Value Stacking: Application of BESS to many typical use cases

Report for Ara Ake by Sapere Research Group

April 2025

sapere

Ara Ake

Future Energy Development

Summary

Introduction

Battery Energy Storage Solutions (BESS) are a critical enabler of New Zealand's renewable energy future. By enhancing system resilience and supporting the uptake of variable renewables, BESS is fast becoming a cornerstone technology in energy innovation. As battery costs continue to decline and new chemistries emerge, the opportunities for widespread adoption are increasing.

Ara Ake, in collaboration with Sapere, previously investigated the potential for a BESS pilot. Findings revealed that relying solely on the New Zealand electricity market does not generate sufficient revenue to make BESS economically viable. Even a real-world network deferral example failed to meet the necessary economic threshold.

However, a BESS could become viable if it provides significant additional value beyond market revenue (such as energy arbitrage and instantaneous reserves). For instance, instead of merely deferring network investment, a BESS that eliminates the need for infrastructure upgrades while leveraging other revenue streams could unlock greater economic benefits. From a national perspective, non-network solutions solving network challenges could deliver substantial value, particularly if they integrate multiple revenue sources.

The following paper commissioned by Ara Ake and delivered by Sapere[1] explores the economic viability of BESS through value stacking where multiple revenue streams such as energy arbitrage, provision of instantaneous reserves, peak demand reduction, frequency response, and network investment deferral are combined to justify investment. It presents scenario modelling of typical use cases across different sectors to assess how BESS can be commercially deployed and where barriers remain.

Key Findings from the Modelling

- **No One-Size-Fits-All:** BESS applications vary widely in context, so each deployment requires tailored business models and technical configurations.
- **Market Revenue Alone Is Not Enough:** Relying solely on energy market revenue (e.g., arbitrage or spot price management) often falls short of covering the high capital costs.
- **Stacking Value Streams Is Essential:** Combining services—such as instantaneous reserves, peak shaving, frequency control, energy arbitrage, and network deferral—significantly improves financial returns and can shift projects from marginal to viable

Typical use cases by sector

Primary	Generator	EDB	Retailer	Commercial/ Industrial	System Operator
Secondary **Generator**	Base case: • Arbitrage • Instantaneous reserve • Intermittent generation firming	Optimise for EDB: • Constraint management and build deferral • Network capital deferral (N and N-1 capacities) • Peak shaving • Power quality This to be coupled with Generator revenue streams: • Arbitrage • Instantaneous reserve • Intermittent generation firming	Optimise for Retailer: • 'Peaker' to take off top due to spot exposure. This to be coupled with Generator revenue streams: • Arbitrage • Instantaneous reserve • Intermittent generation firming	Optimise for Commercial/ Industrial customers: • Peak shaving/ spot price exposure • Onsite transformer upsizing (50% vs. 100%) coupled with Generator revenue streams: • Arbitrage • Instantaneous reserve • Intermittent generation firming	Optimise for System Operator: • Winter peak low residual This would be coupled with Generator revenue streams: • Arbitrage • Instantaneous reserve • Intermittent generation firming

1 David Reeve and Toby Stevenson

Sector-Specific Observations

Electricity Distribution Businesses (EDBs)

- BESS could be most viable where peak demand is spiky but slow growing, enabling cost-effective, smaller deployments.
- Using the flexibility and the potential ability to redeploy BESS as short-term real options could offer EDBs resilience against long-term electrification uncertainty.

Commercial and Industrial Users

- BESS can provide benefits when paired with demand-side management, especially to mitigate peak charges.
- However, many network upgrades benefit from economies of scale, making standalone BESS comparatively less cost-effective.

Retailers and System Operator Applications

- BESS struggles as a financial hedge against price volatility due to unpredictable pricing and shallow price peaks, as BESS needs to have been charged, or kept charged, for use at the highest price peaks while not incurring similarly high charging costs.
- For system operators, BESS can support peak demand, but requires firm services and potentially new incentive mechanisms, such as availability payments.

EV Depots and Non-Network Solutions

- BESS can be a non-network alternative to costly infrastructure upgrades, though feasibility depends on site-specific factors such as space constraints and duty cycle requirements.

CentrePort partnership: A real-world demonstration

CentrePort is installing EV chargers for heavy plant equipment, which could exceed their network capacity. Ara Ake has partnered with CentrePort to deploy a BESS facility that will:

- Demonstrate the ability of BESS to reduce peak demand.
- Explore commercial energy innovation through a non-network solution.
- Provide insights into how battery storage can unlock value for multiple stakeholders, including Wellington Electricity in managing network constraints.

Next Steps for Innovation and Deployment

The report emphasises that success hinges on smart integration of multiple applications. To unlock the full potential of BESS, the following strategies could be considered:

- Deploy flexibly across use cases and sites to optimise utilisation.
- Trial alternative battery technologies for applications with heavy cycling or space constraints.
- Pursue collaborative commercial models, including shared ownership or service-based offerings, to overcome capital cost barriers.
- Encourage greater market participation, particularly in ancillary services, to increase revenue stacking potential.

Conclusion

Although current economic conditions remain challenging for standalone BESS, the findings show considerable promise for solutions that deliver multi-stakeholder value. BESS can increase energy resilience, reduce infrastructure dependence, and unlock new commercial models—especially when supported by thoughtful policy and sector collaboration.

Acknowledgements

This report has been prepared for Ara Ake by Sapere Research Group, specifically by Directors, David Reeve and Toby Stevenson. The report was commissioned by Ara Ake.

Sapere is one of the largest expert consulting firms in Australasia, and a leader in the provision of independent economic, forensic accounting and public policy services. Sapere provide independent expert testimony, strategic advisory services, data analytics and other advice to Australasia's private sector corporate clients, major law firms, government agencies, and regulatory bodies.

For information with regard to conducting any work concerning BESS value stack modelling similar to that presented in this paper, please contact David or Toby via the Sapere website.

Introduction

Ara Ake has commissioned Sapere Research Group to conduct economic modelling to understand the value stack associated with a variety of BESS use cases via a number of potential commercial arrangements across the electricity sector. The value stacks are considered for the following commercial entities:

- Electricity distribution businesses (EDBs), where a BESS could be used for constraint management
- Electricity generators, where a BESS could be used for energy arbitrage, IR and the firming of intermittent renewables
- Electricity retailers, where a BESS could be used for price volatility risk
- Industrial/commercial electricity users, where a BESS could be used for price volatility risk and to solve capacity constraints, and
- Transpower (the system operator), where a BESS could be used for winter peak management.

Table 1 below shows a set of scenarios associated with each entity and these scenarios have been modelled to understand the potential value a BESS could provide, and whether that BESS stacks up economically, assuming a commercial relationship has been developed where one party owns the BESS (the secondary party) to provide another party a service (the primary party) i.e. meaning the asset can provide multiple value streams to multiple parties.

This paper presents a number of assessments of various scenarios where it is likely that a BESS could provide value within the electricity sector to multiple participants (this includes scenarios beyond those detailed in Table 1). These assessments have been based off data simulations to give the reader an idea of what's possible and to be thought provoking with respect where the value in BESS may lie for different sector participants. It is clear that although BESS can be used simply for storage, it certainly isn't all it's good for – this work shows BESS has a very wide array of applications and that you may not even need to own the asset to glean the benefits.

Table 1: A matrix showing the some of the potential commercial arrangements associated with gaining multiple value streams from a BESS. There are effectively an infinite number of combinations of who the primary party (the purchaser of a service offered by the BESS) and secondary party (the BESS owner) could be, but for all cases modelled in this work (and for simplicity), the generator is the owner of the asset so has the secondary value streams of arbitrage and IR, with the primary use cases spread across other players in industry,

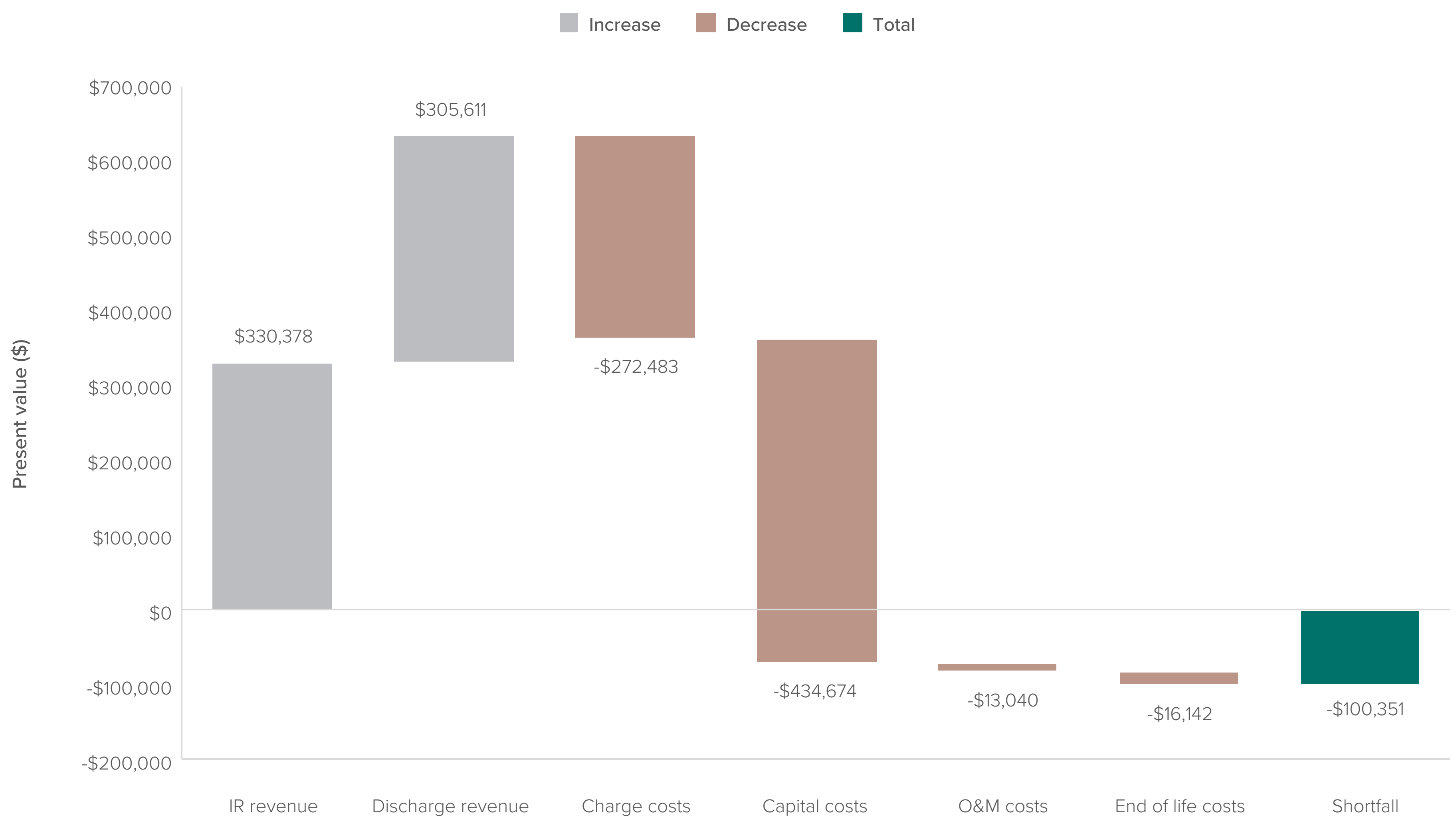
Primary	Generator	EDB	Retailer	Commercial/Industrial	System Operator
Secondary **Generator**	Base case: • Arbitrage • Instantaneous reserve • Intermittent generation firming	Optimise for EDB: • Constraint management and build deferral • Network capital deferral (N and N-1 capacities) • Peak shaving • Power quality This to be coupled with Generator revenue streams: • Arbitrage • Instantaneous reserve • Intermittent generation firming	Optimise for Retailer: • 'Peaker' to take off top due to spot exposure. This to be coupled with Generator revenue streams: • Arbitrage • Instantaneous reserve • Intermittent generation firming	Optimise for Commercial/ Industrial customers: • Peak shaving/spot price exposure • Onsite transformer upsizing (50% vs. 100%) coupled with Generator revenue streams: • Arbitrage • Instantaneous reserve • Intermittent generation firming	Optimise for System Operator: • Winter peak low residual This would be coupled with Generator revenue streams: • Arbitrage • Instantaneous reserve • Intermittent generation firming

Assessment of BESS use cases

Market revenue only

To establish the counterfactual for other use cases, the case for market revenue only is also established. To show the case for market revenue only, the same BESS configuration as used for the EDB use case is used (see section EDB line services). This uses a 0.6MW inverter capacity and a 1.1MWh battery capacity. This is a good configuration for market revenue as it picks up single period price differences, which are the highest, and still has capacity for IR. The relatively small battery keeps the capital cost low.

Figure 1: Present value of revenue and costs for market revenue only case



The market revenue shortfall for this BESS configuration is $100k i.e. the BESS does not break even over its lifetime.

For use cases that require relatively larger battery sizes (i.e. multiple hours of charge and/or discharge time) then relatively small extra market revenue will be achieved while battery costs will be a lot higher. Therefore, market revenue will make a much smaller contribution to such use cases (which suggests a larger shortfall).

Importantly, with respect to the recently or soon-to-be commissioned gentailer BESS installations, other value streams to them such as exposure to reserves are obviously not captured here.

For completeness, operations and maintenance (O&M) and end of life costs have been included in this calculation. For the subsequent use case assessments, both the BESS and an alternative investment have O&M costs. To directly compare upfront capital costs, the revenue and cost comparisons don't include O&M costs as this modelling approach has taken the assumption that these will cancel out to a very small number.[2]

EDB line services

For potential assessments of the use of BESS for lines services, three generic use cases have been proposed as shown in Table 2.

Table 2: The cases are for using a BESS to manage N capacity, N-1 capacity, and voltage.

Case	N capacity	N-1 capacity	Power quality
Primary	Reserved capacity		Scheduled discharge
Secondary	Price arbitrage IR		Price arbitrage
Premise	Slowly growing peak demand reaches 1MWh over peak capacity over 10 years		Feeder with low voltage mostly controlled by reactive power but needs active voltage over peak (1MWh)
Result case	Boundary conditions – the economic benefit from the primary case to stack up		

The cases of N capacity and N-1 capacity are both about managing to a peak capacity using a BESS to handle demand in excess of capacity. In the N-1 capacity example, the BESS must simply be charged ready to respond for a trip of the largest distribution component it is covering. For the N capacity case, the BESS must be ready to discharge during the peaks to meet the extra demand. In both of these cases, the BESS is covering a naturally growing peak demand.

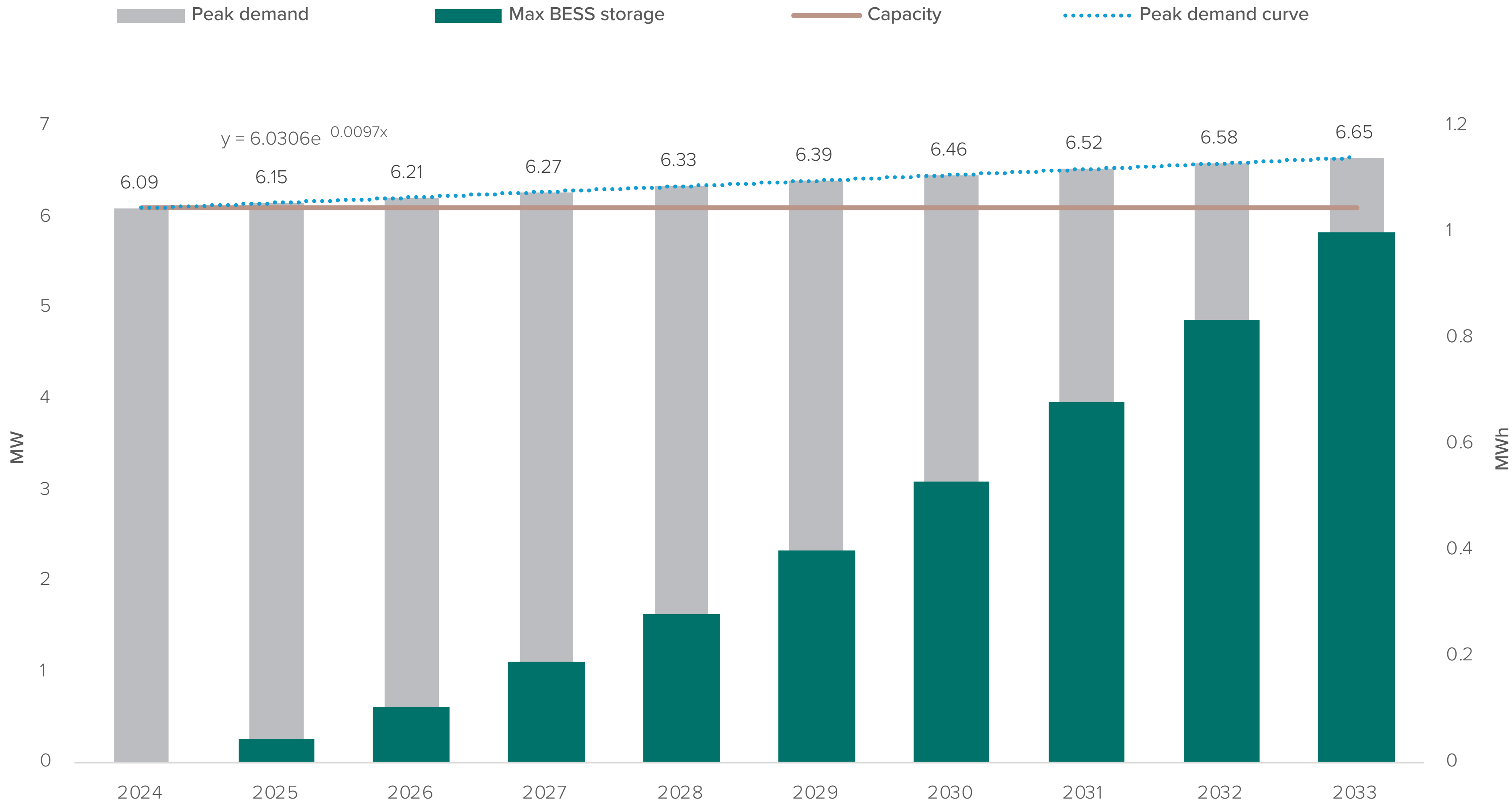
For the power quality case, a BESS is deployed at a point in a feeder where voltage is low. The BESS is providing voltage management services in two ways. First, dynamic reactive power support is supporting voltage most of the time, but it is assumed that at peaks the voltage also needs the BESS to generate, providing an active voltage source.

N capacity modelling

The EDB demand used in this assessment considered the growth of a feeder level demand profile by a defined amount over ten years (the profile grows at 1% per annum, which gradually lifts the peak as well). The EDB's feeder demand profile was created by simulating a proportion of baseload, a proportion of daytime load and a morning and evening peak based on normal distributions. The evening peak was weighted higher and longer than the morning peak, and then the profile was scaled for day of the week, time of year, and growth of just under 1% per annum. Figure 2 shows how peak demand grows over the simulated period and what that means for the maximum required level of BESS storage each year. Even by 2033, the network capacity is only exceeded during the peaks over the months of June, July, and August.

2 O&M costs could be higher in reality see Newell et al. (2022) for a detailed analysis

Figure 2: Growth in peaks and BESS storage for EDB simulation

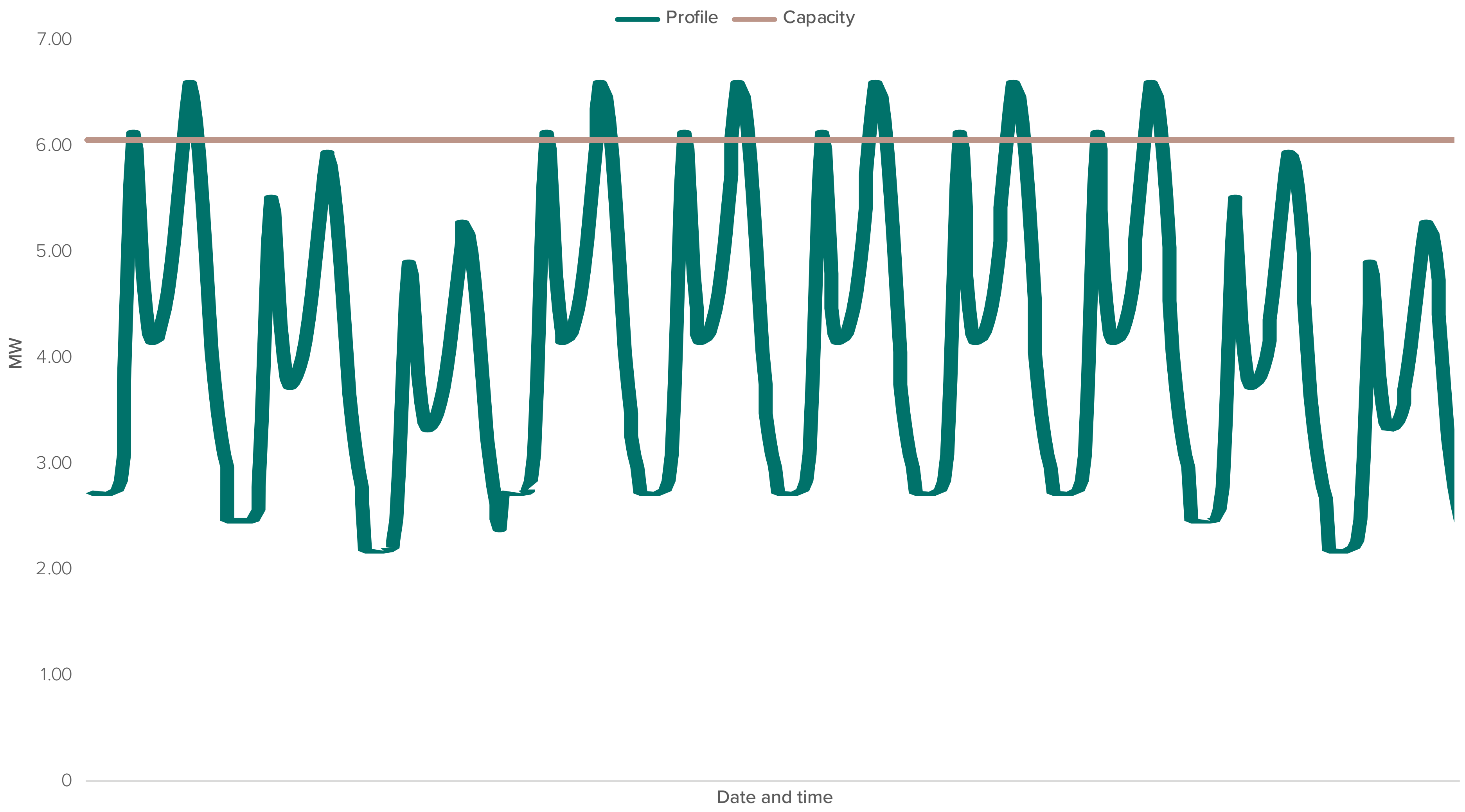


The network capacity assumed was just enough for the first year of demand (6.1MW). This peak number was the result of the simulation inputs chosen and the target of 1MWh of BESS energy to meet the peak capacity after 10 years of growth at 1% p.a.

The simulated data does not account for all variability in a real feeder demand, but creates a credible number and volume (energy and capacity) of peaks that exceed the notional network capacity over 10 years.

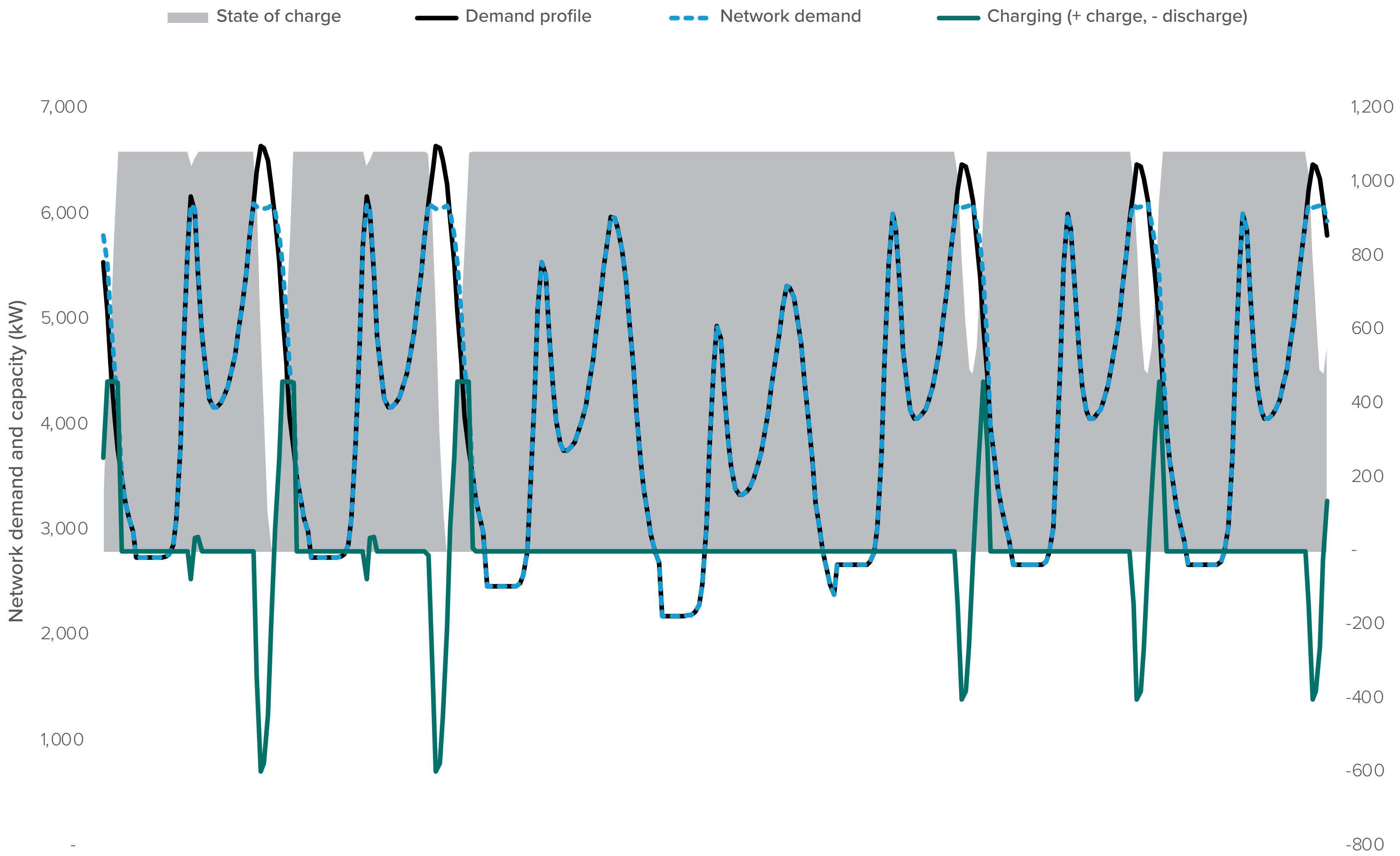
Figure 3 shows the simulated profile for 30 days from 1 July 2033. This is the highest the peak reaches in this simulation.

Figure 3: Simulated EDB feeder profile - 30 days from 1 July 2033



This profile was then passed through the maximise capacity BESS logic in Sapere'. This not only defines the BESS specifications but gives the time profile for when the BESS must be reserved to provide network services. Figure 4 shows a period of BESS operation over July 2033, when the network peak is the highest.

Figure 4: BESS operation over July 2033 simulated peak



In Figure 4, the orange line is the demand profile peaking mostly on weekday evenings but starting to also exceed the network capacity during weekday mornings. The Sapere gold line shows the network demand where the BESS has successfully limited the peak demand to the network capacity of 6.1MW. The purple line shows the BESS discharging to meet the demand peak and then charging again when demand falls below the capacity limit. The grey shaded area is the charge in the battery. The July 2033 peak is the highest peak in the series and is the point where the battery fully discharges to meet the peak.

The specification derived from the modelling is shown in Table 3, in turn giving indicative costs as shown in the waterfall chart in Figure 5.

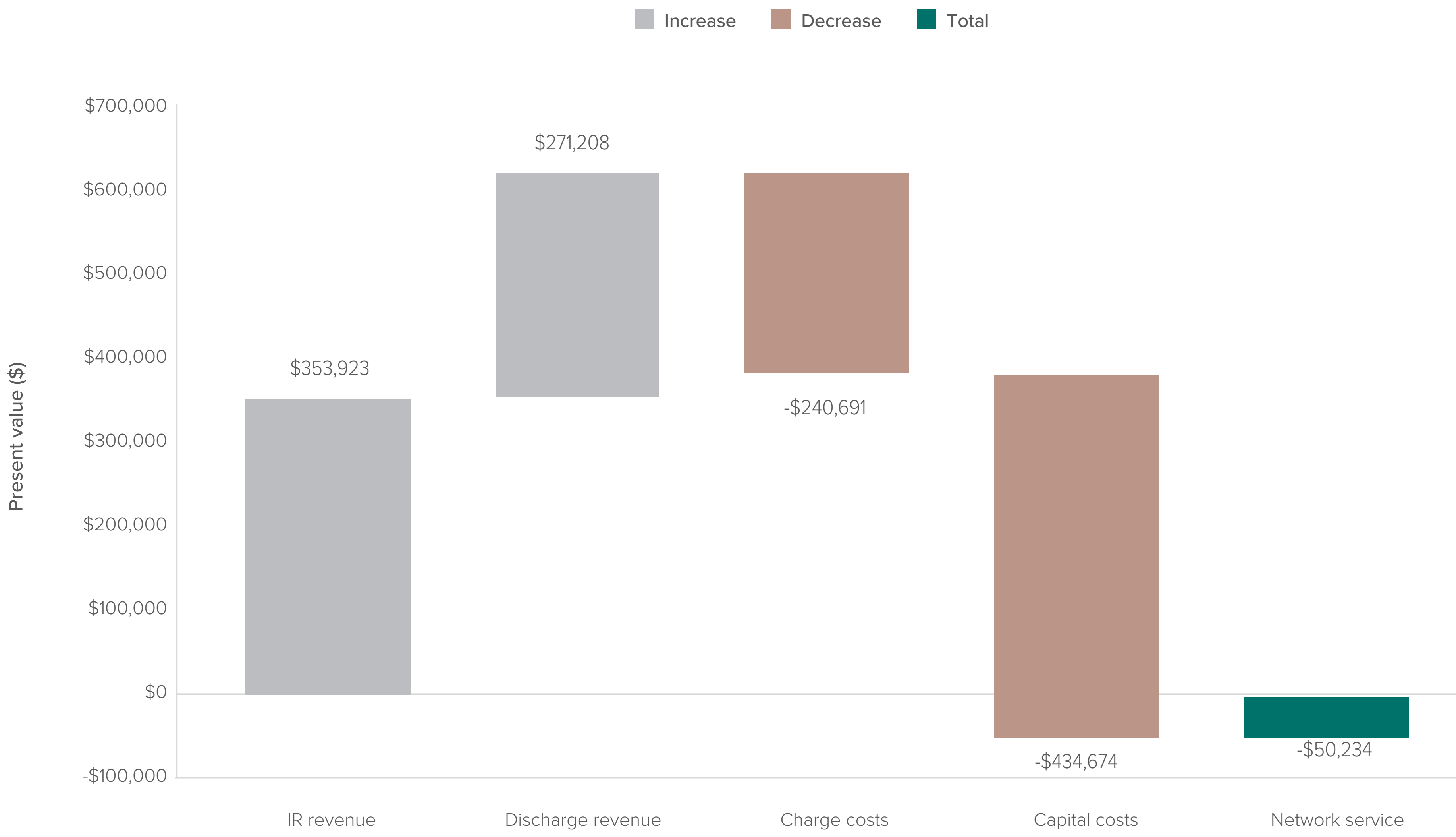
The capital costs for a Li-ion BESS installation are based on the costs in Ara Ake's BESS report, which are detailed in Appendix B, Modelling assumptions. These costs are likely to be understated as the BESS in the modelling has been perfectly sized where, in practice, there would likely be some conservatism in its sizing. BESS also come in standard sizes which would likely make the actual design larger than intended.

While the capital costs are potentially optimistic, a conservative approach has been used to assess the cost basis for deferring network capacity upgrades (which is discussed lower in the section).

Table 3: BESS specification for N capacity on simulated EDB feeder

Characteristic	Value	Unit
Average demand	3,498	kW
Network capacity limit	6,100	kW
Maximum BESS power (charging)	461	kW
Maximum BESS power (discharging)	597	kW
BESS energy storage	1,085	kWh
Max BESS charge (or discharge) time	3.5	hours
BESS utilisation for network service	2	%

Figure 5: Waterfall chart of revenue and costs and required contribution for network services



As the BESS is only utilised for 2% of the whole ten-year period on average (starting at 0% in 2024, rising to 2% by 2029, and 4% by 2033), there is the opportunity to use the BESS for market revenue. To use the BESS for market revenue, the operator must be sure that it does not need to be used for network capacity in a similar time period as otherwise, using the BESS for market revenue could lead to insufficient capacity for the network. In the case of an EDB feeder load, its assumed that the network peaks are substantially predictable on a daily basis. Running this availability through Sapere's market revenue logic yielded the revenues and costs in Figure 5.

This 'perfect foresight' scenario uses the BESS to manage N capacity and for market revenue at any other time that it can. The perfect foresight scenario is more constrained than the market only approach in the section, Market revenue only, but yields a higher revenue. This is not an error but highlights why forecasting gives worse results than hindcasting. The revenue increase comes from a short period of very high reserve prices that are not forecasted and, as a result, the market only scenario was not able to take advantage of the high reserve prices. However, the high reserve prices did, coincidentally, occur when the BESS was scheduled to be available for capacity. As the BESS was scheduled to be fully charged for a peak, but the whole capacity was not required for that peak when the high prices occurred, the BESS was able to capture the reserve revenue under the perfect foresight scenario.

While the perfect foresight scenario was lifted by very high reserve prices, the average prices are not that greatly affected, and a significant range of future prices is possible. Therefore, Sapere are comfortable presenting the perfect foresight output as is.

The contribution that needs to be recovered from the EDB to the BESS owner (in this case, a Generator) for providing a service to give N capacity for ten years is an upfront cost of $50,000 (a BESS network services charge), assuming the use of a standard Li-ion battery chemistry. This is a conservative assessment as most battery chemistries have a design life of longer than ten years.

This means that the BESS would be preferable if the cost to upgrade lines by 600kW would cost more than $50,000. This could be the case if upstream capacity needs to be upgraded as well, e.g. the lines right back to a zone substation. However, it wouldn't be economic to simply defer a $50,000 upgrade.

As the cost of a potentially deferable network investment increases, the time value of money saved becomes larger relative to the BESS network services charge. Therefore, assuming a discount rate for EDBs of 6% p.a., only when the cost of the line upgrade today exceeds $114,000 it becomes cheaper to defer the investment for ten years and pay the BESS network services charge in this specific scenario (with low energy requirements to meet the network peaks).

The relationship between the cost to upgrade lines and the required BESS network services charge is linear, another one dollar of cost adds a dollar to the charge and vice versa, but only for a specific BESS configuration. If peaks are of longer duration, requiring more energy, then the BESS will cost more for only the same capacity increase.

N-1 capacity modelling

The example in the previous section is for N capacity. In that example, both the BESS and the existing network capacity is required to supply the downstream load. If either component is out of service during the peak, supply is interrupted. A BESS can also be used to increase N-1 capacity. In this case, there would be two existing network lines supplying the downstream load, but the point is reached that if either one of them trips during the peak, then supply is interrupted. By adding a BESS to help augment the peak ensures that if any one of the components is out of service (one of the two lines or the BESS), peak demand can still be supplied.

The N-1 capacity scenario is very similar to the N capacity scenario except that, rather than discharging when the demand profile exceeds the N-1 network capacity limit, the BESS holds the energy to be available if a network asset trips, i.e. in Figure 4 the orange discharge line would not normally exceed the Sapere gold line except when one of the network lines is out of service. However, the BESS still needs to be charged during the peaks in case one of the network lines trips out unexpectedly.

The results are very similar in this scenario to the N capacity scenario as the only difference is that 2% of the time the BESS is not discharging or earning energy revenue but must still be charged and waiting. However, the BESS is still able to capture the IR opportunities that lifted the N capacity scenario revenue (IR and N-1 can be supplied concurrently).

Similar value is available to defer network investment and could be economic in this scenario.

Power quality modelling

BESS can also be designed to provide power quality through voltage support. Voltage support can be provided in four principal ways (active power, reactive power, step up transformers, and line upgrades) and a BESS can provide support through the first two of these ways, and thus potentially avoid the costs associated with either of the latter two ways. When discharging, a BESS can provide a new active voltage source in the network with fast voltage regulation. This increases system strength and stability locally.

Even if the BESS is not discharging, it can provide reactive power. Reactive power applies out of phase voltage to a system. By providing leading voltage (capacitive), the resulting sum of vectors (representing the size and phase angle of the voltage components) leads to higher absolute voltage. There is a limit to how much stabilising influence reactive power can have but it is helped by fast voltage response, which an inverter can do.

In the power quality scenario, the same dynamics are at play as for the capacity scenarios. A BESS is generally needed to support voltage, which it can be designed to do while earning market revenue. However, during high peaks a further contribution to stability is needed requiring the BESS to discharge and provide a local active voltage source. This power quality scenario yields the same economic outcomes as the N capacity scenario. In the power quality scenario, the BESS is operated to produce energy at the system peaks to provide an active voltage source during these peak periods rather than manage to a capacity limit. When not peaking the BESS is able to both pursue market revenue and provide dynamic reactive power to a voltage regulating characteristic. However, being designed to do this may incur more cost.

This means that the same deferred investment of $50,000, for a standard Li-ion BESS, needs to be made up from voltage support services, assuming that the investment is permanently deferred. This could be economically feasible, but network voltage support can be relatively cheap (a voltage regulator – step up transformer – could cost less than $50,000). However, a BESS would have better performance than a voltage regulator, which doesn't provide increased system strength, and may be a better option in some situations. Being able to provide active and reactive power would provide more local system strength than purely reactive voltage regulation.

EDB services conclusions and insights

BESS is likely to be economic in the specific scenario simulated for this exercise. The BESS was economic because relatively spiky peaks grew at 1% p.a. compounding. The spiky peaks and low growth meant that a reasonable proportion of extra power was needed but not much energy. This kept the battery relatively small and capital costs low. This also led to a BESS specification suited to maximise market revenue. If the peaks had longer durations and/or growth was much faster, then a larger battery would have been required, leading to much higher capital costs. Longer duration peaks would also lead to higher capital costs but not proportionally more market revenue.

Consider that, if electrification is ignored for the moment, the profile and growth modelled is reasonably typical of many EDB feeders. However, the addition of more electric heating and water heating, industrial process heat, and EVs would lead to faster peak growth and/or longer peak durations. These future electrification scenarios would challenge BESS economics. However, the level, and especially timing, of electrification throughout distribution networks is highly uncertain.

This leads to considering whether the value of BESS may not be so much as a long-term solution for specific situations but more as a general supply of short-term solutions that create optionality. Investing in powerlines in case demand growth occurs, that doesn't then eventuate, would lift total costs considerably. While there are also costs in redeploying BESS, they can be redeployed. Designing them to be easily redeployed adds costs but these costs should be relatively low compared to significant excess network capacity. A fleet of configurable BESS that can be redeployed could cater for feeders that are facing capacity issues but where the timing and nature of future electrification is highly uncertain. Running a coordinated fleet would increase the utilisation of the BESS and delaying network investments until there is more certainty about future demand would be highly valuable.

Retailer services

The modelling in this paper focused on hedging options and concluded that BESS cannot really provide a hedging option to retailers beyond its natural market revenue contribution. An additional area of value which was not explored was volume risk, which could be looked at in subsequent studies. Sapere had considered whether a BESS could provide a real call option for a portfolio. However, a BESS cannot provide a complete equivalent to an option call.

The first reason that BESS isn't equivalent to an option call is because a BESS doesn't provide a firm call option. The BESS mostly resembles what is known as an American call option, but it is a more limited form of American option. American options can be called at any time up to, and including, the expiry date for each posted price. This makes American options useful for peaking loads that might coincide with very high prices. For a standard American option, there is no limit on the number of times the strike can be called, although a limit could be a bespoke term. A BESS can only be 'struck' for as many periods as it has charge for. Therefore, it is a limited option.

The second reason that a BESS doesn't provide a firm option is, to produce when prices are very high, the BESS must have sufficient charge to do so. Even if the BESS has enough capacity, it must be charged by the time it is required. A call option operates with perfect foresight - it can be called retrospectively based on actual prices. For the BESS to be producing, the high price must be forecasted or predicted. Given that the highest price spikes may not be forecasted or may occur after a period of high prices that discharges the BESS, then the BESS may not produce during these price spikes.[3]

The third reason that a BESS is not a firm call option is because the premium potentially increases when the BESS is called. Figure 6 shows the theoretical basis for a cap option. A cap option pays back the buyer for differences in prices that exceed a strike price. The value of the cap is the expected value of the settlements plus a risk premium. This can also be expressed as the equivalent floor option that would have the same expected settlements. Figure 6 shows that the fair price for the cap option of a given strike price, once adjusted for risk, shouldn't exceed the white area below an equivalent floor price.

3 The highest price spikes can be highly unpredictable. They are often caused by plant trips, or during periods where market solutions might be finely balanced between offered generation and scarcity prices. In these cases, small changes in market inputs, say higher demand than forecast, can yield unpredicted price spikes.

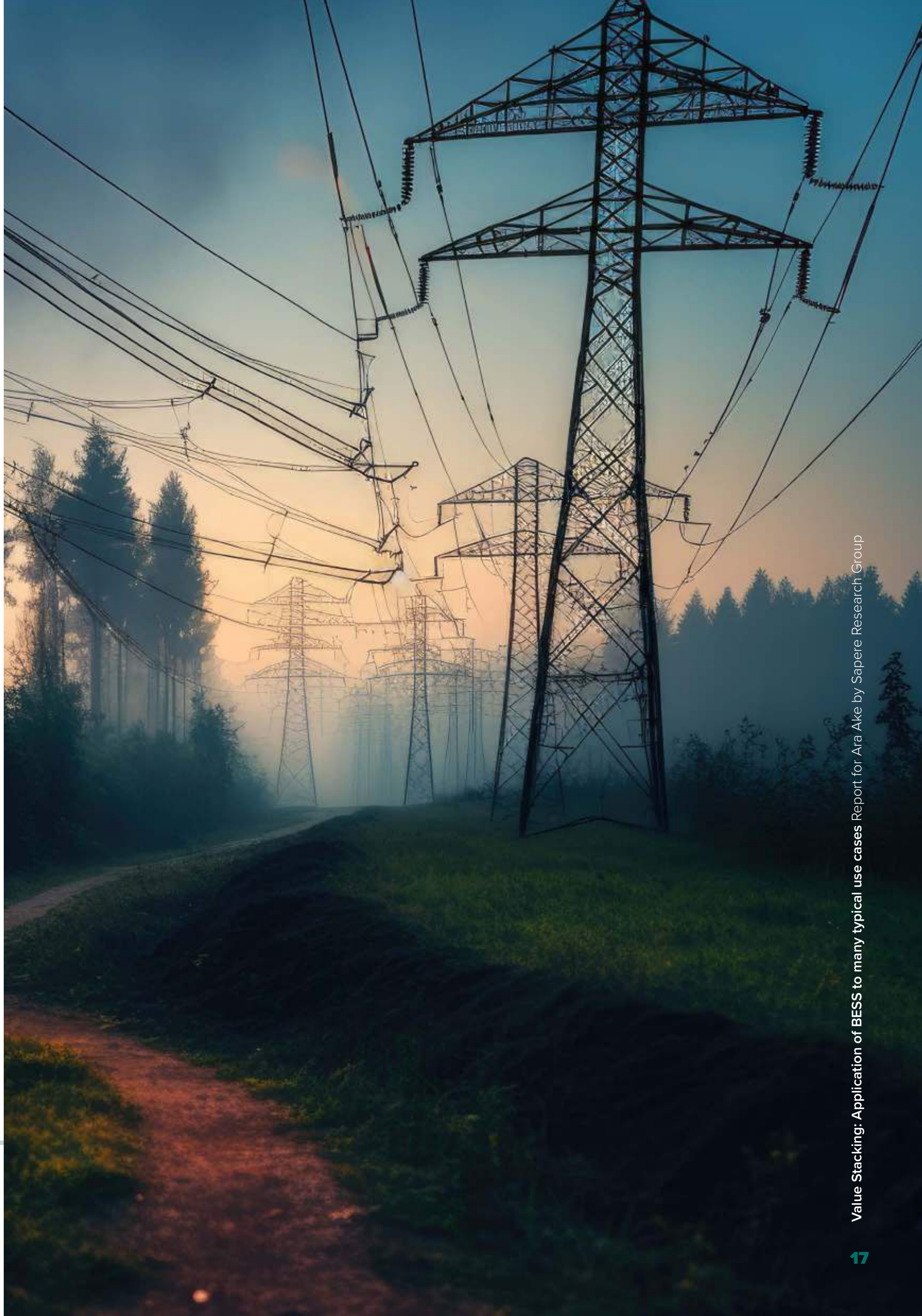
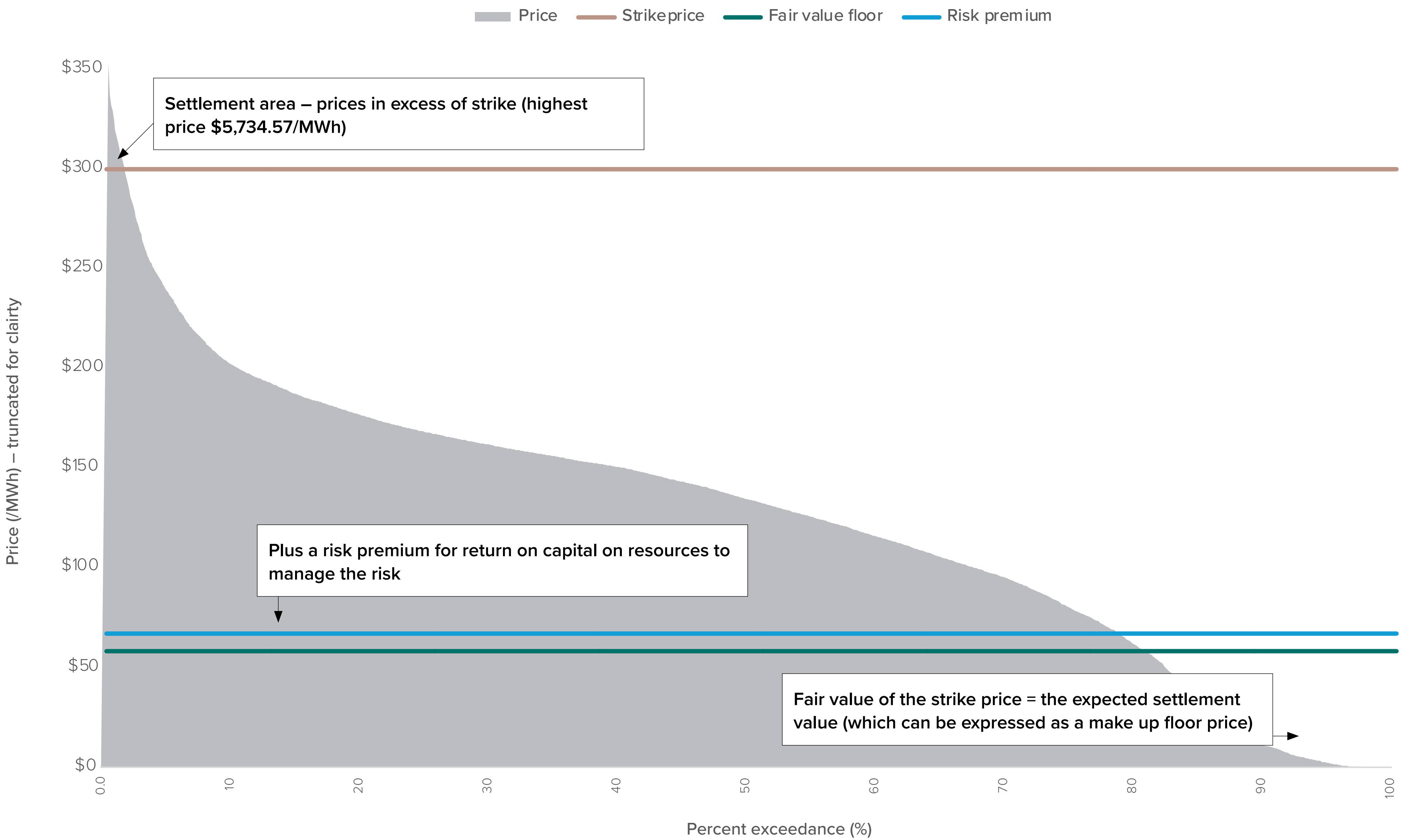


Figure 6: Valuation and operation of a call option



The cost for a BESS to provide a physical hedge at a given strike price can accrue in two ways. First, if the high price is a price arbitrage opportunity, then the BESS can achieve that price cover from market revenue and there is no additional cost. If the high price is not an arbitrage opportunity, then there is a cost to cover that price which is the cost to charge the BESS, plus any incremental battery degradation cost plus a risk premium. If we ignore battery degradation costs, the BESS would be an equivalent cost to a cap option if it could charge during the periods when prices are below the equivalent floor price. However, a BESS is limited in how long it can hold charge without missing out on other opportunities. As 80% of prices in the scenario in Figure 6 are higher than the equivalent floor price then the BESS can be expected to be more expensive than a cap option and yet, is less firm.

Sapere's conclusion is that there is no extra value in using a BESS to manage prices for a sales portfolio. If a strike price too low is sought, then the cash losses from inefficient price arbitrage significantly increase the premium (i.e. a negative contribution to capital recovery). At a high strike price (e.g. greater than $1,000/MWh) then price arbitrage is likely to cover the price anyway, if forecasted in time. If the high strike price isn't forecasted in time, then the BESS will likely be an ineffective hedge anyway.

Commercial/Industrial services

For the commercial/industrial use cases we assessed two simulated scenarios as shown in Table 4

Table 4: The cases are for using a BESS for peak shaving and shot exposure, and to maximise utilisation.

Case	Peak shaving and spot exposure	Maximise utilisation
Primary	Real option price cap Reserved capacity	Maximise utilisation
Secondary	Price arbitrage IR	Price arbitrage IR
Premise	A daytime weighted load (say 1MW) with an intermittent peak (say 0.5MW) and a 1.5MW supply adds 0.3MW of baseload, i.e. the daytime peak has increased to 1.8MW.	24 hour load that intermittently varies from 0.5MW to 1.5MW seeks to minimise its peak demand charges
Result case	Boundary conditions – the economic benefit from the primary case to stack up	

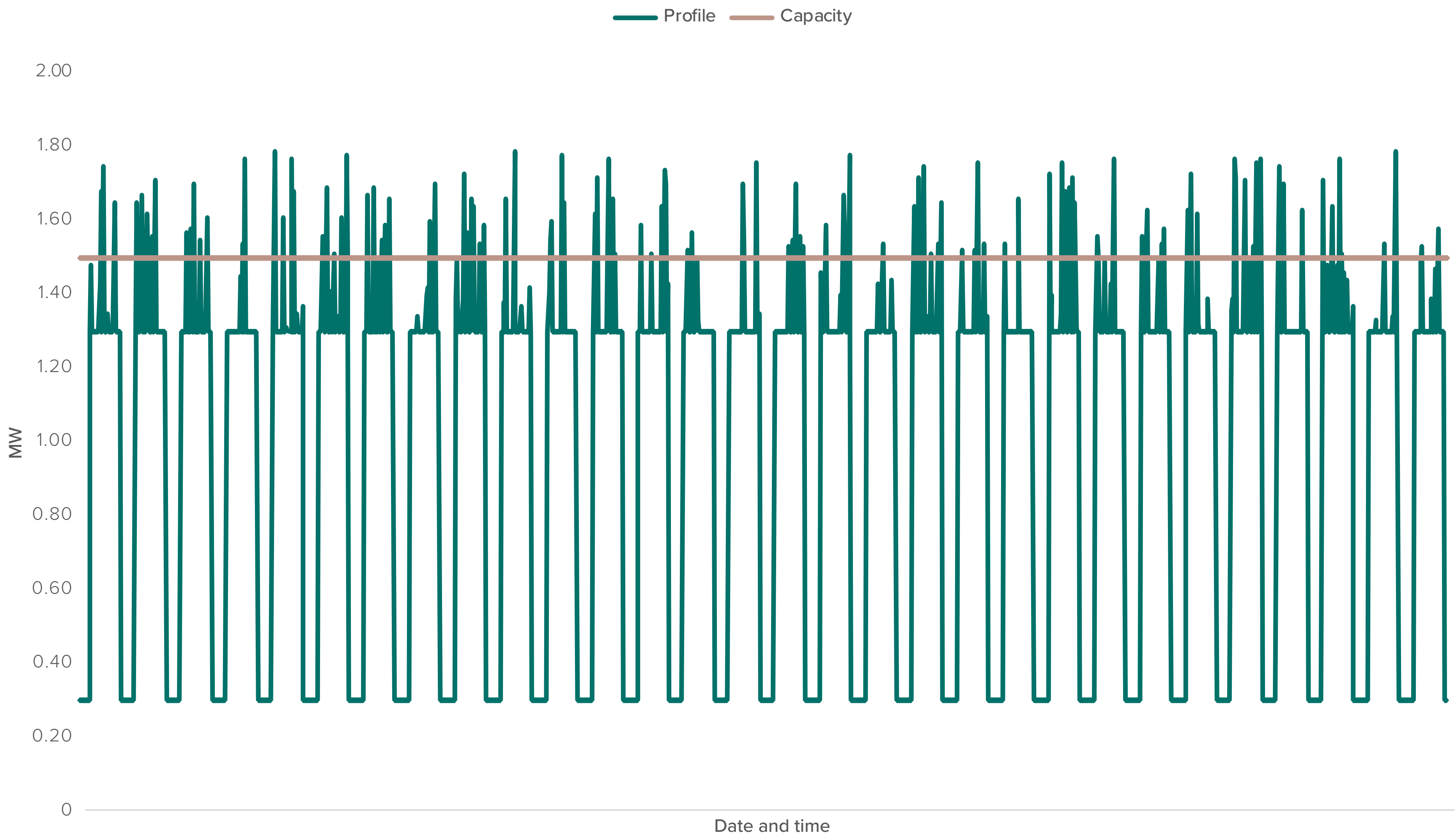
The first case simulates an intermittently peaking load and how a BESS might facilitate this peaking load while maintaining a network capacity by shaving the peak. This might be a case where a intermittently peaking load is added or a load with an intermittent peak might add more baseload. This load is simulated to reduce demand overnight. When demand is low, the BESS can pursue market revenue.

The second example is a more variable load that operates 24/7. The objective is to minimise network charges for the demand using the BESS. Network charges can vary in their method of application, e.g. Coincident Peak Demand (CPD), Anytime Maximum Demand (AMD), etc. As commercial/industrial loads can be a significant proportion of local demand, and can set local peaks, the modelling has set out to 'flatten' demand as much as possible which is consistent with most network pricing methodologies. The demand has a single period autocorrelation, i.e. the demand in the next period is influenced by the demand in the current period. This means that the demand can linger at high levels, but also at lower levels.

Peak shaving and spot exposure

The simulated day time load with random, intermittent peak demand is shown in Figure 7.

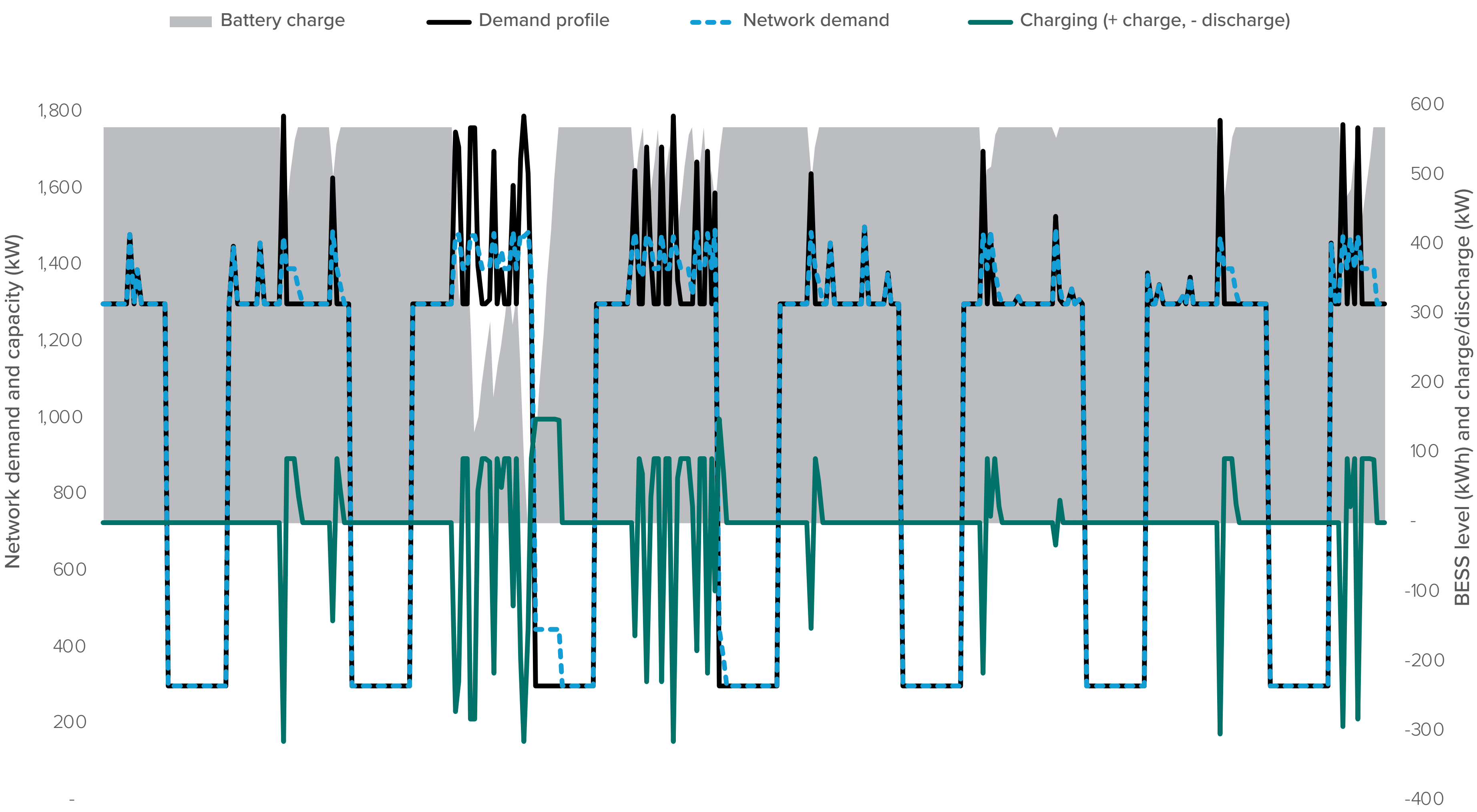
Figure 7: Simulated daytime commercial/industrial load - 30 days over July



This simulation considers the case where an addition to the normal load of the commercial/industrial site leads to peaks exceeding the network capacity limit. However, the limit is occasionally exceeded. The nature of the simulated load is that it is a seven-day operation that operates for two shifts a day and backs off overnight. On top of the daytime baseload, there is a randomly occurring process that consumes significant power. This process has a 1 in 5 chance of occurring and consuming a random amount of peak power up to 0.5MW above the 1.3MW daytime baseload.

Passing this profile through Sapere's maximise capacity logic gives a feasible BESS solution as shown in Figure 8.

Figure 8: BESS operation over July simulated C&I peak shaving



Again, the BESS is successful at limiting the network demand to the capacity limit (1.5MW). The maximum battery discharge required occurs after a series of longer peaks relatively quickly and the BESS has insufficient time to recharge between the peaks. The duration of the peak makes a difference because the day after the maximum discharge, more peaks occur, but each is shorter and the battery recharges between them. As shown in Figure 8, the BESS is working hard on occasions, and this may limit some battery chemistries in practice.

This operating regime requires the specification shown in Table 5.

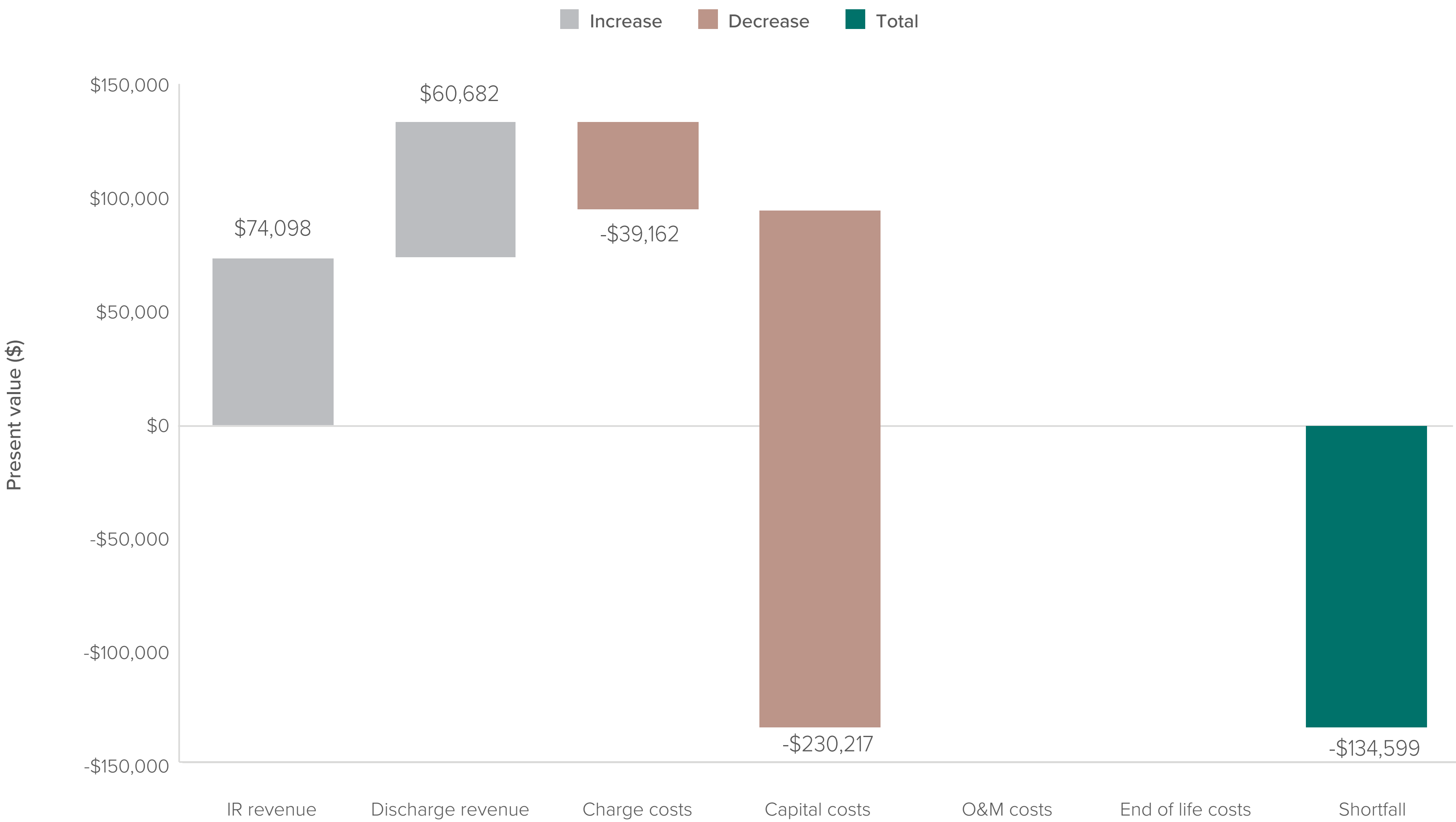
Table 5: BESS specification for peak shaving on simulated C&I load

Characteristic	Value	Unit
Average demand	1,084	kW
Network capacity limit	1,500	kW
Maximum BESS power (charging)	150	kW
Maximum BESS power (discharging)	325	kW
BESS energy storage	569	kWh
Max BESS charge (or discharge) time	5.5	hours
BESS utilisation for network service	25	%

Apart from the quick ramping the BESS must do, which might not suit all chemistries, this is an ideal application for a BESS. Saying that, the maximum charge/discharge time is possibly at the limit of Li-ion at 5.5 hours (Typically Li-ion batteries are designed to discharge at maximum power for up to five hours).

The peaks are quite high, but the energy needed to meet them is quite low. This keeps the capital costs of the BESS low. Indicative costs are shown in Figure 10.

Figure 9: Waterfall chart of revenues and costs for BESS for C&I peak shaving



As previously noted, O&M and end of life costs have been assumed to be approximately equal to O&M costs from a supply capacity alternative and are set to zero. This assumption allows a direct comparison to upfront costs.

Again, these costs might be understated as a bespoke design will be needed to meet the required specification. As noted above, Li-ion doesn't meet the maximum charge hours, but only just misses. This doesn't mean that Li-ion couldn't be used but that larger battery capacity may be required to stay within thermal design limits.

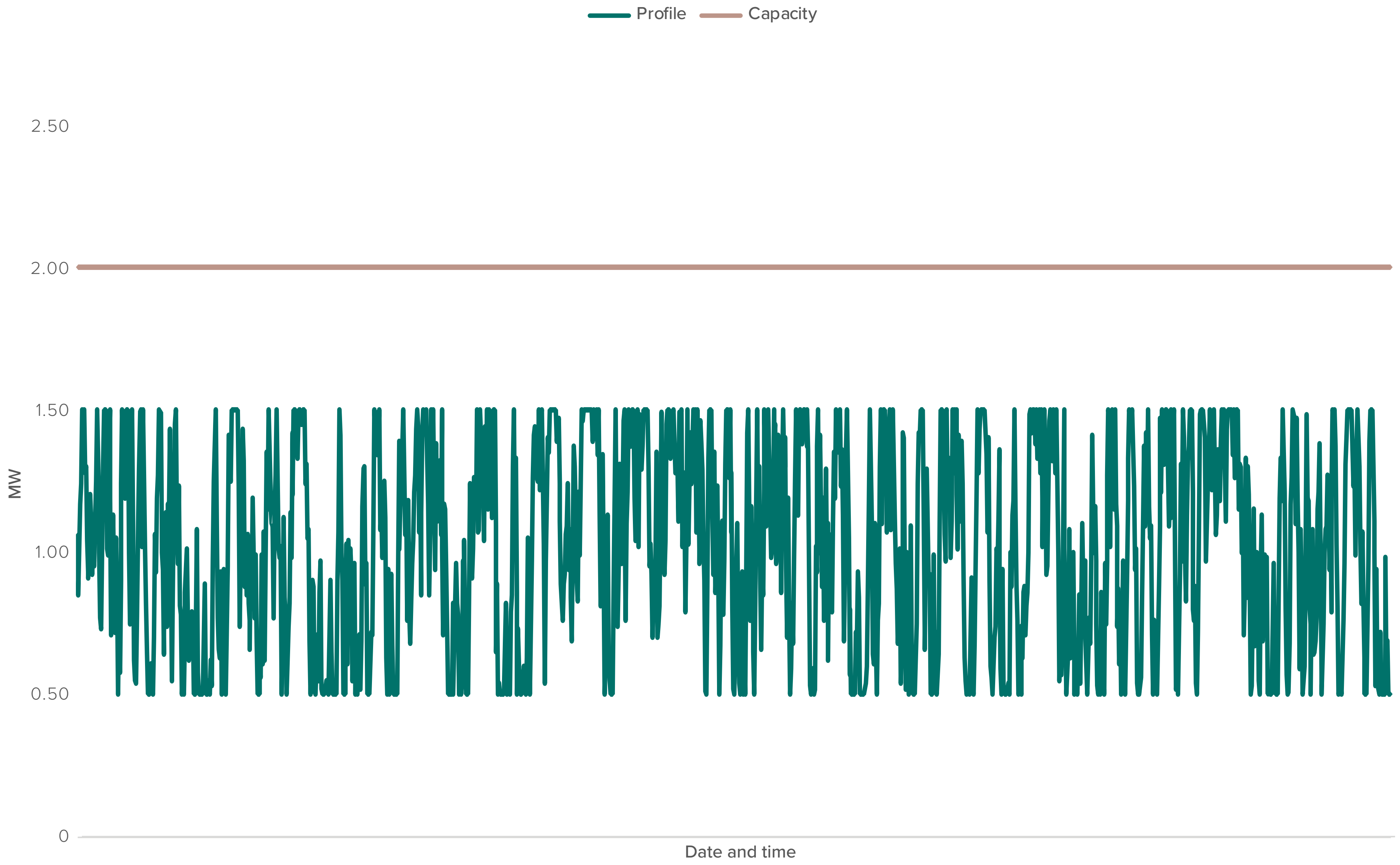
There is little market revenue with this application. As the peak demand in this scenario is random and unpredictable, the BESS must be charged when it can and remain ready for a peak. Therefore, the BESS can only be used for market revenue for a short period overnight. This gives only $14,250 of average annual market revenue, or a PV of $95,620 discounted over 10 years.

The result is a BESS shortfall of $135,000. As the simulated commercial/industrial demand is not forecasted to grow then a capacity investment can be avoided not just deferred. This means the BESS is economic for any capacity investment that costs more than $135,000 (assuming a commercial agreement is in place between the BESS owner and the C&I customer). Again, there is a dollar for dollar increase in the shortfall, and the value of avoided investment required, for higher BESS costs.

Maximise utilisation

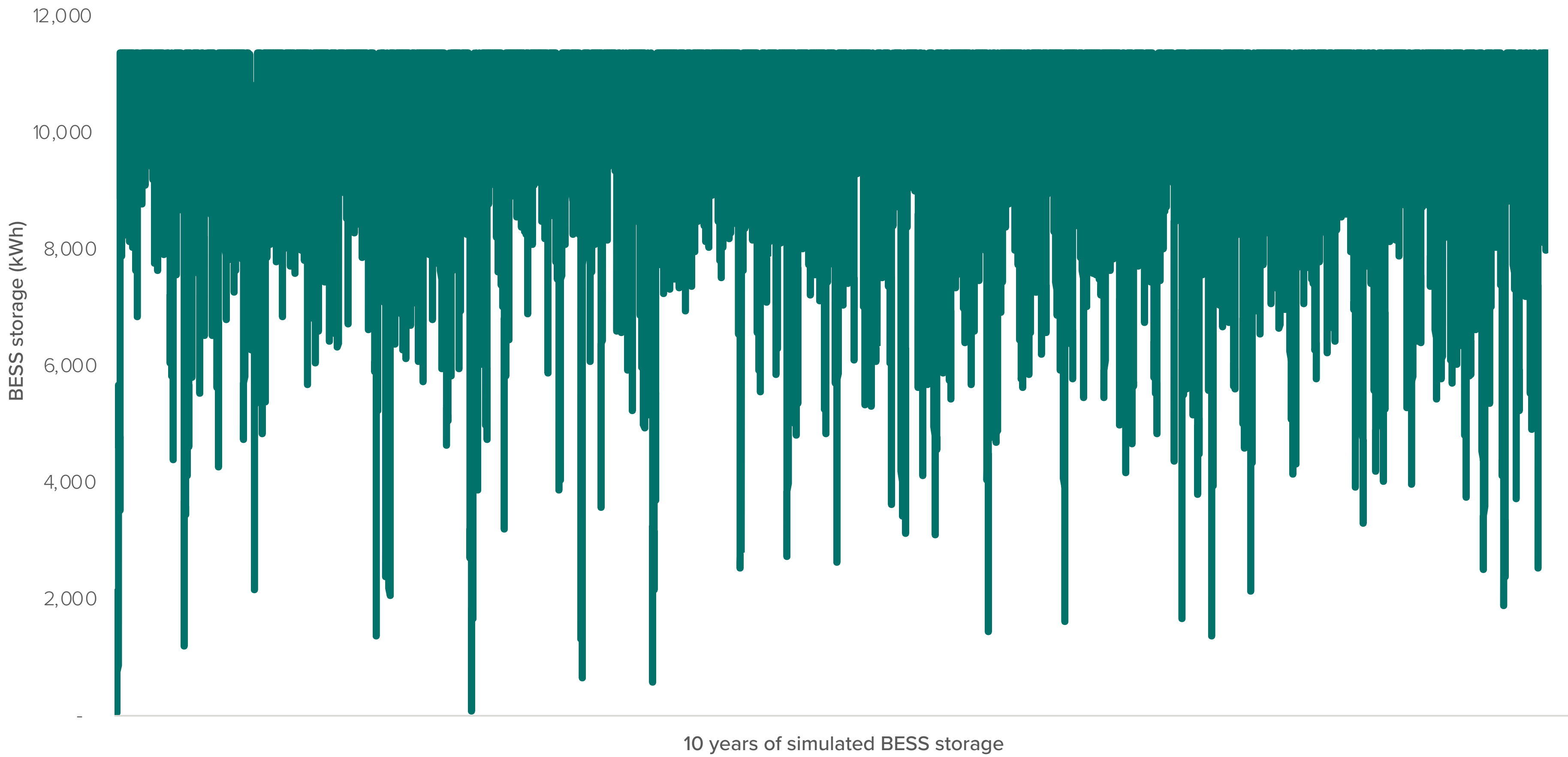
The second commercial/industrial scenario is a varying 24/7 demand. The demand varies around an average consumption with a one period autocorrelation, i.e. the current period load in the simulation influences the next period load. The simulation gives the demand profile shown in Figure 10.

Figure 10: Simulated 24/7 commercial/industrial load - 30 days from 1 July 2033



This demand is well within the capacity limit but is subject to network charges. The objective of this simulation is to see how low the peak demand can be reduced to ensure that this load minimises network charges. However, this modelling proved to be difficult. A feature of the load profile simulated is that it did not have a repeating pattern. Therefore, it varies the energy required to meet the demand each month and even each year. Periods in the simulation where the demand was regularly exceeding capacity and needing battery storage were offset by periods where the demand was consistently lower, but these periods could be weeks or months apart (illustrated in Figure 11). This leads to a large battery storage requirement as the BESS seeks to hold storage while still catering for significant daily volatility. Also from a technical perspective, holding minimum charges for long periods might be challenging for BESS.

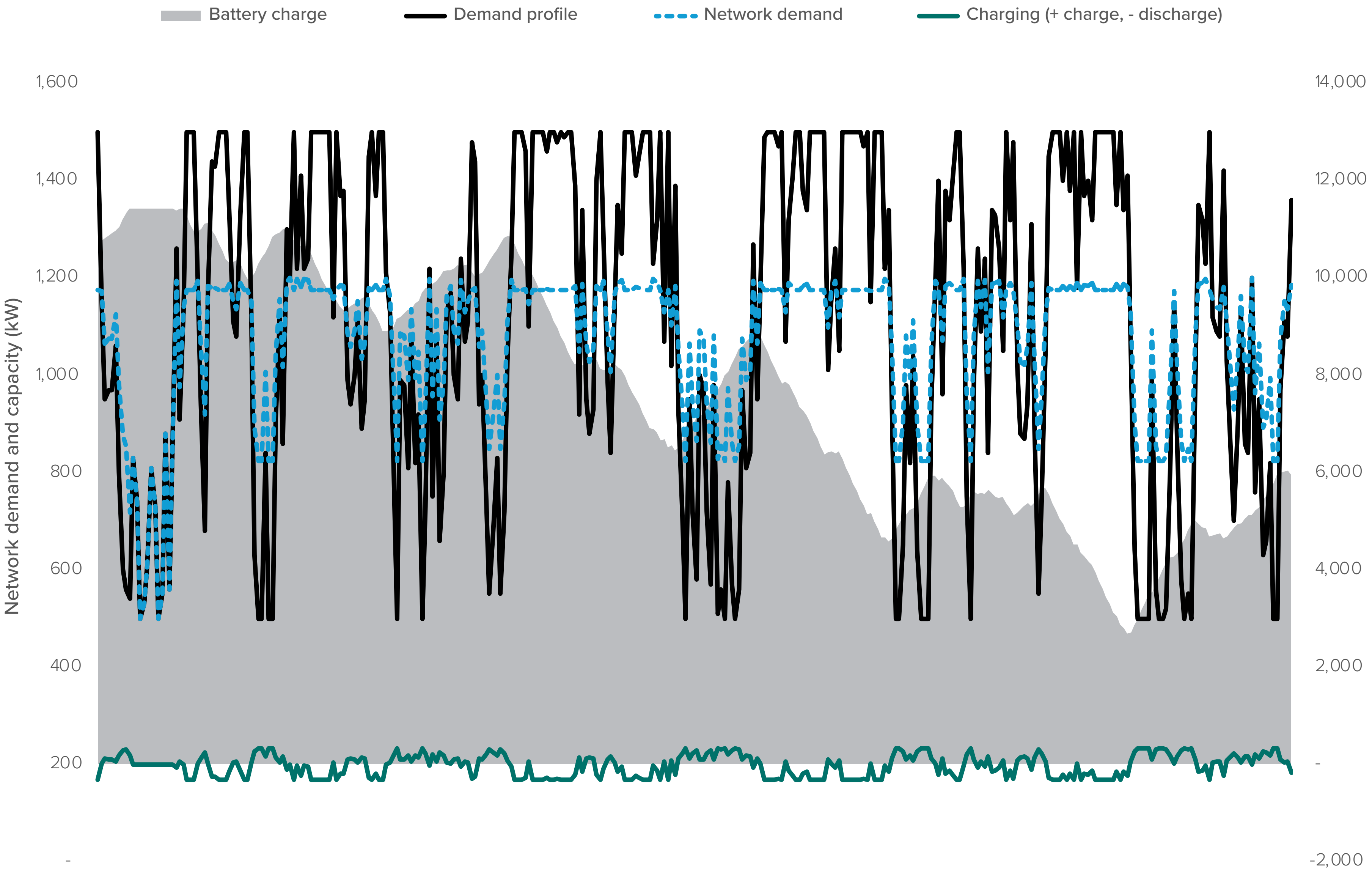
Figure 11: Long-term BESS storage trend with inconsistent industrial load



Generally, using a BESS to manage peak demand is going to work best for repeating demand patterns more like the peak shaving example in the section, Peak shaving and spot exposure. This both reduces the battery size requirements and makes achieving market revenue more likely.

The approach for other scenarios was to run the scenario and derive the value that would have to be obtained from providing a service to another party to justify the investment. However, in this case Sapere found that the BESS is uneconomic for this application. The model could find feasible solutions that would limit the network capacity, but the BESS required in each case was large and got exponentially larger as the utilisation increased. Figure 12 shows a typical period of BESS operation - in this case, network demand is successfully reduced by 300kW but needs a 11.5MWh battery.

Figure 12: Example of a feasible solution for reducing network demand with an inconsistent load



Even if the peak demand were reduced by 1kW then this would need a 3kW inverter (to meet the charging rate) and a 7kWh battery. This would cost a minimum of $2,700 (at grid scale economics). A typical distribution charge rate might be as high as $50/kVA p.a[4]. which would give a ten-year PV of $335. This wouldn't build a 1kW, 1kWh BESS at grid scale economics.

There is no contribution from market revenue in this case because the demand is unpredictable.

Commercial/industrial service conclusion and insights

BESS are physical systems with asset costs that increase significantly with the storage required. There are significant economies of scale with existing network capacity and so network charges are lower than can be achieved by using a BESS. Limiting network charges might be an added benefit but, for a BESS to be economic for network services, it needs to avoid or defer incremental network investment.

The duration of peaks affects the amount of battery storage that is needed to shave a peak and, therefore, shorter peaks are more likely to be economic to avoid than longer ones. This also applies to inconsistent loads over longer durations (weeks, months, or longer) as this requires a BESS to hold storage for long periods, even if day to day peaks are relatively short.

Market revenue can help reduce the costat must be recovered for network services, but commercial/industrial demand can be unpredictable. The more unpredictable demand is the less market revenue can be realised. A BESS might be best optimised in parallel with demand management. If demand management can limit peak durations and make demand more predictable then a BESS may be able to economically avoid incremental network investment.

4 Charge rates could vary significantly across EDBs, other estimates are as high as $150-250 /kVA/yr. This modelling was done before DPP4 determinations.

System operator services

This is the case where a BESS is providing peak support services to the system operator (SO) to manage peak security.

Originally, Sapere had proposed assessing SO services as a real option price cap responding to very high prices (at least $3,000/MWh) on the basis that these strongly aligned to system peaks where SO would be looking for firm generation. However, upon assessing the logic, Sapere have realised that this does not work. If the BESS is allowed to price arbitrage, then it will likely respond to these prices anyway, and if they don't, then the charge costs must have been similarly high simply moving load to potentially a new peak or creating a longer one. This is explained further under the Retailer services section.

Similarly, to support the SO and improve peak security, the BESS would need to meet a certain specification, e.g. be capable of providing 2 hours of capacity within 5 hours notice. To be a service for the SO, there would need to be both a specification of the service and scheduling and dispatch of the service, as there is a chance that the highest peaks don't correspond to high price differences.

Therefore, Sapere have now thought about the SO service more in terms of an ancillary service rather than a response to spot prices. The Authority is progressing a change of ancillary service based on expanding the frequency keeping market and allowing asymmetric operating bands (to allow for higher increases in response at times).[5] Current frequency market prices can't be used to assess the value of the new ancillary service as current frequency prices don't show any scarcity and it's not clear how they would. It also isn't clear yet how a security specification would be applied.

Overall, the modelling approach taken aligns with the ancillary service specification recommended by the CE Forum to the Authority in late 2022 (see **Ara Ake's Winter Peak Innovation Pilot** which was based off this recommendation). This specification was developed in conjunction with the SO and is a credible specification (2 hours of reserve within 5 hours notice). An assessment was then conducted on the revenue that still needs to be recovered by a BESS that meets the specification, in turn, implying a barrier price for the new ancillary service.

Peak energy ancillary service

As a modelling starting point, it is of interest to assess a per MW cost for a service to the SO. Using a 1MW, 2MWh BESS specification, capital cost would range between $800,000 to $1,200,000. The market revenue would be mostly available as this ancillary service should only be required a few times a year, say five, and would reserve BESS capacity for 14 periods (5 hours notice plus 2 hours of availability), leading to a total of 70 periods in a year. As can be seen in Figure 13, there are reliably a few periods a year of high peaks. However, these high peaks do not reliably occur at the same time. They typically occur during winter evenings when there is a severe cold front across New Zealand. Although, peak shortfalls can also occur at more moderate peaks if plant is out of service and there is low contribution from intermittent generation.

5 Potential solutions for peak electricity capacity issues, Decision Paper (EA – July 2024),paragraphs 3.20 and 3.21

Figure 13: Load duration curves (not including transmission losses)

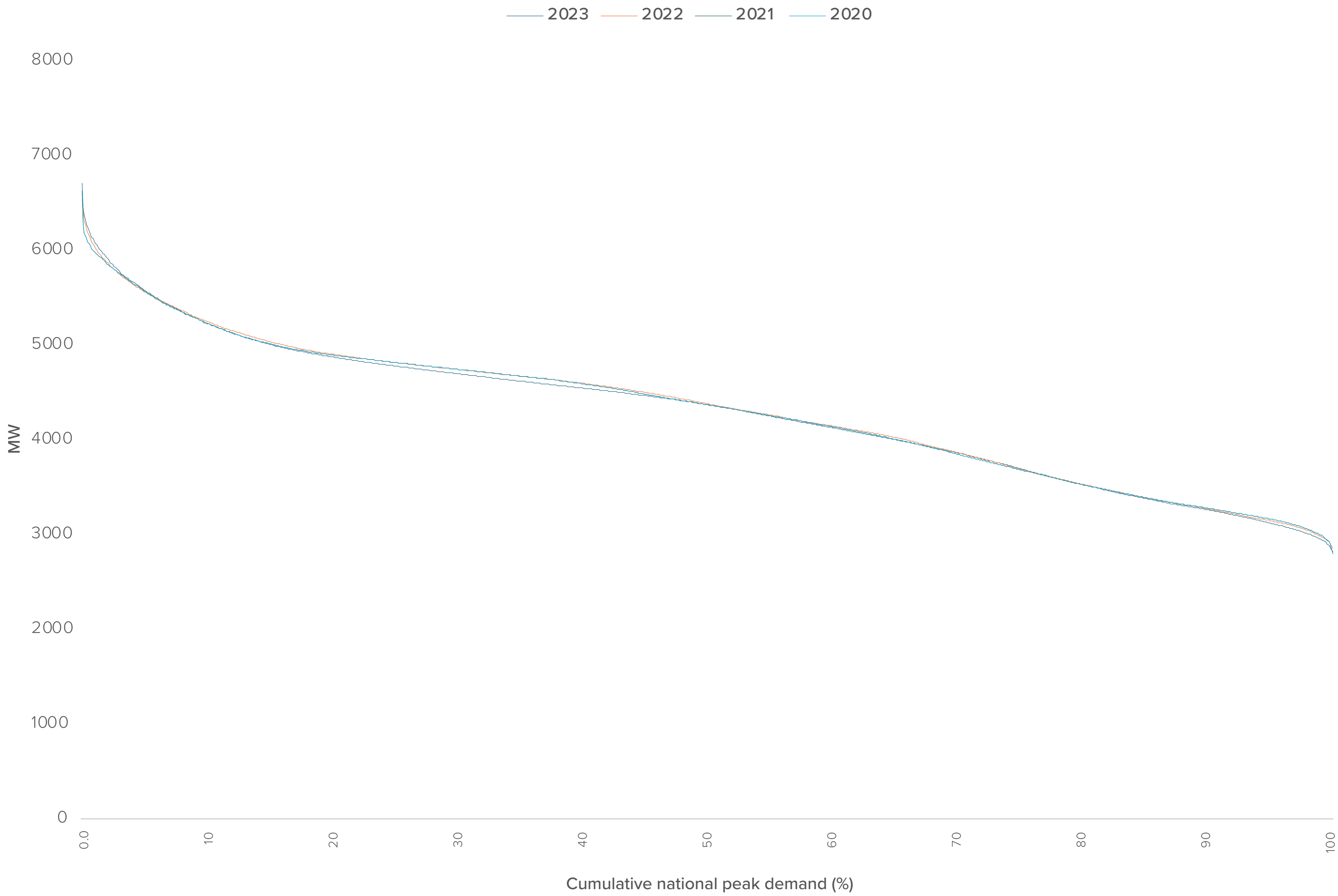
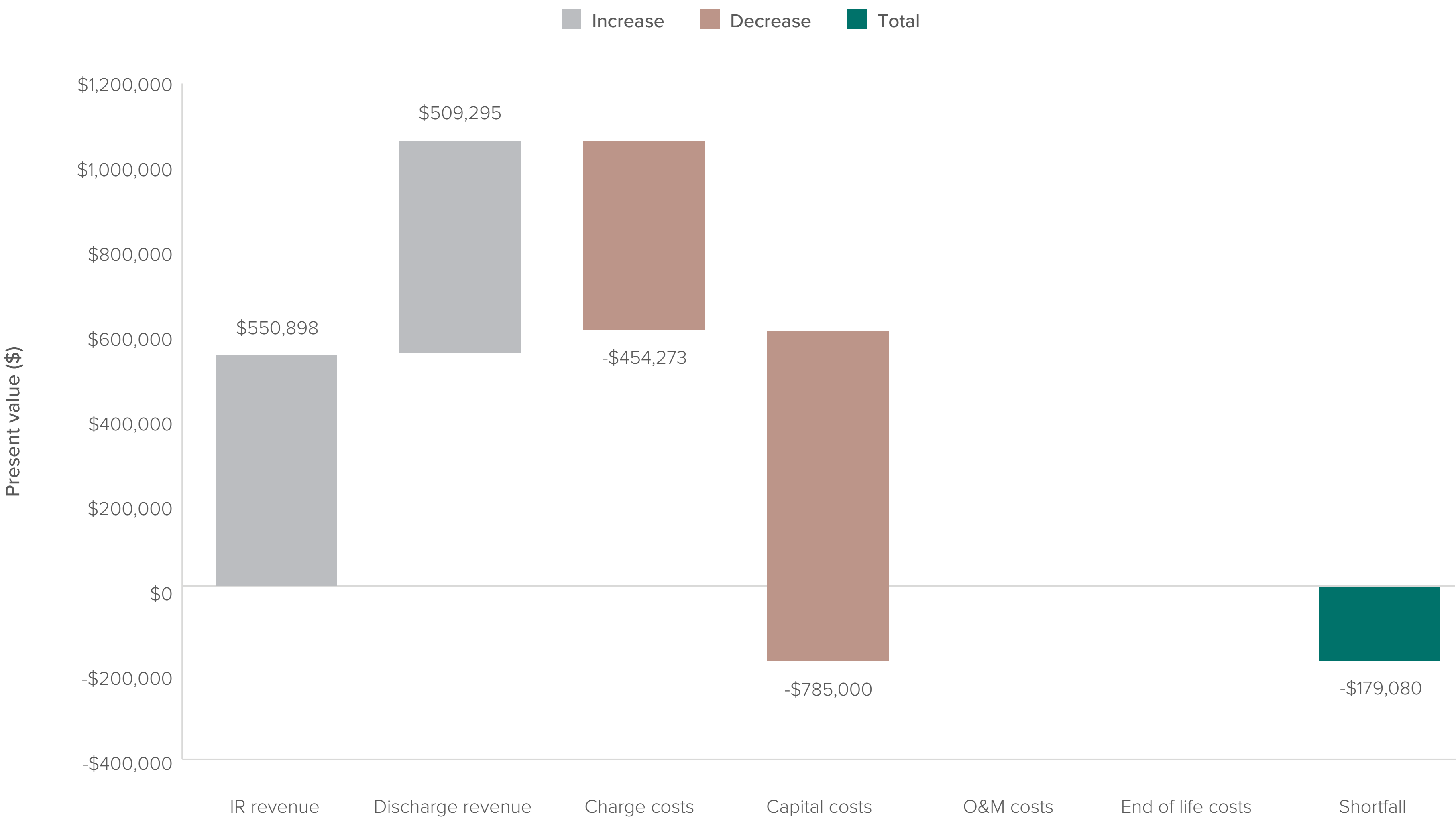


Figure 14: Revenue and costs for SO peak support



The BESS is assessed as achieving the market revenue as shown in Figure 14. The shortfall (for a BESS of capital cost of $800,000) of $179,000 would need an annuity of $26,700 (for 10 years at an 8% discount rate). For ten hours of availability, this would mean an availability price of $2,670/MWh. However, this needs to be earned over what the BESS would have earned anyway. Given that energy prices could well be approaching $10,000/MWh in such a scenario, and because the BESS may have had to charge at similar high prices, then the BESS would need to be priced at up to $12,670/MWh.

For comparison, (if the BESS ended up costing $1m for the same BESS configuration) then the annuity payments shortfall is $58,700. For ten hours of availability then this would mean an availability price of $5,870/MWh. Then the BESS would need to be priced at up to $15,870/MWh.

System operator service conclusions and insights

Due to the problems of forecast prices not necessarily reflecting scarce conditions in time for a BESS, then a BESS isn't necessarily a firm service for the SO if it is responding only to price differences and reserve prices. However, a BESS could meet the ancillary service specification that might be required by the SO.

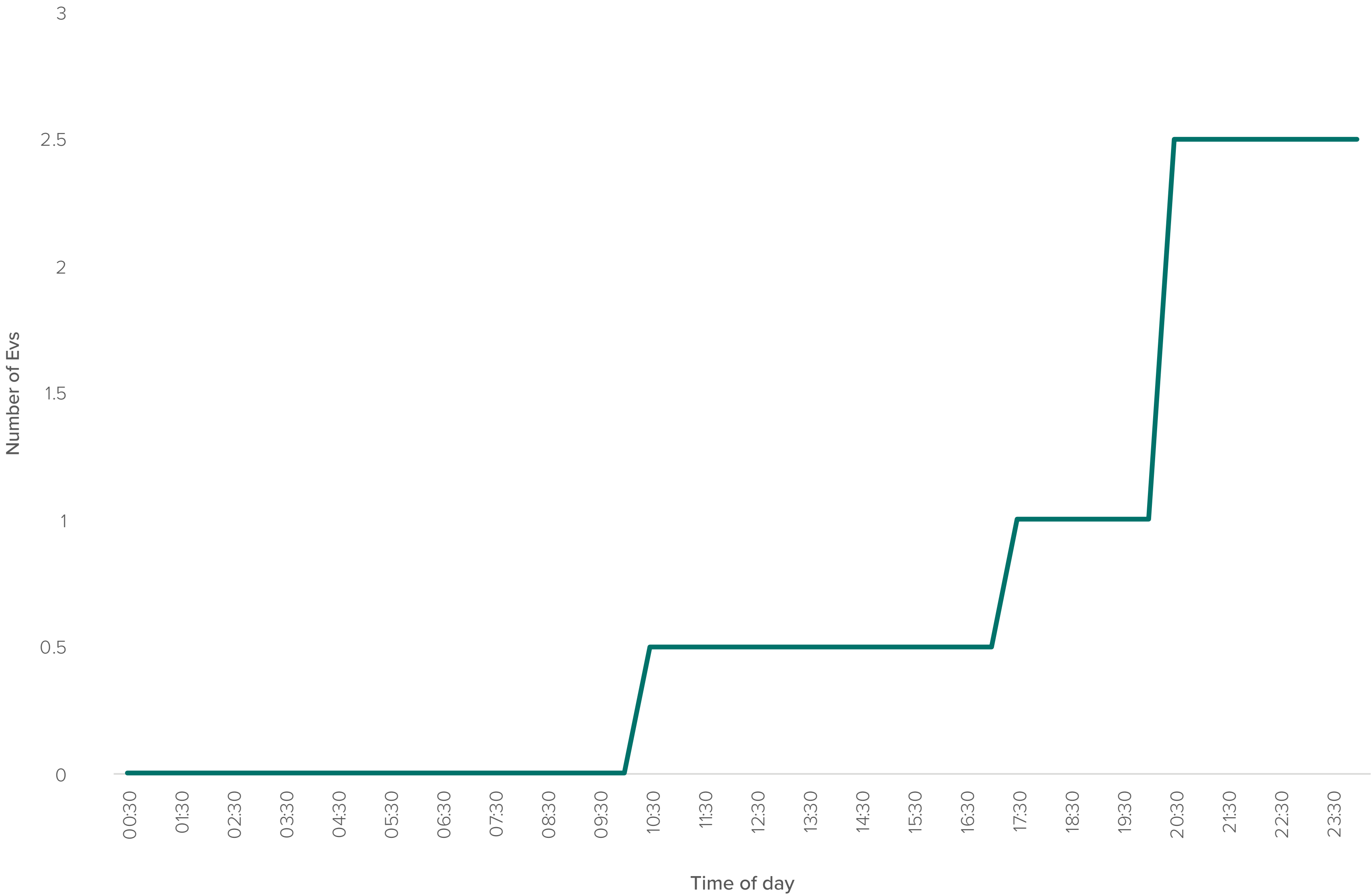
At current Li-ion BESS costs, with market revenue, a Li-ion BESS would need a premium over spot prices of around $3,000/MWh to be economic. However, this would drop dramatically if there were more occasions when the ancillary service was called. Although, in theory, this should only change for a change in expected annual calls rather than just for variability between years. Nevertheless, as more use in the ancillary service would reduce the market revenue available then the availability payment for the BESS would need to be additive to the prevailing spot price.

EV depot service

A transport or construction depot is an example where the conversion to EVs would significantly increase both energy consumption and peak capacity needs. There is a case for using a BESS to maximise the utilisation of existing network capacity, especially where it can avoid network upgrades. The BESS that would be needed would be expensive, but network upgrades could also be very expensive.

Sapere have simulated a case where about 25-30 larger EVs that use 100kW chargers are used predominantly through the day, every day except Sunday. There is some ad-hoc charging through the day and some charging must occur at the end of the day. Most charging starts late in the day and carries on through the night, but this still creates a local peak. There is just enough existing network capacity to manage the energy requirement, but significantly more peak capacity is required. This is a case where the EV depot has managed its fleet to avoid network and market peaks but still has a local connection challenge.

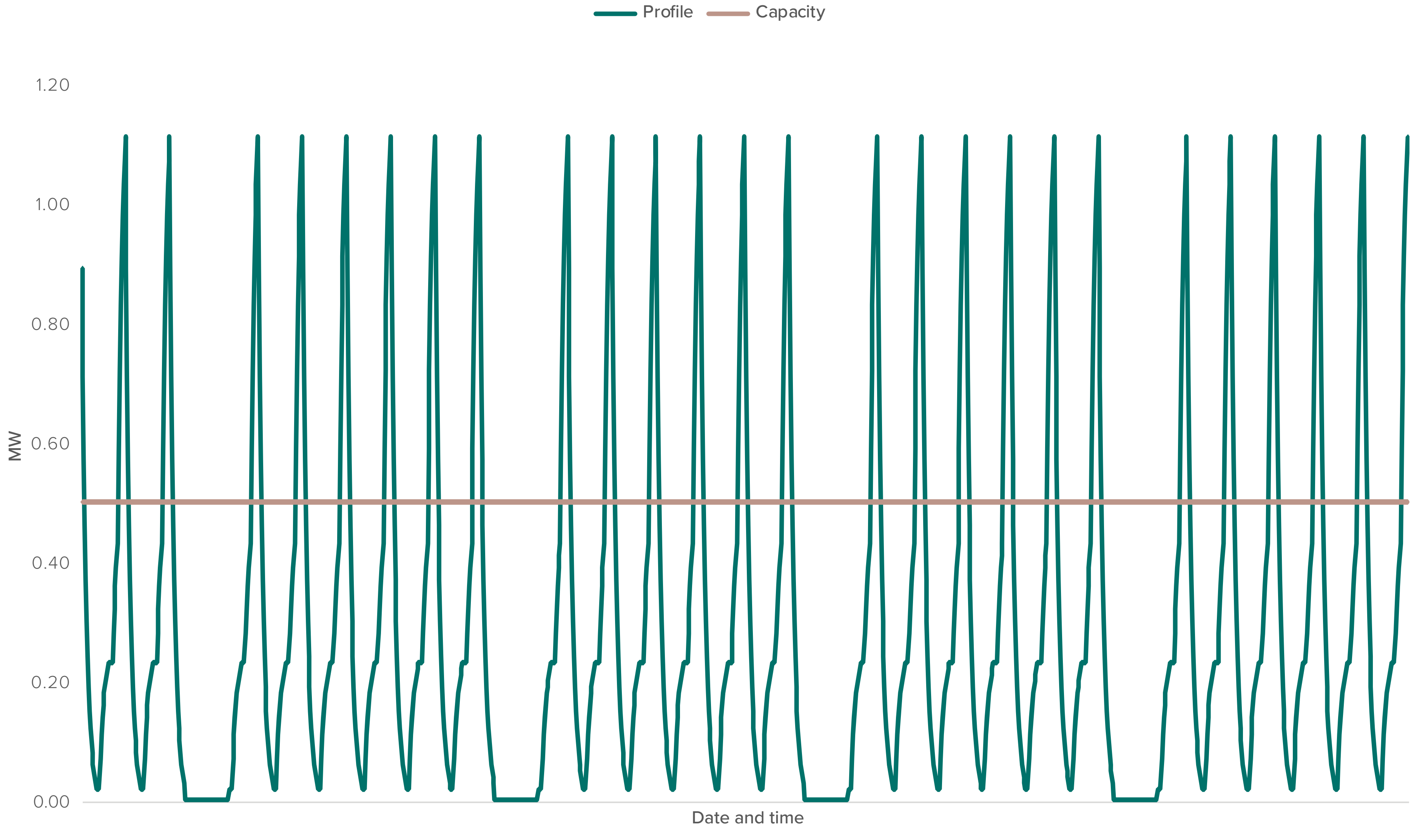
Figure 15: Time when vehicles start charging for EV depot simulation



EV capacity utilisation

The EV depot charging profile simulated is shown in Figure 16.

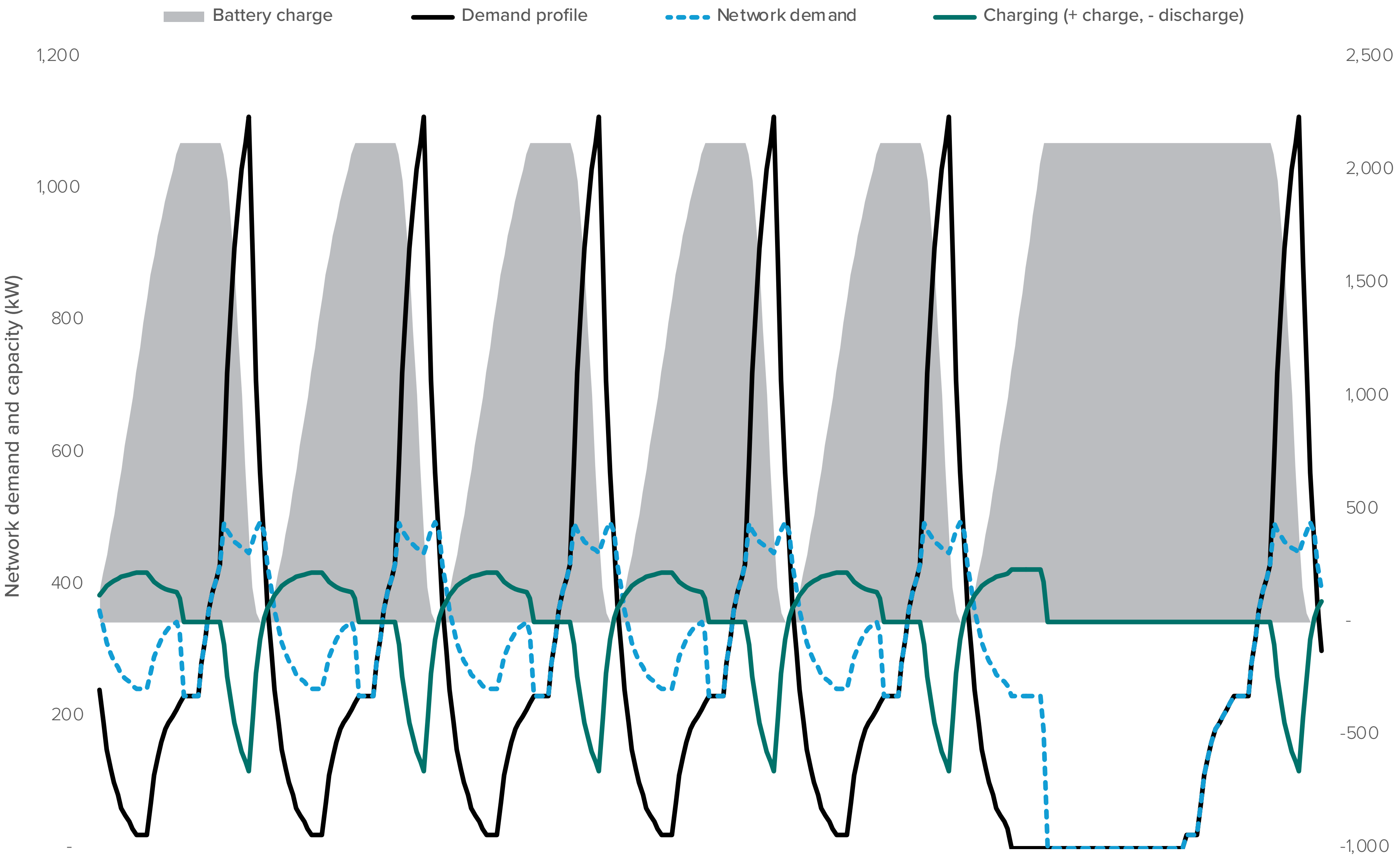
Figure 16: Simulated EV depot charging demand - 30 days over July



The peak demand in this profile occurs at 11:30pm and charging mostly occurs between 7:00pm and 5:00am. This fits quite well with national demand but creates a local peak.

This profile was passed through Sapere's maximise capacity logic and resulted in the BESS operation as shown in Figure 17.

Figure 17: BESS operation over July for simulated EV depot capacity management



The BESS successfully limits the network demand and mitigates an otherwise high peak. However, the BESS is working hard and fully cycles six days a week.

This application uses a relatively large battery but is offsetting a significant peak demand. The required BESS specifications are shown below.

Table 6: BESS specification for peak shaving on simulated EV depot charging load

Characteristic	Value	Unit
Average demand	320	kW
Network capacity limit	500	kW
Maximum BESS power (charging)	230	kW
Maximum BESS power (discharging)	662	kW
BESS energy storage	2,120	kWh
Max BESS charge (or discharge) time	13	hours
BESS utilisation for network service	65	%

The relatively large battery (compared to the power output) leads to a cost of nominally $770,000 for Li-ion (noting however that Li-ion cannot do the maximum charge hours required by this scenario due to thermal constraints). This is a costly configuration for 660kW of network capacity, and a bespoke design is also required, likely resulting in the BESS costs exceeding $1 million.

As the BESS cycles hard, plus being utilised to 65%, the model does not considered market revenue. This leaves the BESS with a high cost to be recovered, however, the BESS is effectively increasing the peak capacity to the EV depot by 130%. The cost to increase the network capacity to this level could well be more than the BESS cost of circa $1 million if upstream reinforcement is necessary. As EV depots can be relatively remote, a BESS could well be effective in the right situation.

EV depot service conclusions and insights

A BESS solution for an EV depot could be very expensive, but the avoided network expansions could be more expensive. The application of a BESS solution to an EV charging depot would be site specific and depend on incremental network costs.

The duty cycle and other specifications may prove too difficult to deploy Li-ion technology. Also, as a sizeable battery is needed, then space might be an issue. This application might well be better suited to a new battery chemistry that can handle heavy cycling, long duty cycles, and that can be stacked to minimise footprint.

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Appendix A: Modelling approach

The modelling presented in this paper was produced from Sapere's BESS value stack model. The specifics to the approach belong to Sapere, but the high-level modelling approach for various value streams is provided below.

Price arbitrage

The price arbitrage value stream looks for the next cycling opportunity, and the best time to charge and discharge, maximising the price differences based on PRSS (Price-Responsive Short Schedule) and the average prices 24 hours out.

This is a function of the BESS specifications of power capacity, energy capacity, charge rates, alongside the opportunity costs which are associated with the cost of battery degradation or implied cycling cost.

Energy arbitrage logic in the model allows for partial charge or discharge, thereby enabling the algorithm to optimise for different battery chemistries, sizes and use cases.

Instantaneous reserve

Instantaneous reserve is always offered, and assumed to be dispatched, when the BESS is not discharging based upon battery ramp rates and when able to reserve 15 minutes of charge (to meet the sustained instantaneous reserve – SIR - specification). BESS can be offered when charging as Interruptible Load (IL).

Reserved capacity

Used for defining battery and inverter spec for meeting peak need and reserving service times for meeting peak (i.e. not allowing price arbitrage), but allowing IR. Used for N-1 capacity.

Maximise utilisation

This logic uses a BESS to try to keep demand below a capacity limit. The logic first roughly assesses whether there is sufficient capacity or whether new capacity is needed (a power connection cannot supply more energy than its maximum utilisation, i.e. capacity (or load) factor = 1, the capacity also needs to be adjusted for charging losses).

After setting up the input capacity (adding an increment if necessary) then there is a pass through of the demand profile that keeps the supply from the notional network within its capacity limit. On this first pass the power and energy is drawn from an imaginary, infinite source. Any time the capacity exceeds demand then the energy is 'repaid' but only to the point that any energy 'borrowed' to that point has been repaid. The maximum energy borrowed from the energy source defines the size of the battery.

The second pass tries to use the battery capacity to meet the demand profile without exceeding the capacity limit. However, this pass can still need to 'borrow' energy from the imaginary energy source. This can happen because the starting charge in the battery isn't sufficient for the first time it is required. This second pass establishes the starting charge. However, there is also a sanity check. If the required starting charge is greater than the battery capacity, then this indicates that that the combined capacity of the battery and the network capacity is insufficient to meet the demand profile in practice.

The final pass checks that the defined battery capacity does meet the demand profile and doesn't exceed the network capacity limit doing so. As well as confirming the battery size and starting charge this run establishes the maximum charge and discharge power, and the minimum and maximum hours of charging and discharging, which provides the design specification for the BESS.

Scheduled discharge

Scheduled discharge has the same modelling logic as for maximising utilisation just with the network capacity limit set higher.

Real option price cap

This isn't a valuable application of BESS. This was thought through when assessing the retailer use case and is more fully explained in the section, Retailer services.

Market revenue only

To establish the counterfactual for other use cases, the case for market revenue only is also established. To show the case for market revenue only, the same BESS configuration as used for the EDB use case is used (see section EDB line services). This uses a 0.6MW inverter capacity and a 1.1MWh battery capacity. This is a good configuration for market revenue as it picks up single period price differences, which are the highest, and still has capacity for IR. The relatively small battery keeps the capital cost low.

The market revenue shortfall for this BESS configuration is $100k i.e. the BESS does not break even over its lifetime.

For use cases that require relatively larger battery sizes (i.e. multiple hours of charge and/or discharge time) then relatively small extra market revenue will be achieved while battery costs will be a lot higher. Therefore, market revenue will make a much smaller contribution to such use cases (which suggests a larger shortfall).

Importantly, with respect to the recently or soon-to-be commissioned gentailer BESS installations, other value streams to them such as exposure to reserves are obviously not captured here.

For completeness, operations and maintenance (O&M) and end of life costs have been included in this calculation. For the subsequent use case assessments, both the BESS and an alternative investment have O&M costs. To directly compare upfront capital costs, the revenue and cost comparisons don't include O&M costs as these are assumed to cancel out to a very small number.

Retailer services

This work has concluded that BESS cannot really provide a hedging option to retailers beyond its natural market revenue contribution. Sapere had considered whether a BESS could provide a real call option for a portfolio. However, a BESS cannot provide a complete equivalent to an option call.

The first reason that BESS isn't equivalent to an option call is because a BESS doesn't provide a firm call option. The BESS mostly resembles what is known as an American call option, but it is a more limited form of American option. American options can be called at any time up to, and including, the expiry date for each posted price. This makes American options useful for peaking loads that might coincide with very high prices. For a standard American option, there is no limit on the number of times the strike can be called, although a limit could be a bespoke term. A BESS can only be 'struck' for as many periods as it has charge for. Therefore, it is a limited option.

The second reason that a BESS doesn't provide a firm option is, to produce when prices are very high, the BESS must have sufficient charge to do so. Even if the BESS has enough capacity, it must be charged by the time it is required. A call option operates with perfect foresight - it can be called retrospectively based on actual prices. For the BESS to be producing, the high price must be forecasted or predicted. Given that the highest price spikes may not be forecasted or may occur after a period of high prices that discharges the BESS, then the BESS may not produce during these price spikes.[6]

The third reason that a BESS is not a firm call option is because the premium potentially increases when the BESS is called. Figure 6 shows the theoretical basis for a cap option. A cap option pays back the buyer for differences in prices that exceed a strike price. The value of the cap is the expected value of the settlements plus a risk premium. This can also be expressed as the equivalent floor option that would have the same expected settlements. Figure 6 shows that the fair price for the cap option of a given strike price, once adjusted for risk, shouldn't exceed the white area below an equivalent floor price.

EDB services conclusions and insights

BESS is likely to be economic in the specific scenario simulated for this exercise. The BESS was economic because relatively spiky peaks grew at 1% p.a. compounding. The spiky peaks and low growth meant that a reasonable proportion of extra power was needed but not much energy. This kept the battery relatively small and capital costs low. This also led to a BESS specification suited to maximise market revenue. If the peaks had longer durations and/or growth was much faster, then a larger battery would have been required, leading to much higher capital costs. Longer duration peaks would also lead to higher capital costs but not proportionally more market revenue.

Consider that, if electrification is ignored for the moment, the profile and growth modelled is reasonably typical of many EDB feeders. However, the addition of more electric heating and water heating, industrial process heat, and EVs would lead to faster peak growth and/or longer peak durations. These future electrification scenarios

6 The highest price spikes can be highly unpredictable. They are often caused by plant trips, or during periods where market solutions might be finely balanced between offered generation and scarcity prices. In these cases, small changes in market inputs, say higher demand than forecast, can yield unpredicted price spikes.

would challenge BESS economics. However, the level, and especially timing, of electrification throughout distribution networks is highly uncertain.

This leads to considering whether the value of BESS may not be so much as a long-term solution for specific situations but more as a general supply of short-term solutions that create optionality. Investing in powerlines in case demand growth occurs, that doesn't then eventuate, would lift total costs considerably. While there are also costs in redeploying BESS, they can be redeployed. Designing them to be easily redeployed adds costs but these costs should be relatively low compared to significant excess network capacity. A fleet of configurable BESS that can be redeployed could cater for feeders that are facing capacity issues but where the timing and nature of future electrification is highly uncertain. Running a coordinated fleet would increase the utilisation of the BESS and delaying network investments until there is more certainty about future demand would be highly valuable.

EV depot service conclusions and insights

A BESS solution for an EV depot could be very expensive, but the avoided network expansions could be more expensive. The application of a BESS solution to an EV charging depot would be site specific and depend on incremental network costs.

The duty cycle and other specifications may prove too difficult to deploy Li-ion technology. Also, as a sizeable battery is needed, then space might be an issue. This application might well be better suited to a new battery chemistry that can handle heavy cycling, long duty cycles, and that can be stacked to minimise footprint.

System operator service conclusions and insights

Due to the problems of forecast prices not necessarily reflecting scarce conditions in time for a BESS, then a BESS isn't necessarily a firm service for the SO if it is responding only to price differences and reserve prices. However, a BESS could meet the ancillary service specification that might be required by the SO.

At current Li-ion BESS costs, with market revenue, a Li-ion BESS would need a premium over spot prices of around $3,000/MWh to be economic. However, this would drop dramatically if there were more occasions when the ancillary service was called. Although, in theory, this should only change for a change in expected annual calls rather than just for variability between years. Nevertheless, as more use in the ancillary service would reduce the market revenue available then the availability payment for the BESS would need to be additive to the prevailing spot price.

Commercial/industrial service conclusion and insights

BESS are physical systems with asset costs that increase significantly with the storage required. There are significant economies of scale with existing network capacity and so network charges are lower than can be achieved by using a BESS. Limiting network charges might be an added benefit but, for a BESS to be economic for network services, it needs to avoid or defer incremental network investment.

The duration of peaks affects the amount of battery storage that is needed to shave a peak and, therefore, shorter peaks are more likely to be economic to avoid than longer ones. This also applies to inconsistent loads over longer durations (weeks, months, or longer) as this requires a BESS to hold storage for long periods, even if day to day peaks are relatively short.

Market revenue can help reduce the cost that must be recovered for network services, but commercial/industrial demand can be unpredictable. The more unpredictable demand is the less market revenue can be realised. A BESS might be best optimised in parallel with demand management. If demand management can limit peak durations and make demand more predictable then a BESS may be able to economically avoid incremental network investment.

Appendix B: Modelling assumptions

Table 7: Summary of modelling assumptions

Assumption	Value	Source
Round trip efficiency	85%	Ara Ake battery report
One way efficiency	92%	Evenly split between charge and discharge
Modelling time period	0.5 hours	Aligned with NZ electricity market (NZEM) trading periods
Li-ion min charge hours	1 hour	Ara Ake battery report
Li-ion max charge hours	5 hours	Ara Ake battery report
Li-ion per kW cost	$150/kW	Ara Ake battery report
Li-ion per kWh cost	$310/kWh	Ara Ake battery report
Investment life	10 years	Conservative choice well within battery life
Discount rate (BESS investment)	8%	Estimate based on previous modelling
Discount rate (network investment)	6%	Estimate based on previous modelling

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