could be achieved through selective improvement of controllability of the system, such as redeveloping the Tarraleah scheme to be more controllable

Under the future energy mix that was modelled, schemes with more storage (which are more flexible and controllable) are substantially more valuable than those which have smaller storages. *Battery of the Nation* presents a unique cost advantage in that pumped hydro installation (or redevelopment of existing stations) located at the upper end of a series of cascaded hydropower stations amplifies the contribution of the new asset as the released water from the station passes through all downstream power stations.

Increasing the controllability of a greater proportion of hydropower assets in Tasmania would result in more cost-effective energy dispatch and lower prices for consumers. In addition, connecting pumped hydro to existing storages reduces construction costs, benefits from the water already being utilised for energy production and tends to be located near pre-existing transmission – all resulting in more cost-effective deployment of the new assets through leveraging existing assets. It is because of this existing infrastructure that Tasmania should be a national priority for pumped hydro investment.

5.2.2 Wind development in Tasmania

There is a need to source large amounts of energy generation for the future NEM as the high capacity factor coal generators retire. Representatives from each of the major generators in Australia have publicly stated that further investment in coal is seen as expensive and risky.

Reports such as the Finkel Report and AEMO's Integrated System Plan Consultation Paper are all identifying that the variable renewable energy generators are expected to provide a majority of the energy in the future market.

The scale of new energy required means that there will be substantial opportunity for developing variable renewable energy projects and *Battery of the Nation* suggests that these will be built on economic merit. Wind or solar will have an established cost of energy, and any project which can meet this cost of energy is likely to be built.

For example, if a wind project can make $60/MWh it will be built regardless of how that energy is used. Similarly, if there is too much coincident generation, this will suppress the price and the wind projects would make less money per MWh of generation. This provides a useful comparison to test the relative optimisation of the model.

In the future, it will be more relevant to talk about income per year per MW installed, as this will be increasingly affected by differences such as spill (curtailment) and capacity factor. However levelised cost of energy has been used throughout this report due to the concept's familiarity.

Tasmania has world class wind energy potential. Woolnorth and Musselroe are among the highest capacity factor wind farms in the world and this would increase further with modern wind turbine technology.

Analysis, detailed later in this section, shows that Tasmanian wind also has a comparably low correlation with mainland options, meaning the Tasmanian wind farms produce power at different times reducing the need for ‘firming’. This high value wind is still relatively undeveloped and will be unlocked with the addition of further interconnection.

It is assumed that Australia’s wind or solar resources will be developed in a rational manner with more valuable sites being built first; therefore Tasmanian wind potential would be highly prioritised when coordinated with further interconnection and local storage investment.

5.2.2.1 Existing plant performance

Analysis of existing wind farms in Tasmania contrasted with wind farms in other regions indicates strong advantages to wind development in Tasmania. The most apparent benefit is simply stronger wind and few days of low wind output. This results in higher capacity factor – or more simply – more energy for every turbine that is installed.

Table 6 shows analysis of actual wind farm generation data from existing wind plant from July 1 2015 to June 30 2017. The relative benefit in terms of capacity factor has historically been very strong.

The value of this wind was then assessed against the Victorian spot price as a central market[6]. The relative value of aggregated Tasmanian wind is substantially higher than the aggregated wind generation from other states – there is in fact a premium on top of the capacity factor benefit based on the value of diversity.

Tasmanian wind has a higher chance of producing during times of energy scarcity and a lower chance of producing in times of energy surplus in Victoria. A direct comparison of real wind energy built in Tasmania contrasted with real wind energy built in Victoria shows that the Tasmanian energy has a total value benefit of ~31% per MW installed.

This ability to generate at different times can help spread the availability of wind energy across a broader timespan and increase its overall reliability in the NEM. This is a substantial benefit. It should also be noted that this benefit does not exist if the energy cannot be transferred to a load source – so interconnection is a prerequisite for further development[7].

The *Battery of the Nation* Future State NEM analysis models new wind development only in the context of sufficiently increased interconnection and storage.

[6] All regions with active wind farms during this period were connected to Victoria and this would also be the logical market that developments proposed by *Battery of the Nation* would either export into or potentially even merge with under higher interconnection levels.

[7] System studies have shown that further major wind development beyond Cattle Hill and Granville Harbour is likely to be challenging in the Tasmanian system without further asset development.

	NSW	SA	TAS	VIC	Volume Weighted Mean
Average Capacity Factor (%)	0.32	0.33	0.39	0.31	0.33
Relative Capacity Factor (% improvement in capacity against Volume Weighted Mean)	-0.40	0.25	18.33	-4.83	N/A
Annual Average Generation at Vic Spot Price – calculated half hourly ('000 $/MW)	299	289	361	271	291
Relative Value (% improvement in value against Volume Weighted Mean)	2.67	-0.54	24.06	-6.86	N/A
Relative Value of Timing (% improvement in value, excluding capacity factor benefit)	3.08	-0.78	4.84	-2.12	N/A

Table 6. Comparison of value of average wind energy installed in each region

5.2.2.2 Modelled impact of wind for *Battery of the Nation*

Tasmanian energy developments would unlock substantial new investment in Tasmania's high quality wind resource.

During the dispatch modelling the NoTasDev case, a counterfactual modelling run, was undertaken with exactly the same assumptions, only without the addition of the developments proposed by *Battery of the Nation*.

This allows the analysis of the impact of *Battery of the Nation* in terms of the change in wind generation patterns across the NEM. This analysis has used the last 5 years of the modelled data (2046/47 to 2050/51) to capture the full effects of the change.

Table 7 shows the modelled correlations of half hourly wind generation of the states in the NEM, including a correlation with the volume weighted total wind generation across the entire NEM.

Post-processing of the modelled data shows that Tasmania has the least correlated wind resource in the nation – meaning that during periods of low wind generation on the mainland, there will be a higher incidence of wind generation in Tasmania than in any other state. This finding replicates observed wind generation patterns that already exist in the NEM[8] and further validates the input data for the modelling.

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[8] It is worth noting that the correlation between Tasmania and New South Wales is substantially understated, the correlation between Tasmania and Victoria is slightly overstated and the correlations between Victoria and New South Wales and Victoria and South Australia are both understated. This does impact the model results although it is difficult to estimate the magnitude of the effect. This is an area for improvement in future modelling. The observed wind generation patterns show that by aggregating wind to daily averages, the correlation between regions increases. This is a logical outcome based on large scale weather patterns. Unfortunately the modelled outputs show a slight decrease in correlations, particularly with reference to Tasmanian weather patterns. This would have the tendency to underestimate the importance of longer term storage, particularly in Tasmania. This is considered to be an inaccuracy which increases the conservatism of this report.

	Tasmania	Victoria	South Australia	New South Wales	Queensland
Tasmania	1				
Victoria	0.5475	1			
South Australia	0.0729	0.4836	1		
New South Wales	0.0568	0.3252	0.2682	1	
Queensland	-0.1051	-0.0496	0.0234	0.2797	1

Table 7. Correlation of modelled half hourly wind energy generation between regions in the NEM

This has notable value in terms of the management of the resources across the NEM. Sharing resource diversity is recognised as a cost-effective way to balance the energy system. Tasmania's wind has an inherent advantage compared with other states.

Table 8 shows the relative correlation of wind energy in individual regions compared with the total wind generation in the NEM.

Observations over years of generation data also show that as the wind is aggregated over longer periods (e.g. daily) the regional correlations increase. The weather patterns that drive daily wind generation tend to be larger and therefore affect larger geographical areas.

One common belief is that wind diversity across the nation will largely smooth out variation in generation. This comes from the misconception that it is always windy somewhere in the NEM and is "confirmed" by analysis of the annualised diurnal cycle of the national wind generation.

However, this approach loses the resolution required to adequately capture the profile of high wind generation and low wind generation times. Figure 39 shows histogram data for the national wind generation from the NoTasDev modelling run (no further energy developments in Tasmania beyond Cattle Hill and Granville Harbour wind farms) and the 5IC Strong scenario which represents the largest wind penetration in Tasmania as part of a *Battery of the Nation* build out; more detail can be found in Appendix D.

The plots show the aggregated wind generation across the NEM in terms of the relative amount of time spent in each decile of the histogram spread across total capacity. For example, in the NoTasDev case, across the entire NEM, the aggregated wind was producing less than 10% of total capacity for about 5% of the time.

Comparing the two traces highlights that with substantial contribution from Tasmania, the national wind profile spends far more time in the most useful range and less time generating low amounts of energy. It also spends slightly less time generating in the very high range. On first impression, this may be seen as a loss – yet these events result in substantial energy generation and consequently cause energy spill.

Additional energy at these times has very little value to the market. The change in this profile would logically indicate that Tasmanian wind would therefore have strong benefit in terms of the additional value due to the relative timing – much like the benefit demonstrated in Table 6.

Scenarios	Tasmania	Victoria	South Australia	New South Wales	Queensland
NoTasDev	0.285	0.697	0.555	0.877	0.302
5IC Strong	0.549	0.748	0.492	0.769	0.176

Table 8. Correlation of modelled half hourly wind energy in each region with total national wind

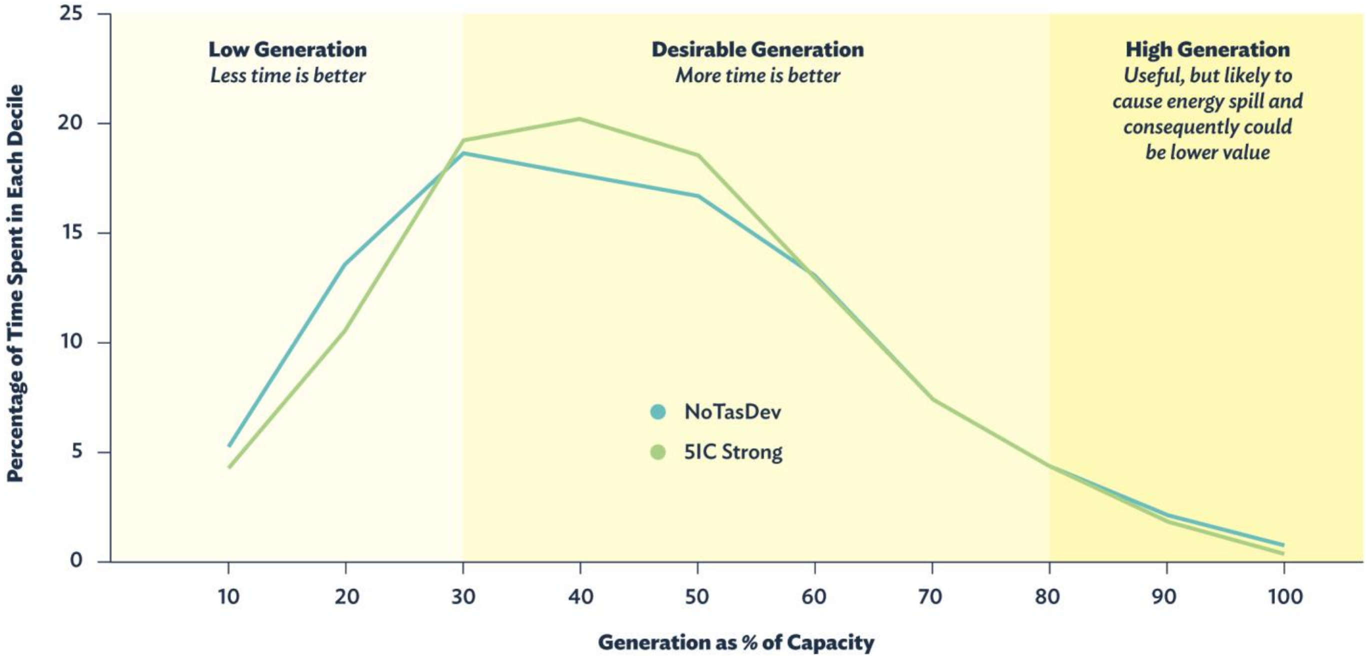

Figure 39. National wind generation profile

It should be noted that the diversity value of wind in Tasmania is also influenced by the increasing solar penetration.

Unlike wind, solar patterns across a state (and even much of the NEM) are frequently coincident and consequently solar can have a significant influence on energy generation patterns; including in regions where solar is not the dominant energy producer. This influence was noted in the modelling results, even for Victoria[9].

Tasmania's daily wind generation profile is reasonably flat with a late afternoon/early evening peak. This is presently a valuable shape (at least in terms of annual averages).

However, Victorian wind has a strong anti-correlation with solar which gains more relevance in later years and starts to impact the value advantage of Tasmanian wind, see Figure 40.

The growth in solar may erode some of the diversity value of Tasmania's wind, but wind is event driven and does not often exhibit "average" behaviour.

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[9] Within this modelling, assumptions were chosen to be conservative in terms of the benefit of the *Battery of the Nation* vision, see Appendix C. One of these conservative assumptions was a steep learning curve for solar which results in it outcompeting wind in later decades – even in more southern states. However, generically, wind and solar are expected to reach cost parity in terms of energy production at approximately $50-$60/MWh. Wind has characteristics which require more large scale and long term storage, which would favour *Battery of the Nation* more strongly.

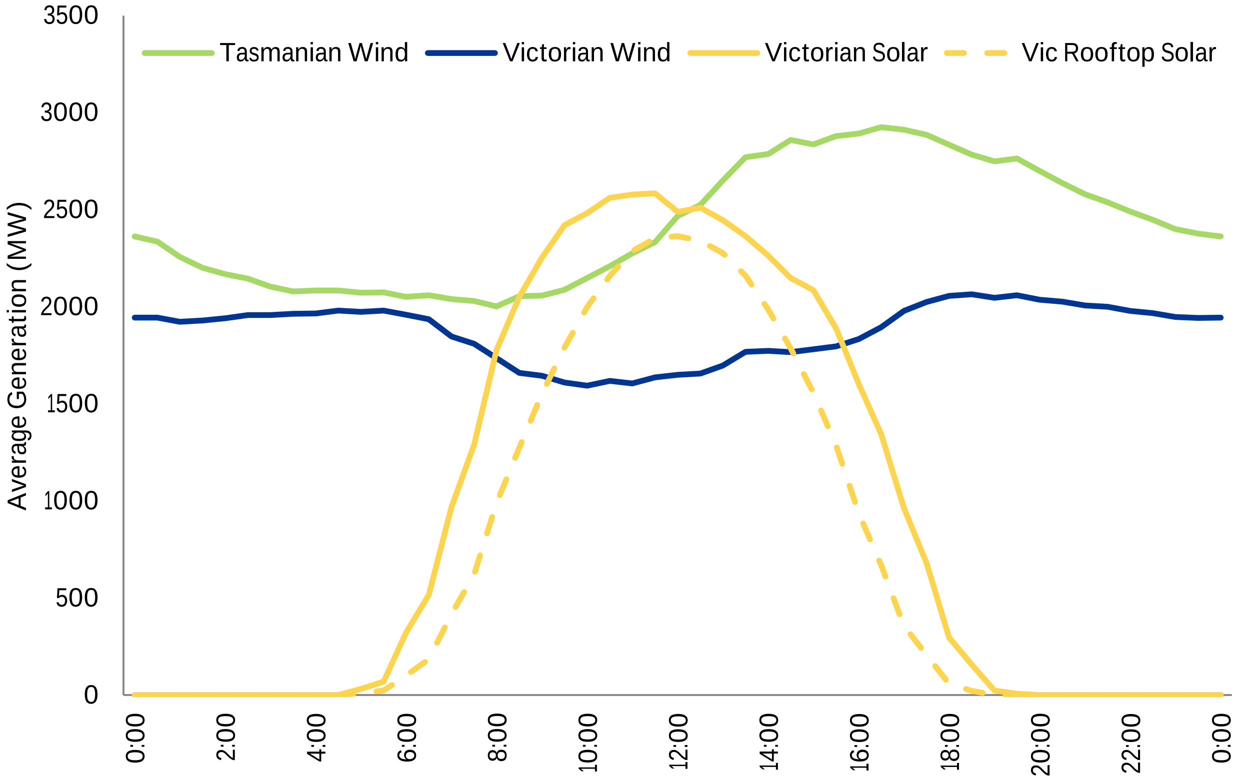


Figure 40. Average modelled generation profile in 2050-51 (5IC Strong)

Initial examination of Figure 40 may lead to the assumption that wind tends to be reasonably consistent and able to replicate baseload energy. However, familiarity with actual operations of wind plant indicates that this is not true as evidenced in Figure 39.

Market experience indicates that the occurrence of consecutive days with little wind generation is not uncommon, and it is considered useful to explore this more quantitatively.

Each occurrence of two consecutive days of low wind generation (<20% of maximum capacity across the entire NEM) was counted for each year in the modelling; these results are shown in Figure 41. In the early years, these sustained periods of low wind generation occur approximately every two weeks. As more wind generation is installed, this frequency drops to 20 events a year under the NoTasDev modelling run.

With the largest *Battery of the Nation* scenario, the frequency drops to 15 events a year. Note that once the modelled *Battery of the Nation* wind build out finalises in the early 2040s, the relative influence of Tasmanian wind reduces over time and the count of low wind energy periods starts to rise again.

There is a measurable benefit in building wind generation in Tasmania. Tasmanian wind generation provides some level of system balancing, reducing the need for storage.

However, no matter how much geographic diversity is achieved in the NEM – there are still extended periods of low wind energy output.

> *No matter how much geographic diversity is achieved in the NEM – there are still extended periods of low wind energy output.*

Using a stricter measure of consecutive half hours of low generation, each year in the modelling of the NoTasDev still records a period with around 90 hours of continuous low wind generation.

The 5IC Strong modelling only shows this reducing to around 80 hours of continuous low wind generation. The NEM will need supply options that can fill these extended gaps. This storage will have a synergistic relationship with the variable renewables.

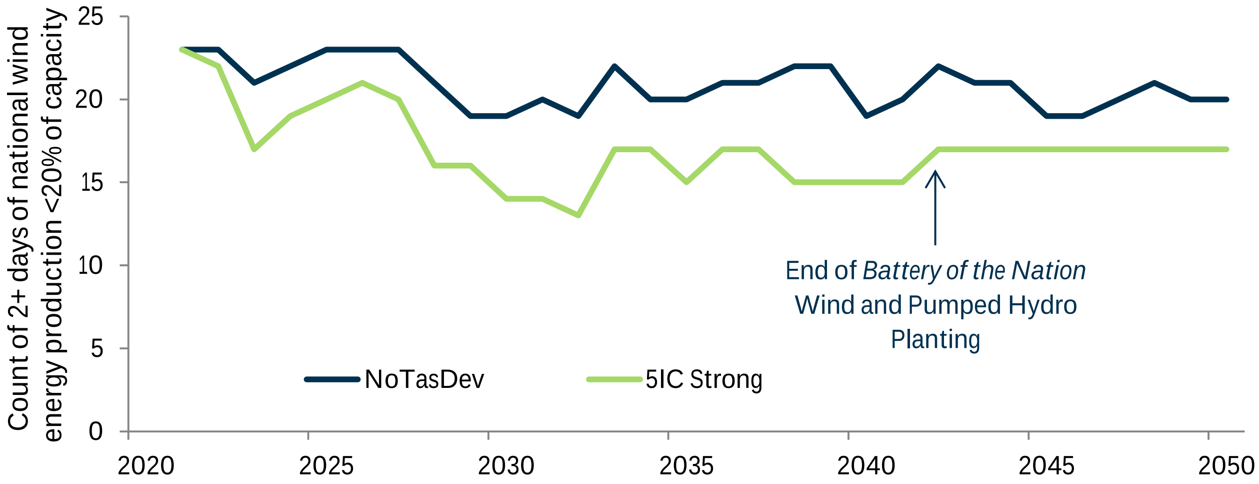


Figure 41. Count of sustained low wind periods

5.2.2.3 Return on investment for Tasmanian wind energy

An argument often used against substantial penetration of variable renewable energy sources is that once the market reaches saturation (and there would be times of excess generation), it would be illogical to continue to build.

However, the following figures highlight that variable renewable energy sources can produce excess energy (sold at zero price) for some periods if the remaining time still results in a return on investment that will meet the levelised cost of energy for the generator.

The assumptions for the modelling presented in this report allow for wind to reach a levelised cost of energy of approximately $50-$60/MWh; it should be noted that this is also reflected in the Finkel Report. This means that while wind continues to make $50-$60/MWh, the wind farms are returning on investment. Returns greater than this provide a price signal for further investment.

Figure 42 shows the annual income for wind projects across the NEM (excluding renewable energy certificates). It is possible to see that even under 5IC Strong (which has 6500 MW of wind energy installed in Tasmania) the wind projects are still making a substantial profit. There are still price signals to build in most years. Comparison of 5IC Strong and 5IC Low show the relative impact of adding substantial wind capacity in Tasmania.

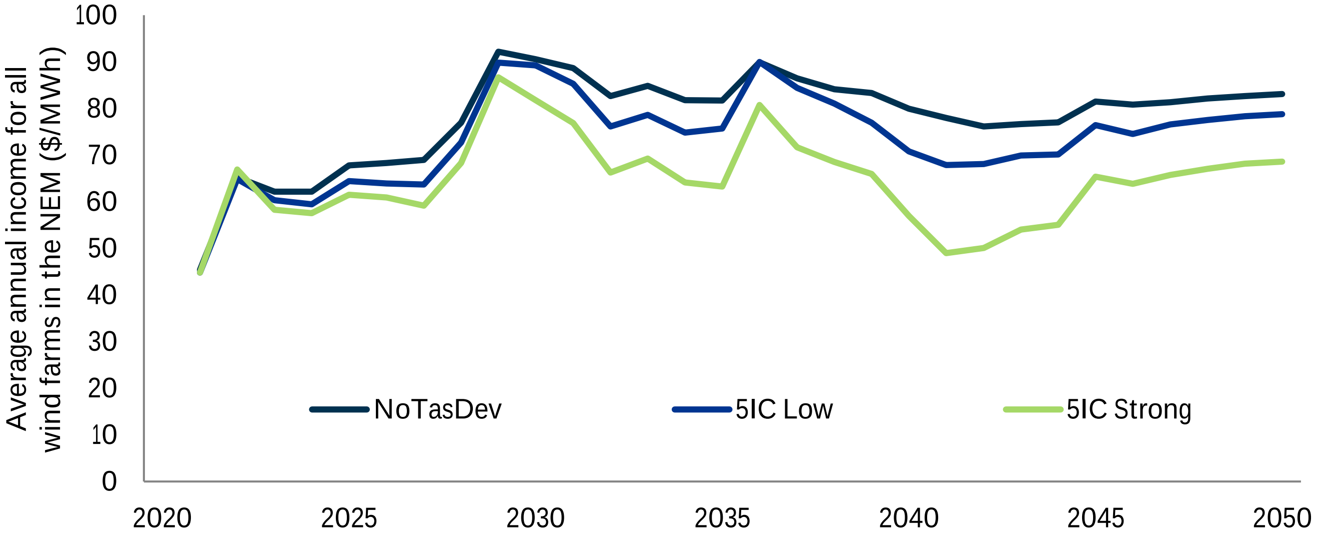


Figure 42. Annual wind income average across all wind projects in the NEM

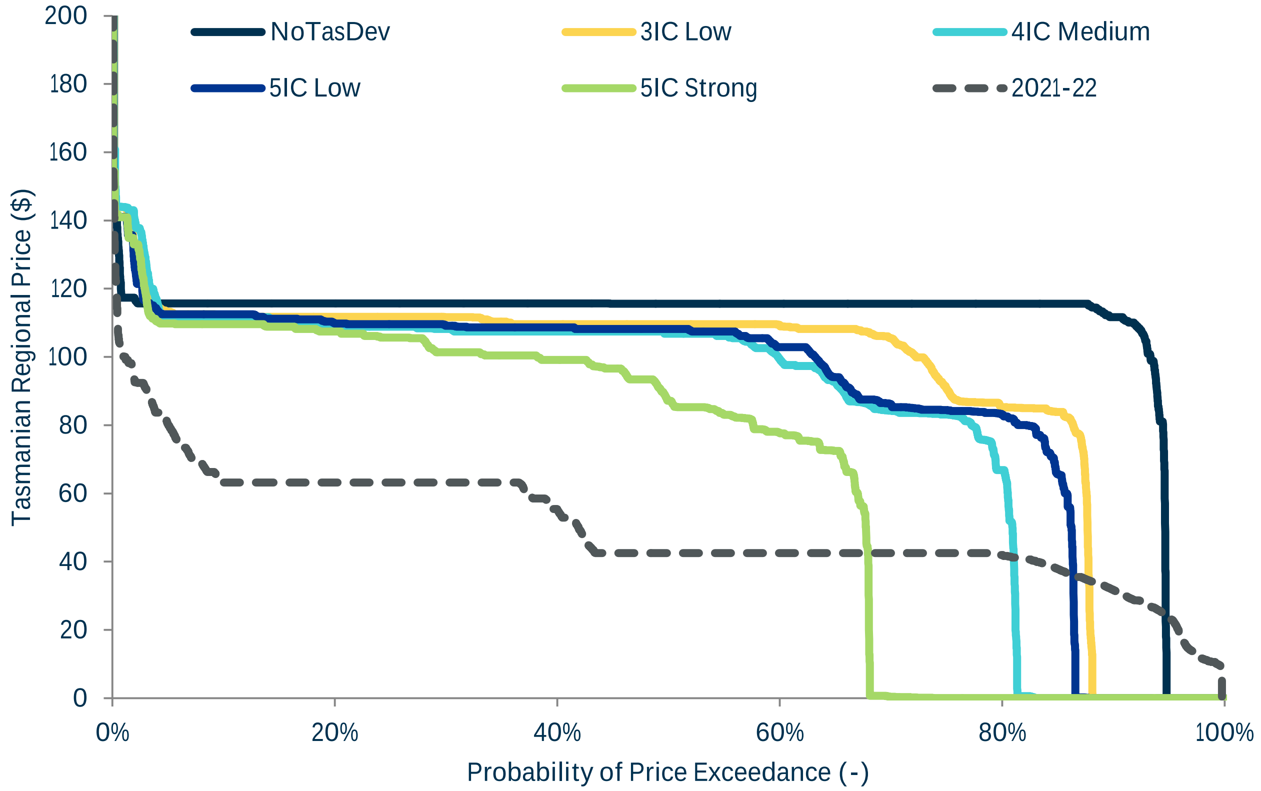


Figure 43. Comparison of price duration curves from various scenarios

Even with the price signal to build more wind there is a substantial amount of 'spill'. Figure 43 shows the price duration curves for all scenarios in the last year of the modelling contrasted with the first year of modelling (when there was little variation between the scenarios). The trace for 2021-2022 is reasonably familiar and reflects the power system operating fairly well with an energy mix very similar to today. In later years the price duration curve essentially acts as a step function where the price is set by gas (~$115) or excess energy spill ($0).

With increasing amounts of both pumped hydro and wind to help provide energy for pumping, the price duration curve starts to be set by hydro or pumped hydro more often. This contributes substantially to the savings identified by *Battery of the Nation*.

Increased wind and pumped hydro mean that the price is set more often by hydropower options, contributing to substantial savings identified by Battery of the Nation.

It should be noted that a step function price duration curve is considered unrealistic and highlights the need for different market mechanisms.

5.2.2.4 Scale of the opportunity for wind in Tasmania

In order to establish that substantial wind development in Tasmania is credible, a wind opportunity mapping exercise was undertaken based on knowledge of the land, and resource modelling, see Figure 44.

It was established that there are in excess of 8500 MW of wind sites already identified – arguably more considering other developers will have their own views. There are certainly sufficient opportunities to meet even the most ambitious wind build outs considered by *Battery of the Nation*.

There are substantial opportunities in the West and Centre of Tasmania, both have active wind farm development underway and already have established transmission to service hydropower generators. The North West has tremendous potential; one developer is considering two extremely large wind farms in the area. This would likely receive benefit from substantial transmission as part of the construction of the second interconnector.

The North East also has strong potential, although would need dedicated transmission to unlock the potential, most likely as part of a renewable energy zone initiative.

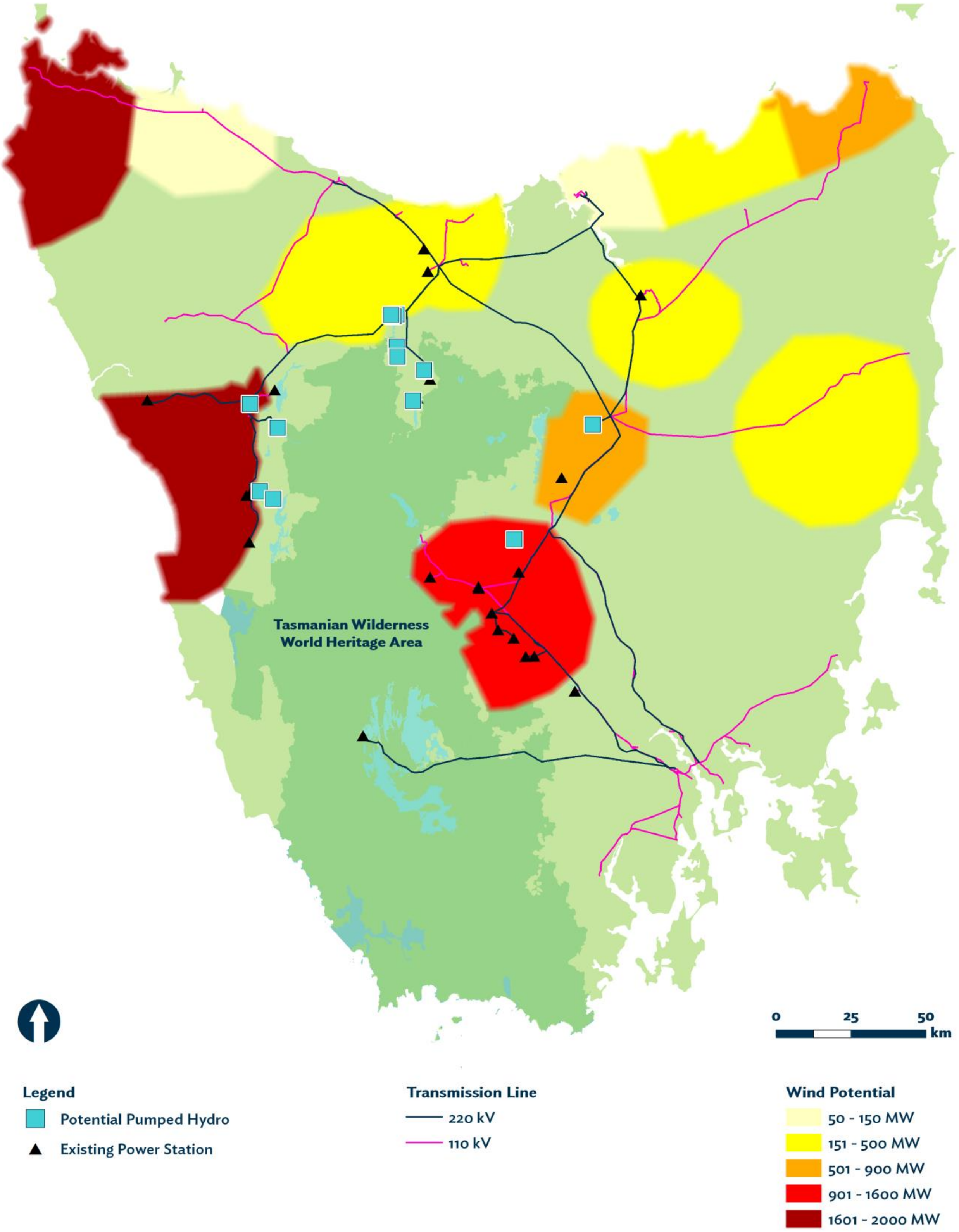


Figure 44. New renewable energy opportunities across Tasmania

Some initial work was undertaken to establish the relative competitiveness of the levelised cost of energy for wind energy from these zones. By careful placement of suitable substations clusters of wind farms can be cost-effective. Some indicative modelling on this showed that the potential for these zones allowed shorter transmission lines, reducing the per unit cost of transmission by 50% compared with mainland opportunities.

Analysing a range of factors indicated that there are GWs of wind potential that could be developed at a lower levelised cost of energy than prospective wind farms that are under development on the mainland.

Substantial growth of wind development in Tasmania could also potentially reduce construction, operations and maintenance costs due to economies of scale in logistics, crane availability and maintenance staffing. It is also considered likely that land access in Tasmania would be easier and potentially more cost effective than mainland options – although as competition for sites increase, the value of good land for wind development may raise as well.

It is even possible that entire zones could be developed to optimise the levelised cost of energy through coordinated planning, be it through a single developer, a consortium or through centralised planning. This could save many of the costs and risks associated with development such as:

- Coordinated wind monitoring,
- Coordinated environmental surveys and approvals,
- Coordinated community engagement – possibly even including coordinated landholder agreements,
- Transportation upgrades (at least to the zone) – potentially including new transportation hubs,
- Turbine and balance of plant standardisation,
- Connection agreement pro forma, and,
- Civil works coordination.

These opportunities for economies of scale and cost savings are not unique to Tasmania – yet may be an important consideration in the cost-effectiveness of a renewable energy zone and how they are developed.

As highlighted in the challenge facing the NEM, there is a growing need for new energy and it is expected that wind developments will provide a lot of that energy. It is not a matter of whether the wind farms will be built, but instead where they will be built.

Further interconnection will not only unlock the opportunity for pumped hydro in Tasmania, it will also unlock the opportunity for wind development. Tasmanian wind is expected to be highly competitive with mainland options and will be built as long as it is economic do so.

5.2.3 Solar development in Tasmania

At present the levelised cost of energy for solar photovoltaics is more expensive than wind when comparing the most favourable locations around Australia. However, the learning curve (cost reduction) of solar is forecast to continue to reduce at a rapid rate.

The projections adopted by AEMO for the Integrated System Planning come from CSIRO's Electricity Generation Technology Cost Projections [CSIRO 2017b]. This work shows solar photovoltaics dropping in levelised cost to match wind, and even be more competitive in the best locations, by 2030. By 2050 solar photovoltaics are projected to have a substantial advantage in terms of the levelised cost of energy.

It should be noted that these projections are unusual in their extended learning rate. CSIRO notes that it has treated both solar photovoltaics and electrochemical batteries differently.

Electricity Generation Technology Cost Projections, 2017, CSIRO

> "Since future science and engineering advances are likely but unknowable in advance, rather than apply the standard approach which implies innovations peter out with growing maturity, the alternative approach we take for these two technologies (solar photovoltaics and electrochemical batteries) is to apply their high historically observed learning rate indefinitely. In practice, this means these technologies can achieve steeper cost reduction curves for longer than other technologies."

This assumption leads to substantially reduced costs for each of these technologies and the statement that the unknown engineering advances are expected to continue is considered more a statement of belief than science. In addition, the authors highlight that CSIRO’s cost projections for solar have tended to be more bullish than other projections.

Nevertheless, the modelling for *Battery of the Nation* did adopt a strong learning rate for solar which sees the levelised cost of energy for solar drop to well below that of wind by the later stages of the modelling.

The acceptance of this work makes this a defensible assumption; although it is acknowledged that this is likely to be a conservative assumption from the perspective of Tasmanian wind value in *Battery of the Nation*.

Cheaper solar may displace wind in the later years of the modelling – although it should be noted that the relative coincidence of solar will also limit the value of its energy. Equally, substantial solar photovoltaic generation tends to promote the use of storage since any energy that would be used to meet at night time demand will need to be stored.

In this first phase of the modelling, the majority of new Tasmanian generation was built in response to mainland retirements beginning in 2028. In this period, solar photovoltaic generation was not yet cost-competitive with wind in Tasmania, especially given local capacity factors. This is expected to be a topic for further investigation in the future.

There are four key factors that need further consideration:

- solar irradiance
- technology options
- effect of latitude, and
- time of generation.

Firstly, solar irradiance is typically assessed as either:

- Global Horizontal Irradiance (GHI), which measures the solar irradiance from all angles on a flat plate; or,
- Direct Normal Irradiance (DNI), which measures the solar irradiance that is normal (coming at right angles) to a plate tilted towards the sun at all times.

The levelised cost of energy slightly oversimplifies the technology options. For solar photovoltaic installations there are three broad technology categories: fixed location, single axis tracking (i.e. following the sun from the east to the west) and dual axis tracking (following the daily progress of the sun and also the seasonal height of the sun in the sky).

Tracking technologies add complexity and cost for the payback of higher efficiency. However, at present dual axis tracking is usually considered the least competitive of these options, even though it obtains the highest efficiency from the available DNI.

Consequently, GHI is often considered a better indicator of solar potential. Advances in tracking technology may change this situation in future years, although expert advice indicated that fixed or single axis tracking options are likely to dominate the market in the foreseeable future.

In order to explore Tasmanian potential work was undertaken to compare the GHI and DNI at three sites Tasmania (Poatina), Victoria (Mildura) and Queensland (Lilyvale). First the theoretical maximum irradiance at each location was established by considering ‘clear sky’ irradiance, not affected by clouds of aerosols (e.g. humidity, airborne particulates, etc.) or any of the other factors which reduce or scatter the irradiance.

Figure 45 shows that in summer the Tasmanian GHI is competitive with mainland options and even generates slightly more from the longer days. However, in winter the potential energy generation is substantially reduced. This is the key limiting factor for the energy available from GHI in Tasmania.

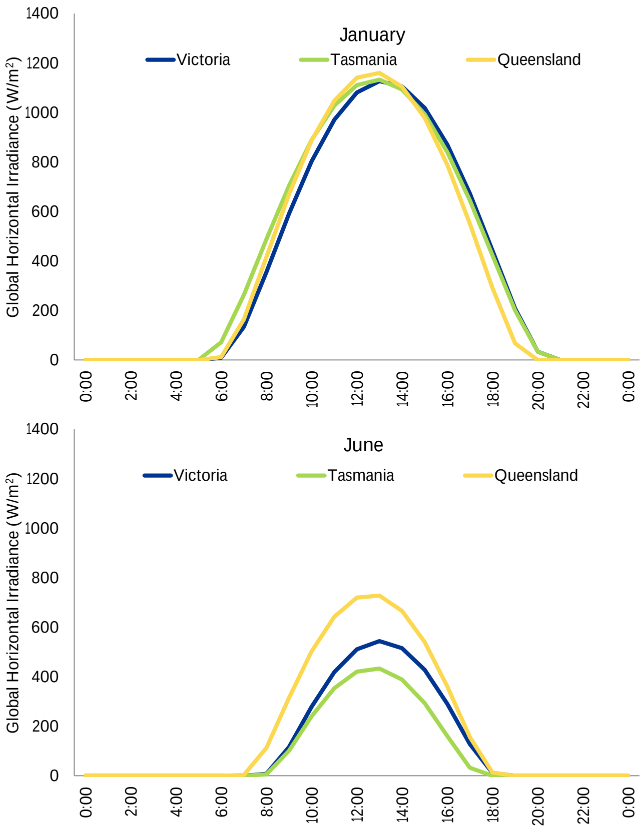


Figure 45. Comparison of clear sky GHI across three sample sites in Australia during the months of January and June

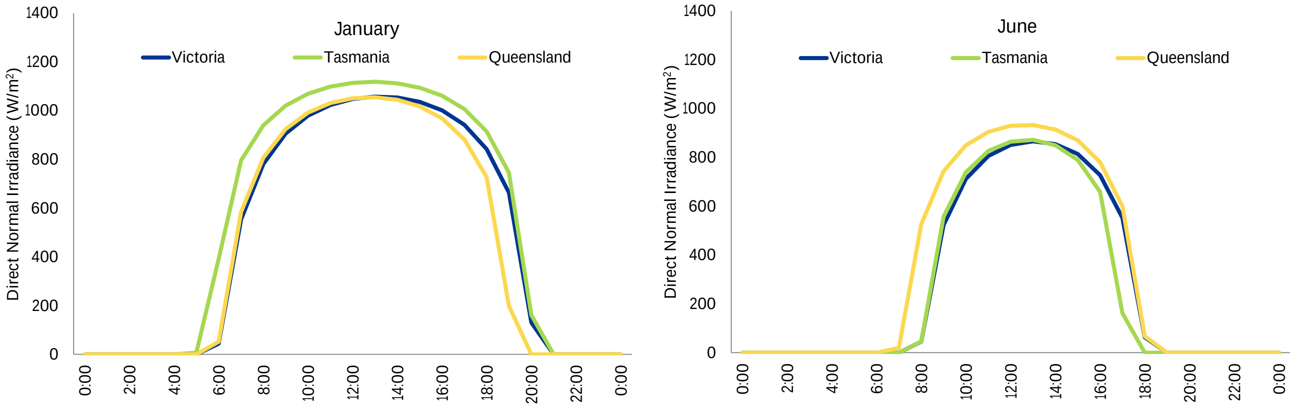


Figure 46. Comparison of clear sky DNI across three sample sites in Australia during the months of January and June

Figure 46 shows the clear sky DNI for the three locations highlighting that the longer days in summer result in a substantial theoretical benefit to the Tasmanian site. It shows again that there is a comparative reduction in energy during the winter months in Tasmania, only this time the reduction is of a similar scale to the gain.

By just considering the clear sky irradiance, it appears that the DNI in Tasmania provides a strong opportunity for development. However, there are still the other factors that need to be included in the comparison.

As noted above, the previous figures presented theoretical irradiances that did not take into consideration the impacts of the atmosphere. Figure 47 and Figure 48 show the same data – but this time the data is modified to account for the atmosphere.

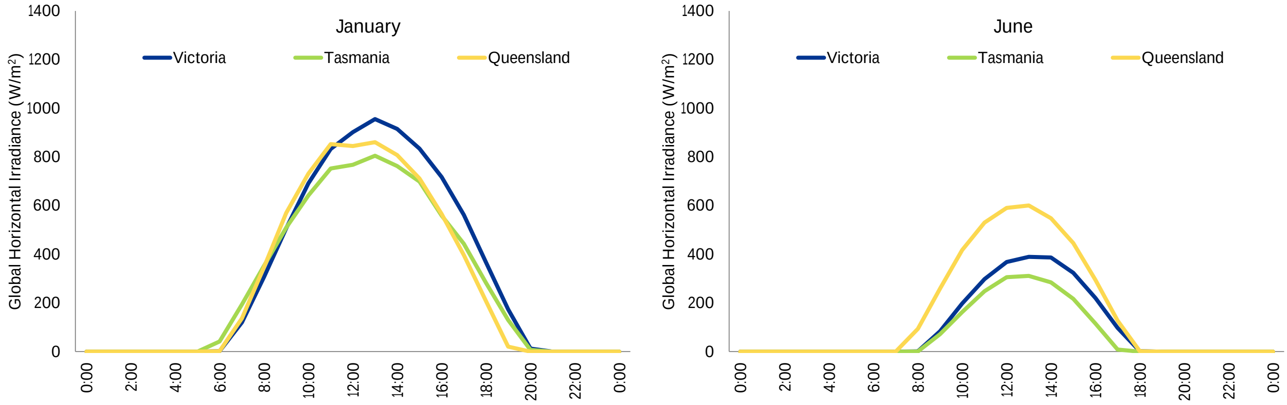


Figure 47. Comparison of annual average GHI across three sample sites in Australia. Note: this is based on observations rather than theoretical clear sky calculations

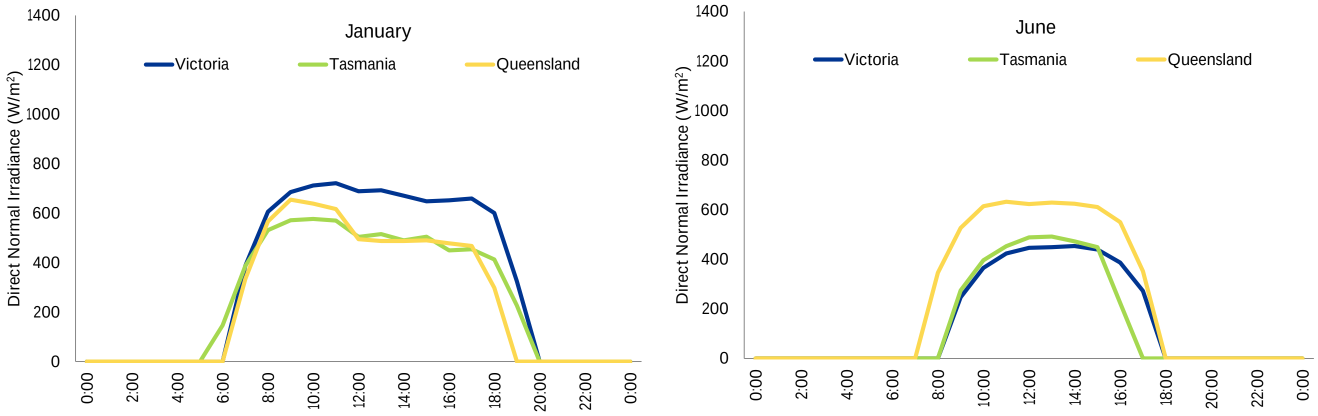


Figure 48. Comparison of annual average DNI across three sample sites in Australia. Note: this is based on observations rather than theoretical clear sky calculations

There is little overall impact in terms of the GHI. Mildura appears to have slightly less impact from clouds, but the scattering due to aerosols has little impact on the GHI.

The Tasmanian opportunity for DNI is somewhat degraded. This can be explained in terms of both presence of clouds (which impacts strongly on DNI) but also the humidity in the air and the distance through the atmosphere. At lower latitudes the sun is lower in the sky which results in a longer path through the atmosphere, increasing the opportunity for the irradiance to be scattered by whatever aerosols are present. It can observed that for both the GHI and the DNI Tasmania has lower irradiance than the mainland options.

While it is noted that Tasmania's resource is lower, it should also be noted that in summer it generates over a longer period in the day. As explained in Section 5.1.1, with substantial addition of solar, particularly rooftop solar, the minimum demand occurs in the middle of the day, the peak demand occurs in the evening hours and there are steep changes in the demand profile as solar generation ramps up or ramps down. This presents a potential opportunity for latitudinal solar diversity to increase in value.

Additional solar power output in summer is also potentially advantageous in Tasmania, because this exhibits a negative correlation with run-of-river hydropower, which is most abundant in winter.

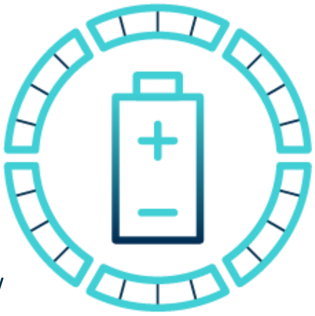
However, the full value of solar power in Tasmania has not yet been tested as part of the *Battery of the Nation* dispatch modelling.

5.2.3.1 Residential generation

While the focus of this work is primarily on centralised and industrial scale options that are likely to be required to address the challenges facing the NEM, rooftop photovoltaics deserve a special mention.

Under present tariff structures significant consumer investment in solar photovoltaic technologies is expected in coming decades. It is also possible that there may be significant investment in household electrochemical batteries.

These technologies have the potential to contribute substantially to the future energy mix. However, the number and size of systems installed will be dependent on government policy and technology commercialisation.



Consumer energy charges and feed-in tariffs currently do not provide accurate signals to the consumer as to the most beneficial use of these technologies from a whole system cost perspective.

For example, there are very few instances of urban households choosing to disconnect from the electricity grid. It is not an economic proposition to have sufficient reserves and storage to disconnect. This means that even households with substantial rooftop PV, and potentially storage, are still connected to the network.

As a rule of thumb, approximately half the energy bill goes towards network costs of transmission and distribution. Electricity networks need to be built to handle the peak (maximum) instantaneous electricity use over the decades-long life of those assets and their costs are included as regulated charges in the tariff.

Installation of rooftop PV (and storage) can reduce energy bills, yet this also reduces the contribution towards the shared grid infrastructure. This then means that the costs for that infrastructure are disproportionately borne by others. This is not considered to be the optimal use of resources across the NEM.

Although it is also important to note that from the perspective of this modelling, substantial solar growth is expected and it makes little difference whether the solar is residential or industrial.

Consumer-level (behind-the-meter) battery technology has potential to reduce the amount of centralised firming required – but household batteries are not yet economic. The uptake of electric vehicles will also introduce potential for grid-connected storage to the system.

However, there is little certainty about the extent of uptake, and more importantly whether policy will successfully incentivise the use (and potential degradation) of the storage capability in vehicles to displace other grid support services. It should be noted that behind-the-meter investment is expected to be limited to short-term storage, a few hours at most.

This will not displace the longer-term storage options presented by the *Battery of the Nation*.

5.2.4 Establishing the cost of transmission/interconnection

During the course of this work the *Battery of the Nation* concept has gained substantial credence. Six months ago (mid-2017) a second interconnector to Tasmania was considered to be a possible outcome sometime in the 2030s; the idea of a third interconnector was considered ambitious and no-one was considering a fourth or fifth.

In order to extract the potential value from Tasmania's natural benefits, substantial interconnection will be required and will be required in a timely manner to meet the opportunity and resolve the problems. The recent announcement by ARENA and the Tasmanian Government to support the business case study of a second interconnector is welcomed by *Battery of the Nation*.

Throughout the Future State NEM analysis, TasNetworks have collaborated with Hydro Tasmania to develop and understand current transmission infrastructure suitability, including asset lifetime expectancy, capacity and other limitations, and to determine appropriate transmission corridor developments, interconnector route options, interconnector landing locations and potential upgrades of existing infrastructure linkages.

Development in Tasmania will need upgrades and enhancements to transmission infrastructure.

The planning has taken particular note of interconnection options, resulting in a North West Tasmania transmission development plan, and identification of contingent projects driven by additional Bass Strait interconnection, new wind generation development, and transmission rationalisation in central Tasmania.

TasNetworks has included the following contingent projects in its 2019-24 Revenue Proposal for submission to the Australian Energy Regulator:

1. Second Bass Strait Interconnector, for which a business case study is presently underway.
2. Expansion of transmission capacity from Palmerston to Sheffield.
3. Rationalisation of the southern transmission system to replace the existing 110kV lines, linked to the Tarraleah redevelopment proposal which recently completed pre-feasibility and will shortly commence feasibility.
4. Expansion of transmission capacity in the North West.

Battery of the Nation represents a substantial change to the role that Tasmania plays in the NEM and such an initiative will require significant upgrade in transmission infrastructure and increased interconnection to mainland Australia.

Increased transmission and interconnection will increase the efficiency of resource sharing across the NEM. AEMO has commenced work leading an Integrated System Plan with input from industry participants from around the NEM. The preliminary analyses of renewable energy zones align well with projects currently under consideration for transmission development in regions across the NEM, including *Battery of the Nation*.

AEMO ISP consultation paper, Dec. 2017

> *"…increasing the capacity of interconnection between NEM regions could be pivotal to meeting Australia's long-term energy targets, providing the advantage of the geographic diversity of renewable resources so regions could export power when there is local generation surplus, and import power when needed to meet supply."*

In developing the plan, AEMO proposes to model impacts of specific potential projects, such as additional Bass Strait interconnection. This is critical to initiatives such as *Battery of the Nation*. To properly understand the integrated cost of an energy development project, all elements, including transmission, must be assessed.

It is important to understand that the same topography in Tasmania that facilitates competitive pumped hydro energy storage provides challenges for transmission network development, although shorter distances also provide the opportunity for cost saving.

5.2.4.1 Comparison of interconnection options

Traditionally the fact that Bass Strait separates Tasmania from the mainland has been seen as a challenging and expensive hurdle to overcome in relation to interconnection. A common misconception about Bass Strait interconnection is that it is prohibitively expensive. When Basslink was first commissioned it was an ambitious project in terms of undersea high voltage direct current cables around the world. Since that time technology has progressed substantially as has experience with these installations.

To further develop the case for interconnection and Tasmanian renewable energy development, the relative cost-effectiveness of transmission and interconnection options was explored. A simplified map of the existing Tasmanian transmission network is shown in Figure 49.

At present there are some weaknesses which would need to be addressed as part of an interconnection project, particularly in the north-west and also the central line from Sheffield to Palmerston. While the exact order and scale of Bass Strait interconnection is far from established, some potential lines were proposed to be able to establish comparative interconnection options and costs.

Figure 49. Transmission map of Tasmania showing 220kV lines in navy blue, 110kV lines in teal and interconnection in blue

Second interconnector: For the purpose of this comparison, the second interconnector has been assumed to connect Port Latta and Anglesea. In addition to the interconnector, transmission capacity from Port Latta to Burnie, Burnie to Sheffield and Sheffield to Palmerston would all need to be strengthened.

Third interconnector: The third interconnector has been assumed to connect Burnie to Melbourne directly (likely landing near the ageing Newport combined cycle gas turbine). This opportunity to provide substantial power into the heart of Melbourne has substantial value since transmission corridors in major cities are often extremely expensive and both Sydney and Melbourne would benefit from more power provided into the city centres.

However, the nature of that opportunity also means that it would need to be operated nearly exclusively as Tasmanian export and so has been identified as more suitable for the third interconnector; according to *Battery of the Nation* build out scenarios, by that time Tasmania will predominantly be an energy exporter.

In order to utilise this link, the Burnie to Sheffield line is strengthened further and the transmission south of Palmerston is strengthened to provide better access to the resources in the south.

Fourth interconnector: The fourth interconnector has been assumed to connect Burnie to Tyabb. It also assumes strengthening of the Farrell to Burnie line to provide better access to the resources on the west coast of Tasmania.

Fifth interconnector: Finally, the fifth interconnector has been assumed to go between George Town and a suitable place to access the transmission corridors in the Latrobe Valley. This is expected to trigger further strengthening of the Sheffield to Palmerston backbone, the Palmerston to George Town line and has also been assumed to trigger additional transmission to the north east to access the wind resources there.

Again, this potential scenario of interconnectors is purely designed to provide an opportunity for comparison.

Information from the AEMO Integrated System Plan and a fact sheet from ElectraNet [ElectraNet 2016] were used for the base comparison of mainland interconnector options.

There are many options being considered across the NEM, the options selected for this comparison were purely chosen based on available information. The results are shown in Figure 50.

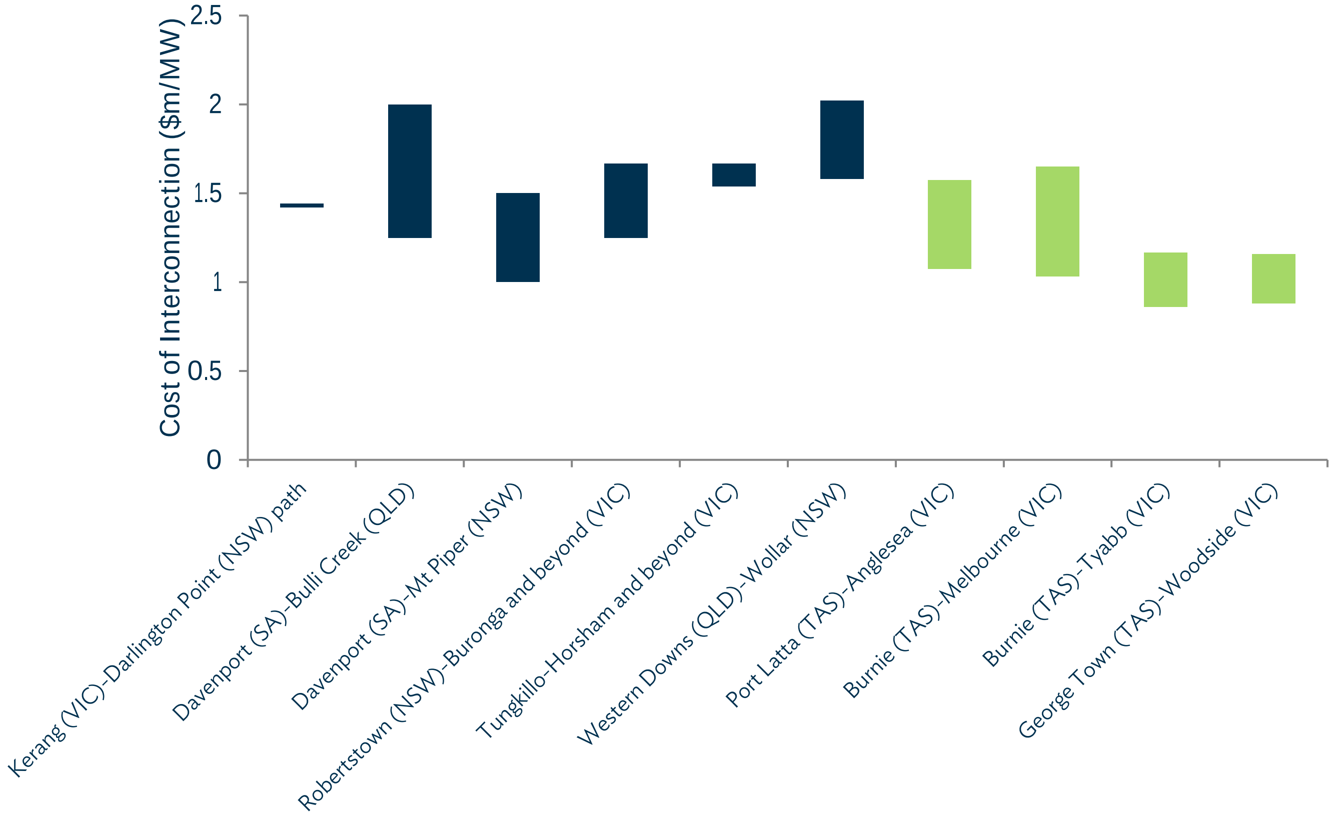


Figure 50. Per unit cost ranges for interconnection comparing mainland options (navy blue) with Bass Strait options (green)

Contrary to most assumptions, interconnection across Bass Strait is not prohibitively expensive. The routes of transmission are typically two to three times shorter than interconnection options on the mainland. The options for Bass Strait interconnection would also enjoy substantially lower losses due to both shorter distances and the use of high voltage direct current (HVDC) cables. Moreover, experience has shown that HVDC infrastructure can supply services from its power electronics which may add further value to the market, although it cannot transfer inertia.

Another important point is that the transmission required to unlock new renewable energy zones has been considered as integral parts of the interconnection for the purpose of this analysis. This would provide access to several thousand MWs of wind energy potential and a similar amount of pumped hydro potential as highlighted in Figure 44.

Other regions also have substantial opportunities for renewable energy zones, yet these are not necessarily accessed through the interconnection options provided above. For example, the far north Queensland opportunities are likely to need over 1000 km of strong transmission, likely to be sourced at a cost of approximately $2 million/km (based on the cost of a 500 kV line).

Even the opportunities in New South Wales are likely to require long and large transmission lines that may cost an average of approximately $500 million per zone.

The advantage of short on-island transmission for Tasmania would also result in lower losses and higher overall system efficiency, especially with substantial wind energy being transferred to nearby pumped hydro storages.

It is preferable that the issue of interconnection in the NEM be resolved at a whole-of-system level. This would drive the most efficient outcome to resolve a national challenge.

The relatively low cost of transmission and interconnection for Tasmanian options is a substantial advantage for *Battery of the Nation*. Furthermore, the opportunities presented by Tasmania are modular in nature, allowing for optionality.

This benefit is afforded by the shorter distances required meaning that multiple transmission lines/interconnectors are still cost effective, unlike some of the distances being faced by options on the mainland.

It should be noted that *Battery of the Nation* sees substantial value in diversity of resource and technology. This analysis is not intended to deny that other opportunities exist, indeed they are also seen as valuable; however, the *Battery of the Nation* proposal is economically competitive and will therefore provide benefit as a priority initiative in terms of energy equity / affordability.

5.2.5 Competitive options for responsive dispatchable supply

A core part of the challenge facing the NEM is that the generation mix is changing with large amounts of reasonably reliable generation plant likely to be replaced with large amounts of wind and solar generation, which is variable in nature. Australia has high reliability standards and consequently substantial quantities of dispatchable energy are required to produce an equitable and economic outcome for the NEM.

Section 5.1 addresses a number of the options to provide energy reliability. The optimal mix of supply options is likely to utilise a range of technologies, each providing the services for which they are most effective. Assessing a complete market need and priority across various national options is difficult since the required quantity of each of the services (and even the full definition of services and markets) are not yet established.

However, it is possible to compare options at a high level in terms of identifying which services can be provided at lowest cost by which technologies. The primary technologies that can provide responsive (i.e. fast change) dispatchable energy are open cycle gas turbines, conventional hydropower, pumped hydro and electrochemical batteries.

Conventional hydropower has a number of advantages for the system, but the options for new conventional hydropower plant are limited. **Given the scale of the challenge facing the NEM, it is considered that new hydropower stations are unlikely to have material effect on the balance in the power system.**

This leaves three technologies which can substantially contribute to the challenge: pumped hydro, open cycle gas turbines (OCGTs) and battery storage.

Of the three technologies, OCGTs are the most established in the NEM. While OCGTs are often thought of as pure peak capacity, the reality of their operations shows that when operating they usually operate for a period of hours – providing both capacity and energy [AEC 2017]. This concept of 'sustained capacity' is critical to operating a power system with significant penetration of variable renewable energy; especially if the intention is to use storage for firming.

Assuming sufficient gas supply and pipeline capacity (an assumption which is coming under more scrutiny in the market[10]), gas can generate new energy with theoretically unlimited ability to sustain capacity while also being able to respond reasonably rapidly to varying needs for generation. These characteristics have made gas a critical part of the energy security mix in the NEM for decades.

Recent gas prices have resulted in gas becoming increasingly expensive and it is worthwhile exploring the economics of gas compared against another option for sustained capacity: pumped hydro. The relative cost effectiveness of pumped hydro compared with batteries, particularly in terms of storage duration, is also worthy of comparison.

Key Information

For this comparison the pumped hydro capital costs for *Battery of the Nation* have been split into three bands:

- Low: $1.05 million per MW
- Mid: $1.3 million per MW, and
- High: $1.5 million per MW

The *Battery of the Nation* initiative also includes an options study for pumped hydro opportunities in Tasmania [HT 2018a]. This study identified 4800 MW of potential pumped hydro opportunities with approximately 140 GWh of total storage in this price range.

As pumped hydro energy storage project costs are highly site dependent, it is not meaningful to relate these costs per MW to storage size, other than to say that these projects have a range of storage durations from half a day to several days.

5.2.5.1 Comparison of pumped hydro and Open Cycle Gas Turbine (OCGT)

This section provides a high-level financial analysis comparing pumped hydro energy storage with OCGTs. Flexible plant can target high price periods – yet financing plant on this basis can be risky due to substantial year-to-year variance. The following financial analysis therefore adopts a value-stacking approach of both spot market and contract market returns.

The present spot market model is centred on a concept of short run marginal cost (SRMC). The theory is that each plant bids into the generation stack at their cost to generate. Under this model, the plant that is highest in the stack does not make any return on investment from the spot price.

The modelling undertaken for *Battery of the Nation* adheres strictly to this principle. The operators of assets which are usually dispatched at prices near their SRMC achieve their financial return through selling 'cap contracts'.

Cap contracts are essentially insurance products. The seller (generator) is paid the 'cap price' throughout the year as a form of premium. The buyer (consumer) receives certainty that they will not have to pay more than the 'strike price' (i.e. the cap, commonly traded at $300). The seller will cover these contracts by ensuring that they always generate into prices higher than the cap, at least to the volume of their cap contracts, to avoid paying the high spot prices themselves to meet the contracts.

For the purpose of this analysis it is assumed that OCGTs will be able to cover cap contracts in the future five minute settlement market, although there is some uncertainty about whether conventional gas turbines would be able to respond fast enough[11] [AEC 2017]. For this comparison, it is assumed that the market cap price will be set by OCGT peaking plant operators to cover the plant's fixed costs: annualised capital costs plus fixed operation and maintenance costs (FOM).

The following assumptions are taken from the modelling assumptions, largely based on the 2016 National Transmission and Network Development Plan (NTNDP); see Appendix C.

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[10] There is an increasing level of attention on gas pipeline capacity and costs – most modelling studies, including Finkel and AEMO's recent commencement on the Integrated System Plan, end up with substantial OCGT capacity. This may require substantial additional investment in gas pipelines – which is unlikely to be economic when considering all costs.

[11] More expensive aeroderivative plant would be able to respond more quickly. For the purposes of this analysis the lower cost conventional turbines have been considered viable to ensure a conservative comparison.

	2030-31 Returns		OCGT	Pumped Hydro		
				Low	Mid	High
Fixed Costs	Capital	$m/MW	1.1	1.05	1.3	1.5
	Annualised capital cost	$/MW p.a.	93 138	88 905	110 073	127 007
	FOM	$/MW p.a.	14 443	28 000	28 000	28 000
	Total annualised cost	$/MW p.a.	107 581	116 905	138 073	155 007
Variable Costs	VOM	$/MWh	10.00	0.15		
	Station net efficiency	--	99%	80%		
	Heat rate	GJ/MWh	12	--		
	Fuel price	$/GJ	10.50	--		
	Fuel/pumping cost	$/MWh	127.27	53.13		
	SRMC	$/MWh	137.27	66.56		
Revenue	Capacity factor	%	10.0%	20.0%		
	Gen-weighted price	$/MWh	152.85	110.58		
	Net generation income	$/MWh	15.58	44.02		
	Annual net generation income	$/MW/yr	13 646	77 119		
	Cap price	$/MWh	12.28	12.28		
	Cap income	$/MW/yr	107 581	107 581		
Totals	Total income	$/MW/yr	121 227	184 700	184 700	184 700
	Total annualised cost	$/MW p.a.	107 581	116 905	138 073	155 007
	Net profit	$/MW/yr	13 646	67 795	46 627	29 693

Table 9. Comparison of incomes and costs for pumped hydro and OCGT

Amortising an OCGT capital cost of $1.1 million per MW, across a 30 year period with a weighted-average cost of capital of 7.5%, results in an annualised capital cost of $93 138 per MW. Allowing for an average OCGT FOM of $14 443 per MW, results in a total annualised cost of $107 581 per MW. To cover the total annualised cost, a cap price of $12.28 per MWh is required across a year.

4800 MW of Tasmanian pumped hydro energy storage opportunities have been identified by the *Battery of the Nation* initiative [HT 2018a] with prices from $1.05 - $1.5 million/MW – this is sufficient for even the strongest *Battery of the Nation* scenario modelled to date. The analysis above uses a low ($1.05 million per MW), medium ($1.3 million per MW) and high ($1.5 million per MW) price.

In order to back their cap contracts, both the OCGT and pumped hydro must always be able to generate into prices in excess of the cap strike price (e.g. $300/MWh). Within the modelling, prices greater than $300 are rare. Across all modelled scenarios, across all years, prices in Victoria or Tasmania are greater than $300 less than 0.25% of the time. Historically, these prices occur more often, although there is substantial variance from year to year.

Below the cap strike price there is an ability to make additional revenue from gas-fired generation or pumped hydro arbitrage[12] (storing at low price periods and supplying at high price periods). The energy values for these calculations are based on a capped price of $300, given the assumptions above for cap contracts as a revenue stream.

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[12] In the future NEM it is expected that there will be a broader set of services that adequately incentivise investment in assets that can provide the required services to support the power system. For the purposes of this analysis the calculations have been limited to energy value only, which is considered to be a conservative position for the total benefit of pumped hydro energy storage.

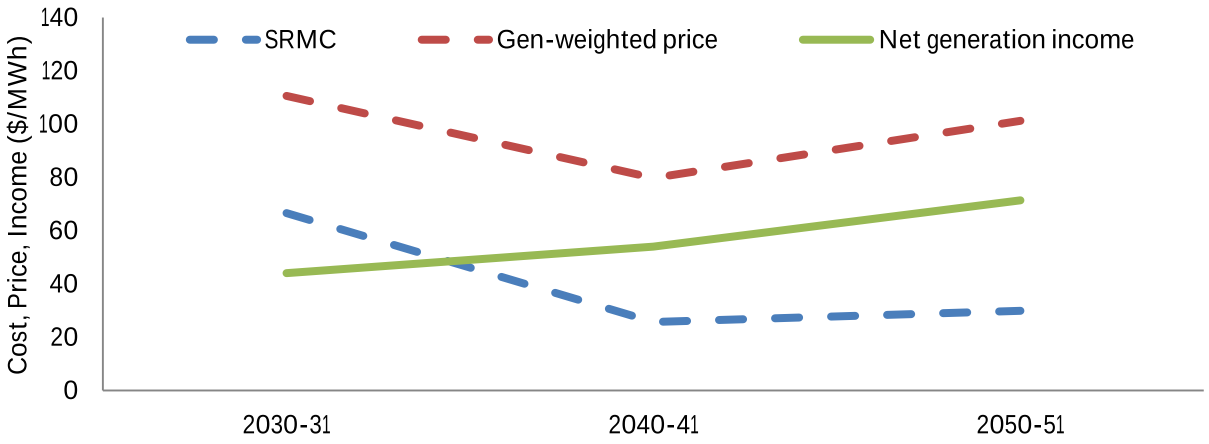

Figure 51. Pumped hydro net income increases over the decades of the modelling, initially due to a reduction in pumping costs then later due to a rise in prices as the relative influence of *Battery of the Nation* developments reduces

To establish a comparison of additional income streams, typical behaviours were considered for 2030-2031, an early year in the coal retirements schedule where there will be substantial opportunity to enter the market. The comparison has been presented for Tasmanian[13] pumped hydro and Victorian OCGT. For the purpose of this calculation the pumped hydro plant is considered to be a 'generator' whose 'fuel cost' is the load-weighted cost of the pumped energy, factored by the round-trip efficiency (~80%). The remaining parameters come from earlier calculations or the assumptions detailed in Appendix C. The comparison is shown in Table 9.

Operation and maintenance costs for pumped hydro used in this section of the analysis are the midpoint of two studies, Sandia National Laboratory (SNL 2015) and Black and Veatch (BVC 2012). This gives a fixed operation and maintenance cost (FOM) of $28 000 MW each year, and a variable operations and maintenance cost (VOM) of $0.15/MWh.

The net profit of the Tasmanian pumped hydro options all make substantially higher returns than the OCGT, even with the conservative assumptions taken. Moreover, gas prices would have to be as low as $9.00/GJ for gas to reach approximate parity with the higher price pumped hydro options and it would have to be as low as $5.40/GJ to reach cost parity with the low cost pumped hydro options.

It is also worth noting that as more wind and solar displace thermal generation, the benefit of storage increases. Similar analysis was undertaken for 2040-41 which is at the end of the modelled *Battery of the Nation* building phase and 2050-51 the end of the entire modelling period. The short run marginal cost falls from $67/MWh down to $26/MWh when low cost variable renewable energy is in excess at times, demonstrated by Figure 43 from Section 5.2.2.3.

Figure 51 shows that the pumped hydro returns are shown to grow across the period of the modelling. Initially, the cost of pumping reduces substantially, increasing the value of arbitrage. Later in the modelling the prices start to rise again as more thermal retirements occur without any corresponding response from *Battery of the Nation* build outs.

The net profit of pumped hydro energy storage is certainly competitive with gas, in fact, while pumped hydro returns increase in 2040-41, gas returns fall to barely breaking even as the price of energy reduces substantially and the gas has little opportunity to operate at prices that would exceed the short run marginal cost of their supply.

Pumped hydro opportunities in Tasmania are of a similar cost to new OCGT plant, yet have a much lower short run marginal cost. This provides pumped hydro the opportunity to provide more cost competitive energy and cap contracts while still returning a positive net profit. The viable opportunities for pumped hydro at the costs possible in Tasmania will be valuable in the future market. Finally, it is worth noting again that OCGT may not be able to support cap contracts in a market with five minute settlements either – which will potentially add further value to the assets flexible enough to respond within such timeframes.

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[13] Tasmanian pumped hydro costs and incomes have been calculated with respect to the Victorian price, adjusted for interconnector losses. This is necessary because the model allows substantial price separation, whereby a significant proportion of pumped hydro income is assigned to interregional residues. Using loss-adjusted Victorian price captures the full value of the service being studied.

5.2.5.2 Comparison of pumped hydro and electrochemical batteries

Electrochemical batteries are becoming much more cost-effective and while the technologies that provide electrochemical storage are quite different from pumped hydro, they both offer similar services to the market at face value. Section 5.1.2 shows that electrochemical batteries and pumped hydro are both able to provide responsive capacity and system security services.

The key differentiator between the two technologies (at least in terms of high level comparison) is the scalability, both technical and economic. Typically storage is priced on a $/kWh or $/MWh basis, yet when compared/plotted against other technologies the implicit assumption is typically one hour duration.

Electrochemical batteries are very cost-competitive for providing short-term storage. However, batteries are unlikely to be cost effective to provide the longer term storage that will also be required, even under aggressive cost reduction expectations.

Figure 52 shows a comparison of electrochemical batteries against pumped hydro using the high cost from *Battery of the Nation*. These are the two main storage technologies being considered in the Australian market. To undertake a balanced comparison, the batteries were considered to be rebuilt every ten years to achieve a 40 year life (although pumped hydro arguably has a much longer life, discount economics make that benefit difficult to realise).

When being rebuilt the batteries were costed at the forecast costs for the year in which they would be rebuilt, and these were also discounted at a rate of 7.5% back to the year of initial installation to recognise the value of deferred payments.

For this analysis the battery costs were derived from CSIRO’s Electricity Generation Technology Cost Projections [CSIRO 2017b], the same source that AEMO is using for its Integrated System Planning consultation paper.

The figure shows that electrochemical batteries are already cost competitive for single hour storage. For services dedicated to very short-term capacity, such as frequency control or urban congestion relief, batteries are already the cheapest form of storage.

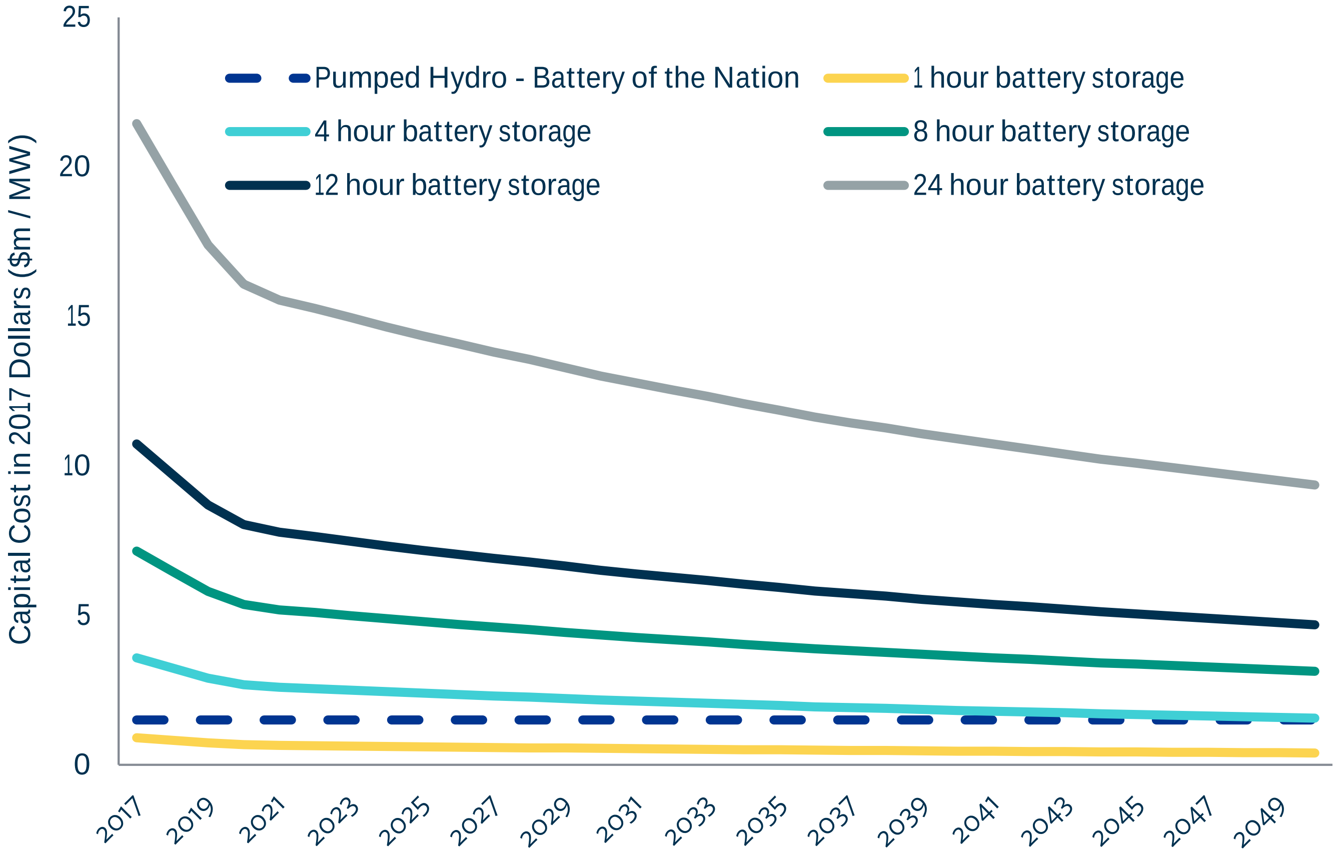


Figure 52. Capital costs for 40 year storage assets (with future expenditure recognised and discounted at 7.5%). Batteries are already cost effective for one hour storage, but are not competitive for longer durations

If longer storage duration is required, batteries rapidly lose their ability to economically scale.

According to these cost forecasts, four hour battery storage will only become cost competitive with Tasmanian pumped hydro energy storage by 2050. The cost and storage size of the pumped hydro opportunities are more influenced by geography and hydrology than electrical or mechanical plant costs and it is not possible to effectively scale these down to smaller installations.

The median size of the Tasmanian pumped hydro opportunities is 24 hours and duration has little correlation to the range of costs from $1.05 to $1.5 million per MW. In fact, the pumped hydro reports from *Battery of the Nation* highlight that there is 4800 MW of potential pumped hydro opportunities with approximately 140 GWh of storage at a price below $1.5 million per MW [HT 2018a, HT 2017]. On this basis, it is considered unlikely that developments over $1.5 million would be selected.

Electrochemical batteries are not cost competitive for storages of several hours of duration, yet they already have the edge for short-term duration.

This demonstrates that a portfolio of energy storage technologies will be needed to provide the best outcomes for energy consumers with the right mix of capacity and duration to supply the services required to support the power system.

A portfolio of energy storage technologies will be needed to provide the best outcomes for energy consumers.

5.2.5.3 The value of long term storage

The actual requirements for storage are difficult to assess because they vary over time as the energy mix of the NEM changes. It is only possible to estimate required levels of capacity and duration if the energy mix is also fixed.

However, understanding the relative value of storage duration is critical to understanding the opportunity for pumped hydro in terms of dispatchable and responsive supply of energy.

One way to assess the value of storage duration is to consider the relative price volatility over a range of time windows. Figure 53 shows a plot of the standard deviation of Victorian prices over different time periods based on the final year of the modelling under the NoTasDev scenario.

For example, the value for two hours is the average (over a full year) of the standard deviation of prices in all 2 hour blocks of time for that year. Standard deviation is one measure of the volatility over the period. Storages of a given size are able to capture the value between periods of low price and high price.

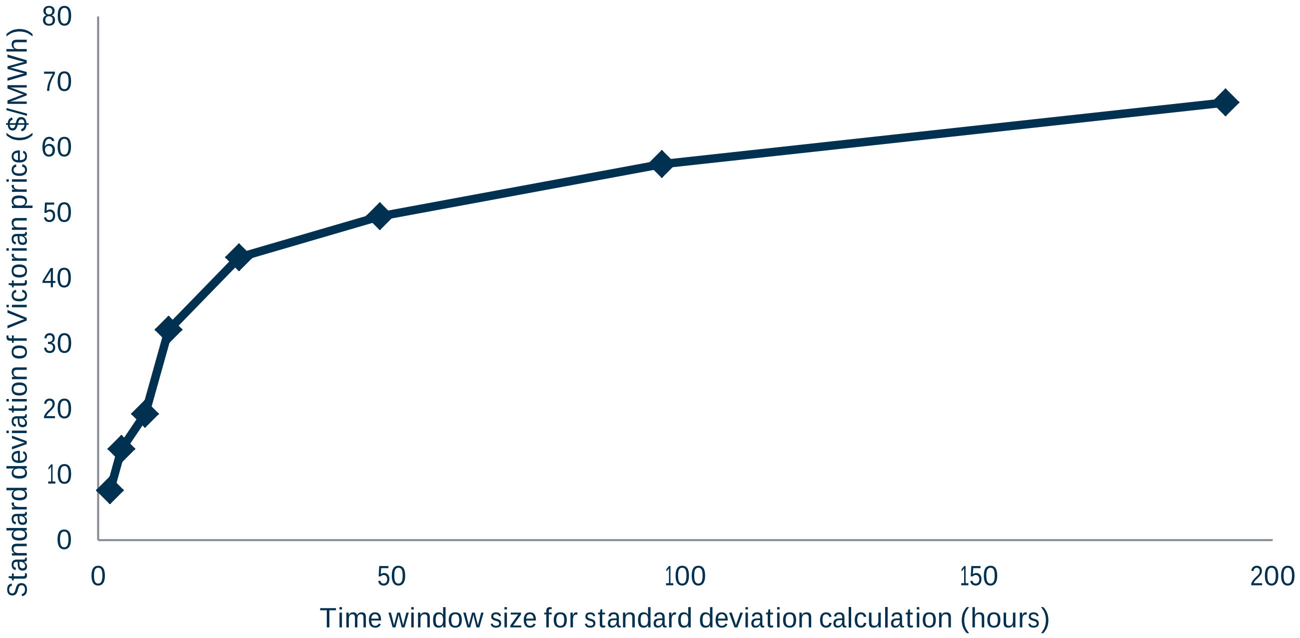


Figure 53. Price volatility of Victorian spot prices over a given window of time under the NoTasDev scenario

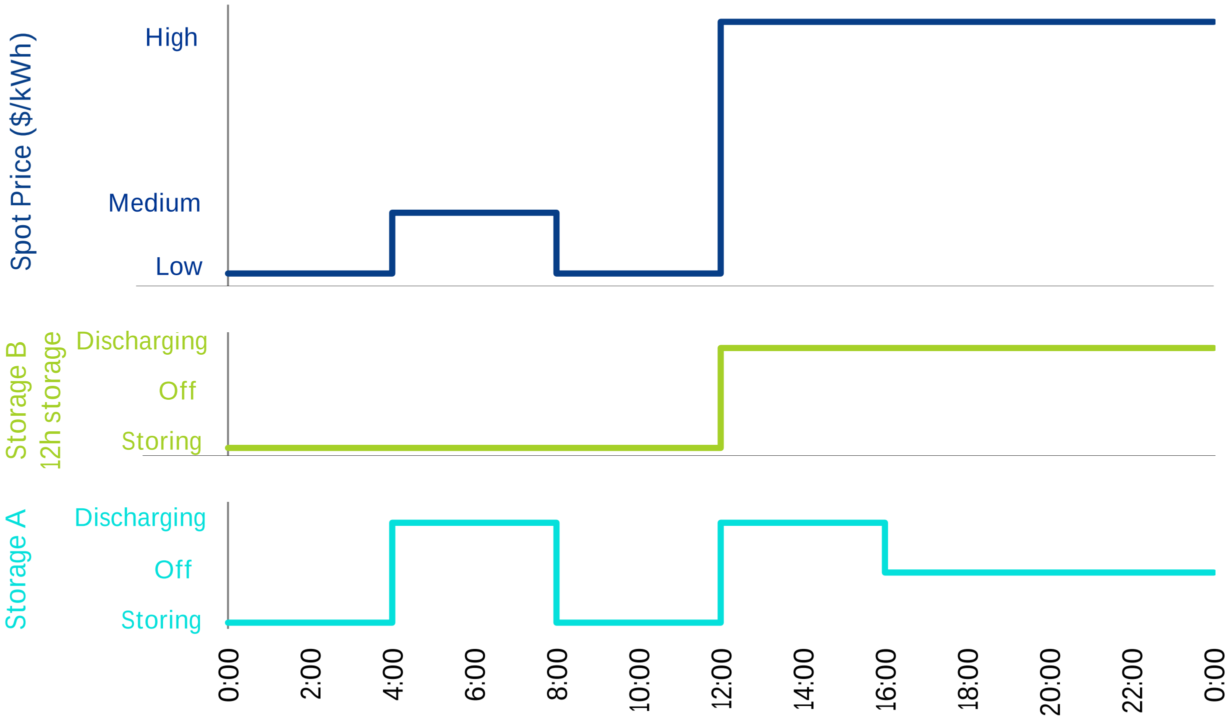


Figure 54. Illustration of difference in storage operation opportunities

There is a step increase in value between 8 and 12 hours and a relative reduction in benefit beyond approximately 24 hours. This aligns with the effect of being able to efficiently capture the morning and evening fast rates of change. In approximate terms, a storage system that has x hours of storage can optimally arbitrage over a period around $2x$ in size, accounting for x hours of storing and x hours of supplying.

Note that smaller storages could achieve the same price arbitrage, but would do so inefficiently. For example, a four hour storage could target a 12 hour arbitrage opportunity by storing the four cheapest hours of energy and supplying the four most expensive hours, but to achieve this outcome the storage will need to hold for four hours, resulting in a period of inactivity. This may or may not be the most economical way to use this asset and depends largely on market conditions. The different arbitrage opportunities of different size storages are illustrated in Figure 54.

There is greater value in being able to arbitrage over longer time periods. This is essentially why larger storages can extract more value from their arbitrage operation.

Moreover, an imperfect forecast will result in additional value in longer duration storages both for energy security and for efficiently meeting the highest price periods. There are already examples of storage capacity being withheld from the market to try to target higher prices which may or may not eventuate.

One of the modelled sensitivities was introducing substantial amounts of electrochemical batteries on the mainland ranging in size from 1 to 8 hours on top of the 5IC Strong scenario.

Figure 55 shows the income in 2050 (the last year of the study period) for various storages plotted against their duration.

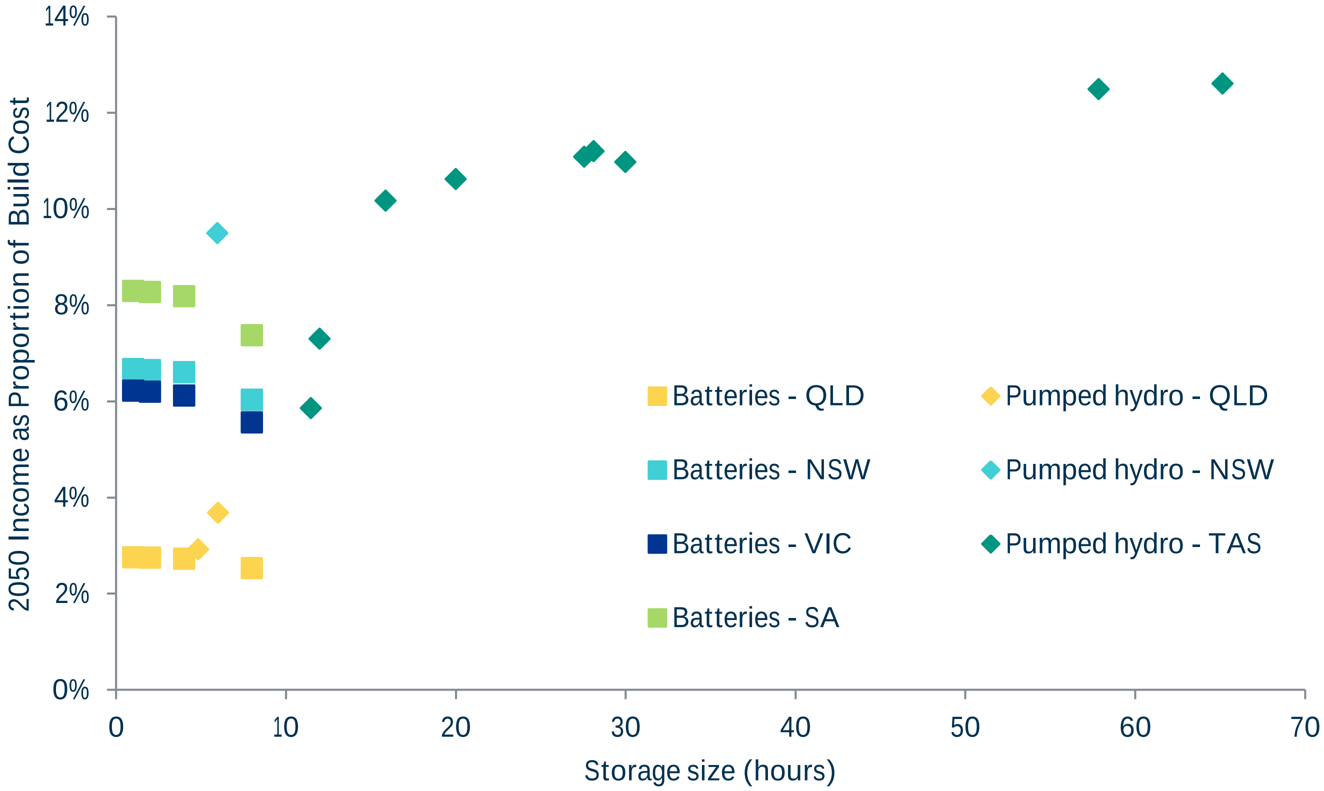


Figure 55. Returns for different duration storages

The differing income of batteries in different states is indicative that further model optimisation is required to determine the appropriate storage penetration in each state. The income for each storage for the year (calculated as energy arbitrage only) is compared to the cost to rebuild at 2050 prices.

Battery cost curves were based on the working for Figure 52. Pumped hydro costs were levelised at $1.3 million/MW so that the plot would highlight the value of storage generally rather than the value of specific opportunities.

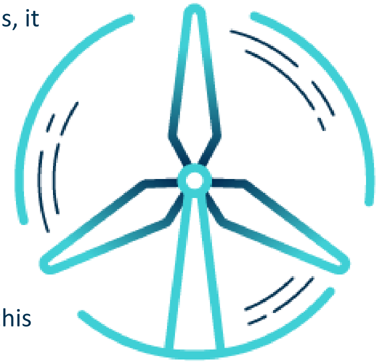
Tasmanian pumped hydro income is calculated with respect to Victorian spot price, adjusted for interconnector losses. This adjusts for the fact that the model redirects a significant portion of the income to inter-regional residues, whereas realistically the operator would not forfeit this value stream.

The comparison shows that returns for batteries are fairly static with durations up to about 4 hours. Given that CSIRO prices scale linearly with MWh in storage, this indicates that value of storage increases proportional to duration for up to four hours. The eight hour batteries have slightly lower relative income - this reflects that build price increases faster than income.

However, as highlighted in Figure 52, pumped hydro energy storage scales very well for longer storage duration. Consequently, the pumped hydro opportunities show up as having greater value than batteries given that they are capturing the longer duration opportunities. However, it is also possible that there is simply too much short-term duration storage in this scenario which may suppress the need, and therefore value, of the shorter duration storage.

When designing the scenarios, it was hypothesised that substantial wind penetration in a region would support the use of storage and would particularly favour longer storages.

Figure 56 contrasts two scenarios that demonstrate this difference:



- 5IC Low: Five interconnectors, high levels of storage and proportionally low wind penetration
- 5IC Strong: Five interconnectors, high levels of storage and a strong level of wind penetration

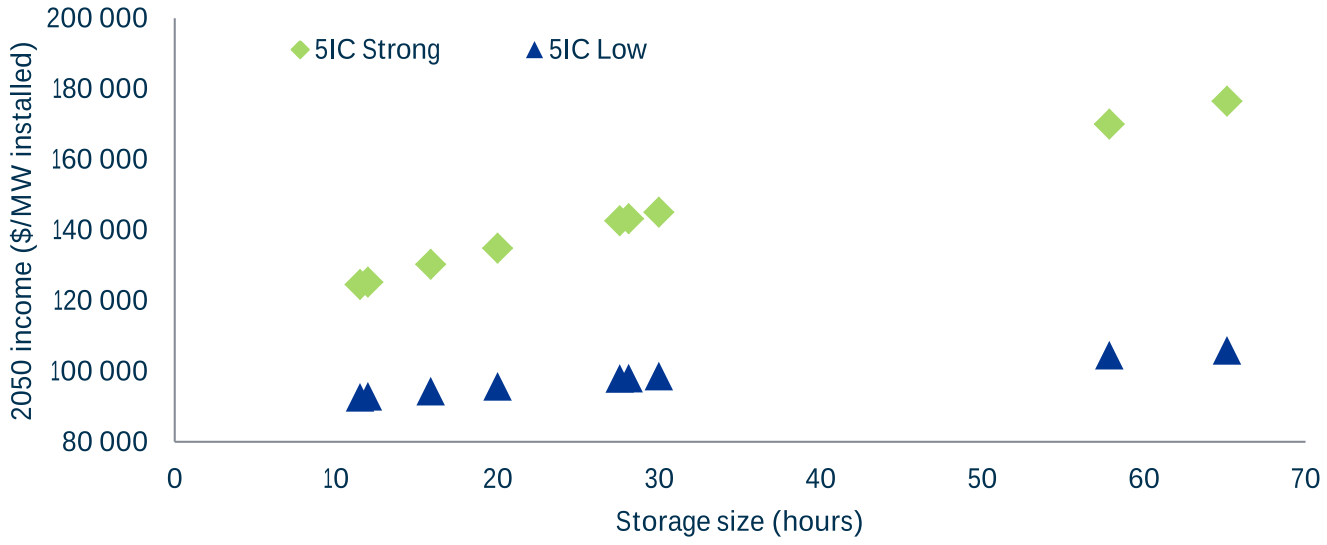


Figure 56. Comparative normalised income of pumped hydro plant under different levels of wind penetration

Comparing the 5IC Strong scenario with the 5IC Low scenario showed that the relative value of longer storages increased with increased local wind penetration (the steepness of the line increased). It should be noted that the optimal storage capacity will be highly dependent on the rest of the generation mix, particularly the ratio of peaking plant to variable renewable energy.

5.2.6 Delivery of new firm energy

The coordinated development opportunity of Tasmanian pumped hydro, wind and interconnection is cost competitive against all other realistic options for the future energy system.

This analysis shows that Tasmania has cost effective options to deliver firm new energy to the mainland at a highly competitive price. Tasmania's ability to produce and deliver energy at a lower cost is primarily due to:

- repurposing flexible assets presently delivering baseload energy;
- utilisation of existing storages to provide cost effective long duration pumped hydro; and
- high quality wind resource.

The Tasmanian integrated suite of options was compared with mainland options for providing a firm "stream" of energy as part of a new energy zone. This work aligns with the renewable energy zone approach raised in the Integrated System Plan [ISP 2017], although this analysis may include non-renewable energy and requires an additional objective of delivery of firmed energy.

For the purpose of this analysis, the ability to deliver a stream of 600 MW (based off the assumed size of the second interconnector) was tested.

This analysis is intended to highlight the difference in the opportunities at a relative level. The analysis does not account for the benefits of regional resource sharing or diversity, and is therefore expected to present a conservative view of the value of the Tasmanian offering. This is because the nature of the interconnection would bring substantial diversity of renewable energy resources and would also join loads and existing generation more strongly, allowing for more efficient dispatch across regional boundaries.

Two potential options were explored for the development of a new energy zone capable of supplying a firm 600 MW to Melbourne inclusive of losses, one in northwest Victoria and one in northwest Tasmania. The total cost for each suite of projects is made up of seven elements, shown in Table 10.

Each cost element was divided by the total energy delivered to calculate the contribution of that element to the total levelised cost of energy.

Cost Element	Calculation
Wind	For the purposes of this analysis, wind has been chosen to represent the new VRE. It is expected that wind will dominate VRE development in both Tasmania and Victoria until at least 2030. These cost curves are based on CSIRO 2017b. This is also consistent with AEMO ISP Consultation paper [AEMO 2017]. Applying the wind turbine build cost and fixed operations and maintenance costs from the EY assumptions, detailed in Appendix C. The build costs are factored by a weighted average cost of capital of 7.5% over a 40 year period. The actual wind generation also came from the EY dispatch modelling data, scaled to the size required.
Battery	Applying the battery cost curve from Figure 52, scaled to deliver the required capacity to deliver 600 MW. One solution has batteries scaled to provide storage requirements to fully mimic firming by pumped hydro. This leads to the most uncompetitive solution. Another solution has batteries being utilised for one hour storage in conjunction with gas firming for longer periods. This solution is considered more a more realistic future market solution. The cost is spread across all hours of the year. Any energy that was stored had a 10% loss factor applied to account for the efficiency of electrochemical batteries.
Gas plant costs	Applying the open cycle gas turbine build cost and fixed operations and maintenance costs from the EY assumptions, detailed in Appendix C. The build costs are factored by a weighted average cost of capital of 7.5% over a 40 year period.
Gas variable costs	The cost to firm variable energy sources to achieve continuous delivery of 600 MW. This comprises of the gas cost and the variable operations and maintenance costs, detailed in Appendix C.
Pumped hydro energy storage	For Victoria, the pumped hydro cost was assumed to be $2 million/MW to account for the likely need to develop new large scale upper and lower storages. For Tasmania the pumped hydro cost assumed a high end cost for the identified pumped hydro opportunities at $1.5 million/MW. Both sets of pumped hydro projects were scaled to deliver the required capacity for 600 MW plus losses. The pumped hydro storages were assumed to hold 60 hours of storage in both regions – this is a large storage size. The cost is spread across all hours of the year. Any energy that was stored had a 22% loss factor applied to account for the efficiency of pumped hydro.
Transmission	The Victorian zone was modelled with a 400km 220kV transmission line (at $1 million/km) to the northwest of Victoria to be able to access substantial new resources. This was calculated to have losses of approximately 9.5%, resulting in the need to deliver an additional 57 MW sent-out, to achieve the delivered stream of 600 MW.

Repurpose existing hydropower assets	In the Tasmanian suite of projects spilled wind energy was used to shift energy from existing hydropower plant to another time. This is recognising the benefit of the existing assets, deferring generation when there is sufficient variable renewable energy. Two options are presented: • one suite of projects shifted 8% of the annual energy production • one suite of projects shifted 12% of the annual energy production Repurposing a lower proportion of the annual energy production makes this flexibility available to later installations. Note that changes in the cost to operate are uncertain, but even a 20% increase in maintenance costs would only result in an attributable cost of $2 or $3 per MWh depending on how much the existing assets are repurposed. This is considered below the threshold of uncertainty for this work and is not material for the following comparisons.

Table 10. Cost elements and the core assumptions made in the calculation of their contribution to the total cost of energy

Figure 57 shows a comparison of options representing a range of approaches to deliver a 600 MW stream of energy. There are five Victorian options with varying technologies and two Tasmanian options.

A ‘gas only’ option was considered that accounted for both gas prices and the cost of the plant, but was assumed able to be built without the need for substantial additional transmission line (i.e. this is not a new energy zone, but a base case comparison to highlight the cost without wind or storage).

The option of primarily firming using batteries is shown to be uncompetitive for sustained capacity to firm wind. Batteries are expected to deliver valuable system services in the future market, but this comparison highlights that the niche for batteries is not firming of energy.

Three more options were considered for Victoria with substantial wind backed by Victorian pumped hydro and some minimal gas firming, small batteries as gas cost avoidance, and purely wind and gas. After optimisation, these were all found to be able to reach similar prices. Given the assumptions used, wind backed by gas was found to the most cost-effective. However, even a small increase in the gas price beyond those from the 2016 Electricity Statement of Opportunities would potentially change the order of the cost for these suites of projects; see Appendix C for more details.

Lastly, two options are shown for Tasmania, with different levels of wind generation and different levels of reliance on shifting energy production from the existing assets. Both Tasmanian options are substantially cheaper than the alternatives – including the cost of transmission. As noted previously, this is a conservative view: the value of diversity for Tasmanian wind is not considered and the value of interconnection (joining regions and existing energy sources and loads) is not considered. The case for Tasmania looks much stronger if these considerations are taken into account.

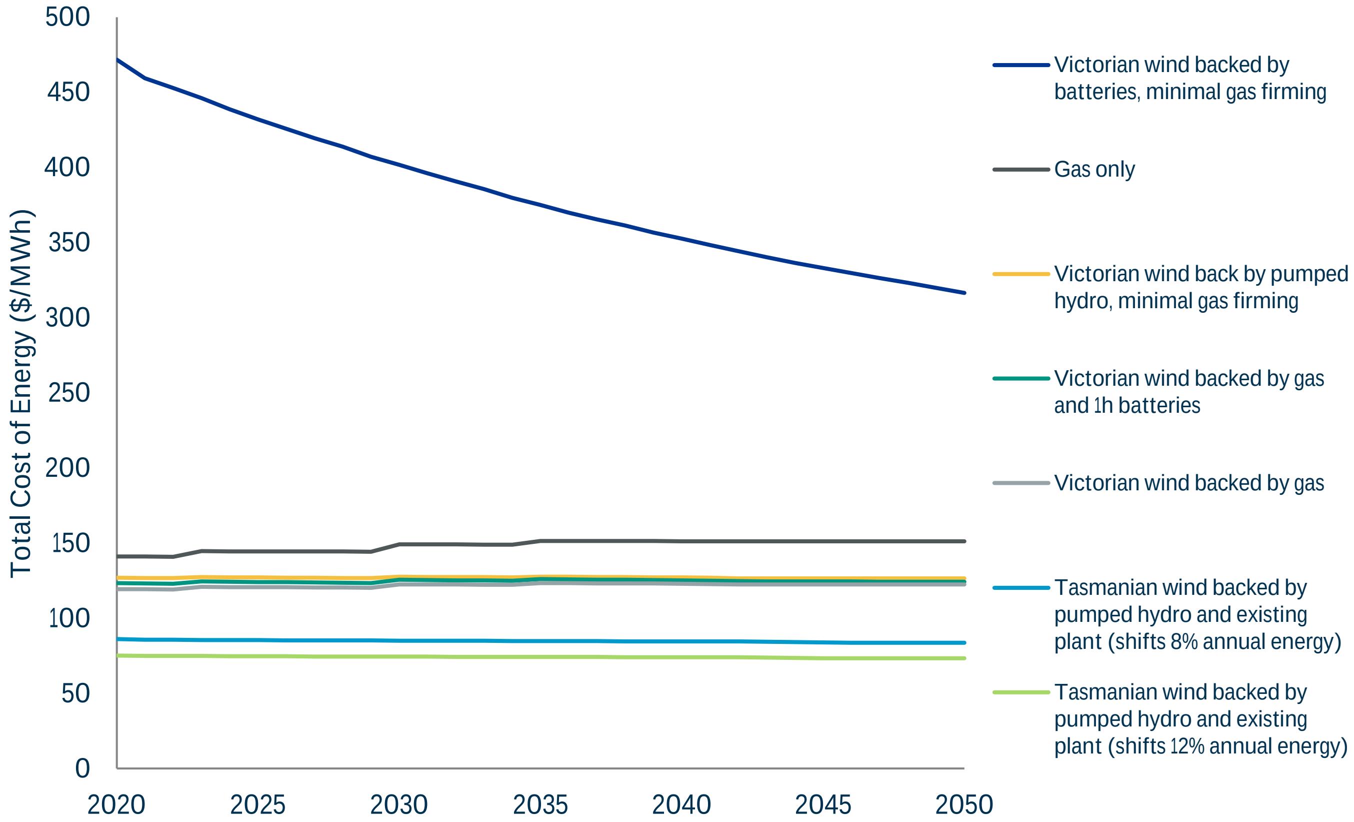


Figure 57. Comparison of fully firmed energy solutions to deliver a 600 MW stream of energy from a new energy zone to the Victorian load centre

It is important to understand the relative contributors to the costs in order to understand the sensitivities to changes in assumptions. Figure 58 shows the split of costs all scaled to compare with a baseline of open cycle gas only using the data from Figure 57. Note that the major battery build out has been left off this figure as it was not comparable to the cost of gas only.

The major cost drivers are the cost of wind and the variable cost of utilising the gas plant. The savings achieved from the Tasmanian options are robust; substantial increases in either transmission or pumped hydro costs would not affect the cost competitive nature of the options.

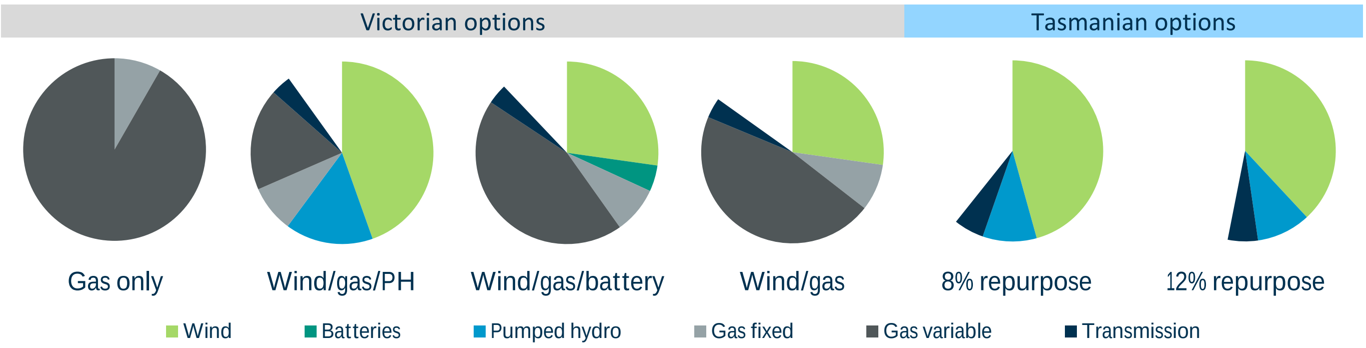


Figure 58. Cost-based comparison of options to deliver 100% firm streams of new energy to Victoria's load centre. The key contributors cost are identified and all charts have been referenced against 'gas only' as a base price. The comparison is for the first year from Figure 57

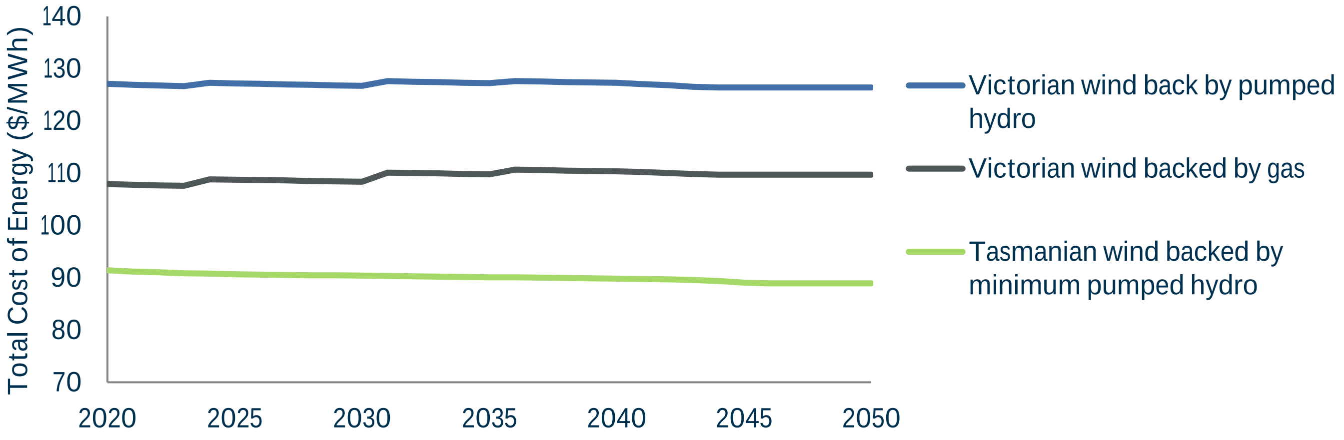


Figure 59. Comparison of firmed energy solutions targeting 600 MW at 90% capacity factor

The above analysis is based on a concept of "firm" energy being 100% available (with the exception of possible outages). However, to date there is no industry consensus on the definition of firmed energy. Another potential interpretation may be to achieve capacity factors similar to those of existing high capacity factor plant.

For the next analyses, see Figure 59, a target was set to achieve a 90% capacity factor to emulate a very high capacity factor plant. It is likely that Tasmania could achieve this outcome by firming new wind with existing assets thereby achieving a very low cost. However, it was considered more informative and conservative to undertake a comparison of entirely new plant designed to deliver this service. The results shown do not include the use of existing generation assets and so provide a direct comparison.

It is important to note that Tasmanian options are able to produce and deliver the energy at a lower cost, even when disregarding the value of repurposing existing assets. Figure 59 shows a disparity between the cost of the solutions with Victorian pumped hydro compared with the Tasmanian pumped hydro. After some optimisation, this was found to be attributable to two key factors: the assumed cost of the pumped hydro in Victoria being greater than that in Tasmania (due to topography, need for large storages and the synergies with existing infrastructure in Victoria) and the relative value of wind.

It is possible that some pumped hydro sites in Victoria may be identified at a lower cost than $2 million/MW, but it is considered unlikely that they will have storage duration of 60 hours or greater since the storages may be smaller and would need low capacity to achieve long duration, resulting in higher cost per unit.

Even though the wind in each case had the same capital cost (detailed in Appendix C), the relative capacity factors and the pattern of the wind energy duration curve meant that more capacity was needed in Victoria to achieve the 90% capacity factor stream of energy, which contributed to the overall cost differential. Note that this simplified comparison does not capture the value of the geographic diversity of additional Tasmanian wind in the national variable renewable energy portfolio, nor the joining of two regions for resource and load sharing.

Figure 60 explores the impact of wind diversity on the optimal ratio of variable renewable energy to pumped hydro energy storage. By optimising the balance between pumped hydro and wind it is possible to fractionally improve the overall cost (compared to the data shown in Figure 59). This is achieved by a small increase in the pumped hydro capacity and a decrease in the wind installation.

Increasing the diversity of the wind by sourcing the wind energy from two different wind sites in Tasmania allowed a reduction in the installed wind capacity required to deliver the same energy service. The wind diversity also changed the optimal balance between wind generation capacity and pumped hydro energy storage capacity. Diversity marginally decreased the variability, which in turn slightly reduced the scale of wind spill and the need for storage.

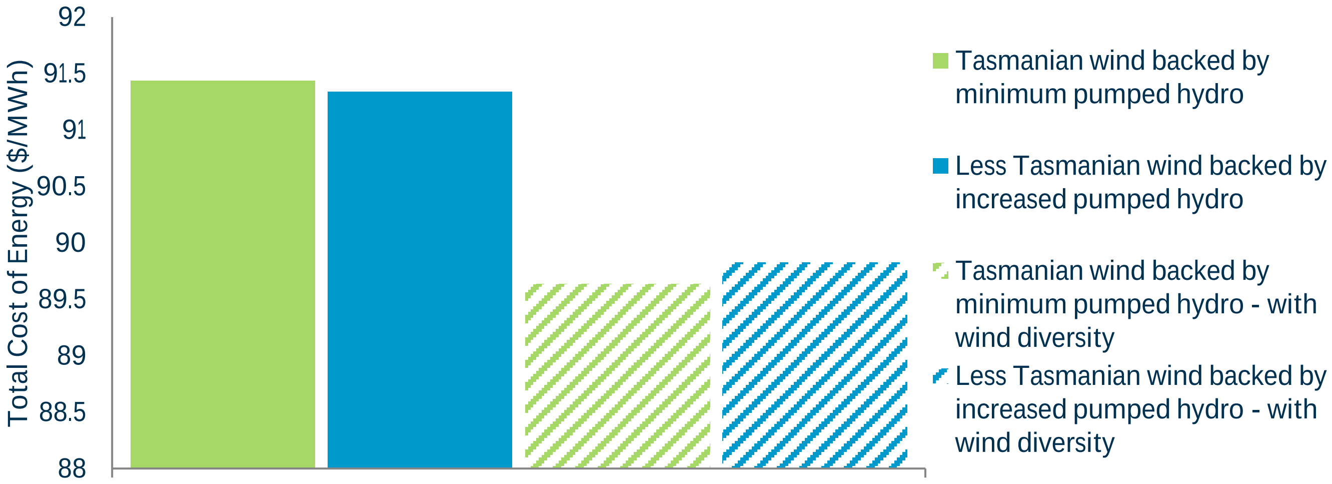


Figure 60. Comparison of the impact of on-island wind diversity

This analysis demonstrates that Tasmania has cost effective options to deliver firm new energy at a highly competitive price. The key cost drivers have been identified as the new energy sources, namely variable renewable energy capital and/or the fuel for gas-fired plant. The transmission costs and capital for storage services (putting aside batteries) make a comparably small contribution to the total cost of energy. The ability to change the operations of Tasmanian hydropower plant also offer a cost-effective way to firm new energy sources at very low cost.

5.2.7 Cost of the integrated solution

At present the NEM is going through a period of change. The health of the NEM has been identified as needing attention [ESB 2017] and the energy mix will change over time as the older technologies retire and are replaced by technologies with different characteristics.

While the specifics of what services and market structures will exist in the future NEM are yet to be established, most system planning – including AEMO's Integrated System Plan – acknowledge the need for more variable renewable energy, more interconnection and more storage.

Depending on the actual characteristics of the energy mix in the NEM there is also likely to be a need for more sustained capacity (i.e. secure, responsive and dispatchable energy) as well as more options to provide hedging and risk management services such as cap contracts.

This section of the report on Energy Equity has established:

- Tasmania has the ability to repurpose existing assets and leverage these for additional value of up to 25% in some cases.
  - Increasing controllability in the Mersey-Forth (a cascaded system of approximately 250 MW of run-of-river hydropower) could act as a capacity multiplier for pumped hydro in that area. Redeveloping the Tarraleah scheme could increase the controllability of the Derwent, potentially increasing the controllability of approximately 350 MW of (presently) run-of-river hydropower plant.
- Tasmania has strong wind resources that are cost competitive with the best sites around the country.
  - Moreover, one of the key benefits identified in the planning for renewable energy zones is the value of diversity. Tasmanian wind has substantially different wind patterns to the rest of the nation and would add valuable diversity as well as high quality wind resources. This is a relatively untapped potential and so there are still many highly suitable sites. The total scale of the opportunity is large and credible.
- Tasmanian solar opportunities would potentially add some latitudinal diversity – particularly in terms of taking advantage of earlier and later generation potential in summer.
  - However, solar development in Tasmania is not expected to be competitive with mainland options unless those shoulder time periods are extremely valuable. Then, even if they are, it is likely that Tasmania has cheaper options to provide energy into those times through storage.
- Tasmanian interconnection is cost competitive. The options are among the cheapest in the NEM, even allowing for upper cost limits. The interconnection is also expected to be highly efficient, both in terms of low losses due to the use of HVDC technology, but also enjoying very high rates of utilisation.

  - By the end of the modelling for the 5IC strong scenario the Tasmanian interconnectors had utilisation rates of approximately 60% while the other interconnectors around Australia averaged 40%. The NSW1-QLD1 interconnector was the notable exception which showed a similar utilisation rate to the Bass Strait interconnection. This interconnection was also bundled with on-island transmission necessary to unlock substantial renewable energy development opportunities; making the comparison of the Tasmanian interconnection even more attractive since it acted as both interconnector investment and renewable energy zone investment.
- In terms of flexible dispatchable supply, Tasmanian pumped hydro is shown to be able to cost-effectively displace open cycle gas turbines.
  - The pumped hydro is also cost competitive with battery storages with four hours or more of storage. There are a number of advantages to longer term storage and analysis has shown that pumped hydro opportunities in Tasmania have been shown to have greater returns on investment than other options in the NEM. However, defining the requirement for longer duration storages will be important to better understand the total opportunity.

In every aspect (except solar) Tasmania has strong cost advantages which have been shown to be cost competitive with other alternatives. The combination of Tasmania’s strong, diverse wind resources with valuable pumped hydro opportunities substantially lessens the reliance on gas usage in the NEM. This acts to reduce the resource cost of energy in the NEM by up to 20% (comparing the 5IC strong wind scenario with the NoTasDev case).

The resource cost for energy in the NEM is modelled to reduce by up to 30% for Victoria and up to 50% for Tasmania. The comparison of the resource costs in for the generation-weighted average across the NEM, Tasmania and Victoria is shown in Figure 61. Under the NoTasDev case, Tasmania’s prices rise over the modelling period and go from being a low cost region to the highest cost region.

By contrast, under a strong *Battery of the Nation* scenario Tasmania predominantly becomes a net exporter and consequently enjoys the lowest prices in the NEM. There are two major events that are also worth highlighting on this figure. Around 2030 there is a substantial reduction of coal fired assets in New South Wales.

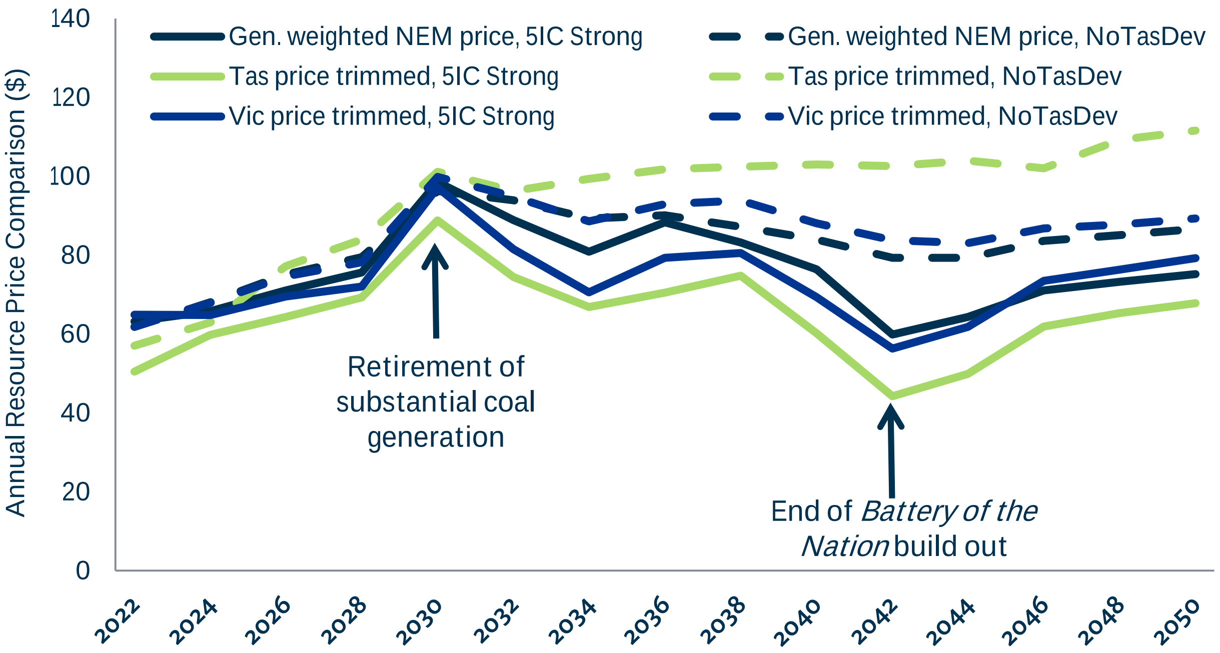


Figure 61. Comparison of annual resource costs (analogous to spot price) for Tasmania, Victoria and the generation weighted NEM-wide average for the NoTasDev and largest *Battery of the Nation* scenario. It is worth noting that more diverse generation combined with system balancing solutions, such as offered by *Battery of the Nation*, would continue to add value beyond the end of the modelled build out

Even under the most ambitious *Battery of the Nation* scenario the response was not sufficient to meet the change in the energy mix, resulting in a price spike. This rapidly reduces as more generation is brought online and highlights that the timing of *Battery of the Nation* planting was not optimised.

The second major event occurs in the early 2040s when the *Battery of the Nation* scenario build outs stop and the rest of the nation continues to respond to loss of generation through the same means identified in the NoTasDev case. The price rise associated with this event indicates that the Tasmanian storages were already (at least close to) fully utilised.

Over the final decade of the modelling the price starts rising back up towards the NoTasDev case as gas starts to play a more dominant role in price setting again.

In terms of high level estimates, $3.5 billion in interconnection and transmission could unlock investment of $4.5 billion in pumped hydro to build 3500 MW of pumped hydro storage, leveraging a further benefit of approximately 500-600 MW of increased controllability from existing plant.

This could provide 4000 MW of secure reliable energy sustained over a period of days. This scale at this price is competitive with all other storage opportunities in Australia.

Moreover, the nature of the opportunity is modular and can be broken into smaller discrete investments.

Electrochemical batteries cannot provide this scale of service for this price (even without transmission). Other attractive pumped hydro opportunities certainly exist on the mainland, yet those under active investigation are either of lesser scale or would not match this offering on a dollar per MW of storage basis.

This would also unlock cost competitive, high quality and diverse wind energy without further need for investment in transmission and produce the benefit of further interconnecting two regions to improve resource sharing, provide regional stimulus, improve system security and reliability and reduce carbon emissions compared with a gas balanced system.

5.3 Energy sustainability

The *Battery of the Nation* initiative addresses all three aspects of the energy trilemma, and a key part of this is energy sustainability.

The initiative is developing a roadmap to allow increased utilisation of low-cost variable renewable energy, while supporting the stability and reliability of the electricity network in a cost-effective manner. This allows Australia the option of reducing its dependence on fossil fuels and avoiding the associated cost and environmental risks.

5.3.1 Enabling renewable energy

The *Battery of the Nation* initiative supports Australia to embrace cost-effective renewable energy generation while maintaining secure, reliable electricity supply.

The reduction in installed OCGT capacity (discussed in Section 5.1.8) is the key driver of a decrease in total greenhouse gas emissions from the electricity sector of 16% by 2050, when the strongest *Battery of the Nation* case is compared with the NoTasDev case.

Figure 62 illustrates that while the NoTasDev case meets the electricity industry's pro-rata share of Australia's Paris Agreement emissions reductions (a constraint applied to the model); the developments proposed by *Battery of the Nation* could also facilitate a significant further reduction through more efficient and effective use of energy from wind and solar plant.

Although this modelling took the conservative stance of only meeting pro rata reductions, it is deemed possible that the industry will need to contribute more than its pro-rata share of emissions reductions to compensate for other sectors which will find it more difficult to meet their targets.

Analysis to date has indicated that the initiative will deliver significant benefit to the Australian energy system under existing renewable energy and emissions reductions policy.

However, the initiative also contributes to the viability of substantially increased renewable energy penetration, broadening the options available for long term energy development in Australia and potentially enabling more aggressive carbon abatement targets for the electricity sector should federal policy change.

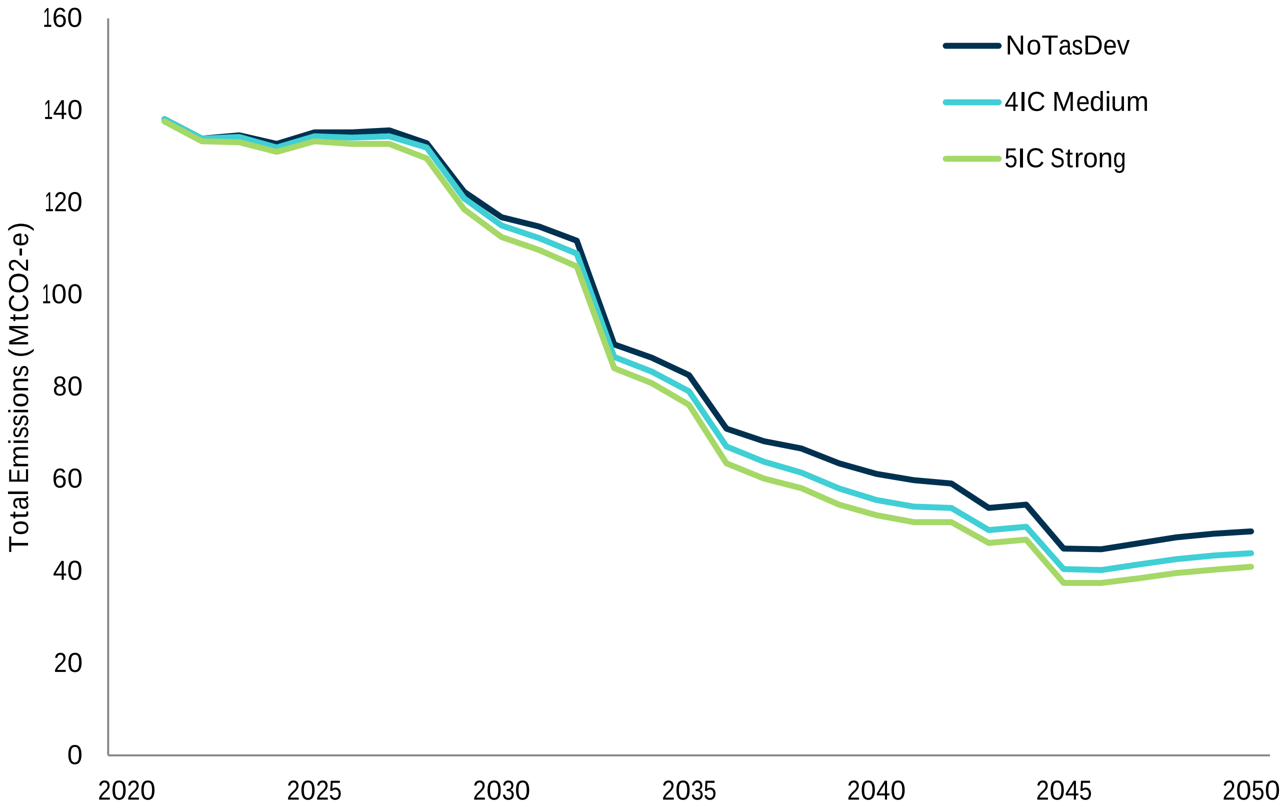


Figure 62. Annual greenhouse gas emissions. Note that in the later years with a strong build out, there is approximately a nine million tonne reduction in CO_2-e compared with the NoTasDev case

Figure 63. The Hydro Tasmania water management journey. Hydro Tasmania's water management practices have developed over the past 100 years, from early development, through a phase of increasing environmental awareness and activism, to several decades of sustained focus on continual improvement in social and environmental outcomes

5.3.2 Social and environmental accountability

***Battery of the Nation* has four competitive fundamentals: existing hydropower, wind, transmission and pumped hydro energy storage. However, as an integrated solution, the cost-effective pumped hydro, built on existing capability and assets, is at the heart of the initiative.**

The initiative would represent a substantial change to Tasmania's power system and understanding social and environmental aspects is critical to the success of such projects; Hydro Tasmania will have a key role to play in this change.

Hydro Tasmania's management of social and environmental impacts from the hydropower system has mirrored the journey of both society and the industry over the last 100 years, stylised in Figure 63.

During this journey, past experiences have led Hydro Tasmania towards its vision of being Australia's leading clean energy business; building value for its owners, customers and people.

Through past experience, Hydro Tasmania is well connected with the construction and ongoing operation and maintenance of a significant hydropower network that has provided Tasmania with a secure and reliable energy supply for over a century.

Hydro Tasmania's journey began with construction to supply affordable and secure electricity to fuel the development of Tasmania over 100 years ago. Changes in community expectations and increased environmental awareness towards the end of the hydro-industrialisation period created a change in how communities viewed hydropower developments.

The hydropower industry globally had lost its social licence and a new era of learning and innovating to develop and apply contemporary environmental and social standards to new and existing hydropower developments had commenced.

Since the 1990s Hydro Tasmania has been working to engage and consult with communities and key stakeholder groups and apply leading environmental practices to its existing operations to maximise the value and broaden the benefits of hydropower infrastructure in Tasmania.

The new era that Hydro Tasmania represents recognises the past achievements, strives to continuously improve, and focuses on collaboration with the community whilst offering new opportunities for sustainable development across multiple projects such as *Battery of the Nation*.

5.3.2.1 Managing for multiple uses

Hydro Tasmania’s commitment to economic, environment and social sustainability is at the forefront of business objectives. The water assets operated and managed by Hydro Tasmania facilitate multiple uses by Tasmanians, including irrigation, drinking water and recreation.

Currently, Hydro Tasmania manages these demands for water through a combination of voluntary and regulated commitments.

Consequently, Hydro Tasmania is experienced at managing a suite of environmental and social risks in its day-to-day operations of its existing system.

Hydro Tasmania has a strong track record in managing the environmental and social impacts of its operations, working collaboratively on a daily basis with external stakeholders.

The potential changes to the Tasmanian hydropower system proposed by the *Battery of the Nation* initiative will continue to support other water users and deliver multiple use benefits for Tasmanian communities.

Hydro Tasmania will endeavour to maintain its existing commitments and will work with concerned or affected external parties to find solutions to multiple use.

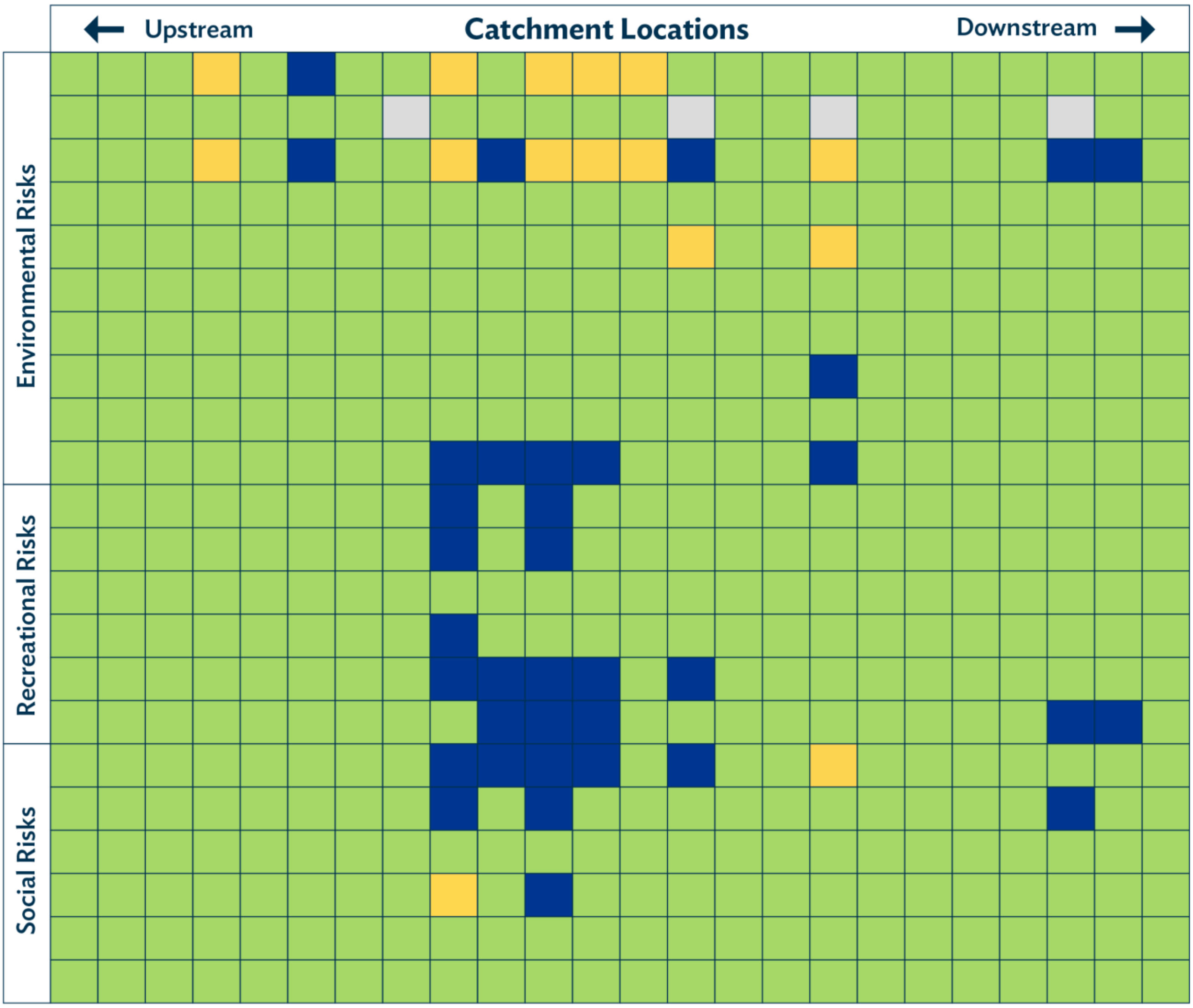


Figure 64. Example social and environmental unmitigated risk heatmap with all sensitive information redacted. Grey is not applicable, green is a low risk, blue is a moderate risk, yellow is a high risk that needs active management and red is an extreme risk. Note that no extreme risks have been identified

5.3.2.2 Environmental and social risks

As part of this initiative, Hydro Tasmania undertook a preliminary assessment of how environmental and social risks would transform if water management changes occurred in response to operating in a market with much higher levels of variable generation and greater interconnection to mainland Australia. An example of the unmitigated risk heatmaps is shown in Figure 64, with all commercial-in-confidence information removed.

The preliminary findings from this work identified that there will be an increase in environmental and social risks at particular locations, but that the impacts are at a local level and not widespread throughout the system. The assessment identified the changed risks from first principles, by understanding the possible changes to the way water is managed and the impacts these changes can have on environmental and social values before any potential mitigations were applied.

No new risks (outside of the suite of existing environmental and social risks currently being managed) were identified in the assessment; however the priority and location of some risks may change.

The risk assessment excluded site-specific risks that would result from development of pumped hydro systems, as these are location specific and will be examined in the pre-feasibility/feasibility stage of any pumped hydro project.

Further work is required to understand the magnitude of these risks (as further modelling provides more information on the extent of water management changes at individual sites), the fundamental process that would cause the risk to occur (e.g. changes to equilibrium pore pressure in sediments), identify appropriate mitigations and re-assess the risks post-mitigation.

Tasmania's hydropower system is an integrated network of generating assets. This may provide opportunities to mitigate risks that would not exist in stand-alone hydropower developments. Exploring these opportunities is part of the work required to identify effective mitigations for these risks.

The risk assessment identified three classifications for the environmental and social risks:

- **Not negotiable.** Those risks where the outcomes cannot be compromised; e.g. Matters of National Environmental Significance or protecting ecosystem integrity,
- **Negotiable**. Those that will require negotiation with external parties and;
- **No negotiation is required.** Those risks where there are no external impacts as a result of the change.

Adopting this approach means that the key social and environmental values are integrated into the system operation under further interconnection scenarios, therefore the assessment of project viability incorporates these assessments.

Tasmania's freshwater resources already show trends (in yield) consistent with projections from climate change. Climate change projections suggest that important ecosystems may be under stress from events in the future. The changes in system operation that would arise from providing firming services to the NEM potentially offer opportunities to protect some sensitive ecosystems from the impacts of climate change.to mitigate these ecosystem risks.

New Tasmanian developments may warrant diversification from Hydro Tasmania's traditional operation and market strategy. With careful environmental and social risk identification, planning and management, Hydro Tasmania remains confident it can mitigate the risks appropriately to facilitate a satisfactory operational outcome.

It can be assured that if the key risks identified can't be mitigated to a standard that meets public or scientific expectation, processes are in place to diversify its options or ensure that the businesses environmental and social integrity remains intact.

This issue remains pivotal to Hydro Tasmania's fabric and is identified as a key pillar in business sustainability.

5.3.3 Regional development and resource diversity

The *Battery of the Nation* vision is of a future Australia where each region contributes its local renewable energy resources to a strongly interconnected NEM, leveraging intra- and inter-regional diversity in resources to optimise energy security, equity and sustainability. This provides a national benefit and would be built upon regional investment, often in areas which may be economically depressed.

Strengthening economies of regional locations through development and investment is a substantial benefit of this initiative.

Weather-driven renewable energy sources benefit from geographic diversity. Different levels of generation from different locations increases the utility of the energy produced and reduces the impact of variability.

On a broader level, the difference in sunset and sunrise times with latitude (seasonal differences in number of sunlight hours) and longitude reduce the rate of change of national solar energy generation at the start and end of the day.

Different regions also have different types of renewable energy resources which are particularly strong, or particularly suitable for energy generation. Table 11 details the average wind and solar (fixed and single axis tracking photovoltaics) capacity factors for the areas within each state, which were used as inputs to the *Battery of the Nation* dispatch modelling.

The weather traces that underpin these values were provided by EY, the expert modelling consultant employed for this analysis.

	Wind	Solar Fixed	Solar SAT
QLD	33%	25.1%	29.9%
NSW	36%	24.4%	28.4%
VIC	36%	22.6%	26.0%
SA	37%	23.3%	27.0%
TAS	40%	21.5%	24.0%

Table 11. State average wind and solar capacity factors

The capacity factor differences drive investment in different types of generation infrastructure in different regions.

Figure 65 illustrates the diurnal average interconnector flows in the strongest *Battery of the Nation* investment scenario.

As discussed in section 5.1.9 solar power has a strong diurnal cycle, while wind has a weak diurnal cycle. Therefore interconnector flows are largely northwards overnight and southwards during the day, with weaker diurnal cycles for the interconnection running approximately east-west between South Australia and the rest of the NEM. Note that a weaker diurnal cycle does not indicate lower total flows.

Geographic diversity of variable renewable energy sources supports investment in renewable energy, as discussed in Sections 5.1, 5.2.2 and 5.2.3.

This allows Australia the option of reducing its dependence on fossil fuels and avoiding the associated cost and environmental risks.

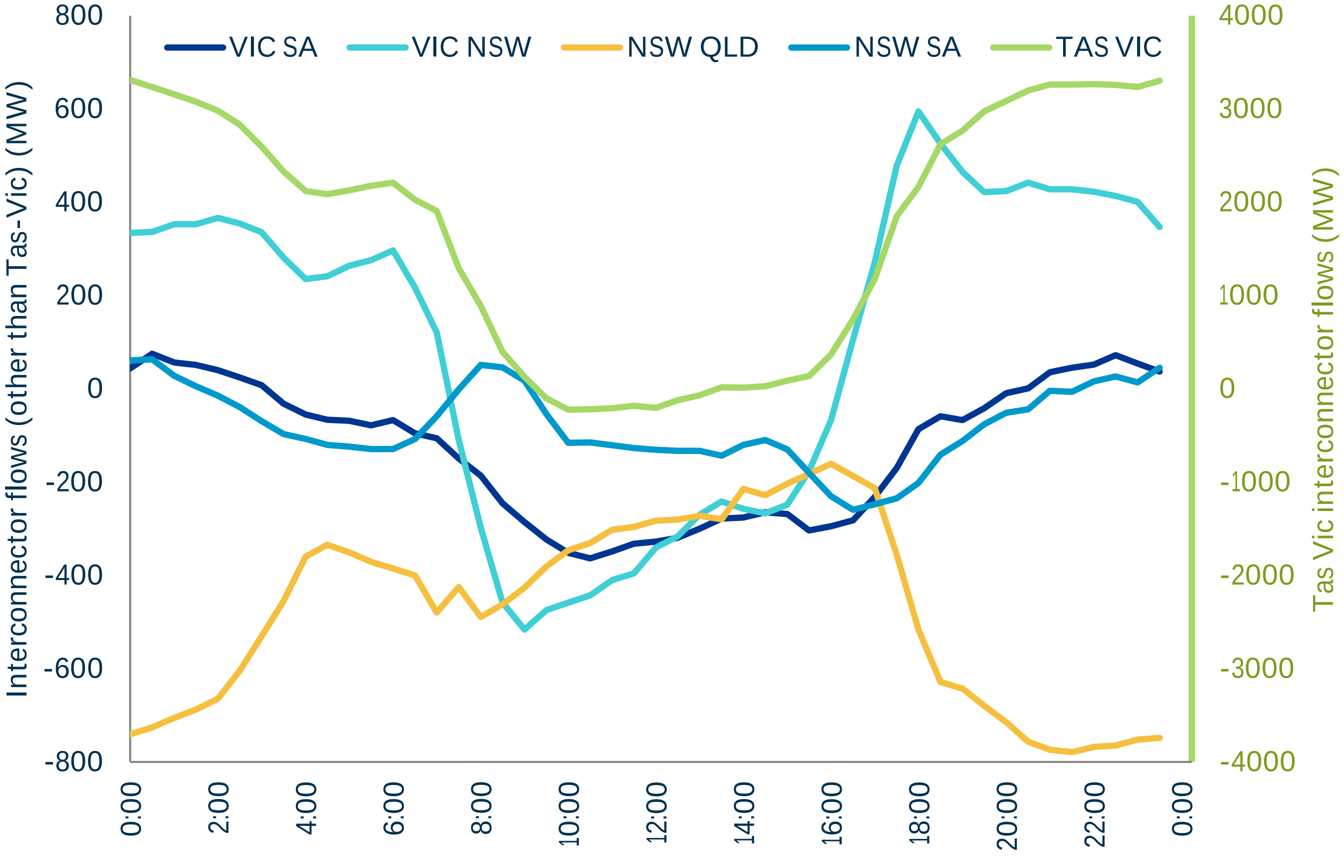


Figure 65. Diurnal average interconnector flows for 5IC Strong in 2050

5.3.4 Improving the energy sustainability of the NEM

Australia is well placed to improve its ranking in energy sustainability. According to the World Energy Council, Australia is ranked as a "C" in the sustainability of its energy sector [WEC 2017]. This will naturally improve as carbon intensive generation sources are replaced with cleaner and renewable sources of energy.

Battery of the Nation presents the opportunity for further improvement in Australia's sustainability, reducing reliance on gas fired generation for sustained capacity to balance the variable renewable energy sources.

Developments proposed by *Battery of the Nation* would support regional economies and would be of particular significance for the regional areas in Tasmania.

The modelling undertaken in this work compared a range of scenarios, using consistent assumptions, to explore the value of the *Battery of the Nation* options. Figure 66 and Figure 67 show the modelled outcomes for gas utilisation and CO_2-equivalent emissions.

The base case is the NoTasDev case, a counterfactual scenario, with the projected coal generation retirements being replaced with substantial variable renewable energy that is firmed and balanced by open cycle gas turbine generation. This results in much higher usage of gas, but since the gas-fired generation has significantly lower emissions than the coal it is displacing, the net outcome is a reduction in emissions.

The largest scale scenario for *Battery of the Nation* (5IC Strong) was compared against the NoTasDev case and found to substantially reduce the reliance on open cycle gas turbine generation. This resulted in substantial cost reduction, as detailed in Section 5.2.

Two sensitivities on the 5IC Strong scenario were plotted to highlight the relative impacts of additional storage and an explicit carbon price on the utilisation of gas, shown in Figure 66. Up until 2033 the carbon price had little impact on gas utilisation, indicating that when gas was used, there was sufficient value to overcome the impact of the carbon price.

However, the carbon price did result in a reduction in emissions due to reduction in the competitiveness of coal generation, shown by Figure 67. In the financial year starting 2033, there was a large retirement of coal generation and the role that open cycle gas generation plays was modelled to change. At this point a carbon price or additional storage (i.e. the "Battery" sensitivity) was found to both further reduce gas utilisation and emissions.

The 5IC Strong scenario made a substantial impact to both gas usage and emissions and was found to deliver a relative CO_2-equivalent emission reduction of up to nine million tonnes per year during the latter stages of the development compared with the NoTasDev case.

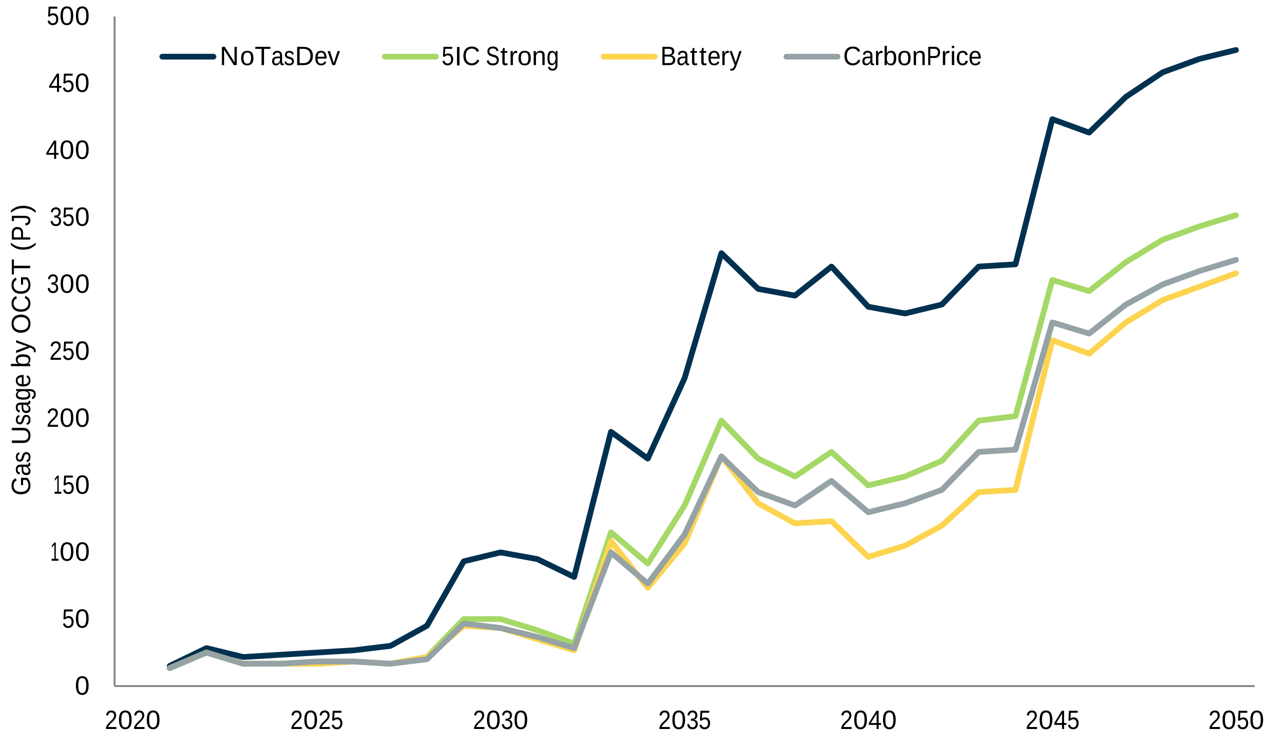


Figure 66. Gas usage by open cycle gas turbines comparing NoTasDev, 5IC Strong and two sensitivities on 5IC Strong

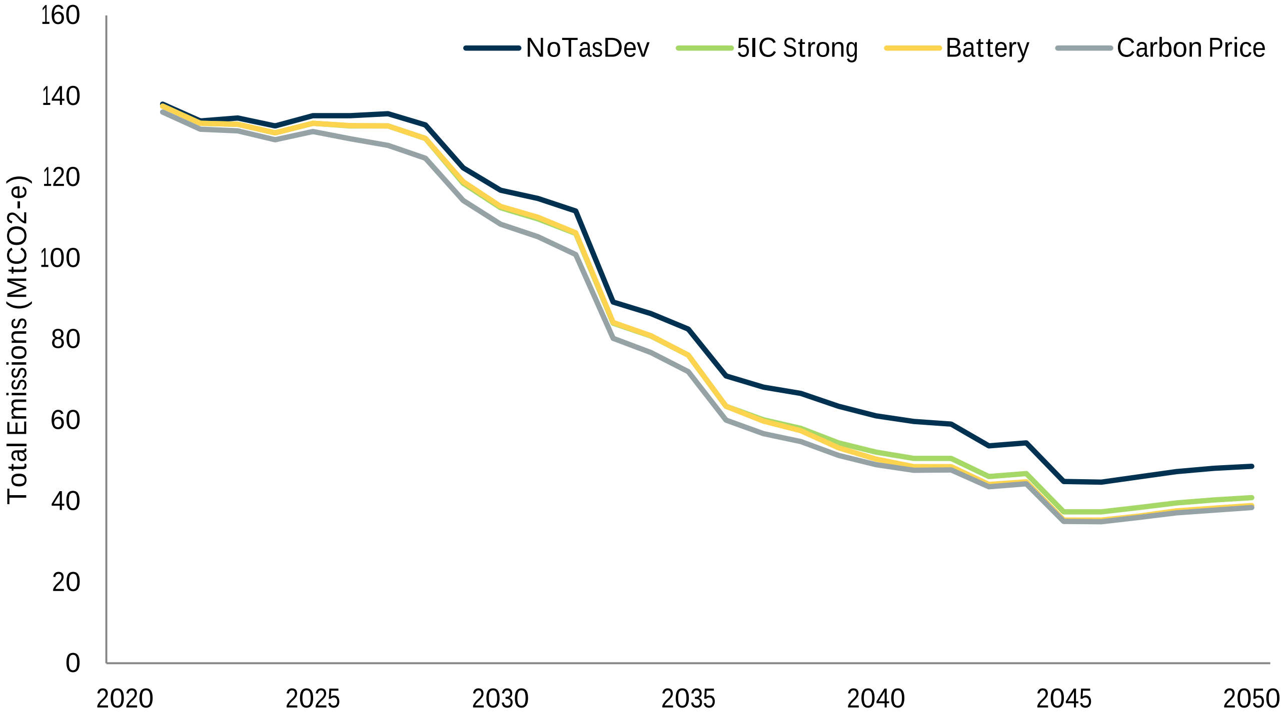


Figure 67. Modelled CO_2-equivalent emissions comparing NoTasDev, 5IC Strong and two sensitivities on 5IC Strong

6.0

Opportunities, risks and sensitivities

Australia must respond to the challenges facing the NEM. This presents an opportunity for the NEM to undertake coordinated planning to set Australia up to meet the targets of the energy trilemma: a secure, affordable and sustainable energy future. Tasmania has substantial advantages that would support this transition.

Australia must respond to the challenges facing the NEM and there is limited possibility of "business as usual". There will be transformation of Australia's energy sector and if the nation fails to plan carefully, it is unlikely that the optimal outcome will be reached.

This presents an opportunity for the NEM to undertake coordinated planning to set Australia up to meet the targets of the energy trilemma: a secure, equitable and sustainable energy future. In particular, Tasmania has an opportunity to play a much larger role in the NEM and contribute to meeting the targets of the energy trilemma.

There are also risks and sensitivities which must be carefully considered in planning for this energy transformation. While Tasmania has a number of substantial advantages, this opportunity is time bound. Retiring coal generation must be replaced over the next two decades and without careful and proactive planning it will be difficult to displace operators and technologies that opportunistically fill the gap. The modelling in this report indicates that this may not produce the most cost-efficient outcome.

AEMO's Integrated System Plan is working towards a coordinated plan for Australia's energy future and this is expected to be an iterative process which develops and adapts over time in response to new information and changing conditions.

Taking a long-term view (of several decades) is required to enable coordinated investment decisions across a wide range of parties. This investment profile must include timely and appropriate network investment as well as careful definition of the other system services that are needed to efficiently and effectively manage the security and reliability of the system. Without a proper definition of these services, with the market structures to adequately reward and manage risk, the improper incentives for investment may result in an inefficient energy mix.

While this work has explored some sensitivities, there are a range of potential enablers, obstacles and blockers. There are also outcomes which will reinforce or undermine the effectiveness of this initiative. Due to the scale of the change being considered, both for Tasmania and also for the NEM more broadly, this is an ever-changing list of opportunities, risks and sensitivities and needs further and ongoing consideration. The following topics are all areas of potential opportunity, risk or sensitivity; although it should not be considered to be an exhaustive list.

6.1 Definition of system services

The scale of the challenge that the NEM is facing means that there is no single solution.

There are a range of technologies which have a variety of strengths and if judiciously planned these strengths can be coordinated to best achieve the balance of the energy trilemma in the national interest. Use of a suite of options will result in flexibility, with the ability to ramp-up investment in a strategically managed transition.

By defining the services that are required in the market, it will be possible to use market forces to ensure a low-cost energy future. Technology proponents and developers will respond to the investment signals and work to value stack benefits to make their opportunities more attractive within the market mechanisms in place.

For example, electrochemical battery developers will identify an advantage of being able to cost-effectively provide short duration response and combine this with the ability to install in locations of maximal advantage. Meanwhile, developers of pumped hydro projects will identify opportunities to maximise storage size and combine this with co-located or nearby renewable energy, particularly wind.

AEMO has already provided an abstracted definition of the services required to successfully operate a power system, shown in Table 12.

	Pre-requisite / attribute	Description
Operational pre-requisites	Visibility of the power system	Ability to measure or derive accurate data on energy demand, power system flows, and generation output in real time.
	Predictability of the power system	Ability to forecast upcoming power system conditions and have confidence in how the system will perform.
	Controllability of the power system	Ability to manage generation dispatch and configure power system services to maintain system security and reliability.
Technical attributes	Resource adequacy	There is a sufficient overall portfolio of energy resources to continuously achieve the real-time balancing of supply and demand.
	Frequency management	Ability to maintain system frequency within acceptable limits.
	Voltage management	Ability to maintain voltages on the network within acceptable limits.
	Ability to restore system	Ability to restart and restore the system in the unlikely event of a major supply disruption.

Table 12. Excerpt from the Integrated System Plan [ISP 2017]

The technical attributes, from Table 12, have traditionally been identified as the areas of concern and markets have been created to help manage each of these requirements: energy, frequency control ancillary services, network control ancillary services, and system restart ancillary services. The changing energy mix may start to affect the "operational pre-requisites", particularly predictability and controllability. With a changing energy mix, there may need to be new options to meet these attributes.

- Real-time balancing of supply and demand may be more challenging in a system with substantial energy at low cost (not using this would be lost opportunity); this may promote the need for storage markets or some other way to recognise the value of storage. One specific value might also be the idea of a fully dispatchable load to help manage unexpected generation.
- Less certainty of resource availability may promote day ahead markets to incentivise more secure energy provision. It may also promote the creation of specific firming services to help manage risk, both to customers, retailer and the system. Another market which may be useful to help manage these risks is a capacity market.
- Loss of large machines that provide substantial inertia may mean that frequency changes will occur faster and could promote the need for an inertia market (<200 ms) and potentially also a fast frequency response market (200 ms-5 s).
- Rapid changes in generation may need greater availability of fast change (ramping) assets to manage the system.
- A weaker/lighter system may have more issues with fault levels, which may also promote the valuation of services that can help manage fault levels through locational stability and protection.

Lastly, it should also be noted that the present dispatch market mechanism is centred on the concept of short run marginal cost, which is itself largely a derivative of fuel cost. A system built purely from variable renewable energy sources, conventional hydropower and storage would have no real short run marginal cost and would potentially break the market mechanism, or at least the theory behind it. There will need to be substantial redesign of the market to accommodate this kind of change.

Careful market design and communication will be essential to facilitate a smooth transition. An additional, and beneficial, consequence of market transition would be to reduce, or even break, the association between Australia’s electricity prices and the international price of oil/gas, thereby improving Australia’s energy independence and security and driving down prices for consumers.

6.2 Timeliness of response

Battery of the Nation **provides a clear pathway to increased system security, improved affordability and is a step towards supporting a 100% renewable and sustainable electricity system – however, the window of opportunity is limited;** there must be a major infrastructure refresh over the next two decades and once this has occurred it will be hard to displace incumbent technologies.

Reacting only to investment triggers will likely lead to suboptimal solutions driven by first mover advantage rather than long-term efficiency. This could ultimately mean that Australia's energy economy is uncompetitive internationally. Similarly, investment without both economic and timing optionality can also be ineffective. The ability to plan, bundle and fast-track efficient options for long term outcomes will better optimise our national electricity system.

6.3 State-based interests

Energy security is a national issue that is built on a legacy of state-based assets and jurisdictions. The accountability for energy security at a jurisdictional level is a strong influence in decision making. Controlling individual accountabilities is a natural response, yet this will reduce the cross-regional optimisation from leveraging the nation's resources and diversity of energy sources.

All states have a major role to play and will require new development. Many of the new development opportunities are expected to occur in regional locations, creating economic benefits outside the large capital cities. These benefits can be assessed as being of high value and individual states may choose to support local development over national optimisation – even if the economic incentives are not there. This may ultimately result in higher prices to customers – or alternatively higher taxes to tax payers.

While there is ultimately little that can be done to limit this risk, it is likely to be in the national interest to have limited state-based influence in development patterns that increase the overall cost of energy.

One potential option could be the recognition of interconnection, and potentially substantial interconnection, to be a national issue. Deeper interconnection to optimise all of system outcomes will also challenge the pre-existing jurisdictional (state) boundaries in the NEM. These changes could drive a very different view of the regions and how they operate as a market. In the extreme, the market could evolve to disaggregated pricing nodes and dispense with traditional state boundaries.

Breaking the divisions between the regions would be a clear stimulus for national optimisation of the energy mix, state-based investments would be contributing to a larger pool with little differentiation of the source of generation or load.

6.4 Changes in demand

The core task for any power system is the real-time balance of supply and demand. *Battery of the Nation* has focussed its efforts on exploring the supply side of that equation since it is expected to be the driver of the upcoming challenges facing the NEM. However, the size of the challenge may be impacted by changes in demand.

6.4.1 Demand Response

Demand response is likely to play a more significant role in the future, although the scale of this change is yet to be determined.

Mass residential customer appetite to be actively involved in changing their power consumption is yet to be tested and the economic return on the inconvenience may not be enough to promote action. "Set-and-forget" aggregation solutions may provide a better mechanism to unlock this potential value, although these are also yet to be proven on a large scale. This continues to be an important sensitivity.

Industrial demand response may be more likely to play a role, but it is expected that this will be targeted at resolving the super-peak imbalances to avoid brown-outs at high cost rather than operating at a more day-to-day basis. Most industry is expected to prefer to focus on its value chain and core business rather than pursuing what could be a disruptive business model of stop-start operation.

At a macroeconomic level, the avoidance of regular disruption to industry is considered to be a more effective outcome for Australia. Nevertheless, the use of demand response to address large and rare events (such as system contingencies) is likely to become more valuable.

Tasmania already has a Frequency Control Special Protection Scheme that works well to help manage the large effect of a Basslink tripping contingency in a relatively small system. Other such schemes are expected to be used to help manage the largest system events in NEM in the future.

6.4.2 Electric vehicles

The interaction of electric vehicles with the grid is a topic of significant uncertainty. There is a potential that the vehicles could be active participants in the grid providing substantial storage capacity.

This employment of under-utilised assets could act as a disruptor to the electricity storage market, much like other asset sharing disruptors such as ride-sharing services affected the taxi industry and or room rent services affected the accommodation industry.

However, should this occur, it is expected to primarily provide short duration storage and so does not have significant impact on the opportunity presented by *Battery of the Nation*. Moreover, with present battery technology the use of the battery through charge and discharge affects the life of this valuable asset and many industry experts expect that car owners will be unlikely to want to devalue their cars to participate in supporting the energy system.

The most likely outcome may be some middle ground, possibly enabled through an aggregator, where the electric cars are usually seen as a load – but in times of super-peak imbalances may be called upon up to a limited number of times per year, an equivalent to industrial load shedding.

6.4.3 Industrial loads

Many of the large industrial loads around Australia are closely situated with coal plants and may be based on shared economics. There is debate among the energy system planners and modellers that as large generators retire the associated industrial loads may retire as well. Theoretically this is captured in the demand data forecasts adopted from the National Transmission and Network Development Plan data, although often the specifics attract more attention as the forecast retirements get closer.

A substantial reduction in industrial load could substantially impact the total quantity of generation required. It would also significantly impact Australia’s economy.

An alternative view could be put that Australia has substantial opportunities for renewable energy – arguably the strongest opportunity in the world considering land availability. **If wind and solar are expected to be the low cost energy generators of the future, this would mean that Australia may have the most affordable energy in the world, thus attracting more energy intensive industry and increasing the size of the opportunity.**

There is even credible consideration of the creation of hydrogen (through the use of renewable energy) as an export energy source, even though the round trip efficiency of that process has extremely high losses.

6.4.4 Behind the meter supply and storage

If power prices rise sufficiently, distributed generation will become commercially attractive. However, there are presently hidden costs that bias this outcome: the ability to avoid paying for distribution while using the service is commonly understood to be a problem for retail and especially distribution.

As more people exit the market they put the costs for poles and wires onto a smaller portion of the population, yet still rely on the grid to manage their net energy needs. This may force a more cost-reflective policy. Batteries could enable some customers to actually go off grid, but the economics are far from commercial at this stage and continue to be uneconomic in the foreseeable future.

The actual characteristics of behind the meter generation will primarily be from rooftop solar and will therefore compete with solar generation in terms of timing of resource. This is not expected to have substantial impact on the opportunities being assessed by *Battery of the Nation*.

6.5 Changes in energy mix

While the changes in the energy mix have been a key consideration for this work, it continues to have substantial uncertainty and will be a key sensitivity for the future NEM. If wind and solar are able to cost-effectively be replaced by dispatchable generation that can meet the energy trilemma it is unlikely that *Battery of the Nation* would be feasible.

No such options are credible at present, at least none that can provide substantial capacity and large volume energy. Biomass, geothermal, wave, tidal and solar thermal technologies are all options which may influence the energy mix in the future to varying levels.

6.6 Price volatility

The volatility of the market is a key sensitivity. Storage requires some level of price spread to achieve arbitrage, and without that the projects would have to be solely supported through alternative means, which is considered unlikely.

Another major consideration is the behaviour patterns of market participants. Businesses cannot only make their short run marginal cost, they need a return on their capital. This also has the tendency to increase volatility – especially at the higher end of the price duration curve where a generator that only operates infrequently is setting the price.

Higher incidence of outages and contingencies, especially with ageing plant, is expected to increase volatility as the reserve margins in the market continue to reduce. All these aspects are likely to further favour the development of storage. Figure 68 shows the impact of a single price spike over a period of hours. Capping the price[14] over those hours to a maximum of $1000 results in a substantially different annual average diurnal price curve. This single price spike can show how important price volatility can be to the incomes of a generator and the cost effectiveness of the market.

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[14] The assumption is that a super-peak imbalance demand response service similar to Tasmania’s Special Protection Service could be a cost effective way to limit the most extreme prices, at least in terms of energy resource cost due to unplanned outages.

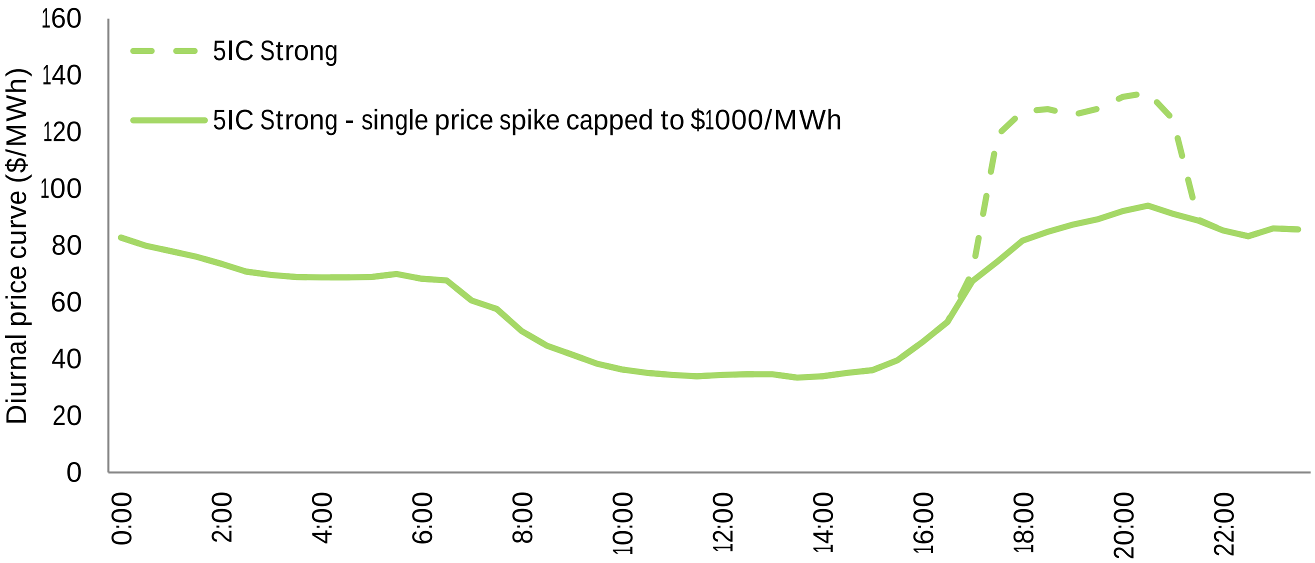

Figure 68. The impact of a single period of high prices

6.7 Carbon abatement targets

Carbon abatement targets can make a substantial difference to the energy mix being considered. If it is determined that the electricity industry must take on more than its share of emissions reductions, this could have substantial impact on the energy mix and the speed of change.

A "fast change" scenario such as the one proposed in the Integrated System Plan [ISP 2017] would likely promote more large-scale storage.

Already there are multiple studies on 100% renewables futures for the Australian NEM. Under such a situation it is expected that the value of large storage reserves would increase substantially.

6.8 Environmental/social concerns or opportunities particular to specific sites

Work has been undertaken at a system wide level to establish that the *Battery of the Nation* opportunity is credible, but as the work progresses to finer levels of detail, individual sites become of more relevance and this will start identifying relevant concerns or opportunities related to specific sites that may incentivise or discourage the development of particular sites.

Local environmental, social and recreational values will need to be assessed and the potential impacts associated with *Battery of the Nation* will need to be understood in more detail. There is potential that compromises will be required to maintain existing values, which may change certain details of the *Battery of the Nation* initiative.

One particular area of interest is the potential effect of climate change on precipitation patterns, wind and solar around Australia.

Much of the *Battery of the Nation* vision relies on weather driven renewables and changes in weather patterns may affect the performance of the individual assets. These risks will need to be carefully and thoroughly assessed in pre-feasibility and feasibility assessments associated with *Battery of the Nation*.

7.0

Next Steps

Analysis shows that Tasmania has a key role to play in the future NEM as Australia plans the replacement of retiring energy infrastructure. The *Battery of the Nation* vision needs to be continually assessed against increasingly certain views of the future state NEM.

During this first phase of the Future State NEM analysis, a number of simplifications and assumptions were made due to the complex nature of the work.

Further work is required to refine this analysis and understand the interplay between Tasmanian developments and likely mainland developments. Additional modelling will be required for *Battery of the Nation* to further test sensitivities and assumptions and to improve optimisation against future market constructs.

Initial projections show that Tasmania has a key role to play and is considered highly likely to fit towards the top of the stack of potential projects as Australia needs to replace retiring energy infrastructure.

The *Battery of the Nation* vision needs to be continually assessed against increasingly certain views of the future state NEM as the options and consequences are further explored and the uncertainties are resolved, or at least limited.

The analysis will trigger key resolutions required for influencing policy and regulatory direction at a State and Federal level to assist the implementation of a clear roadmap or strategy for how Tasmania can move towards its *Battery of the Nation* vision in a practical and sustainable manner.

During the transformation of the NEM, it is likely that new information will arise which will require re-evaluation of the outcomes. Nevertheless, there is still work that can be done to understand the potential enablers, blockers and sensitivities in order to make a robust plan for a variety of future scenarios.

The following themes need extended exploration as part of the second phase of the Future State NEM analysis. Some may be better undertaken as part of a coordinated national effort:

- **Greater understanding of the required services and markets in the future electricity system**

  Better understanding of the physical services that the market requires, and the markets that will support the delivery of those services, will be necessary for the second phase of the Future State NEM analysis.

  To improve optimisation, the ability to assess value against relevant future services and markets is critical. The interdependency of the underlying time series (demand, price, wind, solar, water/rain, storage etc.) makes this a complex issue to address; far more complicated than a system based on purchased fuel.

  The determination of the services and markets would be more useful to the nation if coordinated on a national level by a federal agency. The services must support the physical operations of the system and the markets must allow for both price signals and risk management/hedging.

- **Management of an energy system with a high proportion of generation with $0 fuel costs**

  As the penetration increases of technologies with near-zero ‘fuel’ costs, new challenges arise in terms of capital investment planning since the ‘floor-setting’ short run marginal cost is essentially $0.

  This will likely affect the market constructs that will be required to support continued and cost-effective development of the full suite of technologies in the future energy mix.

- **Requirements for storage**

  A consequence of the non-optimisation of the modelling to date is that the size of storage required is also not optimised. Two characteristics need to be balanced in terms of storage – capacity and duration.

  Capacity is frequently discussed and understood in order to make storage work like generation – but duration is critical for system reliability and reserves. Industry reports suggest an extremely wide variety of answers to these questions, highlighting the uncertainty of the optimisation.

  To date, *Battery of the Nation* has established that its cost-effective pumped hydro energy storage will be competitive as part of a value-stacked renewable energy zone, but the national need for storage (and even the best size for individual projects) needs further analysis.

  Each proponent will need to have a view on the energy mix, but this will likely be centralised around AEMO’s Integrated System Plan efforts.

- **Valuation of the full set of services from High Voltage Direct Current (HVDC).**

  HVDC transmission is controlled by power electronics similar to that of an electrochemical battery. The services and system security responses that an HVDC transmission line can provide are very similar to those that a battery can provide, at least in terms of frequency regulation.

  However, this needs further exploration in terms of the duration of those services as well as any limitations based on physical characteristics of joining regions. This will be valuable work to undertake in terms of the full value proposition for the business case study of the second interconnector between Victoria and Tasmania.

- **Spot and contract markets will alter under the five-minute settlements rule change.**

  Five-minute settlements will change the behaviours of the markets. It will no longer be possible to retrospectively take advantage of short-term price spikes.

  This is expected to reduce volatility in the market caused by adjustments to dispatchable capacity, but there will still be volatility and it is likely to increase with the addition of variable energy sources.

  Five-minute settlements also mean that cap contracts will be more risky to sell because a seller cannot necessarily respond fast enough to capitalise on a short-duration price spike. This may drive further changes in how assets are valued in the future market and will be important for understanding asset investments in the future.

  Assets that can supply energy at very short notice will likely attract a further premium.

- **Impacts on individual hydropower storages**

  The Future State NEM analysis undertook high-level investigations of the feasibility of substantial changes to Hydro Tasmania’s existing hydropower schemes and cascades, which show that the risks appear manageable at a system-wide level.

  Further study will be required by Hydro Tasmania to understand site-specific interactions as the macro-level view is resolved down to consider impacts at the level of individual storages and schemes.

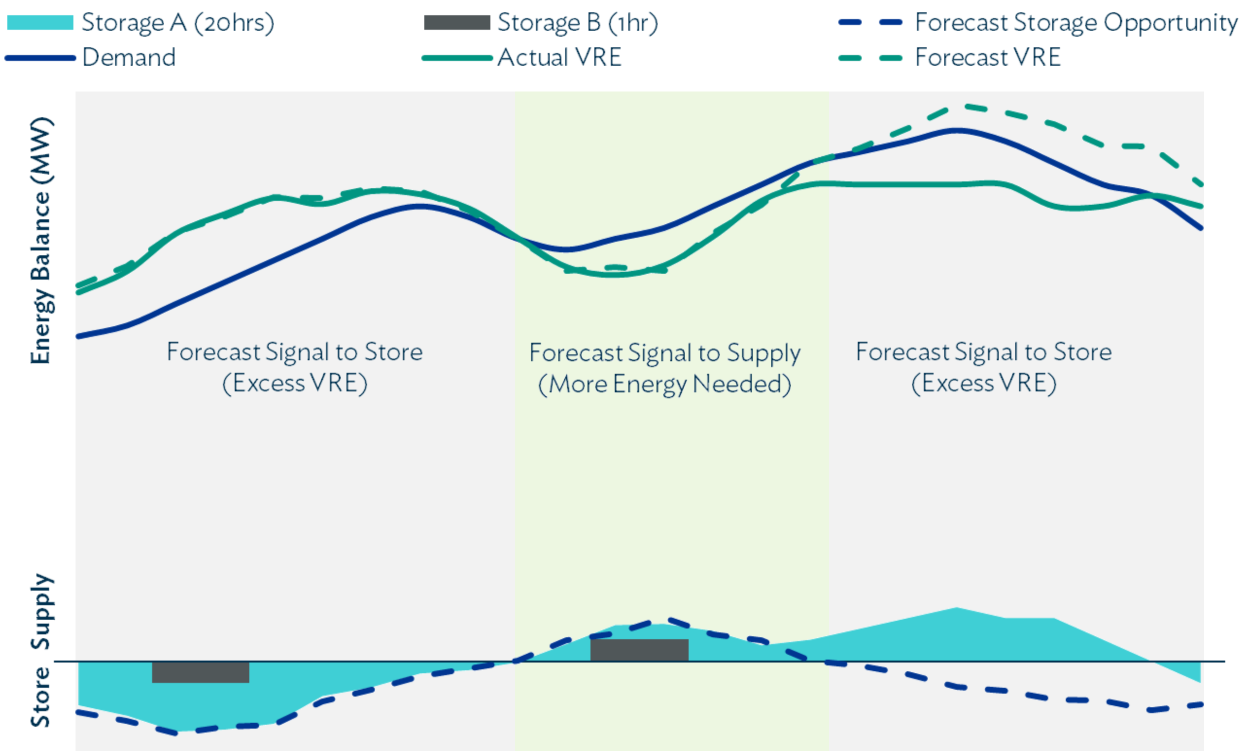

Figure 69. Longer duration storages will help manage imperfect forecasts. Shorter storages are likely to operate to maximise short-term revenue according to forecast system balance. The additional energy in longer duration storages will be available to supply in the case of lower-than-forecast variable renewable energy (and this may be a time of relative scarcity)

- **Imperfect foresight**

  Most system models assume participants have perfect foresight over a certain time period. This assumption allows optimisation of the use of plant – storing energy at the lowest possible prices and supplying energy at the highest possible prices to maximise system value.

  However, with imperfect foresight, longer duration storages will have additional value, demonstrated in Figure 69.

- **System security and changes in the nature and definition of contingencies.**

  The change in the energy mix, especially the introduction of very high penetrations of variable renewable energy, will alter the nature of the requirements for system security. Transmission outages may become the largest asset-based contingencies as individual generation assets become smaller and more distributed.

  However, large forecast errors may also become a source of pseudo-contingencies that could credibly (and potentially more frequently) impact the operations of the market. This is strongly related to the need to define the required system services. Quantification of the required services is likely to change due to a change in the drivers of the requirements.

Tasmania offers unique benefits that make the *Battery of the Nation* initiative a keystone in the transformation of the NEM. The business case for the second Bass Strait interconnector has already commenced. This is a critical step on the journey for Tasmania to play a larger role in the NEM.

The *Battery of the Nation* initiative offers economies of scale, and diversity and quality of variable renewable energy resources combined with large-scale storage that is able to be built with economic and timing optionality.

Further work is required to maximise the opportunities and mitigate the threats to this initiative over the coming decades.This report is only the first stage of the investigation.

To better understand the case for a larger Tasmanian role in a future NEM, the analysis will continue to be developed from stage 1 (model, assumptions and scenarios) to define a clear case for Tasmania as a high priority renewable energy zone.

Appendices

Appendix A. Glossary

2IC	Second Bass Strait interconnector: undersea high voltage direct current cable connection
3IC / 4IC / 5IC	Additional Bass Strait interconnectors
AEMO	Australian Energy Market Operator
ANU	Australian National University
AREMI	Australian Renewable Energy Mapping Infrastructure. An Australian Government-funded renewable energy data source
ARENA	Australian Renewable Energy Agency
Balancing	Maintaining an equilibrium between supply and demand
BoM	Bureau of Meteorology
Cap contract	A supply contract between a buyer and seller, whereby the buyer is assured that he or she will not have to pay more than a given maximum price. The most common cap price for which contracts are currently sold in the NEM is $300
CCGT	Combined cycle gas turbine
Class I/II/III	International wind turbine classifications, based on available wind resource
COAG	Council of Australian Governments
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DNI	Direct normal irradiance
Energy trilemma	Refers to the competing interests of energy equity, security and sustainability, as assessed by the World Energy Council (https://trilemma.worldenergy.org/)
ESB	Energy Security Board
ESOO	Electricity Statement of Opportunities
EY	Ernst & Young
FCAS	Frequency control ancillary services
Firming	A service that fills the 'gaps' in variable energy supply such that a reliable and consistent supply is delivered to the market
FOM	Fixed operation and maintenance costs. Refers to maintenance costs which are assumed to be independent of utilisation
GHI	Global horizontal irradiance

Global Wind Atlas	A World Bank supported global wind resource data repository
HVDC	High voltage direct current
IC	Interconnector
ISP	Integrated System Plan
LCOE	Levelised cost of energy
LPG	Liquefied petroleum gas
LRET	Large Renewable Energy Target
MERRA-2	Modern-Era Retrospective analysis for Research and Applications, Version 2. A National Aeronautics and Space Administration (NASA) earth systems data resource
MW	Megawatt. A measure of power (instantaneous energy)
MWh	Megawatt-hour. A measure of energy - one Megawatt-hour is one Megawatt, sustained for an hour
NEG	National Energy Guarantee
NEM	National Electricity Market
NoTasDev	A counterfactual with no further energy developments in Tasmania beyond Cattle Hill and Granville Harbour wind farms
NTNDP	National Transmission Network Development Plan
OCGT	Open cycle gas turbine
PV	Solar photovoltaic
Resource cost	The cost to produce energy. Also used as a proxy for spot price in the dispatch model
REZ	Renewable energy zone
RIT-T	Regulated Investment Test - Transmission
SMRC	Short run marginal cost
Storage capacity	The rated (maximum) instantaneous power output of a storage unit
Storage duration	The time for which a storage unit can discharge at full output before refilling
USE	Unserved energy
VOM	Variable operation and maintenance costs. Refers to maintenance costs which are dependent on how heavily a plant is utilised
VRE	Variable renewable energy
WACC	Weighted average cost of capital
WAsP	Wind resource assessment software

Appendix B. References

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Appendix C. Assumptions

Carbon Price

Assumption: No explicit carbon price was used, and instead a trajectory-based constraint was placed on the model to meet the targets from the Paris Agreement.

- Carbon pricing is not current government policy. Although policies will vary over the modelled period, the absence of a carbon price is the most conservative approach with regards to the value of *Battery of the Nation*.
- The constraint for a carbon trajectory was set to meet already established international obligations (i.e. COP-21, 26-28% emissions reductions from NEM by 2030).

Renewable energy targets

Assumption: Meet legislated LRET, including VRET 2020 target (650 MW auction) and QLD RET (400 MW auction).

- *Battery of the Nation* introduces a substantially different set of options for new variable renewable energy. The combined use of scheduled wind development in Tasmania and a constraint on carbon emissions is expected to develop the optimal projects without additional external influence.

New renewable generation

Assumption: Committed renewable energy developments

- Renewable energy planted to meet LRET.
- Cattle Hill and Granville Harbour wind farms assumed to be committed projects.
- SA-NSW interconnector assumed to be built in 2022.
- Kidston pumped hydro energy storage assumed committed.
- After this point:
  - Tasmanian pumped hydro, wind and interconnectors were planted according to the “Build Out” scenarios.
- Additional renewable generation was planted where economic.

Thermal generation retirements/developments

Assumption: Actual announced retirements, economic retirement, and age-based retirement.

- Actual announced retirements were included.
- Age-based retirements:
  - Coal: 50 year life
  - Gas: 40 year life (may be rebuilt if economic)
  - Wind: 25 year life (may be rebuilt if economic)
  - Solar: 25 year life (may be rebuilt if economic)
  - Battery: 12 year life (may be rebuilt if economic)
  - Hydro: 100 year life (assume Tarraleah rebuilt as per pre-feasibility and feasibility underway as part of *Battery of the Nation*)

Electricity demand and energy

Energy Forecast Assumption: 2017 AEMO ESOO Neutral case, with Tasmanian strong case

- Aggressive investment in energy infrastructure development in Tasmania would drive local industry and economic activity more generally.
  - However, it is also noted that variation to Tasmanian energy demand is not strongly material for the total NEM demand.

Peak Demand Assumption: 2017 AEMO ESOO Neutral case, with Tasmanian strong case

- Aggressive investment in energy infrastructure development in Tasmania would drive local industry and economic activity more generally.
  - However, it is also noted that variation to Tasmanian peak demand is not strongly material for the total NEM demand.
  - Note: The way that EY models the system, demand growth more broadly in Australia is separate to behind the meter installations and so accurately captures the relative growth in peak demand for dispatchable energy.

Rooftop PV

Assumption: 2017 AEMO ESOO Neutral case

- Previous modelling has shown that this has minimal impact on the overall saturation of photovoltaics in the market, as utility-scale photovoltaics are typically found to increase proportionally as rooftop photovoltaics decreases.

Industrial demand

Assumption: 2017 AEMO ESOO Neutral case

Fuel prices

Gas Price Assumption: Gas price 2016 AEMO ESOO, with coal retirements

- These numbers are provided by the Core Energy Group (often seen as providing low/conservative gas prices) – but they are used by AEMO and are also the highest forecasts that we have access to without creating our own.
  - Note: the forecasts are slightly lower than today's prices. This is considered conservative for this particular project.

Coal Price Assumption: Coal prices are based on EY experience at a per plant basis.

New entrant parameters

Assumption: 2016 NTNDP, with amendments:

- 2016 NTNDP assumes single axis tracking solar PV has greater auxiliaries than dual axis. The dual axis auxiliary allowance was raised to 1% as well.
- Gas FOM and VOM for new entrants were based on existing plant parameters as the split between FOM and VOM for new entrants was substantially different and considered less reliable.

Capex

Assumption: 2016 NTNDP, EY market analysis and industry consultation. See table below, in $/MW installed.

	Brown Coal	Black Coal	CCGT	OCGT	Solar PV - Fixed	Solar PV - SAT	Wind	Battery (4 hours)
2016-17	4024	3216	1568	1107	1448	1700	2156	2072
2017-18	4004	3201	1568	1102	1363	1600	2087	1744
2018-19	3985	3186	1568	1097	1320	1550	2020	1500
2019-20	3965	3171	1568	1092	1265	1485	2000	1292
2020-21	3946	3155	1558	1086	1231	1445	1980	1140
2021-22	3927	3140	1549	1081	1196	1405	1970	1020
2022-23	3908	3125	1543	1076	1163	1364	1965	900
2023-24	3888	3111	1537	1071	1128	1324	1960	812
2024-25	3869	3096	1535	1066	1093	1284	1956	764
2025-26	3851	3081	1532	1061	1059	1244	1953	736
2026-27	3832	3066	1530	1057	1024	1203	1950	712
2027-28	3813	3052	1528	1052	991	1163	1948	692
2028-29	3794	3037	1528	1047	956	1123	1946	680
2029-30	3776	3023	1528	1042	923	1083	1944	668
2030-31	3757	3008	1528	1037	888	1042	1942	649
2031-32	3739	2994	1526	1032	853	1002	1940	630
2032-33	3721	2980	1526	1027	819	962	1938	610
2033-34	3703	2966	1526	1023	784	922	1936	591
2034-35	3685	2952	1526	1018	750	881	1934	574
2035-36	3667	2938	1526	1013	717	841	1932	557
2036-37	3649	2924	1526	1008	714	838	1930	541
2037-38	3631	2910	1526	1004	712	836	1928	526
2038-39	3613	2896	1526	999	710	833	1926	511
2039-40	3596	2882	1526	995	707	830	1924	497
2040-41	3578	2869	1526	990	705	827	1922	483
2041-42	3561	2855	1526	985	703	825	1920	470
2042-43	3543	2842	1526	981	700	822	1918	457
2043-44	3526	2828	1526	976	698	819	1912	445
2044-45	3509	2815	1526	972	695	816	1905	433
2045-46	3492	2801	1526	967	694	814	1894	421
2046-47	3475	2788	1526	963	691	811	1890	410
2047-48	3475	2788	1526	963	691	811	1890	410
2048-49	3475	2788	1526	963	691	811	1890	410
2049-50	3475	2788	1526	963	691	811	1890	410
2050-51	3475	2788	1526	963	691	811	1890	410

New entrant wind and solar capacity factors

Assumption: EY assumptions based on internal research, as set out in the table below.

- Note: Advice was provided that dual axis tracking systems are not yet competitive and so were not investigated at this point in the analysis.

Wind			Solar Tilted Plate			Solar Single Axis Tracking		
Region	**NTNDP zone**	**Capacity factor**	**Region**	**NTNDP zone**	**Capacity factor**	**Region**	**NTNDP zone**	**Capacity factor**
QLD	NQ	33%	**QLD**	NQ	26.0%	**QLD**	NQ	31.0%
QLD	CQ	33%	**QLD**	CQ	25.5%	**QLD**	CQ	30.5%
QLD	SWQ	33%	**QLD**	SWQ	25.0%	**QLD**	SWQ	30.0%
QLD	SEQ	33%	**QLD**	SEQ	24.0%	**QLD**	SEQ	28.0%
NSW	NNS	36%	**NSW**	NNS	25.0%	**NSW**	NNS	29.5%
NSW	NCEN	36%	**NSW**	NCEN	24.0%	**NSW**	NCEN	28.0%
NSW	CAN	36%	**NSW**	CAN	23.0%	**NSW**	CAN	26.0%
NSW	SWNSW	36%	**NSW**	SWNSW	25.5%	**NSW**	SWNSW	30.0%
VIC	NVIC	36%	**VIC**	NVIC	24.0%	**VIC**	NVIC	28.0%
VIC	CVIC	36%	**VIC**	CVIC	24.5%	**VIC**	CVIC	28.5%
VIC	MEL	36%	**VIC**	MEL	22.0%	**VIC**	MEL	25.0%
VIC	LV	36%	**VIC**	LV	20.0%	**VIC**	LV	22.5%
SA	SESA	36%	**SA**	SESA	22.0%	**SA**	SESA	25.0%
SA	ADE	36%	**SA**	ADE	23.0%	**SA**	ADE	27.0%
SA	NSA	38%	**SA**	NSA	25.0%	**SA**	NSA	29.0%
TAS	TAS	40%	**TAS**	TAS	21.5%	**TAS**	TAS	24.0%

Residential and commercial storage

Assumption: 2017 AEMO ESOO Neutral case

Electric vehicles

Assumption: 2017 AEMO ESOO. Data post 2037 are extrapolated from the AEMO data.

Hydro modelling plan

Assumption: EY proprietary H2Opt software based on a simplified six-pond model of the Hydro Tasmania schemes.

- Past experience has shown that this suitably represents our existing system and hydrology, albeit using a simplified hydrological model.
- A sensitivity was explored where careful implementation of pumped hydro makes traditional hydro schemes with less storage more controllable; particularly the Mersey-Forth and Derwent.

Bidding strategy for large-scale wind and solar generators

- ***Assumption:*** All wind and solar generators bid their available capacity at -$40/MWh up to 2029-30. From 2030-31, they bid $0/MWh as their short-run marginal cost.

Hydro Tasmania storage levels and inflows

Assumption: Aggregated model based on long term average rainfall and annual probabilities.

- This was based on the climate inputs defined by the Tamblyn Report. These were considered fairly balanced and accurate.
- This does not account for major climate change. In the period of time being discussed, significant climate change is a risk, and will need to be addressed in a later phase of the project.

Basslink bidding strategy

Assumption: All available capacity at $0/MWh.

- This is consistent with existing arrangements.
- All new links were also considered to be regulated.

Appendix D. Build out scenarios

Interconnector Sizing

Interconnector	Size (MW)
Basslink	500 MW sustained
2IC	600 MW sustained
3IC	800 MW sustained
4IC	900 MW sustained
5IC	1000 MW sustained

Scenario Definition

Scenario	Total Pumped Hydro (PH) (MW)	Total Wind (MW)	Total IC (MW)	Annual PH Gen (TWh)	Annual PH Demand (TWh)	Annual Wind Gen (TWh)	Annual Non-PH Demand (TWh)	Total Annual Demand (TWh)	Annual Existing Hydro Gen (TWh)	Net Energy Export (TWh)
NoTasDev	0	600	500	0	0	2.1	10.5	10.5	9.0	0.6
3IC Low	1500	2000	1900	3.3	4.1	7.0	10.5	14.6	9.0	4.7
4IC Medium	2500	3700	2800	5.5	6.8	13.0	10.5	17.3	9.0	10.1
5IC Low	3500	3500	3800	7.7	9.6	12.3	10.5	20.1	9.0	8.8
5IC Strong	3500	6500	3800	7.7	9.6	22.8	10.5	20.1	9.0	19.4

Note: The ‘strong’, ‘medium’ and ‘low’ descriptor for the scenario details the level of wind penetration since the pumped hydro build out is determined entirely by the interconnection opportunity. The NoTasDev case is a counterfactual with no further energy developments in Tasmania beyond Cattle Hill and Granville Harbour wind farms.

Scenario Validation

A number of situations were tested for initial validation of proposed pumped hydro, wind and interconnection balance for the modelling scenarios, before inputting these scenarios to the full dispatch modelling process.

- ***Local demand***: set according to either maximum or minimum demand in Tasmania, according to the situation being considered.
- ***Available supply:*** was calculated from existing hydropower capacity, plus pumped hydro capacity, plus wind at a given capacity factor.
- ***IC Flow:*** set by the build out in the scenario.
- ***Max. demand:*** the addition of local demand, pumping demand and interconnection.
- ***Difference:*** The excess identified in the given situation between available supply and maximum demand.
- ***Local supply:*** Tasmanian wind generation plus Tasmanian conventional hydropower generation (existing plant).

Situation 1: High Victorian prices, scarce available generation

- Low Tasmanian wind (5% capacity) – assumption is that the prices are high due to low wind availability and having to use more expensive generation options.
- High Tasmanian demand (1800 MW) – assumption is that the prices are high due to high demand.

Confirm that interconnection is sufficient to export available Tasmanian hydro, including pumped hydro

Scenario	Local Demand (MW)	Available Supply (MW)	IC Flow* (MW)	Max. Demand (MW)	Difference (%)
3IC Low	1800	3600	1800	3600	0.0%
4IC Medium	1800	4685	2800	4600	1.8%
5IC Low	1800	5675	3800	5600	1.3%
5IC Strong	1800	5825	3800	5600	3.9%

*** Northerly interconnector flows (in this case, exporting to Victoria) are positive**

Findings:

- Almost all of the available hydropower can be utilised.

Situation 2: Low prices, preference to store and run at minimum dispatchable generation levels while wind in Tasmania is strong

- High Tasmanian wind (100% capacity).
- Minimum hydro (environmental flow requirements).
- Low Tasmanian demand.

Confirm that interconnection/pumping is sufficient to utilise available wind, plus minimum hydro (environmental flow requirements)

Scenario	Local Demand (MW)	Pumped Hydro Demand (MW)	Max. Demand (MW)	IC Flow* (MW)	IC Capacity* (MW)
3IC Low	800	1500	2048	-252	±1800
4IC Medium	800	2500	3748	448	±2800
5IC Low	800	3500	3548	-752	±3800
5IC Strong	800	3500	6548	2248	±3800

*** Northerly interconnector flows (in this case, exporting to Victoria) are positive**

Findings:

- All of the available wind can be stored or exported.
- In low wind build out scenarios, low cost energy will be imported from Victoria to fill storages in this situation.
- The interconnectors are not constrained in either direction.

Situation 3: Low prices, preference to store and run at minimum dispatchable generation levels while importing from Victoria

- Relatively low Tasmanian wind (20% capacity).
- Minimum hydro (environmental flow requirements).
- Moderate Tasmanian demand.

Confirm that interconnection is sufficient to import and store excess Victorian generation

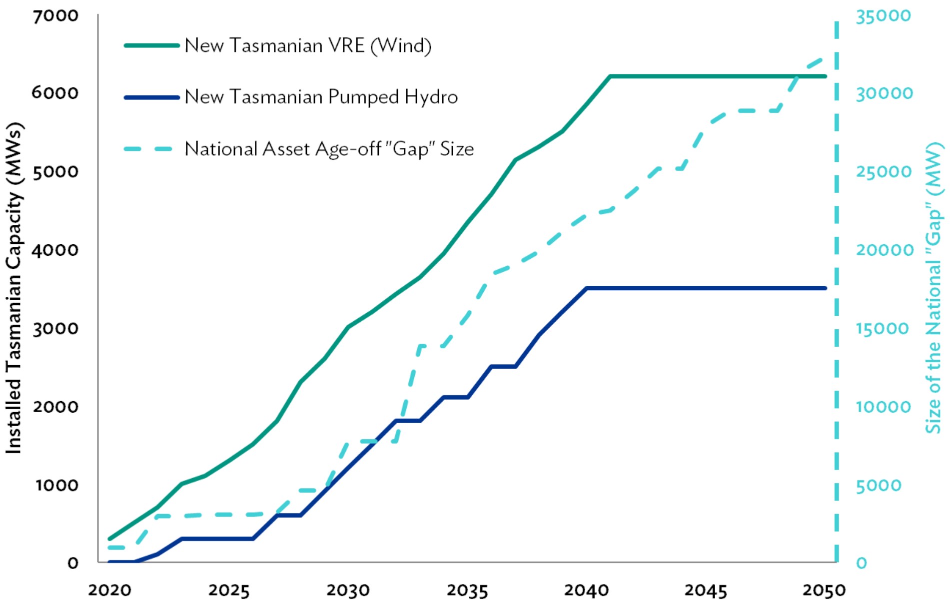
Scenario	Local Demand (MW)	Max Pumped Hydro Demand (MW)	Local Supply (MW)	IC Flow* (MW)	Actual Demand (MW)	Difference (%)
3IC Low	1200	1500	448	-1900	2348	13.0%
4IC Medium	1200	2500	788	-2800	3588	3.0%
5IC Low	1200	3500	748	-3800	4548	3.2%
5IC Strong	1200	3500	1348	-3352	4700	0.0%

*** Northerly interconnector flows (in this case, exporting to Victoria) are positive**

Findings:

- In 3IC, low wind scenario, there is insufficient interconnection to fill pumped hydro storages at maximum rate, when local generation is low. In other scenarios, the interconnection is close to sufficient or sufficient.

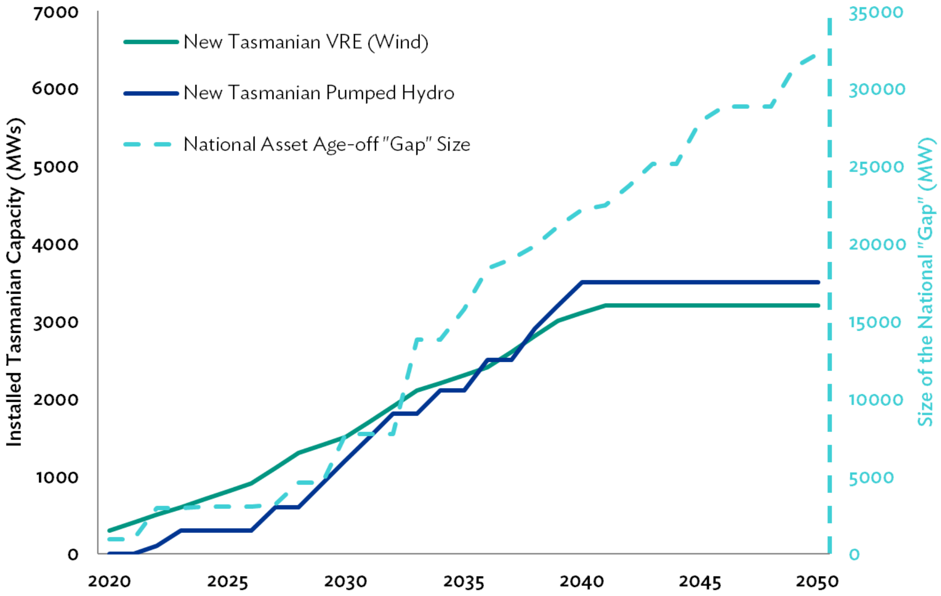
5IC Strong



	Wind Installation						Pumped Hydro Energy Storage Installation					
	North West	North	North East	Central	South	West	North West	North	North East	Central	South	West
2018												
2019					150							
2020						150						
2021	200											
2022	200							100				
2023	300							200				
2024	100											
2025	200											
2026	200											
2027	200	100						300				
2028	100	200			200							
2029		100			200			300				
2030				200	200							300
2031					200			300				
2032			120		100					300		
2033			120			100						
2034			200			100				300		
2035			200	200								
2036			200	160								400
2037	200		200	40								
2038	160							200				200
2039						200					300	
2040		200				150					300	
2041		200			150							
2042												

Basslink 2IC 3IC 4IC 5IC

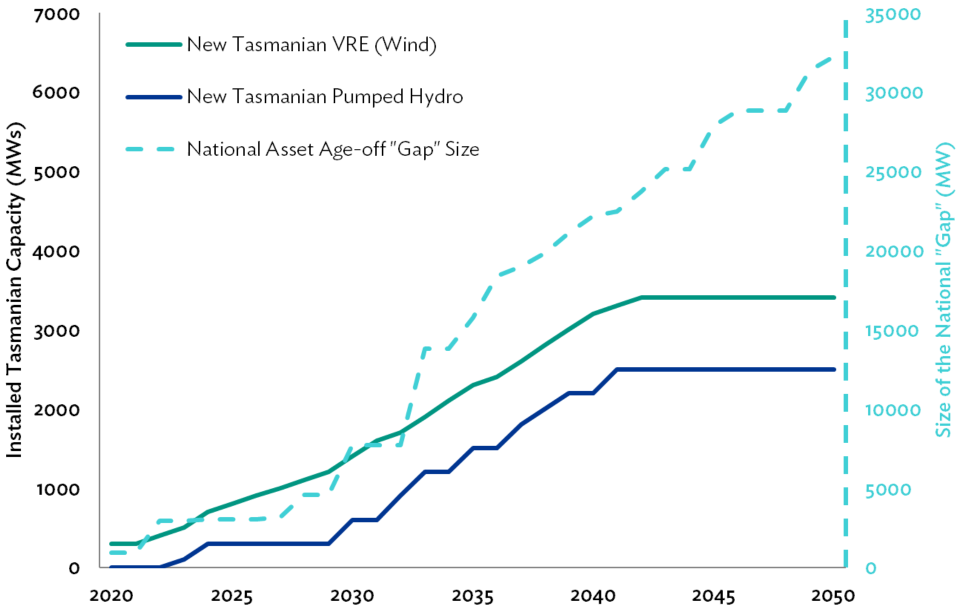
5IC Low



	Wind Installation						Pumped Hydro Energy Storage Installation					
	North West	North	North East	Central	South	West	North West	North	North East	Central	South	West
2018												
2019					150							
2020						150						
2021	100											
2022	100							100				
2023	100							200				
2024	100											
2025	100											
2026	100											
2027	200							300				
2028	200											
2029	100							300				
2030	100											300
2031	100				100			300				
2032					200					300		
2033					200							
2034					100					300		
2035					100							
2036					100							400
2037					100	100						
2038		100				100		200				200
2039		100				100					300	
2040		100									300	
2041		100										
2042												

Basslink 2iC 3iC 4iC 5iC

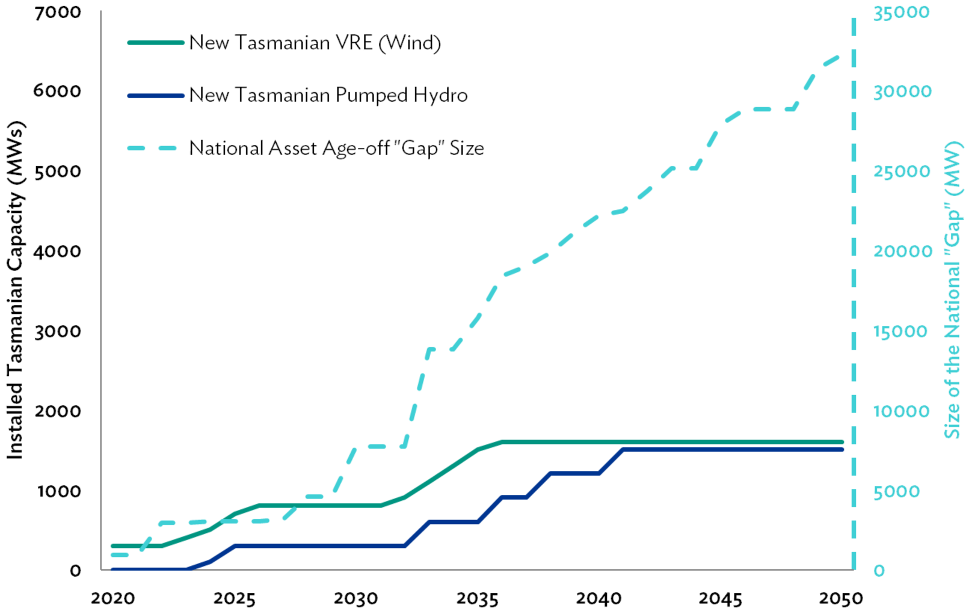
4IC Medium



	Wind Installation						Pumped Hydro Energy Storage Installation					
	North West	North	North East	Central	South	West	North West	North	North East	Central	South	West
2018												
2019					150							
2020						150						
2021												
2022	100											
2023	100							100				
2024	200							200				
2025	100											
2026	100											
2027	100											
2028	100											
2029	100											
2030	200							300				
2031	200											
2032	100							300				
2033	100	100										300
2034		200										
2035		100			100			300				
2036					100							
2037					200					300		
2038					200						200	
2039					200			200				
2040					100	100						
2041						100				300		
2042						100						

Basslink 2IC 3IC 4IC

3IC Low



	Wind Installation						Pumped Hydro Energy Storage Installation					
	North West	North	North East	Central	South	West	North West	North	North East	Central	South	West
2018												
2019					150							
2020						150						
2021												
2022												
2023	100											
2024	100							100				
2025	200							200				
2026	100											
2027												
2028												
2029												
2030												
2031												
2032	100											
2033	200							300				
2034	100				100							
2035	100				100							
2036	100							300				
2037												
2038												300
2039												
2040												
2041								300				
2042												

Basslink 2IC 3IC

Pumped Hydro Projects – assumed for modelling

Note that these are different from the shortlist presented in the Battery of the Nation pumped hydro concept study report (HT 2018a). The pumped hydro shortlist was developed in parallel with this work. As such, this list was taken from preliminary work which has been developed significantly since.

Project Name	Installed Capacity (MW)	Energy in Storage (MWh)	Hours at Maximum Capacity in Storage
Mersey Forth Large 2	300	17125	57.1
Mersey Forth Medium 1	300	8270	27.6
Mersey Forth Large 1	300	19545	65.2
Mersey Forth Medium 2	300	8995	30.0
Mersey Forth Small 1	300	2295	7.7
West Coast Large 1	600	16873	28.1
West Coast Small 1	300	3593	12.0
Poatina Large 1	600	27806	46.3
Derwent Small 1	300	5265	17.6
Derwent Small 2	300	6000	20.0
Derwent Small 3	300	4760	15.9

Appendix E. Sensitivities not modelled

A number of sensitivities cannot (or will not) be captured by this phase of the modelling exercise. These include:

Inertia regulation/market and/or fault level regulation/market

- Model outputs will be checked for broadly acceptable inertia outcomes. In initial stages of the project, this will be addressed in a cursory manner.
  - Note that given DC interconnection with the rest of the NEM, Tasmania can provide fast frequency response but not inertia to the NEM.
  - Previous work by Oakley Greenwood for broadly similar scenarios found that security costs around a 10% uplift in a zero carbon situation (given all assumption etc.). This is clearly significant, but should not stop the project proceeding as the cost implications are second order in scale.

Climate change impacts

- Climate change impacts on hydro generation or load are not considered in this modelling. This will be addressed through discussion and potentially later studies.

Dynamic gas price effects of changing energy mix

- Explicit impact of shortage on gas prices during peak periods and as gas usage may rise in a substantially lower coal-based system.
  - This may also lead to market gaming which has not been captured.
- Core model assumes a predetermined price rise, which includes allowance for coal retirement.

Changes to market price cap

- Potential changes to the market price cap. This is less relevant as EY uses the value of lost load in its calculation which is approximately two times higher than the present market price cap.

Capacity Market

- The impact of a capacity market on the *Battery of the Nation* concept. However, as noted, a capacity market can be considered to be analogous to mandatory cap contracts from a generator's perspective and this has been considered as accompanying analysis.

RIT-T process

- Interconnection installation will be "forced" in this model, and captured in the total cost. The process to assess and regulate transmission or interconnection as part of a renewable energy zone or coordinated planning process may require changes to the regulations.

Accepted lower reliability

- Reducing the mandated system reliability could reduce network costs and may avoid some cost associated with ensuring that superpeak imbalance is met. This will be considered through discussion and possibly future modelling work. Some efforts have been established externally to Hydro Tasmania to better understand this requirement and the appetite of our consumers to pay for this level of service.

Extended coal plant life

- There is a potential scenario of minimal change where investment is made to extend existing plant life and the problem is deferred to future generations. This could affect the viability of the initiative and should be modelled when testing the enablers and blockers in a future phase.

Discount rates

- Lower discount rates would incentivise investment into longer-term solutions, recognising value of the assets beyond 20 years. This is particularly important for long life assets such as hydro plant and transmission.

Prepared by

Hydro Tasmania

ABN 48 072 377 158

Hobart Office

4 Elizabeth Street
Hobart, Tasmania 7000
Australia

Postal Address

GPO 355
Hobart, Tasmania 7001

Email

batteryofthenation@hydro.com.au