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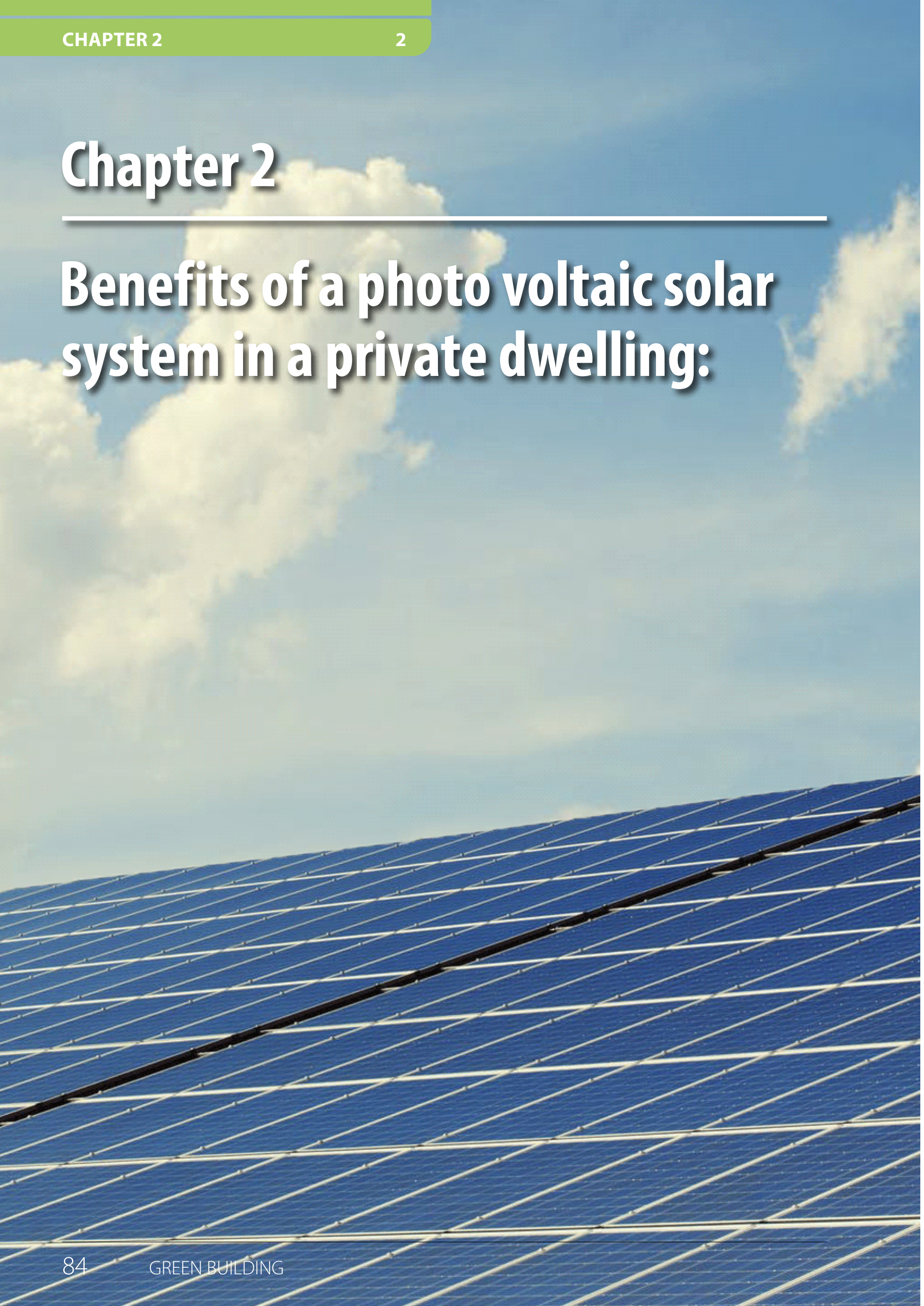


Chapter 2

Benefits of a photo voltaic solar system in a private dwelling:

1. Introduction

South Africa is experiencing an electricity crisis which started in 2008 when the nationally dominant energy supplier, Eskom, announced that it needed to shed load to cope with the energy demand. Eskom generally needs to have at least 15% of its generation capacity in reserve for the network to remain stable according to the local press (News 24, 2020).

The subsequent rolling blackouts caused a crisis in the South African economy and even before the advent of Covid-19; annual growth was projected to be as low as 0.5% (Businesstech, 2020a). Subsequently South Africa has been downgraded by Moody's Investor Service (the last institution that graded South Africa above junk status) to below investment grade (Businesstech, 2020b).

The rolling blackouts or load shedding has had a serious effect on business and households. Many small businesses were struggling due to a lack of ability to operate or having to operate with emergency generators at significant cost.

The advent of the Covid-19 pandemic in South Africa in March 2020, and lockdown, caused energy demand to drop, the reduction estimated to be between 7500 MW and 9000 MW, and hence no blackouts were experienced (IOL, 2020). However, pressures returned as the economy opened up in June/ July 2020. Due to remaining effects of Covid-19, Eskom may not be able to deploy its full staff complement due to social distancing regulations (IOL, 2020). This could exacerbate the energy supply situation.

Worldwide there has been a move towards alternative, green energy sources including solar and wind harvesting accounting for about 30% of all energy use by 2040 (IEA, 2019c). The use of solar energy in private dwellings has been documented by a number of authors. A study on the effectiveness of solar thermal heating of houses in five European countries showed that the results can differ widely and are dependent on the type of solar system and the local weather in the country (Louvet et al. 2019).

The use of a hybrid photovoltaic (PV) and thermal storage system in houses was discussed by Huang et al. (2019). They found that the dual storage system utilising both batteries and a hot water thermal storage system is effective when partially replacing energy demand in a house. Kolendo and Krawczyk (2018) found that the performance of solar systems in houses depend on the solar potential of the geographic location, the sun exposure, the slope of the roof and the shape of the roof.

This paper describes the performance of a solar system in a private dwelling in Pretoria situated in the Tshwane Municipality, South Africa and analyses the efficiency and efficacy of the system, as well as the benefit obtained.

2.Literature

South Africa is not the only country with an energy crisis. This is a global problem. The literature review aims to highlight the benefits of renewable energy sources and the barriers to implementation, with a focus on solar energy.

2.1. Energy challenge

The continued increase in the global energy demand coupled with stagnant oil production, price instability, economic growth and an awareness of the health and environmental implications of releasing greenhouse gasses into the atmosphere has led to a multifaceted and complex energy problem (Kumar et al., 2010; Markides, 2013). Renewable energy sources offer solutions to many of these problems by providing a secure and reliable energy supply with lower carbon emissions (Ramos et al., 2017). Renewable energy sources, however, only supplied 26% of the world's total energy in 2018 (IEA, 2019a). Therefore, the development of these renewable clean energy sources should be a top priority.

The building sector is one of the sectors with the highest demand for energy. Buildings consume about 40% of the primary end-use energy in both the USA and European Union (Communities Commission of the European, 2006; Li and Wen, 2014b, 2014a) and account for nearly 40% of the total direct and indirect CO2 emissions globally (IE, 2020). This makes buildings and the building construction sector, sources of unexploited energy efficiency.

One of the main focuses in residential buildings has been reducing energy consumption and increasing energy performance through sustainable building designs (Tam et al., 2017). Coupling this with the introduction of renewable energy sources has led to the development of energy efficient buildings.

Where energy efficient buildings draw energy from outside equal to or less than the energy produced on site, these buildings are known as Zero Energy Buildings (ZEB) (Carrilho da Graça et al., 2012). Several renewable energy systems are available for buildings including small wind and hydro electrical generators and solar panels (thermal and electric). Globally extra effort, on a technological and political front, have been directed to solar energy systems due to their potential to deliver clean sustainable energy (Tam et al., 2017).

2.2. Solar energy system classification

According to Timilsina et al. (2011) solar energy systems can be classified into the following continuum:

- Passive and active;
- Thermal and photovoltaic; and
- Concentrating and non-concentrating.

Passive solar energy systems collect energy without altering the heat or light into any other form, for example through the design of a building maximizing the use of daylight or heat (Bradford, 2006). Active solar energy systems harness solar energy by transforming or storing it for other applications and can be classified into photovoltaic (PV) or solar thermal systems.

PV systems transform radiant energy into electrical energy when light falls on a semi-conductor material. Crystalline silicon-based PV cells and thin film technologies with different semi-conductor material are the types of PV systems available in the market today. In contrast, solar thermal systems use heat from the sun for direct heat or thermal application or electricity generation (Timilsina et al., 2011). Over the past few years researchers have also developed a hybrid photovoltaic-thermal (PV-T) systems.

PV-T system help to maintain a low cost of solar energy production by maximizing the energy generated per square meter of roof coverage. This system generates both useful thermal energy and electricity from the same contact area. It can also be integrated with conversion or energy storages devices to provide multiple outputs (Ramos et al., 2017).

2.3. Advantages of using solar energy

From a primary energy perspective , solar energy is abundant, sustainable and clean (Ramos et al., 2017).

It addresses the energy problem on an economic, health, environmental and security level (Xiang et al., 2018).

The potential annual technical energy supply that can be generated from solar energy is significant, especially in Sub-Sahara Africa where there is an abundance of annual clear sky irradiance and clearance with large patches of available land. From Table 1 it is clear that the technical potential solar energy supply in Sub-Sahara Africa alone is significantly greater than the primary energy demand for the whole of Africa.

Table 1: Annual technical minimum and maximum potential of solar energy and primary energy demand in Million tonnes of oil equivalent (Mtoe) (Timilsina, Kurdgerlashvili and Narbel, 2011; IEA, 2019b)

	Annual technical minimum	Annual technical maximum	Primary energy demand 2008	Primary energy demand 2018	Primary energy demand 2040
Sub-Sahara Africa	8 860	227 529	505	-	-
Africa	-	-	-	831	1300

Solar energy systems are also resilient to political instability and oil or gas price fluctuations since their cost is an upfront investment and running costs for operation and maintenance is minimal (Ramos et al., 2017). Solar PV systems can operate for more than 20 years with little deterioration.

For example, researchers have observed only a 0.5% power output loss per year on average (Jordan and Kurtz, 2013).

A study comparing life cycle costing effectiveness of PV solar systems for residential dwellings in eight major cities in Australia, conducted over 25 years, found significant financial saving for residential owners. The study showed that all residential owners not only covered the initial installation cost, but also benefitted from the life cycle cost saving within the first 15 years (Tam et al., 2017). The researchers observed savings of between $273 (R 2 730) and $53 021 (R 530 210) on the life cycle cost, with percentages of between 0.35% and 123%. Capacity ranges of the PV systems investigated were 1.5kW to 5 kW in relation to the number of occupants in the dwelling and the researchers compared different types of grid connections. These grid connections included gross-feed-in-tariff (GFIT)2 , net-feed-in-tariffs (NFIT) and a buy-back scheme.

In Tehran a four-member family home, utilizing both passive and active solar energy strategies, was investigated by Eshraghi et al. (2014). The annual electricity consumption was 4 105 kWh while the electricity generated by solar system was 11 543 kWh. The household sold the excess electricity to the grid. An economic analysis conducted by the researcher found that with the price of electricity close to that of the European Union and interest rates at 4.9%, the payback period for this system was 10 years. Unfortunately, due to high interest rates and low price of energy in Iran the researchers deemed the investment in this system as unjustified. For South Africa, this may not be the case, due to the instability of electricity supply due to the rolling blackouts as well as the expected increase in electricity prices over the next few years.

Usually financial gains are achieved through limited or no interaction with the electricity grid, known as self-consumption or independence, in other words the user generates the energy required onsite, thus reducing the electricity bill (Ramos et al., 2017).

In conclusion, the increased focus on climate change caused by carbon emissions and the looming energy crisis in some countries make solar power systems attractive and they can assist in solving the problem. Household solar systems may hold the key to success, due to the high demand buildings place on energy supply. Household solar systems will not only help solve the problem but hold many benefits for operators of distribution grids and the household itself.

The benefits for individual households, which include stable energy supply and financial gain, depend on many factors. These include the type of grid connection, energy storage devices, geographical location and climate, to name just a few. This case study enhances understanding of the potential benefits that can be obtained from a solar system in a private dwelling.

2.4. Forecasting of PV generation

Meteorological factors such as atmospheric and module temperature, humidity, wind pressure, wind direction and solar irradiance play a major role in the generation of PV power. Variability of environmental factors results in power output changes for PV systems; this therefore, makes forecasting PV power generation difficult. Accurately forecasting power generated by PV systems can reduce uncertainties of PV power on the grid, maintain the quality of the power, ensure system reliability and increase the infiltration level of PV systems. Two broad classes for forecasting models exist namely direct and indirect models (Das et al., 2018).

For the indirect model, researchers forecast solar irradiance on different time scales by using methods such as statistical, image-based and hybrid artificial neural network (ANN) or numerical weather prediction (NWP) (Hocaoglu et al., 2008; Mellit and Pavan, 2010; Capizzi et al., 2012; Wang et al., 2012; Tanaka et al., 2013). The predicted solar irradiance is input data for commercial PV simulation software packages that include for example TRNSYSM, HOMER and PVFORM (Dalton et al., 2009). Industry then uses these software packages to forecast power generation by PV systems. The direct model, on the other hand, forecasts power generation by PV systems directly using historical data samples that include meteorological and associated PV power output data (Das et al., 2018).

Using both direct and indirect methods, Kudo et al. (2009) showed that the direct method was better at forecasting the next-day power generation of a PV system. Direct forecasting can therefore achieve accurate forecasting of the power generated by PV systems and a comprehensive literature review on short-term direct forecasting was conducted by Das et al. (2018). The authors emphasized the importance of the correlation between input (meteorological) and output (PV power generation) values for an accurate forecasting model. PV output and meteorological data can contain peaks, non-stationary components and gaps that may result in forecast errors.

To overcome this, preprocessing of input data is required and using one of several available methods. These include normalization (Das et al., 2018), stationary, historical lag identification (Raza et al., 2016), wavelet transform (WT) (Das et al., 2018), trend-free time series (Azadeh et al., 2007), and self-organizing map (Yang et al., 2014). Solar data is usually subjected to both preprocessing and post-processing.

For PV power forecasting anti-normalization and wavelet reconstruction are the most popular methods (Das et al., 2018).

PV power forecasting methods can be classified into four types based on historical PV power generation outputs. These include (1) persistence, (2) statistical, (3) machine-learning and (4) hybrid methods (Figure 1).

Persistence models are used as a benchmark and only use PV power output data for forecasting. In this model, the PV output is equal to the output of the previous day at the same time interval and for similar sunny weather (Das et al., 2018). The accuracy for this model decreases significantly with time intervals greater than one hour and increased cloud cover (Diagne et al., 2013).

The statistical method uses statistical analysis to forecast power generation using different input variables. Autoregressive moving average (ARMA) and Autoregressive integrated moving average (ARIMA) models are examples of linear statistical methods. ARMA extracts statistical properties form stationary time-series data while ARIMA can handle non-stationary data (Reikard, 2009).

Machine-learning models are intelligent and can handle linear, non-linear and non-stationary data patters. This model however requires larger data sets compared to persistence and statistical methods to forecast accurately (Das et al., 2018). Artificial neural network (ANN) method is an example of a machine-learning model. This method is popular due to its increased accuracy, self-adaptively, robustness, fault-tolerance and inference capabilities (Yang et al., 2014). Despite this, the method is complex due multi-layered network architecture and may have a reduced reliability due to its requirement of a random initial data set (Das et al., 2018).

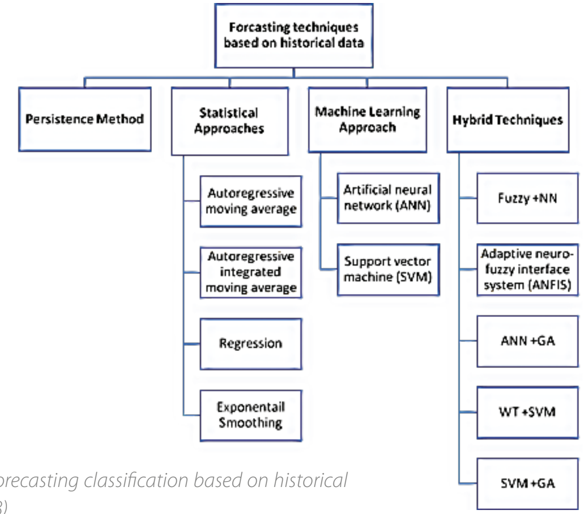


Figure 1: PV power forecasting classification based on historical data (Das et al., 2018)

3. Method

The article describes a case study of a solar electricity supply system installed in a private dwelling in Pretoria), South Africa (coordinates: – 25.774202, 28.343655). The solar panels are orientated North 40o East, at a 26.5o elevation. The output and usage of the electricity from the system was recorded over a one-year period and analysed. Weather data from a weather station 2 km away was obtained and analysed to determine correlation of weather variables with PV generation on an hourly basis. The available data over a 12-month period was used to develop a model for PV generation forecasting.

This model was constructed using the following variables:

- Ambient temperature;
- Cloud opacity;
- Global Horizontal Irradiance;
- Global Tilt Irradiation (GTI) Fixed Tilt, and
- GTI Sun Tracking.

Global Horizontal Irradiation/Irradiance (GHI) is the sum of direct and diffuse radiation received on a horizontal plane. GHI is a reference radiation for the comparison of climatic zones; it is also essential parameter for calculation of radiation on a tilted plane.

Global Tilted Irradiation/Irradiance (GTI) is the total radiation received on a surface with defined tilt and azimuth, fixed or sun-tracking. This is the sum of the scattered radiation, direct and reflected. It is a reference for photovoltaic (PV) applications and can be occasionally affected by shadow.

The temperature variable was included because high temperatures have a negative effect on PV generation and PV output can be reduced by 10 to 25% in high temperatures (CED Greentech, 2020).

The PV generation forecast model was used to predict PV generation for the past five years (2015 to 2019). It was assumed that the PV generation pattern for the next five years from 2019 to 2024 and beyond would be similar. This forecasted PV generation was then used to calculate the savings potential from the installation, as well as to estimate annual economic benefit, to allow the calculation of the payback period for the investment into the installation.

The average PV "sold" back to the grid was used to calculate potential direct savings. Total direct savings were then used to calculate the potential payback period for the installation. Indirect benefit for the occupants was calculated by attaching an economic value to the hours of electricity supply during rolling blackouts.

The research method included:

- Review of literature;
- Description of system;
- Recording of data using the Goodwe Sems portal for 12 months;
- Data analysis and development of prediction model;
- Prediction of potential PV generation over a five year period;
- Benefit cost analysis;
- Analysis of functional performance, and
- Analysis of lessons learnt.

The research question was:

What is the payback period for installation of a PV power generation system at a dwelling in Pretoria and what is its efficiency?

4. Description of the system

4.1. Hardware

The installed system is depicted in Figure 2. It consisted of the following:

- 12 photo voltaic polycrystalline panels – Canadian Solar CS6U 325;
- One Goodwe inverter with 4,6 kW output – GW5048D-ES;
- Two Pylontech lithium batteries – US 2000 2,4 kW (later upgraded to four batteries), and
- One solarised geyser – Geyserwise TSE.

Although the dwelling contains two hot water geysers, the second geyser serves only the guest bathroom and it was decided that it was not cost effective to solarise this. Furthermore, due to the fact that the inverter can only deliver a maximum of 4,6 kW, the scullery, stove and second geyser remained connected directly to the Eskom grid only. This ensures that the inverter is not overloaded when, for example, ironing and using the kettle at the same time. If the inverter is overloaded, it cuts all power and then re-boots after 10 minutes provided that an external power source is available (solar panels or grid power). When the grid power is off and there is no solar energy available the system will remain dormant until either source is restored.

The inverter was set to draw emergency power from the Eskom grid as well as to allow feedback into the grid. This was fortunately allowed due to the "dual way" meter installed at the dwelling in the complex and allowed by the home-owner's association and the electricity metering company. In essence electricity was therefore used by the other houses in the complex and not fed back directly into the municipal supply. The Goodwe inverter is supplied with a "dongle" that allows for Wi-Fi connection to the dwelling's internet.

The inverter needs to be no more than five metres from the internet Wi-Fi source to allow for connection.

4.2. The SEMS portal

The Goodwe inverter is supplied with a portal (and associated mobile application) that records performance data of the system through the Wi-Fi connection that can be downloaded and analysed. Several standard graphs are available on the system. These are described below.

Figure 3 shows the landing page of the SEMS mobile at where the PV generated during the day is shown. The dips in the curve indicate periods of cloud cover. The page also shows the real time status of the system including PV generation and power consumption. This graph can also be displayed for the past month or year.

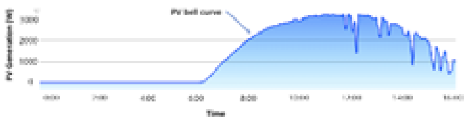


Figure 3: SEMS application front page PV generation curve

The second page in the SEMS application is shown in Figure 4. It contains information on:

- Continuous PV generation for the day (blue curve);
- The state of charge (SOC) of the batteries (green curve);
- The total power consumption at the dwelling (purple curve);
- The meter reading (yellow curve) which can be negative when power consumption is more than the PV supply or positive if the PV supply exceeds consumption, and
- The power used to recharge the batteries (lilac curve).

The graph indicates two periods of load shedding. The first during the day when the PV supply was used for the consumption in the dwelling and the second during the night when the batteries were used to supply power to the dwelling. The green curve during the second period of load shedding indicates the drop in battery SOC and the subsequent increase when the batteries were charged from the grid after the load shedding period. It should be noted that, when the grid is down, the Goodwe inverter automatically doesn't push excess power back to the grid for safety reasons.

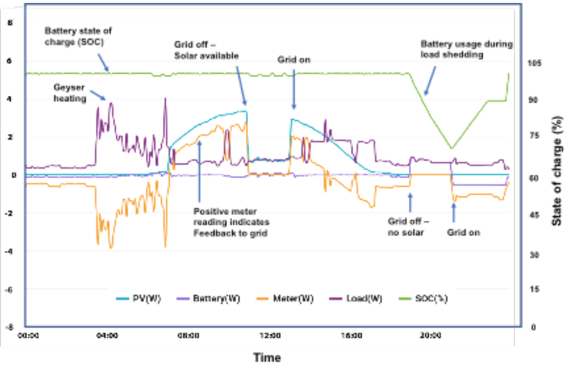


Figure 4: SEMS App graph indicating generation and usage in the system

Figure 5 shows the performance data of the system on a day where there was a prolonged grid supply break of about 12 hours due to a fault on the grid.

During this period the SOC of the batteries (two Pylontech batteries at that stage) dropped to almost 45%. From this data is can be seen that the system was able to supply continuous power during such an event. In the period from 4 pm to 9 pm the batteries used 50% of their capacity of 4,8 kW storage to supply the house.

The Pylontech batteries cannot be discharged to a level of more than 10% of SOC, which implies that the system should be able to supply power for about 7 to 8 hours using only fridges, lights, TV and the kettle.

5. Forecasting of PV generation

In this case study, one year's worth of data was considered, which was insufficient for a machine-learning model, which requires large data sets. The authors thus opted for a statistical method, which required basic computations to give a benchmark forecast. In future projects and with more data, the authors aim to evaluate other models based on the results obtained from this simplistic model.

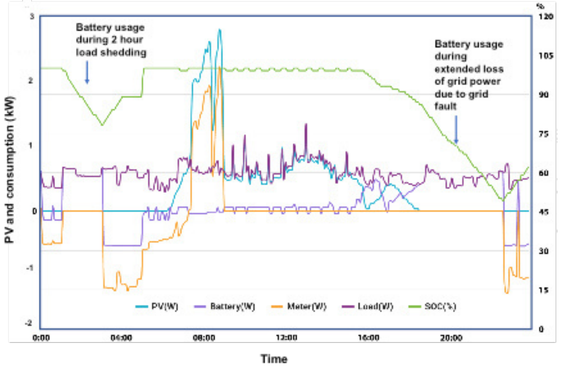


Figure 5: System performance during a prolonged grid fault

The SEMS App also allows for display of daily data over a month and monthly data over a year as depicted in Figures 6 and 7.

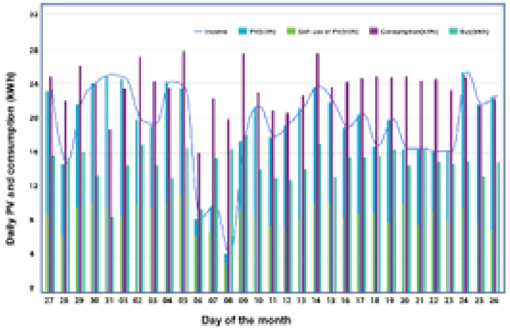


Figure 6: Daily display of PV generation, self-use and consumption

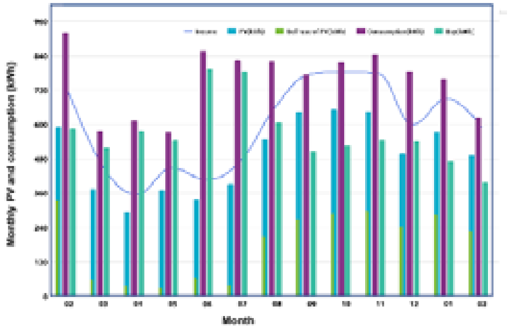


Figure 7: Monthly display of PV generation, self-use and consumption

The weather data collected from a weather station near the dwelling was analysed to determine possible variables that can be used to predict PV generation.

A Python pvlib software library was used to determine a heat map of correlation between PV generation and the variables. The heat map indicated some correlation between PV generation and the following weather variables:

- Ambient temperature;
- Cloud opacity;
- Global Horizontal Irradiation (GHI);
- Global Tilt Irradiation (GTI) – Fixed Tilt, and
- GTI Sun Tracking.

These variables were used to conduct a multiple linear regression analysis in order to build a model that can forecast the PV generated based on the weather variables. The results from the multiple regression analysis are shown in Table 2.

Regression Statistics	
Multiple R	0.858471
R Square	0.736972
Adjusted R Square	0.736581
Standard Error	0.511743
Observations	3369
Variable	Coefficient
Intercept	-1.15117
Tamb	0.059057
Cloudopacity	-0.00134
GHI	0.000944
GtiFixedTilt	0.001943
GtiTracking	-0.00055

The 3 369 observations represent the hourly data of PV generation obtained from the SEMS portal when PV was generated (i.e. daytime) and correlated with the corresponding weather data. The R2 value of 0.74 is deemed sufficient for an estimate of the PV generated. The actual measured PV generation vs the predicted PV generation is plotted in Figure 8.

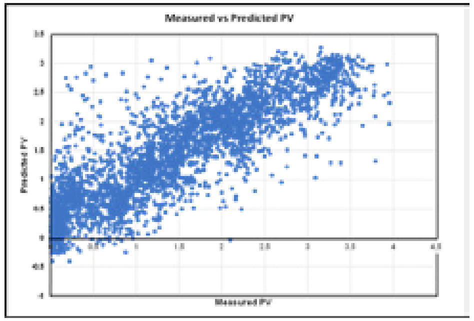


Figure 8: Measured vs predicted PV generation

The model presented in Table 2 was used to calculate predicted monthly PV generation over a 5-year period from 2014 to 2018. The result is depicted in Figure 9 and in Table 3.

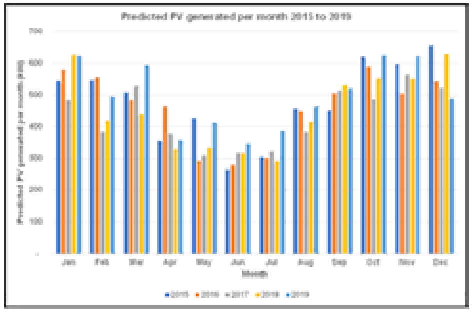


Figure 9: Predicted PV generation based on model in Table 2

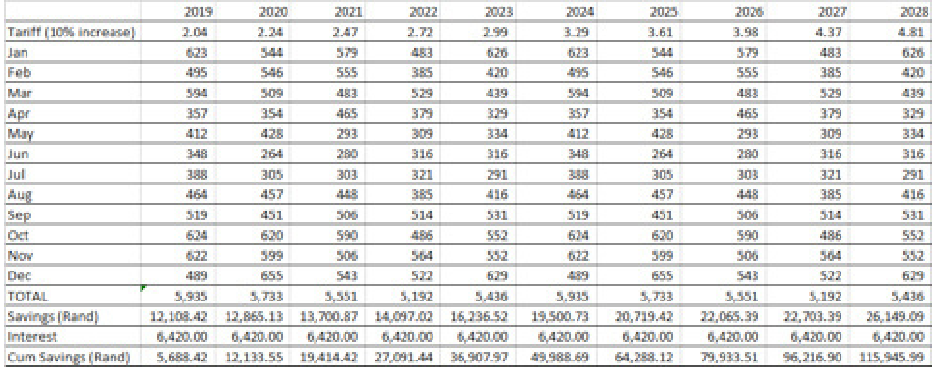
	2015	2016	2017	2018	2019
Jan	544	579	483	626	623
Feb	546	555	385	420	495
Mar	509	483	529	439	594
Apr	354	465	379	329	357
May	428	293	309	334	412
Jun	264	280	316	316	348
Jul	305	303	321	291	388
Aug	457	448	385	416	464
Sep	451	506	514	531	519
Oct	620	590	486	552	624
Nov	599	506	564	552	622
Dec	655	543	522	629	489

Table 3: Detail predicted monthly PV generation from 2015 to 2019 (kW)

The data in Table 3 was then used to calculate the savings due to the self-use of PV power generated and "selling" of PV power back to the grid. The cost of electricity in Tshwane municipality in 2019 was R2.04 per kWh at the location of the dwelling. Eskom has repeatedly asked for significant increases in electricity tariffs and it is expected that electricity tariffs will increase by more than 10% per annum over the next few years and municipalities have been warned to budget for a 15% increase (IOL, 2020b).

The break-even point was calculated for 10% and 15% electricity cost increase respectively. The interest lost due to the investment was calculated at 6% per annum. The savings due to PV power generation is indicated in Table 4 assuming a 10% or 15% annual increase in electricity cost. The initial cost of the system in 2018 was R 107 000 excluding the solar geyser. The break-even point calculations are shown in Figure 10.

Table 4: Savings due to PV self-use and "sell" to the grid at 10% increase of cost of electricity (Rand)



	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Tariff (10% increase)	2.04	2.24	2.47	2.72	2.99	3.29	3.61	3.98	4.37	4.81
Jan	623	544	579	483	626	623	544	579	483	626
Feb	495	546	555	385	420	495	546	555	385	420
Mar	594	509	483	529	439	594	509	483	529	439
Apr	357	354	465	379	329	357	354	465	379	329
May	412	428	293	309	334	412	428	293	309	334
Jun	348	264	280	316	316	348	264	280	316	316
Jul	388	305	303	321	291	388	305	303	321	291
Aug	464	457	448	385	416	464	457	448	385	416
Sep	519	451	506	514	531	519	451	506	514	531
Oct	624	620	590	486	552	624	620	590	486	552
Nov	622	599	506	564	552	622	599	506	564	552
Dec	489	655	543	522	629	489	655	543	522	629
TOTAL	5,935	5,733	5,551	5,192	5,436	5,935	5,733	5,551	5,192	5,436
Savings (Rand)	12,108.42	12,865.13	13,700.87	14,097.02	16,236.52	19,500.73	20,719.42	22,065.39	22,703.39	26,149.09
Interest	6,420.00	6,420.00	6,420.00	6,420.00	6,420.00	6,420.00	6,420.00	6,420.00	6,420.00	6,420.00
Cum Savings (Rand)	5,688.42	12,133.55	19,414.42	27,091.44	36,907.97	49,988.69	64,288.12	79,933.51	96,216.90	115,945.99

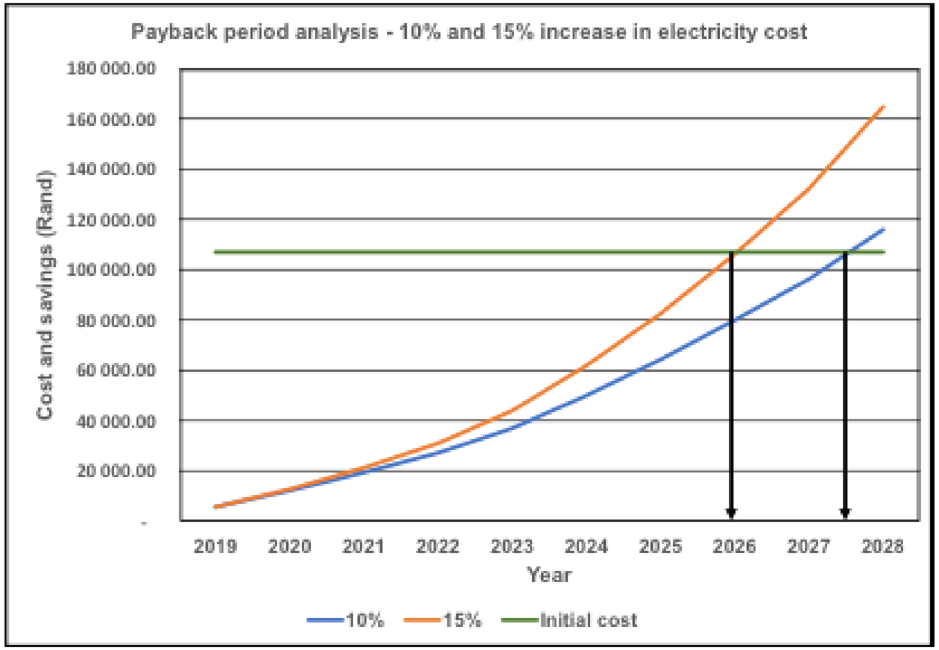


Figure 10: Calculation of payback period

As indicated in Figure 10, the payback periods calculated for 10% and 15% electricity increase are 8 years and 9.5 years respectively. There was also significant additional financial advantage in that the owners of the dwelling could continue with daily operation and work (work from home) during lockdown, load shedding and break downs of the grid.

This benefit is difficult to estimate and accurate data on hours of load shedding per annum is not readily available. However, it was reported that in 2015 for example there was about 247 hours of load shedding (News 24, 2019). If 30% of these were in working hours, that equates to 82 production hours lost in one year.

The results for this study correlate well with the findings from other studies mentioned in the literature review. Homes studied in Australia showed a pay-back period under 15 years and the study in Tehran showed a pay-back period of 10 years (Eshraghi et al., 2014; Tam et al., 2017). The household in Tehran needed a loan to install their system, this was not needed in the Pretoria example studied and a cost of 6% per annum was assumed for loss of interest on the amount invested.

6. Functional performance

Over the analysis period of 18 months the system performed very well for the greater part. During many load shedding periods and a few grid breakdowns constant power supply was available to the dwelling.

This allowed occupants to continue working with significant economic benefit.

A few aspects of the system performance can be improved. These are discussed below:

6.1. Overloads

The inverter can deliver a maximum of 4,2 kW. Ironing clothes while boiling the kettle therefore leads to a power cut from the inverter. If either solar power or the grid power is available, it will then automatically reboot in about 10 minutes. However, at night time when there is no solar power available and the grid is off, the system will not reboot irrespective of available battery power. This could be improved.

6.2. Geyser timer

The solar geyser operates from a pump that is driven by a small PV panel. As soon as the sun is up in the morning the pump therefore starts running. However, in summer this can be as early as 6 a.m. The water in the solar geyser heating system at that point in time is cold, which implies that the hot water in the geyser (generated using the grid during the night) then becomes cold. A similar problem occurs in the afternoon. The hot water in the geyser becomes cold when the pump continues running after 4 p.m. due to the cooling of the water in the solar geyser thermal heating system. The problem was solved by adding a timer to the power supply between the small solar panel and the geyser pump. The timer was set to run the pump from 9 a.m. to 3 p.m.

6.3. Battery back-up time

The initial two Pylontech batteries provided about 4,3 kW (at 90% discharge level) of stored power. Whereas this is more than adequate for load shedding, it could be insufficient during longer grid break down periods.

Consequently, after about 12 months of operation, two extra batteries were added to the system. This provides sufficient power to ensure that operations, including work-from-home, could continue uninterrupted.

6.4. Wi-Fi connection

The inverter connects to the dwelling's Wi-Fi through a Wi-Fi radio module. Significant problems were experienced with this connection initially, with numerous data transfer breaks although it did not influence power supply to the dwelling.

The problem was alleviated by replacing the radio module which improved the performance significantly.

On occasion, when the system trips or if the dwelling Wi-Fi router is reset, the connection is lost and then needs to be restarted. This restarting process involves the disconnection of the radio module from the system for at least 10 minutes and then restarting using the phone application. On occasion it was required to systematically shut down the whole system and then restart it after 10 minutes before the Wi-Fi reconnected to the router.

Some of the connection problems were alleviated by laying a network cable from the router to a position close to the inverter and setting up an access point so that the Wi-Fi signal is transmitted over a very short distance.

This could be improved by adding a network cable plug-in option to the inverter.

7. Concluding remarks

This case study showed that a solar power energy system is a viable investment option for this private dwelling in Pretoria, South Africa. Not only will the system likely achieve the payback period within a reasonable time, but additional benefits included the possibility to work during grid failure or load shedding. In the process, a benchmark solar power forecasting model for this system was developed that can be improved and refined as more PV data is generated in the coming months and years. Overall, the system performed very well, with only a few minor improvements suggested.

Despite the evident benefits from a system like this some barriers exist for households to adopt this technology. The initial installation cost remains high and not all South African households have the ability to invest in such a system. The authors suggest investigating financial incentives used by other countries to improve the infiltration of this technology. Another barrier to consider is that not all grid connections in South Africa allow for electricity feedback to the grid.

A change in regulation for "selling" of electricity to the grid can assist in alleviating South Africa's energy crisis. As load shedding and break downs continue in South Africa, solarising a private dwelling becomes an attractive option due to the additional benefits of continuous power supply obtained.

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