THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

CREATE CHANGE

2020 Performance Review

UQ’s 1.1 MW Battery Project

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Note that all values in this report are in $AUD and are exclusive of GST unless otherwise stated.

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1. Executive Summary

As part of the University of Queensland's energy leadership ambitions, a 1.1MW / 2.2 MWh Tesla Powerpack battery system was constructed at the St Lucia campus in late 2019—the state's largest behind-the-meter installation at the time.

This coincided with UQ's move to become the first university in Australia to participate directly in the wholesale electricity spot market as part of the Warwick Solar Farm initiative. At an all-in cost of $2.05 million, the project was funded through the sale of renewable energy certificates created by UQ's existing 6.3 MW behind-the-meter solar PV portfolio. The battery is controlled by a custom system developed by UQ called the Demand Response Engine or DRE.

In early 2020, UQ published the Business Case & Q1 2020 Performance Report for the project. This report was well received within the industry, with the document being downloaded over 2,000 times since publication. Building on this success, a performance review for the full 2020 calendar year has been prepared. Looking at the performance of the project over a full 12-month period enables a range of additional analysis to be undertaken, including looking at how performance varies across quarters, as well as examining technical parameters such as degradation that require observation over longer time horizons.

Table 1 provides an overview of the key figures for the battery. Further background information about the project is available within the Business Case & Q1 2020 Performance Report. Live and historical data about the battery's performance is also available via an online dashboard.

Revenue streams

The UQ battery has been developed to deliver revenue and value from the combination of four distinct services:

Arbitrage

The DRE control system aims to charge the battery when prices are low and discharge when prices are high—maximising the spread between prices to help offset energy costs while respecting the fact that the battery only has a finite storage capacity (roughly two hours at full power). Section 3 discusses the performance of this service in more detail.

Frequency Control Ancillary Services (FCAS)

Through a partnership with Enel X, the battery is paid to remain on standby to respond to sudden disturbances to grid frequency from events such as power plants tripping offline or storms damaging transmission lines. Revenue is earnt by bidding this response capability into three of the NEM's contingency FCAS markets—Raise 6 seconds, Raise 60 seconds, and Raise 5 minutes. Section 4 discusses the performance of this service in more detail.

Virtual cap contract

As a spot price exposed customer, UQ is required to put hedging strategies in place to prudently manage risk. One option available is the use of cap contracts which limit financial exposure to high prices (typically >$300/MWh). These hedging products can be considered as a form of insurance. The battery is able to provide this insurance 'virtually' in place of buying a cap contract by responding quickly to high price events and minimising UQ's exposure. Whilst not an exact replacement for a traditional financial cap, this service has value to UQ nonetheless through avoided premiums. Section 5 discusses the performance of this service in more detail.

Peak demand lopping

It is intended that the battery will help UQ to reduce its monthly peak demand charges by lopping the top off the highest demand intervals of each month. Due to challenges with forecasting, as well as the deployment of this functionality within the demand response engine, this service remains under development and is not included in the 2020 performance review.

Table 1: Battery key figures

Make and model	Tesla Powerpack 2.5
Rated power	1.11 MW
Storage capacity	2.22 MWh (2 hours at full power)*
Depth of discharge	100% of nameplate
Number of battery packs	10 x 222 kWh*
Number of inverters	2 x 555 kVA (at 415 Volts)*
Physical footprint	44 m^2 (including clearances)
Total weight	25.7 tonnes (excluding foundation)
Total project cost	$2.05 million ($954/kWh)**
Date connected	16 October 2019*

* These values have been corrected from the Q1 20 performance report

** This reflects the all-in capital cost to deliver the project, including battery supply under a turn-key EPC contract

2020 performance

From a technical perspective, the battery achieved excellent results across 2020. The key technical metrics analysed in this report are availability, roundtrip efficiency, and degradation. On availability, the battery achieved an uptime of 99.6%, outperforming forecasts. Roundtrip efficiency for the year came in at 85.2%, only slightly below the manufacturer nameplate of 85.5% under standard test conditions and likely accounted for by climatic factors. Degradation over the 12 months to October 2020 (measured from the date of connection) was on track with that expected as per the system warranty.

> The battery delivered a total of $158,000 in value to UQ across 2020.

From a financial perspective, the battery delivered a total of **$158,000** in value to UQ across 2020. Just under half of this was earned during Q1, with Q4 accounting for the next 22%, followed by Q2 and Q3 which made up around 15% each. Figure 1 shows revenue by service, highlighting that FCAS makes up over half of all income, with arbitrage contributing a further 30%, and the virtual cap service contributing around 15%.

The project underperformed total revenue expectations by around 27%. Within this, the arbitrage function overperformed by almost 30%, whilst the FCAS and virtual cap services underperformed by around 25% and 65% respectively. In the case of FCAS, this underperformance was primarily driven by lower than forecast market pricing during Q2 and Q3. The FCAS service also suffered from a lack of participation in the contingency lower market, as well as an absence of co-optimisation between the FCAS and arbitrage functions. These issues are further discussed in section 4. Underperformance by the virtual cap service was driven by financial cap prices being substantially lower during 2020 than forecast at the end of 2018 when the project's financial modelling was completed. This reflects an overall reduction in volatility across the Queensland region of the National Electricity Market (NEM) driven by many factors, including the impacts of COVID-19.

Analysis of the full year performance of the virtual cap service also emphasised some of the shortfalls of the methodology being adopted by UQ for valuing this function. To help address this, an alternatively methodology has been developed and is discussed in section 5.3.

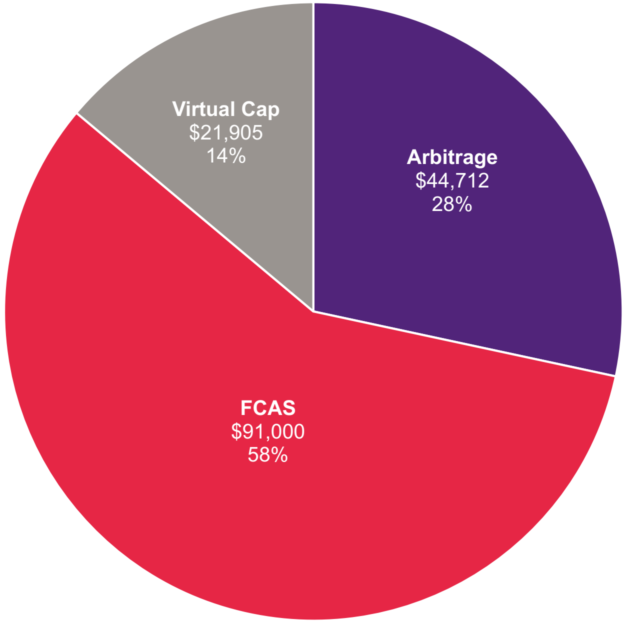
Despite an underperformance of headline revenue, the battery nonetheless performed well throughout 2020 across many other metrics—evident through a deeper analysis of each revenue stream's performance as outlined in the relevant sections of this report. This includes findings such as:

- The average arbitrage spread was 2.2 times higher than the average Queensland energy price. This trend also showed income from arbitrage increasing as average spot prices reduced, and highlights the advantages of assets that can respond quickly and flexibly to market prices.
- The battery earnt the equivalent of $56/MWh for reserving 10 minutes of capacity (0.185 MWh) at all times for FCAS purposes. This is almost 25% more revenue than would have been earned if this same volume of energy was sold at the spot price on a 24x7 basis.
- Whilst the battery isn't able to exactly replicate a financial cap due to inevitable periods of missed coverage, it was able to provide 62% coverage on a volume basis and 64% coverage on a financial basis during spot price intervals >$300/MWh. This was 10% higher than the coverage provided during the same period by Queensland's other major storage asset—the Wivenhoe pumped hydro power station.

Future directions

A number of key areas of focus for future improvements exist which are discussed in each relevant section of this report. From an overall perspective, the performance of the battery during 2020 has solidified its place as a central part of UQ's energy management program now and into the future, despite its size only being a fraction of overall site load. This role will be amplified by a range of forces that are poised to rapidly reshape the energy market over the coming months and years. This includes yet further increases to the penetration of variable renewable energy sources, as well as the pending change to five-minute settlement as of October 2021. The outcomes of the 2020 performance review make clear that the UQ battery, and battery energy storage in general, are well positioned to seize the opportunities that will be created as the energy transition continues to gather momentum.

Figure 1: Breakdown of 2020 revenue by value stream



> The UQ battery, and battery energy storage in general, are well positioned to seize the opportunities that will be created as the energy transition continues to gather momentum.

2. Technical Performance

The overall performance of the St Lucia battery is influenced by its performance across several technical parameters. These are availability, roundtrip efficiency, and degradation. Each is discussed further in the following sections.

2.1 Availability

As with any asset, the battery is expected to experience a degree of downtime across the year. The purple line on Figure 2 shows the percentage availability of the battery each month, with the overall average across the year being 99.6%. This overperformed forecasts which expected availability of 98.5% (five days of cumulative downtime per annum), although limited real-world data or experience was available to inform this assumption at the time.

The two notable instances of reduced availability occurred in January and November. Outages in January were a result of the original configuration of electrical protection settings whereby a momentary loss of comms to metering led to the system isolating and remaining offline until physical intervention. These settings were rectified to better handle momentary outages and have not presented any problems since. Reduced availability in November was the result of a single long duration outage also caused by electrical protection. The exact cause is still under investigation but is expected to be related to upstream hardware (i.e. unrelated to the battery system itself).

Note that the availability figures for January to March have been updated from those presented in the Q1 Performance Report. This is due to a change in the methodology of how availability is calculated. More specifically, the previous approach looked at FCAS availability only which could be negatively impacted by minimum charge levels being slightly below the require 10 minutes reserved for FCAS. The values presented in this report now reflect the true uptime of the battery, independent of which services it was enabled for at the time.

It is also important to note that the availability figures presented in this metric reflect only the uptime of the core battery hardware and do not account for the volume of energy available. For example, if one out of ten packs were offline for maintenance or other reasons, the battery would still be counted as available overall even though it had 10% less useable energy to perform its functions. Indeed, the outage of a single pack did occur on two occasions during 2020. Whilst it is possible to calculate availability inclusive of energy capacity, this is complicated by degradation, as discussed in section 2.3.

2.2 Roundtrip efficiency

The red line on Figure 2 shows the roundtrip efficiency of the battery (total MWh discharged divided by total MWh charged) each month over the year. It is important to note that values for individual months can be skewed by the fact that this calculation does not account for the start and end state of charge of the battery during the period. For example, the battery starting the month empty but ending it fully charged will impact the roundtrip efficiency value for that month. This effect is diminished when aggregated over a full year, which yielded an annual roundtrip efficiency of 85.2%. This compares to the manufacturer nameplate value of 85.5%. The difference between these values is likely accounted for by the often warmer conditions in Brisbane compared to the technical specification value (which is measured at 25°C), operation at varying power levels, electrical losses to the measurement point (the battery meter), and auxiliary losses outside of the Tesla battery scope.

Figure 2: Battery availability and roundtrip efficiency—monthly (annual values annotated)

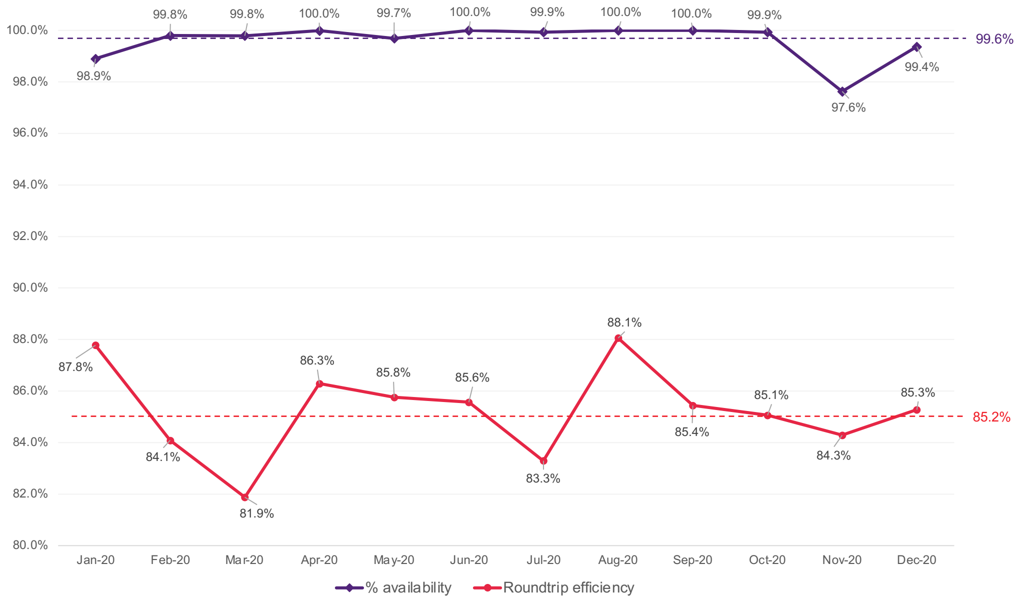
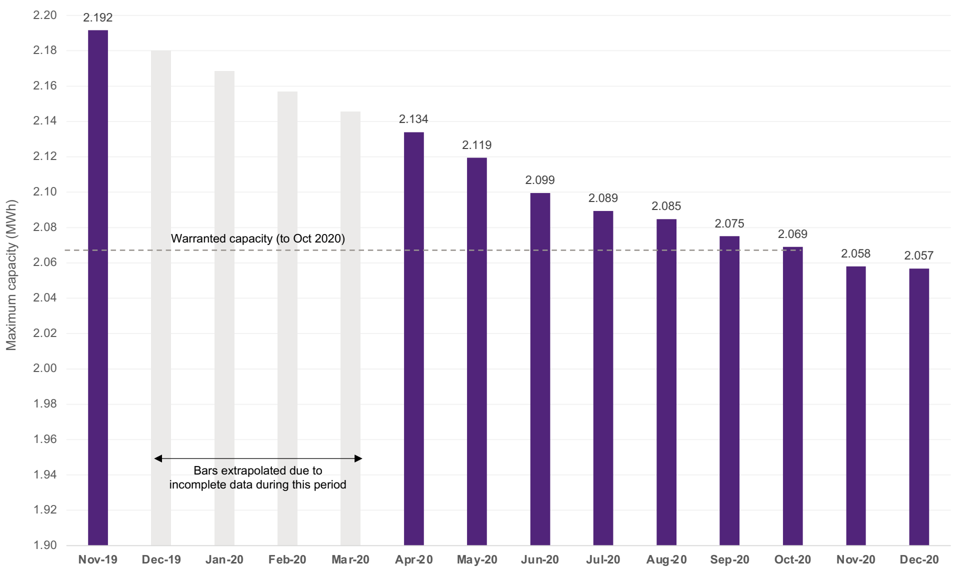


Figure 3: Battery maximum capacity (MWh)—monthly



2.3 Degradation

With the battery having now been in operation for over 12 months, changes to its maximum capacity over time can be meaningfully assessed. Maximum capacity refers to the capacity of the battery at full charge, with the reduction in this value over time being commonly referred to as degradation. Whilst this report covers calendar year 2020, for the purposes of this analysis it is important to consider that the battery was formally connected on 16 October 2019. This means that for warranty purposes changes to maximum capacity are benchmarked against this date.

> Maximum capacity had reduced by just under 7% compared to nameplate as of October 2020—consistent with warranted capacity values.

Figure 3 shows the maximum capacity of the battery in each full month since commissioning. Notably, data for the period December 2019 to March 2020 is not able to be used due to other issues resulting in less than ten full packs being online (and therefore maximum capacity values being artificially lower). The bars for these months have been extrapolated for visualisation purposes only, assuming linear degradation between November 2019 and April 2020.

Maximum capacity had reduced by just under 7% compared to nameplate as of October 2020—consistent with warranted capacity values. As further discussed in section 3.2, throughout the year the battery remained within the utilisation limits required to maintain warranty. This relatively steep reduction in capacity during Year 1 is typical for batteries of this chemistry and is expected to slow down over coming years as the battery heads towards an expected capacity retention of at least 75% at the end of Year 10. Nonetheless, continued monitoring and analysis of this metric over coming years will remain of key interest.

3. Arbitrage

As a spot price exposed energy user, one of the core functions of UQ's battery is to undertake arbitrage—charging to store energy when prices are low and discharging to generate energy when prices are high.

3.1 Financial performance

Net revenue from arbitrage across 2020 totalled just under $45,000. This exceeded business case assumptions by 28% and was primarily a result of realised spreads being higher than forecast. Net revenue by month is shown in Figure 4. Excluding January (which was subject to circumstances driven by natural disasters) this shows an overall trend of increasing arbitrage revenue across the year, with the highest revenue of the year realised in November 2020. On a quarterly basis, Q4 2020 had the highest revenue at $16,500. This is almost double the revenue in each of Q1 2020 and Q2 2020, despite the strong contribution from the month of January.

Figure 5 provides a graphical illustration of cumulative net arbitrage revenue across the year. The line goes up when income is earned from discharging, and down when costs are incurred from charging. Over time, the line would be expected to trend upwards provided the spread in energy price being achieved exceeds the cost associated with roundtrip efficiency losses. Figure 5 shows that while large jumps in net revenue were made on a handful of occasions due to extreme pricing events (such as during January, May, November & December), a slow and steady accumulation of arbitrage revenue from modest spreads throughout the year was equally important in delivering the overall revenue result. Note that the discrepancy between the total value at year's end shown in Figure 5 and the annual net revenue figure reported above is a result of the values in Figure 5 not accounting for ancillary charges (refer to section 3.5).

Figure 4: Net arbitrage revenue—monthly

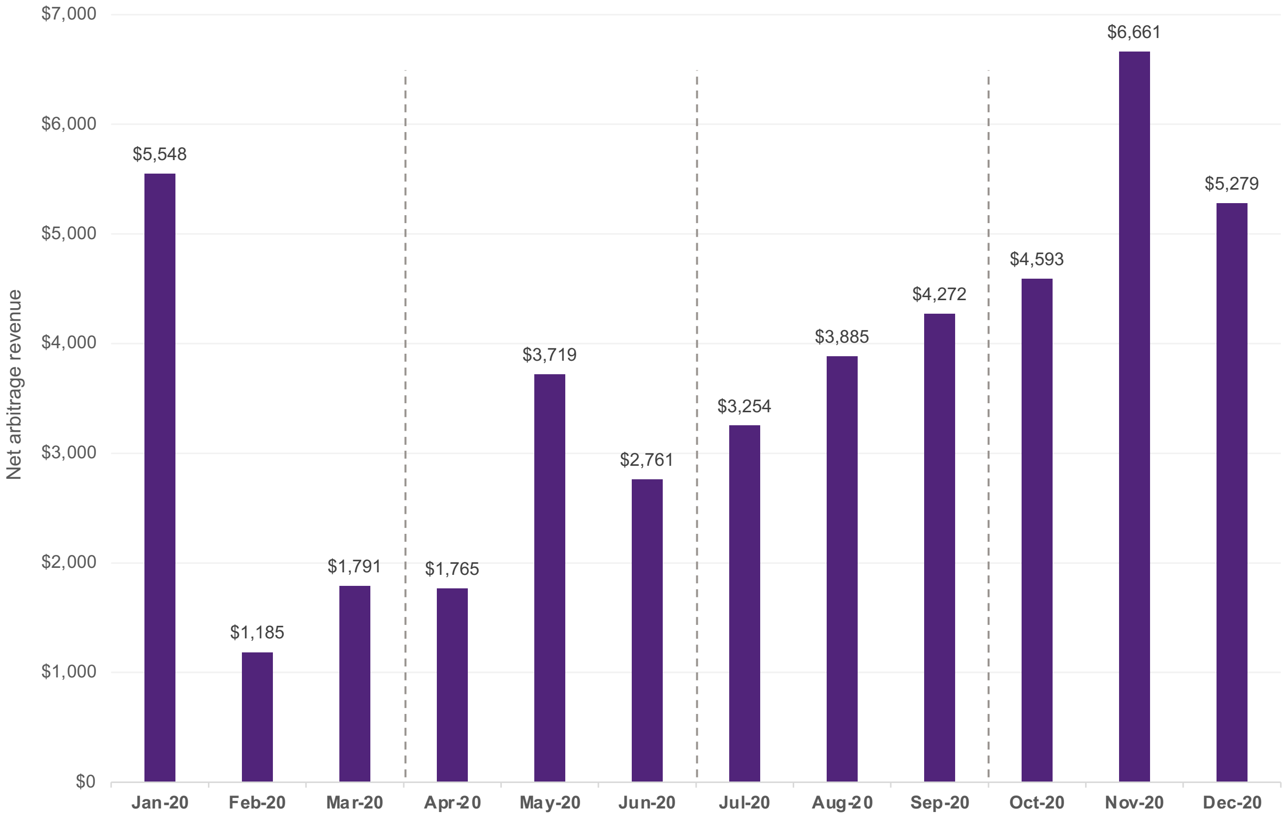
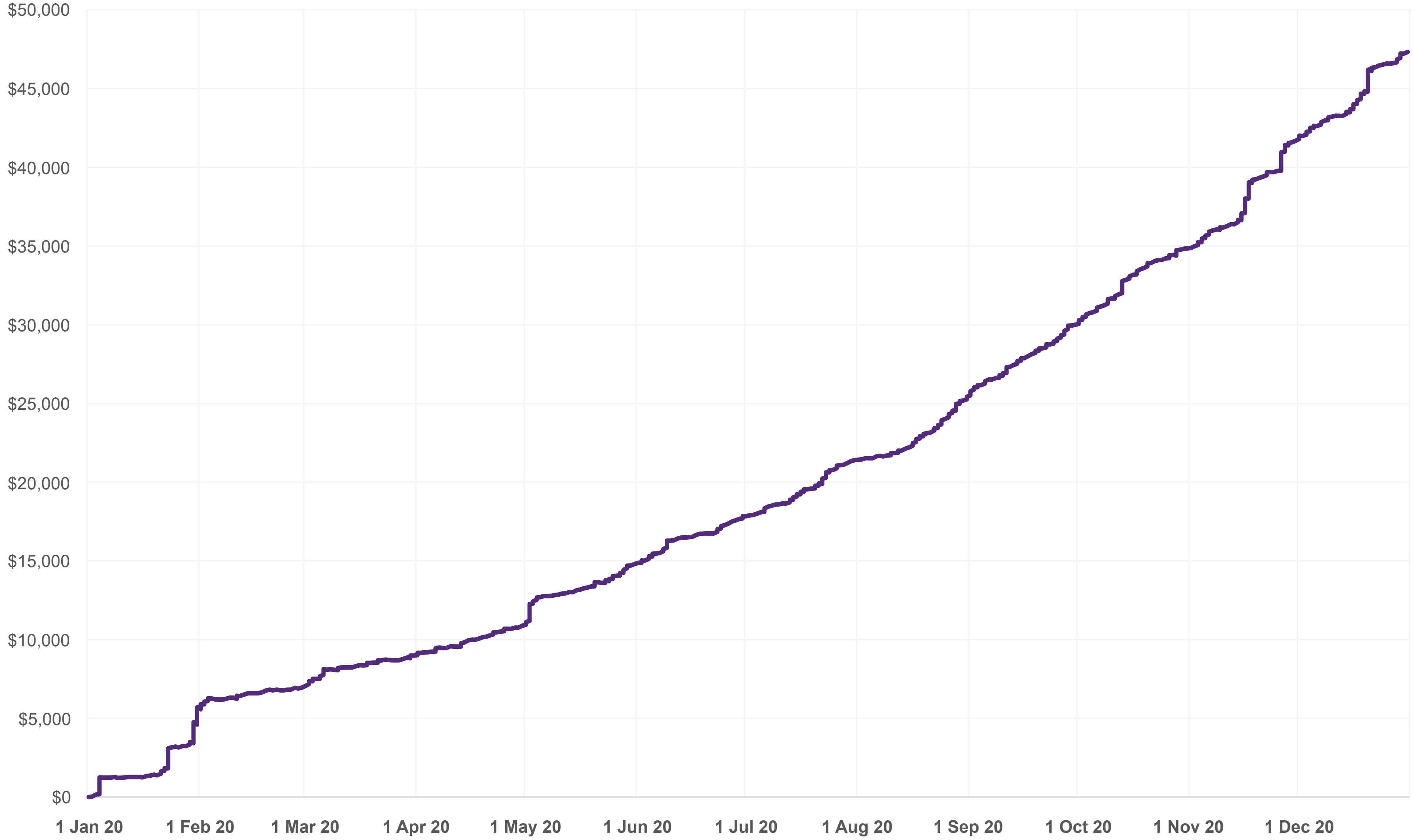


Figure 5: Cumulative arbitrage revenue



3.2 Utilisation analysis

The battery's utilisation is an important metric for measuring the implementation of the arbitrage service, as well as for ensuring the battery's operations remain within relevant warranty limits. There are multiple ways that utilisation can be measured, with UQ opting to sum MWh charged plus MWh discharged to create a metric that is measured on an average MWh per day basis. Figure 6 illustrates the daily utilisation factor per month across 2020, with the annual average and warranty limits illustrated. Although warranty limits are based on MWh of discharged energy only, an inferred daily utilisation limit of 4.56 MWh per day can be calculated by adding the equivalent volume of charge energy needed whilst accounting for roundtrip efficiency losses.

As seen in Figure 6, utilisation of the battery steadily increased across the year, with an average utilisation during 2020 of 3.21 MWh per day. This is around 30% below the warranty limit and implies that, on an average basis, UQ's utilisation of the battery currently has significant headroom to adjust trading strategy. Importantly, even the highest month of utilisation (November) was still almost 8% below the warranty limit (which is assessed on an annual, not monthly basis). The lowest utilisation month (February) had a figure less than half of the warranty limit.

One perspective is that the battery's ideal utilisation profile would see the daily MWh across the year approach as close to the warranty limit as possible, with the caveat that spreads being achieved must still be sufficient to cover roundtrip efficiency losses, ancillary charges, and any other variable operating costs. Beyond this though, it could be argued that even a net spread of $1/MWh would be preferable to the battery's capacity being underutilised and zero revenue being realised.

> UQ's utilisation of the battery currently has significant headroom to adjust trading strategy.

Figure 6: Utilisation factor (average daily MWh charged + MWh discharged)—monthly

Figure 7: Average charge and discharge price ($/MWh)—monthly

Figure 8: QLD RRP vs. average spread—monthly

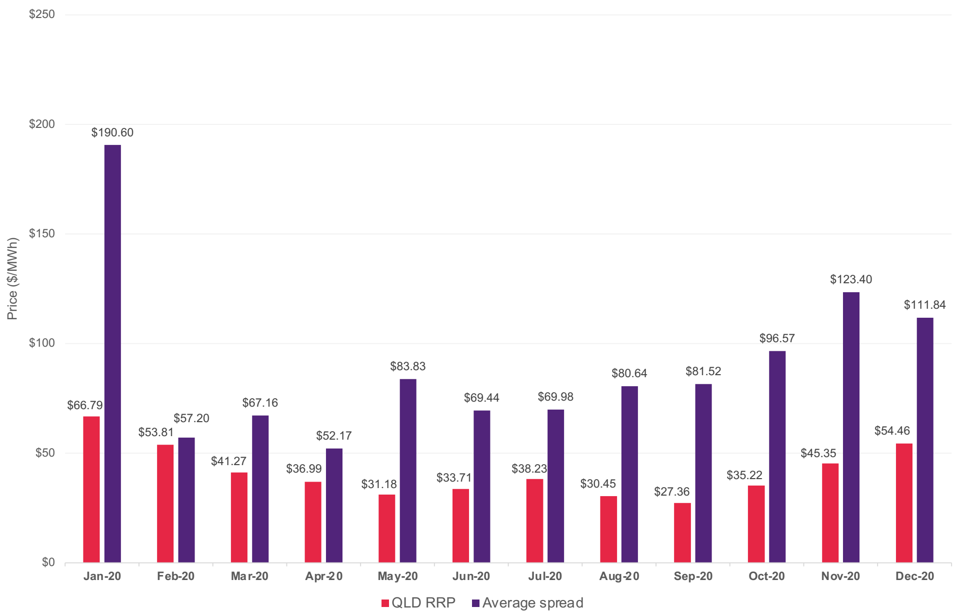
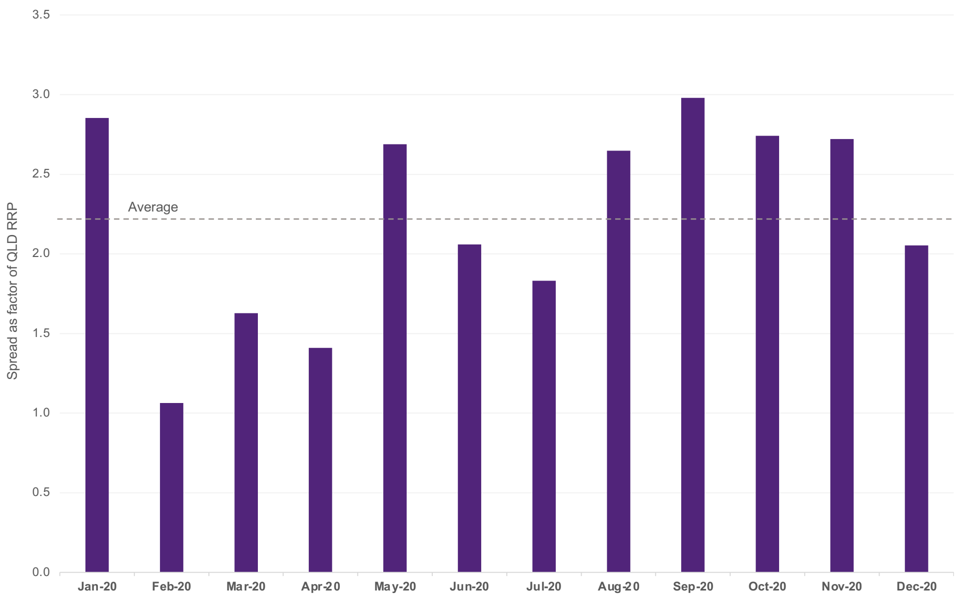


Figure 9: Average spread as a factor of QLD RRP—monthly



This concept is emphasised by the previously shown Figure 5 that highlights the important contribution of everyday spreads (versus infrequent price spikes) towards overall arbitrage revenue. Adopting this operational philosophy assumes that the battery owner is happy to accept the forecast degradation curve (guaranteed by warranty), and that sufficient controls could be enacted to ensure that warranty limits are not inadvertently exceeded. This is further complicated by warranty limits being cumulative over the asset life and is an issue that requires a deliberate strategy and continual monitoring. Following the commencement of UQ tracking this metric, the battery's trading strategy has been gradually adjusted to attempt to increase utilisation, including through a lowering of the minimum spread threshold. This remains an area for future focus and optimisation.

3.3 Price analysis

Alongside utilisation, the other key contributor to overall arbitrage revenue is the average spread captured by the battery. The spread is calculated by subtracting the cost of charging from the income earned from discharging. Each of these values are best assessed by converting them to a $/MWh basis.

Figure 7 illustrates the average charge and average discharge price each month across 2020. In total, the average charge price for the year was $16.29/MWh, compared to an average discharge price of $106.63/MWh. This equates to an overall annual spread of $90.34/MWh. Of note, the average charge price during three out of nine months (May, August & September) was negative. This means that the battery was able to take advantage of negative price intervals to such an extent that the overall result for the month was the battery being paid to charge. While not negative, the month of October also saw a very low average charge price ($2.80/MWh). Average discharge prices were highest in January by a large margin as a result of natural disaster driven volatility, however average discharge prices began to climb again during Q4.

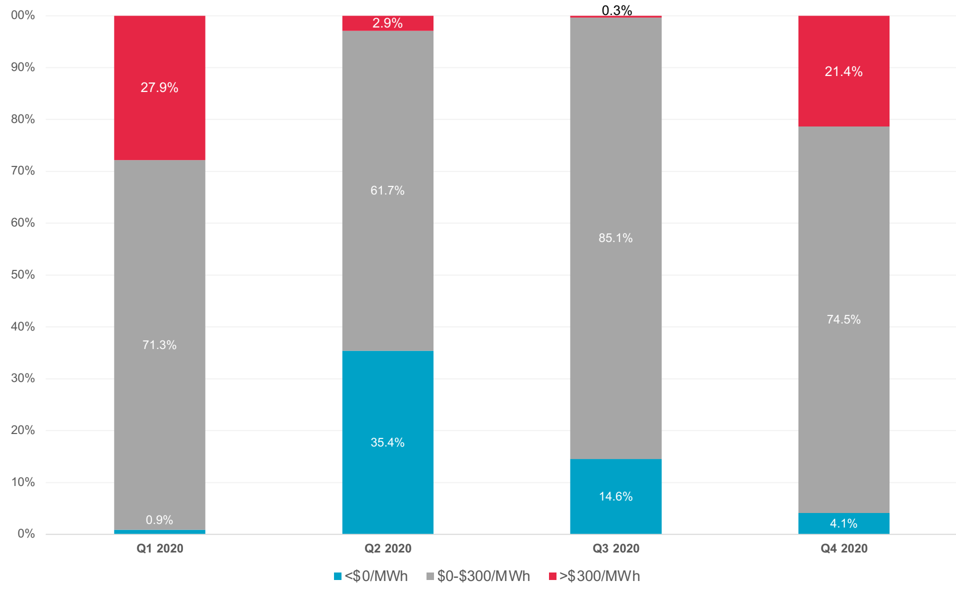
Figure 8 and Figure 9 illustrate a price trend of significant note. Figure 8 shows the average spread achieved by the battery each month compared to the time-weighted Queensland Regional Reference Price (RRP). The RRP is the simple average of the settled price within a region for each trading interval over a period of time and is sometimes also referred to as the 'flat' price. This metric has traditionally been one of the most important and widely cited price signals for each region within the NEM. As illustrated in Figure 8, however, a substantial inverse correlation between the battery's average spread and the QLD RRP can be seen, particularly from Q3 onwards.

Figure 9 plots this using the average battery spread as a factor of the QLD RRP. This shows that on average across the year, the battery achieved a spread that was 2.2 times higher than the QLD RRP. In the highest month (September) this factor was just under 3. Most notably, with the exception of January, the highest factors occurred during months where the QLD RRP would be considered 'low' by recent comparison. This shows that although average energy prices are now lower than at any point in recent years, there is significant hidden volatility within the headline RRP which is able to be captured by flexible assets such as batteries that can pick out both the highest and lowest priced intervals of each day.

> Although average energy prices are now lower than at any point in recent years, there is significant hidden volatility within the headline RRP.

Figure 10 breaks down the portion of income received by the battery each quarter into three price bands—prices higher than $300/MWh, prices between $0/MWh and $300/MWh, and negative priced intervals. This analysis looks only at income received from discharging (or charging if prices were negative) and does not consider the costs of charging. Figure 10 shows a number of interesting trends. Foremost, despite common perceptions about batteries deriving large portions of arbitrage revenue from extremes of pricing (either positive or negative), the majority of income during all quarters came from intervals where prices were within a 'normal' range of $0/MWh to $300/MWh. Across the year these intervals contributed 74% of gross income. During Q1, almost 30% of income was derived from prices above $300/MWh, with almost no income from negative prices. During the following quarter, however, this trend was flipped with more than a third of income being derived from negative price intervals. Q3 saw the vast majority of income from the normal price range, whilst >$300/MWh prices returned to being a material contribution to income in Q4. This kind of price band analysis has important ramifications for how battery revenue is forecast, particularly in the context of cap contract valuation, as further discussed in section 5. This also highlights the importance of reviewing and updating the control parameters used for arbitrage and other services on at least a quarterly basis.

Figure 10: Arbitrage gross income by price band—quarterly



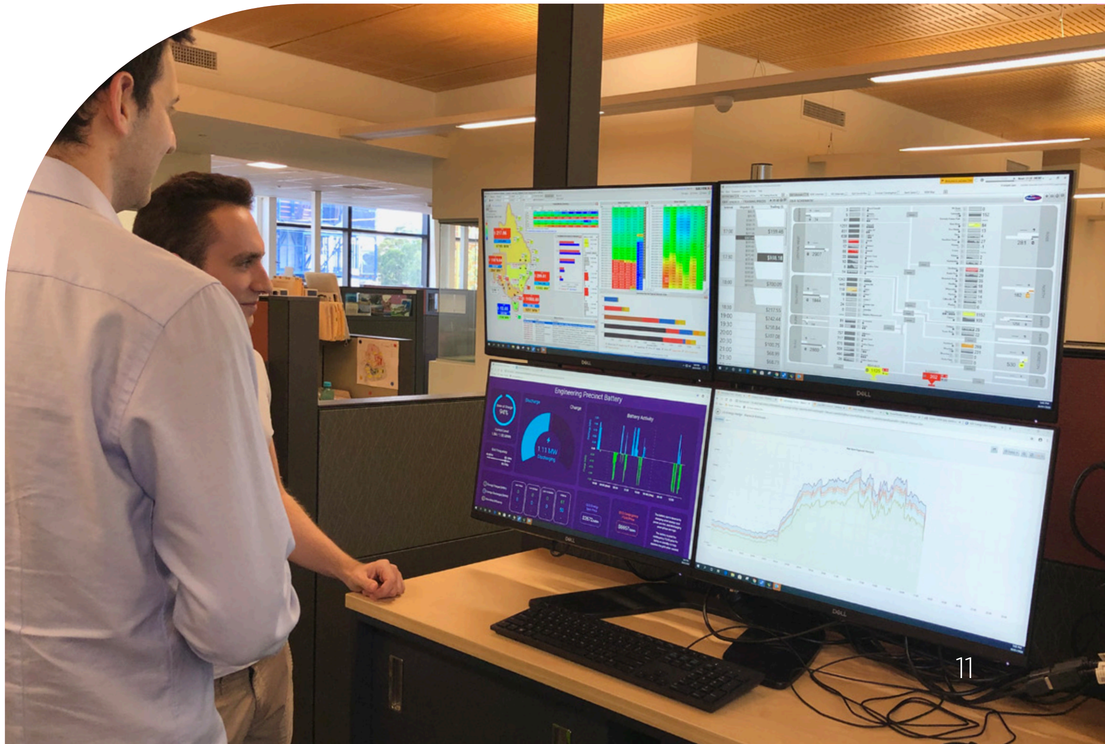


Figure 11: Actual vs. perfect foresight arbitrage revenue—quarterly

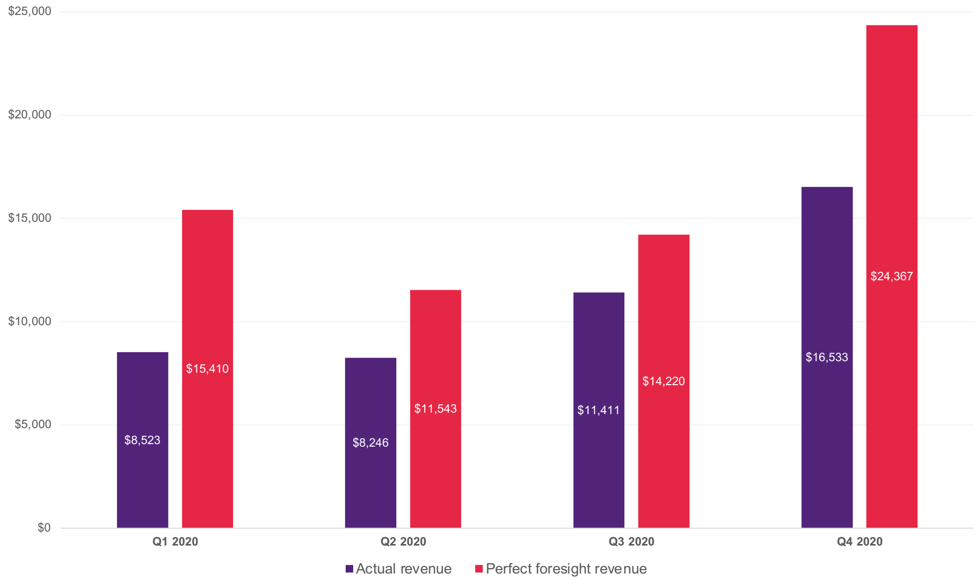
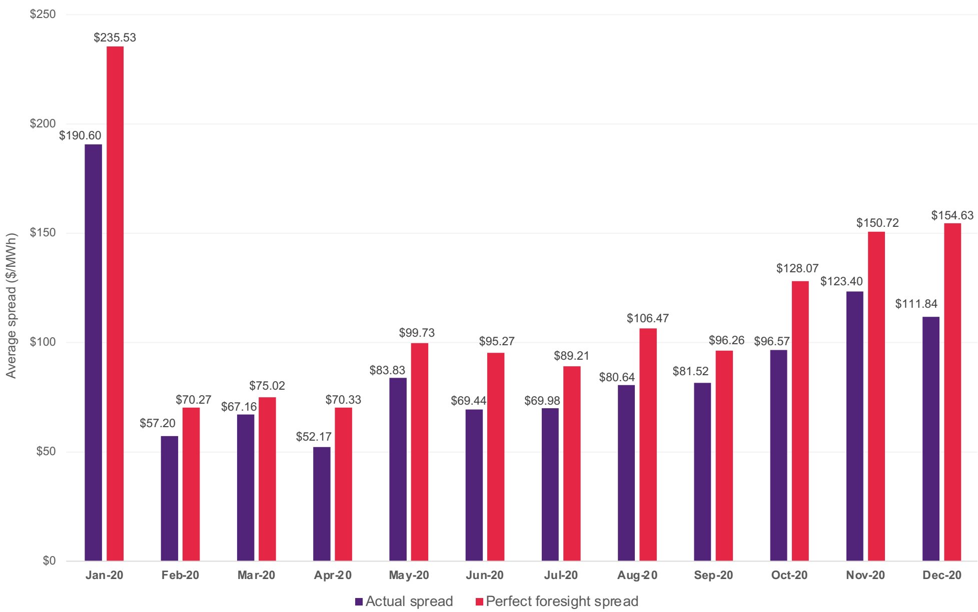


Figure 12: Actual vs. perfect foresight average spread quarterly



3.4 Perfect forecast vs. actual revenue

Perfect foresight refers to the concept of the maximum possible revenue that could have been earnt by the battery assuming that the control algorithm had complete certainty about spot price outcomes. In reality, arbitrage revenue is partly a function of how well the battery's control algorithm makes decisions, but more often how accurate the forecasts of pricing being relied upon are. Due to the fact that perfect foresight is never achievable in practice, comparing results from this scenario with actual results is not a fair benchmark. Analysis of the difference between these two values is useful, however, in the context of better understanding how assets like batteries can be modelled. Very little understanding exists in the public domain of the gap between forecast arbitrage revenue based on past or predicted spot pricing and the real-world operational factors that will impact actual results. This 'discount factor' between hypothetical maximum income and actual results is a key insight for the prediction of battery project revenue. This analysis can be undertaken in the case of the UQ battery by feeding actual spot price outcomes into the demand response engine algorithm (assuming the same control parameters as existed during 2020) to simulate battery behaviour across the year. This approach has some limitations, such as not being able to account for outages nor discharge during contingency FCAS events, but nonetheless provides a useful reference point regarding the question at hand.

Figure 11 shows the comparison between quarterly arbitrage revenue for the actual versus perfect foresight scenarios. Across the year, the perfect foresight scenario yielded 46.6% more income than what was achieved in reality. Put differently, actual results showed a 31.8% discount compared to perfect foresight. This varied significantly across the year, with perfect foresight showing 80% higher income in Q1, whilst only 25% higher income during Q3. Of note, utilisation of the battery was on average 9.4% higher under the perfect forecast scenario, although this was still well within warranty limits. This suggests that even with perfect foresight, considerable scope exists to tune the battery's control algorithm to take advantage of smaller but more frequent spreads.

> Actual results showed a 31.8% discount compared to perfect foresight.

Figure 12 shows the average monthly arbitrage spread achieved in each of the scenarios. Across the year, the perfect foresight scenario achieved an average spread of $116/MWh compared to the actual spread of $90/MWh—a 29% improvement. Significant variation existed between individual months, with the perfect foresight spread in December being 38% higher than actual, while this difference during March was only 12%.

The magnitude of spreads between quarters remained consistent in both scenarios however, with Q4 having the highest spreads, whilst Q2 had the lowest. Notably, the perfect foresight scenario achieved a negative average charge price in four out of twelve months compared to three out of twelve months for the actual results, with average charge prices in October tipping into negative in the perfect foresight scenario.

3.5 Ancillary charges

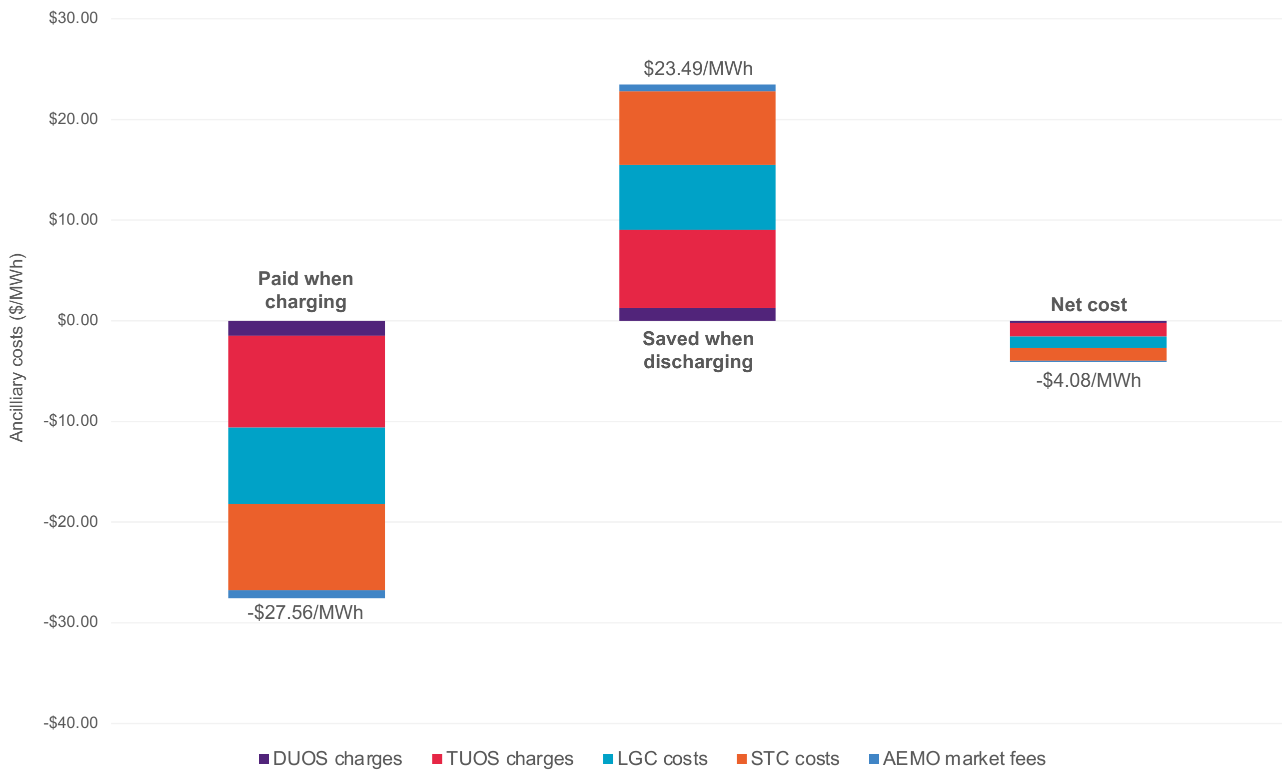
Alongside the direct impact of roundtrip efficiency losses, the other key consideration when assessing arbitrage revenue is the ancillary charges incurred through cycling the battery. These will vary significantly from site to site based on individual network tariffs and market configurations. The following is discussed from UQ's perspective of operating an asset behind-the-meter at a site with relatively low network charges due to the connection voltage and size of load.

In UQ's circumstances, ancillary charges derive from the components of the site's retail electricity bill beyond the simple wholesale cost of the energy used. The ancillary energy charges are levied on a c/kWh basis and include items such as TUOS and DUOS network charges, AEMO market fees, and LGC and STC charges. When charging the battery, UQ incurs additional ancillary energy charges than would otherwise be the case due to the volume of energy measured by the front door meter being increased. When the battery discharges the volume of energy at the front door meter decreases, effectively 'reimbursing' UQ for the extra ancillary energy charges that were incurred during charging. These values do not balance out to zero, however, due to the roundtrip efficiency losses of the battery.

Figure 13 provides an illustration of how this works in practice. The first bar shows that when charging, these ancillary charges add up to a gross amount of $27.56/MWh. When UQ discharges this stored energy, these same charges are avoided. As the volume of energy discharged is less than the volume charged, only $23.49/MWh of value is returned to UQ. This results in an overall ancillary charge of $4.08/MWh. The values presented in Figure 13 are the annual average and are subject to some fluctuation month to month largely due to swings in STC and LGC pricing. These ancillary charges are an unavoidable operating cost of cycling the battery and thus an important input into any calculation of minimum arbitrage spreads required.

> "These ancillary charges are an unavoidable operating cost of cycling the battery and thus an important input into any calculation of minimum arbitrage spreads required.

Figure 13: Ancillary charges—average $/MWh across year



3.6 Future directions

The arbitrage function is the most well-developed revenue stream for the battery. Notwithstanding this, further opportunities for refinement and improvement exist. As discussed in section 3.2, further work is required to optimise the balance between the minimum spread threshold adopted by the trading algorithm and the desire to maximise utilisation within warranty limits. Considering that on a cumulative basis the battery's throughput is currently well below warranty limits, this affords a degree of freedom to trial different approaches to this issue. The other primary area of work related to the arbitrage function involves the co-optimisation of this service alongside others, such as FCAS, to ensure the best overall net outcome for the battery during each interval. This is discussed further in section 4.3.

> "The arbitrage function is the most well-developed revenue stream for the battery.

4. Frequency Control Ancillary Services (FCAS)

Through partnership with aggregator Enel X, the St Lucia battery is able to offer Frequency Control Ancillary Services (FCAS) into the NEM. Under this arrangement, the battery is paid to remain on standby to quickly discharge energy to help arrest a fall in grid frequency following events such as a transmission line or generator tripping.

This service (discharging energy to increase frequency) is known as 'contingency raise' FCAS. It is important to note that the battery earns revenue from FCAS for every interval it is available, regardless of whether a contingency event occurs or not.

4.1 Financial performance

Income from FCAS was the largest contributor to overall battery revenue at $91,000 across the year (58% of total revenue). Figure 14 shows FCAS income by month, noting that these values have been rounded due to commercial considerations.

Despite comprising more than half of all revenue, FCAS income underperformed forecasts by around 25%. This was primarily due to softer than expected FCAS pricing through Q2 and Q3, as clearly seen in Figure 14. Of note, FCAS revenue for the year was derived from the contingency raise service only. It has traditionally been the case that limited value existed in the contingency lower market, however an increased prevalence of network constraints leading to unusual FCAS pricing outcomes is challenging this assumption. Indeed, it is likely that the battery would have achieved target FCAS revenue had it been registered to also offer contingency lower services into the market.

Figure 14: FCAS revenue—monthly

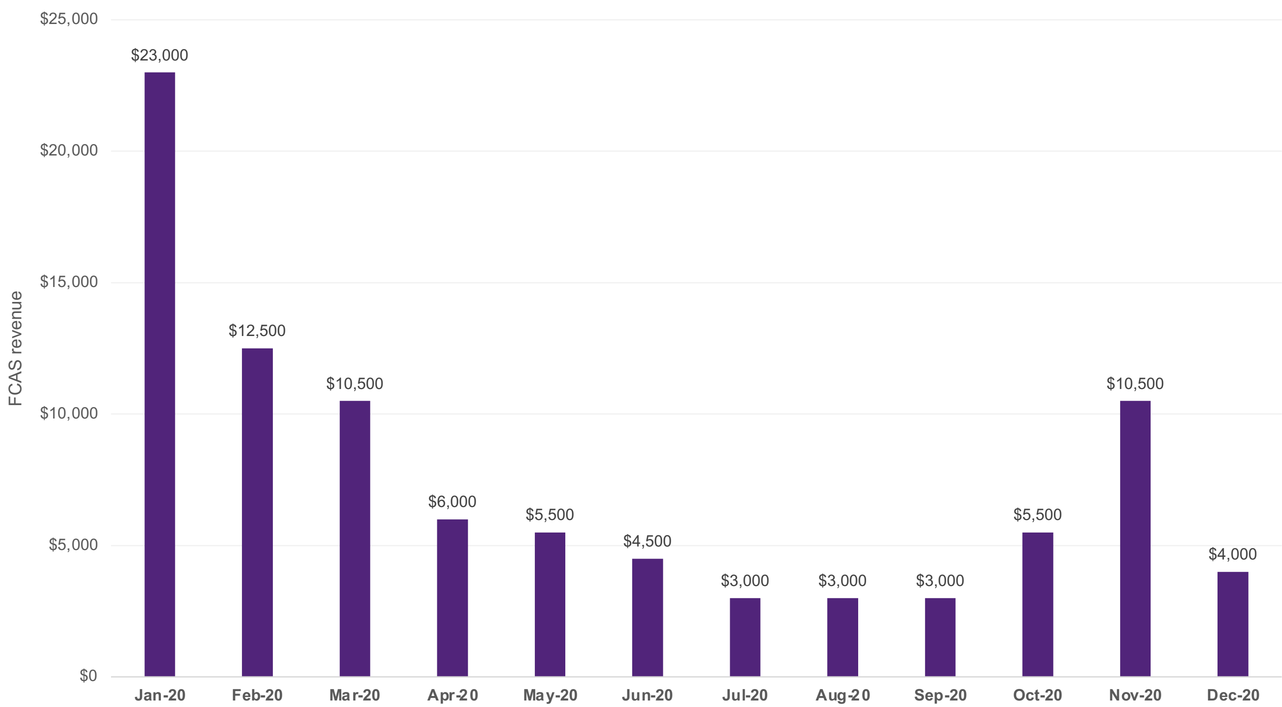


Figure 15: Number of FCAS events—monthly

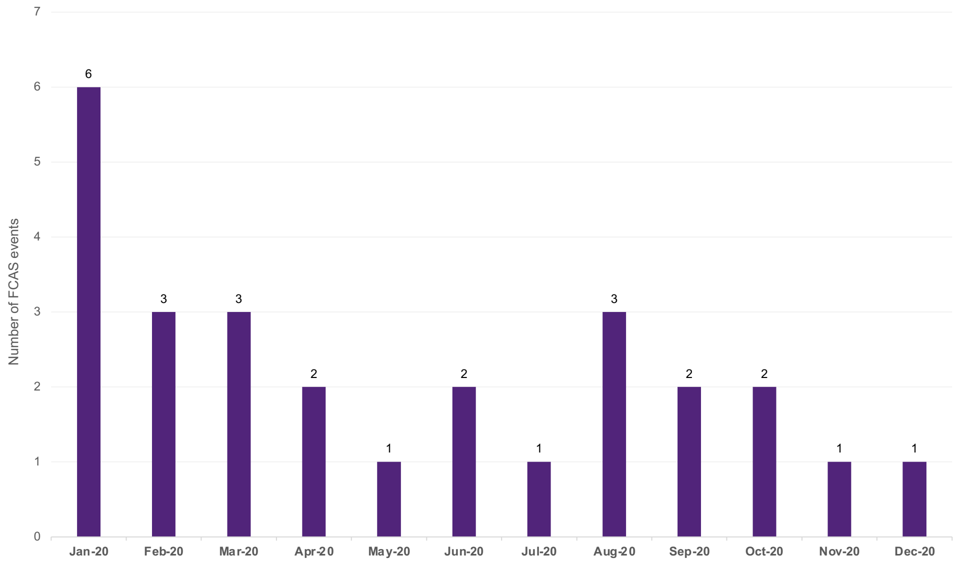
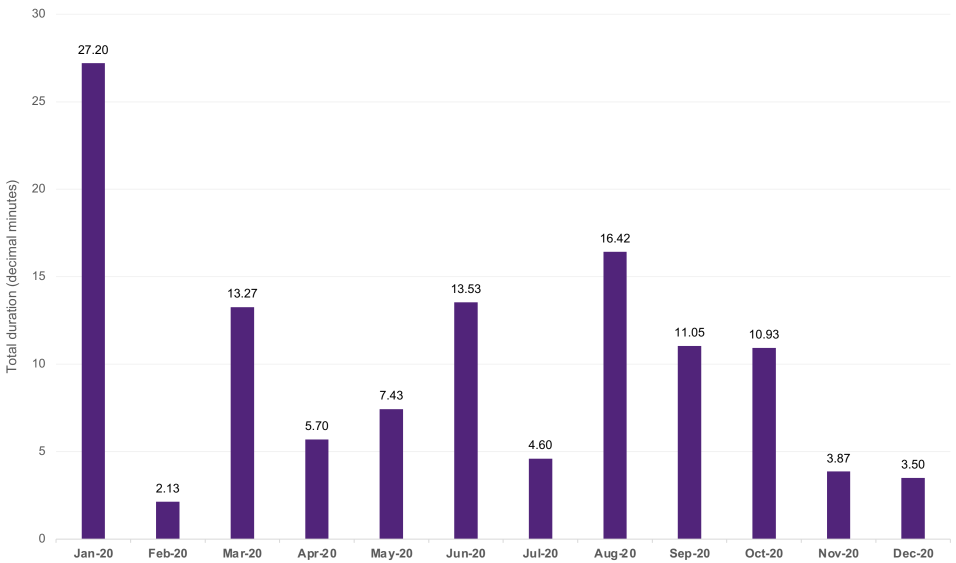


Figure 16: Total duration of FCAS events—monthly



Contingency lower participation involves the battery remaining on standby to stabilise frequency in the grid through rapidly charging in response to events such as the sudden disconnection of a large load (e.g. a smelter).

FCAS revenue was also impacted by a current lack of co-optimisation of this service with arbitrage. Although this only impacted a handful of intervals across the year, it nonetheless represents an area that requires future improvement. This issue is further discussed in section 4.3.

> It is likely that the battery would have achieved target FCAS revenue had it been set up to also offer contingency lower services into the market.

4.2 Utilisation analysis

Despite being on standby to provide FCAS at all times (except if the battery is already discharging), contingency FCAS events typically occur only a small number of times each year. During 2020, the battery responded to a total of 27 discreet FCAS events. Figure 15 shows the number of FCAS events per month. This is dominated by January, where a combination of bushfires in New South Wales & Victoria, as well a storms in South Australia, led to significant impacts on the transmission network and a higher than average number of contingency FCAS events. Notably, at least one FCAS event occurred in every month of the year.

Figure 16 shows the total duration of these FCAS events each month. Across the year, these FCAS events totalled just under two hours—119.63 minutes. As expected, January had the longest duration of events at just under half an hour. The average event duration across the year was 4.43 minutes.

Converting FCAS event duration to the volume of energy discharged equals 2.21 MWh of total energy delivered for this purpose. Note that the values for total MWh discharged presented in section 3 are already inclusive of this volume.

The return from the energy discharged for FCAS purposes equates to $41,176/MWh, although it should be cautioned that this metric has little practical relevance as FCAS markets are priced on the basis of available energy, not delivered energy. A more relevant metric would be the value delivered for the portion of energy that is reserved in the battery at all times for FCAS purposes. In the case of the St Lucia battery, this equates to 10 minutes at full discharge (0.185MWh). On this basis, the value delivered from reserving this volume of energy at all times was around $56/MWh, noting that this is on a 24x7 basis (compared to arbitrage which only occurs at best for 4 hours per day). For comparison, the Queensland RRP for spot energy (also measured on a 24x7 basis) was substantially lower, at around $45/MWh. This suggests that the small portion of energy reserved for FCAS purposes was more highly valued by the NEM during 2020 than generating that same volume of energy continuously across the year.

> The value delivered from reserving 0.185 MWh of energy at all times was around $56/MWh.

4.3 Future directions

As outlined in section 4.1, the ability to access the contingency lower FCAS market is a key priority. This is currently being progressed in partnership with Enel X. Once set up to offer this service into the market, further refinements will be required to the way in which the battery is traded. Similar to how 10 minutes of discharge is always reserved for contingency raise FCAS purposes, consideration will be required as to how it can be ensured sufficient headroom exists for the battery to charge in response to a contingency lower event.

> These numbers highlight the importance of co-optimising the arbitrage and FCAS functions, even for relatively rare market events.

The reservation of 10 minutes headroom at both the top and bottom of the battery's cycle does present risks to arbitrage income and cap performance and will require further optimisation. Indeed, it is possible that a better approach may be to simply opt the battery out of the contingency lower market once fully charged except in the event of higher-than-average contingency lower pricing, in which case headroom could be freed up to enable the battery to re-enter the market.

The second focus area for FCAS is the implementation of a co-optimisation function alongside arbitrage. It is traditionally the case that FCAS prices and spot energy prices follow each other closely. As a result of this and UQ's commercial arrangements with Enel X, the majority of the time it makes more financial sense to fully discharge during high spot price intervals than to remain on standby for FCAS, even if FCAS prices are also elevated. Network constraints and other factors are challenging this assumption, however, with the afternoon of 17 November 2020 presenting a clear case for the need for optimisation. Over the 2 hour period from 1pm to 3pm, the spot price of energy averaged $620/MWh which presented a substantial arbitrage opportunity that the battery took advantage of. Over this same period, however, the price of the raise 60 second FCAS service averaged $7,870/MWh. With perfect foresight, the battery could have earned $1,150 of gross income from arbitrage during this window. Conversely, a co-optimised strategy would have seen the battery actually charge for two hours at these prices in order to double the capacity able to be offered into the contingency raise FCAS market. This would have resulted in $15,750 of gross FCAS income. Even after subtracting the $1,340 cost that would have been incurred from charging at these prices, a net profit of $14,400 could have been achieved (less revenue sharing arrangements with Enel X). Whilst these numbers unrealistically assume perfect foresight, they nonetheless highlight the importance of co-optimising the arbitrage and FCAS functions, even for relatively rare market events.

5. Virtual cap contract

As a participant in the wholesale electricity spot market, UQ is required to develop risk management strategies to mitigate the potential impacts of market volatility. One option available to help manage this risk is the use of 'cap' contracts. These financial products act as a form of insurance against extreme market prices. The buyer of the cap contract pays a 'premium' and is 'paid out' if and when market prices exceed a set threshold, typically $300/MWh. At the end of a defined period (e.g. a quarter), the cost of the premium minus the revenue from any intervals where the contract paid out is the net value of the cap contract to the buyer.

As a behind-the-meter asset that is able to respond quickly to market price spikes, the UQ battery is able to partially replicate the risk management of a financial cap contract. This 'virtual' cap contract works by the battery discharging stored energy during intervals where prices spike beyond a set threshold (e.g. $300/MWh). This then reduces UQ's load by 1.11 MW and thus UQ's exposure to the high market price by the same volume. The primary shortfall of a virtual cap versus a financial cap is that it is unlikely the battery will be able to respond to every price spike in a way that provides full coverage for each half hour interval. Nonetheless, the battery acting in this manner provides value to UQ through avoided cap premium payments. Further details on the methodology for calculating the value of the virtual cap service are provided in the Business Case and Q1 2020 Performance Report.

5.1 Financial performance

The net value to UQ of the virtual cap service across 2020 was $21,905. This was based on a financial cap premium that would have been payable by UQ of $40,476, with a payout from this contract of $13,583. This results in a net value of the financial cap option being a $26,892 cost across 2020. Assuming a perfect replication of the financial cap function by the battery, this would be the net value delivered to UQ by avoiding purchasing a cap. This however is not the case, with the battery only providing around 65% cover for price intervals >$300/MWh (explored further in section 5.2). The cost of this missed coverage equated to $4,988.

The cost of missed coverage is subtracted from the net cost of the hypothetical financial cap (after payout) to calculate the value of the virtual cap. Figure 17 shows the net value of the virtual cap service each month across 2020. It can be noted that this service had a negative value in some months. In these cases, a financial cap would have delivered more value based on spot market outcomes versus the price paid for the cap. This was only the case in three out of twelve months, however, and across the year a net value for the use of the battery for hedging versus a financial cap accrued.

Value from the virtual cap service underperformed forecasts by almost 65% and was the leading contributor towards the underperformance of headline revenue. This was primarily driven by the underlying value of financial cap contracts in the market being substantially lower during 2020 than assumed in the business case modelling. For comparison, the project's modelling (completed in late 2018) assumed a Cal20 cap price of $7/MWh which compares to the final market price for the year of $4.15/MWh—a 40% difference. The other factor that led to this underperformance was the discrepancy between the market value of caps prior to the start of each quarter (which is the price used in UQ's methodology to replicate hedging activity) and the net value of a cap position at the end of the quarter. Put simply, during parts of the year (particularly Q4) the purchase of a financial cap ended up representing relatively good value to the holder due to the payout received versus the premium paid. Considering that the virtual cap service as measured by UQ is valued in comparison to the net value of holding a financial cap, this dynamic detracted from the value of this service.

Figure 17: Virtual cap net value—monthly

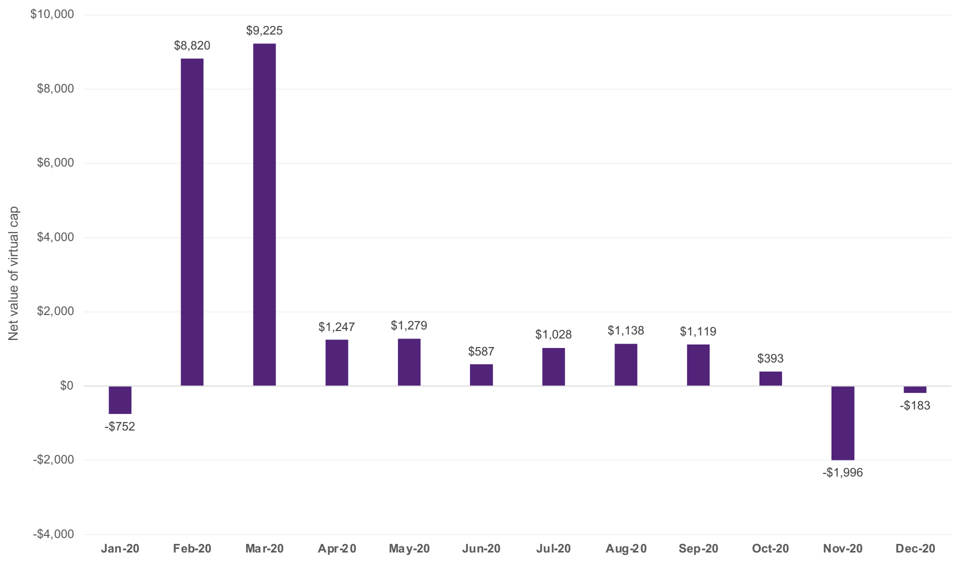
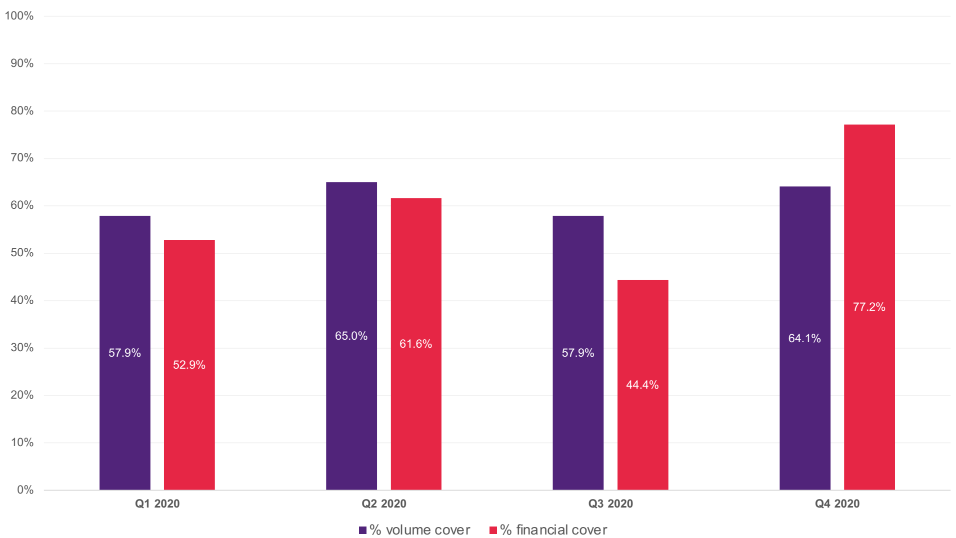


Figure 18: Battery performance by quarter—volume vs. financial cap coverage



It is important to remember that the methodology being adopted by UQ for calculating the value of the cap service provided by the battery is somewhat unique to UQ's circumstances. It can be argued that this is an unfair approach to valuing this service, as the performance of the battery in providing coverage has only a minor influence on the overall calculation compared to the underlying dynamics of the market regarding cap pricing versus actual spot outcomes. This does not fairly reflect the true value of a battery being able to sell cap contracts. To address this, an alternative methodology for valuing this service is discussed in section 5.3.

5.2 Coverage analysis

Considering the nuances of valuing the virtual cap service in UQ's context, analysis of the battery's performance at providing hedging cover during price intervals >$300/MWh provides a way of looking at this function with broader applicability. There are two metrics which can be used to assess the effectiveness of the battery in this regard—volume cover and financial cover. Volume cover refers to how many MWh of discharge the battery produces within the given interval compared to the full duration at nameplate (i.e.1.11 MW of power equates a maximum of 0.555 MWh over a half hour trading interval). The concept of financial cover reflects the fact that not all price intervals >$300/MWh are equal, and that when faced with a choice, it would be better for the battery to discharge during a $2,500/MWh interval than a $500/MWh interval, for example. Financial cover is calculated as the spot price revenue earned from discharge compared to the hypothetical maximum exposure for the interval based on the spot price and a volume of 0.555 MWh.

Figure 18 shows the volume cover and financial cover achieved by the battery for each quarter across 2020. In total across the year, the battery achieved volume cover of 61.4% and financial cover of 63.7%. Despite financial cover slightly exceeding volume cover for the year overall, this was not the case prior to Q4, with all other quarters showing a gap to the downside regarding financial cover performance. Strong performance in Q4, which had the highest number and magnitude of >$300/MWh intervals, was able to reverse this.

Figure 19: Battery performance per cap price event (spot price annotated)

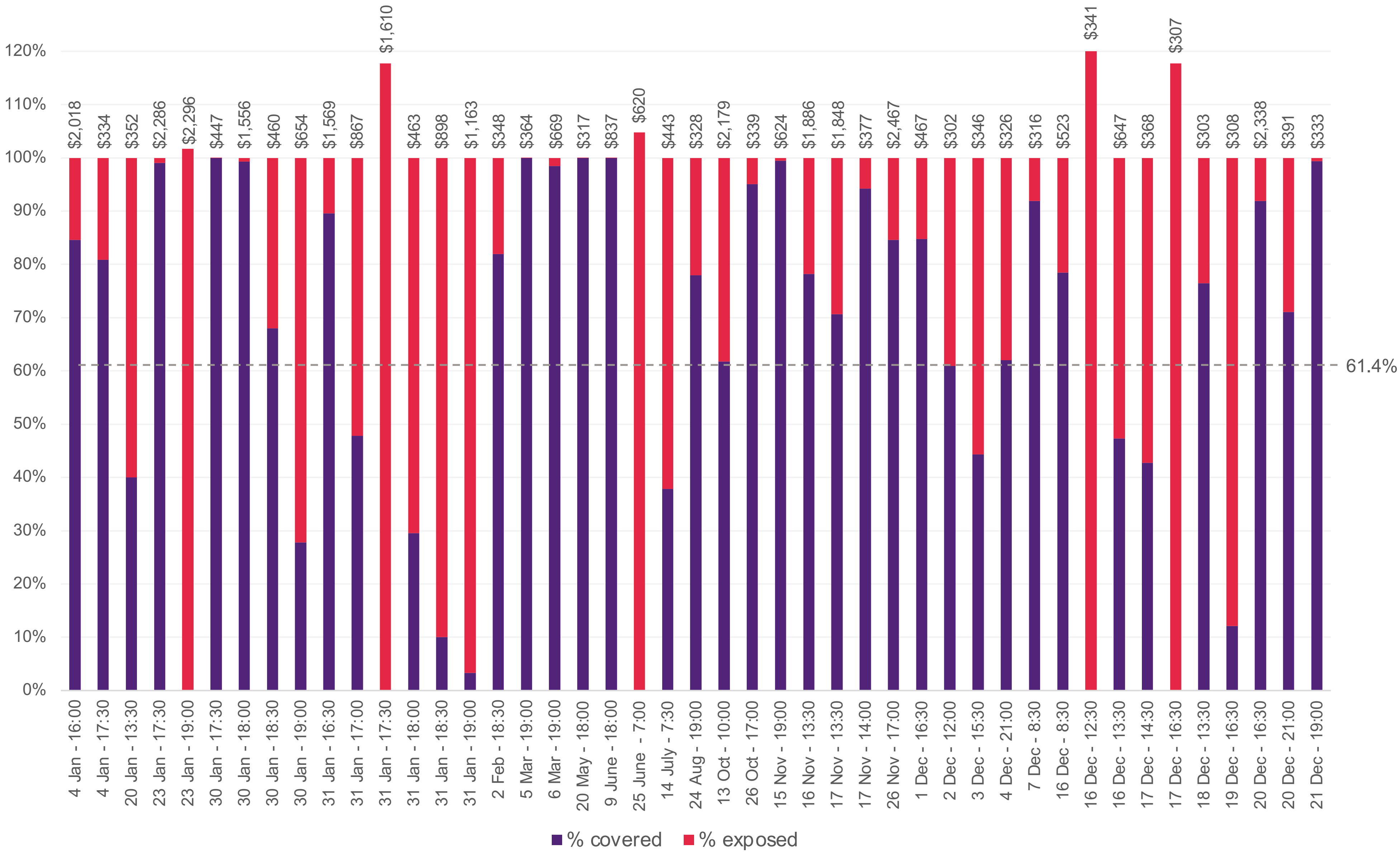


Figure 20: UQ battery vs. Wivenhoe—cap coverage

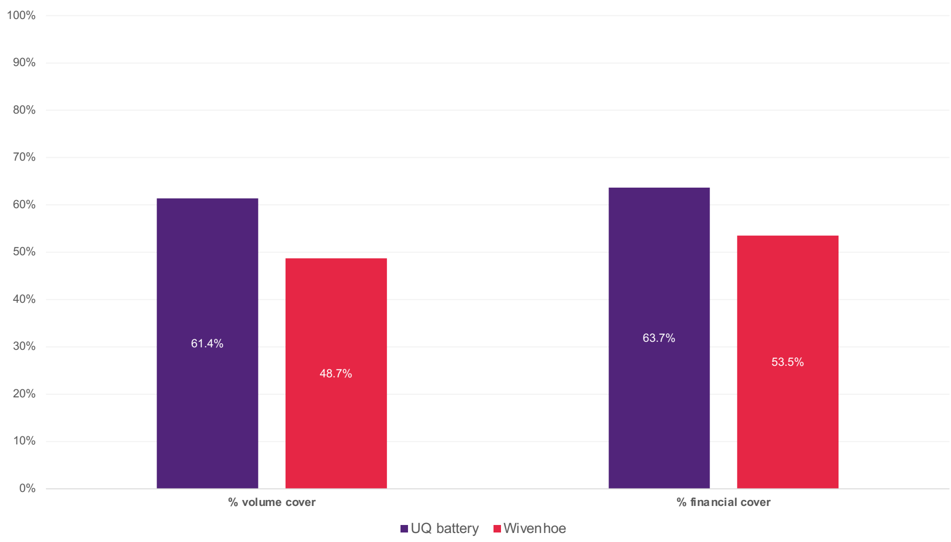


Figure 19 shows the volume cover performance of the battery during each individual interval during 2020 where the spot price exceeded $300/MWh. There was a total of 45 trading intervals >$300/MWh during 2020, of which 18 of them occurred during Q1 and 22 occurred in Q4, whilst only 5 intervals in total occurred during Q2 and Q3 combined. Figure 19 also illustrates one of the unique challenges of batteries (or other energy storage technologies) providing cap coverage. As seen on five occasions throughout the year (most evident on 31 January and 16 + 17 December), the volume left exposed by the battery exceeded 100%. This occurred due to the battery charging during at least part of the interval, thus increasing exposure beyond what would be experienced had there been no response at all. In all cases this was driven by the nuances of the current 5/30 rule whereby unexpected price spikes occur midway through a half-hour trading interval. This also emphasises the primary shortfall of the battery's control algorithm—a reliance on price forecasts that are inherently unreliable and often erratic, especially during volatile market conditions.

> The battery substantially outperformed Wivenhoe on both metrics—with a 13 percentage point lead on volume cover and 10 percentage point lead on financial cover.

In order to contextualise the performance of the battery in providing cap coverage, it can be benchmarked against comparable assets. In this case, the only other relevant comparison in the Queensland region is the Wivenhoe pumped hydro power station. Figure 20 shows the performance of the UQ battery vs. Wivenhoe for the year across both volume cover and financial cover metrics. This shows that the battery substantially outperformed Wivenhoe on both metrics—with a 13 percentage point lead on volume cover and 10 percentage point lead on financial cover. This is despite Wivenhoe being operated by a specialised trading team (versus the battery's algorithmic control) and having a much longer duration of discharge capability. Similar to some of the issues encountered by the UQ battery, there was also one instance where Wivenhoe was pumping during a cap interval, incurring a spot energy cost of around $90,000 despite a quick response once the price spiked.

Figure 21: Sold cap cashflow—quarterly

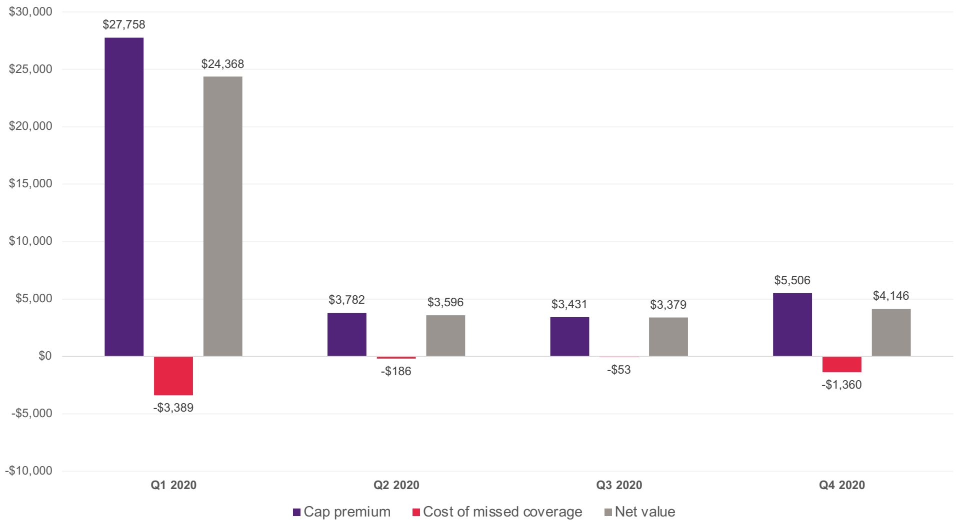
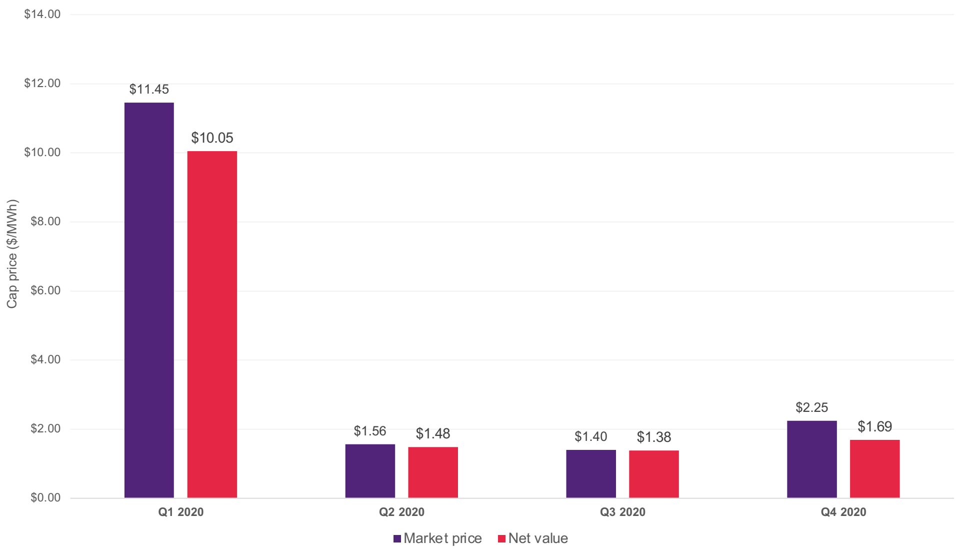


Figure 22: Sold cap net value ($/MWh) vs. market value—quarterly



Lost in the headline figures regarding the battery's coverage performance is an appreciation of how the asset is responding to the kind of sudden and unexpected market volatility that is becoming increasingly common in the NEM and is likely to continue into the future. A prime example of this occurred on Tuesday, 13 October, when the sudden loss of generation in Queensland caused prices to spike from around $25/MWh to $15,000/MWh. While most traditional peaking plants in the market struggled to respond in time, the battery was able to provide coverage for 60% of the trading interval (compared with 30% for the best peaking plant). Further analysis of this event as a case study of batteries vs. peaking plants is available here.

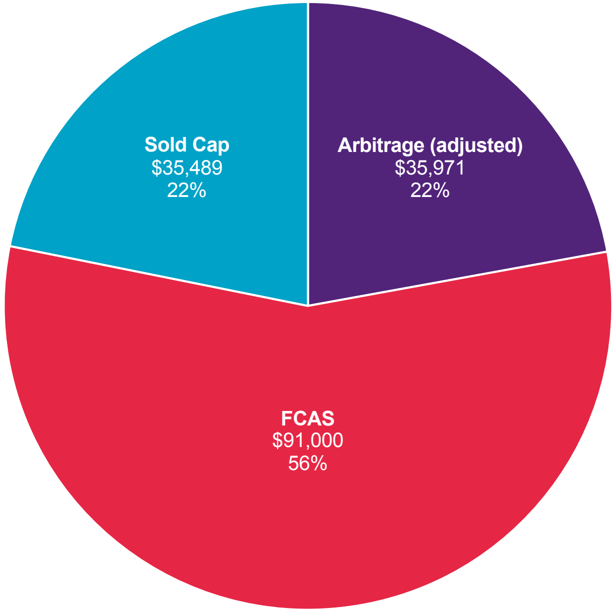
5.3 Alternative valuation—sold cap

As a behind-the-meter asset at a site with a substantial load, the St Lucia battery is inherently geared towards providing hedging for UQ's own spot price exposure. An alternative way of viewing the battery's value as a cap contract though is to consider this service in a more conventional market context. In this way, the battery can be seen as a generation asset that is able to have financial caps sold against it—using discharge income to cover the payout to counterparties to whom the caps are sold. Analysing the battery's performance in this way provides a more conventional point of comparison for other potential battery projects.

Figure 21 breaks down the cashflow by quarter of a hypothetical 1.11 MW cap sold by the battery. The purple bar shows the gross income received from the cap premium. The red bar shows the cost to the seller of the cap as a result of missed coverage—that is intervals >$300/MWh whereby the cap seller had to payout the counterparty but did not receive 1:1 spot revenue to do this. The grey bar shows the net value taking these two factors into account. Figure 21 shows that sold cap net revenue was highest in Q1, as expected. While net revenue in Q2 and Q3 was much lower due to lower market prices for cap premiums, there was also very little cost penalty for missed coverage.

Figure 22 takes the figures presented in Figure 21 and converts these to the net value of the battery's sold cap on a $/MWh basis (red bar). This can then be compared to the relevant market value that caps were sold for prior to the start of each quarter (purple bar). The closer these two numbers are the better a cap sold by the battery performed compared to a traditional financial cap.

Figure 23: Adjusted value breakdown utilising the sold cap valuation methodology



Across the year, a cap sold by the battery would have had a net value of $3.64/MWh. This compares to the market value over the same time of $4.15/MWh—a 12% discount. Q4 had the highest discount at 25%, whilst Q2 and Q3 had discounts of only 5% and 1.5%, respectively. This suggests that the writing of cap contracts during the middle quarters, whilst relatively low revenue, also presents limited risk to the seller. Furthermore, even though the battery only achieved volume and financial coverage around 60% across the year, the impact of this to the net value of a sold cap over the same period was relatively limited.

> Under this methodology, total value is increased to $162,500—3% higher than with the virtual cap approach.

It is important to note that these results reflect the outcomes of one year only, and may be expected to fluctuate in the future depending on underlying market conditions.

Looking through the lens of the sold cap methodology results in a different overall revenue stack for the battery. This is because income from intervals >$300/MWh is currently counted towards arbitrage revenue, but under the sold cap approach would need to instead be used to payout the counterparty. In exchange, however, the seller of the cap receives the full premium over the quarter, with the only cost being that of missed coverage when the battery doesn't fully discharge during a cap interval. Overall, this valuation methodology results in higher total income to UQ, with the new revenue breakdown illustrated in Figure 23. Under this methodology, total value is increased to $162,500—3% higher than with the virtual cap approach. This also sees a more even split between arbitrage and cap revenue, with FCAS still making up around half of total income. The value of cap service regardless of methodology is still ultimately impacted by the lower than forecast market value for caps, with further uncertainty about the future value of this product also existing, as further discussed in section 5.4.

5.4 Future directions

The cap coverage provided by the battery is a function of the core arbitrage algorithm. As a result, any changes made to improve arbitrage outcomes are likely to also assist with cap coverage. An example of this is the concept of trickle charge and trickle discharge. This functionality is designed to deal with erratic forecasts and to begin charging or discharging the battery at a set output no matter what once prices hit a pre-determined threshold. From this threshold, the battery ramps towards full output. For example, the battery may discharge at 300kW at $300/MWh, before ramping to 1.11 MW once prices hit at least $2,000/MWh. This functionality has shown promise at helping to manage erratic price forecasts and ensure the battery provides at least some response to prices that might objectively be considered worthwhile acting upon.

Further work is required to delve into past performance data to better understand why volume was missed in each instance where 100% coverage was not achieved. Whilst full analysis has not been undertaken, it is surmised that a substantial number of these instances occurred as a result of the current 5/30 rule and associated challenges responding to changing prices and forecasts over this timeframe.

> A wider question for this service is what role cap contracts will play in the market going forward.

This alludes to one of the largest changes that will be required to the battery's trading algorithm over coming months—preparation for the introduction of 5-minute settlement from 1 October 2021. Although the battery is inherently well positioned to take advantage of short, sudden price spikes in this market, work is required in order to ensure that control systems are adequately configured to manage the numerous new scenarios that may present themselves.

A wider question for this service is what role cap contracts will play in the market going forward. Indeed, cap contracts are no longer traded on the ASX Energy exchange for any period beyond Q3 2021 and it is understood little appetite to write these contracts exists in the over-the-counter market either. This is a predictable response to the fact that those plants that have traditionally underwritten cap contracts face physical limitations to protecting their position in a 5-minute settlement environment. This may lead to a situation where caps are no longer utilised as a standard hedging instrument. Alternatively, this may also create a significant opportunity for fast response assets like batteries to create a new market that they are uniquely positioned to serve.

6. Appendix A: 2020 Performance Data

Note that costs are represented as a negative value, except energy prices ($/MWh), which reflect conventional market nomenclature.

	Jan-20	Feb-20	Mar-20	Apr-20	May-20	Jun-20	Jul-20	Aug-20	Sep-20	Oct-20	Nov-20	Dec-20	Annual
Technical Performance													
% battery up time	98.9%	99.8%	99.8%	100.0%	99.7%	100.0%	99.9%	100.0%	100.0%	99.9%	97.6%	99.4%	**99.6%**
Roundtrip efficiency (%)	87.8%	84.1%	81.9%	86.3%	85.8%	85.6%	83.3%	88.1%	85.4%	85.1%	84.3%	85.3%	**85.2%**
Maximum capacity (MWh)	NA	NA	NA	2.134	2.119	2.099	2.089	2.085	2.075	2.069	2.058	2.057	**NA**
Arbitrage													
Volume of energy charged (MWh)	35.42	32.05	40.23	45.73	53.57	51.34	64.58	57.19	64.53	58.90	68.58	62.12	**634.22**
Volume of energy discharged (MWh)	31.09	26.95	32.94	39.46	45.94	43.93	53.79	50.36	55.13	50.10	57.80	52.97	**540.46**
Utilisation factor (MWh charge + discharge/day)	2.15	2.03	2.36	2.84	3.21	3.18	3.82	3.47	3.99	3.52	4.21	3.71	**3.21**
Cost of charging	-$2,108	-$1,423	-$1,122	-$924	$524	-$558	-$1,136	$284	$392	-$165	-$1,281	-$2,817	**-$10,334**
Income from discharging	$7,776	$2,738	$3,131	$2,856	$3,402	$3,528	$4,711	$3,811	$4,159	$4,978	$8,213	$8,326	**$57,629**
Ancillary charges (total)	-$120	-$130	-$218	-$167	-$207	-$209	-$321	-$210	-$279	-$220	-$271	-$230	**-$2,583**
Ancillary charges ($/MWh charged)	-$3.40	-$4.06	-$5.42	-$3.65	-$3.86	-$4.07	-$4.97	-$3.68	-$4.33	-$3.74	-$3.94	-$3.71	**-$4.07**
Net arbitrage revenue (total)	$5,548	$1,185	$1,791	$1,765	$3,719	$2,761	$3,254	$3,885	$4,272	$4,593	$6,661	$5,279	**$44,712**
Net arbitrage revenue ($/day)	$179	$41	$58	$59	$120	$92	$105	$125	$142	$148	$222	$170	**$122**
Average charge price ($/MWh)	$59.51	$44.40	$27.89	$20.21	-$9.78	$10.87	$17.59	-$4.97	-$6.08	$2.80	$18.69	$45.35	**$16.29**
Average discharge price ($/MWh)	$250.11	$101.60	$95.05	$72.38	$74.05	$80.31	$87.57	$75.68	$75.45	$99.37	$142.09	$157.19	**$106.63**
Average spread ($/MWh)	$190.60	$57.20	$67.16	$52.17	$83.83	$69.44	$69.98	$80.64	$81.52	$96.57	$123.40	$111.84	**$90.34**
Queensland Regional Reference Price ($/MWh)	$66.79	$53.81	$41.27	$36.99	$31.18	$33.71	$38.23	$30.45	$27.36	$35.22	$45.35	$54.46	**$41.22**
Spread as multiple of QLD RRP	2.85	1.06	1.63	1.41	2.69	2.06	1.83	2.65	2.98	2.74	2.72	2.05	**2.19**
Charge price as % below QLD RRP	-10.9%	-17.5%	-32.4%	-45.4%	-131.4%	-67.8%	-54.0%	-116.3%	-122.2%	-92.0%	-58.8%	-16.7%	**-60.5%**
Discharge price as % above QLD RRP	274.5%	88.8%	130.3%	95.7%	137.5%	138.2%	129.1%	148.5%	175.8%	182.1%	213.3%	188.7%	**158.7%**
Charge price as factor of QLD RRP	0.89	0.83	0.68	0.55	-0.31	0.32	0.46	-0.16	-0.22	0.08	0.41	0.83	**0.40**

	Jan-20	Feb-20	Mar-20	Apr-20	May-20	Jun-20	Jul-20	Aug-20	Sep-20	Oct-20	Nov-20	Dec-20	Annual
Arbitrage (continued)													
Discharge price as factor of QLD RRP	3.74	1.89	2.30	1.96	2.38	2.38	2.29	2.49	2.76	2.82	3.13	2.89	**2.59**
Gross income from negative intervals	$0	$0	$116	$32	$3,402	$216	$208	$895	$841	$800	$67	$15	**$6,592**
Gross income from $0-300/MWh intervals	$4,235	$2,716	$2,777	$2,824	$514	$3,022	$4,473	$3,188	$3,711	$3,514	$5,614	$6,909	**$43,496**
Gross income from >$300/MWh intervals	$3,541	$22	$237	$0	$10	$289	$30	$12	$0	$665	$2,532	$1,402	**$8,742**
Portion of gross income from negative intervals	0.0%	0.0%	3.7%	1.1%	86.6%	6.1%	4.4%	21.8%	18.5%	16.1%	0.8%	0.2%	**11.2%**
Portion of gross income from $0-300/MWh intervals	54.5%	99.2%	88.7%	98.9%	13.1%	85.7%	94.9%	77.9%	81.5%	70.6%	68.4%	83.0%	**73.9%**
Portion of gross income from >$300/MWh intervals	45.5%	0.8%	7.6%	0.0%	0.3%	8.2%	0.6%	0.3%	0.0%	13.4%	30.8%	16.8%	**14.9%**
Arbitrage (perfect foresight analysis)													
Volume of energy charged (MWh)	50.00	47.13	51.40	52.37	56.09	51.03	61.75	53.53	62.24	61.46	70.14	72.44	**689.59**
Volume of energy discharged (MWh)	44.44	41.01	44.20	45.04	47.58	44.02	52.97	46.70	53.49	52.89	60.32	62.30	**594.96**
Utilisation factor (MWh charge + discharge/day)	3.05	3.04	3.08	3.25	3.34	3.17	3.70	3.23	3.86	3.69	4.35	4.35	**3.51**
Utilisation—% difference vs. actual	42.0%	49.4%	30.7%	14.3%	4.2%	-0.2%	-3.1%	-6.8%	-3.3%	4.9%	3.2%	17.1%	**9.4%**
Cost of charging	$2,224	$1,754	$942	$583	-$1,009	$133	$733	-$944	-$920	-$719	$959	$2,300	**$6,037**
Income from discharging	$12,443	$4,408	$4,126	$3,669	$3,889	$4,308	$5,354	$4,148	$4,358	$6,156	$9,916	$11,612	**$74,388**
Ancillary energy charges (total)	-$170	-$192	-$279	-$191	-$216	-$208	-$307	-$197	-$269	-$230	-$277	-$269	**-$2,809**
Net arbitrage revenue total	$10,048	$2,463	$2,905	$2,895	$4,682	$3,967	$4,314	$4,896	$5,009	$6,644	$8,680	$9,043	**$65,542**
Net revenue—% difference vs. actual	81.1%	107.9%	62.2%	64.0%	25.9%	43.7%	32.6%	26.0%	17.2%	44.7%	30.3%	71.3%	**46.6%**
Average charge price ($/MWh)	$44.49	$37.21	$18.33	$11.12	-$17.98	$2.61	$11.87	-$17.64	-$14.78	-$11.69	$13.68	$31.75	**$8.75**
Average discharge price ($/MWh)	$280.01	$107.48	$93.35	$81.45	$81.75	$97.88	$101.08	$88.83	$81.47	$116.38	$164.40	$186.38	**$125.03**
Average spread ($/MWh)	$235.53	$70.27	$75.02	$70.33	$99.73	$95.27	$89.21	$106.47	$96.26	$128.07	$150.72	$154.63	**$116.28**
Average spread—% difference vs. actual	23.6%	22.9%	11.7%	34.8%	19.0%	37.2%	27.5%	32.0%	18.1%	32.6%	22.1%	38.3%	**28.7%**
Frequency Control Ancilliary Services (FCAS)													
FCAS revenue	$23,000	$12,500	$10,500	$6,000	$5,500	$4,500	$3,000	$3,000	$3,000	$5,500	$10,500	$4,000	**$91,000**
Number of FCAS events	6	3	3	2	1	2	1	3	2	2	1	1	**27**
Total duration of events (seconds)	1,632	128	796	342	446	812	276	985	663	656	232	210	**7,178**
Total duration of events (decimal minutes)	27.2	2.1	13.3	5.7	7.4	13.5	4.6	16.4	11.1	10.9	3.9	3.5	**119.6**
Average event duration (seconds)	272	43	265	171	446	406	276	328	331.5	328	232	210	**266**

	Jan-20	Feb-20	Mar-20	Apr-20	May-20	Jun-20	Jul-20	Aug-20	Sep-20	Oct-20	Nov-20	Dec-20	Annual
Frequency Control Ancilliary Services (FCAS) (continued)													
Average event duration (decimal minutes)	4.5	0.7	4.4	2.9	7.4	6.8	4.6	5.5	5.5	5.5	3.9	3.5	**4.4**
Virtual cap contract													
Financial cap price ($/MWh)	$11.45	$11.45	$11.45	$1.56	$1.56	$1.56	$1.40	$1.40	$1.40	$2.25	$2.25	$2.25	**$4.15**
Financial cap gross premium	-$9,456	-$8,846	-$9,456	-$1,247	-$1,288	-$1,247	-$1,156	-$1,156	-$1,119	-$1,855	-$1,795	-$1,855	**-$40,476**
Financial cap gross income	$6,827	$20	$228	$0	$9	$474	$78	$15	$0	$1,062	$3,158	$1,711	**$13,583**
Financial cap net value to UQ	-$2,629	-$8,825	-$9,228	-$1,247	-$1,279	-$773	-$1,078	-$1,141	-$1,119	-$793	$1,363	-$144	**-$26,893**
Number of intervals above $300/MWh	15	1	2	0	1	2	1	1	0	2	5	15	**45**
Maximum potential exposure (MWh)	8.33	0.56	1.11	0.00	0.56	1.11	0.56	0.56	0.00	1.11	2.78	8.33	**24.975**
Maximum potential exposure ($)	-$6,922	-$27	-$241	$0	-$10	-$476	-$79	-$16	$0	-$1,065	-$3,165	-$1,730	**-$13,729**
Volume covered by battery (MWh)	4.23	0.45	1.10	0.00	0.55	0.53	0.21	0.43	0.00	0.87	2.37	4.58	**15.34**
Volume left exposed (MWh)	4.09	0.10	0.01	0.00	0.00	0.58	0.34	0.12	0.00	0.24	0.40	3.74	**9.64**
Volume covered by battery (%)	50.8%	81.9%	99.2%	100.0%	99.9%	47.6%	37.9%	77.9%	100.0%	78.4%	85.4%	55.0%	**61.4%**
Volume left exposed (%)	49.2%	18.1%	0.8%	0.0%	0.1%	52.4%	62.1%	22.1%	0.0%	21.6%	14.6%	45.0%	**38.6%**
Financial exposure covered by battery (%)	51.2%	81.9%	98.7%	100.0%	99.9%	60.8%	37.9%	77.9%	100.0%	62.5%	80.0%	81.1%	**63.7%**
Cost of missed coverage	-$3,381	-$5	-$3	$0	$0	-$186	-$49	-$3	$0	-$400	-$633	-$327	**-$4,988**
Net value to UQ of virtual cap (vs. financial cap)	-$752	$8,820	$9,225	$1,247	$1,279	$587	$1,028	$1,138	$1,119	$393	-$1,996	-$183	**$21,905**
Sold cap contract (alternative methodology)													
Gross income from sale of cap	$9,456	$8,846	$9,456	$1,247	$1,288	$1,247	$1,156	$1,156	$1,119	$1,855	$1,795	$1,855	**$40,476**
Payout to counterparty	$6,922	$27	$241	$0	$10	$476	$79	$16	$0	$1,065	$3,165	$1,730	**$13,729**
Income (>$300/MWh) from battery discharge	$3,541	$22	$237	$0	$10	$289	$30	$12	$0	$665	$2,532	$1,402	**$8,742**
Shortfall between payout and income	-$3,381	-$5	-$3	$0	$0	-$186	-$49	-$3	$0	-$400	-$633	-$327	**-$4,987**
Net value of sold cap (total)	$6,075	$8,841	$9,453	$1,247	$1,289	$1,060	$1,107	$1,153	$1,119	$1,455	$1,163	$1,528	**$35,489**
Net value of sold cap ($/MWh)	$7.36	$11.44	$11.45	$1.56	$1.56	$1.33	$1.34	$1.40	$1.40	$1.76	$1.45	$1.85	**$3.64**
Net value of sold cap—discount to market value	-35.8%	-0.1%	0.0%	0.0%	0.0%	-14.9%	-4.3%	-0.3%	0.0%	-21.5%	-35.2%	-17.6%	**-12.3%**
Adjusted arbitrage revenue (removed >$300/MWh income)	$2,006	$1,163	$1,554	$1,765	$3,709	$2,472	$3,224	$3,873	$4,272	$3,928	$4,129	$3,877	**$35,971**

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