LIGHTING THE WAY TO PROFITABLE RECHARGING: A TECHNO-ECONOMIC ANALYSIS OF WORKPLACE SOLAR-POWERED ELECTRIC VEHICLE CHARGERS IN POTCHEFSTROOM, SOUTH AFRICA

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ABSTRACT

The increased number of electric vehicles (EVs) in South Africa necessitates increased charging infrastructure and reliable electricity supply. Efficient electricity generation and EV charging strategies are required to avoid increasing electrical grid strain. Deploying solar-photovoltaic EV charging stations can reduce electrical grid strain whilst increasing the number of available chargers. By analysing the energy requirement for recharging EVs, as well as the cost associated with a solar-powered charging system, a system configuration that allows for profitable operation can be determined. This approach utilises HOMER GRID software to minimise cost while ensuring system effectiveness. The results of this study can provide valuable information to policymakers, industry stakeholders and investors, enabling them to make informed decisions on the feasibility, development and implementation of workplace charging infrastructure. This research contributes to the integration of EVs and sustainable renewable energy generation by offering a practical solution for workplace EV charging infrastructure.

Keywords: Electric Vehicle, Techno-Economic, Solar, Renewable Energy, Recharging

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1 INTRODUCTION

The global automotive industry is undergoing a paradigm shift towards the electrification of vehicles. The International Energy Agency (IEA) [1] reported that Electric Vehicle (EV) sales accounted for 8.6% of total vehicle sales worldwide. However, the global increase in EV sales is contrasted by low EV sales in South Africa (SA) [2]. In 2023, EV sales accounted for a meagre 0.3% of new vehicle sales in the country [2]. When comparing original BRICS-group members, SA has at least an order of magnitude lower EV sales share [2]. The stark disparity indicates that significant constraints are impeding the adoption of EVs - in developing countries more so.

1.1 Finding the way in the darkness

One of the primary challenges to EV adoption in SA is the sparse network of more than 400 public EV charging stations [3]. Although the density relative to the number of EVs is world-leading, the low number of EVs and the extensive geographical area of SA make these chargers inaccessible to many potential EV owners [4]. Haidar & Rojas [5] found that increasing the number of publicly available EV charging stations will help promote the adoption of EVs. Powering these chargers remains a challenge in the current South African energy system.

A critical issue in SA is ensuring sufficient electricity generation capacity to support an increase in the number of EVs [6]. Effective EV charging, especially fast charging, requires an electrical power supply that far exceeds the daily electrical power demand of the average citizen in SA [7]. According to Pillay [8], if SA reached its Paris Climate Agreement goal of 2,389,950 EVs in 2040, the electricity demand would increase to 2,764 GWh per annum. Research by Calitz [9] found that if SA followed current electrification trends, the additional electrical load could exasperate the current energy crisis - potentially leading to increased rolling blackouts (Loadshedding).

The intermittent nature of the enormous electricity load of EV charging presents significant challenges for Eskom, SA's national electricity utility. Additional studies by Calitz and Bansal [10], and Pillay [11] emphasised that the potential future power demand of EVs requires increased investments in power generation to avoid the risk of overstraining the national electricity grid.

Naidoo [12] states that EVs' environmental impact heavily depends on the source of electricity that is used to charge the EV. The lower emissions of an EV compared to an internal combustion engine vehicle (ICEV) remains one of the key drivers in EV adoption [4]. When considering this, powering an EV from high-carbon emission electricity from a polluting coal-fired power station is much less acceptable than powering an EV from a low-emission Renewable Energy (RE) source. The need to reduce reliance on coal-fired power stations to reduce CO_2 emissions from EVs is supported by the findings of both Buresh et al. [13] and Pillay et al. [11].

One of the core benefits of an EV is that electric power stations of various types and sizes can supply the electricity to power it; this includes small-scale renewable energy plants.

1.2 Shining a light on the opportunity

The adoption of EVs can serve as a helpful buffer that can absorb the excess power production from intermittent renewable energy sources [14], [15]. When using optimised charging strategies, low-cost Solar Photo-Voltaic (SPV) and wind energy can be adopted to reduce the overall cost of electricity by using the low-cost but intermittent nature of RE [9].

Not all RE sources are equal in cost, effectiveness and reliability in certain conditions. On-shore wind and SPV have already reached the point where the Levelized Cost of Energy (LCOE) is less expensive than coal-fired electricity [16], [17]. However, the intermittency of wind energy in most parts of South Africa's high-solar power potential interior region increases the

LCOE of these systems. In a study by Olatayo et al. [18], it was found that the payback period on a small 1kW wind turbine system can reach 255 years, compared to an average of 7 to 10 years for small-scale SPV power production. The more significant intermittency and higher wind power installation costs compared to SPV, make SPV power a more financially feasible option with a lower LCOE [19].

The combination of sunshine-dependent, low-cost SPV energy during the day and the stationary nature of EVs during working hours creates various opportunities for using a solar-powered EV charging system (SPEVCS). A study by Buresh et al. [13] has demonstrated that implementing SPEVCS at large businesses and carparks can significantly reduce the impact of additional EVs on the electricity grid. Adding local energy storage can further reduce the reliance on the grid to maintain energy availability for EV charging [20]. This strategy alleviates strain on the national grid by consuming more electricity immediately where it is generated.

Solar energy production peaks on most days during the late morning and early afternoon, coinciding with the period when most vehicle owners are at work. During this period, the national grid's electricity demand is at a local minimum between the morning and evening peaks [21]. This scenario can enable the efficient use of renewably generated electricity to charge EVs and to store the surplus in batteries for use during evening peaks.

A slower, low-power EV charger can be used when an EV is stationary for extended periods, at home or at a workplace. The Small Scale Embedded Generation (SSEG) systems that are available to households and businesses can be enlarged to provide sufficient electricity to recharge EVs. Implementing this charging scenario reduces reliance on the national grid and presents a potential business opportunity.

In an investigation into the feasibility of solar-powered EV carports, Buresh et al. [13] found that charging EV owners a tariff higher than the rate for feeding electricity into the grid but lower than the grid electricity cost creates a mutually beneficial scenario. This situation can be preferred over selling electricity back to the grid at a significantly lower rate and administrative cost [22]. Therefore, businesses benefit from the increased profitability of selling surplus electricity while consumers benefit from the lower cost of operating their EVs. This financial model can incentivise businesses to invest in SPEVCSs and employees to purchase an EV.

Some challenges related to EV adoption can be partially addressed by increasing the number of publicly available EV chargers. However, this will inevitably increase electricity demand in a country with an already overstrained grid. Charging an EV on the current coal-dominated South African grid undermines their CO_2 emission reduction potential. When EVs emit more CO_2 than their ICEV equivalents, one of the primary motivations for adopting EVs is negated. Fortunately, utilising newly installed SPV for EV charging mitigates the environmental and grid impacts of using EVs. Deploying these chargers at workplaces where vehicles are stationary during the effective period of solar power production, a mutually beneficial financial opportunity can arise for the EV owner and employer. EV owners pay a lower electricity tariff than their utility rate, whilst the employers sell electricity at a rate higher than the grid feed-in tariff. This scenario can reduce the financial burden of operating an EV and installing solar power capacity for the EV owner and employer. This study explores the techno-economic implications of increasing the number of EV chargers - thereby addressing one of the critical constraints on increased EV adoption in South Africa [23].

2 LITERATURE REVIEW

Various studies have been conducted on the implementation of SPEVCSs. For this study, the literature review focused on the design and modelling of an SPEVCS. Researchers at Stellenbosch University, under the leadership of MJ Booysen, have confirmed the preliminary technical and financial viability of using SPEVCSs in South Africa [13], [20], [24], [25], [26]. With the technical and financial viability established, further investigation into the conditions of profitable operation can be done. This will be accomplished by conducting a Techno-Economic Analysis (TEA) of SPEVCS.

2.1 Designing the SPEVCS

Before the economics of the system can be considered, the technical configuration of the SPEVCS should first be determined. A study by Mouli et al. [27] investigated the design of a hybrid SPV and local battery storage system to power a DC-DC EV charger. A local battery storage system was determined to help reduce grid dependency and meet charging requirements. The findings of a study by Vermaak and Kusakana [28] further emphasise the importance of using a hybrid energy source system. The authors found that additional energy generation or storage is required to mitigate the intermediary nature of RE.

A hybrid-energy system that provides less intermittent power was developed by Mouli et al. [27]. Based on their research, a system could be designed for this study. Some alterations to the design by Mouli et al. [27] are made due to the study's different requirements. The first change is the replacement of the DC charger with a much less expensive AC charger. This can be done as Vehicle-to-Grid (V2G) charging and discharging are not investigated in this study. A low-power AC charging system will recharge an EV sufficiently over the 6 to 8 hours the vehicle will be stationary during the day.

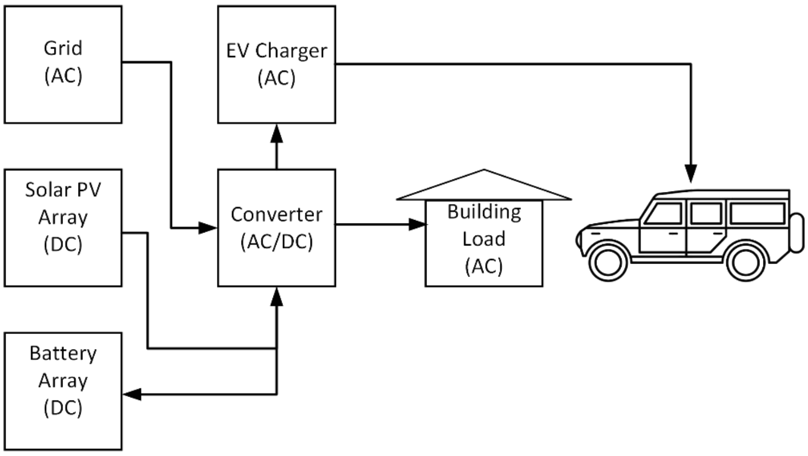

Figure 1: SPEVCS Diagram [27], [29]

The basic system architecture for a SPEVCS, as tested in this study, is shown in Figure 1. Power is generated by the SPV array and then transmitted to the hybrid converter system (converter). This system converts the DC power input into an AC power output that the building can use to power the building load, export to the grid, or, most importantly, recharge the EV. If necessary, the converter combines the power output from the DC SPV and battery systems with AC power from the grid to meet the building and EV electric loads. Additionally, it can redirect DC power to recharge the batteries directly. The SPEVCS's components are discussed in the following sections.

2.2 Modelling the SPEVCS

Each component in the system has a unique functionality that must be combined to supply power to the EV and building successfully. To recharge an EV and power the existing load of the business, energy is required from either the battery, the SPV array or the grid connection. The energy required can be represented by Equations 1 and 2 [30]:

$$E_{Demand_t} = P_t * t \tag{1}$$

Where E_{Demand_t} is the energy demand of the system, P_t is the power requirement and t is the time step over which the power demand persists. The total energy demand over all time steps can be determined per Equation 2.

$$E_{Demand_{Total}} = \sum_{i=1} n_t * E_{Demand_t} \quad (2)$$

However, DC power from the SPV array must be converted into AC power to charge the EV through the selected charger. Therefore, a converter is required. This converter also converts the AC power from the electricity grid into DC power to charge the system's battery. This converter does not have perfect efficiency when converting the various current types. The efficiency of the system can be described by Equation 3 [30]:

$$\eta_{coverter} = \frac{P_{output}}{P_{input}} \quad (3)$$

The efficiency ratio of the converter is noted with $\eta_{converter}$. The input power from the AC or DC source that needs to be converted is indicated with P_{input}, whilst the output power is noted with P_{output}.

The primary power source of the system is the SPV array. The SPV modules generate power from the sun's radiation using semiconductors. The power production of these modules is described by Equation 4 [31].

$$P_{PV} = Y_{PV} f_{PV} \left(\frac{\bar{G}_T}{\bar{G}_{T,STC}}\right) \left[1 + \alpha_P \left(T_c - T_{c,STC}\right)\right] \quad (4)$$

The power produced from the SPV array is represented by P_{PV}. The rated capacity and derating factor of the array are noted by Y_{PV} and f_{PV} respectively. The ratio of $\bar{G}_T$ and $\bar{G}_{T,STC}$ represents the effective solar radiation incident on the SPV modules compared to standard test conditions. α_P represents the temperature coefficient of the power. The PV cell temperature in the current time step is noted by T_c whilst the PV cell temperature under standard lab conditions is noted by $T_{c,STC}$.

If the SPV array's power production exceeds the building and EV charger's power requirements, excess production can be diverted to the battery storage. The battery storage unit utilises chemical reactions to store the excess electricity for later use. Suppose the battery SPV system does not produce enough power to meet the demand of the building and EV charger. In that case, the system controller releases energy from the battery to supplement the deficit. The battery power, P_B, can be described by Equation 5.

$$P_B = P - P_{PV}, P \leq P_{PV} \quad (5)$$

When P_B is smaller than 0, the battery is being recharged with excess SPV power. Suppose the power demand of the building and EV charger exceeds the available power from the battery and SPV array. In that case, power is imported from the electricity grid to meet the demand. Electricity is exported to the grid when the battery is fully charged, and the load power requirement is less than PV power production. The power import and export to and from the grid can be represented by equation 6 [30].

$$P_G = \begin{cases} P - P_{PV}, \ P \leq P_{PV} + P_B \\ P - P_{PV} - P_{B_{max}}, \ P \geq P_{PV} + P_{B_{max}} \end{cases} \quad (6)$$

The maximum power that the system's battery can deliver at the current time step is represented by $P_{B_{max}}$. When P_G is smaller than 0, electricity is being exported into the electricity grid.

3 METHODOLOGY

The TEA of this study was conducted using HOMER Grid 1.10 [32]. The analysis of this study included the development of a case study model focusing on a building at the North-West

University in South Africa. Whilst conducting this analysis, various economic values were calculated and analysed to determine the financial feasibility of using SPEVCSs.

3.1 Energy simulation tool

The chosen software, HOMER Grid that was utilised to conduct the TEA of this system was developed by the US National Renewable Energy Laboratory (NREL) [33]. The software is suited to model and analyse hybrid energy systems to determine the economic and technical feasibility of implementing a system. [28], [30], [34], [35], [36], [37], [38], [39]. One of the critical features of this software is the ability to conduct sensitivity analysis and optimise microgrid systems. Additionally, HOMER Grid adds the ability to add EV recharging to the microgrid that is being simulated [30].

3.2 Model development

Various inputs are required to develop a HOMER Grid model. The first is where the system is planned to be located, known in this study as the study area and the electric load scheduled for the system. After this, data on this location's solar radiation and other atmospheric conditions must be imported into the model. The input resource data input is followed by local tariff information and the selection of appropriate incentives - if applicable.

The technical information can be entered once the location information has been entered into the model. The technical information relates to the equipment specification, including additional loads such as EV recharging and project information. Finally, the financial information that will influence the system's implementation, such as discount rates and system cost, must be entered.

After the model inputs have been finalised, the variables that have been selected to be optimised can be optimised, and HOMER Grid can choose an ideal configuration. Optimisation mainly takes place by varying the size and type of RE sources and the battery and converter size. The various combinations of these systems must meet the minimum energy requirements specified for the model. The variations that meet the minimum energy requirements of the system are then evaluated based on specific economic indicators.

3.3 Optimal system evaluation criterion

To determine the optimal solution that meets the requirements of the system, the different SPEVCS configurations were objectively compared. The economic indicators that HOMER used to compare the various configurations are the Net Present Cost (NPC) and Cost of Energy (COE) [30], [34], [35], [38], [39]. The calculation of the NPC of the system is shown by Equation 7:

$$NPC = \frac{C_{total,annual}}{CRF} \tag{7}$$

The total annualised cost of the system to supply electricity is represented by $C_{total,annual}$. The Capital Recovery Factor (CRF) calculation is described by Equation 8:

$$CRF(i,N) = \frac{i(1+i)^N}{(1+i)^{N-1}} \tag{8}$$

The real discount rate is represented by i whilst N represents the number of years over which the project is implemented. The COE calculation of the system is indicated by Equation 9:

$$COE = \frac{C_{total,annual}}{E_{total,used}} \tag{9}$$

The $E_{total,used}$ represents the total amount of electricity consumed over a year. This is calculated by adding the total amount of electricity generated and used by the system, E_{iu}, and the amount of electricity that was imported from the electricity grid, E_g, as shown by Equation 10:

$$E_{total,used} = E_{iu} + E_g \quad (10)$$

4 CASE STUDY

The study area of this case study is a building of the Faculty of Engineering of the North-West University's Potchefstroom campus. The North-West University's Potchefstroom Campus is located in the North-West province of South Africa. The building is located at 26°40 "S 27°05'41.0" E [32]. Olatayo et al. [18] found that the solar radiation potential in this region is significantly higher than the wind potential. The main reason for selecting this specific location is the ease of accessing load data and the potential for higher EV adoption rates under higher-educated individuals [40].

4.1 Local electrical load profile

The function of the building determines the load profile of the case study and when it is used. For this case study, a complex of academic buildings that serve as offices, practical laboratories and workshops was chosen. These buildings are typically used between 07:00 and 16:00 from Monday to Friday. After hours, some building functions, such as computer server operations, remain active and require electrical power. The hourly average load profile, computed from measured data, of the chosen engineering buildings is depicted in Figure 2.

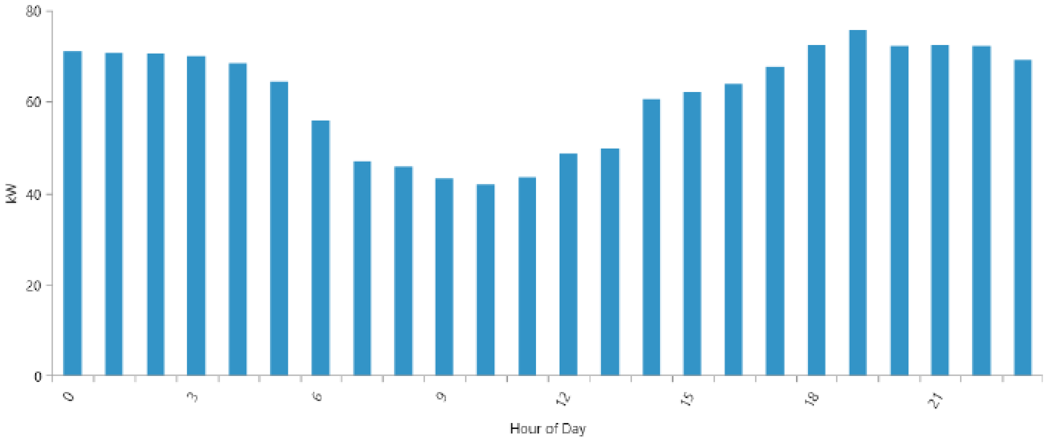

Figure 2: Daily Load Profile of the Engineering buildings

Subsequently, the load profile for each month is shown in Figure 3. The maximum power requirement of these buildings is 251.34 kW, whilst the daily average energy consumption is 1 932.9 kWh. An important note for this study is that the impact of intermittent electricity blackouts will not be considered.

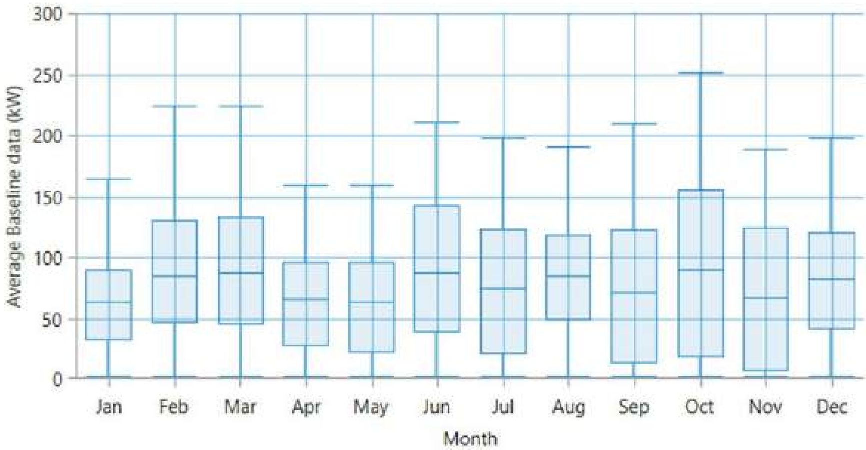

Figure 3: Seasonal Load Variation of Engineering Buildings

4.2 Environmental data

The solar radiation data required to develop the HOMER Grid model was obtained from the NREL's National Solar Radiation Database (NSRDB) [41]. HOMER Grid uses Global Horizontal Irradiation data to calculate the daily energy potential and clearness rating. This data is fed into the SPV model to determine the power output per time step. The daily average energy potential and the clearness over the same period has been summarised and is shown in Figure 4.

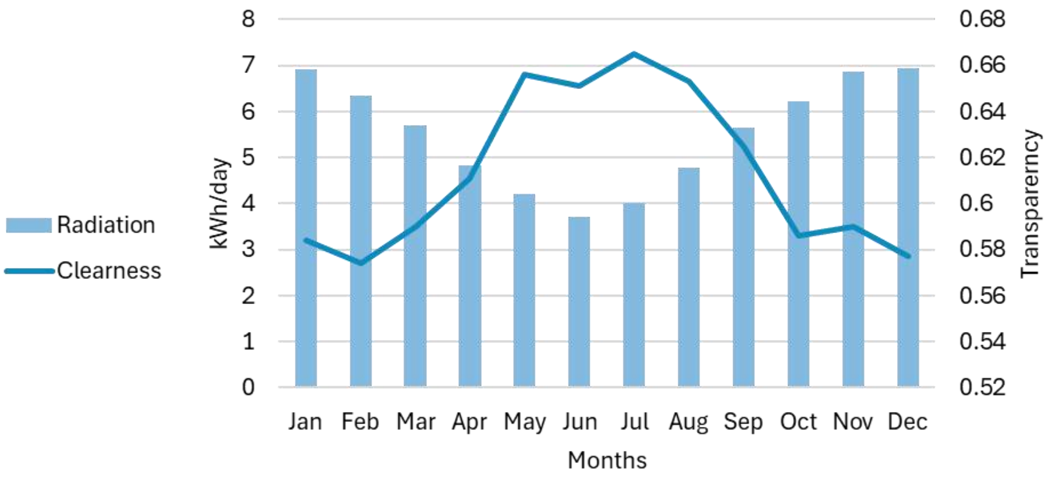

Figure 4: Average daily solar radiation and clearness

The ambient temperature around SPV modules has an impact on the power production capacity of these modules [27]. HOMER Grid utilises the ambient temperature in calculations to determine the power output of these modules as they heat up and cool down during their daily cycles. The temperature data obtained for this model is obtained from the NSRDB [41]. A summary of the temperature variations per month is included in Figure 5.

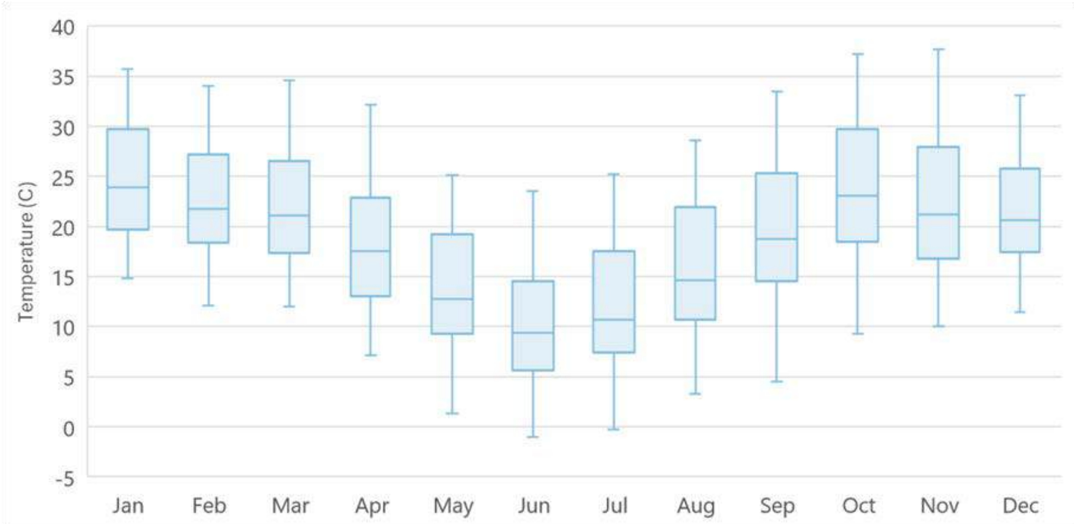

Figure 5: Monthly Temperature Ranges

4.3 System Configuration

The grid-connected hybrid SPV/battery EV charging system consists of an SPV array, converter(s), a battery array, a grid connection, the local electrical load and the EV charging load. Each of the model inputs have distinct characteristics that influence the model's operation. HOMER Grid has built-in models of various off-the-shelf components that can be implemented in the HOMER Grid model. The main characteristics of the SPV array modules, battery modules, converters and the grid connection itself are indicated in this sub-section. An overview of the HOMER Grid model is shown in Figure 6.

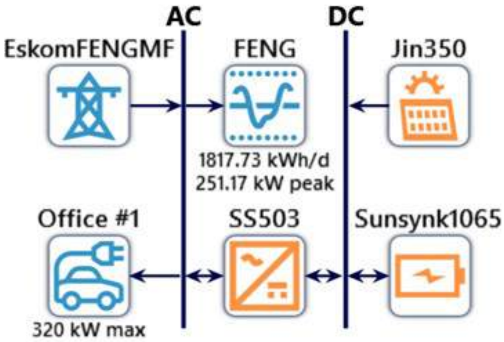

Figure 6: Block diagram of PV/Battery/Grid Hybrid system

The chosen SPV module is Jinko Solar Co., Ltd.350JKM350PP-72-V. The main characteristics of this SPV module are indicated in Table 1. HOMER Grid automatically calculates the ideal slope of the PV modules. The excess energy generated by the SPV array can be stored in a battery system.

Table 1: Solar Photo-voltaic System Configuration

Parameter	Value	Unit
Capacity	0.350	$kW/module$
Maximum system capacity	500	kW
PV Slope	26.8	°
Derating Factor	85	%
Temperature effects on power	-0.440	$\%/°C$
Nominal Operating Temperature	45.3	$°C$
Efficiency of PV arrays	13	%
Capital Cost	4,117	R/kW
Replacement Cost	2,058	R/kW
Operation and Maintenance Cost	205	$R/year/kW$

The specific battery unit used is the SunSynk Battery Lithium-Iron Phosphate 10.65kWh. The characteristics of the battery system are indicated in Table 2.

Table 2: Battery System Configuration

Parameter	Value	Unit
Nominal Voltage	51.2	V
Nominal Capacity	9.22	kWh
Round trip efficiency	98	%
Lifetime throughput	80,000	kWh
Minimum State of Charge	20	%
String Size	4	$units$
Capital Cost	55,000	$R/unit$
Replacement Cost	35,000	$R/unit$
Operation and Maintenance Cost	550	$R/year/unit$

The converter system functions to convert DC power into AC and vice versa. The converter system used in this model is SunSynk-50K-SG01HP3-EU-BM4. It must be noted that the South African renewable energy marketplace places emphasis on lower costs and higher value products. The details of the converter system are shown in Table 3:

Table 3: Converter System Configuration

Parameter	Value	Unit
Capacity	50	kW
Efficiency	97	%
Capital Cost	115,000	$R/unit$
Replacement Cost	75,000	$R/unit$
Operation and Maintenance Cost	1,500	$R/year/unit$

HOMER Grid allows a significant amount of variability in EV charging. The variability of EV charging is shown in Figure 7

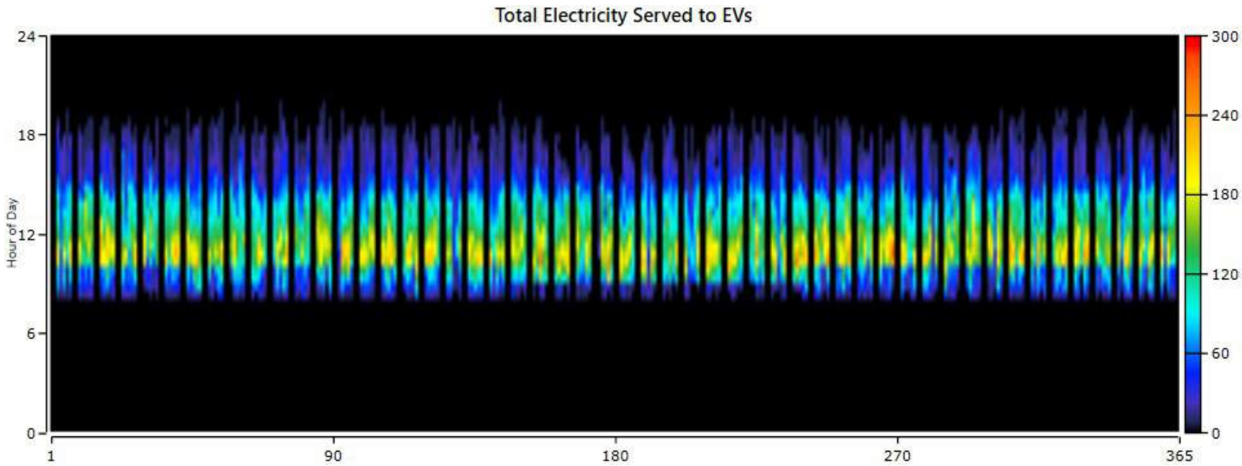

Figure 7: Variation in power requirement for EV charging.

The standard configuration of chargers used for this study is indicated in Table 4. The Capital Costn and Operation and Maintenance Cost represents the per charger costs of the System Fixed Capital Cost System Fixed Operation and Maintenance Cost respectively in Table 5.

Table 4: Electric Vehicle Charger Configuration

Parameter	Value	Unit
Number of chargers	40	$chargers$
Maximum charging rate	8	kW
Electricity cost	2.50	R/kWh
Number of charging sessions	40	$sessions$
Capital Cost	10,000	$R/unit$
Replacement Cost	10,000	$R/unit$
Operation and Maintenance Cost	500	$R/unit/year$

4.4 Economic project parameters

The economic analysis in this study requires certain inputs to be performed. Eskom's MegaFlex Local Authority tariff was used for this study [42]. HOMER Grid automatically utilises the parameters indicated in Table 5 in conjunction with Eskom's tariffs to perform the economic analysis.

Table 5: Economic Project Parameters

Parameter	Value	Unit
Nominal discount rate	8.25	%
Expected inflation rate	6	%
Electricity cost inflation rate	13	%
Project Lifetime	15	$years$
System Fixed Capital Cost	400000	R
System Fixed Operation and Maintenance Cost	20000	R

5 RESULTS

The Techno-Economic Analysis (TEA) is carried out with HOMER Grid. The technical analysis was conducted by inputting the load demand and resource data into HOMER Grid's electricity generation and consumption models. The model considered the power generated by the SPV system, the battery charging and discharging, the load of EV charging, and the base load of the buildings. A small example of the energy production, import and power of solar power production and electrical load on the state of charge can be seen in Figure 8. The red line represents the power production from the SPV array, the yellow line represents the electrical load of the system, and the blue line indicates the battery's state of charge (SoC).

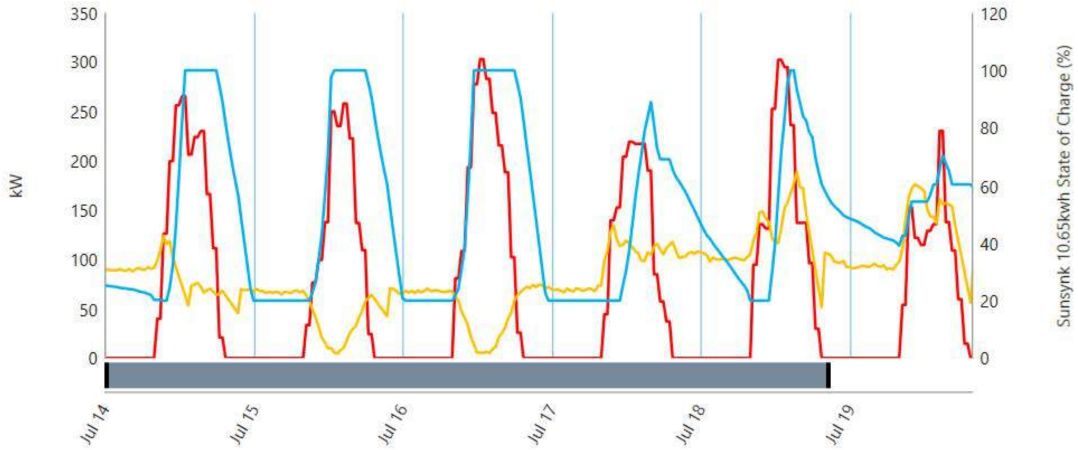

Figure 8: Solar Power, AC Load and Battery State of Charge

5.1 Optimal configuration

HOMER Grid groups the analysis findings into four distinct categories, with the most optimal configuration for each category. One of the four configurations will be the most optimal configuration out of all four configurations. The four categories of configurations are determined by their energy sources. The first category only obtains electricity from the electricity grid. The second category uses SPV and the electricity grid as a hybrid energy supply. The third category is a hybrid system combining the electricity grid and the battery system. Finally, the fourth category uses the SPV array, batteries and the grid to supply energy to the system. The results for each category is shown in Table 6.

HOMER Grid conducts the optimisation over a given search space. The search space for the converter and SPV system is between 0 kW and 500 kW. The converter system was incremented in 50 kW steps to represent the addition of a converter unit with each step. The SPV array always tended towards the upper limit of the optimisation range. The 500 kW array size limit was imposed due to limited space availability for the system. The search space for the battery system was 10 to 100 string units in 10-unit increments.

Table 6: Best configurations per category

Architecture	SPV (kW)	Battery (kWh)	Converter (kW)	NPC (R)	LCOE (R/kWh)	Operating cost (MR/yr)	CAPEX (MR)
Grid	0	0	0	59.9	5.38	4.68	0.4
Battery/Grid	0	922	250	52.0	4.66	3.57	6.48
PV/Grid	500	0	300	22.4	1.35	1.51	3.15
PV/Battery/Grid	500	1106	300	6.95	0.52	-0.22	9.75

The optimal configuration was determined by comparing it to a grid-only electricity supply to meet the system's load. The most optimal configuration is a hybrid system that combines SPV and grid connection with a battery system to absorb excess electricity production for later use. The system consists of 500 kW of SPV, 1106 kWh of battery and 300 kW of converter capacity.

The most optimal system requires a large Capital Expense (CAPEX) of R9.75 million compared to the R400,000 CAPEX required for the base system. However, from the first day of operation, the system generates revenue from electricity sales. Consequently, as the operational expense of the SPV and battery system is significantly lower than the base case, the NPC of the system is considerably lower. This is illustrated by comparing the discounted cumulative cash flow of the base and the proposed system in Figure 9. The total NPC of the best case is R6.95 million, the LCOE is R0.515 per kWh of electricity, and the operating cost of the system is -R219,868 per year. The discounted payback of the proposed system is 4.2 years, whilst the Internal Rate of Return (IRR) is 31%.

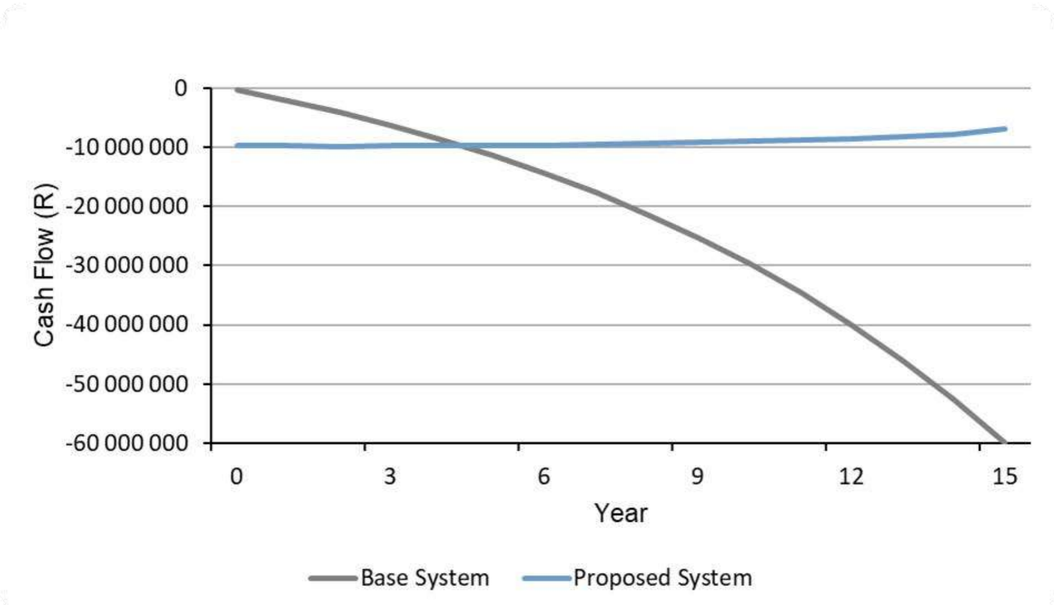

Figure 9: Base Case and Proposed Case Discounted Cumulative Cash Flow

5.2 Sensitivity Analysis

A sensitivity analysis was conducted to test the impact of changes to the SPEVCS. The sensitivity analysis was performed by varying the cost of the SPEVCS and the number of recharging sessions per day. The aim of varying these variables is to test the potential profitability of the system under different future use cases.

5.2.1 Reducing system costs

Three different SPV, battery and converter system costs were considered. These costs were created to equal 50%, 75%, and 100% of the SPEVCS' cost. These three cost points provide a broad range of potential future system costs. The result of the sensitivity analysis of the various energy system costs is shown in Table 7.

Table 7: Reduced System Cost Sensitivity Analysis

Ratio of SPEVCS cost (%)	Battery (kWh)	NPC (MR)	LCOE (R/kWh)	Operating cost (MR/year)	CAPEX (MR)
100%	1106	6.95	0.515	-0.22	9.75
75%	1106	4.12	0.305	-0.26	7.41
50%	1475	1.1	0.083	-0.40	6.17

Additionally, a reduction of 30% in battery cost was tested. The significant reduction in battery price scenario was tested as current expectations are that new battery chemistries, such as Sodium-Ion, will significantly reduce the cost of energy storage within the next five to ten years [43], [44]. The results of this sensitivity analysis, as optimised by HOMER Grid, are a CAPEX of R7.77 million, an LCOE of R0.350 per kWh, an Operating Cost of R239,668 per year, and an NPC of 4.72 million.

5.2.2 Changing the number of charging sessions

Another important system variation is the average number of charging sessions per day. This change represents changes in the number of EVs that employees own. For this study, a variation of 20, 30, 40, and 60 charging sessions were tested. For the 20 and 30 charging sessions, 20 charging stations were used. For the 40 and 60 charging sessions, 40 charging stations were used. The result of the sensitivity analysis is shown in Table 8.

Table 8: Charging Session Sensitivity Analysis

Charging Stations (chargers)	Charging sessions (sessions per day)	Battery (kWh)	NPC (R)	LCOE (R/kWh)	Operating cost (MR/yr)	CAPEX (MR)
20	**20**	1475	12.3	1.01	0.05	11.6
20	**30**	1475	11.5	0.94	-0.01	11.6
40	**40**	1106	6.95	0.515	-0.22	9.75
40	**60**	1106	6.40	0.47	-0.26	9.75

The results of this sensitivity analysis confirm that increased EV adoption and charging requirements can yield improved revenue from the SPEVCS. Additionally, selling electricity to the EV owner reduces the need to store electricity to generate value from its work.

6 CONCLUSION AND RECOMMENDATIONS

During this case study, HOMER Grid was utilised to conduct a Techno-Economic Analysis (TEA) of a Solar-Powered Electric Vehicle Charging System (SPEVCS) at the North-West University, Potchefstroom Campus in South Africa. The SPEVCS consists of a Solar Photo-Voltaic (SPV) array, battery system and the national electrical grid.

The results demonstrate that an SPV-dominated SPEVCS offers the most cost-effective solution to recharging Electric Vehicles and providing power for the building's electricity demand, compared to a national electricity grid-dominated SPEVCS. Unfortunately, under current SPEVCS cost and electricity tariff conditions, the profitable operation of an SPEVCS appears challenging. Beyond the long-term cost reductions achieved by technological development, policy adjustments can be made to reduce the cost of implementing SPEVCSs at workplaces in South Africa.

Despite the economic constraints, the long-term energy cost savings from implementing a SPEVCS warrant serious consideration for implementing such a system in businesses. Increasing the prevalence of SPEVCS at South African businesses can help to increase the number of publicly available charging points for EV owners. Additionally, using SPV for electricity can help reduce emissions and the reliance of businesses and EVs on the national electricity grid.

Implementing more SPEVCSs will help increase the number of publicly available EV chargers that won't destabilise the grid or increase emissions. Thus, one of the main limitations to the adoption of EVs can be addressed in a more holistic, financially sustainable way.

In summary, although current conditions are challenging, adopting SPEVCSs presents a promising solution to the need for more, sustainably power EV charging points in South Africa.

6.1 Limitations

One of the study's main limitations was the unavailability of EV recharging data. Additionally, the high cost of using HOMER Grid makes further application of these findings on others less accessible.

6.2 Future Recommendations

For future studies, this can be applied to various regions in South Africa and internationally to compare the financial viability of using SPEVCS at different locations and under different use cases. Additionally, although this study focuses on deploying EV charging stations, further investigations can be made by applying this methodology to different electricity use cases, such as electrified mining operations.

One of the main limitations of HOMER Grid is its high cost and unnecessary functions for certain types of investigations. Developing a lower-cost simulation method that focuses explicitly on modelling SPEVCSs without unnecessary functionalities might enable more individuals or organisations to investigate the potential deployment of SPEVCSs.

Batteries are crucial to enable the technical independence of the SPEVCS from the grid, yet their contribution to system cost is significant. Therefore, innovations in battery technology can meaningfully reduce the system's total cost. Subsequently, when the cost of energy storage has decreased significantly from the date of writing (July 2024), a future re-evaluation of the financial viability of SPEVCS could yield promising results.

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