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Solar PV Advisory Pre-Feasibility Study

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Full title of report	[redacted] Solar PV Advisory	
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Brief project description	This report serves as a pre-feasibility study, which aimed at investigating the effect of installing a rooftop Solar PV system at [redacted]. The study involved a techno-economic investigation by identifying potential installation space, investigating the current and the simulated consumption profile, investigating the municipal regulations and solar modelling to determine the performance of two proposed systems. The first is a 1.6kWp PV installation with existing panels yet to be installed. The second is a fully optimized system to find the lowest Net Present Cost (NPC) option for the client. The second option will include storage and allow for more solar PV capacity.	
Key findings	There are multiple viable options. The report outlines a possible Grid tied Solar PV system and two battery tied hybrid systems.	
Keywords	Rooftop PV, Solar PV, Feasibility study	

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List of Abbreviations

kW	Kilo Watt
kWh	Kilo Watt-hour
LCOE	Levelized Cost of Energy
MW	Mega Watt
NPV	Net Present Value
NPC	Net Present Cost
PPM	Prepayment Meter
PV	Photovoltaic
SSEG	Small Scale Embedded Generation
kWp	Kilo Watt Peak
Wp	Watt Peak

Introduction

This study was conducted to investigate the feasibility of installing a solar photovoltaic (PV) system [redacted], Cape Town. The study considered potential rooftop areas of the household for PV installation. Systems with and without battery storage where investigated. The purpose of the installation would be to offset electrical consumption from the grid to result in financial savings over time.

This document serves to compare two possible options. The first option is installing a grid-tied 1.6kWp set of PV panels with the necessary inverters and system controls, as the client has already procured 5 320Wp PV panels.

The second option is a fully optimized system that was financially optimized for the client. This includes sizing the system, investigating storage potential and the policy and regulations regarding small-scale embedded generation. A maximum viable capacity was determined through computational simulation. This was then compared to the consumption of the household and financially modelled to optimize a system with the sensitivity on NPC and capital investment.

A breakdown of the options is shown in Figure 1.

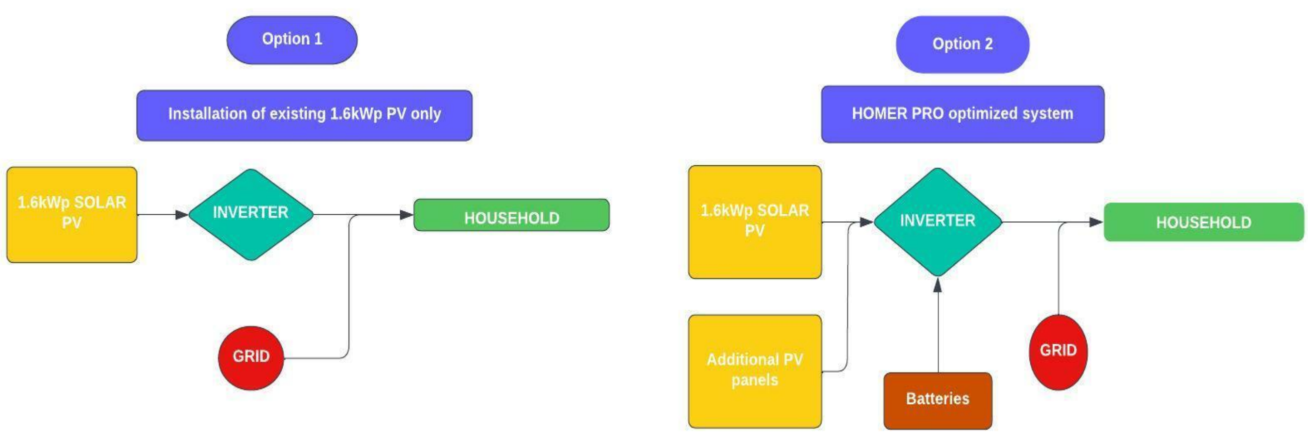

Figure 1: Breakdown of options investigated

1. Site Information and Background

The building layout of [redacted] is shown below in Figure 2. Sections 1-4 are on the main house, which is a double story building. Section 5 is the roof of a carport. Section 6 is a single-story maids' quarters. There are multiple large trees which will create shading challenges. Removing the trees is not an option as per the client's request.

The south facing sections of the roof are excluded from the study due to low irradiance. Sections 1,2 and 6 are at a tilt of 30°. Sections 4, 3 and 5 are horizontal and may need mounting structures installed. Figure 3 shows the house from the north.

Figure 2: Layout of [redacted]

Figure 3 [redacted] *from a northern perspective*

Unfortunately, the only electrical data that is available is a yearly summary of electricity consumption by month. Electricity is bought on a pre-paid metering system. This leads to reactive charging of electricity that is regular but not exactly monthly. Figure 4 shows this data.

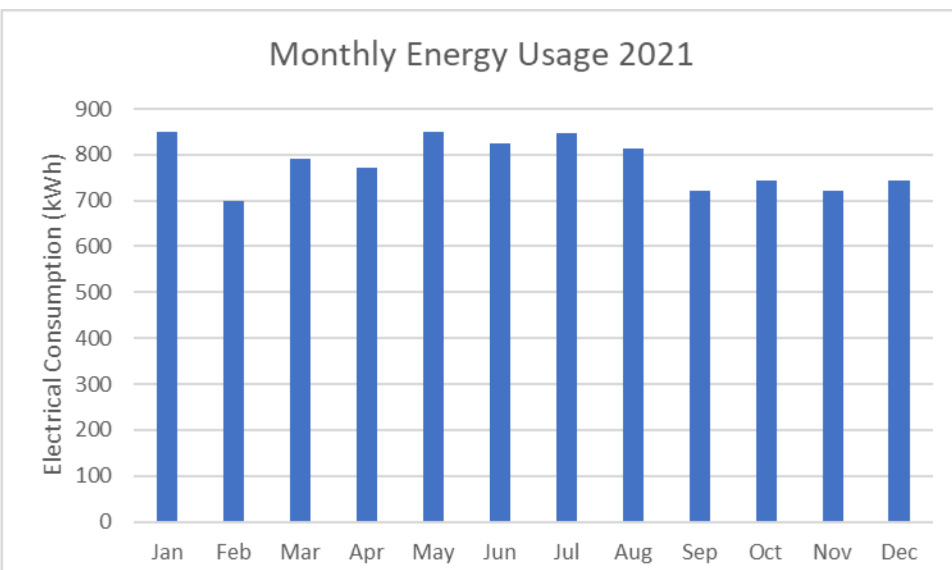

Figure 4:Monthly energy supplied by the Grid

2. Solar Resource

The map in Figure 5 shows the potential solar resources available to South Africa measured in kWh/kWp per year. This is the amount of electrical energy can be produced (kWh) per installed peak capacity(kWp) over an annual period.

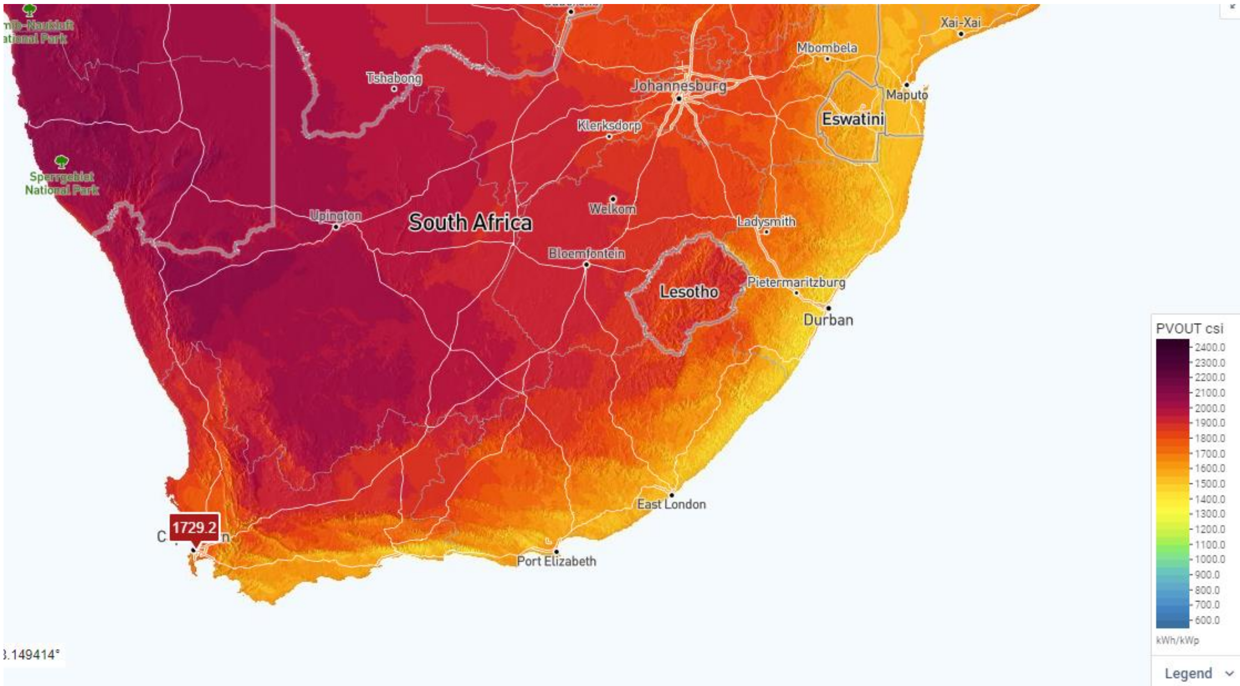

Figure 5: PV potential for South Africa measured in kWh/kWp per year (Solargis Prospect 2022)

The annual solar irradiance for [redacted] is 1729.2 kWh/kW_p, according to the SolarGis Prospect PV output map in Figure 5. This is an extremely positive number with 1400 kWh/kWp being considered a lower limit in SA.

PVsyst and Homer Pro, which use a combination of satellite data, ground data and synthetic data to approximate the PV yield for the exact location of the site were used to estimate the production capabilities of the PV system in the simulations.

3. Regulations and Tariffs

The City of Cape Town allows Small Scale Embedded Generation (SSEG) so long as they meet the outlined requirements. Some of the relevant requirements to the type of system are outlined below.

- All SEGG's, regardless of generation capacity, within the City's licensed area of supply, must complete the relevant sections of the application process and only proceed after written approval is received from the city.
- Grid-tied system with export: The customer is allowed to export excess electricity onto the grid but needs to remain a Net Consumer.

  This must be done through a bi-directional AMI (Advanced Metering Infrastructure) meter. The city will supply and install the meter at the consumer's cost.

- Grid tied system with no export: The customer must install reverse power flow blocking protection to ensure that no excess electricity is being exported to the grid.

  The customer may keep an existing PPM (Prepayment Meter) in place on the relevant tariff.

  Any customer with a credit meter that draws less than 100A will be required to have their credit meter replaced with a PPM at the city's cost.

  Any customer that draw's more than 100A will have to reduce their capacity below 100A or have a bi-directional AMI meter installed, at the customers cost.

- Grid tied Hybrid: The customer must have an external automatic change-over switch between the network supply and the storage supply.
- The electricity produced by the SSEG system must be consumed on the property which the SSEG is located or exported to the City's network for purchase by the city. (Unless a wheeling deal has been permitted)

Below is a (non-exhaustive) list of the most relevant regulations, standards, and specifications:

- Electricity Regulation Act 4 of 2006 and Electricity Regulation Amendment Act 28 of 2007
- South African Grid Codes (Distribution, Transmission and Renewable Power Plants)
- Occupational Health and Safety Act 85 of 1993
- City of Cape Town Electricity Supply By-law, 2010
- SANS 10142: All Parts

- SANS 474/NRS 057: Code of practice for electricity metering
- NRS 097 Series
- City of Cape Town Standard for Interconnection of Embedded Generation (EEB 705).

All SSEG sites need to be registered with the municipality to ensure that grid safety is maintained. The process for registering a SSEG is outlined below in Figure 6. This is the link to download the relevant application forms: (http://www.capetown.gov.za/elecserviceforms)

Figure 6: SSEG application and Approval Process

Further information related to the registration of SSEG system with the City of Cape Town can be found here:

https://www.youtube.com/watch?v=mnh6ewoxEzo&t=142

4. Solar Modelling

The household consists of 6 possible rooftop orientations that are possible options for PV installation. Each orientation has its own PV generation capabilities that are determined by its Azimuth angle, tilt, far and near shading effects.

An iterative simulation process was used to find the areas with the highest solar yield. This determined the maximum viable capacity of the household, as well as the potential of the orientations with respect to each other.

4.1. Solar modelling Option 1 (installation of existing PV panels only):

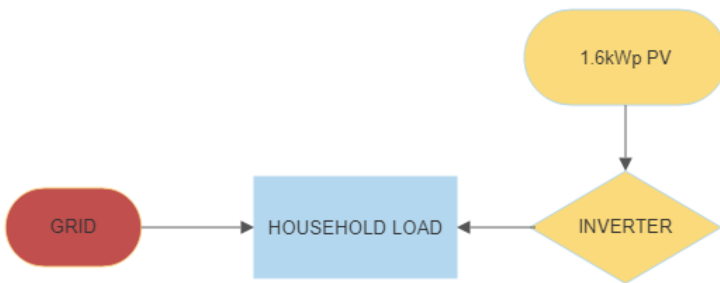

Figure 7: Summary of option 1

The first investigation will be to find the optimal location to install the existing PV panels and model their expected annual generation capacity.

The north facing section of roof experiences very little shading and has a small azimuth angle (6°), making it ideal for the placement of PV panels.

Figure 8: Azimuth angle of the North facing roof

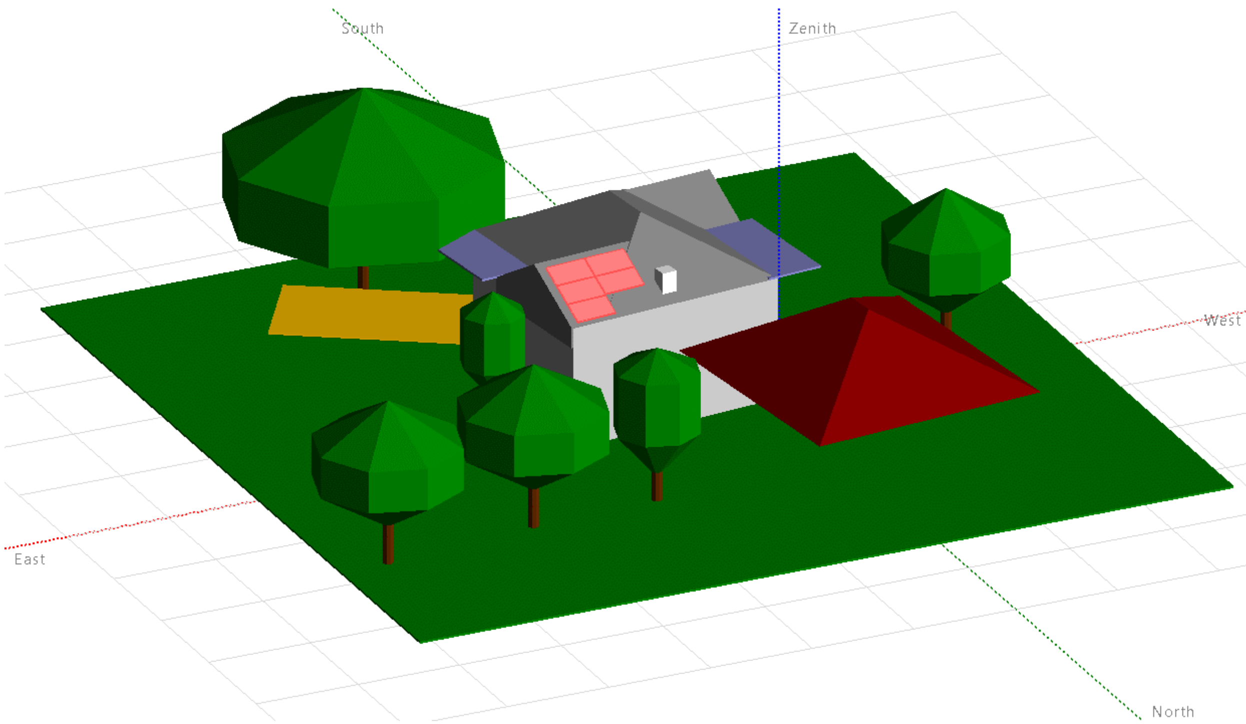

Figure 8: 3D render to determine the near shading effects

Figure 9 shows a 3D render of the PVsyst model. The model illustrates the shading issues that will be present over the car port from the large tree. It also shows the perfect fit of the 5 panels on the north facing roof with very little shading.

The model considered shading from both the proximity (near shading) and the horizon line (far shading). The near shading loss results can be seen in figure 10. The annual near shading irradiance loss was simulated to be 1.0%, which is acceptable. The far shading loss was determined to be 1.2%, this largely due to Table Mountain in the West. The model used a default annual soiling loss of 3%.

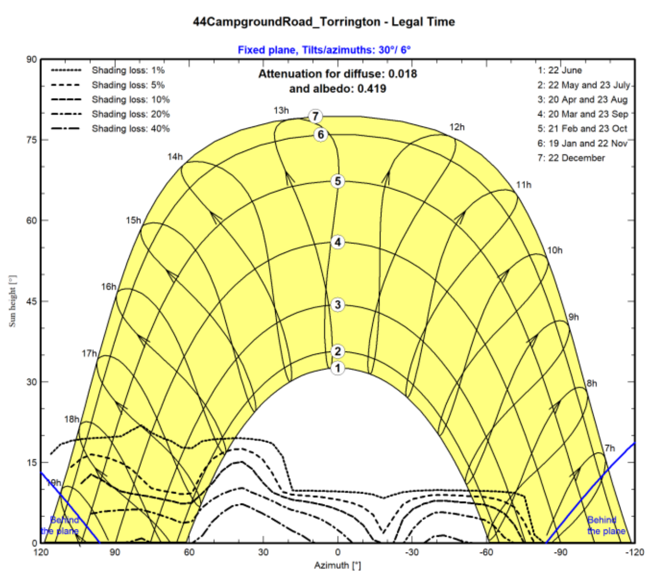

Figure 10: Near shading losses

Option 1 has a capacity of $1.6kW_p$, comprised of the 5 enerSOL modules that have already been purchased ($320kW_p$ each). The simulation made use of Sunways 1.5kW inverter, chosen because of its wide operating range that allows the relatively small system to drop to low voltages during peak heat or shading.

The system has a performance ratio of 77% along with a specific production of $1668kWh/kW_p/yr$. This results in an annual energy generation of 2669kWh per year (2.67MW/yr).

Figure 10 shows the predicted new average daily energy required by the grid combined with the daily energy supplied by the PV panels. The system is too small to make feeding energy back into the grid an option. This means that a bi-directional meter will not be necessary. However reverse power flow blocking will still need to be installed, as per the regulations of the municipality.

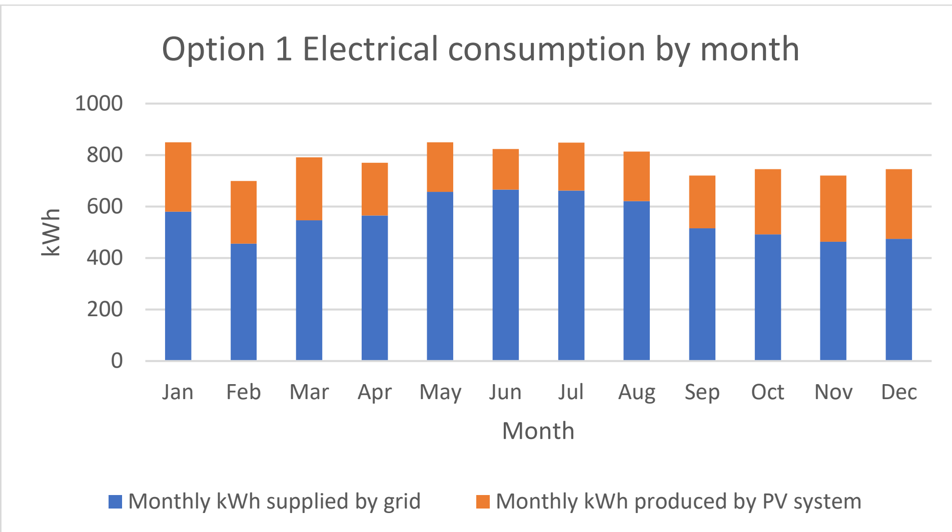

Figure 90: Option 1 composition of energy

The yearly total energy supplied by the grid is now 6655.54 kWh and the total yearly energy supplied by the PV system is 2669 kWh. The PV system is therefore suppling 28.62% of the household's electricity.

4.2. Solar modelling Option 2(Best case optimization done with Homer Pro)

The simulation inputs were aimed at mitigating the effects of loadshedding while optimising the financial viability of the system, focusing on the Levelized Cost of Energy (LCOE). Therefore, the simulation included 100 Grid outages with a mean length of 2hrs each. The household load was allowed an annual downtime of 1% to incentivise keeping the electricity on via a storage system.

The enerSOL PV panels that have already been purchased where limited to a max capacity of $1.6kW_p$ and given a capital cost of $R1000/kW_p$ to cover installation. Additional PV panels could then be purchased from a stepped cost format. Both the batteries and the inverter used a similar stepped format.

Homer Pro proposed two different systems as can be seen in table 2, system 1 having the lowest Net Present Cost (NPC) and LCOE. It does however require the highest capital investment at R43 281.73 due to the purchase of an additional $1.94kW_p$ of PV panels.

System 2 makes use of only the existing 1.6kW$_p$ of enerSOL solar panels that the client has already purchased. The installation of 2kWh of LI batteries will allow the client to use basic utilities and appliances during load-shedding. The batteries will be able to run lights, computers, and TVs. Bigger appliances such as the oven, geyser, washing machine will drain the battery very quickly, and it will be advised that they are not used during loadshedding

Table 1: Homer Pro Optimized results

Homer System	Existing PV (kW$_p$)	New PV (kW$_p$)	Battery Capacity (kW)	Converter (kW)
System 1	1.6	1.94	2	1.55
System 2	1.6	0	2	1.09

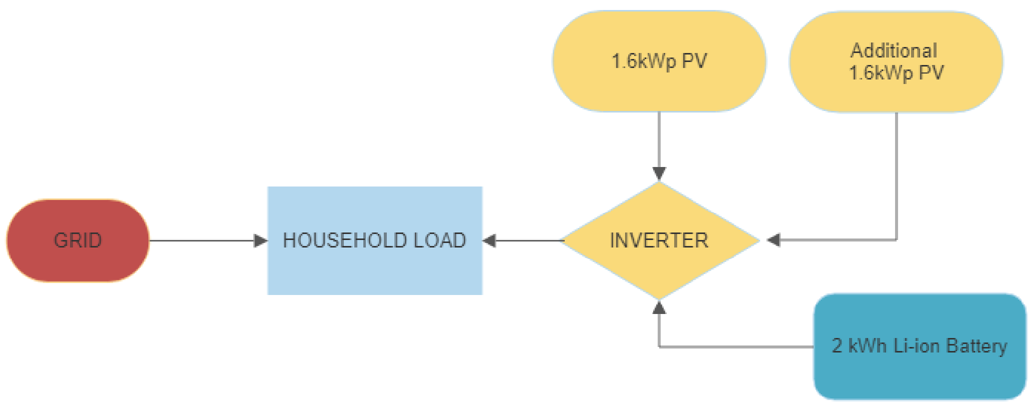

Figure 10: Option 2- System 1 summary

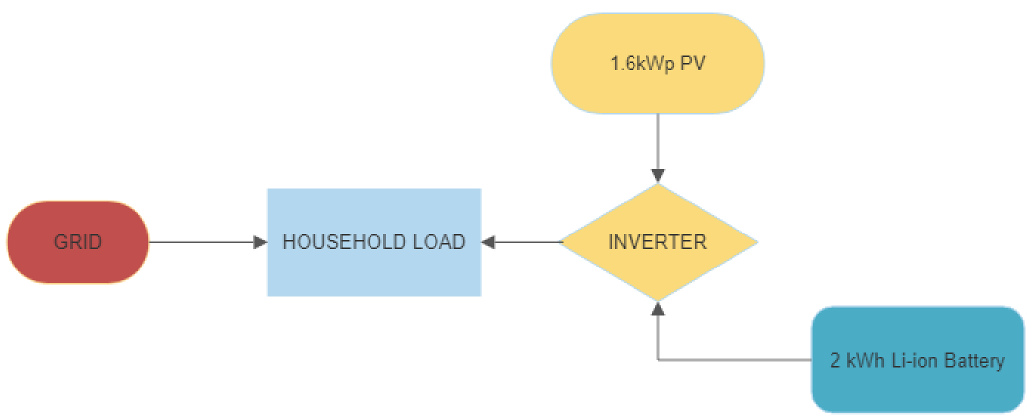

Figure 11: Option 2 - System 2 summary

Figure 13 provides a visual indicator of the state of charge for the Li-ion Batteries. The red indicates fully charged while the blue indicates empty. The system will only allow the batteries to discharge to 20% of their capacity. As can be seen they will be kept fully charged and mostly just used for loadshedding periods. They are also emptier during winter due to the PV not producing as much during the rainy season in Cape Town.

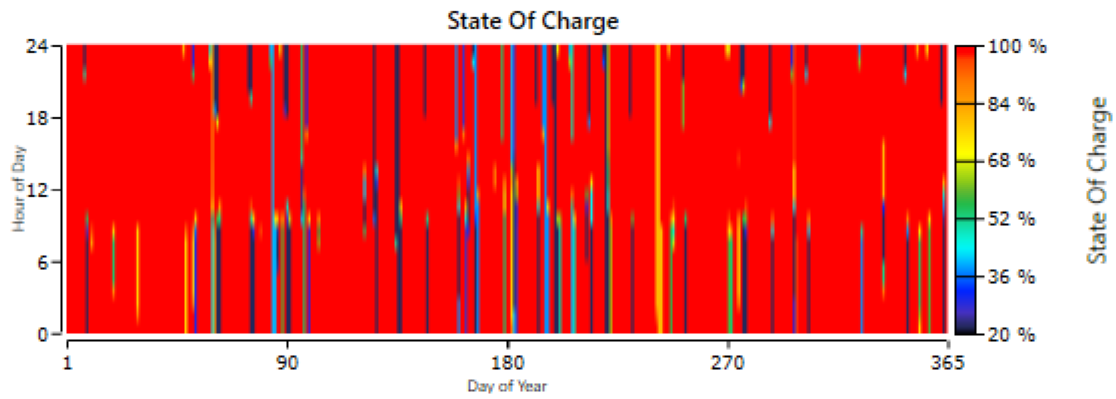

Figure13: Battery State of charge

The electrical characteristics of System 2 (1.6kW$_p$ Solar PV and 2kWh of storage) are similar to the characteristics of Option 1, discussed in section 4.1 (installation of 1.6kW$_p$ Solar PV only).

The rest of this section will examine the electrical properties of the Homer System 1 (1.6kW$_p$ Solar PV, additional 1.94kW$_p$ Solar PV and 2kWh storage)

Given the limited roof space, it is recommend to install a further 1.6kW$_p$ rather than 1.9kW$_p$ as the Homer sim indicates for a total of 3.2kW$_p$. As seen in the PVsyst render below. PVsyst has a more accurate Solar Resource model and PVsyst simulations indicate that the energy generated per kW$_p$ would be slightly higher than the Homer Pro simulations expect. Therefore, with a slightly lower PV capacity, the installation will be easier (one roof orientation), and the system does not need to compromise by putting extra panels in sub-optimal locations.

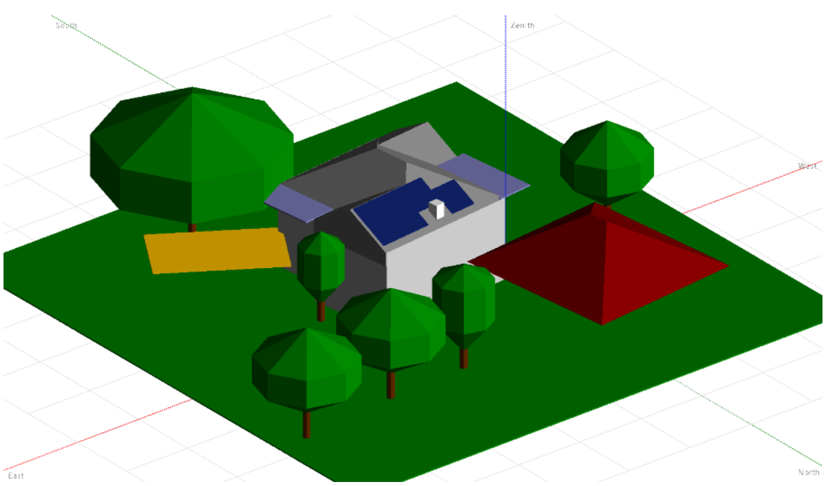

Figure 14: Placement of the 10 320Wp enerSOL panels

Figure 15 shows how during the summer months the system relies more on solar energy and during the winter months more heavily on the grid.

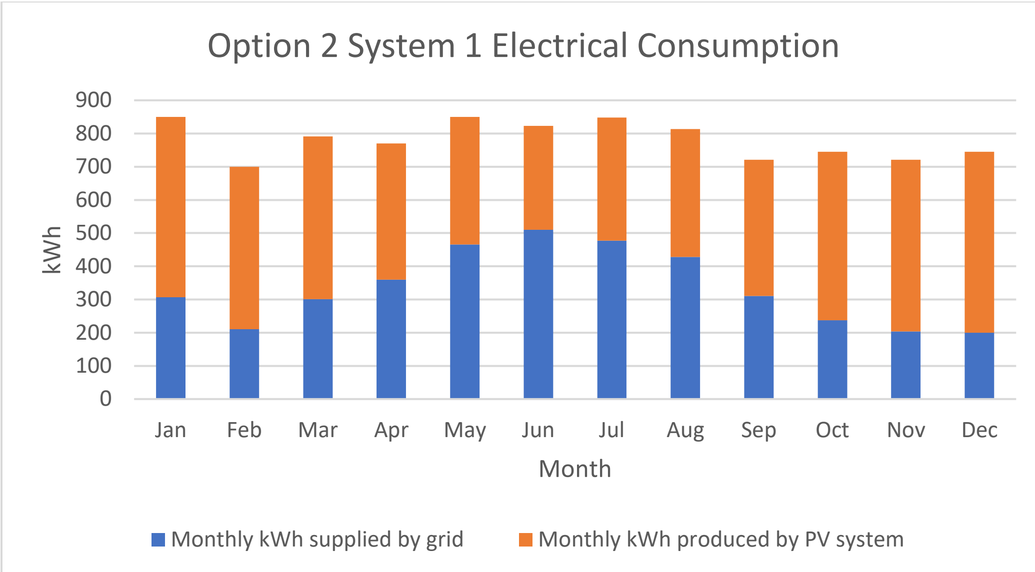

Figure 15: Option 2 - System 1 Grid and PV usage

This system is also too small to sell energy back to the grid and therefore only a reverse power flow blocking will need to be installed rather than a bi-directional meter.

5. Financial analysis

With a dramatic decrease in the price of PV installations over the last 10 years, solar PV has become a financially competitive option to conventional energy. Despite the high initial capital required for solar PV systems, their long life (20-25years) and low maintenance costs make them a good long-term investment that typically pay themselves off within the first 6-9 years. Money is saved by reducing the energy required from the grid, which has an exponential cost trend.

The first option that was examined is the installation of an inverter and the already purchased 1.6kW$_p$ of PV panels. This is the cheapest and simplest system that can be installed.

Option 2 we explore will be to find the system with the lowest NPC to optimize savings over the 20-year project lifetime, as well as mitigating the effects of loadshedding.

5.1. Electricity Tariff

The household at [redacted] is currently running a pre-paid meter with a staged tariff.

Table 2: Eskom Grid Structure

kWh Bracket	Cost per kWh
0-600 kWh	R2.09
600kWh <	R2.88

A peak demand charge has been excluded from the study as it was not included in the cost breakdown of electricity.

Homer Pro does not allow for staged tariffs. Once the 1.6kW$_p$ panels have been installed the system will very rarely go above a 600kWh usage. This means that the predicted costs will still be accurate. However, the simulations base case (no solar installed) will be a lower value than reality. This means that the actual savings should be higher than the predicted savings.

5.2. Input Parameters for Option 1

The system was analysed using a financial model. The inputs of the model included the proposed PV panels as well as typical grid parameters such as load shedding.

For the first option the model excluded all forms of storage and only simulated the financial model of installing the 1.6kW$_p$ of PV panels. These panels were modelled with a R1000/kW$_p$ capital investment as they have already been purchased and will only need to be installed. Inverters were modelled with a 15-year lifespan, and a staged cost as shown in Table 4. Table 5 summarises the remaining simulation inputs.

Table 3: Inverter staged cost

kW$_p$	**Capital (R)**	**Replacement (R)**	**Operating Cost (R)**
1	7 200	5 760	150
8	43 200	34 560	500

Table 4: Option 1 further inputs

Funding Scenario	100% capital funded
Inflation	6.0%
Project lifespan	20 years
Eskom shortages	Conservative estimate of 2 shortages per week for 2hrs each (104 2hr shortages per year)
PV degradation	Linear degradation to 80% of original production (1% per year)

Finally, we can see the results of the financial simulation in Table 6, along with the main system components.

The Net Present Cost includes the cost of purchasing the outstanding electricity from the grid.

Table 5: Option 1 Financial results

PV	1.6 kW$_p$
Inverter	1.10 kW$_p$
Net Present Cost	R238 254
Cost of Energy	1.72 R/kWh
Initial Capital	R9 322

5.3 Input Parameters for option 2

Additional PV panels and storage in the form of Li-ion batteries were included in the model. Inverters used the same pricing structure as for the simulation for Option 1. Load shedding was included in the simulation, with a maximum household annual capacity shortage set to 1%.

A summary of the simulation inputs can be found in Table 7, the results of which are shown in Table 10.

Table 7: Option 2 Simulation inputs

Funding Scenario	100% capital funded
Inflation	6.0%
Project lifespan	20 years
Eskom shortages	Conservative estimate of 2 shortages per week for 2hrs each (104, 2hr shortages per year)
Annual Capacity Shortage	1%
PV degradation	Linear degradation to 80% of original production (1% per year)

Table6: Homer PRO option 2 Simulation results

Homer System	Existing PV (kW)	New PV (kW)	LI ASM (kW)	Converter (kW)	Cost/NPC (R)	Cost/COE (R)	Cost/Initial capital (R)
System 1	1.6	1.94	2	1.55	237 903	1.70	43 932
System 2	1.6		2	1.09	254 186	1.82	25 268

The proposed Homer Pro System 1 has an even lower NPC at R237 903 and a much higher renewable penetration of 37%. However, it does come with the high initial capital of R43 932. As mentioned above in the solar modelling section, given the available obstructed north facing roof and for ease of installation I would recommend installing the existing 1.6kW$_p$ PV panels and a further 1.6kW$_p$ rather than 1.9kW$_p$.

Conclusion

The study outlined three viable systems that could be implemented.

Option 1:

Installation of the existing 1.6kW_p PV panels with no storage. (Grid Tied)

This option has a comparable NPC of R238 254. Its major advantages are the low initial capital required. The only further expenditure is the purchase of an inverter at about R 9 322 and installation fees.

The major disadvantage is that it does not have any form of storage and therefore does not help to mitigate the effects of load shedding as electricity from the PV panels will not be available when the grid is offline.

Option 2

System 1

Installation of a total 3.2kW_p PV, an inverter and a 2kWh storage system. (Hybrid Battery Grid system)

This is the option with the lowest NPC at R 237 903. The major advantage of the system is that the storage and panels will allow for the use of most appliances and lighting during loadshedding. As well as having a high Renewable penetration of 37%, lifting some load off the coal industry.

The major disadvantage is the high initial cost of R 43 932 to purchase the extra equipment.

System 2

Installation of the existing 1.6kW_p PV, an inverter and 2kWh storage. (Hybrid Battery Grid system)

This system has the highest NPC at R 254 186. The added storage is purely to help mitigate the effects of loadshedding.

This system has an initial capital of R25 268.

PV Installation

There are many companies based in cape town that do home PV installations. The PV Green Card system has been developed to ensure that installers meet safety and regulation requirements. Ensure that your chosen installer has been PV green card certified.

References and Software:

Don Fitzgerald, (2019) PPS Solar Advisory, CRSES

Homer Pro, 2020, Version 3.14.3 [Software]

PVsyst,2020, Version 7.0 [Software]

SolarGIS Prospect, 2021, Version 1.1 [Software], https://apps.solargis.com/prospect/map?s=-33.966999,25.6