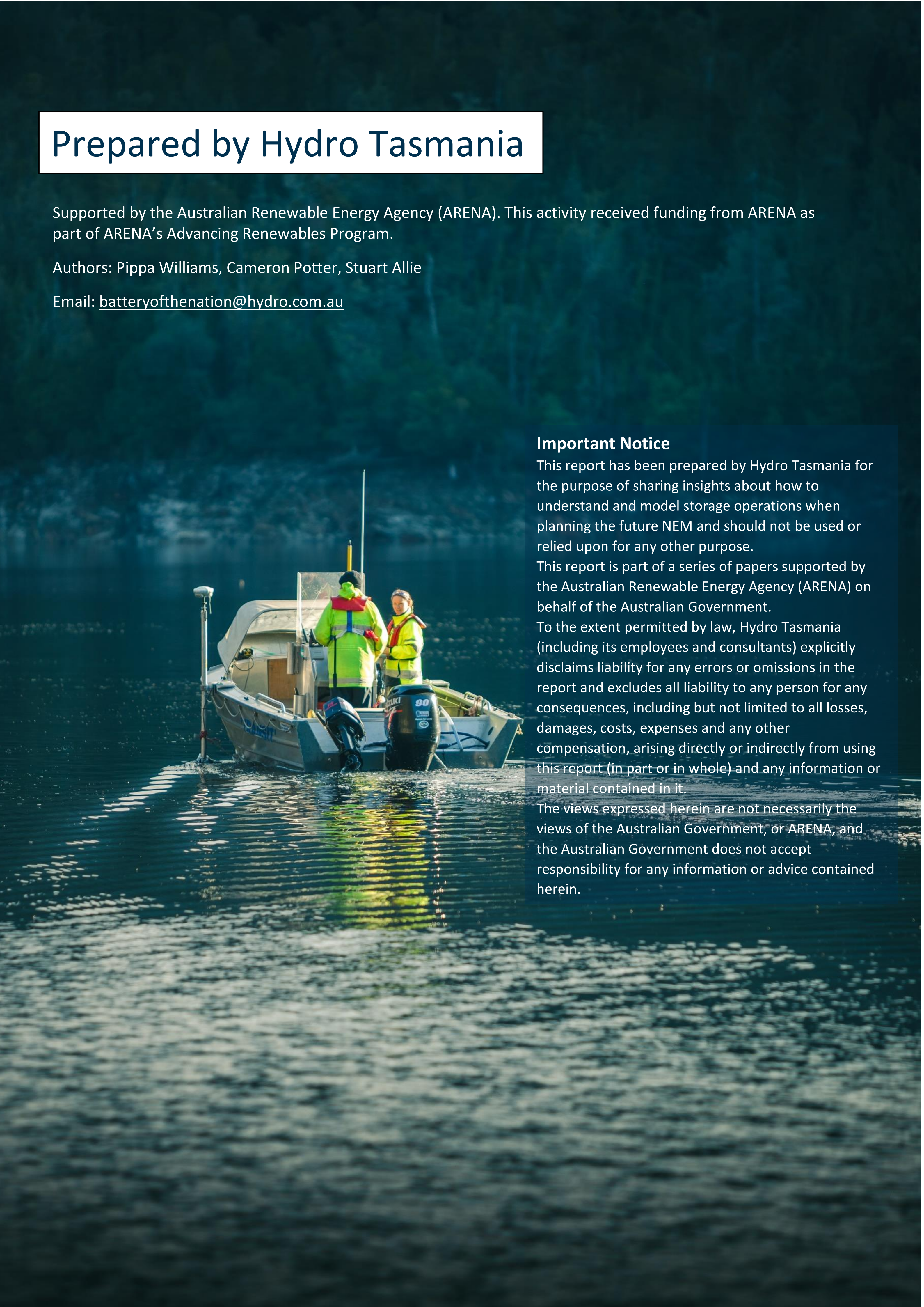
# *Battery of the Nation*

## Operation of storages without perfect foresight

**Developing a more accurate understanding of the operation of energy storages with a more realistic forecast of the future market**

September 2019



# Prepared by Hydro Tasmania

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**Important Notice**

# Foreword

Australia's National Electricity Market (NEM) is in transition. The technology mix and therefore the operations of the future market are expected to change, and storage is expected to play a much larger role and needs to be better understood. The shifting technology mix impacts our understanding of the future market and is influencing the relative importance of the assumptions and simplifications used in modelling the future NEM, particularly those affecting how stored energy is managed.

To date, models have been able to assume perfect foresight without materially compromising outcomes. Energy storage has primarily been provided by hydropower generators that have either been sufficiently large or sufficiently immaterial to the reliability of the system that short-term forecast uncertainty has had little importance. In fact, for some storages, daily or seasonal operation profiles (patterns of operation) were applied; implicitly indicating that the market forecasts had no relevance to the operations of these assets.

Storage is set to play a much greater role in the future NEM – even under the slowest change scenarios. Understanding how storage might realistically operate in the future is critical to understanding the potential reliability of the system and the relative value of different storage technologies.

Understanding imperfect forecasts will result in more realistic expectations of storage operation. The analysis presented in this paper finds that longer storages are better able to manage forecast uncertainty. They are more likely to have energy in storage at times when it will be needed and will better support the reliability and security of the future NEM. Prioritising longer duration storage will result in a more robust NEM.

Steve Davy

Hydro Tasmania Chief Executive Officer

September 2019

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# Executive Summary

Australia is planning and preparing for a very different electricity system. Low cost wind and solar will become the dominant providers of energy, and flexible supply options will be needed to help manage the system. Storage is projected to play a major role in this transformation.

Hydropower, including pumped hydro energy storage, has been present in the National Electricity Market (NEM) since it began operation in 1998. However, it is not well represented in the models used for power system planning, due to the simplifications used to reduce model complexity to a manageable level.

Many generation types can be modelled as having infinite fuel – the generator will operate whenever the price is more than its short-run marginal cost. Energy storage operation requires more active decision-making about the energy in storage, which requires a view of the future.

Perfect foresight has been a convenient simplification in power system modelling. Perfect foresight means that all decisions are made with full knowledge of all relevant information at all times: past, present and future. This means that 'perfect' decisions will be made. However, in the real electricity market, decision-makers do not have complete information. Uncertainty in forecasting is particularly relevant for storages since it determines the value of energy in storage – both when choosing to supply and when choosing to store[1]. The simplification of perfect foresight is becoming material in planning for the NEM and leading to conclusions which underplay the need for storage – particularly long duration storage.

This paper uses a mathematical optimisation model (linear program) to show that while all storages will lose some value when relying on an uncertain view of the future price (a proxy for the supply-demand balance) long duration storages are more robust, see Figure 1.

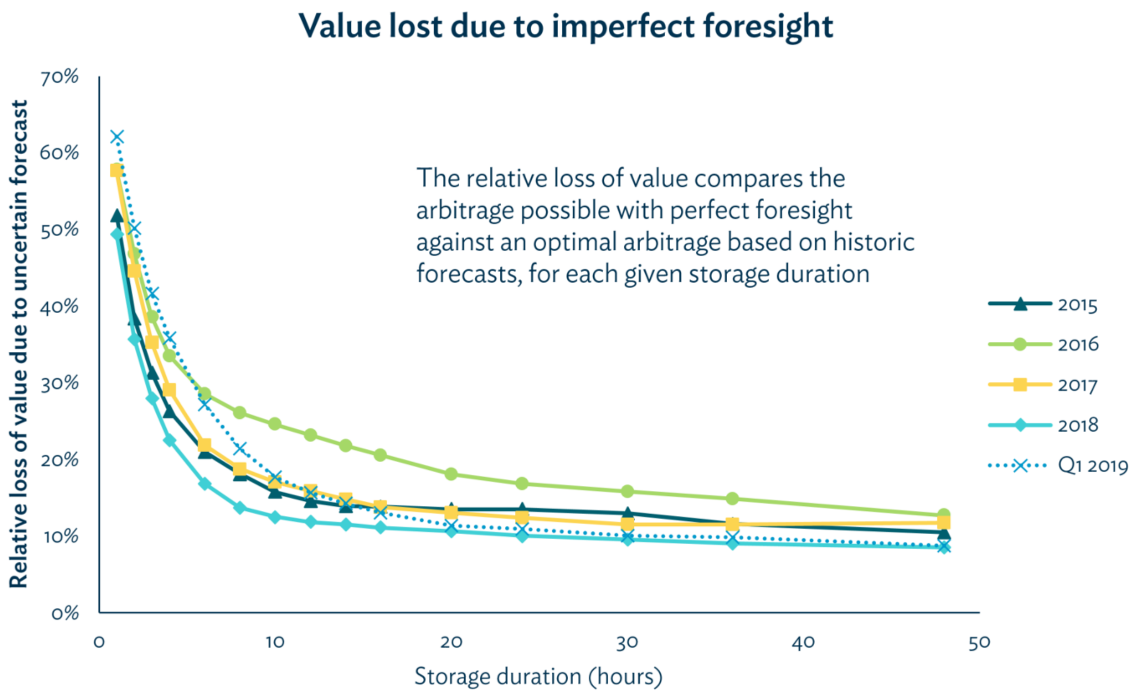



**Figure 1.** Lost value due to imperfect foresight for various duration storages

1 Other implications of imperfect foresight, for example ensuring short-notice gas availability, may also become material. However, these are not the focus of this paper.

With imperfect foresight, shorter storages lose a significant proportion of their theoretical (perfect foresight) value. Storages with longer durations (12 to 24 hours or more) were found to perform similarly to the expectations of the existing modelling efforts. However, even these show some loss of value.

This loss of value can be offset by building longer duration storages, to achieve the value anticipated by a perfect foresight model. For example, to achieve the same value as a two hour storage with perfect foresight, a storage of duration over four hours would be needed using more realistic foresight. It is also important to recognise that this is on the basis of past market behaviour – in a future with more variable energy sources, these ratios would be expected to change.

*To achieve a similar value outcome when imperfect foresight is considered, 2-3 times longer storage duration is required.*

It is likely that the NEM will need more storage than the present models are projecting, to be able to meet the same level of reliability. Combining this with the impact of scarcity pricing will show that the existing models must be adjusted to truly identify a least-cost electricity system for the future.

# 1. Preparing for the future NEM

The NEM is in a period of rapid transformation. Reductions in the cost of variable renewable energy, along with the aging and deterioration of Australia's coal fleet, have led to a situation where the most likely future energy mix is very different to the present state. Australia needs to plan to manage a very different electricity system. One notable change is the relevance of energy storage, which is expected to play a much more significant role in the future NEM.

The NEM's existing market structures are optimised to make the best use of coal-fired generation, maximising the value of these large investments made several decades ago. However, as coal retires, it is being replaced by different technologies because new coal-fired generation is no longer the lowest cost form of energy production. Decisions about future policy and market design need to achieve the most efficient outcome for Australia under this new technological paradigm. This has been recognised by the Council of Australian Governments (COAG) Energy Council and a review of market design is underway[2]. To inform this process, it is important to understand the potential behaviours of the power system in the future.

Modelling the future NEM can provide insight on power system behaviours to inform the policy decisions and market design, ideally to achieve the most efficient outcome for Australia. However, accurately capturing the behaviours of the power system during the transformation of the NEM will be challenging[3]. The physical characteristics of the power system will change and therefore the responses of the system will change. Today's models, which were optimised to represent the existing system, will lose accuracy. Simplifications and assumptions that may have been suitable for the past may not be sufficiently accurate for the future. Technologies that introduce new and different characteristics to the NEM will be especially difficult to represent.

Models are inherently simplified versions of a possible future. The simplifications and assumptions allow modellers to assess the impact of various drivers under future scenarios. Every simplification and assumption introduces error; the models are refined and adjusted over time to better capture the behaviour of a system. Models that are regularly challenged by a range of experts tend to be robust and well-understood. However, when circumstances change rapidly, even a well-tuned model must be challenged and updated.

# 2. The market is shifting towards storage

Until 2017, projections of the future NEM saw retiring coal plant replaced predominantly by gas and wind generation. However, the rapid reduction in the cost of solar and storage and increases in the price of gas has meant more recent projections have favoured wind and solar firmed by storage. Consequently, a future system dependent on energy storage is thoroughly plausible. For example, AEMO's 2018 Integrated System Plan (ISP)[4] projected 28 times as much energy to be supplied by storage in 2040 compared to 2018 in its 'Neutral' scenario, and 37 times as much in its 'Fast Change' scenario, see Figure 2.

[2] COAG Energy Council, *Post 2025 Market Design for the National Electricity Market (NEM)*, March 2019: http://www.coagenergycouncil.gov.au/publications/post-2025-market-design-national-electricity-market-nem

[3] This challenge is addressed more broadly in Hydro Tasmania's white paper, *Challenges in modelling the transforming NEM*: https://www.hydro.com.au/clean-energy/battery-of-the-nation/future-state

[4] AEMO, Integrated System Plan for the National Electricity Market, 2018: https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/ISP/2018/Integrated-System-Plan-2018_final.pdf

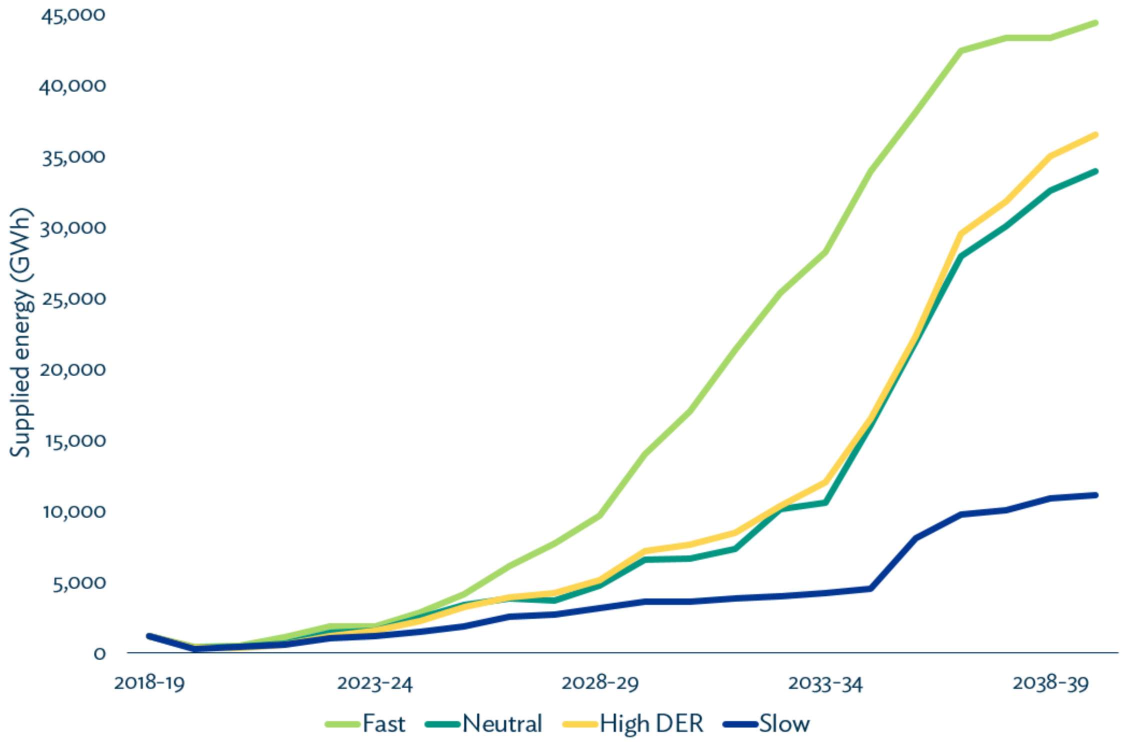



**Figure 2.** The projected energy supplied from storages in the 2018 ISP

In short, storage is projected to become the dominant supplier of flexible dispatchable energy[5]. While both pumped hydro and batteries exist in the market today, storage plays a relatively minor role and is often overlooked and inadequately represented in the market structures[6].

Operational decision making is dependent on forecasts of future energy availability and demand. Storage relies heavily on choosing when to operate – it must store energy during times of plenty to supply during times of scarcity. With the increasing importance of storage to the operations of the NEM, it is important to understand the key influences on its performance.

# 3. Perfect foresight in power system models

Models of the national electricity market use the assumption of 'perfect foresight'. While there are a range of simplifications in these models, perfect foresight is particularly relevant since it strongly affects the operation (and effectiveness) of storage.

Perfect foresight means that all decisions are made with full knowledge of all relevant information at all times: past, present and future. This means that 'perfect' decisions will be made in selecting new developments and optimising for efficient operation (subject to modelling simplifications and assumptions).

In the real electricity market, decision-makers do not have complete information. They should have a good understanding of the past and a live view of the present but only informed estimates about the future.

5 It is important to understand that storage is a net consumer of energy – this analysis is focussing on the ability to supply energy when needed.

6 There is no participant type for storage and participants must register as both a generator and a load.

## 3.1 Practical considerations for choosing perfect foresight

Perfect foresight is a useful approximation for the workability and computational efficiency of market models. Since all information is available at all times, there is no need to manage what is known at a given point in time. Imperfect foresight is computationally expensive because the optimisation must be repeated for each time step in the model since the available information keeps changing. This is demonstrated in Figure 3.

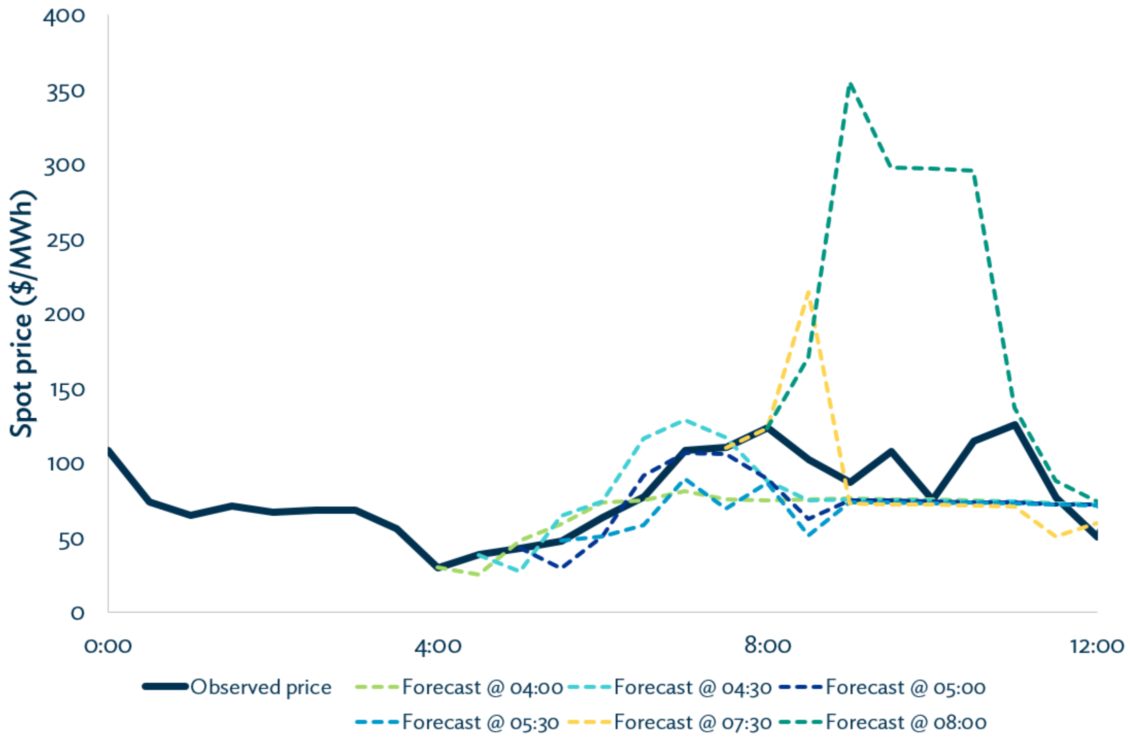



**Figure 3.** A demonstration of observed price and real forecasts over a morning in autumn

Even if the computation efficiency could be overcome, it is difficult to manufacture a realistic imperfect forecast for a projected future scenario. To properly represent an imperfect forecast, the sources of uncertainty must be understood, as well as their inter-relationships.

Factors such as wind and solar resource availability and demand may be based on historic data which can be paired with historic forecasts before being scaled to create projections. Random generator outages may also be included. However, uncertainty due to bidding behaviour, participants' response and exposure to uncertainty and portfolio factors (including contract position) make it difficult to produce realistic imperfect forecasts for a future scenario.

## 3.2 Perfect foresight in resource allocation

Historically, perfect foresight has mostly impacted the modelling of new developments in the system, i.e. building new hypothetical power plants. This process is called the 'resource allocation' phase of modelling. A 'perfect' new supply mix is built based on perfectly-informed investment decisions. For example, when deciding whether, and when, to build a wind farm, the model knows the full output profile for every hour for the life of the asset. It also knows the future electricity demand at every point in time, the output of every other power station, etc. This results in a highly-tuned optimal outcome, but not a realistic outcome.

With perfect foresight, the amount of capacity to be built will cover requirements in a minimal manner to achieve the least-cost outcome. In reality, the supply mix will be developed by operators who would weigh the likelihood and impact of various futures (along with a variety of other decision-making factors) in deciding what to build and when to build it.

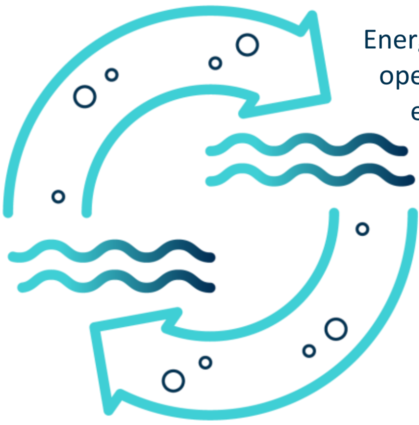
Previously, the impacts of these inaccuracies were relatively unimportant – the degree of change was limited and most supply options were not energy constrained. However, greater penetrations of variable renewable energy and energy-constrained storages make this inaccuracy much more substantial.

Perfect foresight in resource allocation delivers an optimal resource mix given the inputs, yet in reality, full knowledge of the future is not available. Perfect foresight is likely to underestimate the actual requirement. Resources may be selected that help balance particular challenges, but the real situation is likely to have different challenges which will need a different resource mix. For example, whether an impactful outage occurs during the day or the night, during a highly windy period or during a wind drought may well change the optimal resource mix. However, in reality, that outage may occur at a different time in a different way to a different asset. The finely-tuned resource mix is actually quite likely to be inadequate for the challenges that occur in reality. There are a large range of uncertainties that will affect the supply mix and resource allocation, and these will be covered by an associated paper[7].

It is likely to be more valuable to plan for more transmission and more supply, particularly flexible and dispatchable supply, that can be used to manage future outcomes different to those captured in model.

## 3.3 Perfect foresight for dispatch decisions

The results of resource allocation are typically sense-checked using more detailed 'dispatch modelling', using data with hourly or half-hourly time steps. Many generation types can be modelled as having infinite fuel – the generator will operate whenever the price is more than its short-run marginal cost. When modelling a system with plentiful fuel, perfect foresight has limited impact on dispatch modelling – generators offer supply at a price and then are dispatched or not depending on need (as indicated by spot price). Energy storage operation requires more active decision-making about the energy in storage, which requires a view of the future. With increasing reliance on storage for energy balancing, the assumption of perfect foresight for dispatch operations will become critical because the dispatch will depend on both need and the availability of energy in storage.



Energy storages will not be operated with perfect foresight – operators will not have a perfect forecast of the future. For example, the operator may choose to fill the storage during a period of moderate energy availability, to prepare for a period of scarcity which does not eventuate. Similarly, an unforeseen period of scarcity may occur (e.g. due to an unplanned generator outage or weather forecast uncertainty).

7 This challenge is addressed more broadly in Hydro Tasmania's white paper, *Challenges in modelling the transforming NEM*: https://www.hydro.com.au/clean-energy/battery-of-the-nation/future-state

### 3.3.1 A simple case study of operation decisions

The impact of imperfect foresight on electricity storage operation is significant, particularly for shorter duration storages such as batteries and small pumped hydro, see Figure 4.

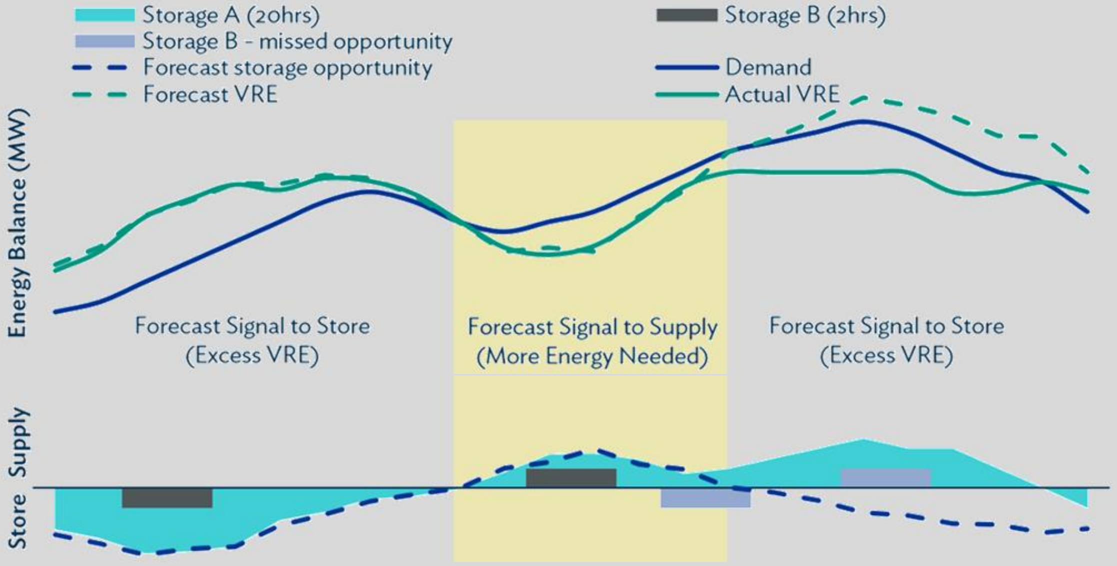



**Figure 4.** Illustrative storage operation[8] with an imperfect forecast for wind and solar (VRE)

In this example, the forecast is for a day with plentiful wind and solar in the morning and evening and a slight shortfall in the middle of the day.

Storage A has 20 hours of storage duration – that is, when full, it can supply energy for 20 hours before it is empty. Storage B only has 2 hours of storage duration.

The operator of Storage A looked at this forecast and planned the following actions:

- Consume and store energy throughout the morning while the surplus is available
- Supply energy to the market around midday
- Refill the storage in the evening when the VRE is projected to be plentiful

The operator of Storage B would forecast similar opportunities, although when planning, it can only operate for shorter periods and would try to identify the peaks more explicitly.

The morning and the midday forecasts were very accurate, however the VRE is less abundant in the evening. Electricity is more expensive than expected and the storage operators have to re-examine their plan. Is there an opportunity to refill their storages with the view that later prices will be high enough to justify this action? Will the forecast VRE still occur, just later in the day? Is there enough energy in storage to respond to the opportunity as it stands?

In Figure 4, the operator of Storage A was able to continue operation by drawing upon stored energy. The operator of Storage B could not make the same choice without a better forecast.

A model with perfect foresight has full knowledge of supply, demand and prices and would choose to store in the early afternoon, even though Storage A is choosing the supply at that time. This would give Storage B some energy in storage for the evening peak. A model with perfect foresight will overestimate the capability of storages, particularly those with shorter durations.

[8] In reality the remaining demand and the responses of other participants are also uncertain – this is just a simplified example to illustrate the concept.

Even in today's market, imperfect foresight can be shown to impact on how a hypothetical storage extracts arbitrage value from the market.

Analysis confirms that the capability of storages will be overestimated since they will not be operated optimally. This will mean that slightly more storage, particularly longer duration storages that are more robust to forecast uncertainty, will be beneficial to manage future outcomes. This impacts the dispatch model outcomes, but also needs to be considered for the investment/development outcomes during the resource allocation phase of the model.

# 4. Methodology to assess the impact of forecast uncertainty on dispatch decisions

The analysis presented in this paper was designed to better understand the realistic behaviour of storages of varying durations in the context of uncertain operational decisions. In the NEM, the impact of imperfect foresight can be analysed using the spot price. Times of abundance and scarcity lead to market signals reflected in the spot price. The relative impact of imperfect foresight, and therefore imperfect storage operation, can be quantified in terms of the spot income of a hypothetical storage.

The developed methodology draws strongly on earlier work by McConnell, Forcey and Sandiford[9] and was designed to maximise objectivity and repeatability. A linear programming approach was used to determine storage operation which would maximise revenue for each storage duration (MWh storage capacity / MW power capacity). Historic data was used to ensure a realistic representation of recorded price paired with realistic forecasts. The linear program would produce an optimal schedule to maximise profit, a proxy for responding to surplus and scarcity, based on the available information.

Victorian price data[10] was paired with historic forecasts from 2015 through to 2018. These prices were capped at $300 to reduce the skewing influence of rare, high price events on outcomes. The very high prices are an important part of why storage is required – but supplying into, or missing, a single event can substantially change the performance of an asset. The forecast data set available for this study contained relatively few high price events, and in an imperfect foresight scenario, there is an element of chance involved in whether or not energy in storage is available at these times, particularly for short (e.g. 1 – 8 hour) storages. Chance also significantly impacts the frequency, severity and duration of high-price events. Therefore, capped prices were used to minimise the skewing effect of rare events on overall outcomes.

The linear program took a database of Hydro Tasmania's historic price forecasts, which had a half-hourly resolution and were available up to six days ahead. For each half-hour time step of the optimisation, the most recent forecast which was available at that time step was retrieved from the database. Optimisation was then performed using actual prices for the first time step (the dispatch), and the 'latest' available forecast for the subsequent time steps (the planned schedule), to the end of the forecast period. Considering Figure 3, the planned operation would change over the short time period shown to adapt to the most recent view of the uncertain future.

9 McConnell, Forcey and Sandiford, *Estimating the value of electricity storage in an energy-only wholesale market*, 2015: https://energy.unimelb.edu.au/__data/assets/pdf_file/0004/2015770/1-s2.0-S0306261915010740-main.pdf

10 Victorian price data was used because Victoria is the most interconnected region in the NEM.

In each optimisation time step, an operating decision was made based on the imperfect view of the future. The rate of supply/discharge and cost/revenue were recorded. The energy in storage was updated and the next optimisation was commenced for the next time step. This was designed to represent the operation if the optimal bid had been made based on the best information available at that time.

A comparison optimisation was then undertaken, with 14 days' worth of actual price data available to the model ('perfect forecast')[11].

A range of storage options with different durations were assessed to understand the relative impact of imperfect foresight. For simplicity of comparison, each storage was assumed not to impact prices; to operate in isolation, not in a portfolio; have no participation in the FCAS market; and not be subject to contracts (although some associated work considered the impact of cap contracts). The storage operated purely to maximise arbitrage value, given the assumed efficiency (81.5% round-trip storage efficiency, 97% transmission/transformer efficiency each way). The assumed efficiency was constant for all storage durations.

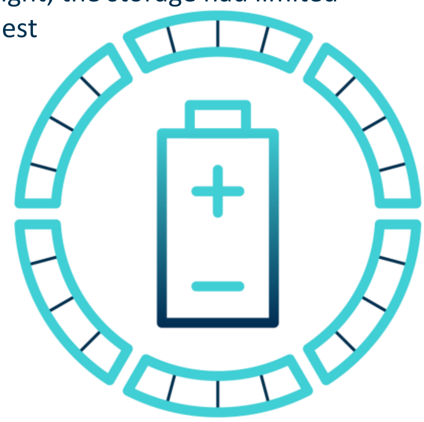
The linear programming approach was not able to optimise for starts and stops (or cycles). High rates of cycling impact equipment life and maintenance costs. This is a topic for future consideration, potentially using non-linear optimisation, and is discussed in Section 6.

# 5. The impact of imperfect foresight

## 5.1 Storage operation

The impact of imperfect foresight on the value achieved by storage is primarily due to differences in storage operation. When an opportunity arises, the storage may not have enough energy, or space, to maximise it. Alternatively, it might wait for an anticipated better opportunity which doesn't arise.

Figure 5 illustrates an example day at the start of the data set used. It contrasts the operations of a storage with two hours of duration against the operations of a storage with six and 12 hours of duration - each optimised for half-hourly operation with and without perfect foresight. As the example day has some price volatility, the storage responds to the opportunities. The storage with two hours of duration performed very differently with and without perfect foresight. For example, without perfect foresight, the storage had limited space to store when prices are very low. Similarly, at the highest price in the day, it chose not to supply, because the forecast anticipated higher prices in the subsequent time periods and the model chose to hold the energy for more profitable use later. By contrast, the storage with 12 hours of duration performed in much the same way with or without perfect foresight. It was substantially more robust to forecast uncertainty. The six hour storage did manage to capture the very highest price in the day, but was already full when the very lowest prices occurred, and missed operating into many of the high price periods.



[11] Initial results indicated that much of the value of a storage could be captured with a perfect foresight period of 3-4 times the storage duration, when compared to a full year's perfect foresight.

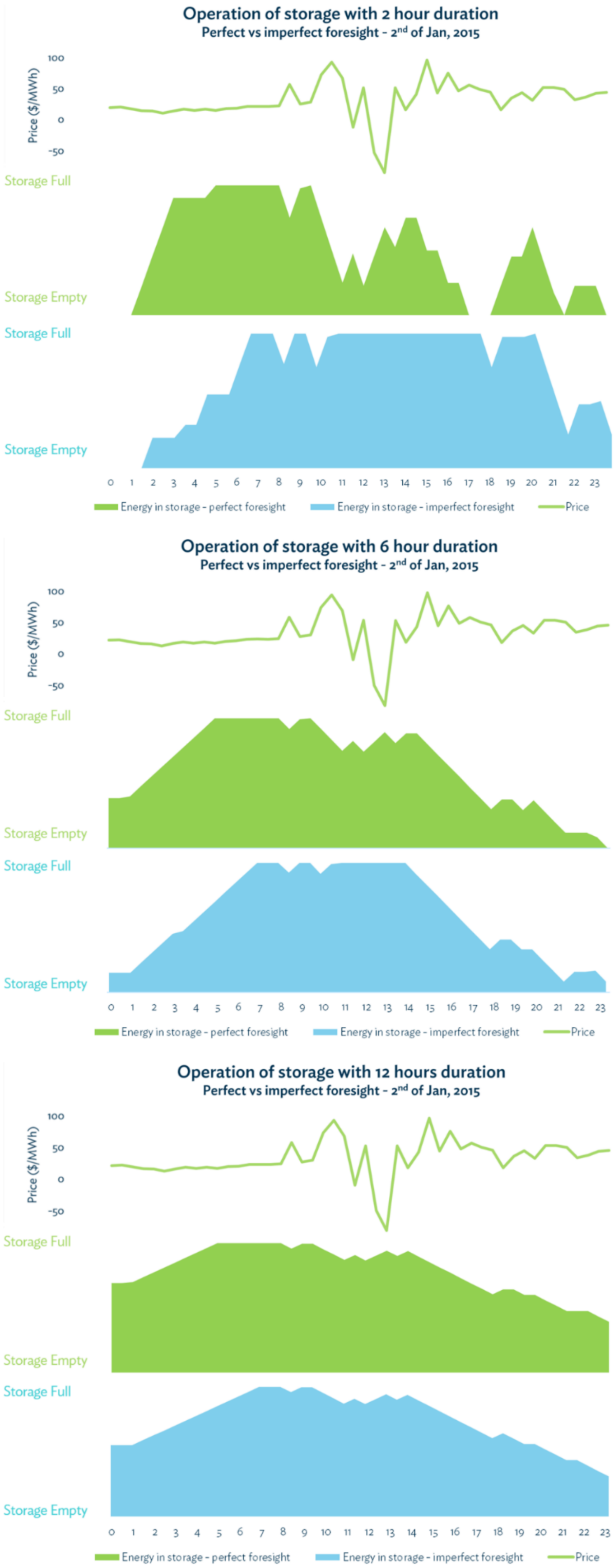



**Figure 5.** Example day's operation of a 2, 6 and 12 hour duration storage – with and without perfect foresight

## 5.2 Value comparison

Operations based on realistic forecasts rather than perfect foresight was found to have notable impact on the relative value of storages. The impact of imperfect foresight was assessed using the methodology described in Section 4. Hypothetical storages of varying durations were assessed across several years of data to understand the impacts of imperfect foresight on a range of situations. The comparative loss of value due to imperfect forecasts is depicted in Figure 6. This plot only shows the ability of a storage to *maintain* value and does not show the additional arbitrage value that longer duration storages can achieve. Nor does it show the fact that storage is becoming more valuable over times – for example storages would have made as much in Q1 of 2019 as they would have in all of 2015. The comparative loss was calculated for each storage duration using the following equation:

$$\frac{\left(Income_{perfect} - Income_{imperfect}\right)}{Income_{perfect}} \times 100\%$$

where, $\text{Income}_{\text{forecast\_type}}$ is the optimal operation given the available information.

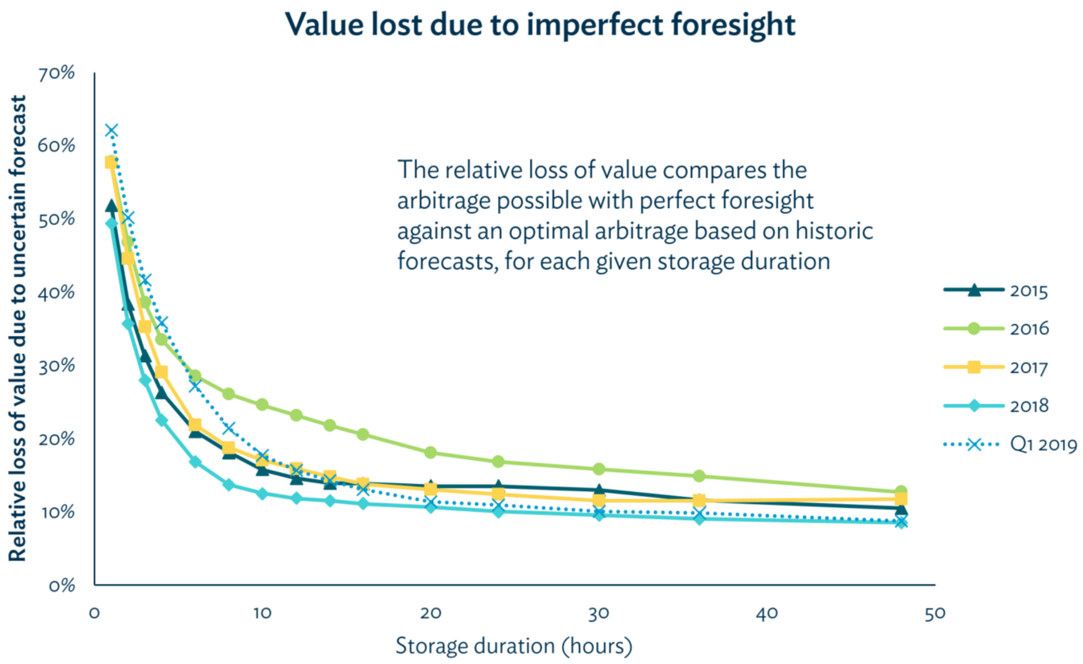



**Figure 6.** Lost value due to imperfect foresight for various duration storages

The relative loss of value due to uncertainty changed from year to year, but a strong conclusion can be made.

*With more realistic forecasts, storages less with than 12 hours of duration can be expected to lose a significant proportion of their value.*

Storages with only one hour of duration were unable to capture even half of the value achieved with perfect foresight. In contrast, longer storages were much more robust to forecast uncertainty; a storage with 48 hours of duration maintained around 90% of the maximum possible value. This may influence the relative valuation of supply options when planning for the future system.

Further inspection of Figure 6 shows that 2016 was an outlier. In general, the hypothetical storages lost more value, yet the longer duration storages were less affected. While it is difficult to provide conclusive evidence for the drivers of price patterns, 2016 was notable in that Basslink, the interconnector between Tasmania and Victoria, was out of service for approximately the first six months. In effect, this removed 500 MW of flexible low-cost supply, and conversely 500 MW of flexible load, from the Victorian market. This would have affected the Victorian price.

At the time of analysis, the first quarter 2019 outcomes were available. This quarter also shows significantly more difference in the impact of forecasts than other years. These characteristics, insufficient flexible sustained capacity and times of extended surplus, could be representative of likely trends in the future power system.

## 5.3 Duration required to achieve similar outcomes to the model

Imperfect foresight reduces the effective value of a storage compared with the operations under the assumption of perfect foresight. It is possible to achieve similar value to modelled outcomes by increasing the effective storage durations. Figure 7 shows the relationship between equivalent-value storages (of different durations) using perfect versus imperfect foresight[12].

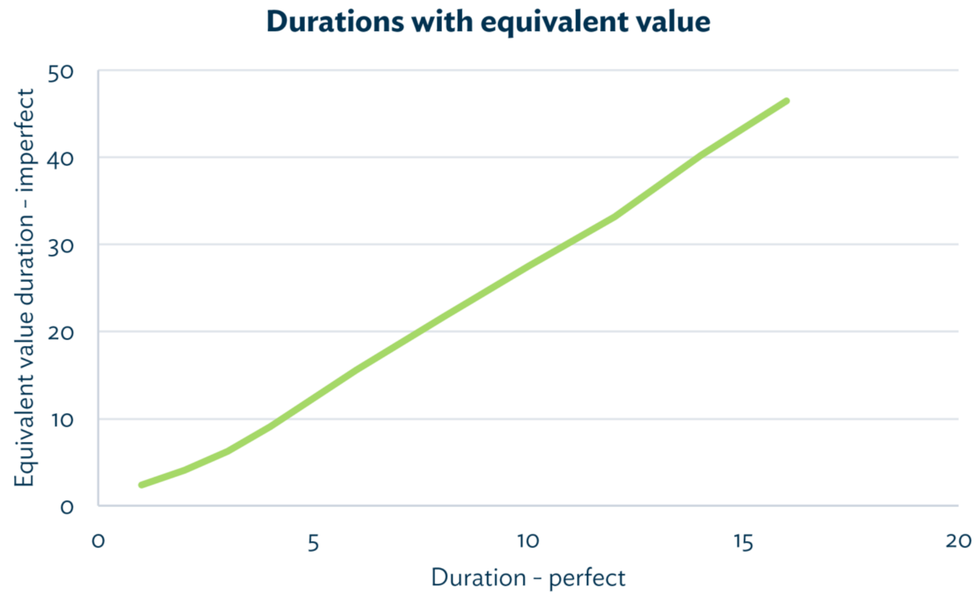



**Figure 7.** For a given duration storage modelled using the perfect foresight assumption, similar value could be achieved in an imperfect foresight model using a longer duration storage

To achieve the same value as a two hour storage with perfect foresight, a storage duration of just over four hours would be needed using more realistic foresight. Similarly, to achieve the same value as an eight hour storage with perfect foresight, a storage with approximately 22 hours of duration was required when using more realistic foresight. The increased value of a longer-term storage is due to a mixture of greater robustness to forecast uncertainty, along with the greater underlying value of longer duration storage. It is also important to recognise that this is on the basis of past market behaviour. In a future with more variable energy sources, these ratios would be expected to change.

[12] The values compared were the totals for the capped price optimisation over all modelled quarters.

## 5.4 Forecast uncertainty in the future NEM

In the future market, there is projected to be significantly more variable renewable energy which will increase the uncertainty of supply-side forecasts. The introduction of electric vehicles may also increase demand-side uncertainty, particularly in the early years while consumer charging habits develop and stabilise. The nature of the sensitivity of price to the relative scarcity of supply may mean that even small variations may have a large influence on price.

Variability from a variety of sources, on both sides of the supply-demand balance, is expected to increase the uncertainty of the forecasts. These uncertainties will also occur over longer time scales as the weather-driven renewables become more influential in the daily operation of the system. More sustained capacity will be required to help manage the system and longer duration storages will be more robust to the increased uncertainty.

Additionally, if multiple storages were all acting with the same (or similar) forecast information, uncertainty in forecasts could drive similar behaviour patterns and impact the price. This could create a vicious cycle of storage response, potentially exacerbating cases of unforeseen abundance or scarcity – particularly for shorter duration storages. Longer-term storages are less likely to be affected by small variations in price. Longer duration storages can maintain a high utilisation while arbitraging over a longer period of time.

## 5.5 Consideration of the influence of cap contracts

One way to obtain increased revenue certainty is to sell cap contracts – essentially insurance that limits the customers' exposure to very high prices in return for a small premium every hour. While a cap contract is a financial agreement that anyone can enter in to, they are often sold by generators to customers such as retailers or major industrials. Both are essentially exchanging a chance of very high prices (an upside risk for the generator, a downside risk for the retailer) for a fixed price, which is useful for reducing budget risk.

Imperfect foresight increases the likelihood that a generator may fail to supply into high price periods, increasing the risk of providing a cap contract – particularly for shorter duration storages. Longer duration storages are more resilient and likely to help put downward pressure on cap prices, assisting customers in managing their risk.

## 5.6 Managing uncertainty by maintaining a reserve

One option to increase resilience to forecast uncertainty is to maintain a reserve of energy ready to respond in case of unpredicted outcomes. The Hornsdale Power Reserve in South Australia has such an arrangement. 70 MW and 10 MWh are reserved for managing ancillary services and the remaining 30 MW and 119MWh are available for arbitrage trading in the NEM[13]. Storages may also find benefit from keeping a reserve to benefit from unforeseen arbitrage opportunities, or to cover cap contracts.

An attempt was made to quantify this benefit, however, the value of this is highly dependent on the risk appetite of the storage operator. Small revenue benefits could be found, but the larger value is likely to be found in the risk management aspects. When considering this

[13] ARENA, https://arena.gov.au/assets/2019/02/hornsdale-power-reserve.pdf

analysis in a realistic context, it will also be influenced by whether the generator is a sole asset, or part of a portfolio of generation assets with which risk may be managed. Nonetheless, analysis confirmed that longer duration storages could generally hold a valuable reserve with little impact on opportunity while shorter duration storages lose more arbitrage opportunities by holding a reserve.

# 6. Using this information to improve planning

Using optimised mathematical modelling, it has been shown that there is a strong difference in value between operation under perfect foresight (a coarse assumption) and more realistic[14] operations. It was found that the use of more realistic forecasts will have significantly greater impact on shorter duration storages than longer duration storages.

Storage is expected to play a much more significant role in the future NEM. We must rapidly mature our understanding of how a storage-driven network may behave. Different technologies (e.g. electrochemical batteries vs pumped hydro) will bring different advantages. In trying to plan for what is required, it is critical to understand the services that storages can realistically provide – and spot market arbitrage value is a useful proxy for the ability to provide reliability or firming services.

This paper has shown that perfect foresight, a central assumption in modelling, may substantially over-estimate the value of shorter-duration storages. As the NEM transitions towards increased reliance on variable sources of energy, more flexible supply will be needed. The International Energy Agency (IEA) has developed a framework to understand the degree of flexibility that will be required as the penetration of variable renewable energy increases, shown in Table 1. At present, the NEM is largely considered to be in Phase 2 and approaching Phase 3. Some regions have very high penetrations of variable supply, although the longer-term flexibility requirements are generally provided by interconnection. As wind and solar continue to establish themselves as the cheapest energy source and the total penetration in the NEM continues to increase, it is expected that there will be increasing need for more sustained flexible supply. Even in Phase 3, it is projected that there will be an increased need for medium-term flexibility – requiring hours to days of flexible supply.

**Table 1.** An excerpt from IEA's paper: *Status of Power System Transformation 2018*[15] showing the varying requirements for flexible generation changing with variable renewable energy penetration

| Phase | Phase 1 | Phase 2 | Phase 3 | Phase 4 | Phase 5 | Phase 6 |
|---|---|---|---|---|---|---|
| Becomes a main priority | Typically no system flexibility issues | Short-term flexibility | Short-term flexibility<br><br>Medium-term flexibility | Ultra-short-term flexibility<br><br>Medium-term flexibility<br><br>Long-term flexibility | Long-term flexibility<br><br>Very long-term flexibility | Very long-term flexibility |

[14] It is worth noting that these operations have a range of assumptions and are still an idealised version of how storage assets are likely to operate.

[15] IEA, *Status of Power System Transformation 2018*: https://webstore.iea.org/status-of-power-system-transformation-2018

*In a realistic situation with imperfect forecasts, longer duration storages are able to retain more of the maximum possible value.*

By overestimating the value (a proxy for capability) of storages, we are underestimating the real scale of storage required in the optimal supply mix, demonstrated in Figure 8. This will affect infrastructure and policy planning in terms of designing a cost-effective and reliable future electricity market. Longer duration (deep) storages can be expected to better maintain their value to the system, and thus should be preferenced in planning for reliability. However, all storages will lose some value due to forecast uncertainty, and more storage will be required than projected by models with perfect foresight.

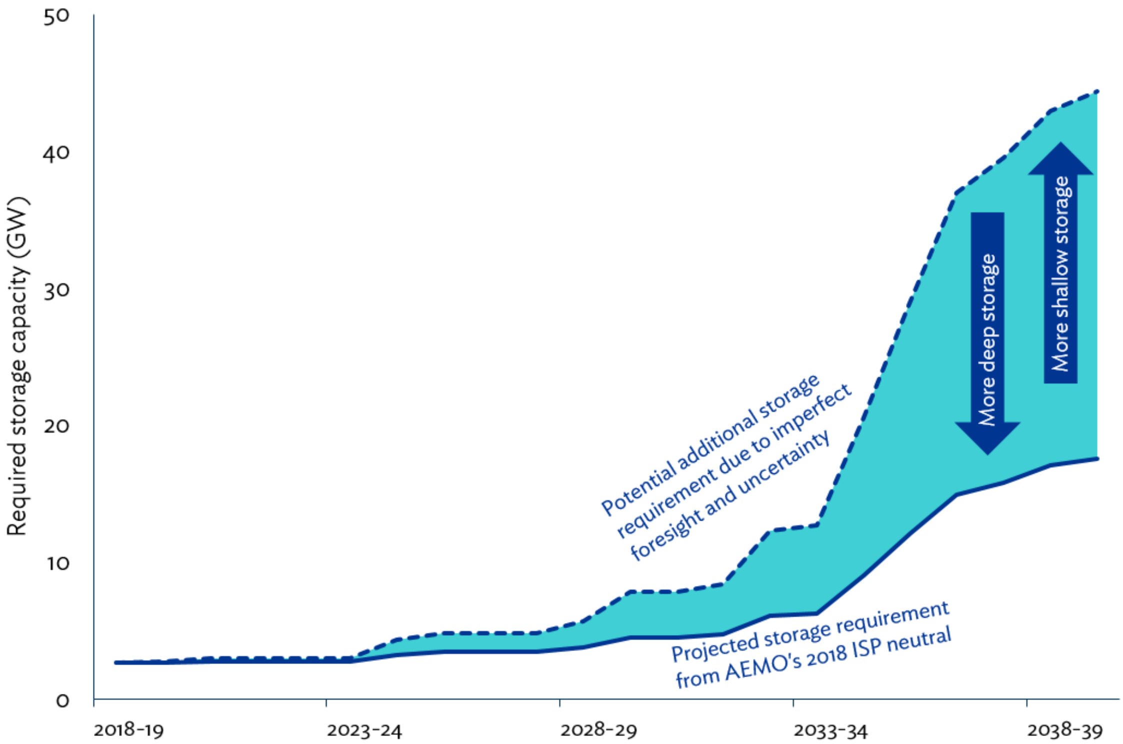



**Figure 8.** Potential increase in projected storage requirement after accounting for imperfect foresight; longer duration (deep) storages will minimise this increase

## 6.1 Next steps for the industry

To accurately reflect storage behaviour in the future market, modelling must account for forecast uncertainty. The analysis presented in this paper is limited to historic data, to avoid the need to synthesise new forecasts. Future market behaviours will change. Supply and demand will become more variable, driving a change in scarcity pricing and the need for a physical response. Realistic synthetic forecasts should be developed to enable the industry to properly assess future operations rather than relying on past behaviour to represent a rapidly changing system. While this is being developed, the information provided in this paper can be used to adjust models to provide a better approximation for impact of forecast uncertainty on the optimal asset mix.

### 6.1.1 Better representing future uncertainty

Projecting the impact of imperfect foresight into the future will require a more bottom-up approach. This would require inputs such as historic wind, solar and demand forecasts, paired with the actual data which is scaled to provide the basis of forward projections. This must be adjusted to reflect other uncertainties in the market such as bidding behaviour. The impact of the additional uncertainties could be compared to historic data using hindcasting to determine how much of the uncertainty has been captured. A methodology for compensating for the residual uncertainty would need to be developed once the scale and nature of the residual uncertainty is known.

Furthermore, the linear program has no mechanism to reduce confidence in a forecast. Considering a machine learning algorithm, such as a neural network, could better handle the knowledge of uncertainty in the forecast.

### 6.1.2 Better understanding the cost of cycling the storages

Another area to consider is the use of non-linear optimisation tools. As noted in the methodology, no limits or costs have been considered for starts and stops. In this modelling, storages are free to cycle as often as their efficiency allows. Without any modelling of cycling costs or limits, the optimisation resulted in around 3000 starts per year (around 900 full charge/discharge cycles) for the shorter duration storages, potentially substantially shortening the operating life of electrochemical storages[16]. The longer duration storages also had a relatively high rate of cycling at around 2000 starts a year (around 60 full charge/discharge cycles), which could result in increased maintenance costs.

Larger storages were optimally operated with fewer starts due to economically arbitraging over a wider period of time. It is considered that if there was a way to account for the cost of start/stops in the optimisation, a more realistic outcome would be achieved. It is also inferred that longer storages would be able to better manage a reduced cycling rate. Better representing the cost of cycling a storage will be critical to understanding least-cost operation.

### 6.1.3 Inclusion in system wide modelling

It may be argued that this is a great deal of complexity and is not feasible to incorporate directly into a full system time-sequential model – yet this paper highlights that the largest change in the secure operation of the power system is also the least understood. What is clear is that in the real world where forecasts are not perfect, longer duration storages are more likely to perform as expected and it is also likely that the entire system will require more storage than is currently being planned on the basis of modelling using perfect foresight.

In the long term, it would be valuable to develop a more nuanced view of the impact of forecast uncertainty on modelled storage dispatch. While a more integrated approach is developed, modelling would benefit from accounting for lost value from storages of different durations. It is important to recognise that longer duration storages are less affected by forecast uncertainty. Models could be adapted to recognise the full cost of the storage, but only operate across a restricted duration to reflect the difference in value achievable without perfect foresight.

[16] The number of cycles for electrochemical batteries is still being established. Deep discharges and fast charging is known to shorten the life substantially. The degradation also occurs gradually over time. There is no clear point at which the battery is non-functional. Nevertheless, 3000 cycles in a year would likely shorten the practical life of a lithium ion battery to a few years at most.

Market dispatch models have assumed perfect foresight as a convenient simplification with little impact when energy (fuel) is plentiful. However, as energy storage takes on a larger role in the future NEM, this assumption becomes strongly impactful.

While full integration of imperfect foresight into market models may be difficult in the short term, this impact must be considered as a material driver to the likely future energy mix, and therefore the most optimal market and network design. Longer duration storages should be preferenced as being more robust to future operations in a real market – and more than that, the NEM will likely need more storage than presently being planned.