

Economic analysis for centralized battery energy storage system with reused battery from EV in Australia

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Abstract. With battery energy storage technology development, the centralized battery energy storage system (CBESS) has a broad prospect in developing electricity. In the meantime, the retired lithium-ion batteries from electric vehicles (EV) offer a new option for battery energy storage systems (BESS). This paper studies the centralized reused battery energy storage system (CRBESS) in South Australia by replacing the new lithium-ion batteries with lithium-ion second-life batteries (SLB) and evaluating the economic benefits with economic indicators as net present value (NPV), discounted payback period (DPBP), Internal rate of return (IRR) to depict a comprehensive understanding of the development potential of the CRBESS with the lithium-ion SLB as the energy storage system. This paper proposes a calculation method of frequency control ancillary services (FCAS) revenue referring to market share rate (MSR) when building the economic model. Moreover, the residual value of lithium-ion batteries is considered. This paper uses the economic model to calculate the profitability and development potential of CRBESS. From an economic perspective, the superiority and feasibility of CRBESS compared with CBESS were analyzed.

1 Introduction & Context

The global energy storage market is developing rapidly. According to a forecast, by 2022, the energy storage market's annual sales can reach over US\$26 billion, with a compound annual growth rate of 46.5%[1]. Another analysis predicts that its growth may be more gradual but still firm. This analysis signifies that by 2025, the global energy storage market will grow at a compound annual growth rate of 16%, and annual sales will reach US\$7 billion[2]. Globally, energy storage capacity increased by 2.9GW in 2019, down nearly 30% from 2018, marking the global energy storage market's first contraction in a decade[3].

Battery energy storage is a promising energy storage technology in Australia. According to the Smart Energy Council's forecast report on the Australian energy storage market, Australia will add 1GW to 3GW of battery energy storage systems by 2020[4].

The rapid development of battery energy storage is inseparable from decreased cost and improved technology performance, especially in lithium-ion batteries. Meanwhile, benefiting

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from the rapid growth of electric vehicle technology, lithium-ion batteries' quantity and manufacturing process have been significantly increased. Transferring lithium-ion batteries caused by overproduction in manufacturing or retired lithium-ion batteries from electric vehicles to grid-scale applications has become a new choice. The retired lithium-ion SLB of electric vehicles has a lower cost than new batteries[5, 6]. Generally, when a new battery's capacity degrades to 70-80%, it cannot meet the requirements of electric vehicles[7]. These batteries can be returned to the market as SLB after they have been repaired and passed a performance test series. The lithium-ion SLB can fully meet the requirements of the battery energy storage system[8].

In 2019, electric vehicles' global sales exceeded 2.1 million, bringing the stock of electric vehicles to 7.2 million[9]. In 2020, the first batch of electric vehicle batteries had reached their retirement age, and in the next ten years, the number of retired batteries will increase sharply. By 2030, the SLB capacity from electric vehicles will reach 275GWh[10]. It provides a massive opportunity for battery energy storage. The application of SLB from an electric vehicle to centralized battery energy storage systems conforms to the rapid development trend of the energy storage market in Australia and solves the problem of the use of retired batteries and reduces energy waste. It could also achieve the goal of sustainable development.

Therefore, this paper analyzes the economic benefits of using the lithium-ion SLB from the electric vehicle as a centralized energy storage system in the Australian grid and compares it with the centralized energy storage system with new batteries to understand the potential development of CRBESS in Australia comprehensively. This paper's contributions include: First, a new auxiliary market revenue calculation model is proposed, which combines MCR to make the economic models of CBESS and CRBESS more accurate. The second uses economic indicators NPV, DPBP, and IRR to compare the economic benefits of CBESS and CRBESS and consider the recycling revenue of lithium-ion batteries. Because the residual value of lithium-ion is considerable, it is included in the economic evaluation process. Third, through energy storage configuration optimization, forecast the future development of CRBESS. Fourth, analyze the economic sensitivity of NPV and IRR, and find the economically sensitive factors of CRBESS and CBESS from investment and profit, to improve the economic benefits.

2 Methodology

2.1 Data & Assumptions

Table 1. Technical data assumptions for CBESS and CRBESS.

Variable	CBESS	CRBESS	Unit
Power	100	100	MW
Capacity	100	100	MWh
Design life	20	20	Year
DoD	80 [12-15]	80[6, 20, 21]	%
Lifecycle	3000[12-15]	3000[6, 20, 21]	
Round trip efficiency	95[16,17]	95 [22-25]	%
Annual Degradation Rate	2.8[18]	3.3[26]	%
Capacity reduction rate	0	80	%

The following study details various technical parameters for CBESS. Assume that a CBESS (100MW/100MWh) is built in South Australia with a design life of 20 years. BESS uses lithium-ion batteries because most of the reused batteries from EV are lithium-ion batteries[11]. Compared with CBESS, CRBESS only changed the type of battery, replacing

the new lithium-ion battery with a lithium-ion SLB retired from EV. After the retired battery of an electric vehicle is returned to the factory for repair, the capacity will become 80% of the new battery[19]. Therefore, in CRBESS uses lithium-ion SLB modeling, its capacity reduction rate is 80%. All the technical assumptions for CBESS and CRBESS are listed in Table 1 with references.

2.2 Economic Model

The project's economic benefit significantly affects investors' investment willingness [27], which is also an important indicator to evaluate the development potential of CBESS and CRBESS.

2.2.1 Cost Model

The project's cost model consists of four parts: *initial cost*, *operation and maintenance cost*, *energy loss cost*, and *replacement cost*. The following chapters will introduce the calculation method of each cost in detail.

The project's **initial cost** includes capital cost, power conversion system cost, the balance of plant cost, construction, and commissioning cost. Where C_{ini} is the initial cost of the project (\$), C_{cap} is the cost of BESS in purchasing a direct current (DC) energy storage unit, the unit is (\$/kWh). C_{pcs} is the cost of the power conversion system. Because the connection between BESS and the grid requires rectification and inverter processes, and the PCS includes rectifiers, inverters, and controllers needed for the procedure, PCS cost consists of the cost of packaging in addition to the cost of the above equipment, and the unit is (\$/kW)[28]. C_{bop} is the balance of plant cost, which includes the cost of transformers and other auxiliary equipment, as well as the cost of wiring, the unit is (\$/kW)[29]. $C_{c\&c}$ is the cost of construction and commissioning, includes site design costs, costs related to equipment purchase/transportation, labor costs, the unit is (\$/kWh)[29].

The equation is shown as follow:

$$C_{ini} = C_{cap} \times E + C_{pcs} \times P + C_{bop} \times P + C_{c\&c} \times E \quad (1)$$

The **operation and maintenance costs** include fixed operations and maintenance costs and variable operations and maintenance costs. Where $C_{o\&m}$ is the cost of operation and maintenance (\$), $C_{f_o\&m}$ is the fixed operations and maintenance cost includes the operations and maintenance cost of BESS during the life cycle, which is normalized with the rated power, the unit is (\$/kW). $C_{v_o\&m}$ is the cost of variable operation and maintenance; it includes all costs to operate the BESS, which normalized with the annual energy discharge, the unit is (\$/kWh). Fixed O&M cost includes labor cost, daily operation and maintenance, planned maintenance, and other general costs[28]. Variable O&M cost includes consumables for energy storage and maintenance of large equipment. Few resources provide specific variable O&M cost values[30, 31].

The equation is shown as follow:

$$C_{o\&m} = C_{f_o\&m} \times P + C_{v_o\&m} \times E \quad (2)$$

The **energy loss cost** is the power loss caused by RTE, which could have been sold back to the grid. The equation is shown as follow:

$$C_{loss} = E \times DoD \times (1 - RTE) \times M_{peak} \quad (3)$$

Where C_{loss} is the cost of energy loss (\$), DoD is the value of depth of discharge (%), RTE is the value of round-trip efficiency (%), M_{peak} is the time-of-use (ToU) peak price (\$/kWh).

The **replacement cost** is battery replacement and the PCS's major maintenance to keep the system operational. The equation is shown as follow:

$$C_{re} = C_{cap} \times E + C_{pcs} \times P + C_{c\&c} \times E \tag{4}$$

Considering the time value of money, it is necessary to calculate future costs in the first year. The equation is shown as follows:

$$r = \frac{d-i}{1+i} \tag{5}$$

$$C = \sum_1^n \left(\frac{C_{o\&m}}{1+r} \right)^{t_s} + \sum_1^n \left(\frac{C_{loss}}{1+r} \right)^{t_s} + \sum_1^t \left(\frac{C_{re}}{1+r} \right)^{t_r} + C_{ini} \tag{6}$$

Where C is the total cost of BESS in the design life (\$), d is the nominal discounted rate (%), and i is the inflation rate (%), respectively. r is the real discounted rate. n is the total lifetime of the project (year), t_s is the used time (year), t is the replacement times during the design life (year), t_r is the year of replacement (year).

2.2.2 Revenue model

The revenue model of the project consists of three parts: *energy arbitrage revenue*, *ancillary service revenue*, and *battery recycle revenue*.

The **energy arbitrage** uses the time-of-use electricity prices to earn the difference between charging and discharging, which is discharging in peak price period and charging in off-peak price period[32].

The equation is shown as follows:

$$R_{ea} = (E_{dis} \times M_{peak} - E_{cha} \times M_{off-peak}) \times 365 \tag{7}$$

$$R_{ea} = \left(\begin{matrix} E \times Dod \times RTE \times M_{peak} \\ -E \times Dod \times M_{off-peak} \end{matrix} \right) \times 365 \tag{8}$$

Where R_{ea} is the revenue of energy arbitrage (\$), M_{peak} and $M_{off-peak}$ are the ToU peak price and off-peak price (\$/kWh), respectively. According to the 2020-2025 tariff structure statement published by SA Power Networks, Small Business (<160MWh) tariff structure and charging parameters are shown in Table 2.

Table 2. Tariff structure statement for small business (<160MWh)[33].

	Time	Price	Unit
Peak	5:00pm-9:00pm	0.2253	\$/kWh
Off-peak	All other time	0.1568	\$/kWh

Australian Energy Market Operator (AEMO) uses frequency Control Auxiliary Service (FCAS) to safely and reliably maintain the electric power system's frequency stability. The FCAS benefiting process for BESS can be roughly described as: AEMO predicts the FCAS demand in the next 5 minutes based on the real-time collected data information from supervisory control and data acquisition (SCADA), and then allocates market supply according to the BESS registered capacity with AEMO and the bidding price for ancillary service. BESS is paid according to the number of ancillary services provided and the price of ancillary services. The national electricity market dispatch engine (NEMDE) determines the

clearing price of eight FCAS markets for every dispatch interval, and the FCAS provider will be paid based on this price[34]. The calculation formula of remuneration is as follow:

$$M_{payment} = E_{MW} \times M_{clearing} \div 12 \quad (9)$$

Where the $M_{payment}$ is the payment for FCAS providers (\$), E_{MW} is the amount of capacity enabled by NEMDE (MW), $M_{clearing}$ is the clearing price in the dispatch interval (\$/MW).

Usually, the clearing price unit is \$/MW/hour, but the dispatch interval is 5 minutes, and the FCAS provider will also get paid every 5 minutes[34]. The FCAS provider's payment will be provided by the participant who caused the frequency change[34]. The equation is shown as follow:

$$R_{FCAS} = R_{Freg} + R_{Fcon} \quad (10)$$

Where R_{FCAS} is the revenue of frequency control ancillary services (\$), R_{Freg} is the revenue of Regulation FCAS (\$), R_{Fcon} is the revenue of Contingency FCAS (\$). Assume that the BESS registers all eight FCAS markets. According to the Aurecon report in 2019, a large-scale battery energy storage system generally registers its total charge/discharge capacity in Regulation raise/lower FCAS markets, registers in contingency FCAS markets by following the requirements from AEMO[44]. The calculation of the Contingency FCAS capacity formula is shown below.

$$E_{r-Fcon} = 100 \times \frac{1}{r_D} \times \frac{(\min(F_{dev}, F_{dif}) - F_{dea})}{50} \times P \quad (11)$$

Where E_{r-Fcon} is the registered capacity in Contingency FCAS markets of BESS (MW), r_D is the droop rate (%) whose minimum value is 1.7% for any BESS regardless of its capacity, F_{dev} is the maximum battery charge or discharge frequency deviation, which is 1, F_{dif} is the absolute value of frequency difference between 50Hz and reference frequency, which is 0.5, F_{dea} is the frequency dead band, which is 0.15. The result needs to be rounded down[35].

AEMO purchases FCAS (MW) volume required for each dispatch interval from different FCAS providers, based on their registered capacity and bidding price. Therefore, the profitability of FCAS providers is determined by their market participation and registration capacity.

$$R_{FCAS} = \left(\begin{array}{l} E_{m-regr} \times M_{regr} \times \alpha \\ + E_{m-regl} \times M_{regl} \times \beta \\ + E_{r-conr6s} \times M_{conr6s} \\ + E_{r-conr60s} \times M_{conr60s} \\ + E_{r-conr5min} \times M_{conr5min} \\ + E_{r-conl6s} \times M_{conl6s} \\ + E_{r-conl60s} \times M_{conl60s} \\ + E_{r-conl5min} \times M_{conl5min} \end{array} \right) \div 12 \times 365 \times 24 \times 12 \quad (12)$$

Where E_{m-regr} , E_{m-regl} refer to the regulation raise FCAS market procurement (MW) and the Regulation lower FCAS market procurement (MW).

$E_{r-conr6s}$, $E_{r-conr60s}$, $E_{r-conr5min}$, $E_{r-conl6s}$, $E_{r-conl60s}$, $E_{r-conl5min}$ refer to the registered capacity of BESS in the contingency raise 6s FCAS market, contingency raise 60s FCAS market, contingency raise 5min FCAS market, Contingency lower 6s FCAS market, Contingency lower 60s FCAS market, contingency 5min FCAS market (MW), respectively.

α , β refer to the market share rate in regulation raise/lower FCAS markets (%).

M_{regl} , M_{regh} , M_{conr6s} , $M_{conr60s}$, $M_{conr5min}$, M_{conl6s} , $M_{conl60s}$, $M_{conl5min}$ refer to the average clearing price in eight FCAS markets (\$/MW/hour).

At the end of the use phase, the anode metal can be disassembled and recovered to recover the residual value. The **recycle revenue** equation is shown as follows:

$$R_{recycle} = R_{lithium} + R_{iron} + R_{al} + R_{copper} \quad (13)$$

$$R_{recycle} = \frac{E \times 1000}{D_{battery} \times 1000} \times \left[\begin{array}{l} (W_{lithium} \times M_{lithium}) \\ + (W_{iron} \times M_{iron}) \\ + (W_{al} \times M_{al}) \\ + (W_{copper} \times M_{copper}) \end{array} \right] \quad (14)$$

Where $R_{recycle}$ is the battery recycle revenue (\$), $D_{battery}$ is the battery energy density (kWh/kg), $W_{lithium}$, W_{iron} , W_{al} , W_{copper} are the weight of lithium, iron, aluminum, and copper (kg/ton), respectively. $M_{lithium}$, M_{iron} , M_{al} , M_{copper} are the price of lithium, iron, aluminum, and copper (\$/ton), respectively.

The **total revenue** in the design life equation is shown in equation (16) below where R is the total revenue in the design life (\$).

$$R = \sum_1^n \left[\frac{R_{ea}}{1+r} \right]^{ts} + \sum_1^n \left[\frac{R_{FCAS}}{1+r} \right]^{ts} + \sum_1^t \left\{ \frac{R_{recycle}}{1+r} \right\}^{tr} \quad (15)$$

2.3 Economic index

Economic indicators can analyze economic performance and predict future performance. When investors make project investment decisions to measure the project's economic benefits, there are many economic indicators used to evaluate the project's feasibility.

The **Net present value (NPV)** is the difference between the present value of cash inflow and cash outflow over a period, considering the time value of money and the risk-return of investment. If the NPV is positive, it means that the project's expected benefit is higher than the anticipated cost; if the NPV is negative, it means that the investment will result in a net loss[49]. The equation is shown as follows:

$$NPV_{LS} = -C_{ini} + \sum_1^n \left(\frac{CF_{in} - CF_{out}}{1+r} \right)^{ts} \quad (16)$$

The **discounted payback period (DPBP)** is calculated by discounting the future cash flow to calculate the number of years required to reach the balance of payments from the initial investment. The shorter the discounted payback period, the shorter the time for the project to recover costs. The equation is shown below.

$$DPBP = t_{s0} + \frac{NPV_{ts0}}{CF_{ts1}} \quad (17)$$

Where $DPBP$ is the discounted payback period (year), t_{s0} is the last year with negative NPV, NPV_{ts0} is the discounted cumulative cash flow at the end of t_{s0} (\$), CF_{ts1} is the discounted cash flow in the next year of t_{s0} (\$).

The **internal rate of return (IRR)** is used to estimate the potential investment capacity. It shows the degree of currency depreciation that the project investment income can withstand. A discount rate makes the net present value of all cash flows equal to zero in the discounted cash flow analysis. In general, when the internal rate of return is greater than the actual

discount rate, the project is feasible. The equation is shown below, where *irr* is the internal rate of return (%).

$$NPV = -C_{ini} + \sum_1^n \left(\frac{CF_{in} - CF_{out}}{1 + irr} \right)^{t_s} = 0 \quad (18)$$

2.4 Economic parameters

Table 3 below lists all assumed parameters for economic modeling and analysis. Variable O&M cost is not considered in the following analysis. The life cycle and safety of LiFePO4 are higher, and it is more prevalent in the secondary use market[41]. Therefore, LiFePO4 batteries are the research object in the following analysis.

Table 3. Economic parameters definition [28, 37, 38, 39, 40, 41-44].

Economic parameter	Value	Unit			
Nominal discounted rate	7	%			
Inflation rate	1.97	%			
Real discounted rate	4.7	%			
Market share rate	10	%			
Reg Raise market capacity	130	MW			
Reg Lower market capacity	120	MW			
Peak price	225.3	\$/MWh			
Off-peak price	156.8	\$/MWh			
Reg Raise Price	27.97	\$/MW			
Reg Lower Price	15.06	\$/MW			
Raise 6s Price	11.35	\$/MW			
Raise 60s Price	7.57	\$/MW			
Raise 5min Price	15.49	\$/MW			
Lower 6s Price	0.14	\$/MW			
Lower 60s Price	0.57	\$/MW			
Lower 5min Price	0.37	\$/MW			
Economic parameter	CBESS	CRBESS	Unit		
Capital Cost	250	50	\$/kWh		
Power Conversion System	270	270	\$/kW		
Balance of Plant	99	99	\$/kW		
Construction and Commissioning	100	100	\$/kWh		
O&M Fixed	60	60	\$/kW-year		
O&M Variable	0	0	\$/kWh-year		
Energy Density	0.25	0.14	kWh/kg		
Type of material	Weight	Unit	Price	Unit	Efficiency
Lithium	12	kg/ton	12000	\$/ton	80%
Iron/Steel	432	kg/ton	120	\$/ton	52%
Aluminum	65	kg/ton	1900	\$/ton	42%
Copper	82	kg/ton	7000	\$/ton	90%

3 Results & Discussion

The following section analyzes the economic performance of CBESS and CRBESS in detail under the economic model above.

3.1 Cost composition

According to Figure 1 and Figure 2 below, among the total cost in the design life of CBESS and CRBESS, O&M cost is the highest cost, accounting for 30%-40% of the total cost. The initial cost and replacement cost are close in proportion, accounting for 30% of the total cost. Energy loss cost is the smallest cost item, accounting for only 0.01% of the total cost. After using lithium-ion SLB, the cost of BESS has dropped by 19.63% during the design life. The main reason is that the price of lithium-ion SLB is much lower than that of new batteries. Although the cost has fallen, CRBESS still has a high O&M cost, and its cost proportion has increased significantly.

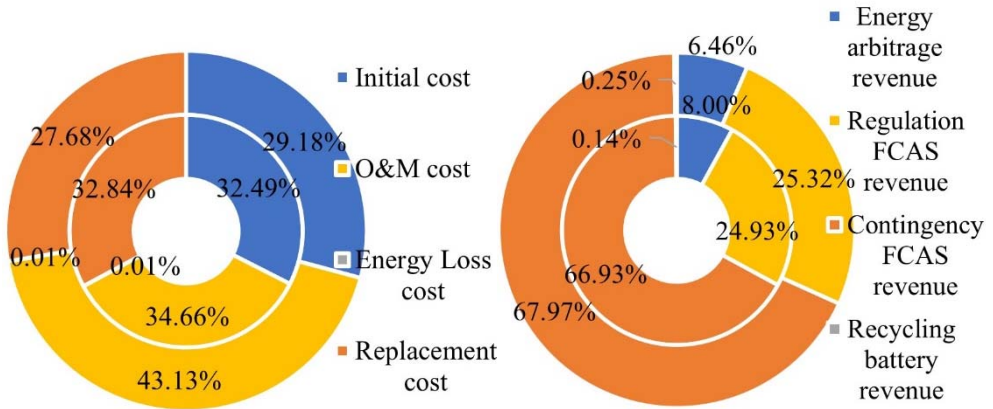


Fig. 1. Percentage of cost for CBESS (inside) vs CRBESS (outside).

Fig. 2. Percentage of Revenue for CBESS (inside) vs CRBESS (outside).

CBESS and CRBESS mainly benefit from FCAS markets, accounting for 90% of the total revenue. The revenue of Contingency FCAS is approximately three times that of Regulation FCAS. Figure 3 and Figure 4, changing the new batteries to SLB slightly reduced the energy arbitrage revenue because of the reduction in battery capacity, but almost not influence BESS's revenue in the design life.

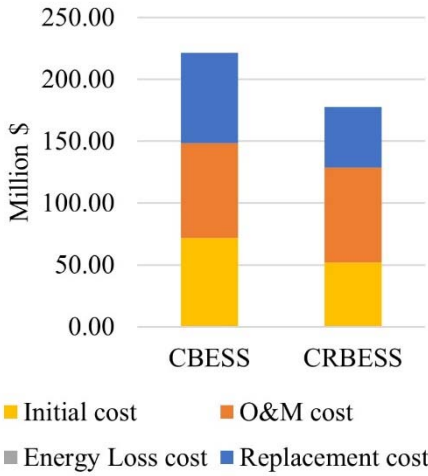


Fig. 3. Cost structure of CBESS vs CRBESS.

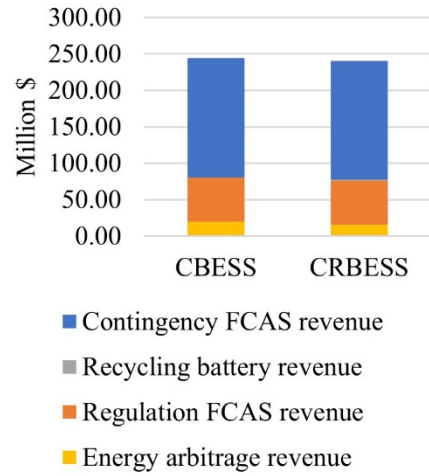


Fig. 4. Revenue structure of CBESS vs CRBESS.

3.2 Economic indicator results

Table 4 below shows the economic indicators calculated for CBESS and CRBESS. According to the results, the NPV in the design life and NPV in the battery lifespan of CBESS and CRBESS are positive, which means that both projects are feasible. However, the NPV in the design life of CRBESS is about three times that of CBESS, which indicates that the expected benefits of CRBESS are much higher than CBESS. The discounted payback period of CRBESS is about 30% shorter than that of CBESS, which means CRBESS can reach the balance of payments faster. The internal rate of return of CRBESS is about two times that of CBESS, which means that CRBESS can withstand a higher currency depreciation, and it has a higher annualized rate for investors. Figure 5 shows the cumulative cash flow and IRR rate of CBESS and CRBESS in the battery lifespan.

Table 4. Economic results of CBESS and CRBESS.

	NPV-dl (million \$)	NPV-ls (million \$)	DPBP (year)	IRR (%)
CBESS	23.23	4.78	6.34	6.78
CRBESS	62.93	22.87	4.41	16.14

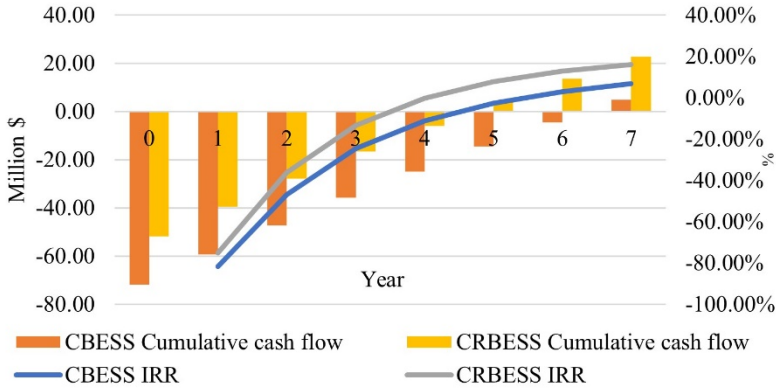


Fig. 5. Cumulative cash flow and IRR of CBESS in battery lifespan.

3.2.1 BESS configuration optimization

This section analyzes the configuration optimization of CBESS and CRBESS based on NPV in battery lifespan, and the results are shown in Figure 6 and Figure 7. When NPV-Is is calculated, the MSR value needs to be estimated. Regulation FCAS Markets grows at a slower and smaller rate than BESS. With the increasing scale of BESS, MSR cannot maintain stable growth. Due to the limitation of market size, the MSR growth rate will decline. However, the MSR growth rate should not change within 50MW because AEMO's procurement in the Regulation FCAS Market is expected to increase by 50MW. According to the analysis results, THE NPV of CBESS will peak at about 200MW/200MWh and then decline continuously. The NPV of CRBESS will decrease with the increase of scale, and investors cannot make profits at about 150MW/150MWh. It is because the increase in income cannot balance the input of costs. CBESS still has an ample increment space in the Australian electricity market, while CRBESS has a small increment space.

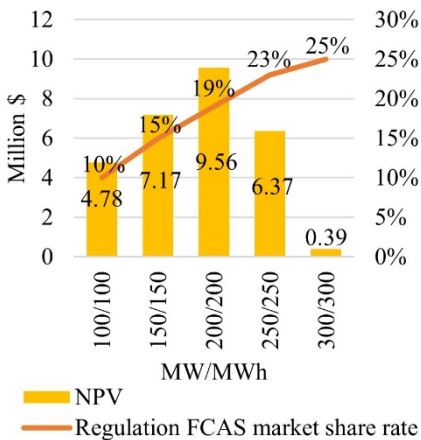


Fig. 6. NPV in battery lifespan with various CBESS scale.

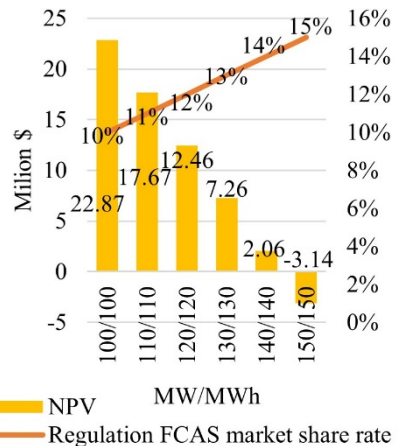


Fig. 7. NPV in battery lifespan with various CRBESS scale.

3.2.2 Sensitivity analysis

Sensitivity analysis is aimed to analyze uncertainty in the economic performance of a project.

Analyze multiple sensitive factors that impact economic indicators, measure their impact on economic indicators, and then judge the project's ability to withstand risks. NPV and IRR are researched in the following study, representing the project's profitability and investment ability.

The sensitivity analysis for NPV in the battery lifespan of CBESS and CRBESS is shown in Figures 8 and 9. According to the results, O&M cost has the most significant influence on BESS'S NPV in battery life. In contrast, raising the FCAS market has a more significant influence on BESS's NPV than that of the Lower FCAS market. Price difference refers to the difference between peak and off-peak prices, affecting BESS's revenue on energy arbitrage. Compared with CBESS, CRBESS profitability was reduced by the price difference and significantly reduced by capital cost.

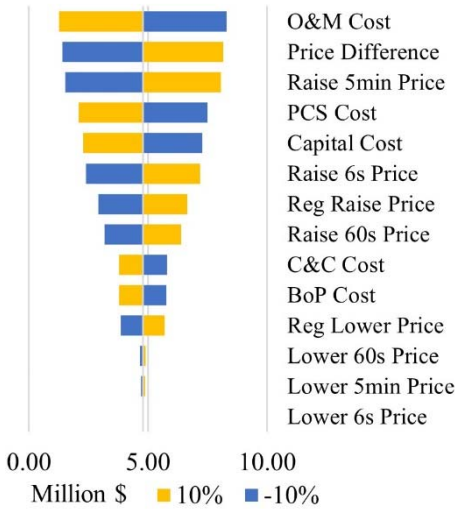


Fig. 8. Sensitivity of CBESS NPV in the battery lifespan.

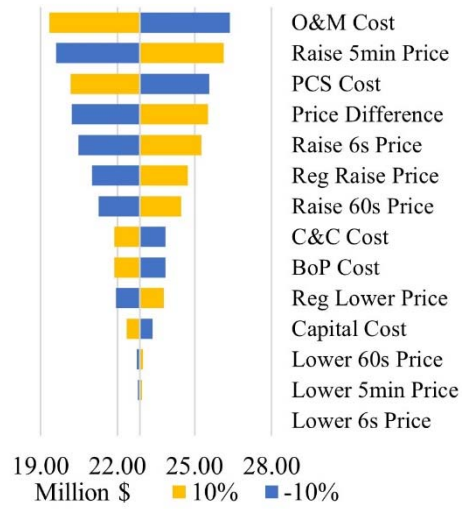


Fig. 9. Sensitivity of CRBESS NPV in the battery lifespan.

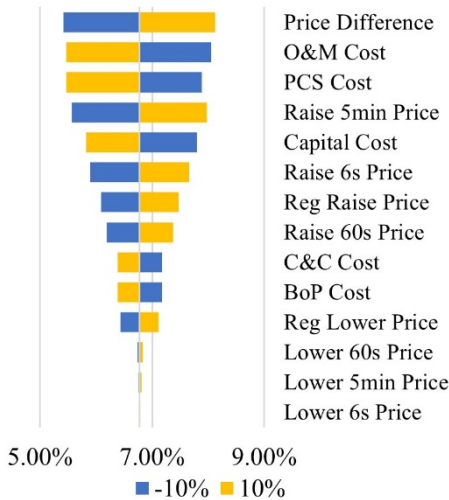


Fig. 10. Sensitivity of CBESS IRR in the battery lifespan.

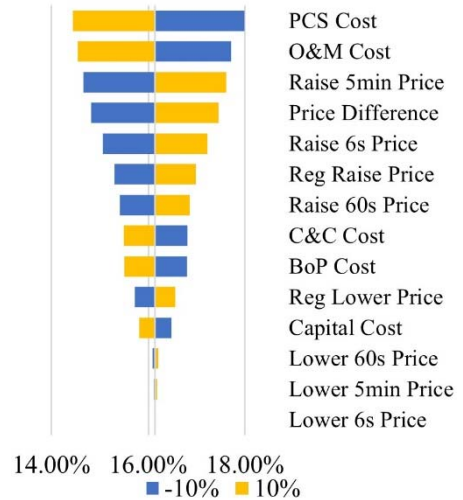


Fig. 11. Sensitivity of CRBESS IRR in the battery lifespan.

The sensitivity analysis for IRR in the battery lifespan of CBESS and CRBESS is shown

in Figures 10 and 11. According to the results, For BESS, the top three factors affecting IRR are price difference, O&M cost, and PCS cost. For CRBESS, the impact of the price difference on IRR is slightly smaller than that of CBESS, but the impact of capital cost on IRR is much more significant than CBESS.

4 Conclusion

The use of lithium-ion SLB from EV to build a centralized battery energy storage system in Australia is found to have economic benefits compared with new batteries. Under the same conditions, The NPV of CRBESS is about three times that of CBESS, the IRR is about two times that of CBESS, and the payback period is about 2/3 of that of CBESS.

From the analysis of cost composition and revenue composition, it can be found that after using lithium-ion SLB, the cost of BESS has dropped by 30%, and the revenue is almost unchanged. Because the lithium-ion SLB is lower than that of new batteries, the technical performance of the battery has not changed significantly. The main difference between the lithium-ion SLB and the new battery is the battery capacity, which mainly affects BESS's revenue in energy arbitrage. However, whether it is CBESS or CRBESS, its energy arbitrage revenue accounts for no more than 10% of the total revenue, which shows that the change in battery capacity has little effect on BESS's revenue.

From BESS configuration optimization results, it is still beneficial to expand the scale of CBESS. The maximum NPV can be reached at 200MW/200MWh, and there is still profit when the scale of CBESS reaches 300MW/300MWh. But CRBESS is the opposite. Expanding the scale of CRBESS will cause the NPV to decline continuously, and it will lose profitability at 150MW/150MWh. It is because CRBESS relatively increases its profitability by reducing costs. However, as the scale of CRBESS increases and the cost increases faster than the profitability rate, CRBESS cannot maintain its high profitability. It shows that the development space of new lithium-ion batteries is larger than that of lithium-ion SLB. It also indicates that CBESS has a more vital ability to cope with the risk of cost increment.

From the sensitivity analysis of project profitability and investment ability, CRBESS reduces the sensitivity of capital cost. However, the sensitive factors O&M cost, price difference, PCS cost, and FCAS market price still significantly impact BESS's profitability and investment ability.

Overall, it is economically feasible to replace the new lithium-ion battery in CBESS with lithium-ion SLB from EV and build CRBESS. However, under the existing technical and market conditions, the expansion of CRBESS will be restricted economically. At present, the best way is to transform the existing CBESS into CRBESS or partially reconstruct it, which can maximize the benefits of BESS. In the future, CRBESS can combine artificial intelligence technology and big data technology to optimize the automatic dispatch deeply and accurately predict market demand and price changes, further improve economic performance.

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