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An Update on the Cost Comparison of Chemical and Thermal Storage for Power Generation in Namibia

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Abstract. Based on a previous study, this paper presents a new cost comparison between chemical and thermal energy storage application in power generation [1]. Despite the methodology of the analysis remaining the same as the previous study, the existing cost input data used in the previous study is updated with new cost input data derived from the latest bids received in the Battery Energy Storage System Project procured by Namibia Power Corporation in 2023. The study was derived from an electricity supply challenge within the Southern African Power Pool (SAPP). The unique mismatch between the supply and demand of electricity has caused extreme price variations during peak and off-peak periods. The objective of the study was to determine a suitable economical solution to counterbalance the effect of the extreme price variations. Following this cost comparison analysis, it can be inferred that thermal energy storage has become increasingly financially viable compared to chemical storage for power generation.

Keywords: Power Generation, Thermal Energy Storage, Chemical Energy Storage, Cost Comparison, Levelised Cost of Electricity (LCOE), Cost Benefit Ratio (CBR), Internal Rate of Return (IRR)

1. Introduction

Mitigating carbon emissions to avoid damage to the environment is considered a high priority if humanity is to sustain itself in the future. In response, climate change mitigation and adaptation policies have revolutionized the energy policy framework for countries worldwide. Renewable energy policies have disincentivised dependence on fossil fuels and fossil fuel-based power generation sources, while conversely renewable energy policies have incentivised the deployment of renewable energy power generation sources [2].

Following the implementation of renewable energy policy and the deployment of renewable energy sources combined with financing restrictions and carbon taxes on fossil fuel-based energy sources, a challenge has emerged within the SAPP region [2].

As shown **Figure 1**, despite the increase in the average cost of electricity, a large deviation in the hourly price of electricity is apparent [3]. The price of electricity (in terms of Day Ahead Market (DAM)) has become increasingly more elastic and unstable, indicating a time varying mismatch between electricity supply and demand within the SAPP region. To address this challenge, new sustainable power generation technologies and financial mechanisms are required to offset the electricity supply deficit to satisfy the electricity demand and to ensure security of electricity supply.

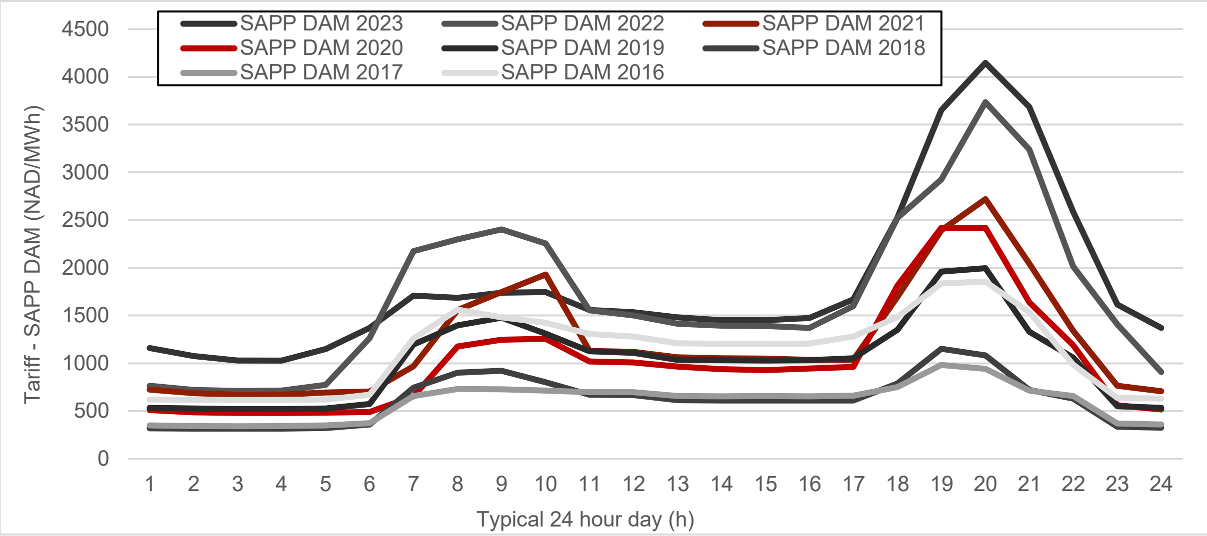

Figure 1. *The escalation in the average cost of electricity for every hour of an ordinary day from 2016 to 2023 in the SAPP [3].*

2. Research Objective, Method, and Implementation

Based on a previous study, this study presents a new cost comparison between chemical and thermal energy storage applications in power generation [1].

Considering the latest market data for chemical storage systems (e.g., lithium-ion batteries), the objective of this study compared to the previous study was to determine if thermal energy storage systems (i.e., molten salt storage systems) have become more cost competitive and more economically efficient than chemical storage systems (i.e., Lithium-ion batteries). To ensure maximum market efficiency, the study was designed to be as simplified as possible to avoid any introduction of factors that may introduce information opacity.

This case study comprised a cost benefit analysis and a Levelised Cost of Electricity (LCOE) analysis. Using the two cost evaluation techniques, the study determined the cost of utilising arbitrage by using the proposed storage energy technologies to shift the dispatch of power generation from off-peak to peak time-of-use periods with the objective to offset the electricity supply deficit. Following this technique, the study compared the cost of repurposing NamPower's Van Eck Thermal Power Station with the option to equip it either with a thermal energy storage system (TESS) (i.e., molten salt storage systems) or a chemical energy storage system (BESS) (i.e., Lithium-ion batteries).

The thermal energy storage technical concept required that the thermal energy storage system be retrofitted to the existing Van Eck Thermal Power Station to be converted into a Carnot battery. The chemical energy storage technical concept required that the Van Eck Power Station be decommissioned and replaced with a lithium-ion battery system.

This case study was a quantitative study and used primary and secondary data. This study used the same methodology as the original study (including the technical and financial model), except the new study used new input data to generate a new set of comparable results [1]. The primary data (i.e., new input data) comprised cost information derived from the latest bids received in the Battery Energy Storage System (BESS) Project procured by Namibia Power Corporation in 2023. Secondary data included SAPP DAM time series; Capital, Operational and Maintenance Cost estimates; technical data from Van Eck Power Station, and technical modelling software [4].

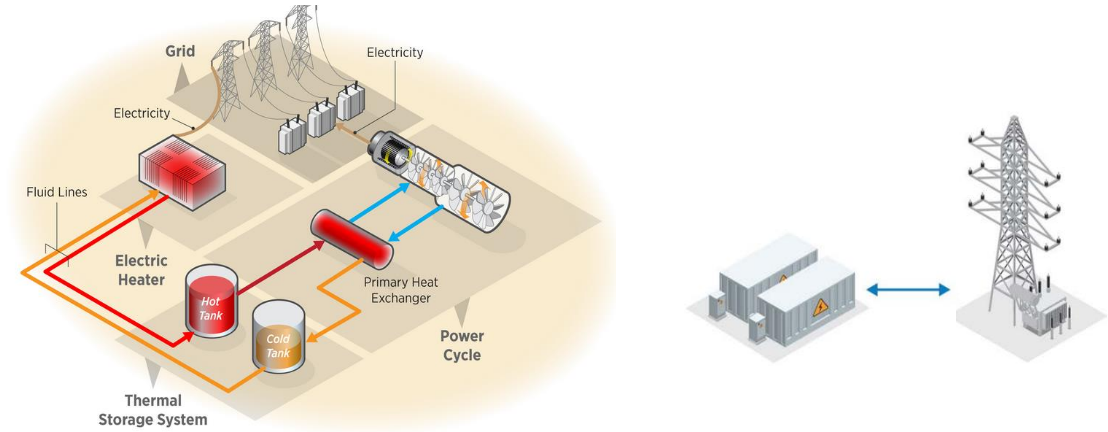

Figure 2. *A visual representation of the model configuration for TESS retrofitted to an existing coal fired power plant (left) and BESS (right) [4].*

The study was split into two parts. With reference to **Figure 2**, the first part of the study included the development of a technical model. The technical model estimated the forecasted power generated (kWh) for both technologies over the project lifetime of 25 years. System Advisor Model (SAM) developed by National Renewal Energy Laboratory (NREL) was used to perform the technical analysis. The second part of the study included a financial model. The financial analysis projected the project cash flow to calculate the cost benefit ratio (CBR), Internal Rate of Return (IRR), and Levelised Cost of Electricity (LCOE) [5], [6].

Furthermore, a sensitivity analysis was performed to understand the optimum power plant configuration by changing technical and financial independent variables (Starting Tariff Multiplier (ratio), Weighted Average Cost of Capital (WACC), storage capacity (h), and generation capacity (MW).

For this analysis, Battery Energy Storage System (BESS – as chemical storage) was considered as the reference plant for the comparison with the Thermal Energy Storage System (TESS) retrofitted to an existing coal-fired power plant. These two scenarios were replicated as closely as possible to validate an accurate comparison.

A summary of the methodology is shown in **Figure 3**. The revenue for both scenarios was optimised by only considering dispatch of both technologies during peak time-of-use periods where the price difference in the arbitrage process was maximum.

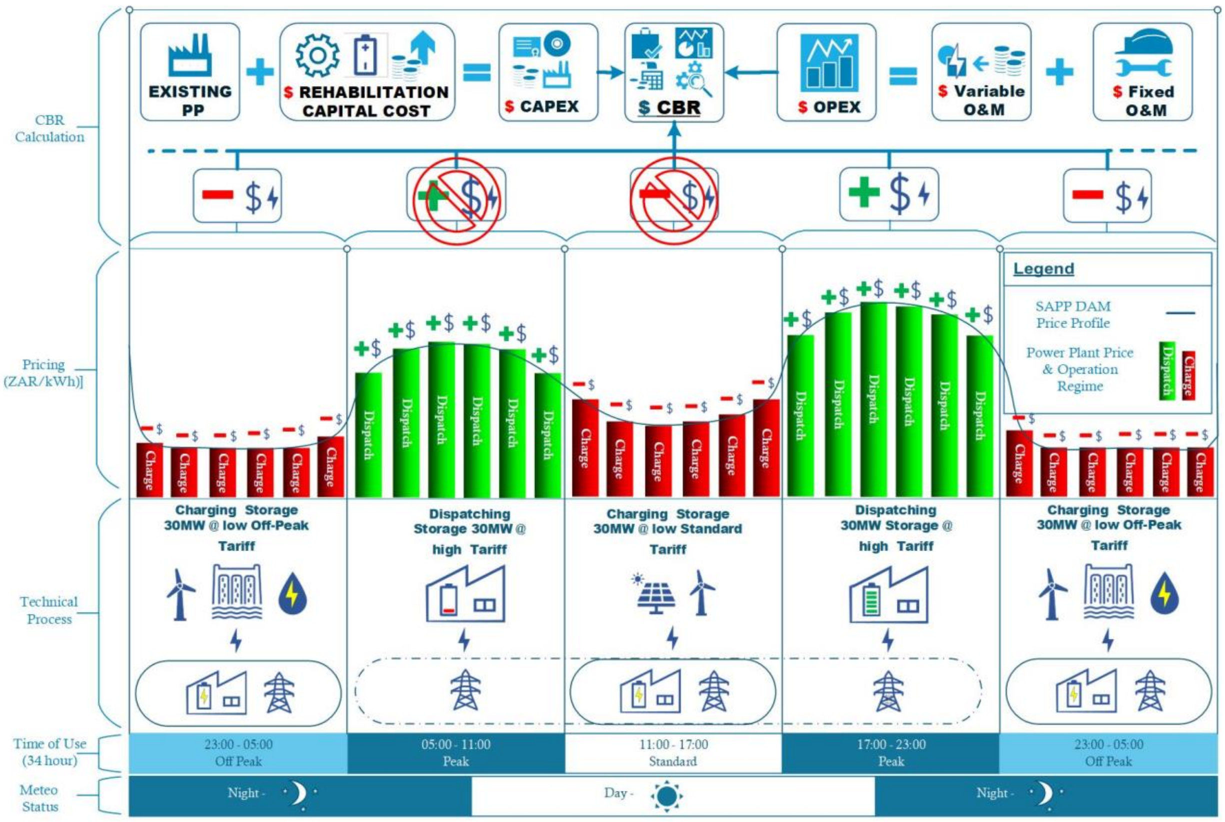

Figure 3. *Case study concept and methodology [1].*

3. Results and Discussion

3.1 Technical Model

For the range of technical independent variables, namely storage capacity and generation capacity, a set of power generation time series were developed over a period of 25 years for both BESS and TESS technologies as illustrated by the example in the figures below.

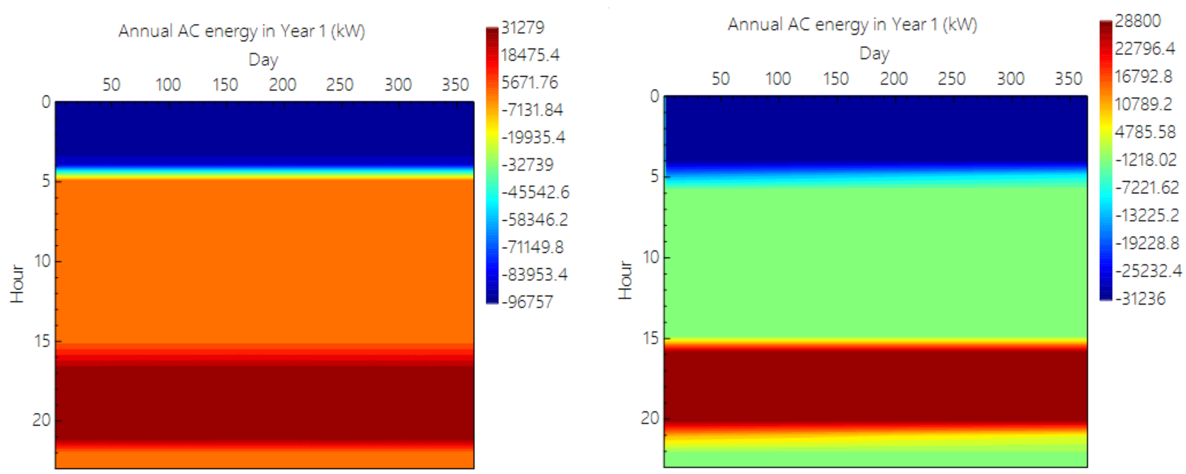

Figure 4. *The power plant storage charging process (blue) and power plant discharging process (red) for a 24-hour day over 365 days of a year for TESS retrofitted to Van Eck coal fired power station(left) and BESS (right) [4].*

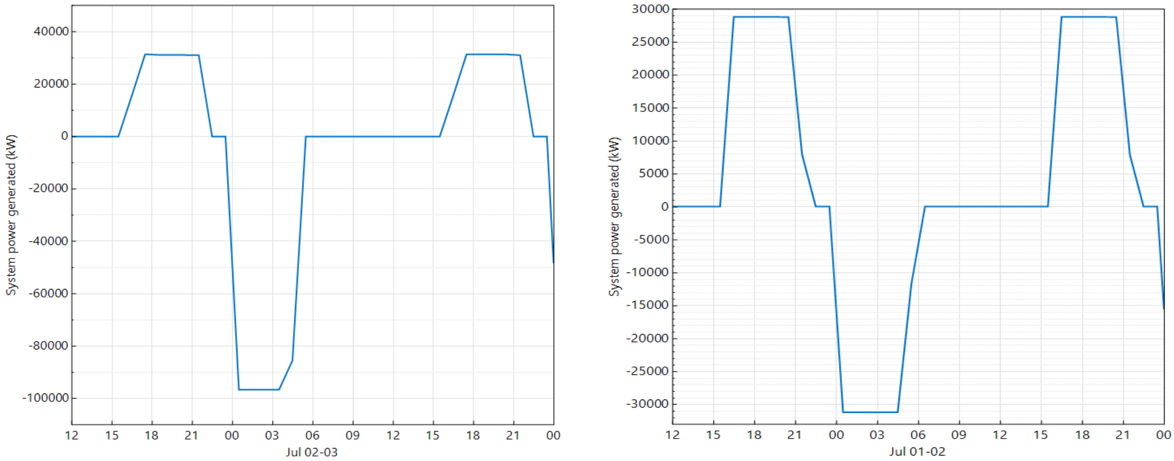

Figure 5. *The dispatch power generation profile (hourly) and electrical consumption profile (hourly) for TESS retrofitted to Van Eck coal fired power plant (left) and BESS (right) [4].*

As shown in **Figure 4** and **Figure 5**, for both technologies, electrical energy (kWh) was stored during off-peak time-of-use periods. Following the storage of electrical energy in the form of chemical energy or thermal energy, the chemical energy and thermal energy was dispatched to generate power during peak time-of-use periods.

Through a series of iterations, the power generation time series was configured to generate electrical energy to match the highest SAPP DAM price of electricity (during peak time-of-use periods) in the SAPP DAM price time series. The power generation regime ensured that maximum revenue was generated for the power generation projects of both technologies.

3.2 Financial Model

Using the SAPP DAM 2022 tariff time series extrapolated over 25-year project lifetime (25 x 219000 data points) with a 5.8% cost escalation per annum and the power generation time series, an annual revenue time series and energy consumption cost time series was generated for the cashflow model as shown in **Figure 6** and **Figure 7**.

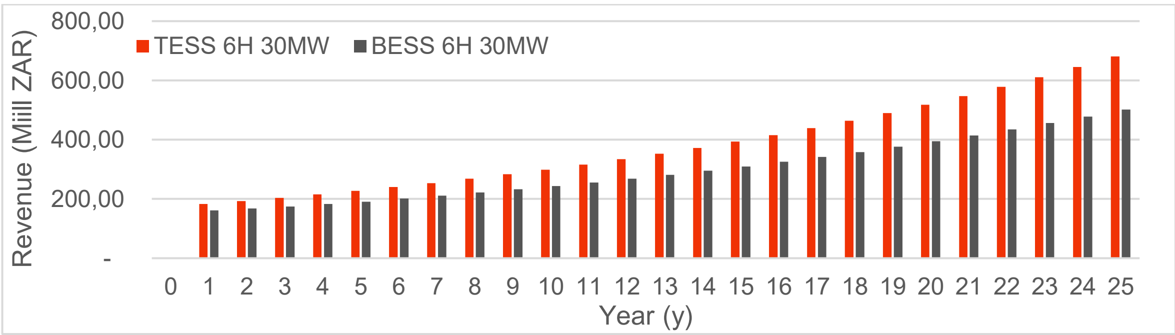

Figure 6. *Annual time series of future value of revenue generation for BESS and TESS retrofitted to Van Eck coal fired power station, Windhoek [1].*

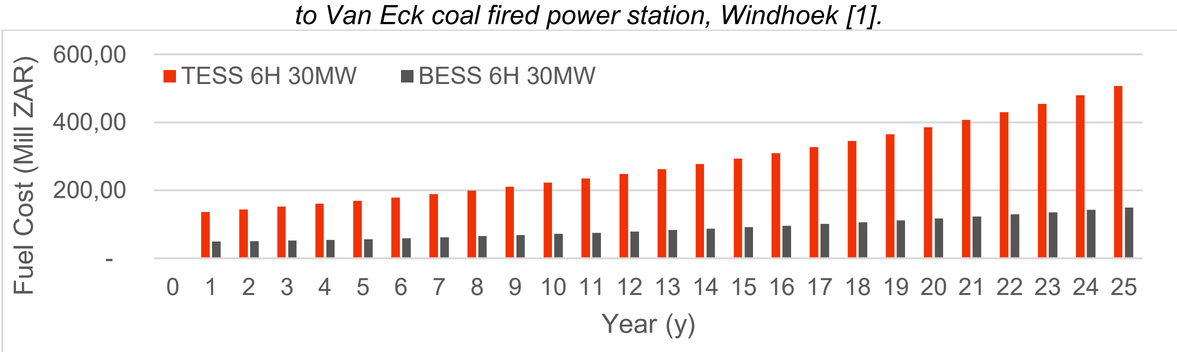

Figure 7. *Annual time series of future value of electrical energy consumption/ fuel cost for BESS and TESS retrofitted to Van Eck coal fired power station, Windhoek [1].*

Based on the previous study, the key assumptions used for the cashflow analysis for each of the scenarios are included in **Table 1**. To ensure information symmetry ("like" for "like") and distinctly comparable results, opacity factors such as variance in country tax regimes (i.e. depreciation tax shields, tax subsidies, etc.) and grants were not considered for the study.

Table 1. *List of key assumptions for cash flow analysis.*

Key Assumption	
Generation Capacity – Base case (MW)	30
Storage Capacity – Base Case (h)	4
Weighted Average Cost of Capital (WACC) – Base Case (%)	12%
Foreign Exchange Rate (USD/ZAR)	18
Escalation Factor - Consumer Price Index (CPI, %)	5.8%
Tax, Grants, etc (NAD)	N/A

An initial set of cash flow iterations revealed that capital cost (i.e. storage capacity) had the most significant effect in terms of value for money for thermal storage technology [7], [8]. To maintain favourable financial results as shown in the previous study, for a function of storage capacity, the base case generation capacity was selected to be 30 MW [1].

Following the sensitivity analysis for the different scenarios for a fixed generation capacity of 30 MW, the results of the dependent variables (CBR, LCOE, IRR) was recorded on a heatmap against the axis of independent variables (Starting Tariff Multiple (Ratio), WACC (%), and storage capacity(h)).

Table 2. *Results of the sensitivity analysis (CBR, LCOE, IRR) for change in technical variables (storage capacity) and financial variables (WACC or Starting Tariff multiple).*

CBR (RATIO) - TESS

No	Name	STARTING TARIFF MULTIPLE (Ratio) 0.95	1	1.1	1.2	WACC (%) 6	9	12	14
1	TESS 4H 30MW	1.15	1.09	0.99	0.91	0.95	1.02	1.09	1.14
2	TESS 6H 30MW	1.20	1.14	1.03	0.95	1.00	1.06	1.14	1.19
3	TESS 8H 30MW	1.40	1.33	1.21	1.11	1.19	1.25	1.33	1.38
4	TESS 10H 30MW	1.45	1.38	1.25	1.15	1.23	1.30	1.38	1.44

**Variation of two variable relative to base case assumptions and parameters*

LCOE (ZAR/MWh) - TESS / **IRR (%) - TESS**

No	Name	WACC (%) 6	9	12	14	STARTING TARIFF MULTIPLE (Ratio) 0.95	1	1.1	1.2
1	TESS 4H 30MW	5750.74	5682.32	5703.13	5759.39	5.90%	8.33%	12.39%	15.90%
2	TESS 6H 30MW	5234.57	5155.39	5153.71	5189.82	2.76%	5.87%	10.57%	14.40%
3	TESS 8H 30MW	5250.41	5122.90	5074.38	5079.93	N/A	N/A	-0.05%	6.57%
4	TESS 10H 30MW	5006.68	4887.94	4844.63	4851.94	N/A	N/A	-5.05%	4.14%

**Variation of two variable relative to base case assumptions and parameters*

CBR (RATIO) - BESS

No	Name	STARTING TARIFF MULTIPLE (Ratio) 0.95	1	1.1	1.2	WACC (%) 6	9	12	14
1	BESS 4H 30MW	1.10	1.04	0.95	0.87	0.70	0.86	1.04	1.18
2	BESS 6H 30MW	1.25	1.18	1.08	0.99	0.80	0.98	1.18	1.34
3	BESS 8H 30MW	1.51	1.44	1.31	1.20	0.97	1.19	1.44	1.62
4	BESS 10H 30MW	2.19	2.08	1.90	1.74	1.37	1.70	2.08	2.37

**Variation of two variable relative to base case assumptions and parameters*

LCOE (ZAR/MWh) - BESS / **IRR (%) - BESS**

No	Name	WACC (%) 6	9	12	14	STARTING TARIFF MULTIPLE (Ratio) 0.95	1	1.1	1.2
1	BESS 4H 30MW	4221.59	4780.53	5420.14	5881.05	10.56%	11.36%	12.88%	14.33%
2	BESS 6H 30MW	4050.36	4628.90	5284.05	5753.41	8.61%	9.38%	10.84%	12.21%
3	BESS 8H 30MW	4153.01	4719.68	5364.93	5828.72	5.62%	6.39%	7.83%	9.16%
4	BESS 10H 30MW	4638.77	5329.47	6121.29	6693.13	0.74%	1.53%	2.94%	4.17%

**Variation of two variable relative to base case assumptions and parameters*

In this scenario, the generation capacity remained fixed while the storage capacity varied. For each sensitivity analysis scenario, either the starting tariff multiple (multiple of escalated SAPP DAM 2022 prices) or the WACC varied in combination with the variation in the storage capacity.

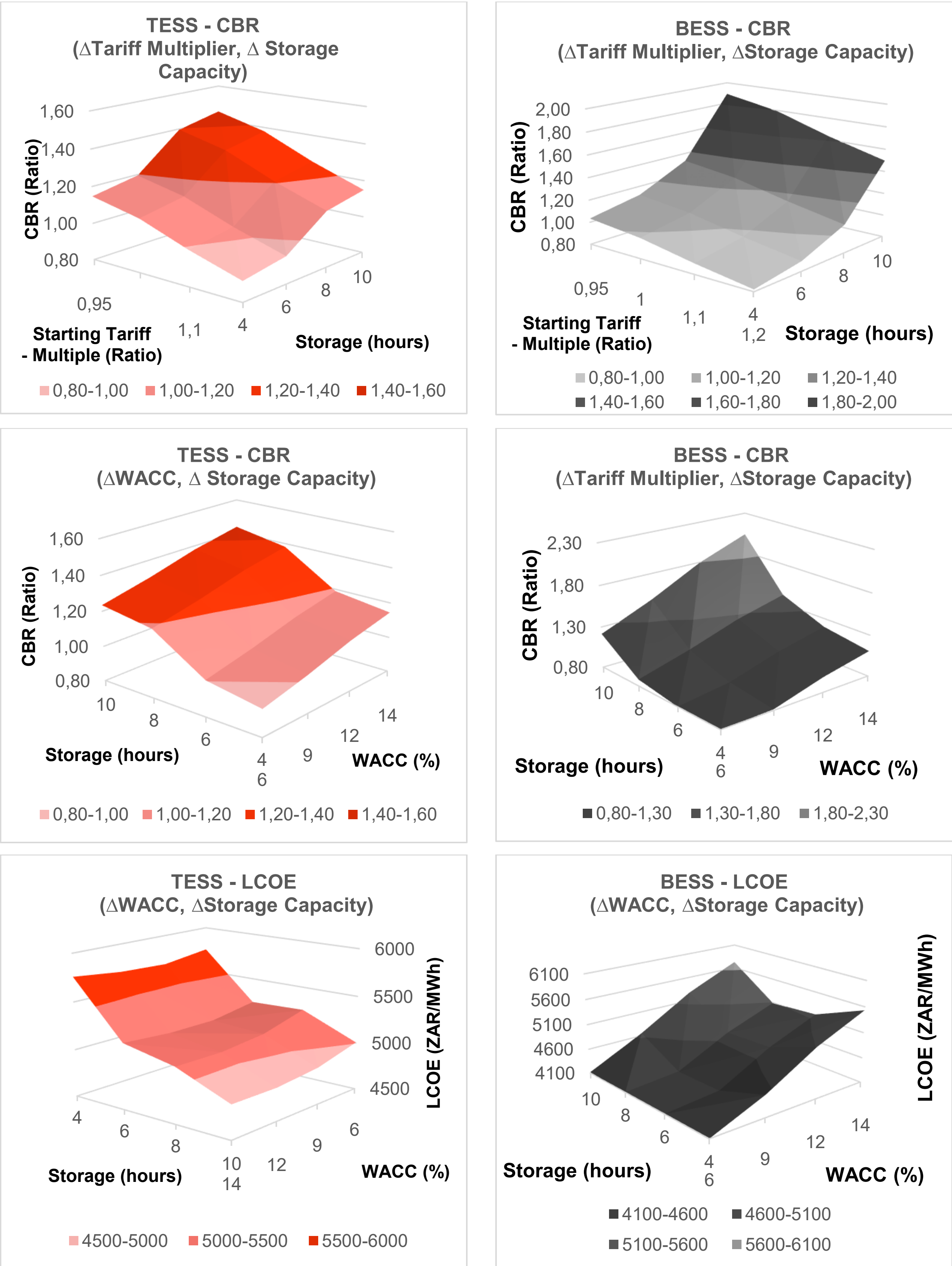

Figure 8. *Three (3) dimensional surfaces illustrating the effect in change of independent variables on the dependent variable from the base case scenario*

In terms of value for money (inferring low CBR) for both technologies, **Figure 8** and **Table 2** shows that CBR is low when the starting tariff is high, WACC is low, and storage capacity is low. The CBR for BESS 4H 30MW is below 1 at a starting tariff multiple of 1.1 (compared to starting tariff multiple of 1 in the previous study). For BESS 4H 30MW, a WACC or IRR of below 11.36% (compared to 12.29% in previous study) is sufficient to generate the cashflow to service the project during a payback period of 25-years. For TESS 4h 30MW, a WACC or IRR of 8.33% is sufficient to generate the cashflow to payback the project cost over the 25-year period. In addition, the CBR for TESS 4h 30MW is below 1 when the starting tariff multiple is 1.1.

If the WACC for thermal storage is less than 8.33% or the starting tariff multiple exceeds 1.1, the CBR will be less than 1 which implies that the TESS 4H 30MW tariff will be more affordable than the forecasted SAPP DAM prices. Changing the storage capacity from TESS 6H 30MW to TESS 4H 30MW, the LCOE increased from 5153.71 ZAR/MWh to 5703.13 ZAR/MWh. Despite the increase in LCOE, the CBR improved in the change from 6-hour to 4-hour storage capacity. This contradiction infers a deficiency in the LCOE standard equation which introduces erroneous results. The LCOE evaluation technique has an inability to quantify the positive influence of dispatched power generation at different time-of-use periods when affordable and competitive market related prices maximise the revenue for power generation projects. Contrary, this positive effect improves the CBR.

Notably, CBR shows an inverse correlation to LCOE as storage capacity increases.

4. Conclusion

Considering the use of market data, the results of this study compared to the previous study showed that for the chemical energy storage systems (lithium-ion battery technology) the internal rate of return (IRR) declined while the cost benefit ratio and levelized cost of electricity (LCOE) increased. This inferred that thermal energy storage retrofitted to an existing coal fired power station had become more financially competitive and economically efficient compared to chemical energy storage.

For changes in the independent variable and fixed storage capacity (generation capacity (MW)), the results showed a similar trend to previous study [1].

In comparing the LCOE and CBR evaluation techniques, this study has exposed the fatal flaw associated with the LCOE evaluation technique to objectively evaluate the value for money of power generation projects. This coincides with previous evaluations of the LCOE technique [9], [10]. The LCOE technique is proven to introduce information opacity arising to the misrepresentation of results. This effect unfairly marginalises other generation technologies and undermines economic efficiency.

With an IRR of 8.33% for thermal energy storage compared to an IRR of 11.36% for chemical energy storage, this study shows that both technologies may require concessional finance or grant funding to compete with other more economically viable power generation sources.

Considering that the SAPP DAM prices forms the basis for this study in the SADC region, similar economic viability case studies can be performed worldwide.

Data availability statement

All input data to this study can be accessed from the references provided in the article except pricing information derived from Namibia Power Corporation bids which was used to formulate the capital cost. The bid pricing data remains confidential.

Underlying and related material

There are no underlying and related material based on this study except as stipulated in the references.

Author contributions

Arno Rory Pfohl: Conceptualization, Methodology, Formal analysis, Investigation, Visualization, Writing- original draft preparation. **Ernst Krige:** Writing- Review and Editing. **Benedictus Mingel**i: Writing- Reviewing and Editing.

Competing interests

The authors declare that they have no competing interests.

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