Case study: Grid parity analysis of a PV- BESS hybrid

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Abstract

Using a proprietary technical and economic model for the optimal sizing of a grid-connected PV-BESS combination for a mine in development located in the Northern Cape of South Africa. This paper presents the analysis of grid parity dynamics based on the levelized cost of electricity concept to examine the timings and conditions for a PV-BESS to reach grid parity.

Levelized cost of electricity (LCOE), Net Present Value (NPV), Battery Energy Storage (BESS)

1.0. Introduction

PV systems have developed in the last years into a highly competitive power generation option. Energy from PV is however not fully dispatch able and is subject to the intermittency of solar irradiation. These challenges can be addressed with BESS systems. Battery technology and manufacturing capacity have developed rapidly in recent years mainly driven by e-mobility. BESS costs have reduced to levels where PV plus Battery can provide dispatch able power at competitive prices. One noteworthy example is the World's largest BESS called Horns dale Power reserve in South Australia. The 100 MW/129 MWh BESS is co-located to a windfarm and additionally provides exceptional high speed ancillary services to stabilize the grid. The advancement of BESS technology and continued cost reductions in PV and BESS, lead to the forecast that a growing number of high energy users such as mines or grid operators will find it beneficial to opt for energy or ancillary services from PV-BESS [1].

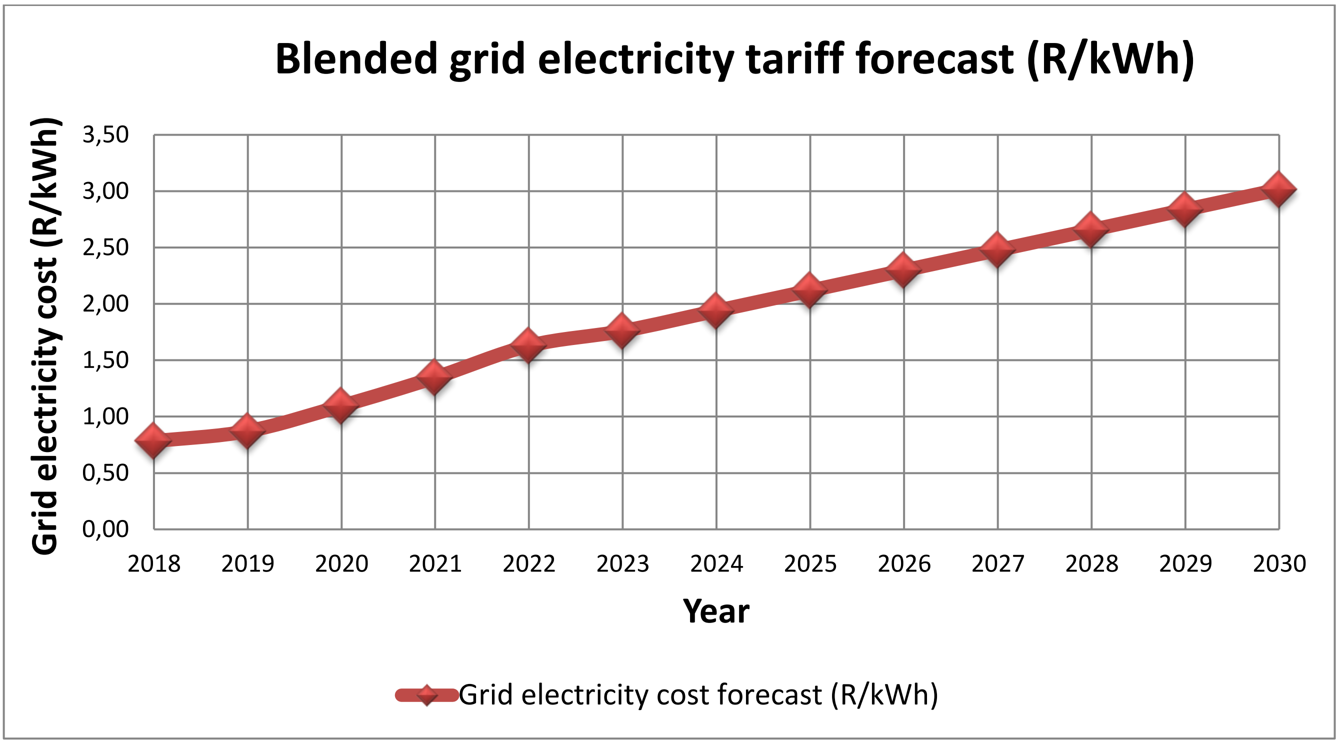
After the successful construction and commissioning of the award winning and world's largest fully off-grid solar-diesel-and battery storage plant of 10.6MW PV coupled with 6MW of battery storage and 19MW of diesel for the De Grussa Copper-Gold Mine in 2016, the juwi Group has since seen significant interest in Hybrid systems arising from the commercial and industrial sector and most specifically, the mining sector. In a Cost and SWOT analysis study conducted by Zharan, on integration of RE into the mining industry, a research finding from Navigant shows that the number of mining projects that will utilize renewable energy technologies for its operations is set to increase. Navigant reports that by 2020, mining operations worldwide will deploy more than 1,438 megawatts in renewable energy [1]. This equates to an expected deployment of 500MW RE projects for the mining industry in the next 2 years. To address the growing needs of the PV-Hybrid market juwi has designated dedicated and competent teams in South Africa and Australia to provide EPC and O&M services for hybrid solar and wind systems integrated with battery energy storage and thermal generators (diesel, HFO, gas).

This paper, presents the preliminary findings from an ongoing case study being performed on a hypothetical mine in development to determine the most economical, secure and environmentally sustainable solution for the energy needs of this mine. The mine seeks to incorporate renewable energy sources into its planned energy mix while maintaining security of supply at the lowest possible tariff and if possible and beneficial, mitigate future electricity price risks from the grid. Using a proprietary technical and economic model for the optimal sizing of a grid-connected PV-BESS solution for the mine situated in the Northern Cape of South Africa with an estimated life of mine of 13 years and an average load demand of 35 MW. The paper presents the results of the analysis of grid parity dynamics based on the levelized cost of electricity (LCOE) concept to examine and determine the timings and conditions under which this mine could supplement its energy needs with solar energy without incurring higher cost or a decrease in reliability of power.

2.0. Methodology

Various studies have proven an increase in stability and security of supply of renewable energy can be achieved by incorporating a storage component [2,3]. However, due to the historically high cost of batteries or other storage technologies, the timing of adding energy storage needs to be well considered. This study utilizes proprietary software designed to simulate the operation of a Hybrid system by making energy balance calculations in each time interval of the year and then determines feasible configurations under the conditions specified and estimates the net present value (NPV) of installing and operating the system over the lifetime of the project from which the least cost of energy (LCOE) is calculated. For this analysis, it is important to note that the simulations used in the model, only takes into account the energy shifting function and the associated revenue stream. As such, this LCOE analysis does not take into account any additional revenue streams that batteries are able to generate such as ancillary services, peak shifting, frequency controls or other ancillary services or energy sale to the grid via price arbitrage. Additionally, the paper does not take into account any carbon taxes to be paid by the mine for its emissions. The software defines the levelized cost of energy (LCOE) as the average cost per kWh of useful electrical energy produced by the system.

The simulation takes into account three main inputs: forecasted reductions in PV system Capex Cost, forecasted reductions in BESS cost and the forecasted increments in Eskom grid electricity tariff for the mine between 2018 and 2030. The PV and Battery storage systems costs applied in this study were based on current South African and global market prices, selected market research and price forecasts and assumptions by juwi. These prices were then estimated over the project period based on the forecasted trend cost reductions of PV and BESS from 2018 to 2030 [4,5]. The indicative blended tariff that the mine is expected to pay during the 'solar day' in 2018 was calculated using the time of use Eskom megaflex tariffs and escalated over the years from 2019 to 2030 based on market knowledge and historic Eskom tariff trends. A 12% increase in Eskom standard tariff and an 8% increase in Eskom standard charges over the years 2019-2022 [6] followed by an annual flat increase rate of 8% thereafter until 2030. The cost trend forecasts for the main inputs of the simulation have been represented graphically in Figures 1-3 below. Figures 2-3 show two trend lines of "Average" and "High" trend lines for the forecasted cost reductions. The "High" represents the most optimistic view of the forecast. All the simulations for this analysis were based on the Average trend forecasts. Based on market prices, a Year 1 (2018) PV System cost for a single axis tracking system with minimal grid connection costs requirements and a BESS cost for a 0.5c lithium ion battery were assumed.



*Excludes demand charges

Figure 1: Blended grid electricity tariff forecast for the mine (2018-2030)

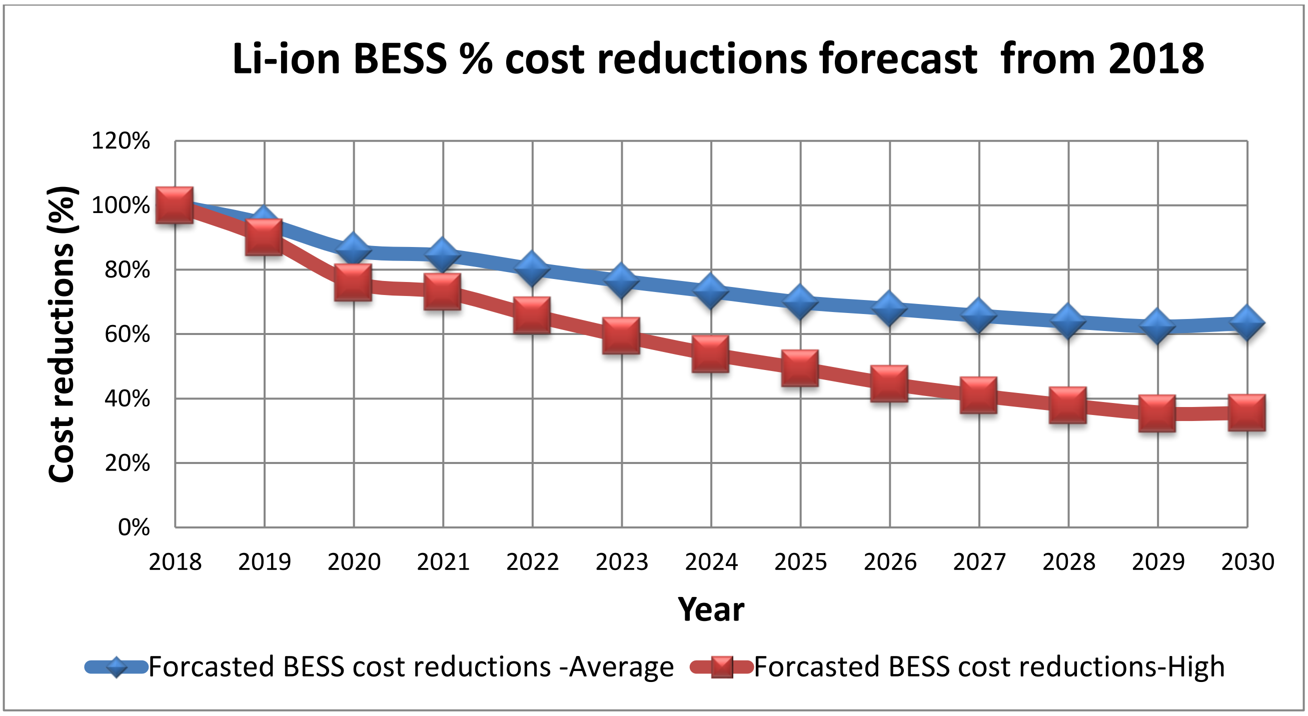


Figure 1: BESS % cost reduction forecast (2018-2030)

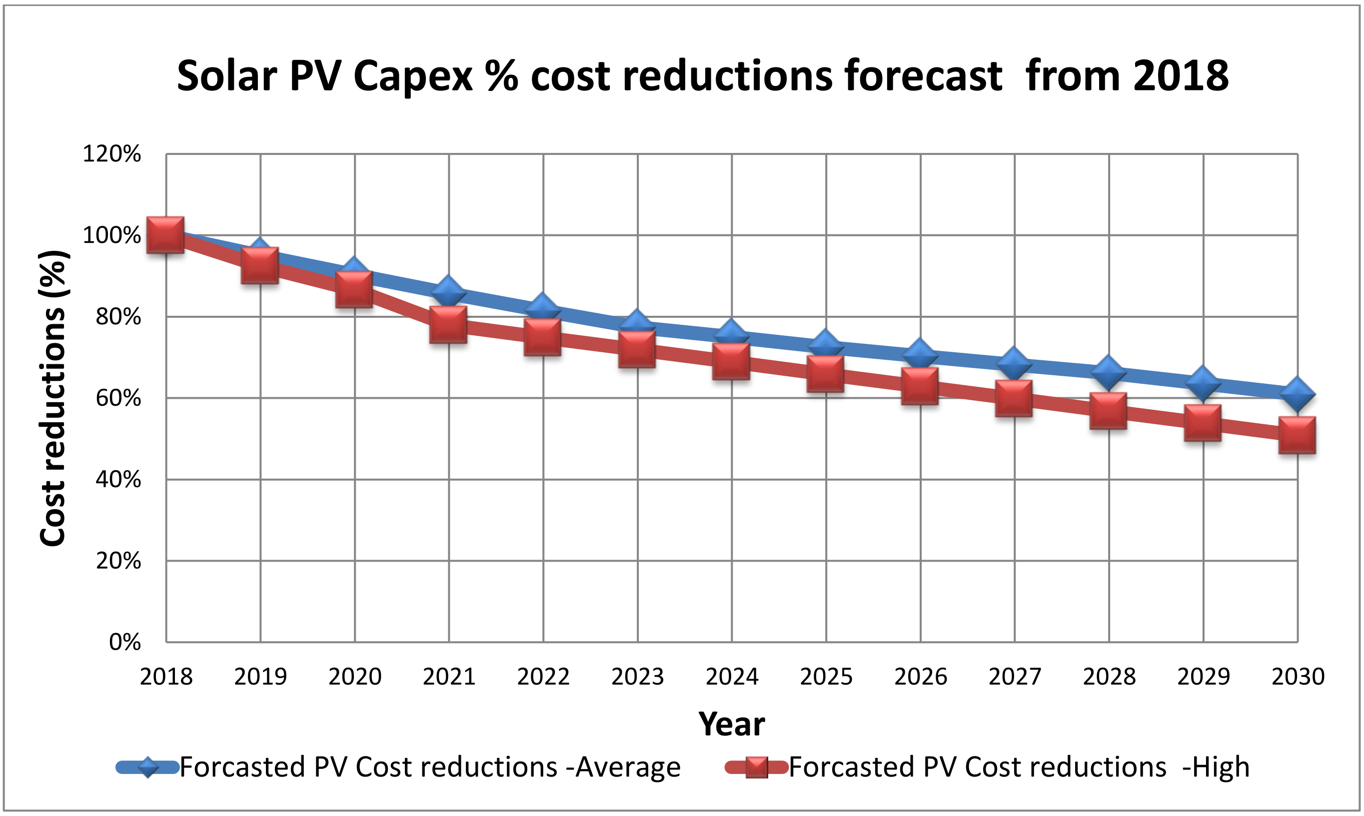


Figure 2: Solar PV capex cost reduction forecast (2018-2030)

Three simulation variants were performed.

1. Variant I – Base case scenario (Grid only)
2. Variant II – Grid - PV only
3. Variant III – Grid - PV - BESS

Variant I determines the LCOE of the Grid electricity using the Eskom TOU Tariff and an assumed average load and peak load demand of 35MW and 38MW respectively and operates for a constant period of 24 hours each day of the year. Variant II determines the LCOE of for the PV system only. Variant III determines the LCOE for the PV-BESS. For each variant, simulations were run on years between 2018 and 2030, with the aim to determine which year the PV-BESS would make economic sense for the mine relative to the grid electricity tariff. Additional input assumptions for the simulations have been provided in Tables 1 and 2 below.

Table 1: General assumptions used in the simulations

Economics:	Value	Units	Comments
Project life time	13	Years	13years LOM
Discount rate	12.00	%	Assumed
Inflation rate	6	%	ZA CPI
Real discount rate	5.66	%	
Mine Load:			
Average load	35	MW	
Peak load	38.23	MW	
Down time	-		100 % grid availability assumed
Daily operation	24	Hours	
Renewables:			
GHI	2248	kWh/m^2/year	from Meteonorm
DNI	2902	kWh/m^2/year	PVSyst
Sp. Reserve for PV	80	%	of instantaneous output
BESS	300,000	kWh	≈ 4,000 cycles

3.0. Results and Discussions

This section presents the results taking into account the assumptions noted in Section 2 above. The key observations from the simulations have been summarised in the Figures 4-5 below. These illustrations highlight the most economical solutions identified between the years 2018 and 2030. From the results of the simulation, it can be concluded that, it is already economical for the mine to incorporate solar energy into its energy mix to supplement a percentage of its current annual energy requirements. PV-BESS systems become economically viable in the year 2023. Today, the mine could opt to install an optimal size of a 41.67MWp solar PV system to supplement 33% of its annual energy requirements with a 1% curtailment of the energy produced, at an LCOE of R0.6397/kWh as against the grid electricity cost of R0.7824/kWh. The results also show that, it is cheaper for the mine to install any PV capacity within the range of <100MWp at an LCOE ranging between R0.6397/kWh - R 0.7259/kWh at an energy curtailment ranging between 1% and 46%. However any of these PV only options, will be associated with a higher risk of security of energy supply, given the intermittencies associated with the solar energy resource. Nevertheless as the Eskom Grid electricity cost continues to increase in the subsequent years after 2018 and PV systems and BESS costs continue to decrease, Solar PV-BESS become economical shortly in the year 2023. However, it is important to note that this simulation was based on the average trend of forecasted cost reductions for the PV and BES systems represented in Figures 2 and 3 above. On that note, it's worthy to note that PV-BES solutions for the mine could achieve grid parity earlier than 2023 if the PV and BES costs reductions follow the "High" trend.

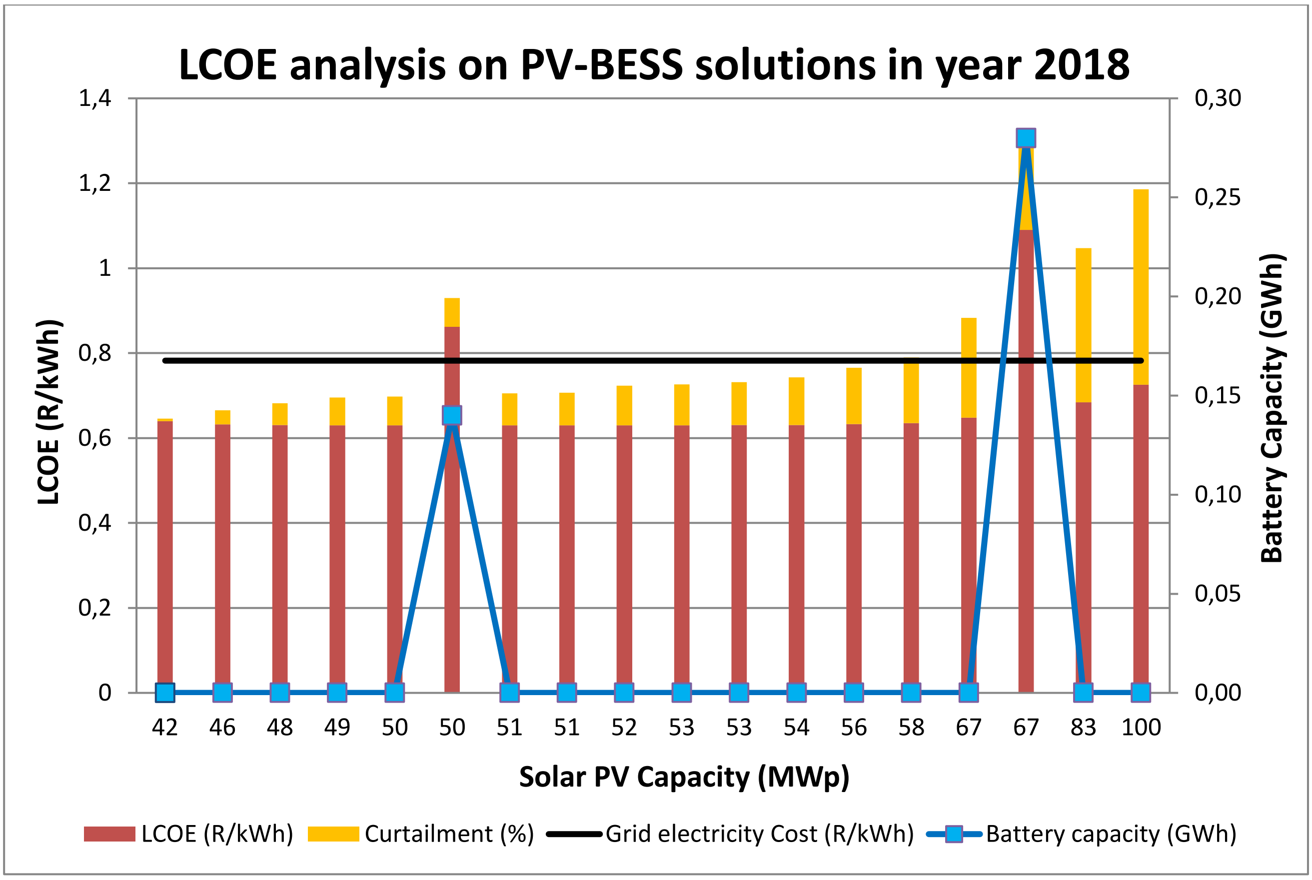


Figure 3: LCOE results on PV-BESS solutions with varying battery capacities and their respective % curtailment

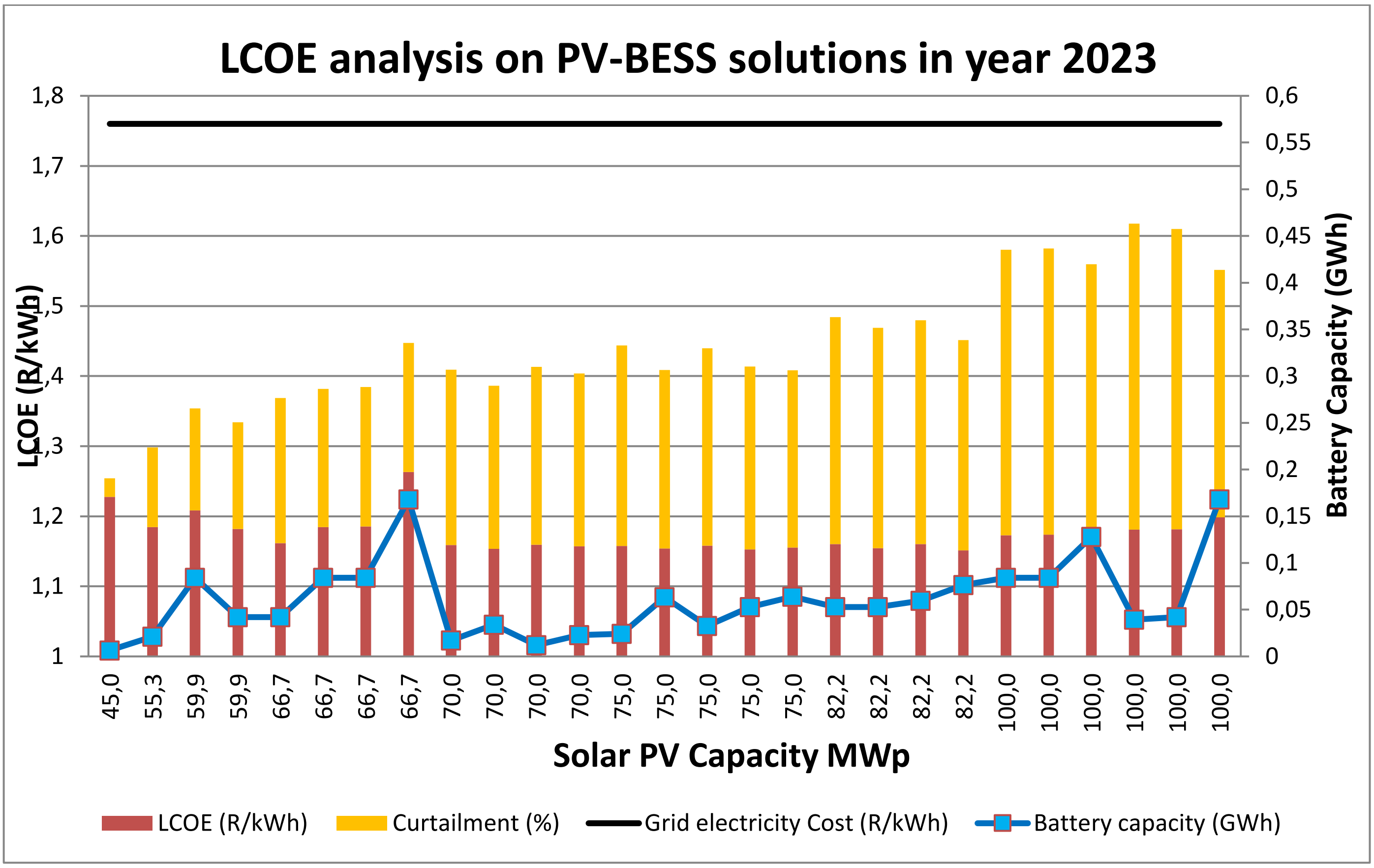


Figure 4 LCOE results on PV-BESS solutions with varying battery capacities and their respective % curtailments

To increase the RE share of the mine's energy mix; the PV capacity should be increased above 41.67MWp. However, without a storage component, the additional energy that will be produced from the any additional PV kWp will be curtailed as excess energy unless there is a sudden increase in the energy demand of the mine. Hence, the addition of a BESS becomes vital to store the excess energy that will be produced from the PV System for later use or to supplement any shortcomings from PV due to cloud cover. For instance, the results show that in 2023, to increase the RE percentage above 33% the mine could install an optimal ~82MWp system with a battery component of about 33MW/76MWh battery a 30% curtailment of energy. The LCOE of this system is calculated to be R1.1515/kWh which was found to be the most economical solution as compared to the estimated Eskom grid energy cost of R1.7600/kWh for the year 2023. Referring to the battery size stated above, this battery system will only be able to cover shortcomings from the PV side during a cloud cover day but cannot provide enough power to serve the load demand of the mine in the event of a full grid outage. For full back up functionality a BESS would have to be adequately sized to serve all critical loads. Using different battery inverter sizes, additional simulations were run with the attempt to determine if the mine could go off-grid in 2023 at a solar energy cost at grid parity. The outcome was that, a complete off-grid solution would not be an economic solution for the mine. For the same PV capacity of 82MWp, with a higher battery capacity such as 40MW/103MWh this battery system is well suited to provide security of supply in events where the mine experiences power outages for a period of 2.5hours. The LCOE of this system calculated to be R1.1617/kWh as compared to the 2023 estimated grid energy cost of R1.7600/kWh. As the battery cost continues to decrease, the battery capacity can be increased to store enough energy to take the mine completely off the grid.

Table 2: Excerpts of the results yielded from the simulations

REF	Year	PV size (MWp)	Battery capacity (MWh)	Battery inverter (MW)	Battery hours (hrs)	LCOE (R/kWh)	Grid (R/kWh)	RE (%)	Curtailment (%)
1	2018	41.67	0	0	0	0.6397	0.7823	33.11	1
2	2023	82.22	76	33	2.30	1.1515	1.7600	44.99	30
3	2023	82.68	103	40	2.57	1.1617	1.7600	45.62	29
4	2023	66.67	84	38	2.20	1.1845	1.7600	41.91	20
5	2023	100	84	38	2.20	1.1727	1.7600	46.40	41

Additional observations include; comparing a 67MWp to a 100MWp system coupled with the same battery capacity of 38MW/84MWh the RE contribution from both systems were calculated to be 41.91% and 46.40% respectively with an energy curtailment of 20% and 41% at an LCOE of R1.1845/kWh and R1.1727/kWh respectively. The model calculated net present value of these two systems as R3.28bn for the 67MWp systems and R3.25bn for the 100MWp system (Reference to No.4 and No.5 in Table 3 above). This implies that, when designing a PV-BESS in 2023, when PV-BESS become an economic option, for the same battery capacity, it is most economical to opt for a larger solar PV plant capacity despite the resulting high percentage energy curtailment associated with a larger PV plant as a larger plant yields a cheaper NPV, cheaper cost of energy (LCOE) and provides a higher RE contribution with reason being that, with PV-BESS the LCOE is additionally reduced by the amount of solar energy that can be stored for later use by the BESS.

Additional benefits from implementing RE into mining operation are the reduction of CO_2 emissions from the mine, and reduced price risk exposure. RE system prices and resulting electricity prices are CAPEX driven and as such reduce the mine's exposure to grid electricity or fuel price volatility. Based on a grid emissions factor of 0.94 t CO_2 e/MWh for South Africa, it is projected that for an 82.22MWp PV plant with a battery storage capacity of 33MW/76MWh and commissioned in 2023, the carbon emissions reductions for the mine is estimated to be about 132,916tCO_2/year which is about a 46% reduction in the estimated emissions compared to pure grid supply. Assuming constant energy requirements for the entire life of the mine, this system will also result in a 34% electricity cost savings of R1.36bn over the operational period of the project.

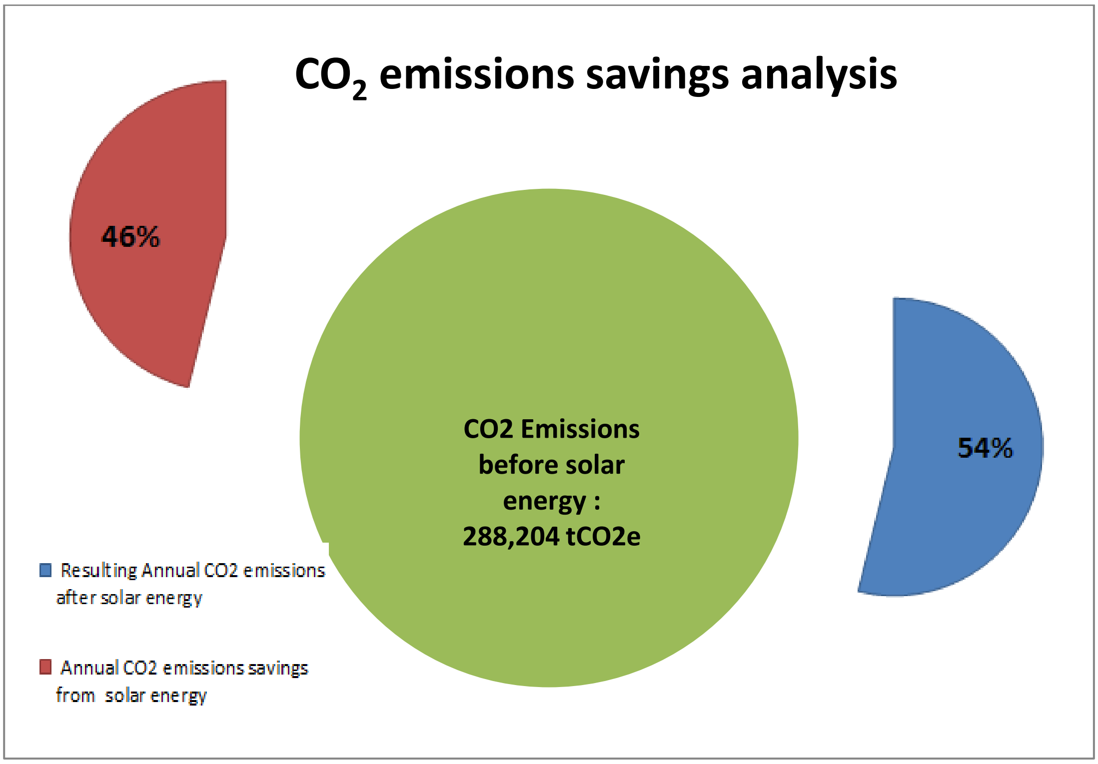


Figure 5: CO_2 emissions savings analysis

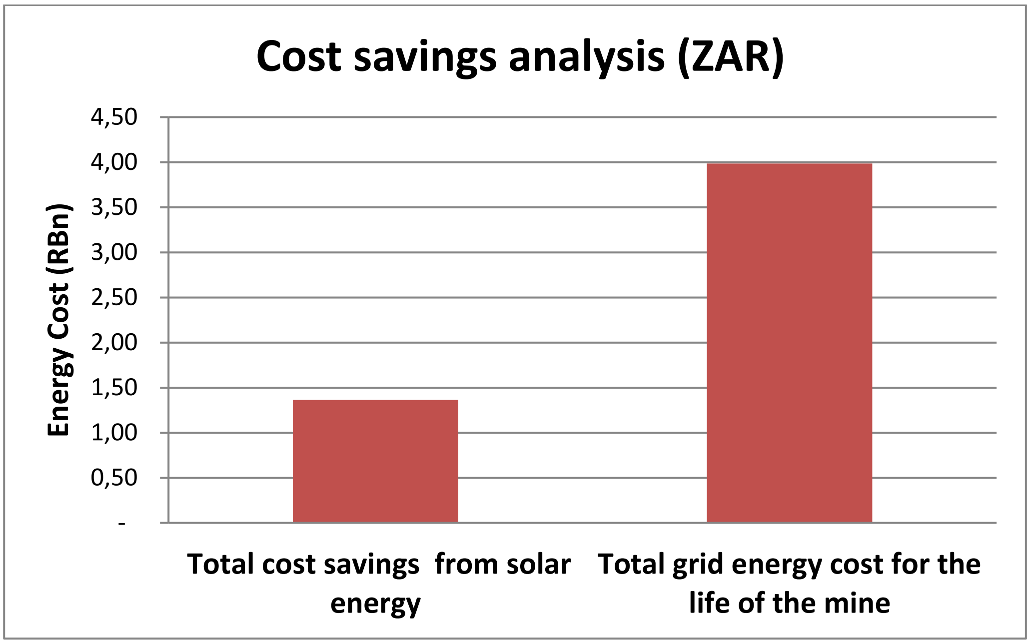


Figure 6: Cost savings analysis (ZAR)

4.0. Conclusions

In present day 2018, based on the Eskom megaflex electricity rates in South Africa, the mine's energy demand and at the given location, a PV power plant behind the meter provides substantial cost and CO_2 savings. For a 42MWp behind the meter PV plant in 2018, the estimated cost and CO_2 savings over the lifetime of the project is R2.45Bn which is equivalent to 61% of the grid electricity cost and a 33% CO_2 savings of 95,439tCO_2e per year. BESS however have not yet reached grid parity but are fast approaching grid parity and are estimated to occur around year 2023. This is only a preliminary assessment; a detailed and in depth analysis is required for each and every site, tariff and revenue structure to conclude an appropriate technology mix PV BESS or other RE sources such as Wind.

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