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“Price Parity” of Solar PV with Storage?

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EXECUTIVE SUMMARY

Network service providers in South Africa have been noticing a trend in declining energy sales from 2008. One of the possible reasons for this trend is that customers are finding alternative energy efficient solutions to supplement their electricity needs and the use of solar Photovoltaic (PV) could account for a large percentage of this. Furthermore, the impact of load shedding has also caused many customers to resort to the use of alternative energy sources for as a means of electricity supply. The installation costs of PV and storage are decreasing due to developments in the performance and efficiencies of the equipment used in these systems. As these costs reduce, it is essential that decision makers in utilities and municipalities be informed of when customers would find it more feasible to defect completely off the grid as this would be the point at which mass sales reduction could potentially occur. This paper would provide 1) projected installation costs for solar PV without storage, 2) projected installation costs for different types of storage and 3) projected Levelised Cost of Energy (LCOE) for solar PV with and without battery storage. This projected cost will be analysed with respect to various scenarios of expected electricity price path to provide insight into the future of PV and battery storage.

1 INTRODUCTION

Globally, there is currently an installed capacity of ~140GW of small scale solar PV. It is anticipated that this penetration will increase to 1 391.9GW by 2040 [1]. Bloomberg New Energy Finance (BNEF) justifies this rapid growth by stating that it is due to the historical decrease of technology prices, a trend which will continue in future. Figure 1 illustrates the global decline in the costs of solar Photovoltaic (PV) crystalline silicon modules – from \$80/W in 1976 to \$0.25/W in 2017.

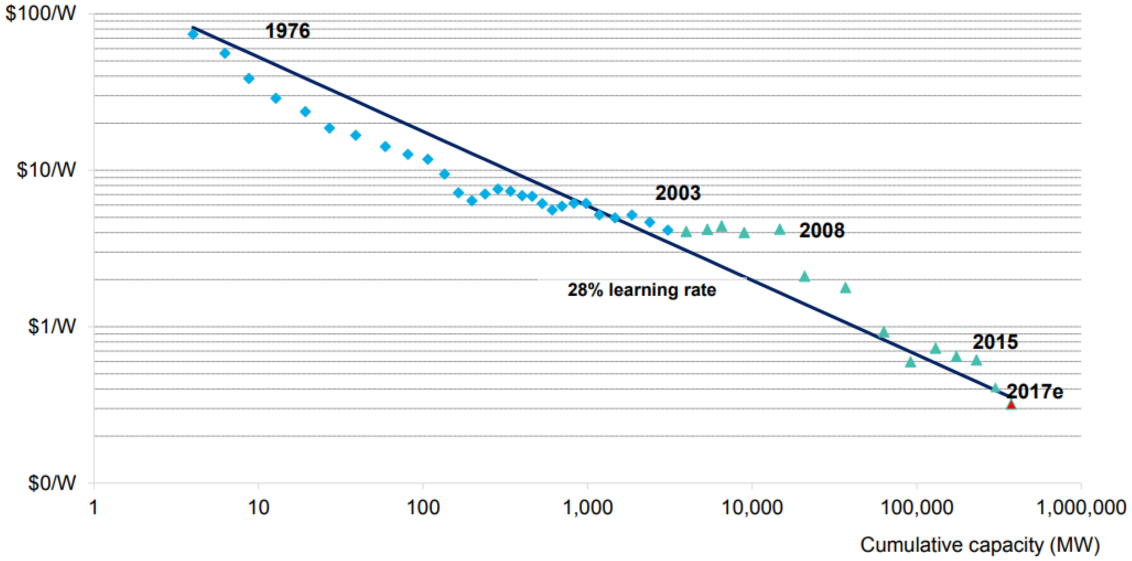

Figure 1: Crystalline silicon solar PV experience curve [1]

The Small Scale Embedded Generation (SSEG) market in South Africa is predominantly owned by rooftop PV. In December 2017, it was estimated that there was ~285MWp of small to medium scale embedded generation (SSEG) installed in South Africa [2]. This includes all installations with a capacity of <5MWp. 5% of the installed capacity is considered to be off-grid installations. The sector that dominates the market was found to be the Commercial and Industrial sector with a penetration of 70% of total installed capacity.

The cost of storage technology is also declining at a significant rate. This is mainly due to developments and research initiatives into technology improvements for large scale roll-out into the transport sector. According to another report by BNEF, the average decline in capital costs for Li-ion batteries from 2010-2016 equates to 16.3% per year and a total of **73%** reduction in just 7 years [3].

Utilities and service providers have been reporting declining sales in electricity sold from 2008. One of the possible reasons for this trend is that customers are finding other energy efficient solutions to supplement their electricity needs and the use of solar PV could be a large portion of this supplementation. Furthermore, the impact of load shedding has also caused many customers to resort to alternative means for electricity supply. The International Energy Agency states that SSEG is increasingly attracting the interest of utilities and policy makers and there are 5 main contributing factors as to why. These are [4]:

- Increasing customer demand for reliable electricity,
- Liberalisation of electricity markets,
- Utilities facing constraints on the construction of new transmission lines,
- Developments in technology of SSEG and decreasing costs and
- Concerns about climate change.

An additional factor could also be electricity price uncertainty and/or increasing electricity tariffs.

There are 4 scenarios that were evaluated for the penetration of SSEG (predominantly rooftop PV) in future years, including 2018; these are represented in Figure 2 [5].

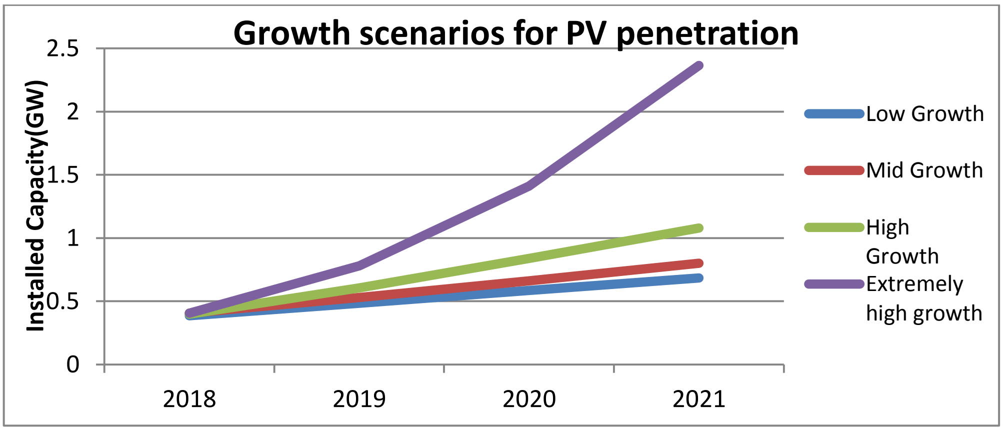

Figure 2: Projected growth scenarios of SSEG in South Africa from 2018-2021 [5]

As the costs of PV and storage continue to decline it becomes more apparent that decision makers at utilities and municipalities be made aware of when customers would consider defecting totally of the grid as this would be the point at which mass sales reduction could occur. This paper provides some answers with regards to that topic. It provides 1) projected installation costs for solar PV without storage and 2) projected LCOE for solar PV with and without battery storage. This projected cost will be analysed with respect to the expected electricity price path to provide insight into the future of PV and battery storage for different segments. The assumption made is that no changes to tariff structures will be made during the years of projection.

2 METHODOLOGY

The steps and methodology used to project the LCOE of solar PV with storage is illustrated in Figure 3 below. The LCOE of PV with storage includes the LCOE of PV + the Levelised Cost of Storage (LCOS).

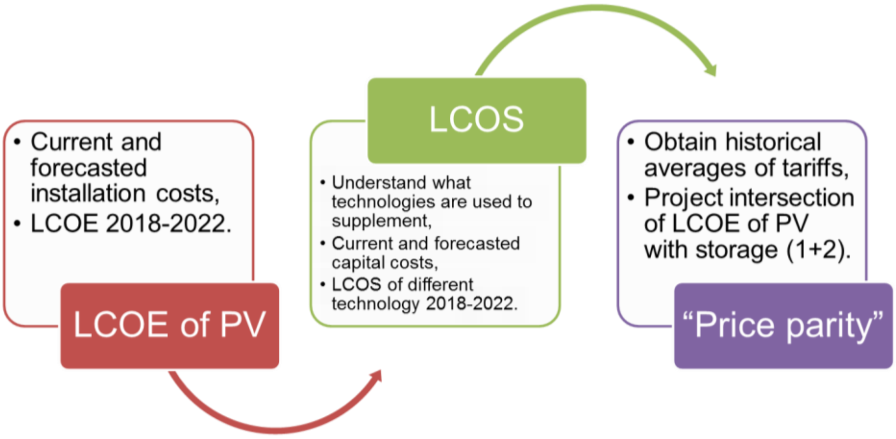

Figure 3: Methodology used to determine LCOE of PV with storage

Current and future installation costs for both PV systems and behind the meter storage technologies are documented in this paper. Future costs are determined by a mixture of extrapolation methods and data available. Using the installation costs, LCOE of PV with storage is computed for 2018-2021. Finally this LCOE is compared to average Eskom tariffs for the projected years to find intersection point. All costs in this paper are determined using literature that is available locally and internationally. The LCOE and LCOS calculation was computed using tools developed by the author. The projected electricity tariffs are represented in 3 different scenarios and this was determined using tariff data from 1996.

During the research phase of this work it was found that the installed costs of a specific technology is directly linked to the utilisation and implementation of the technology. Hence, as the demand increases for a specific technology the costs will decrease accordingly. The costs used in this paper are costs obtained from international and local research reports. The main referenced bodies include International Renewable Energy Agency (IRENA), National Renewable Energy Laboratory (NREL) and Greencape (representing the South African perspective). It must be noted that the "price parity" of PV with storage obtained does not necessarily represent the generation of electricity from a utility in its entirety as other costs such as availability of the grid, frequency support, voltage support, etc. is not considered.

3 PV SYSTEM COSTS

Installed costs of PV systems comprise of various component costs. These components are broken down into 2 major segments; the first being module and the second is Balance of System (BOS) costs. Figure 4 presents a breakdown of all associated costs for the installation of PV systems [6]. The cost of meter exchange from conventional to four-quadrant is not included in these costs.

Module costs	Module make, size and cost
Balance of system (BoS) hardware cost	Inverter
	Racking
	Wiring and cables
	Monitoring system
	Battery
	Other hardware (transformer, protection devices, etc.)
	Duty and transportation cost
BoS soft (non-hardware) costs	Project development/ feasibility study cost
	Customer acquisition (sales and marketing costs)
	System design and procurement
	Subsidies (applications, fees, etc.)
	Permitting (application for permitting with utility provider and other authorities)
	Financing and contract (legal) fees
	Installation cost/ civil works
	Interconnection
	Performance and warranty
	Commissioning cost
	Training and capacity building

Figure 4: Cost breakdown of solar PV systems [6]

The average percentage distribution to all cost components that form an installed PV system, be it residential, commercial or utility scale system is represented in Table 1. This was calculated using cost distributions from United States of America and South Africa. It is evident that the majority of the costs are derived from procuring the modules and accounting for BOS soft costs.

Table 1: Percentage breakdown of cost components for PV systems [7] [8] [9]

Cost component	Residential system (1-10kW)	Commercial system (10kW-2MW)	Utility scale system (2MW-100MW)
Module	**35%**	**45%**	**49%**
Hardware BOS	**16%**	**20%**	**14%**
BOS Soft costs	**49%**	**35%**	**37%**

Research shows that there are efficiency improvements in most of the components included in PV systems. These improvements lead to reduced costs and space required for the installation.

Module costs include costs involved in the manufacturing process of the PV wafers and the assembly process of the entire module. This specific cost has experienced a drastic decline and makes up a large portion of the entire system. According to [6] the decline in module cost experienced from 2009 to 2015 was around 80%. This statement is further supported by Bloomberg New Energy Finance [1], in which they articulate that module costs have decreased by 99.68% from 1975 to 2017. This is primarily due to the conversion efficiency improvements in the semiconductor materials used in the wafer of the modules. In 2017, the global manufacturing cost of modules was between $0.33/W and $0.35/W dropping by ~40% in 4 years [10]. National Renewables Energy Laboratory (NREL) predicts that the ASP of modules will decrease to $0.27/W by 2021 [10].

Inverters and Balance of System (BOS) costs make up the rest of the costs associated with PV systems. Currently, the inverter costs, on average, between $0.06/W and $0.15/W-AC [10] based on the application. There are different types of inverters used for different applications; central inverters are used for utility scale plants, string inverters for commercial sized plants and string or micro-inverters are used for residential applications. The cost of inverters are expected to drop by an average of ~34% from 2015 to 2025 based on application [11]. Balance of system costs (hardware and soft costs) is the last cost component involved in installation of PV systems. The hardware BOS costs are costs for structural and other electrical components, not including the inverter. In 2017, BOS costs in United States of America (USA) were, on average, between $0.71/W and $2.18/W depending on application [12]. In 2015, BOS costs in Africa were, on average, between $1.46/W and $2.8/W depending on application [6]. IRENA expects a 66% reduction in BOS costs for utility scale PV plants from 2015-2025 [11].

The aspects previously mentioned on the cost reductions for components in a PV systems being experienced is evidence enough to assume that total system costs are declining as well. In South Africa, the cost of residential systems have decreased by 36% from 2013-2017 [13]. The cost reduction for utility scale PV plants in various countries is considered to be ~72% on average from 2010-2017 [13]. The cost reduction for commercial scale PV plants in various countries is considered to be ~66% on average from 2009-2017 [13]. Currently, the average total system cost in USA ranges from $2.25/W to $3.83/W depending on the application [10]. The average system cost for utility scale plants ranges from $1.03/W to $1.11/W [12]. In Africa for 2015, average installed costs for residential PV systems were $2.9/W, commercial $2.27/W and utility scale $1.87/W [6]. In South Africa for 2018, Greencape's analysis concluded that installed costs for residential were between R13.5/W and R16.0/W and commercial systems between R10.5/W and R14.0/W. Costs in USA are considered to be higher than that of most countries. The cost in China is considered to be the lowest and decreasing at a much faster rate than other countries.

The total systems costs for each type of system were obtained from international and local literature reviewed. These were averaged out and converted to Rands using the exchange rate for that specific year [14] [15]; the final results are illustrated in Figure 5. The average rand to USD exchange rates for 2015, 2016 and 2017 are R12.8, R14.7 and R13.3 [14] [15], respectively. The installation costs in California are the highest in the world and hence skew the final costs [13].

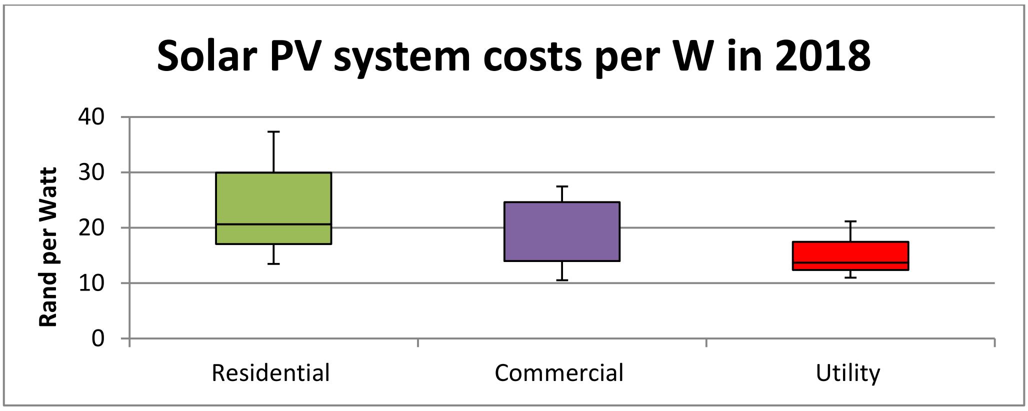

Figure 5: Summary of average system costs per Watt in 2018 for each system in South Africa extracted from various literatures [16] [12] [17] [13] [6] [18]

Using forecasting techniques such as trend extrapolation (extrapolating the past trend for installed costs based on moving averages seen from previous research for those costs) and all the data previously analysed the forecasted installation costs in 3 different scenarios for solar PV for residential, commercial and utility scale systems were derived. The moving averages of all costs were computed from various sources and used to forecast for future years in Rands; hence no exchange rates were required for forecasting of costs. The forecasted optimistic, average and pessimistic installation costs in Rands per Watt for each sector is also represented in Table 2. The installation costs can range from R10.50 to R37.30 per Watt in 2018 and is decreased to R5.50 to R19.54 per Watt in 2022. The major decrease (41.5% on average) arises from the utility scale PV plants in costs in 4 years. Installed costs in the residential sector can experience a 30% decrease in 4 years and 9.5% decrease is expected for commercial PV system costs.

Table 2: Forecasted optimistic, average and pessimistic installation costs in R/W for PV systems for 2018-2022 based on Rands

Installation costs in R/W	2018	2019	2020	2021	2022
1-10kW Optimistic	R 13.50	R 12.66	R 11.81	R 10.13	R 9.28
1-10kW Average	**R 25.40**	**R 23.20**	**R 21.89**	**R 17.50**	**R 14.41**
1-10kW Pessimistic	R 37.30	R 33.75	R 31.97	R 24.87	R 19.54
10kW-2MW Optimistic	R 10.50	R 9.69	R 8.88	R 7.27	R 6.46
10kW-2MW Average	**R 18.98**	**R 16.43**	**R 15.59**	**R 13.93**	**R 12.67**
10kW-2MW Pessimistic	R 27.45	R 23.16	R 22.30	R 20.59	R 18.87
2MW-100MW Optimistic	R 11.01	R 9.63	R 8.25	R 6.88	R 5.50
2MW-100MW Average	**R 16.07**	**R 14.43**	**R 12.33**	**R 9.54**	**R 8.02**
2MW-100MW Pessimistic	R 21.14	R 19.24	R 16.41	R 12.21	R 10.53

4 LCOE OF PV

LCOE is a calculation that is used to compare various power plants with cost structures that differ from each other. The calculation entails summing all costs that are incurred during the lifecycle of the power plant and comparing it to the energy generated during that period of time. The LCOE for PV for each type of system was calculated using a tool that was developed by the author for years 2018-2022. The following formula is used to calculate the LCOE [18]:

$$LCOE = \frac{I_0 + \sum_{t=1}^{n} \frac{A_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{M_{t,el}}{(1+i)^t}}$$

Where:
LCOE – Levelised Cost of Electricity in R/kWh
I_0 – Investment expenditure in R

A_t – Annual cost per year (fixed and variable operating costs)
$M_{t,el}$ – Amount of electricity produced per year in kWh
i – Real interest rate in %
n – Lifetime of the plant
t – Year number (1, 2….n)
The assumptions tabulated in Table 3 were used during the analysis of LCOE for PV systems in South Africa.

Table 3: Assumptions used for LCOE calculation for PV

Parameter	Assumption
Life span of plant	25 years
Installation costs	Average value for each year
Nominal discount rate excl. tax	15.3%
Inverter replacement year	10
Inverter replacement as % of capital	3%
Energy yield	PVSyst (average 1770kWh/kWp/year)
Degradation factor for PV modules per year	0.5%
Operations and Maintenance (O&M) cost	1.5% of capital cost per year
Inflation rate per year	5%

Three scenarios of forecasted LCOE's for different sized PV systems in the years 2018-2022 were computed using the assumptions above and the final results for the average LCOE is illustrated in Figure 6 below.

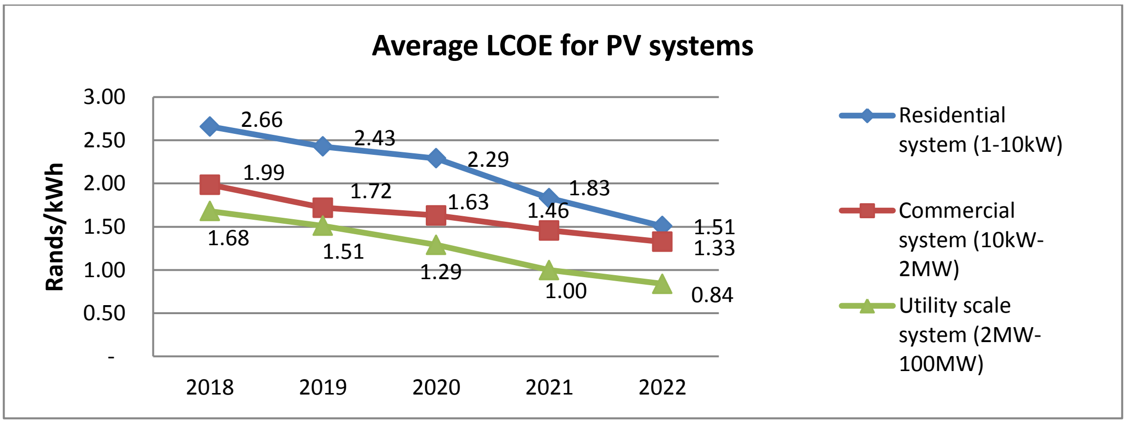

Figure 6: Average LCOE (R/kWh) of PV systems from 2018-2022

The optimistic, average and pessimistic LCOE ranges are tabulated in Table 4 below.

Table 4: Optimistic, average and pessimistic LCOE in R/kWh for different sized PV systems for 2018-2022

LCOE in R/kWh	2018	2019	2020	2021	2022
1-10kW Optimistic	R 0.91	R 0.86	R 0.81	R 0.69	R 0.63
1-10kW Median	**R 2.66**	**R 2.43**	**R 2.29**	**R 1.83**	**R 1.51**
1-10kW Pessimistic	R 2.52	R 2.29	R 2.16	R 1.68	R 1.33
10kW-2MW Optimistic	R 0.71	R 0.66	R 0.60	R 0.50	R 0.44
10kW-2MW Median	**R 1.99**	**R 1.72**	**R 1.63**	**R 1.46**	**R 1.33**
10kW-2MW Pessimistic	R 1.86	R 1.57	R 1.51	R 1.39	R 1.28
2MW-100MW Optimistic	R 0.75	R 0.66	R 0.56	R 0.47	R 0.38
2MW-100MW Median	**R 1.68**	**R 1.51**	**R 1.29**	**R 1.00**	**R 0.84**
2MW-100MW Pessimistic	R 1.43	R 1.31	R 1.11	R 0.83	R 0.72

5 BATTERY STORAGE

Battery storage technology has been utilised for many purposes for many decades. Lead acid batteries are known to be the oldest secondary battery technology and have been in operation for the past 150 years [19]. In 2017, there was a global installed capacity of 3.8GW of battery storage of which, 67.7% is considered to be Lithium ion (Li-ion) technology [20]. As the demand for renewable technologies increase so will the demand for more efficient and durable battery storage technologies. This is due to the intermittent nature of renewables and grid impediments such as unavailability of renewable generation at peak experienced by utilities due to increased penetration of renewable technologies. Energy/battery storage is considered to become one of the key facilitating technologies of the energy transition [19]. Energy storage can provide a number of services to the grid and to the end-user. The main primary and applications that storage can provide are energy management, bridging power, power quality, renewable integration, transmission and distribution deferral, ancillary services, system capacity, renewable smoothing and reliability [21]. Apart from energy storage technologies being segmented into stationary and non-stationary [22], they are also classified into 5 different technology categories. These are electrical, mechanical, electrochemical, chemical and thermal [23]. There are various applications that different energy storage systems can be applied to due to their designs, attributes and make-up. The focus of this paper is on renewable integration consisting of behind-the-meter applications used mainly to reduce electricity consumption from the grid and these are considered to be the following (from most relevant to least) [19]: Li-ion (Nickel Manganese Cobalt), Li-ion (Nickel Cobalt Aluminium), Li-ion (Iron Phosphate), Li-ion (Titatnite), Vanadium redox flow, Zinc bromine flow, Flooded lead acid, Valve-regulated lead acid, Sodium sulphur and Sodium nickel chloride.

Battery storage installed costs include the following [24]: i)Capital costs which consist off – The storage system or otherwise referred to as the fuel costs, Power Conversion System (PCS), power control and management systems and balance of plant costs and ii) Additional costs consisting off – the structural cost, permits and engineering/design costs (Engineering, Procurement and Construction (EPC) included), land acquisition costs, metering and network extension costs, if required. Operational and maintenance costs include component replacement costs (could include entire cell replacement, electrolyte top-up or mechanical system refurbishment), inverter replacement (generally 10 years as with PV), control system upgrades or entire replacement and general operating costs for labour, etc.

From the analysis previously on application based technologies, it was concluded that the technology types that are being commercially applied to PV systems for back-up purposes are generally Lithium Ion, Lead acid, advanced lead acid and Redox flow batteries. Therefore, the future predictions will incorporate these costs only. According to IRENA, installation cost estimates for Li-ion Titanate are currently between $473 and $1 260/kWh and between $200 and $840/kWh for other Li-ion batteries. Their installed costs declined by 60% from Q4 2014 and Q2 2017 in Germany [19]. These costs will further reduce by 54-61% ($80 – $480/kWh dependant on chemistry type) by 2030 due to the expected demand for transport applications. Installation costs for redox flow batteries ranged between $315 and $1 680/kWh in 2016 [19]. These costs are expected to further decline by ~66% to between $108 and $576/kWh in 2030.

The average projected capital cost reduction to 2022 for all relevant technologies for small scale use is depicted in Figure 7 below [25] [24]. This cost was calculated using the average cost reduction extracted from research for the years 2019-2022 for each technology and extrapolated in Rands/kWh for each technology.

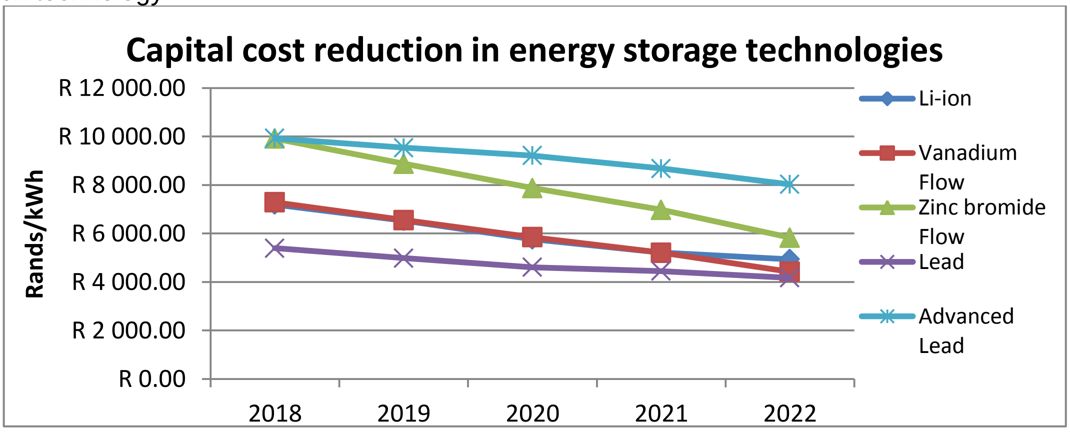

Figure 7: Capital cost reduction in R/kWh for energy storage technologies 2018-2022 [25] [24]

6 LCOS WITH PV

LCOS is defined as the discounted cost per unit of discharged electrical energy [26]. This definition reduces to the calculation expanded in Figure 8 and is in line with recent publications [26] [20] [27].

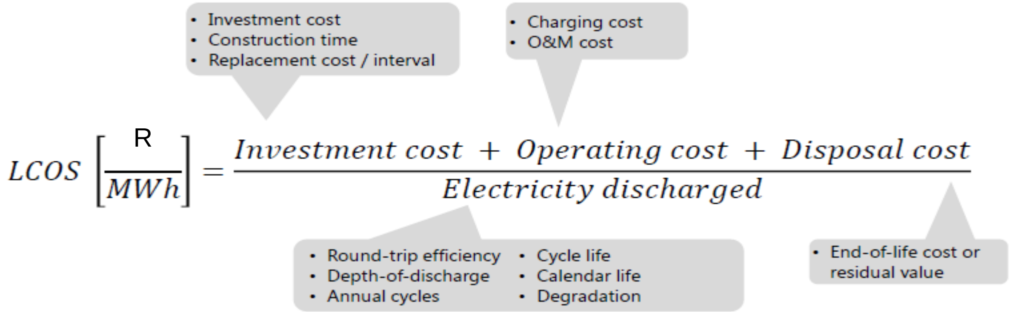

Figure 8: Levelised cost of storage formula [20]

The LCOS for 5 different technologies were computed using the above calculation. The assumptions used to compute LCOS were obtained from research on the respective topics and are as follows [28] [25] [24] [27] [22] [29] [30] [31] [32] [19] [3]:

- The combination of energy storage with PV systems creates value through shared infrastructure such as of having only one Power conversion system (PCS), interconnection and balance of system in the combined plant. The assumption that was made as a result is that the cost of the PCS will be deducted from the installation cost of the battery system. This cost was equated to **30% of the total installation cost** per kWh for each technology,
- The initial average BESS capital costs for each technology will be as per Figure 7,
- Loss of efficiency costs as a result of charging from PV was not considered.

Table 5: Assumptions used to calculate LCOS for different battery technologies

Parameter	Li-ion	Vanadium flow	Zn-Br flow	Lead acid	Advanced lead acid
Project life cycle	25 years				
Real Discount rate	8.4% p.a.				
O&M cost	2% of capital cost (PCS cost not included)				
Average battery system lifespan years	12	18	18	5.5	10
Degradation of battery systems per year	1.84%	1.23%	1.23%	3.98%	2.21%
Disposal cost of capital cost	11.50%	11.50%	11.50%	11.50%	11.50%
Number of cycles per year	365 (1 cycle per day)				
Nominal installed capacity each sector	1MWh for commercial and industrial and 0.06MWh for the residential				
Electricity cost of charging the batteries	R0 as PV system will be used to charge				
Depth of Discharge (DoD)	100%	100%	100%	50%	100%
Roundtrip efficiency	85%	85%	85%	74%	82.50%

The LCOE of PV with different storage technologies were computed and these are illustrated for residential and commercial and industrial systems in Figure 10 and Figure 9, respectively.

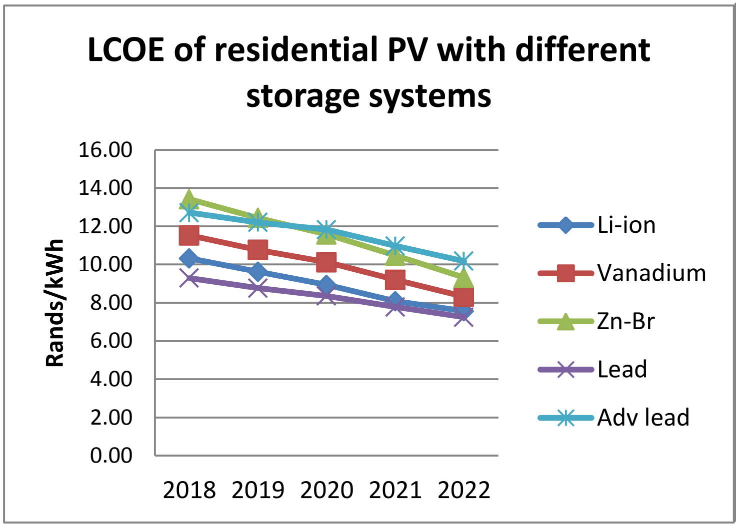

Figure 10: Average LCOE reduction for residential PV systems with different storage technologies for years 2018-2022

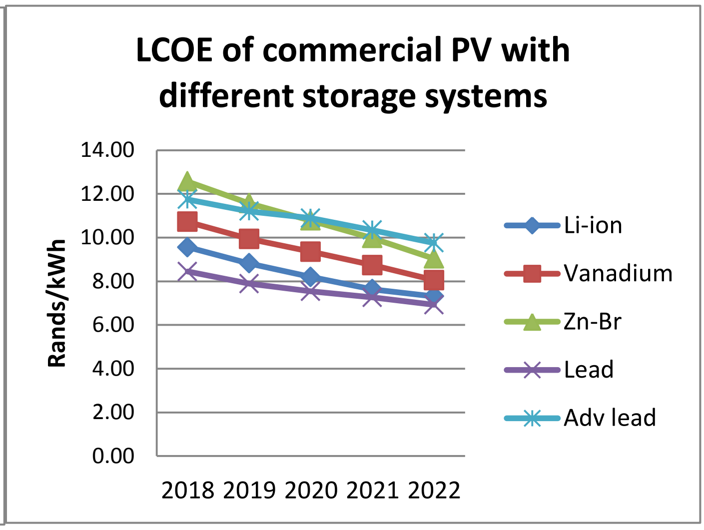

Figure 9: Average LCOE reduction for commercial and industrial PV systems with different storage technologies for years 2018-2022

7 "PRICE PARITY" POINT

The average LCOE of PV systems with different battery storage technologies were projected to identify a possible intersection point with 3 scenarios of Eskom average tariffs for residential and commercial customers (6%p.a., average year on year and 15%p.a.). This "intersection" point is illustrated in Figure 11 below. It is evident that there is no intersection of the average LCOE of PV with storage and forecasted Eskom tariffs before the year 2022, further analysis was completed to determine when this intersection could occur post 2022. This analysis included a very high level projection of the average LCOE of PV with storage using exponential trend extrapolation. The results show that a potential intersection can occur in 2028 for residential users and Lead acid systems if an increase of 15%p.a. for tariffs is implemented from 2018 to 2028 (which is highly unlikely). For commercial and industrial users in the same scenario, the intersection occurs in 2029. A more realistic view is that intersection occurs post 2030 for average tariff increases of 9-10% for customers with Lead acid systems. However, this is still quite high for an average tariff increase in those years.

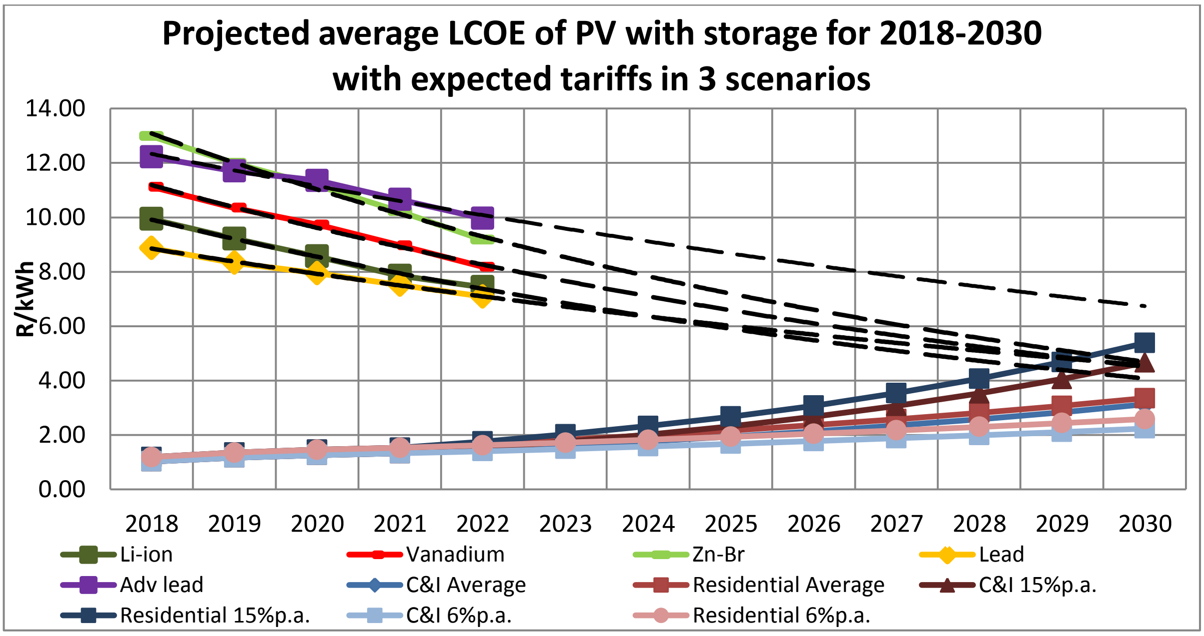

Figure 11: Average forecasted LCOE of PV with different technologies of storage for 2018-2030 plotted with Eskom electricity tariffs in 3 scenarios

An analysis from a paper presented at the Energy storage conference in 2018 indicated that by 2023 grid parity for mining applications would be possible [33]. This could be possible, only if, the customer falls into a municipal jurisdiction and is paying a tariff much higher than the average tariff being paid by Eskom customers. However, for an Eskom customer this cannot be concluded from the analysis provided in this report.

8 CONCLUSION

This paper details the projected installation costs for solar PV without storage, projected LCOE for solar PV with and without battery storage and a projection of LCOE of PV with storage plotted against 3 tariff increase scenarios for Eskom customers. The results provide insight into technology trends and costs for PV and storage technologies. Projection of sales can be further understood by taking these results into account. The possibility of customers installing PV systems to supplement energy needs is a reality already and as costs decrease this effect is to worsen the current state of the business in Eskom. The effect of battery storage on customer deflection is still very adolescent as the installed cost of storage for any technology is quite expensive as seen internationally. This could change in the next few years as a result of performance enhancements and demand increases causing installed costs to decrease and in turn appear as a more attractive solution to supplement energy needs and as a secure supply.

It is envisaged that post 2030, PV with storage **may** appear as a more attractive solution to migrate off-grid and not rely on Eskom supply. However, this may be true only for Eskom supplied customers. Even though this may be the case from the study completed in this report, factors such as loss of supply resulting in loss of revenue (load shedding) for a commercial and industrial customer may result in an off-grid solution being more feasible than having to pay for diesel during load shedding, for example.

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