Value of aligning dispatch and settlement

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Summary points

- More storage capacity is required with 30 minute settlement to realise the same value under 5 minute settlement
- The impact of forecast errors has a substantial impact on the value of storage under 30 minute settlement.
  - The value of storage under 5 minute settlement is generally 60% – 80% higher than 30 minute settlement
  - 5 minute settlement also significantly improves the value of storage in real world cases when the occurrence of price spikes is not perfectly known. Approximately 80%–90% of the 'perfect value' can be capture with 5 minute settlement. By comparison, only 40%–60% of the 'perfect' value is captured under 30 minute settlement.
- 30 minute settlement increases cap contract prices from storage by up to 30% relative to the 5 minute settlement case.
- Cap contract penalty payments can substantially erode the value of providing fast response

1 Introduction

This analysis considers the impact of dispatch and settlement alignment for fast response storage technologies. Within storage technologies, the results are technologically agnostic and are relevant for pumped hydro energy storage or any number of different battery chemistry storage options. Some elements of the analysis may be applicable beyond storage technologies, and could be relevant for other fast response generators (for example diesel gensets) or demand side solutions.

The analysis extends previous modeling investigating the value of storage in wholesale electricity markets McConnell, Forcey, and Sandiford, "Estimating the value of electricity storage in an energy-only wholesale market". This analysis uses the *'small device'* assumption, where by the device is considered to be too small to have a material impact on prices. A description of the extended model can be found in Section 5). Figure below illustrates a sample output of the model.

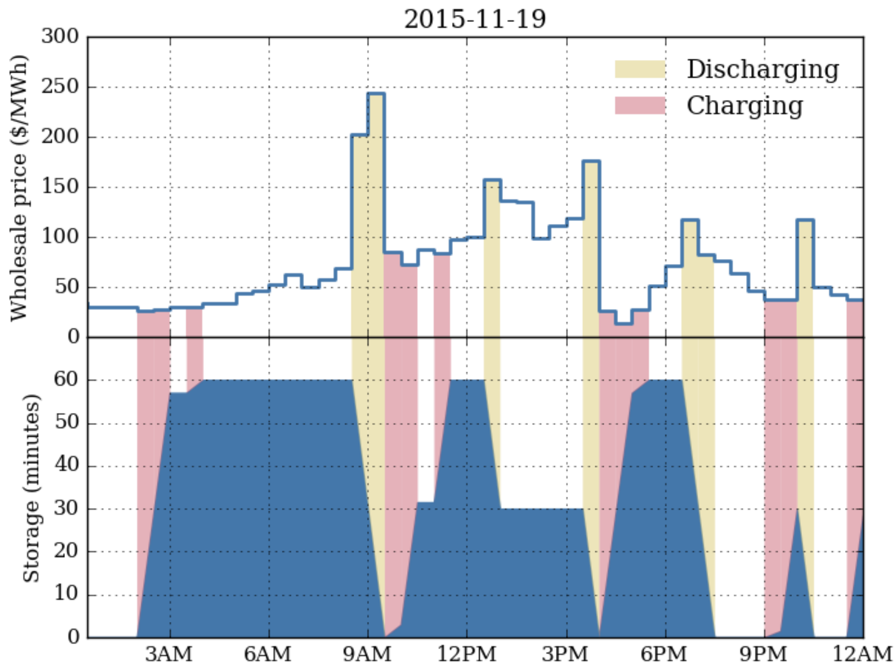

Figure 1: This figure illustrates the optimal operation of storage device for a particular day in the South Australian electricity market region. This scenario investigates a device with 1 hour of storage, settled on the half an hour trading price, with perfect for sight of prices. Trading intervals where the storage device is charging are highlighted in red, while intervals that the device is discharging are highlighted in yellow. The storage level, measured in minutes of energy storage at the rated output is shown in blue.

We focus this analysis on the South Australian market region, as is the most more volatile region in the National Electricity Market (NEM), (see McConnell and Sandiford, (*Winds of change: An analysis of recent changes in the South Australian electricity market*) for more

Table 1: **Trading price and dispatch statistics for South Australia for FY15 and FY16**

	Trading Interval		**Dispatch Interval**	
	FY15	**FY16**	**FY15**	**FY16**
VWP	$42.35	$67.16	$42.49	$67.36
$300	49	185	201	1437
$1,000	37	48	49	88
$5,000	0	1	38	51

details). In particular, we analyse price outcomes from financial year 2015 (FY15[1]) and FY16. These characteristics of these two years differ, as illustrated in Table 1. FY15 represents a low volatility year, whilst FY16 represents a year with high volatility with substantially more ¿$300 price events. This is indicated by the number of high price events on both the 5 minute dispatch intervals and the 30 minute trading intervals.

In this document we first present the scenarios considered. This includes a brief description of the effective incentives provided under the current regime of 5 minute dispatch and 30 minute settlement. This is followed by analysis of the results and then a case study, that considering the impacts of the analysis on a specific technology, lithium ion battery storage. In particular this provides insight into how the value of storage changes under differing dispatch and settlement regimes, and how this would flow through to changes in the price of 'cap-contracts' offered by storage technologies.

2 Simulation scenarios

We considered four major classes of simulation scenarios for analysing the impact of dispatch and settlement alignment. These are described below:

- **Perfect 5/5:** In these scenarios dispatch occurs on a 5 minute timescale, and and settlement occur with respect to the 5 minute prices. Operation is optimised based on the 5 minute prices, which are assumed to be known in advance (*'perfect foresight'*).
- **Perfect 5/30:** These simulation scenarios assume dispatch occurs on a 5 minute basis, but settlement occurs with respect to the 30 minute price. *'Perfect foresight'* of the 30 minute trading interval prices are assumed in this scenario, and operation is optimised based on the 30 minute prices.
- **Forecast 5/5:** Dispatch and settlement are aligned on the 5 minute prices. To capture the uncertainty associated with future prices, these scenarios use forecasts publish by the Australian Enegy Market Operator (AEMO). Both 5 minute price forecasts (for the following hour) and 30 minute price forecasts (until the end of the following trading day) are used in these scenarios. Operation for a given dispatch interval is based on the 5 minute price and all the forecast data known at the time.
- **Forecast 5/30:** Dispatch occurs on a 5 minute basis, but settlement occurs with respect to the 30 minute price. As above, both 5 minute price forecasts (for the following hour) and 30 minute price forecasts (until the end of the following trading day) are used in these scenarios. However in this case, operation is optimised on the expected 30 minute price,

[1] Here we refer to financial years using the two last digits of the year in which it ends. Thus FY16 refers to the period 2015/07/01 through 2016/06/30.

which is based on both the previous dispatch prices, and the forecast data known at the the time. This is particularly relevant for price spikes which are non forecast, which is illustrated below in Figure 2.

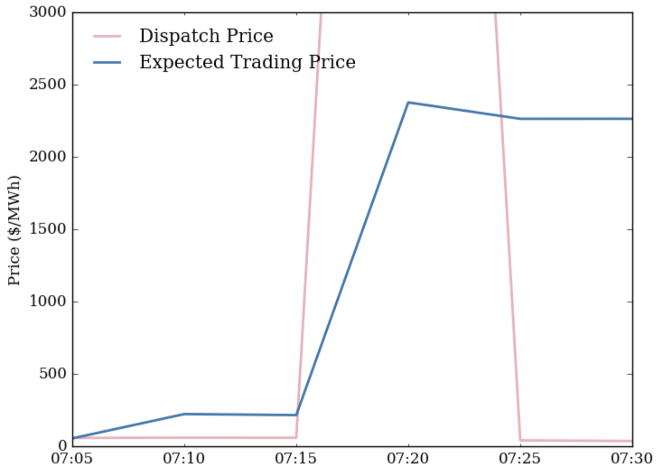

Figure 2: This illustrates the expected trading price for a 30 minute trading interval with an unanticipated price spike in a 5 minute dispatch interval. The 5 minute dispatch price is shown in red and extends to the market price cap of $14,000 at 7:20, while the expected 30 minute trading interval at a given time is shown in blue. The trading price is the simple average of the six dispatch prices over the trading interval. As such, the expected trading price at a given time is determined from the actual price in the previous dispatch intervals and the forecast price for the remain dispatch intervals.

For each of these scenario classes, a range of different parameters were also analysed. This includes a range of round trip efficiencies, as well as differing amounts of storage (hours). Other scenarios considered a 'cycling cost', which acts to limit the amount of charge and discharge cycles that occur. This is relevant for battery storage technologies where high round trip efficiency (e.g 95%) would result in a large number of cycles occuring under optimal operation, which would substantially reduce battery life.

We also considered several forecasting scenarios. In the basic *'forecast only'* scenarios, we only considered operation based on forecast information only. As result, these scenarios can not account for or plan for price spikes that are not forecast. In other forecast scenarios, some amount of energy was reserved unless the spot price was above a specific threshold, in this case $1,000/MWh. The amount of energy reserved was varied from the equivalent of 1 dispatch interval (DI) up to 6 DI. This is functionally equivalent of offering the particular number of DI's into the market at $1,000/MWh.

A range of 1 to 6 DI was considered to reflect to the two different settlement intervals analysed (5 minutes and 30 minutes). For example, if one non-forecast price spike occurred for with 5 minutes settlement, only one DI worth of energy would need to be reserved. If one non-forecast price spike occurred for with 30 minutes settlement in the first 5 minute DI of a trading interval, enough energy for the remainder of the interval would have to be reserved to fully capture the price spike.

3 Results

As in McConnell, Forcey, and Sandiford, ("Estimating the value of electricity storage in an energy-only wholesale market"), the power rating for the storage device is effectively dimensionless. Under the small device assumptions optimal operation of a 1 kW unit with 5 h storage would be the same as a 20 MW facility with 5 h of storage. As such, the results here are presented in units of dollars per kW per year ($/kW-year). This represents the value a storage device would be expected to generate over year per kW of installed capacity, and can be applied to any sized storage device.

In this section we compare the differing outcomes of optimal operation under 30 minute settlement and 5 minute settlement. Specifically, we compare the revenue generated in each case as if a storage device was operated as a 'merchant' plant, paying and receiving spot market prices without any hedging arrangements.

3.1 Perfect scenarios

We first test value of storage under the assumption of 'perfect foresight' of electricity prices. A range of configurations were analysed, including but not limited to different amounts of storage and different round trip efficiencies.

In general, the maximum absolute value generated from a storage device with large amounts of storage (e.g. 6 hours) was unaffected by the length of settlement periods. The amount of storage required (in hours) to achieve this value was however different. With 5 minute settlement, the the same relate level of value could be extracted with less storage. This is illustrated in figure 3.

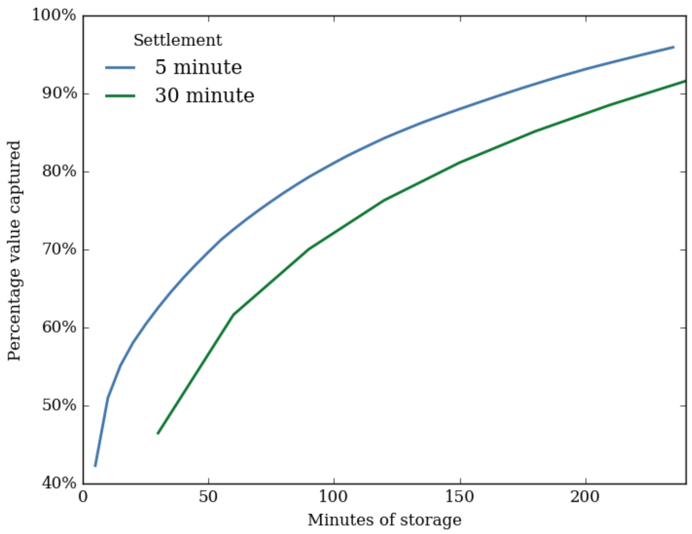

Figure 3: This figure shows the relative value capture with different amounts of storage. The relative value is the value of extracted relative to the total value possible with 6 hours of storage. As can be seen, less storage is required to extract the same value under 5 minute settlement relative to 30 minute settlement.

3.2 The impact of forecasting

In this section we consider the impacts of forecasting and forecast errors. The difference in outcomes and revenues can be very significant, when taking forecasting and forecastng errors into account.

Figure 4 shows a particular day where the revenue was different by almost a factor of six. In this forecast case, 1 kW of storage would have generated $617 of revenue over the course of the day under 5 minute settlement. Optimised with 30 minute settlement, the same 1 kW of storage would only generate $115 of revenue.

What is particularly noteworthy about this example is that it does not involve extreme prices. Both trading and dispatch prices remained below $350 per MWh for the entire day. On another occasion which included extreme price spikes, the difference in daily revenue was much as much as $1,370/kW.

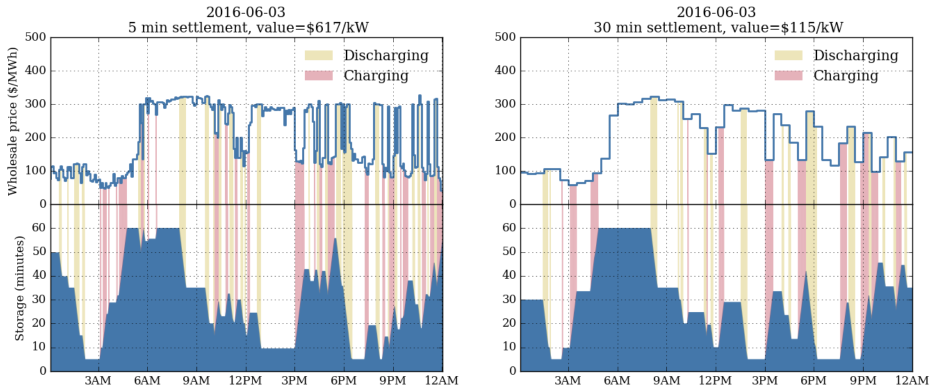

Figure 4: These figures show the difference in optimal operating profile under 5 minute settlement and 30 minute settlement. Both these scenarios analyse a storage device with 1 hour of storage, and use forecast data rather than *'perfect foresight'*. This day does not feature price spikes to the market price price cap ($13,900 for FY16), and yet the difference in revenue outcomes is substantial.

Figures 5 and 6 compare the aggregated value of storage (in $/kW-yr) under 5 minute settlement and 30 minute settlement for FY15 and FY16. There is a substantial difference in values between the two years, reflecting the differing volatility in these years. More interesting is the difference between the 5 minute and 30 settlement values. Across both years, the value of storage under 5 minute settlement is generally 60% − 80% higher. In one case (FY15, with 1 DI of energy reserved for prices greater than $1000), the 5 minute settlement value is 91% great than the 30 minute settlement value.

When using forecast data, 5 minute settlement also significantly improves the value relative to 'perfect' value. Close to 90% of the 'perfect value' is captured in FY15 across varying operating strategies, and 80% is captured in FY16. By comparison, only 40%–60% of the 'perfect' value is captured under 30 minute settlement.

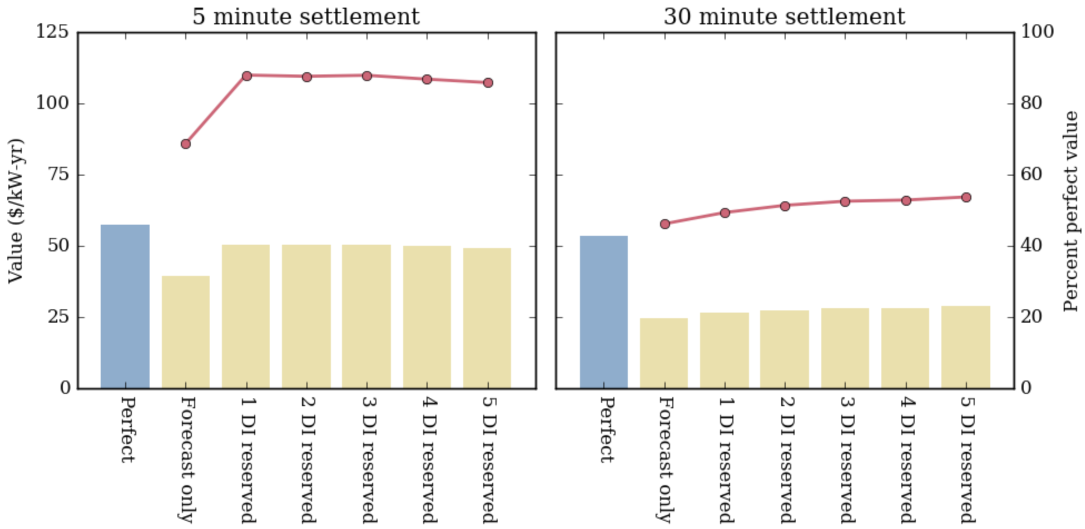

Figure 5: These figures compare the value of storage under the two different settlement periods using different operating strategies in FY15 in South Australia. The blue bar shows the value where operations is optimised with *'perfect forecast'* of prices. The yellow bars represent the value using forecast data to optimise operation, which incorporated the impact of real world price uncertainty. The red line represents the proportion of 'perfect' value capture by the different forecast scenarios.

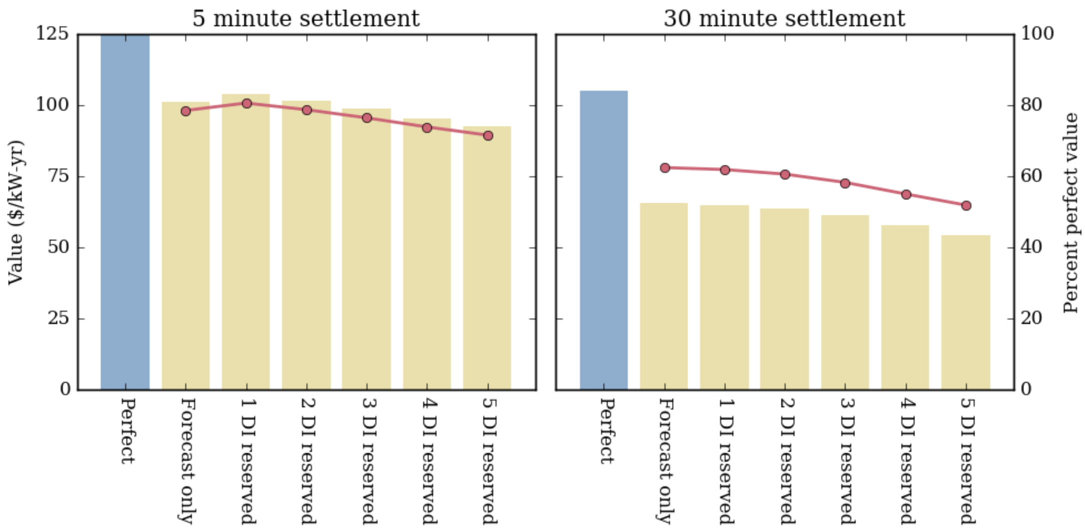

Figure 6: These figures compare the value of storage under the two different settlement periods using different operating strategies in FY16 in South Australia. The blue bar shows the value where operations is optimised with *'perfect forecast'* of prices. The yellow bars represent the value using forecast data to optimise operation, which incorporated the impact of real world price uncertainty. The red line represents the proportion of 'perfect' value capture by the different forecast scenarios.

3.3 Impact on cap contract

Typically participants in the wholesale market utilize a variety of hedging products to manage the volatility in the wholesale spot market. Given that storage provides similar flexibility and capacity to peak generators, and is similarly dependent on and exposed to extreme price events, they would likely be financed in a similar way, using cap contracts. Here we explore this in more detail.

Generally the seller of cap contract compensates the customers when spot prices are above \$300, and in return receives a consistent payment. Generators that sell contracts effectively receive no more than \$300 per MWh (since they are compensating the retailer for prices above this level). In return they might also receive a consistent payment (e.g. \$10/MWh) for every trading interval of the year regardless of whether they are dispatched or not. Importantly, even if they fail to generate when prices are above \$300 and are thus not receiving spot market revenue, they still must compensate the purchaser of the cap contract the difference between \$300 and the spot price.

In this section we consider how these typical contracting arrangements would affect the value under the 5 minute settlement and 30 minute settlement. There are two components to this. Firstly, there is revenue derived a prices below \$300 dollars, which do not require payments to the contract counter party. Secondly, there are payments to contract counter party at prices above \$300 price where the generator is not operating and not receiving spot revenue. Here we refer to these as 'penalty payments'.

Figures 7 and 8 show these the $\leq$ \$300 revenue and penalty payments for FY15 and FY16. As can be seem in 7, the penalty payments completely wipe out any value that might be delivered by from the $\leq$ \$300 opportunities. In FY15 the difference between 5 minute and 30 minute settlement amounts to \$15/kW–year and for FY16 the difference amounts to approximately \$25/kw–yr.

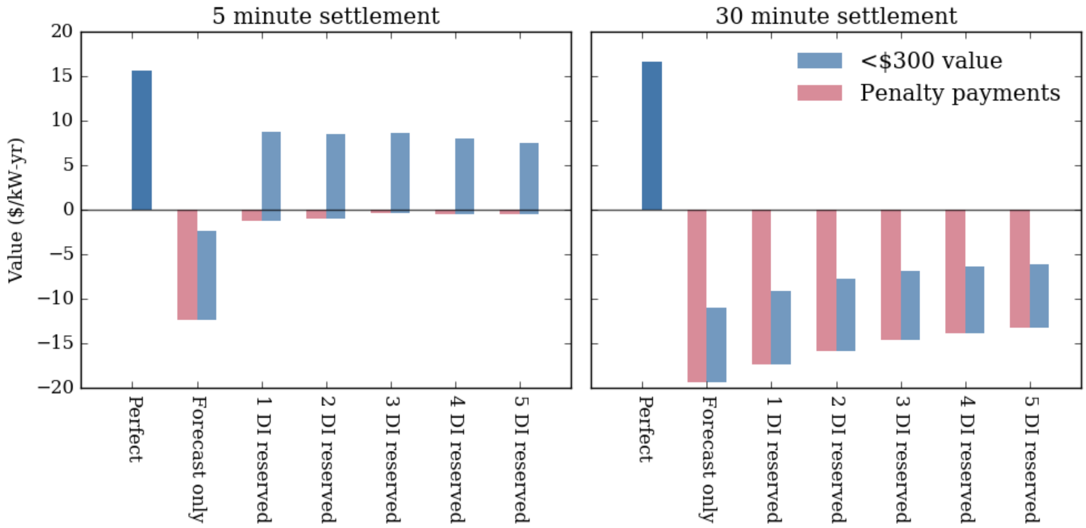

Figure 7: The figures above show the $\leq$ \$300 revenues and penalty payments for FY16. The blue bars represent the $\leq$ \$300 value and the red bars represent the 'penalty payments' that would occur under the cap contract. The the $\leq$ \$300 revenue and penalty payments are aggregated such that the top of the blue bar represents the total impact of these two cash flows.

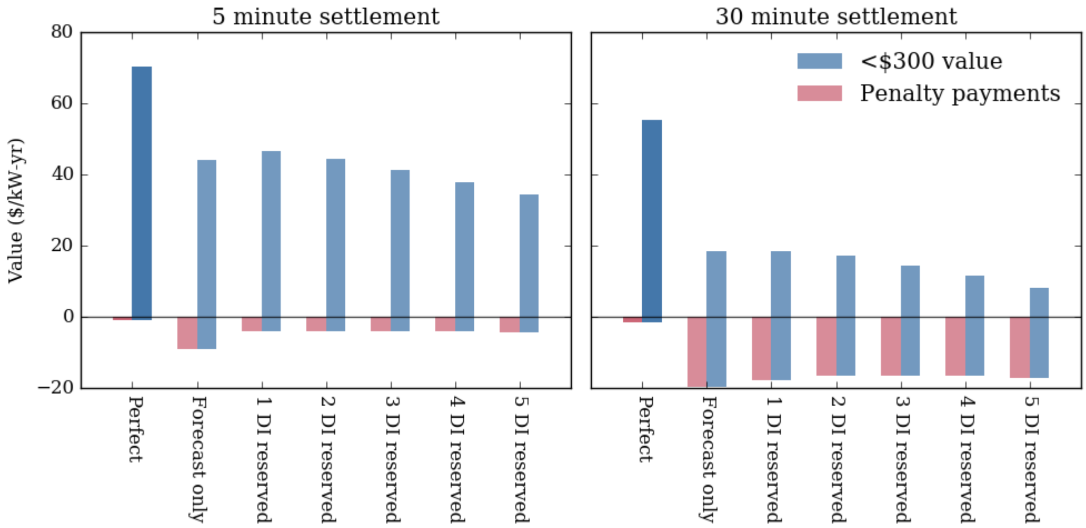

Figure 8: The figures above show the ≤ $300 revenues and penalty payments for FY16. The blue bars represent the ≤ $300 value and the red bars represent the 'penalty payments' that would occur under the cap contract. The the ≤ $300 revenue and penalty payments are aggregated such that the top of the blue bar represents the total impact of these two cash flows.

4 Case study: Lithium Battery Storage

In this section we calculate the 'cost of capacity' of a lithium battery. This measure is analagous to the Levelised Cost of Energy (LCOE) and represents the revenue required for each unit of capacity for the project to be financially viable. This effectively reflects what cap contract price would be needed to finance the battery project.

The input assumptions on battery costs are taken from Lazard, (*Lazard's Levelized Cost of Storage Analysis*), and can be found in table 2 below. We analysed the lithium battery costs for peaker replacement batteries, and assumed 10% discount rate and a 20 economic life, with capital replacement occurring in the 10th year. Another scenario where the economic life is assumed to be only 5 years (with no replacement costs) is shown in the appendix.

Table 2: Battery costs ($/kWh)

	Low	**High**
Initial capital cost (DC)	$399	$1,051
Initial capital cost (AC)	$47	$47
Initial other owners costs	$57	$165
Total initial installed cost	$503	$1,263
10 year replacement cost (DC)	$209	$304
10 year replacement cost (AC)	$32	$32
Total 10 year replacement costs	$241	$336
Operations and maintenance Costs	$8	$13

In calculation the cost of capacity, we considered the additional revenue that is generated for prices below $300. In addition, we take into account the penalty payments that a cap provider would have to make for occasions where the price is above $300, but the battery is not discharging. This is is taken from the analysis in Section 3.3.

Figures 9 and 10 illustrate the cap contract required for the battery to financial viable for FY15 and FY16 respectively. In the less volatile FY15, 30 minute settlement actually *increases* the cost of a cap contract, relative to the perfect 'capacity only' case, where the storage perfectly dispatches when the price is above $300. This is due to the penalty payments that must be made as consequence of forecast errors. The additional arbitrage revenue (from prices below $300) in the 5 minute settlement case mean that a lower cost cap contract can be offered. This additional revenue gives storage technologies a competitive advantage relative to some peak generation technologies that wouldn't necessarily operate at prices below $300.

In the more volatile FY16, the advantage of 5 minute settlement is clearly visible. While the additional revenue from prices below $300 lowers the cost of cap contract in both cases, the impact is considerable larger under 5 minute settlement. For the low cost estimate, 30 minute settlement increased cap contract prices by 30% relative to the 5 minute settlement case.

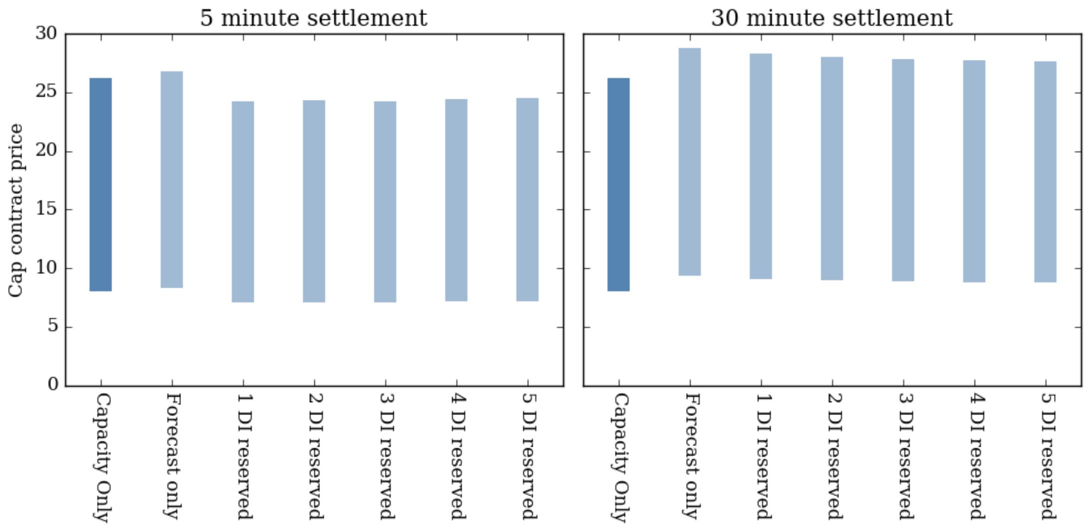

Figure 9: This figure illustrates the range of cap prices that a lithium battery would require to be financially viable under different settlement periods and different operating regimes for FY15. The dark bar represents the cap contract price for a perfectly operated battery, that only operates when prices are above $300.

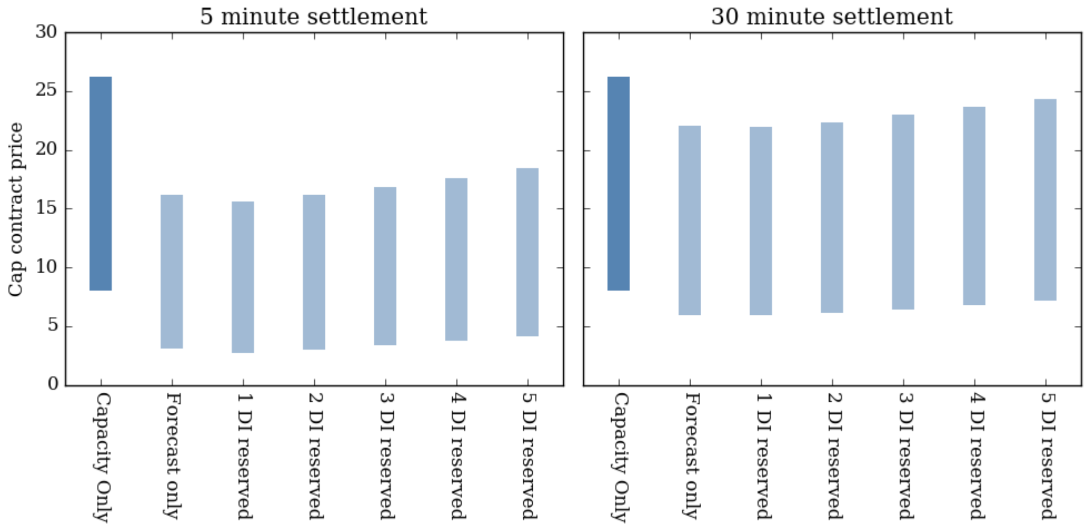

Figure 10: This figure shows the range of cap prices that a lithium battery would require to be financially viable under different settlement periods and different operating regimes for FY16. The dark bar represents the cap contract price for a perfectly operated battery, that only operates when prices are above $300.

5 Model description

This problem is formulated as a maximisation problem (equation 1). The objective is to to maximise revenue, calculated from charging and discharge rates and the price for a given interval (P_i), subject to a variety of constraints. The charging rate (Q_{c_i}) and discharging rate (Q_{d_i}) for each interval at the decisions variables that are optimised in this problem.

The main constraint is the energy balance constraint (equation 2), which ensure the the energy stored at the end of an interval (E_i) is the sum of the energy stored at the beginning of the interval (E_{i-1}) and any changes resulting from charging (Q_{c_i}) or discharging (Q_{d_i}) over the interval. The energy balance equation also takes into account the efficiency of charging (η_c) and discharging (η_d), which represents the losses that occur during the process. The other constraints simply ensure the physical constraints of the storage device (e.g. maximimum charging and discharging rates, and maximum storage amount) are not violated.

The price (P_i) and number of intervals optimised (n) over which the optimisation is performed depends on the scenarios analysed (see Section 2). For *'perfect foresight'* scenarios, the price for all intervals is assumed to be known in advance and all intervals are optimised at once. For forecast scenarios the price is only known for a certain number of periods ahead of time. In these scenarios, all forecast data known at a particular point in time is used to optimise operation for that point in time. Each interval is successively optimised on a rolling basis, based on the optimal results from the previous trading interval, and the all known forecast data for the current interval.

The model is mathematically formulated as follows:
Maximise:

$$\sum_{i=1}^{n} P_i \times (Q_{d_i} - Q_{c_i}) \tag{1}$$

Subject to:

$$0 \leq Q_{d_i} \leq Q_{d_{max}}$$
$$0 \leq Q_{c_i} \leq Q_{c_{max}}$$
$$0 \leq E_i \leq E_{max}$$

$$E_{i-1} + \eta_c Q_{c_i} - \eta_d Q_{c_i} = E_i \tag{2}$$

Where:

$$Q_{c_i} = \text{charge rate at interval } i$$
$$Q_{d_i} = \text{discharge rate for interval } i$$

$$P_i = \text{price at interval } i$$
$$E_i = \text{total energy stored at interval } i$$
$$E_{max} = \text{maximum energy storage}$$
$$Q_{c_{max}} = \text{maximum charge rate}$$
$$Q_{c_{max}} = \text{maximum charge rate}$$
$$\eta_c = \text{charging efficiency}$$
$$\eta_d = \text{discharging efficiency}$$
$$n = \text{number of intervals optimised}$$

References

Lazard. *Lazard's Levelized Cost of Storage Analysis*. Tech. rep. Lazard, Nov. 2015.

McConnell, Dylan, Tim Forcey, and Mike Sandiford. "Estimating the value of electricity storage in an energy-only wholesale market". In: *Applied Energy* 159 (Dec. 2015), pp. 422–432. ISSN: 0306-2619. DOI: 10.1016/j.apenergy.2015.09.006.

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Appendix A 5 year economic life

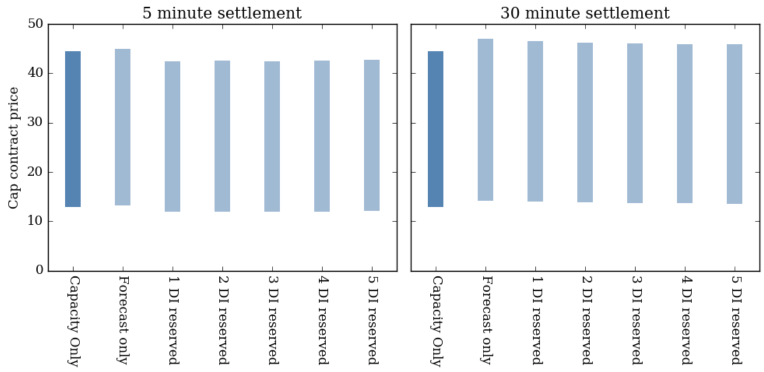

Figure 11: This figure shows the range of cap prices that a lithium battery would require to be financially viable under different settlement periods and different operating regimes for FY15. The dark bar represents the cap contract price for a perfectly operated battery, that only operates when prices are above $300. In this scenario, the battery has an economic life of only 5 years.

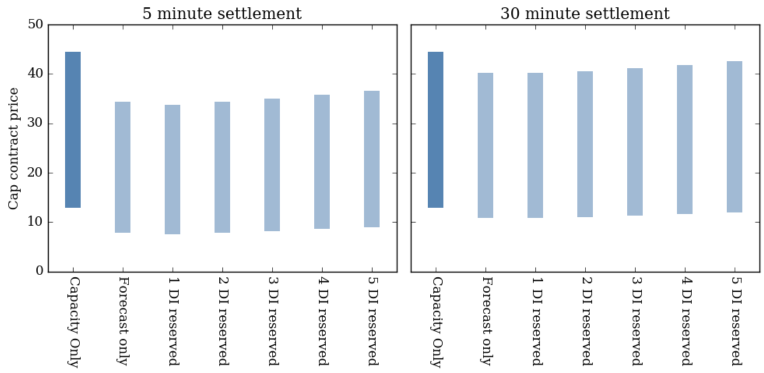

Figure 12: This figure shows the range of cap prices that a lithium battery would require to be financially viable under different settlement periods and different operating regimes for FY15. The dark bar represents the cap contract price for a perfectly operated battery, that only operates when prices are above $300. In this scenario, the battery has an economic life of only 5 years.