Cape Peninsula
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Design and Assessment of Net Zero Energy for Industrial Buildings

by

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DECLARATION

I, Christopher Moult, declare that the contents of this thesis represent my unaided work and that the thesis has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my own opinions and not necessarily those of the Cape Peninsula University of Technology.

17th of January 2023

Signed **Date**

Abstract

The level of greenhouse gases (GHG) that are present in our atmosphere are alarming. These gasses, carbon dioxide, CFCs, and others, many of which are released by burning fossil fuels and organic materials, have built up in the earth's atmosphere. The increasing levels of pollutant gasses in the atmosphere has precipitated the phenomenon known as the greenhouse effect, this in turn has caused Global warming which is affecting the planet's weather. The disastrous effects of climate change caused by the build-up of "greenhouse" gasses and global warming affects our world in many ways, such an unfavourable weather conditions like floods, drought and rising sea levels.

As the global population increases so does the potential of more harmful gas emissions being emitted into the atmosphere. As more factories are built to cater for these growing demands, these factories consume more power and more natural resources to fulfil the populations' wants and needs. Natural vegetation, which absorbs carbon dioxide and emits oxygen, is being removed to make space for these factories, new houses, and other services. This fact that vegetation can no longer process the quantity of carbon dioxide humans pump into the atmosphere is a key contributor to Global warming. Furthermore, Eskom has one of the worst emissions per kilowatt hour (kWh) in the world due to the coal consumption of its power stations, many facilities emitting large amounts of greenhouse gases and thus resulting in a high carbon footprint. To aid in the reduction of carbon dioxide emissions, facilities can adopt a Carbon Neutral status (where the net harmful emissions are equal to zero).

The aim of the present study is to evaluate a cost-effective method that business owners, directors or engineers can follow to assist facilities with their Carbon Neutral journey. The proposed renewable energy solutions for these facilities include the installation of many photovoltaics (PV) to reduce the amount of electrical energy drawn from the National grid and reduce Scope 2 emissions. Moreover, the study will evaluate two facilities, namely Malmesbury Farm and Malmesbury Smallholding as case studies and discuss steps to be taken to minimise their carbon footprint. The initial simulation will be performed using software such as PV Syst and Sunny Design. The data from the simulation and the actual is then compared.

Both sites performed better than initially simulated by the PV Syst and Sunny Design simulations. Malmesbury Farm is on track to achieve an actual calculated return on investment of 125 months, this is 40 months less than simulated in Sunny Design and 1 month longer than simulated in PV Syst. The Malmesbury Smallholding has produced considerably more power than expected and is on track to achieve a calculated return on investment of 117 months. This is 52 months less than Sunny Design simulated and 31 months less than PV Syst simulated.

Both facilities have considerably reduced their Scope 2 emissions, the Malmesbury Farm has reduced their Scope 2 emissions by 100%, where they have consumed 0 kWh from Eskom over the last year becoming a net zero energy consumer of Eskom power and proud Carbon Neutral Scope 2 emitters. The Malmesbury Smallholding has reduced their Scope 2 emissions by 74.43%, where over the past 12 months their Scope 2 emissions have amounted to only 2.26 tCO_2e compared to 8.83 tCO_2e if no PV system was installed. The case studies prove that the installation of PV can considerably reduce a facilities carbon footprint and have a positive financial return on the investment.

Keywords: Carbon Neutral, Energy management, Microgrid, Net Zero, Photovoltaic.

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Abbreviations

GHG – Greenhouse gas

IEEE – Institute of Electrical and Electronics Engineers

IoT – Internet of Things

kWh – Kilowatt hour

LED – Light Emitting Diode

NCCRP – National Climate Change Response Policy

NDC – Nationally Determined Contribution

NDP – National Development Plan

NERSA – National Energy Regulator of South Africa

PV – Photovoltaics

SANS – South African National Standards

SA – South Africa

Definitions

Carbon Neutral – making or resulting in no net release of carbon dioxide into the atmosphere, especially as a result of carbon offsetting.

CO_2e or CO_2-eq – the number of metric tons of CO_2 emissions with the same global warming potential as one metric ton of another greenhouse gas.

Microgrid – a small network of electricity users with a local source of supply that is usually attached to a centralized national grid but can function independently.

Net Zero – a target of completely negating the amount of greenhouse gases produced by human activity, to be achieved by reducing emissions and implementing methods of absorbing carbon dioxide from the atmosphere.

Semiconductors – a solid substance that has a conductivity between that of an insulator and that of most metals, either due to the additional of an impurity or because of temperature effects. Devices made of semiconductors, notably silicon, are essential components of most electronic circuits.

CHAPTER ONE:
INTRODUCTION

1.1 Introduction

A vast percentage of the population are energy consumers; however, energy is expensive and with the added risk of intermittent loadshedding since 2005 it is not always available. Furthermore, heavy industrial facilities are being charged an additional expense (carbon tax) for emitting harmful gases into the atmosphere. Subsequently, many institutions are looking into alternative solutions. Unfortunately, energy consumers are typically not well versed in the energy field and do not fully understand how certain components operate. In most cases, many consumers have an idea of what they want but don't have enough details to properly get started with the project. Moreover, there are various factors pertaining to becoming a Net Zero Consumer. These factors vary from industry to industry, residential and to the physical location (Sciences et al., 2014). In view of the above, consumers need to be guided in exploring various energy saving techniques and need to be made aware that there are many solutions available to them. These sustainable solutions should not only be seen as expenses but rather tools to improve their efficiency, one of the main techniques, is that of installing PV systems.

1.2 Research background

The assessment of Carbon Neutral status among facilities in South Africa have shown, in most cases, to produce more harmful emissions than they consume, thus, contributing to global warming. To aid in the reduction of global warming and to incentivise facilities to become Carbon Neutral, a phased in approach is being implemented to charge facilities carbon tax (South Africa. SARS, 2020:8). This is calculated on the sector that the facility is in, and the quantity of emissions produced and used. Moreover, many of these facilities do not have the knowledge or skills to tackle the task of reducing emissions, hence the present study will serve as an aid and a guide to help reduce such emissions.

1.3 Rationale / justification

The South African energy consumption rationale used to be a fairly cost effective rate per kWh (Matlala, et al., 2016:3). However, this is no longer the case.

The consumer is focused on the final product and not the energy consumption of the process. In South Africa, the energy consumption of equipment is not primarily a deciding factor when selecting equipment (Li et al., 2016). Business owners are naive when it comes to the energy rate that is charged to them. They see it as a direct expense to the company. This misconception is the exact reason for this study. The intention is that the method proposed in the present research would create more ideas and initiatives for facilities to become Carbon Neutral, or at a minimum, reduce their current energy consumption.

South Africa has many advantages because it has a large supply of natural resources and available open land. The per capita consumption is high in comparison to the remainder of the World (Matlala et al., 2016:4). This directly translates to more excess energy being consumed and more potential for reducing the consumers energy consumption.

1.4 Research questions

The important research questions that are discussed in this dissertation are as follow:

- How much Scope 2 emissions are facilities currently producing?
- What is a carbon footprint?
- What are the barriers preventing facilities becoming Carbon Neutral consumers?
- How does Carbon Tax affect a company?
- What type of method is needed for facilities to achieve Carbon Neutral status?
- Which simulation techniques can be used to formulate a suitable feasible option?
- What are the effects of Carbon Neutral / net zero facilities on the environment?
- What are the effects of Carbon Neutral on business operations?
- What information / data needs to be collected to conduct a Design?
- What are the project costs associated with the Design?
- What are the applicable SANS standards?
- What are the local restrictions / standards?
- Which available software will be suitable for this research?

1.5 Problem statement

The world is at a crossroads. Governments have recognised that greenhouse gases have caused global warming, and this could be devastating for mankind, as increasing temperatures result in climatic conditions which could impact on food security. This would negatively affect life on our planet.

It is therefore essential that we actively reduce our greenhouse gas emissions all over the planet to prevent further rises in average temperatures.

This can be reduced with use of Photovoltaics.

1.6 Aims and objectives

The main aim of this research is to establish an efficient method and to compare simulations and actual photovoltaic systems for a facility to become Carbon Neutral.

The following are the objectives of the research:

- To establish key factors that influence the Carbon Neutral status.
- To establish the influence of carbon tax on facilities.
- To evaluate a method which can be used to monitor and curb facilities excessive energy usage.
- To investigate two sites that currently have PV energy interventions and establish cost, payback periods, financial analysis, design considerations.

1.7 Methodology

In all projects there needs to be an aim or objective. This objective needs to be clearly defined so that the team attempting to achieve this aim or objective can find success.

These objectives can be to reduce cost, to reduce the establishments carbon footprint or both.

The methodology which has been implemented in both case studies is detailed below:

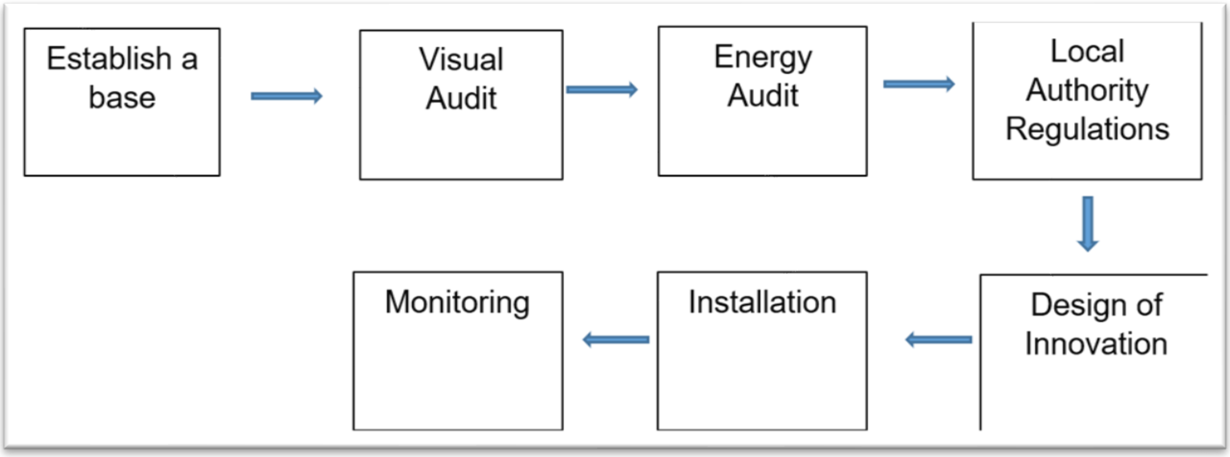


Figure 1: Energy evaluation and intervention implementation method

- **Establish a base**: Becoming a Carbon Neutral consumer requires an in-depth knowledge of the equipment, the process and how the facility or building operates. What is the daily operation at the facility, what days do they operate, when are their high demand times, these are all questions that shall aid in the design. It is important to establish the consumer's energy consumption rate and their required minimum requirements. The Engineer needs to fully understand Scope 1, 2 & 3 GHG emissions and he needs to be able to evaluate and categorise them accordingly. If the process does emit Scope 1 emissions the Process Engineer or Site Manager should be consulted to verify equipment outputs.

- **Visual audit:** Part of establishing a base the Engineer must evaluate how the site is run, where the site is, the distribution method and layout, operating time, critical equipment and processes. Simple fix items such as lighting; replacing incandescent globes with fluorescent or LED globes etc should be investigated. The distribution board (DB) is to be assessed to see how a PV system could be implemented or if a new DB would be required. Roof layouts, area and shading is assessed to establish how suitable the roof or if there is opportunity for a ground mount system so that the total amount of PV can be evaluated.

- **Energy audit and measurement:** The critical hold point. For existing sites, it is possible to conduct an energy and measurement audit. For new sites the engineer will be limited to an equipment audit, this equipment audit shall contain a list of all the energy consumers as well as the emissions of this equipment.

- **Local authority regulations:** This and the design needs to be done together, as the regulations shall guide the design however there needs to be a concept design done to be able to know which regulations to adhere to. All local authorities have their own different standards and regulations.

- **Design of innovations:** The Engineer will take all the information acquired in the above 4 items and determine which interventions are suitable, what equipment will be needed, how it will be installed and the return on investment.

- **The installation:** The Engineers design will dictate how the installation is to be conducted. This must be completed by a trained and qualified personnel. Energy, especially electrical energy is extremely dangerous as it cannot be seen. No adjustments or tampering of electrical equipment and the distribution system should be done by anyone that is not trained and qualified to complete the install.

- **Monitoring:** The monitoring of the facility will determine if the design parameters and calculations made by the Engineer have been met. It is imperative that this data is recorded for later evaluation. In the case of Scope 2 emissions the Energy consumption vs energy production can then be compared. Phased approaches are very common when attempting to achieve a carbon neutral status. This monitoring shall guide the Engineer as to how the initial design compares to what is being achieved in reality. The system may need to be upgraded or adjusted as the process changes or the business expands. These fluctuations will be adapted and mitigated to achieve the target of becoming a Net Zero consumer.

1.8 Delineation

The design that will be implemented in this study will serve as a general guide for consumers in other locations. Moreover, the study will focus on items such as Net Zero, renewable energies (specifically PV Systems), energy efficiency, emission factors, Carbon Tax, Paris Agreement and Eskom’s current state of affairs. Items such as recycling, wind, water reclamation and scope 3 emissions will not be covered in this study.

1.9 Expected outcomes

This thesis is intended to benefit designers, energy managers, business owners and Engineers. It shall guide them on the process and requirements to achieving a Carbon Neutral or Net Zero Energy status for their facility. By the end of this research, the following are the expected outcomes:

- Establishment of a method and real-life example for facilities that wish to have a Carbon Neutral status.
- Establish how emissions factors are calculated.
- Clarification of the various Scopes of emissions.
- How PV can aid customers facilities becoming Carbon Neutral consumers.
- Establishment of possible reduction in operating expenses to become Carbon Neutral.
- Establishment of a PV system that can greatly offset a facilities energy usage.

1.10 Structure of dissertation

This dissertation goes into detail comparing photovoltaic simulations compared with actual installations.

Chapter one is the introduction to this dissertation, it highlights what research has been done prior and what methodology has been taken in this dissertation.

Chapter two gives an overview of the process and what literature pertains to the study.

Chapter three is a detailed review of net zero emissions, items such as greenhouse gases, emission factors and carbon tax.

Chapter four is the design and assessment; this is where the simulation and the actual data is compared.

Chapter five is the conclusion with recommendations for further studies.

CHAPTER TWO:
LITERATURE REVIEW

2.1 Introduction

The study focuses on how PV systems, specifically, can aid facilities in becoming Carbon Neutral. To take all factors into consideration the literature has been divided into 5 main sections namely, environmental, monitoring, cost & design, technical documentations, and solar PV technologies.

2.2 Environmental

When considering the objective of achieving Carbon Neutral status, there are four important factors known as the Four R's to consider. The terms Reduce, Reuse, Recycle and Refuse are checklists which can be used to examine the impact of various factors relevant to becoming a Net Zero Energy consumer (Study et al., 2016). In the pursuit of the balance between carbon emissions related to power generation, (and its subsequent consumption) and the reduction of emissions, Robbins et al. (2016) pointed out that the focus should not only be on the Electrical Energy consumption, but that greenhouse gas emissions play an equally pivotal role in the equation. Generally, distributed renewable energy generators do not produce excessive (if any) undesirable emissions. Karimi (2017) noted previously that the only form of distributed energy generation was that of petrol or diesel generators. With the development in renewable energy generators, many of these fossil fuel consumers are being replaced by PV or wind energy generators.

2.3 Monitoring

To become energy efficient, it is essential to monitor energy usage. Modern metering equipment such as the Meteo Control data logger and energy meters play a pivotal role in achieving efficient processes and energy usage. Once a baseline has been set, energy losses, machine failure or even a machine requiring maintenance can be highlighted and the appropriate action taken.

By monitoring the power flow using accurate real time data, timeous adjustments can be made to improve efficiency. Li et al (2016) envisioned that the energy currently consumed can be reduced by more than 20% by the year 2022, with the aid of power monitoring devices.

Uken (2012) also highlighted that the control of energy can be one of the most cost-effective interventions to implement, with a low outlay and high return. Most generators have an efficiency of less than 50%. This ultimately equates to 50% of the total output power that is lost in the generation process. This means that the cost of generating this power is close to double of what it should be.

Future energy monitoring technologies are being developed to monitor and gather power flows and consumptions. Among these is the rise of the Internet of Things (IoT) devices. Shaikh et al (2017) describes data distribution and collection from micro sensors becoming common in first world countries. Once collected and analysed the data is used to influence market opportunity.

2.4 Cost and design

South Africa used to have one of the lowest costs per kWh, which attracted big industries, such as mining and smelters. However, over the last few years, South Africa has experienced dramatic price increases in electricity cost as mentioned by Matlala et al (2016). To combat these high rises in energy costs, professionals can analyse power consumption data in the form of kW and determine the best solution for that specific application or process. Some of these solutions entails adding variable frequency drive's (VFD's) to control electrical motors or power factor control, with the aim of aligning the real kW power with the apparent kVA power (Matlala et al., 2016).

In modelling and performance evaluation of net zero energy buildings Anderson (2016) discussed suitable on-site renewable energies and the modelling of these renewable energy technologies. One very basic technique includes optimizing the amount of natural light that a building receives. Natural light is effective to reduce a buildings lighting energy consumption, however, it can cause additional heating. This additional heat would then require forced cooling in summer months but less heating in winter months (Anderson, 2016). He continues to discuss how PV is the most commercially feasible source of on-site renewable energy. This is mostly due to the consistency and recent performance enhancements.

From a Carbon emissions perspective, many large global companies have committed to reduce their Carbon emissions by signing a pledge named the Paris Agreement

(Horowitz, 2016). One of the main objectives of the Paris Agreement is to limit the rise in global average temperatures. The intention is to limit the maximum temperature to 1.5˚C above pre-industrial levels. Every 5 years, countries shall indicate their nationally determined contribution and indicate how they plan to curb the effects on global warming for the next 5 years. Many of these interventions and designs are being driven by 1st world countries and then the knowledge is passed onto poorer 3rd world countries. To incentivise facilities to reduce their carbon emissions, a Carbon Tax is applied by the South African Revenue Service (SARS). This tax is primarily aimed at Scope 1 large industrial polluters, which will be further explained later in this dissertation.

2.5 Technical documents

The literature used in this study is predominantly based on findings and technical specifications that were used to establish a Carbon Neutral facility (Pless & Torcellini, 2010). The IEEE technical papers and reports make up the bulk of the literature as these digital libraries contain relevant sources of information. New technologies and findings from other countries will also be highlighted, reviewed and discussed as to their feasibility within the South African market (Bello, 2013).

SANS 5001 (2011) document on energy management systems provide details on how standards are used to improve the energy management system (EMS). This document stipulates the steps that management can take to proactively implement an EMS at their company. Moreover, the energy policy of a company and how the framework is to be set out to achieve successful energy consumption targets were also discussed (Division, 2011).

SANS 10400-XA (2011) further highlights energy usage in buildings. It discusses the architectural building requirements for energy usage. This document highlights and guides the engineers and architects to the maximum energy consumption of different areas or when used for the heating and cooling of buildings (Building & Part, 2011).

2.6 Solar photovoltaic

Solar PV technology and installations are discussed in the SAPVIA Solar PV Installation Guidelines (2017). In this document, the reflected solar radiation and sun paths are the initial factors in designing a PV system. Establishing the location and solar radiation for the area, as well as the mounting method, the surface arrangement is then used to establish the layout and quantity of panels that can be installed. This ultimately equates to the size of the PV system. To reduce losses in the PV system, it is preferred to install PV panels in a series string to increase the voltage while keeping the current consistent.

PV panels are DC sources and produce a DC voltage. Each PV cell is typically around 0.6 V. A 72 cell PV panels standard test condition (STC) open circuit voltage would be around 43 V. The STC is a method of testing PV panels to a defined condition; this being a solar radiation of 1000 W/m^2 and cell temperature of 25˚C with an air mass of 1.5. The series string of panels is therefore added together to form a string voltage. This allowable string voltage is dependent on the specific design parameters of an inverter's Maximum Power Point Tracking (MPPT) allowable voltage. For an industrial string inverter, this can be up to 1500 VDC. The inverter is used to convert the DC voltage produced by the PV panels to an AC voltage that is synced with the utility. This power will then feed back into the local networks. If the power is not consumed by the local network, then it will either be exported to the utility network or used as power control, where a bidirectional current transformer (CT) is installed. The inverter will then throttle the output by adjusting the resistance of the MPPT accordingly (Siegfriedt & Brandt, 2017).

2.7 Eskom

For the last two years the cost of electricity has increased by 9.6% in 2022 and 15.06% in 2021 respectively. It is evident that there is an upward trend in the increase in electricity.

All tariffs and rates have been extracted from the Eskom yearly tariff books (Tariffs & Charges Booklet, 2017), (Tariffs Charges, 2018), (Tariffs & Charges Booklet, 2019), (Prices, 2020), (Prices, 2021), (Tariffs & Charges Booklet, 2022), (Charges Booklet, 2023).

The cost of electricity has increased by 10.69% on average from 1 January 2018 to 31 March 2022.

2.8 South African regulations

The National Energy Regulator of South Africa (NERSA) have a defined document, namely NRS 97-2-1:2017 Grid interconnection of embedded generation, Part 2: small-scale embedded generation. NERSA work with Eskom to ensure a stable grid and that pricing is in line with realistic expectations, one could classify them as technical auditors. This document aims to outline the specifications of how these embedded generators are to be connected to the National Grid (Interconnection & Embedded, 2017).

Page 10 in NRS 97-2-1:2017 explains the 3 Categories of embedded generators, up to 1 MVA.

- Category A1: 0 - 13.8 kVA
- Category A2: 13.8 – 100 kVA
- Category A3: 100 kVA – 1 MVA

These categories have different grid connection requirements.

Page 51, details the connection example of a single phase generator that is smaller or equal to 4,6 kVA.

Page 52, details the connection example of a single phase generator that is smaller or equal to 13,8 kVA.

Page 54 and 58, details the connection example of a three phase generator that is greater than 30 kVA.

Applicable SANS standards,

- SANS 10142-1 – the wiring of premises Part 1: Low-voltage installations
- SANS 10142-2 – the wiring of premises Part 2: Medium-voltage installations above 1 kV a.c. not exceeding 22 kV a.c. and up to and including 3 MVA installed capacity
- SANS 60364-7-712:2018 – Low voltage electrical installation – Part 7-712: Requirements for special installations or locations – Solar photovoltaic (PV) power supply systems

2.9 Summary

Chapter two is a review of the literature currently available. It highlights the Environmental effect of reduced and more efficient energy consumption. The effects and benefits of monitoring energy usage is further discussed. The Cost and design section introduces, for consideration, the Paris agreement, which is a pivotal commitment made by countries to reduce their emissions. Section 2.6 is an overview and design consideration of solar photovoltaics including design and industry standards. Section 2.7 discusses the current state and tariff increases of Eskom. The final Section in chapter 2 is the South African regulations that need to be taken into consideration, namely SANS and NRS.

CHAPTER THREE:
NET ZERO EMISSIONS

3.1 Introduction

Net Zero is the term used to describe an activity which does not emit, or which results in no net release of carbon dioxide into the atmosphere (Anderson, 2016). Net Zero can also describe the result of carbon offsetting. A facilities Net Zero status is dependent on the quantity of greenhouse gases (GHG) it directly or indirectly emits. Carbon Neutral and Net Zero have the same underlying objective; for the facility, building, businesses, and staff to have a net GHG emission of 0 tCO_2e or less.

3.2 Greenhouse gases

These GHG are made up of a variety of harmful and toxic gases. Table 1 indicates the abbreviation name and overview of total emissions.

Table 1: US GHG mix (EPA, 2022)

Name	Abbreviation	Overview of total emissions
Carbon Dioxide	CO_2	79%
Methane	CH_4	11%
Nitrous oxide	N_2O	7%
Hydrofluorocarbons	HFCs	3%
Perfluorocarbons	PFCs	
Sulfur Hexafluoride	SF_6	
Nitrogen trifluoride	NF_3	

Carbon Dioxide is the largest contributor to the GHG mix. It enters the atmosphere through the burning of fossil fuels, such as coal and natural gas.

Methane is the second largest contributor to the GHG mix. It is emitted as a result of the production of coal, natural gas and oil. Livestock and agricultural practices including the decay of organic waste contribute to the production of methane.

Nitrous oxide is the third largest contributor to the GHG mix. Agriculture, industrial activities, the combustion of fossil fuels and solid waste including the treatment of wastewater all emit Nitrous oxide.

Fluorinated gases are made up of Hydrofluorocarbons, Perfluorocarbons, Sulfur Hexafluoride and Nitrogen trifluoride. These are powerful synthetic greenhouse gases that are a biproduct in many residential and commercial applications. These Fluorinated gases are emitted in small quantities in comparison to Carbon Dioxide but have a higher global warming potential (GWP). Ie; 1 tone of Hydrofluorocarbons would have a worse effect on global warming than that of Carbon Dioxide (EPA, 2022)

3.3 Greenhouse gas protocol

The Greenhouse Gas Protocol initiative is a partnership between businesses, NGO's and governments. It is used for GHG corporate accounting standard.

There are three scopes that make up the Greenhouse Gas Protocol namely, Scope 1, 2 and 3.

Scope 1:

Scope 1 involves direct GHG emissions that occur from sources that are owned or controlled by the company. For example, the vehicles of a company, furnaces or boilers.

An example of this is a diesel generator that is used on site to power the facility. The emissions are produced on site.

Scope 2:

Scope 2 involves electricity that has been purchased and consumed by the facility. They do not produce the GHG but are indirectly affected by the emissions. The GHG emissions are physically produced at the facility where the electricity is generated.

Companies are encouraged to install energy saving interventions to reduce their reliance on electricity. In addition to this, co-generation plants such as grid tied PV can be installed to reduce the reliance on utility.

Scope 3:

Scope 3 is made up of other indirect GHG emissions. These are the consequences of the activity of the company. This scope caters for all indirect emissions that are not produced directly by the company but by the products that are used by the company.

3.4 Emissions factor

In 2020 Eskom reported that its annual Scope 1 emissions amounted to 201 375 875 tCO_2e.

The Scope 2 emissions form part of Scope 1 as this is their core business.

Scope 3 emissions amounted to 248 240 tCO_2e.

This results in a total of 201 624 115 tCO_2e (Holdings & Change, 2021) in which during the same period Eskom generated 194 238 GWh.

To get to the emissions factor, the total resulting GHG emissions need to be divided by the electricity generated (Holdings & Change, 2021).

$$\text{Emissions Factor} = \frac{\text{GHG Emissions}}{\text{Total Electriciy Generated}}$$

$$\text{Emissions Factor} = \frac{201\ 624\ 115\ \text{tCO}_2\text{e}}{194\ 238\ \text{GWh}}$$

$$\text{Emissions Factor} = 1\ 036.1532\ \text{tCO}_2\text{e}\ /\text{GWh}$$

$$\text{Emissions Factor} = 1.036\ \text{tCO}_2\text{e}\ /\text{MWh}$$

$$\text{Emissions Factor} = 1.036\ \text{kgCO}_2\text{e}\ /\text{kWh}$$

The value of 1.04 kg CO_2e per kWh is used when accounting for Scope 2 emissions (Holdings & Change, 2021).

Figure 2 shows the emissions factor of comparative countries in Europe. If South Africa was part of Europe, they would have the worst emissions factor in Europe. The high emissions factor is due to a multitude of issues, these being outdated generation fleet, inefficient operation of the generators, constant breakdowns, inefficient transportation of raw materials and general disregard of equipment (Eskom, 2021).

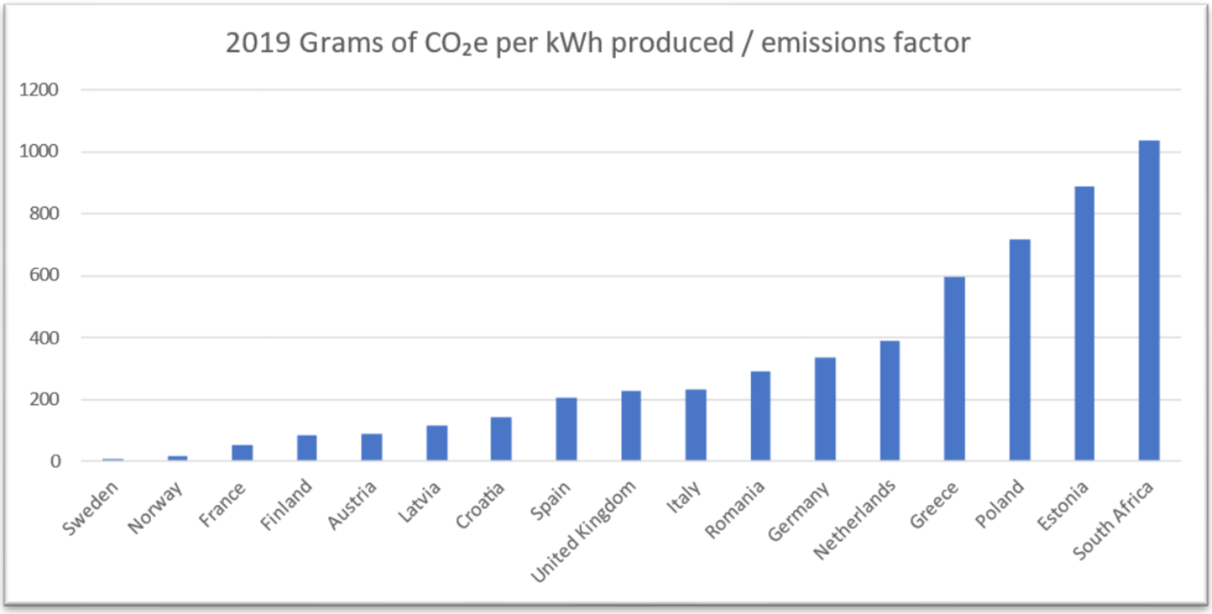


Figure 2: Greenhouse gas emissions intensity of electricity generation for 2019 (European Environment Agency, 2022)

Compared to the rest of Africa, South Africa has the worst CO_2 emissions per capita in the entire continent. In 2020 this value was 7.62 tCO_2e average per capita. Figure 3 is a graphical view of the highest per capita emitters of GHG in Africa.

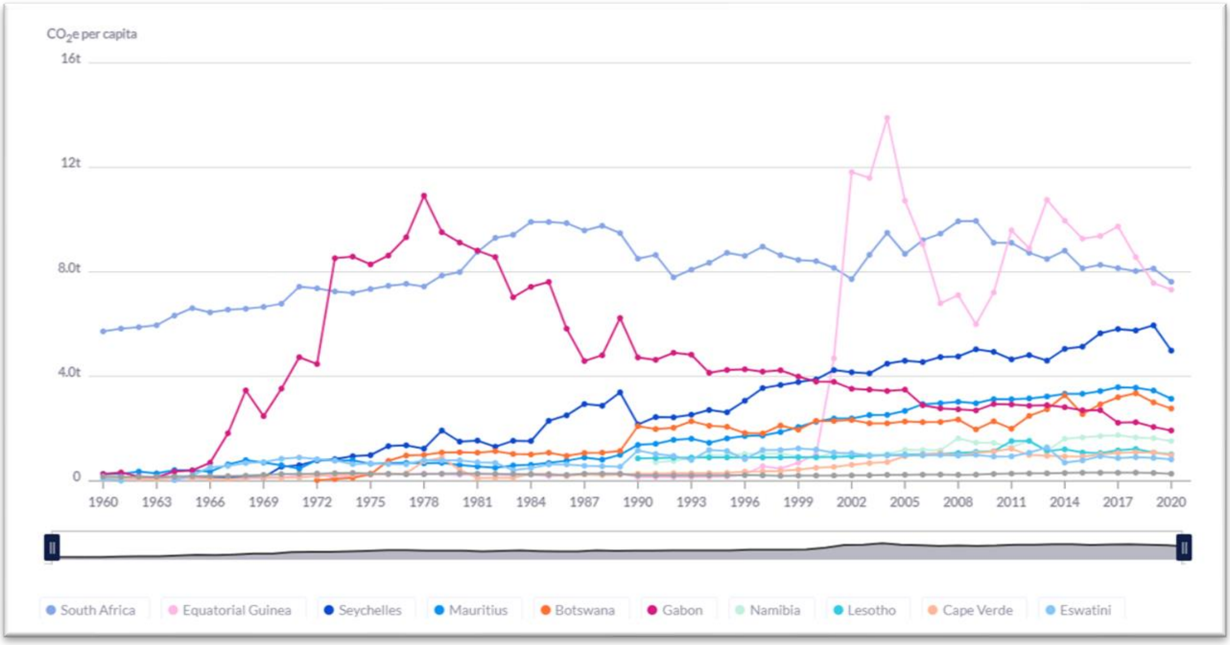


Figure 3: tCO_2e average per capita (Climate Watch, 2022)

Eskom has been reducing its emissions in the second quarter of 2022 – when compared to the previous years' GHG emissions. There has been a consistent reduction over the months of April, May, June and July in 2022 when compared to the same period in 2021. This has been tabulated in Table 2. An average GHG emissions' decrease of 10.22% has been seen between the period of April, May, June and July in 2021 to that of 2022.

Table 2: Eskom total tCO_2e emissions for period from April to July 2021 & 2022 (Eskom, 2022)

Month	2021 (tCO_2e)	2022 (tCO_2e)	Reduction
April	18 473 351,14	16 521 464,00	10,57%
May	19 401 744,27	17 424 561,00	10,19%
June	18 500 405,03	17 074 203,00	7,71%
July	19 142 893,04	16 764 918,00	12,42%

3.5 Carbon tax

To calculate how much GHG emissions a facility is currently responsible for, the three Scopes need to be evaluated. Scope 1 are the direct GHG emissions of the facility. If the facility has vehicles or burns LPG gas for heating. These are examples of direct emitters of GHG.

Once these have been established scope 2 emissions need to be evaluated. Scope 2 are the emissions produced by the facility that provides electricity to the consumers facility. In the case of South Africa, this would be Eskom. Eskom's current emission factor is 1040 grams of CO_2e per kWh produced (Holdings & Change, 2021). Therefore, for every kWh consumed by your facility you need to multiply this by 1040 grams. This will then provide the facility with the Scope 2 emissions.

Scope 3 emissions are the indirect emissions. For example, if your facility gets products delivered, the emissions produced by the delivery vehicle need to be added to the total.

Therefore, to get the total GHG emissions and carbon footprint of a facility, Scope 1,2 & 3 accumulated totals need to be added together.

In most cases Scope 3 emissions do not need to be accounted for by the company acquiring the service as the company providing the service should capture their emissions as their Scope 1 emissions.

- For example, a facility that has used coal for heating in the process

[Scope 1: CO_2 from the coal] + [Scope 2: Electricity used at the facility x 1040 g] + [Scope 3: emissions from the supplier's delivery vehicle (if they do not capture these emissions as their Scope 1 emissions)] = total GHG emissions

In South Africa the carbon tax is only applicable to Scope 1 emitters in 2022. This focuses on facilities that directly produce HFC, CO_2, CH_4, N_2O, C_2F_6, CF_4, SF_6 (SARS, 2022).

C_2F_6, CF_4 are small quantities when compared to the other gases, they are used in South African industries.

C_2F_6 is Hexafluoroethane, this is an etchant and chamber cleaning agent (Linde, 2017).

CF_4 is Tetrafluoromethane, this is used in the electronics industry for plasma degreasing of multilayer printed circuit boards (T. Cf, no date) .

DA 180 is the Environmental Levy Account for Carbon Tax. There are 6 Annexures, the facility is to select the most suitable for their Carbon Tax Account submission (SARS, 2020).

1. DA180.01A.1 – Fuel Combustion (Stationary)
2. DA180.01A.2 – Fuel Combustion (Non-Stationary)
3. DA180.01B.1 – Fugitive (Oil and Natural Gas)
4. DA180.01B.2 – Fugitive (Coal Mining and Handling)
5. DA180.01C – Industrial Process
6. DA180.02 – Carbon Tax Allowances

South Africa's state-owned enterprise, Eskom, emits a combined total 1040 grams of CO_2 per kWh produced. This is amongst the dirtiest power in the world.

Auditing and monitoring of power is one of the most efficient ways to curb facilities excessive energy usage. By monitoring the power, excessive energy users can be identified. All equipment has a power rating, this power rating indicates the maximum power consumption of that specific equipment. When combined with the duty cycle of that equipment, a kWh can be calculated. This kWh should then be compared to the power consumption that is being monitored. These can then be evaluated to establish if there are issues with that equipment; is it running for excessive hours or is it being incorrectly utilised.

3.6 Barriers preventing facilities becoming carbon neutral consumers

In many cases the prominent barrier from preventing facilities from becoming Carbon Neutral is access to funding or cash flow. There are viable solutions, however, a funding mechanism is required to enable these assets to be procured and installed.

In South Africa, a barrier for a facility or company to reduce their Scope 2 emissions is Eskom's tedious process to install grid tied PV systems. In most cases financial institutions will fund these projects as there is a healthy return on investment. However, if Eskom does not approve the export of excess power then the Scope 2 emission reduction is limited to daylight hours, when PV energy can be produced.

If the facility has the appetite to install a battery system to store energy produced in the day and make use of the energy during the night, they could reduce their Scope 2 emissions by 100%. The option of a battery is a premium cost, which does not have a great return on investment (ROI). In some cases, it can create a negative ROI whereby the asset never recoups the initial CAPEX cost. Case study 1 & 2 evaluate this option.

3.7 South Africa greenhouse gas reduction effort and commitments

In 2019 South Africa committed to the 15th Conference of the Parties to the United Nations Convention on Biological Diversity (COP 15) with the aim of curbing greenhouse gas emissions by 34% before 2020 and 42% by 2025. This percentage is related to the Business as usual (BAU) trajectory and subject to support for developed countries (Eskom, 2021).

In 2020 SA's National Determined Contribution (NDC) confirmed its commitment to the Paris agreement where the intention is to curb the emissions from 2020 to 2025, and that between 2025 and 2035 the intentions is that a neutral phase shall occur:

- existing capable businesses decrease their carbon consumption
- new businesses are created
- small non capable businesses expand resulting in more carbon emissions
- after adding all these totals together, the net increase is 0

Post year 2035 the commitment is that the net CO2-eq amount shall reduce year on year (SARS, 2022).

3.8 Method for facilities to achieve carbon neutral status

For a facility to achieve Carbon Neutral status review of the existing Scope 1 & 2 emissions and emitters of GHG is necessary. Scope 1 can be hard to reduce as this often pertains to the processes at the facility. The intention would be to reduce the Scope 1 emissions as far as possible without affecting the business outputs. The next step would be to look at the Scope 2 emissions. The first step in reducing Scope 2 emissions would be to reduce the facilities power consumption by installing efficient equipment and devices. Once this has been completed the installation of a PV system can further reduce the energy consumption to below net zero. If the utility permits the feedback or export of power to the network, it can be possible that the Scope 2 emissions become a negative. This would be if the facility exports more power that what it imports from the utility.

In this event, if the Scope 1 emissions are less that the negative scope 2 emissions (due to the PV system), the facility could therefore be declared Carbon Neutral.

3.9 Design techniques that can be used to formulate a suitable feasible option

There are many design options that facilities can pursue with the aim of achieving a Carbon Neutral status. In all cases, however, the measurement of emissions and energy consumption is paramount. Once measurements have been established, monitored and analysed, interventions can be reviewed.

In many cases the most cost-effective solution is to reduce the usage. For example, in the case of lighting. If the room is not occupied, then turn the lights off or install an automatic system. This saves 100% of the energy and is a simple example that can be implemented in various scenarios, such as heating and cooling.

Only once all these areas have been reviewed and exhausted, the reduction of Scope 2 emissions should be investigated. This would entail the installation of an energy generator, such as a PV system or wind turbine.

3.10 Effects of carbon neutral facilities on the environment

Once a facility has achieved a Carbon Neutral or Net Zero status, they can comfortably know they are not affecting the environment. Depending on the business, if there is a technological intervention that allows the company to operate as normal then there should be no effect.

In many cases the option of PV is selected as this considerably reduces the Scope 2 emissions and in turn reduces the total emission recording.

3.11 Summary

Chapter three discusses Greenhouse gases (GHG), their composition and the concept of Net Zero. Section 3.2 is breakdown of the GHG mix.

The GHG protocol details the concept that there are 3 Scopes or levels where emissions are produced. Scope 1. is on site production, Scope 2. is a consequence of the electrical energy supplier’s production method, for example a coal fired power station. Scope 3 covers products and services used by the enterprise, an example could be the Net Zero status of a cardboard box or other packaging supplier.

Section 3.4 Details the fact that compared to the rest of Africa, South Africa has the worst CO_2 emissions per capita, 3.5 continues with the explanation of an emissions tax which has been introduced in many countries in the world which has the intention of punishing polluters.

The rest of the chapter examines the problems and solutions to achieve a Net Zero status and suggestions to reduce emissions.

CHAPTER FOUR:
DESIGN AND ASSESSMENT OF PHOTOVOLTAIC SYSTEMS

4.1 Introduction

There are two case studies that have been evaluated, namely Malmesbury Farm and Malmesbury Smallholding.

Malmesbury Farm is a production farm that plants crops, waters them and then harvests and sells them. A large portion of their power requirement is the reticulation of water.

Firstly, water is pumped out of the ground from a borehole into a holding tank. Then water from the holding tank is then pumped to the crops. This function is predominately in summer when there is very little to no rain and hot sunny days. The hot sunny days are perfect for energy production from photovoltaic panels. This increased amount of energy is then used for the reticulation of water.

Malmesbury Smallholding is a smaller facility that caters for horses. The loads are predominately household loads with a small amount of power used for the reticulation of water.

Two simulation software's have been used for these facilities, SMA Sunny Design and PV Syst. SMA Sunny Design is specifically catered for SMA inverters, it provides design approval and recommendations. The format and layout is easy to use and understand. PV panel layouts can be super imposed on actual buildings to confirm designs. PV Syst is not associated to a specific brand; the specifications of the inverters is added by the user. This software allows for more detailed loads to be added and provides more detail as to the losses within the system.

4.2 What information and data needs to be collected to conduct a design review

For a design review to be conducted there needs to be an initial evaluation. This evaluation can be acquired by monitoring devices that are used to accumulate totals. In all cases it is important to fully understand the process and manufacturing or business requirements of the facility. In many situations to reduce the Scope 1 emissions is not feasible or possible.

Once all Scope 1 emission reduction interventions have been exhausted, Scope 2 emission reduction and possible offset can be planned and designed. These interventions can range from situation to situation. PV can be used to reduce the total GHG emission and equipment specific interventions such as installing a Variable Frequency Drive (VFD) on motors that Direct on Line (DOL), or replacing all incandescent bulbs with Light Emitting Diode (LED) bulbs.

Once these interventions have been installed, it is paramount that the facility be monitored to assess the effect of these interventions. Data such as voltages, currents, power and power factor, should be recorded and stored. The interval of recorded data should be as small as possible because the more data that is received the more accurate the data potentially is.

4.3 Project costs associated with the design

An initial cost is for various measurement devices, these can range from vehicle tracking to gas analysers, to power meters and monitors. Once the hardware has been catered for and installed, the data is to be analysed. This would commonly be by an Energy Manager or Energy Auditor. The next cost would be that of the proposed intervention suggested by the Energy Manager or Energy Auditor.

4.4 Software used to aid in photovoltaic designs

Sunny Design is a product produced by SMA. This software does not have access to other 3rd party inverters and is only intended for use with SMA inverters. The software has the ability to make use of map data where PV systems can be designed on the intended roof. This adds to the accuracy and overall look of the design. The software allows for the emission factor to be added. This is then used to calculate the total potential CO_2e reduction over a selected period. In addition to the equipment design there is a financial analysis component. This is used to calculate the ROI of the project. Naturally, this is highly dependent on the tariff stated in the software. Once all the required data has been included the software produces a report. This report will highlight any wiring or stringing concerns on the installation. In addition, it indicates the total calculated income generated, energy and CO_2e reduced over the period. The software has a quick learning curve. The issue, however, is that the background calculations are not visible for vetting.

PV Syst is not dedicated to one brand or supplier; it is a standalone system that allows the user to calculate any PV system. It has the ability to input custom individual loads as well as the ability to set their running times. This software does not allow the user to design the PV system using google maps, where with Sunny Design the Engineer has the ability to superimpose PV panels on a google earth image. PV Syst does not calculate the CO_2 emission reduction due to the installation of the intervention. It does display a very comprehensive loss diagram on the 6th page. The software is fairly quick to adapt to. It has a notification bar in the centre, this is extremely helpful as it guides the Engineer to what is not complete and highlights areas of concern. The output is a clear and easy to follow report with all the basic information displayed.

4.5 Case study one – Malmesbury Farm

In April 2016 Malmesbury Farm had their PV system installed. After the solar PV grid tie system had been installed in 2016, the site upgraded with batteries in 2018 to go 100% off grid.

This case study equipment and materials were designed and installed at the experimental phase of the project. The cost for all the equipment and materials was paid for by the owner of Malmesbury Farm.

4.5.1 Photovoltaic system details for case study one

- Installation date: 10/04/2016
- Total PV panels: 60x JKM255P = 15.3 kWp (‘JKM270PP-60-Datasheet.pdf’, 2015)
- Orientation – Northwest (23˚ West of North) at a 13˚ tilt angle.
- PV inverter: SMA Sunny Tri Power 15 kWp [SMA STP 15000TL-30] (Control, 2017)
- Battery inverter: 3x Sunny Island 8 kW (to form a 3 phase network) [SMA Sunny Island 8.0H] (Solar Technology, 2019)
- Batteries: 3x BMZ ESS7 (7 kWh)(Ess, 2017)

Table 3 details the cost of the installed asset.

Table 3: Malmesbury Farm - PV system cost

Model	Description	Unit	Per Unit		Total	
SI8.0H	Sunny Island 8kW	3	R	34 175,04	R	102 525,12
SWDMSI-NR10	Speedwire	1	R	1 468,91	R	1 468,91
SRC20	Sunny Remote Control	1	R	2 939,12	R	2 939,12
HM BT-10	Home Manager	1	R	4 185,70	R	4 185,70
BMZ ESS7	7kWh Lithium Ion Battery	3	R	43 508,35	R	130 525,04
					R	-
STP15000TL-30	Sunny Tri-Power 15kWp PV Inverter	1	R	33 410,54	R	33 410,54
	Electrical Accessories (Cable, CB's, Trunking, DB's etc)	1	R	11 846,39	R	11 846,39
JKM255P	255w PV panels	60	R	1 657,50	R	99 450,00
	PV Panel Mounting Hardware	60	R	282,72	R	16 963,20
			Total		R	403 314,02
			VAT		R	60 497,10
			Total incl.		R	463 811,12

Figure 4 is an aerial photo taken from the North West of the barn. There are 60 panels on the main barn roof. The additional 5 panels on the smaller North roof are used for the workers cottage below.

Figure 4: Malmesbury Farm barn PV

Figure 5 is an aerial image taken from the North. This was taken at 6:35pm in January. There is no shading on the system during daylight hours. There are 3 strings of 20 panels on the roof. These 20 panels are all connected in series to increase the STC Vmp voltage to 616 V (30.8 x 20). The 15 kWp inverter has two MPPT's, two of the panel strings are connected to MPPT A and one string to MPPT B. MPPT A's STC Imp current will be 8.28 x 2 = 16.56 A, whereas MPPT B shall be only one string therefore STC Imp shall be 8.28 A.

Figure 5: Malmesbury Farm aerial photo of the PV system

Figure 6 is an image of the STP15000-TL30 PV inverter. To the left of the inverter is the DC isolators (one per string). This PV inverter has type 1 and 2 surge protection built in internally. This inverter is a AC coupled inverter. This means the inverter uses the DC produced by the panels and converts it, by means of IGBT's to an AC waveform. It subsequently makes use of a transformer to achive the required 400 V AC per phase.

Figure 6: Malmesbury farm SMA Sunny Tri Power 15000TL-30

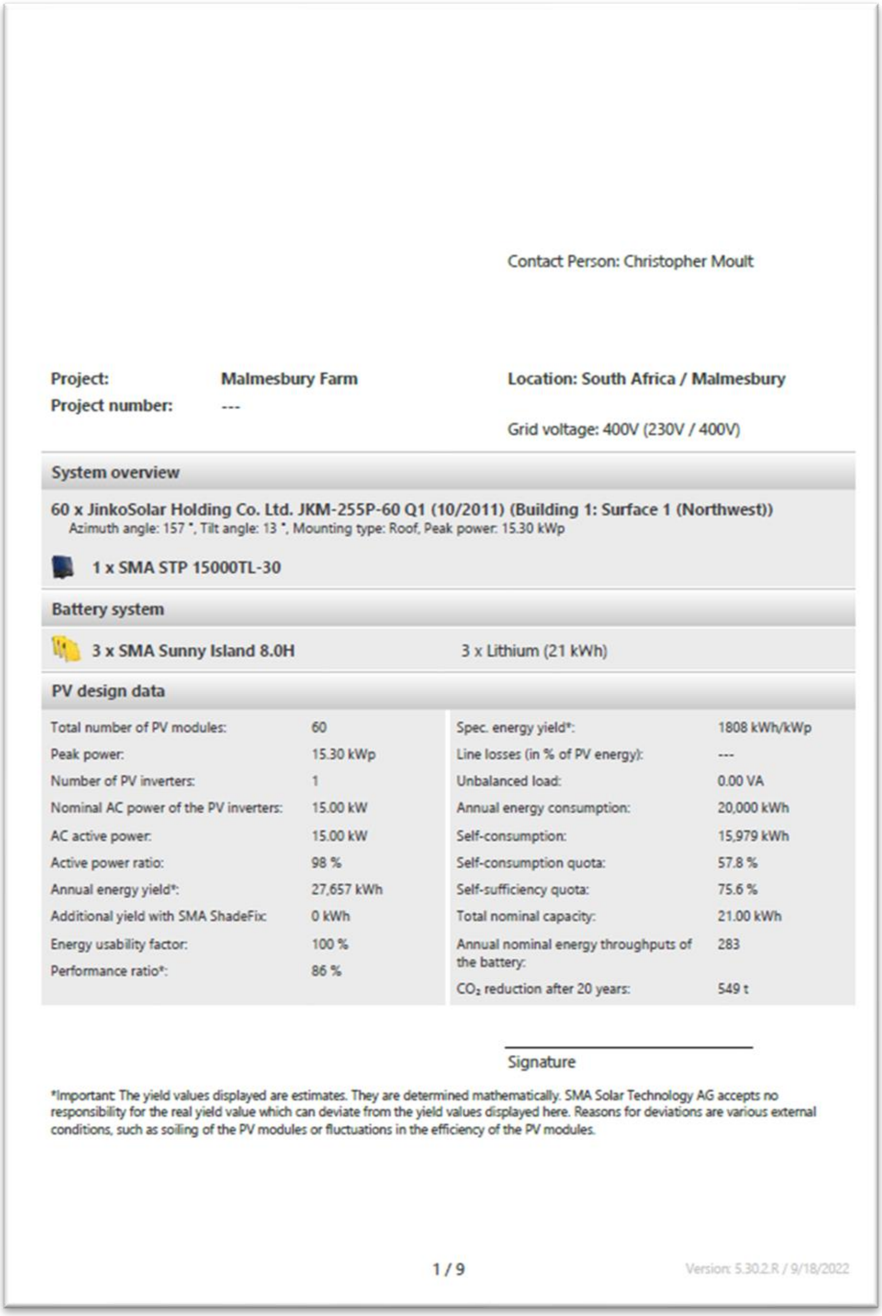
Figure 7 is an image of the three Sunny Island 8 kW inverters. These 3 inverters are connected in parallel with each other. Each inverter is connected to a separate phase and these phases are 120° apart, to form a 3 phase system. The battery inverters manage all the power to and from the farm and the PV inverter. They become the utility or grid when there is no municipal grid to connect to.

Figure 7: Three Sunny Island Units

4.5.2 SMA Sunny Design simulation for case study one

Figure 8 to 16 is a simulation model from SMA Sunny Design, it only takes into account the electricity savings. It does not consider the reduction in service fee that Eskom charges. This model has indicated that the investment shall reach amortization in 13.9 years. A 10% year or year electricity increase was used for the SMA Sunny Design simulation. A 1% of total asset cost annual maintenance fee has been applied. The initial cost of electricity was set at R1.33 per kWh.

Figure 8 is the first page of the Sunny Design report is a summary of the system, this summary details the grid voltage. South Africa has a nominal voltage of 400 V between the 3 phase and 230 V between any phase and neutral (This, 2017). The PV system design data is a summary of the system performance after the size, orientation and quantity of panels has been inserted into the simulation software.



Contact Person: Christopher Moult

Project: **Malmesbury Farm**

Project number: ---

Location: South Africa / Malmesbury

Grid voltage: 400V (230V / 400V)

System overview

60 x JinkoSolar Holding Co. Ltd. JKM-255P-60 Q1 (10/2011) (Building 1: Surface 1 (Northwest))
Azimuth angle: 157 °, Tilt angle: 13 °, Mounting type: Roof, Peak power: 15.30 kWp

1 x SMA STP 15000TL-30

Battery system

3 x SMA Sunny Island 8.0H 3 x Lithium (21 kWh)

PV design data

Total number of PV modules:	60	Spec. energy yield*:	1808 kWh/kWp
Peak power:	15.30 kWp	Line losses (in % of PV energy):	---
Number of PV inverters:	1	Unbalanced load:	0.00 VA
Nominal AC power of the PV inverters:	15.00 kW	Annual energy consumption:	20,000 kWh
AC active power:	15.00 kW	Self-consumption:	15,979 kWh
Active power ratio:	98 %	Self-consumption quota:	57.8 %
Annual energy yield*:	27,657 kWh	Self-sufficiency quota:	75.6 %
Additional yield with SMA ShadeFix:	0 kWh	Total nominal capacity:	21.00 kWh
Energy usability factor:	100 %	Annual nominal energy throughputs of the battery:	283
Performance ratio*:	86 %	CO_2 reduction after 20 years:	549 t

Signature

*Important: The yield values displayed are estimates. They are determined mathematically. SMA Solar Technology AG accepts no responsibility for the real yield value which can deviate from the yield values displayed here. Reasons for deviations are various external conditions, such as soiling of the PV modules or fluctuations in the efficiency of the PV modules.

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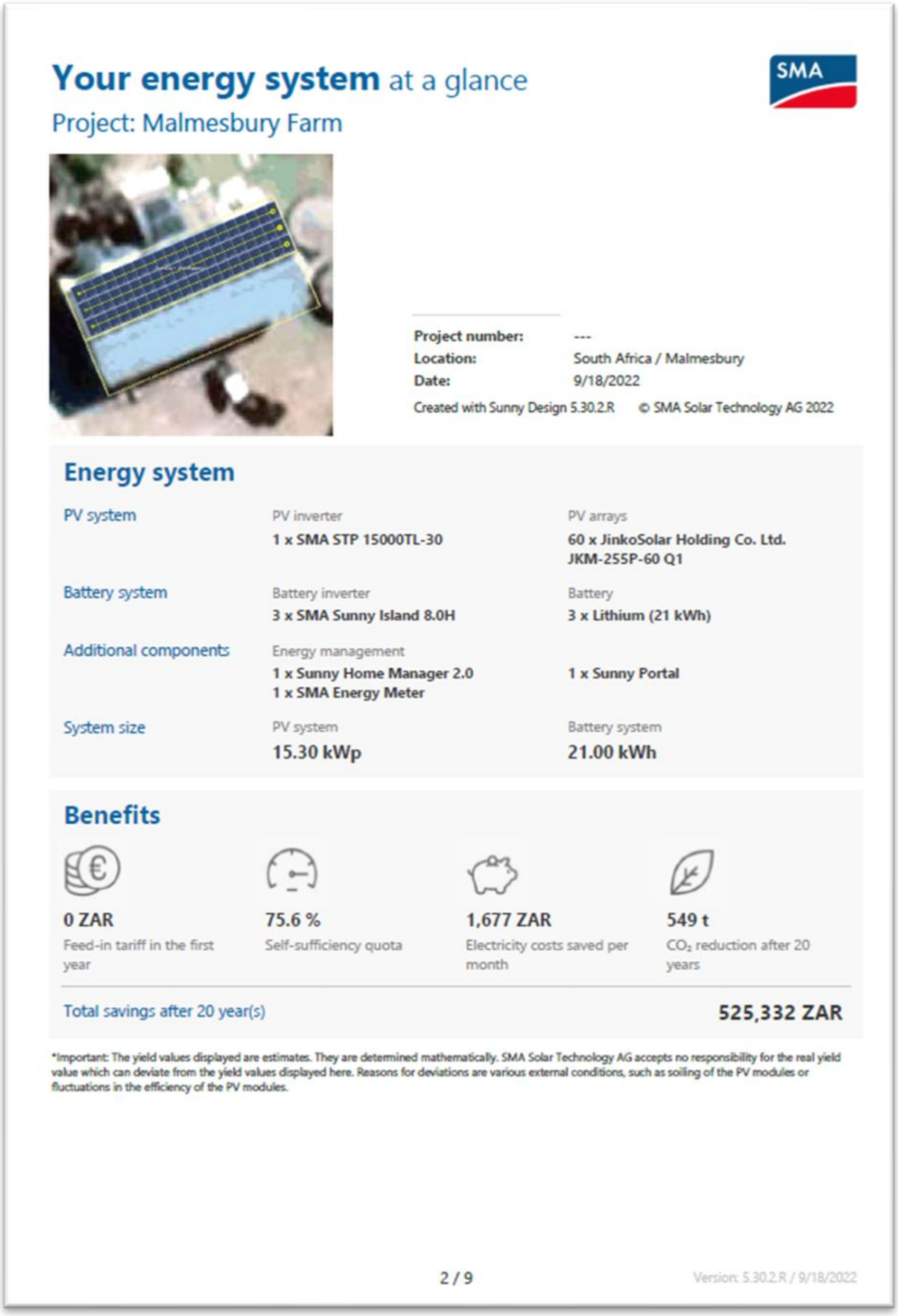
Figure 8: Malmesbury Farm - Sunny Design - page 1

Figure 9 is a summary of the design. The PV system that has been selected along with the panels, battery inverter and batteries have been summarised. The calculated CO_2 reduction over the 20 year period is 549 tones with a total monetary saving of R525 332.00. A simulated image of the PV system on the barn roof is in the top left corner.


Your energy system at a glance

Project: Malmesbury Farm

SMA

Project number:	---
Location:	South Africa / Malmesbury
Date:	9/18/2022

Created with Sunny Design 5.30.2.R © SMA Solar Technology AG 2022

Energy system

PV system	PV inverter **1 x SMA STP 15000TL-30**	PV arrays **60 x JinkoSolar Holding Co. Ltd. JKM-255P-60 Q1**
Battery system	Battery inverter **3 x SMA Sunny Island 8.0H**	Battery **3 x Lithium (21 kWh)**
Additional components	Energy management **1 x Sunny Home Manager 2.0** **1 x SMA Energy Meter**	**1 x Sunny Portal**
System size	PV system **15.30 kWp**	Battery system **21.00 kWh**

Benefits

0 ZAR Feed-in tariff in the first year	**75.6 %** Self-sufficiency quota	**1,677 ZAR** Electricity costs saved per month	**549 t** CO_2 reduction after 20 years

Total savings after 20 year(s) **525,332 ZAR**

*Important: The yield values displayed are estimates. They are determined mathematically. SMA Solar Technology AG accepts no responsibility for the real yield value which can deviate from the yield values displayed here. Reasons for deviations are various external conditions, such as soiling of the PV modules or fluctuations in the efficiency of the PV modules.

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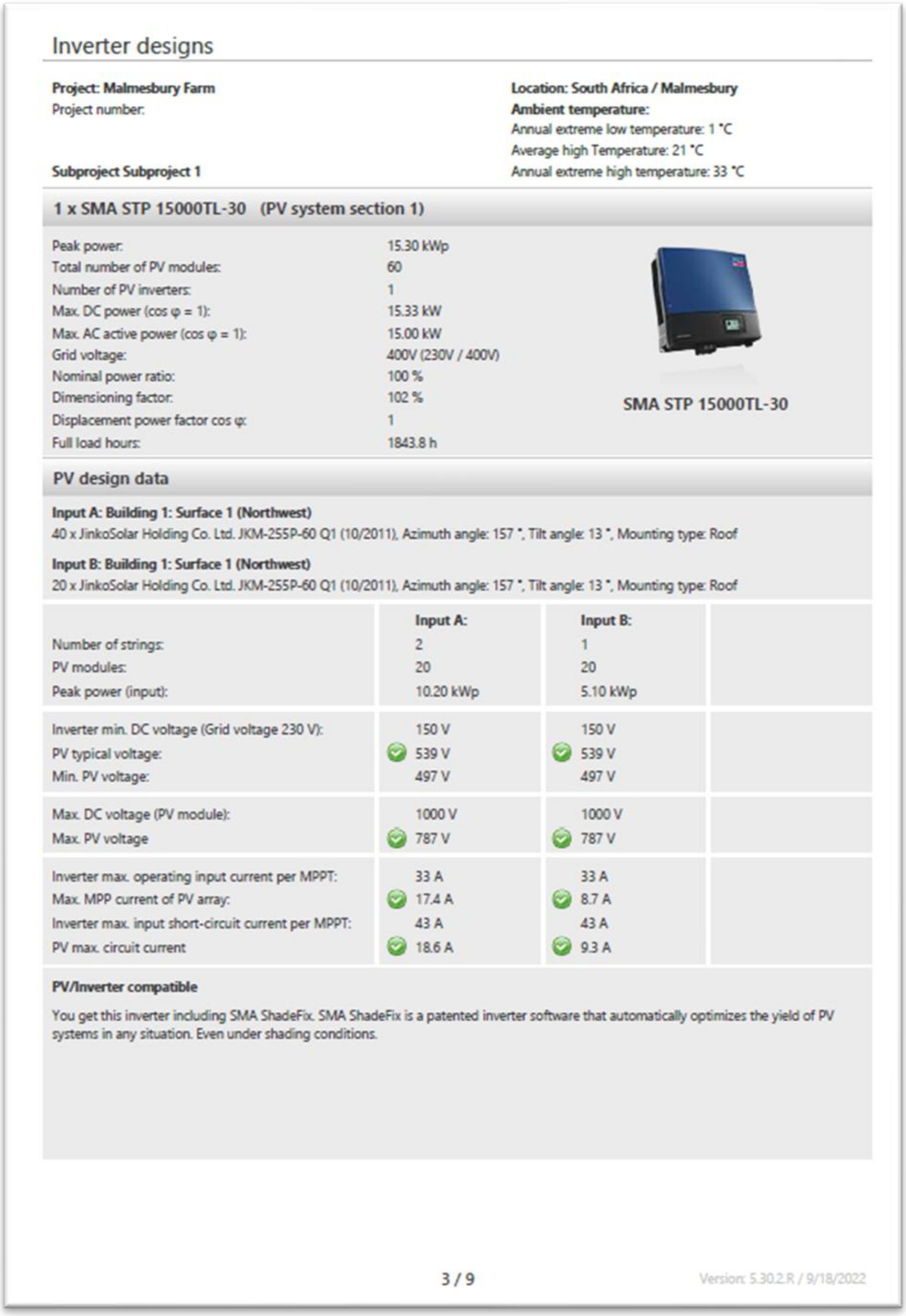
Figure 9: Malmesbury Farm - Sunny Design - page 2

Figure 10 highlights the details of the PV inverter in relation to the location. The peak power is the amount of PV that shall be connected to the inverter. The dimensioning factor is the total amount of PV connected to the inverter compared to the total maximum active power. The full load hours are a calculation as to how much time in a year the inverter will be at max output. The PV design data in Figure 10 is indicating the voltages and currents of the strings of panels under STC conditions. The maximum and minimum voltage for this specific inverter indicates the range in which the MPPT will operate.



Inverter designs

Project: Malmesbury Farm
Project number:

Subproject Subproject 1

Location: South Africa / Malmesbury
Ambient temperature:
Annual extreme low temperature: 1 °C
Average high Temperature: 21 °C
Annual extreme high temperature: 33 °C

1 x SMA STP 15000TL-30 (PV system section 1)

Peak power:	15.30 kWp
Total number of PV modules:	60
Number of PV inverters:	1
Max. DC power (cos φ = 1):	15.33 kW
Max. AC active power (cos φ = 1):	15.00 kW
Grid voltage:	400V (230V / 400V)
Nominal power ratio:	100 %
Dimensioning factor:	102 %
Displacement power factor cos φ:	1
Full load hours:	1843.8 h

PV design data

Input A: Building 1: Surface 1 (Northwest)
40 x JinkoSolar Holding Co. Ltd. JKM-255P-60 Q1 (10/2011), Azimuth angle: 157 °, Tilt angle: 13 °, Mounting type: Roof

Input B: Building 1: Surface 1 (Northwest)
20 x JinkoSolar Holding Co. Ltd. JKM-255P-60 Q1 (10/2011), Azimuth angle: 157 °, Tilt angle: 13 °, Mounting type: Roof

	Input A:	Input B:
Number of strings:	2	1
PV modules:	20	20
Peak power (input):	10.20 kWp	5.10 kWp
Inverter min. DC voltage (Grid voltage 230 V):	150 V	150 V
PV typical voltage:	539 V	539 V
Min. PV voltage:	497 V	497 V
Max. DC voltage (PV module):	1000 V	1000 V
Max. PV voltage	787 V	787 V
Inverter max. operating input current per MPPT:	33 A	33 A
Max. MPP current of PV array:	17.4 A	8.7 A
Inverter max. input short-circuit current per MPPT:	43 A	43 A
PV max. circuit current	18.6 A	9.3 A

PV/Inverter compatible

You get this inverter including SMA ShadeFix. SMA ShadeFix is a patented inverter software that automatically optimizes the yield of PV systems in any situation. Even under shading conditions.

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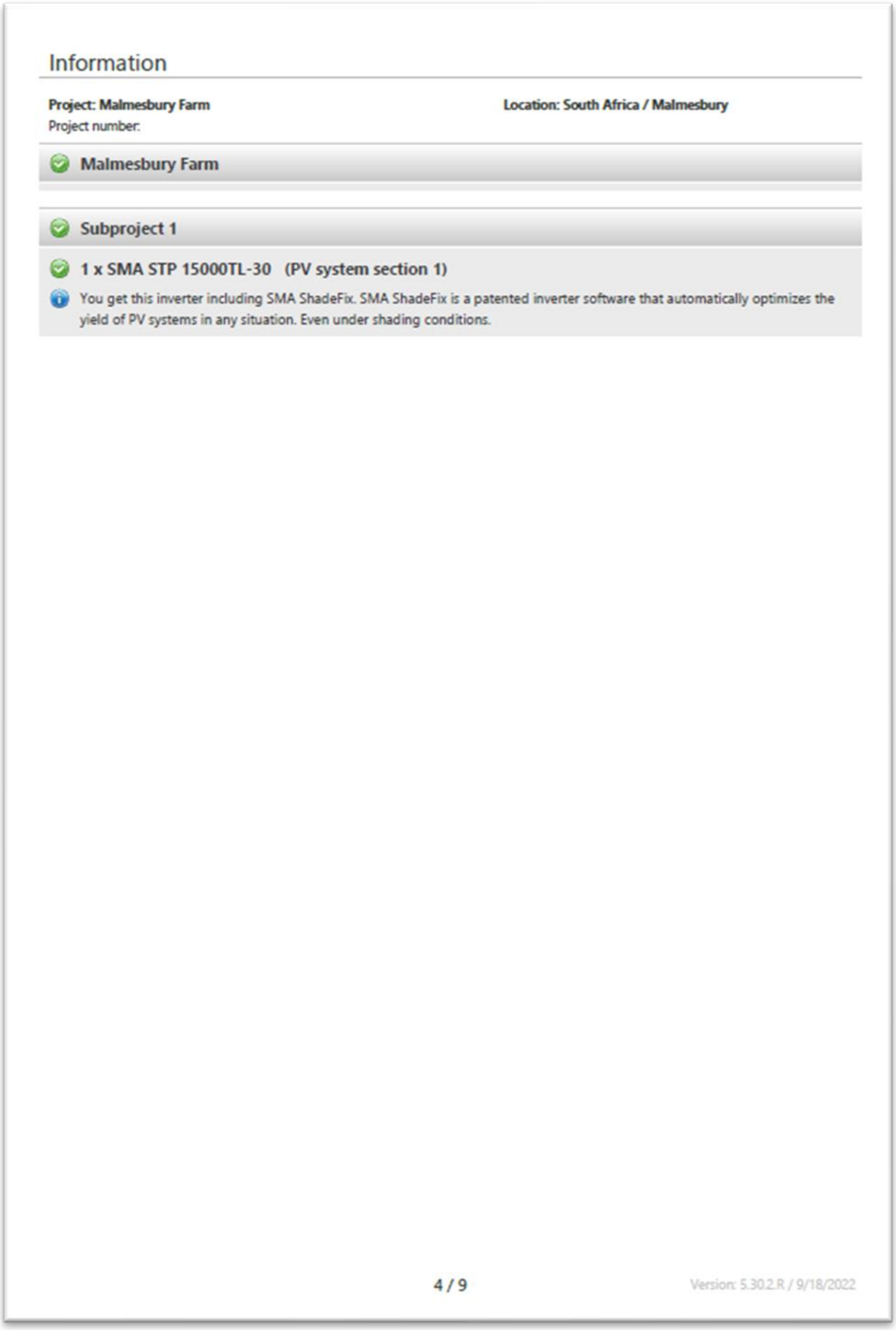
Figure 10: Malmesbury Farm - Sunny Design - page 3

Figure 11 is a check page that confirms the design is suitable and safe. If there are recommendations these shall be displayed towards the end of the paragraph in Figure 11.



Information

Project: Malmesbury Farm **Location: South Africa / Malmesbury**
Project number:

Malmesbury Farm

Subproject 1

1 x SMA STP 15000TL-30 (PV system section 1)

You get this inverter including SMA ShadeFix. SMA ShadeFix is a patented inverter software that automatically optimizes the yield of PV systems in any situation. Even under shading conditions.

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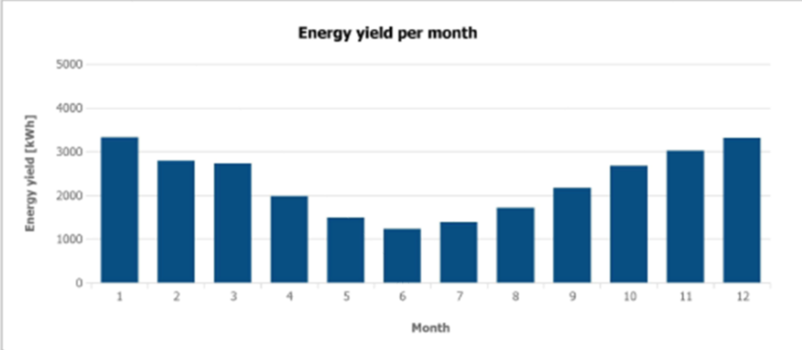
Figure 11: Malmesbury Farm - Sunny Design - page 4

The graph in Figure 12 indicates the expected monthly production throughout the year. As the location of the site is in the Southern Hemisphere and receives winter rains the expected yield over the middle months is considerably lower than the expected production over the summer months.

Monthly values

Project: Malmesbury Farm **Location: South Africa / Malmesbury**
Project number:

Diagram



Table

Month	Energy yield [kWh]	Self-consumption [kWh]	Grid feed-in [kWh]	Purchased electricity [kWh]
1	3309 (12.0 %)	1618	1691	286
2	2775 (10.0 %)	1417	1358	301
3	2709 (9.8 %)	1455	1254	396
4	1968 (7.1 %)	1257	711	449
5	1482 (5.4 %)	1151	331	538
6	1220 (4.4 %)	1003	217	566
7	1377 (5.0 %)	1096	281	536
8	1708 (6.2 %)	1162	546	468
9	2156 (7.8 %)	1269	886	378
10	2660 (9.6 %)	1419	1241	346
11	2999 (10.8 %)	1518	1481	323
12	3294 (11.9 %)	1614	1680	287

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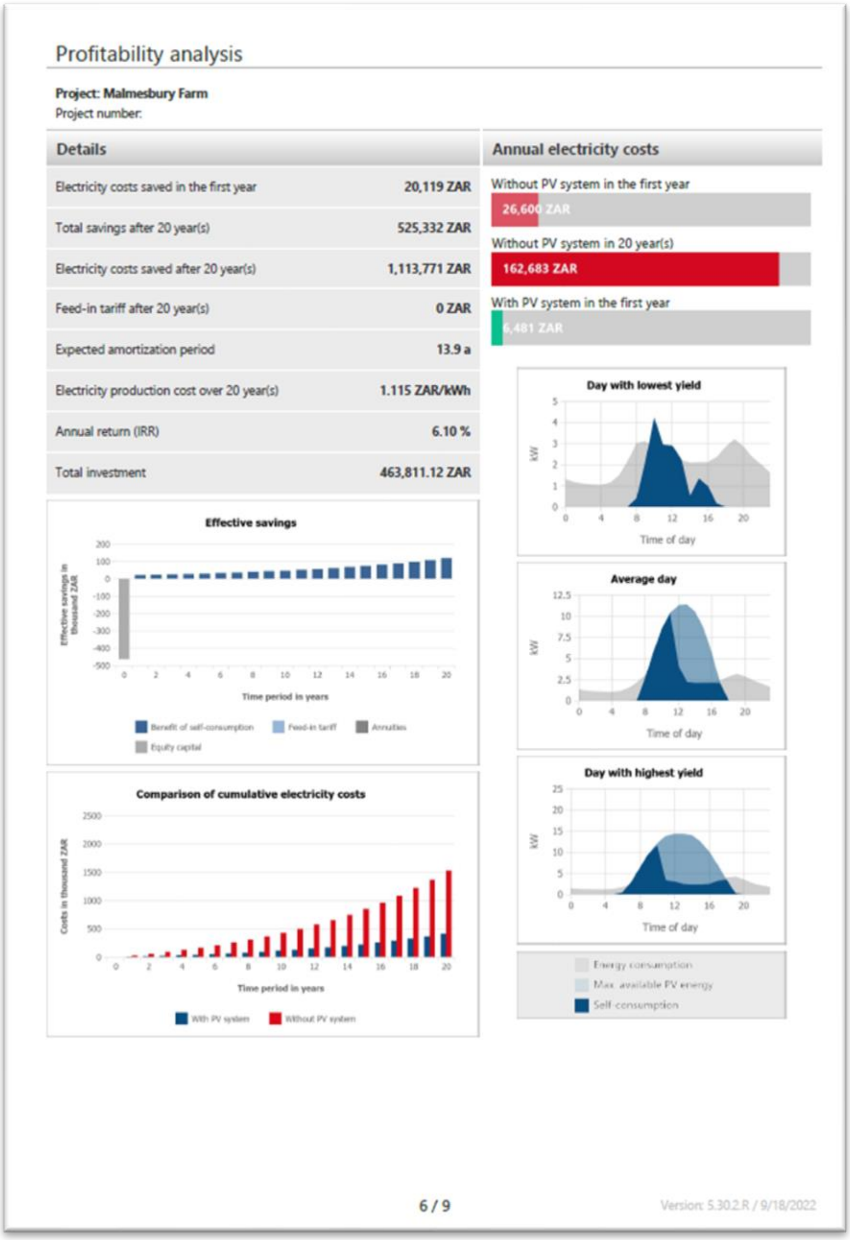
Figure 12: Malmesbury Farm - Sunny Design - page 5

The profitability analysis is possibly the most important page to investors and business owners this is shown in Figure 13. The electricity cost saved is a direct saving to the business once the investment and OPEX costs have been removed from this value the total savings can be deduced. The amortization period is a sum of the total investment value and the operating costs, minus the monthly electricity savings. The amortization value of 13.9 years is an indication of how many months it will take the savings to equal the costs. On the right side of Figure 13 is the lowest production or yield day, below this the average day and then below that the highest day of production. What this is indicating is that on the average or above average day the batteries will be fully charged by 12pm.


Profitability analysis

Project: Malmesbury Farm
Project number:

Details	
Electricity costs saved in the first year	20,119 ZAR
Total savings after 20 year(s)	525,332 ZAR
Electricity costs saved after 20 year(s)	1,113,771 ZAR
Feed-in tariff after 20 year(s)	0 ZAR
Expected amortization period	13.9 a
Electricity production cost over 20 year(s)	1.115 ZAR/kWh
Annual return (IRR)	6.10 %
Total investment	463,811.12 ZAR

Annual electricity costs
Without PV system in the first year 26,600 ZAR
Without PV system in 20 year(s) 162,683 ZAR
With PV system in the first year 6,481 ZAR

Figure 13: Malmesbury Farm - Sunny Design - page 6

Figure 14 is the profitability analysis it is indicating all he financial figures and parameters that have been used to calculate payback periods and an amortization timeframe.

Profitability analysis

Project: Malmesbury Farm
Project number:

Financing

The currency is **ZAR**
The equity ratio is **100 %**
The debt ratio is **0 %**
The grant amount is **0.00 ZAR**
The inflation rate is **3.00 %**
The analysis period of profitability is **20 Years**

Electricity purchase costs and feed-in tariff

The electricity purchase price is **1.33000 ZAR/kWh**
The basic price is **0.00 ZAR/Month.**
Special tariffs are not taken into account
The annual rate of electricity price increase is **10.0 %**
The feed-in tariff is **0.00000 ZAR/kWh**
The duration of the feed-in tariff is **10 Years**
Deduction or feed-in tariff in case of self-consumption is **0.00000 ZAR/kWh**
The selling price on expiration of the remuneration period is **0.00000 ZAR/kWh.**

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Figure 14: Malmesbury Farm - Sunny Design - page 7

Figure 15 is specifically pertaining to the full project cost including all fixed monthly costs.

Cost estimate (non binding)

Project: Malmesbury Farm **Location: South Africa / Malmesbury**
Project number:

Project costs		
Total investment		**463,811.12 ZAR**
Fixed cost		
Annual fixed costs (as percentage of capital expenditure)	1.00 % of investment costs	4,638.11 ZAR

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Figure 15: Malmesbury Farm - Sunny Design - page 8

Figure 16 is displaying the roof layout of the panels. Towards the bottom left corner a North arrow is indicating the orientation. This site is in the Southern Hemisphere and therefore the desired orientation is North facing.

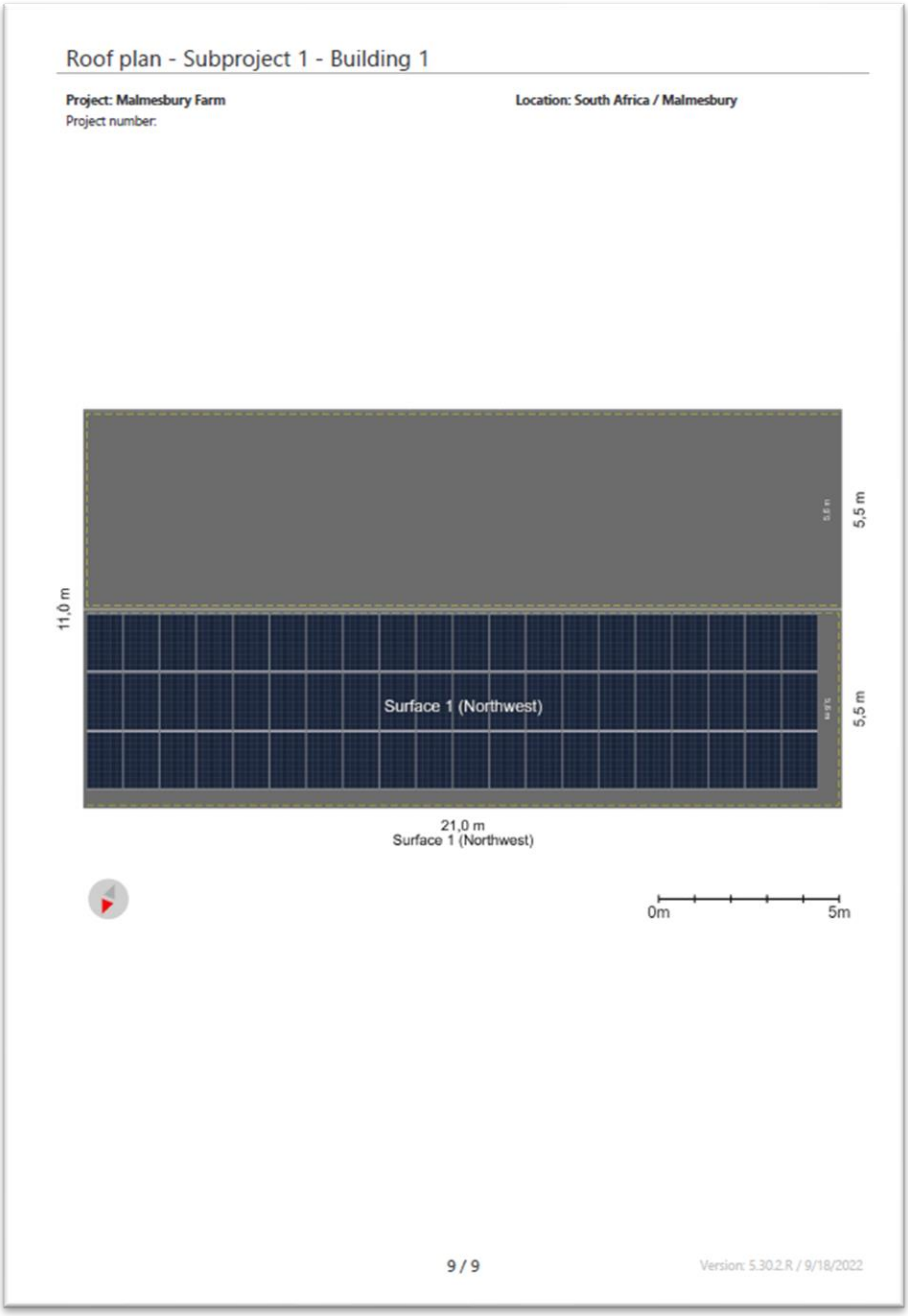
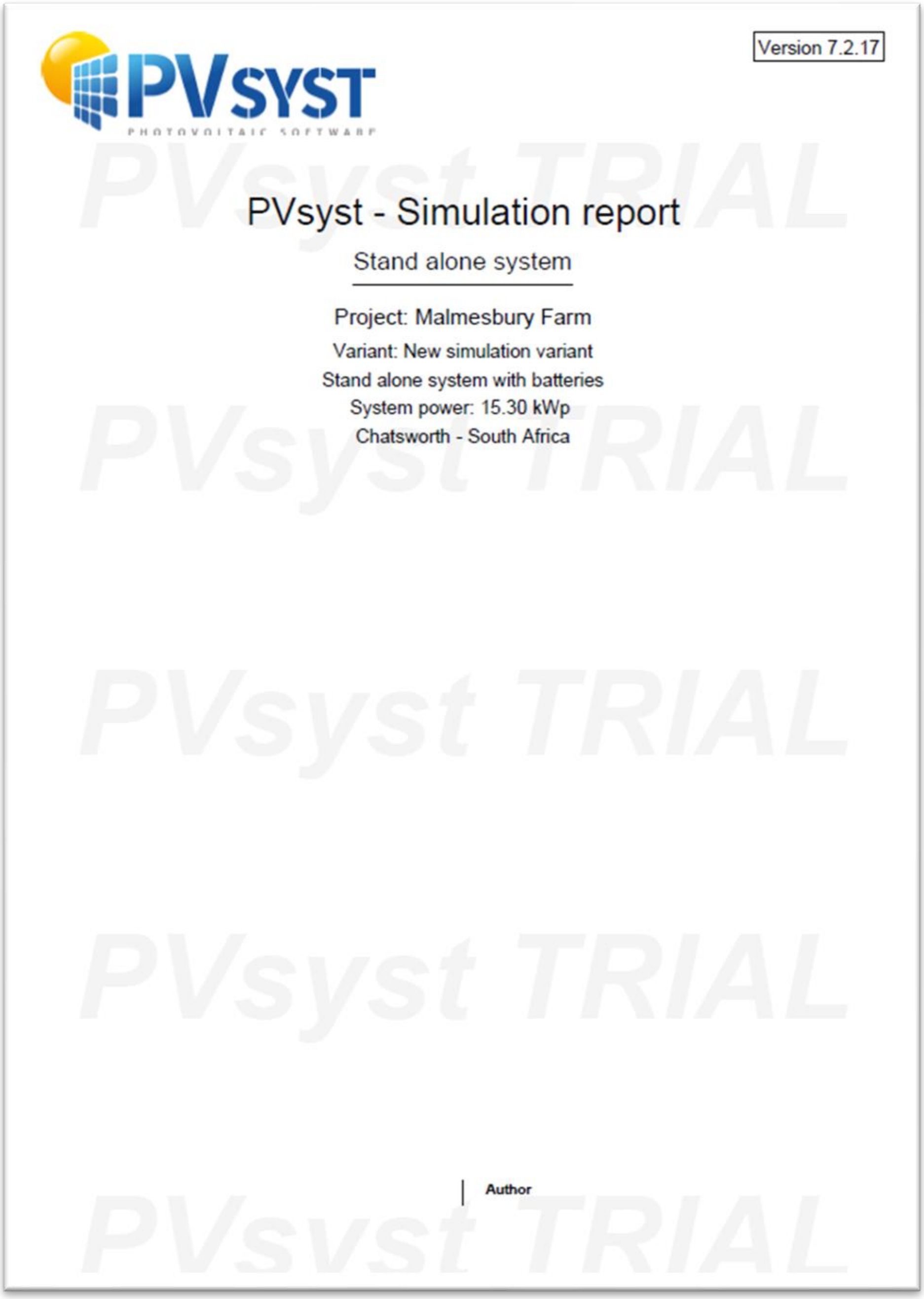


Figure 16: Malmesbury Farm - Sunny Design - page 9

4.5.3 PV Syst. Simulation for case study one

The calculation done by PV Syst is very similar to that of Sunny Design. This calculation has indicated that the payback period is 10.4 years. With PV Syst the actual loads are added for a more accurate calculation. Due to the pumping activities the farm uses 3 times more power in summer compared to winter. December 2907 kWh for the month, July 829 kWh for the month. All major loads such as lights, TV's, PC's, mobile devices, fridge, freezer, dishwasher, clothes washer, irrigation pumps and borehole pumps are added to the users' needs list. This then forms part of the total load of the facility. This is the most accuracy way of establishing a load profile.

Figure 17 is the front page of the PV Syst simulation report. A summary of the system is given on this page.



Version 7.2.17

PVsyst - Simulation report

Stand alone system

Project: Malmesbury Farm

Variant: New simulation variant

Stand alone system with batteries

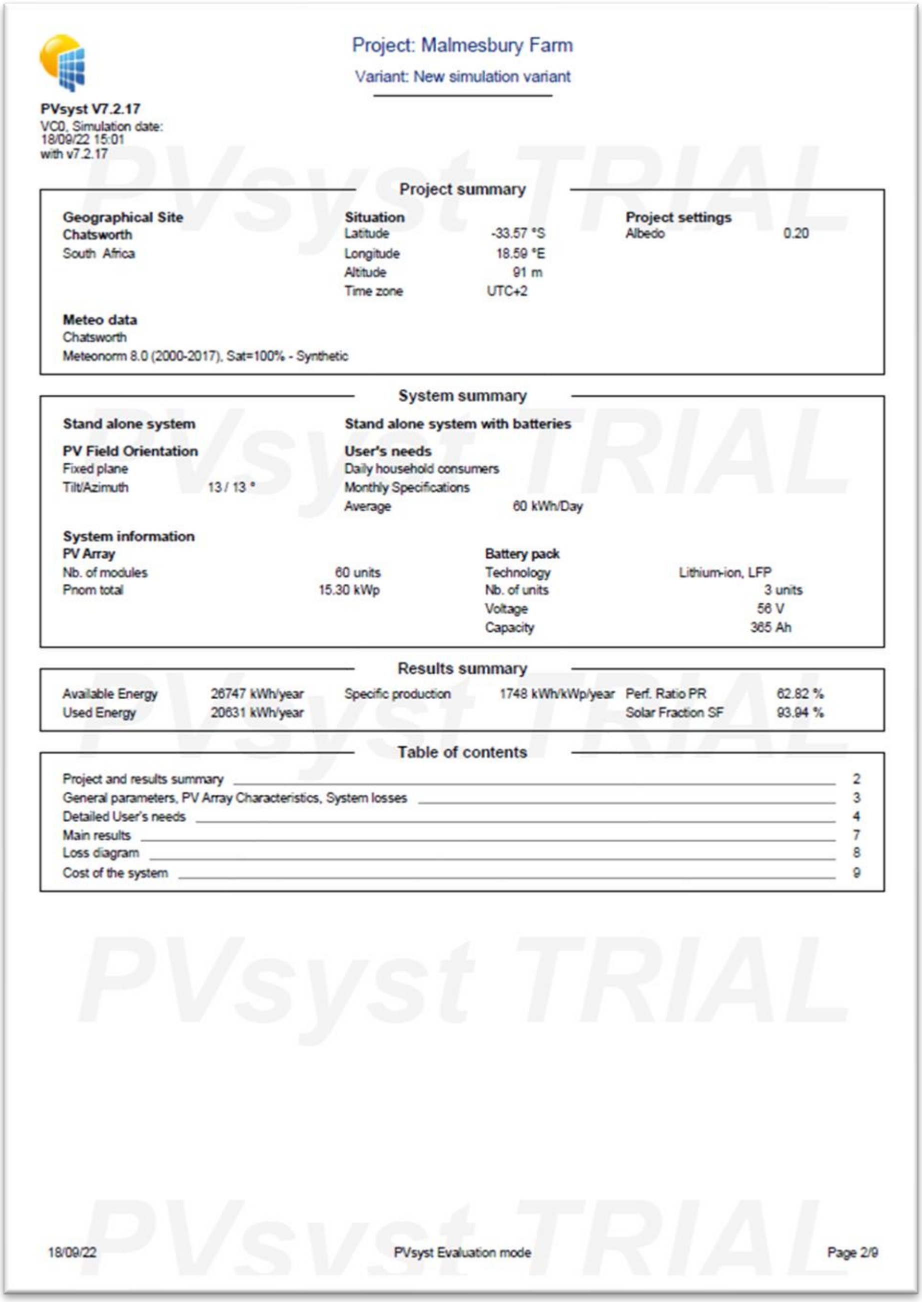
System power: 15.30 kWp

Chatsworth - South Africa

Author

Figure 17: Malmesbury Farm - PV Syst. - page 1

Figure 18 begins with a project summay, this details the location of the site. The system summary highlights the main system criteria, such as the panel tilt angle, number of panels, total kWp, battery technology and size.



Project: Malmesbury Farm

Variant: New simulation variant

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Project summary

Geographical Site	Situation		Project settings	
Chatsworth	Latitude	-33.57 °S	Albedo	0.20
South Africa	Longitude	18.59 °E		
	Altitude	91 m		
	Time zone	UTC+2		

Meteo data
Chatsworth
Meteonorm 8.0 (2000-2017), Sat=100% - Synthetic

System summary

Stand alone system — **Stand alone system with batteries**

PV Field Orientation		User's needs	
Fixed plane		Daily household consumers	
Tilt/Azimuth	13 / 13 °	Monthly Specifications	
		Average	60 kWh/Day

System information

PV Array		Battery pack	
Nb. of modules	60 units	Technology	Lithium-ion, LFP
Pnom total	15.30 kWp	Nb. of units	3 units
		Voltage	56 V
		Capacity	365 Ah

Results summary

Available Energy	26747 kWh/year	Specific production	1748 kWh/kWp/year	Perf. Ratio PR	62.82 %
Used Energy	20631 kWh/year			Solar Fraction SF	93.94 %

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Figure 18: Malmesbury Farm - PV Syst. - page 2

Figure 19 lists the general input parameters, important to note that the average consumption of the facility is 60 kWh per day. The PV arrat characteristics give a breakdown of the PV system design. There are 3 strings of 20 panels per string each, the panels are placed in series strings to increase the voltage, this resuces losses as the current remains the same. On the right hand side of the PV array characteristics is the battery information, this facility is using 3 batteries with a total stored energy of 18.2 kWh. In the PV Syst software, the exact model number of the inverters I not used as this software caters for all manufacturers. The array losses are then summarised, these are further details in Figure 22.

PVsyst V7.2.17
VC0, Simulation date:
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with v7.2.17

Project: Malmesbury Farm
Variant: New simulation variant

General parameters

Stand alone system		**Stand alone system with batteries**			
PV Field Orientation					
Orientation		Sheds configuration		Models used	
Fixed plane		No 3D scene defined		Transposition	Perez
Tilt/Azimuth	13 / 13 °			Diffuse	Perez, Meteonorm
				Circumsolar	separate
User's needs					
Daily household consumers					
Monthly Specifications					
Average	60 kWh/Day				

PV Array Characteristics

PV module		**Battery**	
Manufacturer	Generic	Manufacturer	Generic
Model	JKM 255P-60	Model	ESS 7.0
(Original PVsyst database)		Technology	Lithium-ion, LFP
Unit Nom. Power	255 Wp	Nb. of units	3 in parallel
Number of PV modules	60 units	Discharging min. SOC	10.0 %
Nominal (STC)	15.30 kWp	Stored energy	18.2 kWh
Modules	3 Strings x 20 In series	**Battery Pack Characteristics**	
At operating cond. (50°C)		Voltage	56 V
Pmpp	13.66 kWp	Nominal Capacity	365 Ah (C10)
U mpp	543 V	Temperature	Fixed 20 °C
I mpp	25 A		
Controller		**Battery Management control**	
Universal controller		Threshold commands as	SOC calculation
Technology	MPPT converter	Charging	SOC = 0.96 / 0.80
Temp coeff.	-5.0 mV/°C/Elem.	Discharging	SOC = 0.10 / 0.35
Converter			
Maxi and EURO efficiencies	97.0 / 95.0 %		
Total PV power			
Nominal (STC)	15 kWp		
Total	60 modules		
Module area	98.2 m²		
Cell area	87.6 m²		

Array losses

Thermal Loss factor		**DC wiring losses**		**Serie Diode Loss**	
Module temperature according to irradiance		Global array res.	365 mΩ	Voltage drop	0.7 V
Uc (const)	20.0 W/m²K	Loss Fraction	1.5 % at STC	Loss Fraction	0.1 % at STC
Uv (wind)	0.0 W/m²K/m/s				
Module Quality Loss		**Module mismatch losses**		**Strings Mismatch loss**	
Loss Fraction	-0.8 %	Loss Fraction	2.0 % at MPP	Loss Fraction	0.1 %
IAM loss factor					
ASHRAE Param.: IAM = 1 - bo (1/cosi -1)					
bo Param.	0.05				

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Figure 19: Malmesbury Farm - PV Syst. - page 3

Figure 20 is the detail of the loads seen at the facility, these loads are predominantly during the sunlight hours. The majority of the power is used for pumping, there are two pressureising pumps that are used to irrigate fields. There is one large borehole pump that is used to pump water from the ground. Other than pumping activities the facility is very power efficient.

Project: Malmesbury Farm

Variant: New simulation variant

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with v7.2.17

Detailed User's needs

Daily household consumers, Monthly Specifications, average = 60 kWh/day

January and February

	Number	Power	Use	Energy	Number	Power	Use	Energy
		W	Hour/day	Wh/day		W	Hour/day	Wh/day
Lamps (LED or fluo)	10	6W/lamp	4.0	240	10	6W/lamp	4.0	240
TV / PC / Mobile	2	100W/app	3.5	700	2	100W/app	3.5	700
Fridge / Deep-freeze	2		24	4800	2		24	4800
Dish- and Cloth-washer	2		2	2000	2		2	2000
Pump	2	4000W tot	8.0	64000	2	4000W tot	7.5	60000
Borehole	1	5500W tot	4.0	22000	1	5500W tot	3.5	19250
Stand-by consumers			24.0	24			24.0	24
Total daily energy				93764Wh/day				87014Wh/day

March and April

	Number	Power	Use	Energy	Number	Power	Use	Energy
		W	Hour/day	Wh/day		W	Hour/day	Wh/day
Lamps (LED or fluo)	10	6W/lamp	4.0	240	10	6W/lamp	4.0	240
TV / PC / Mobile	2	100W/app	3.5	700	2	100W/app	3.5	700
Fridge / Deep-freeze	2		24	4800	2		24	4800
Dish- and Cloth-washer	2		2	2000	2		2	2000
Pump	2	4000W tot	7.0	56000	2	4000W tot	3.0	24000
Borehole	1	5500W tot	3.0	16500	1	5500W tot	2.5	13750
Stand-by consumers			24.0	24			24.0	24
Total daily energy				80264Wh/day				45514Wh/day

May and June

	Number	Power	Use	Energy	Number	Power	Use	Energy
		W	Hour/day	Wh/day		W	Hour/day	Wh/day
Lamps (LED or fluo)	10	6W/lamp	4.0	240	10	6W/lamp	4.0	240
TV / PC / Mobile	2	100W/app	3.5	700	2	100W/app	3.5	700
Fridge / Deep-freeze	2		24	4800	2		24	4800
Dish- and Cloth-washer	2		2	2000	2		2	2000
Pump	2	4000W tot	2.5	20000	2	4000W tot	2.0	16000
Borehole	1	5500W tot	1.0	5500	1	5500W tot	1.0	5500
Stand-by consumers			24.0	24			24.0	24
Total daily energy				33264Wh/day				29264Wh/day

July and August

	Number	Power	Use	Energy	Number	Power	Use	Energy
		W	Hour/day	Wh/day		W	Hour/day	Wh/day
Lamps (LED or fluo)	10	6W/lamp	4.0	240	10	6W/lamp	4.0	240
TV / PC / Mobile	2	100W/app	3.5	700	2	100W/app	3.5	700
Fridge / Deep-freeze	2		24	4800	2		24	4800
Dish- and Cloth-washer	2		2	2000	2		2	2000
Pump	2	4000W tot	2.0	16000	2	4000W tot	3.0	24000
Borehole	1	5500W tot	1.0	5500	1	5500W tot	1.0	5500
Stand-by consumers			24.0	24			24.0	24
Total daily energy				29264Wh/day				37264Wh/day

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Figure 20: Malmesbury Farm - PV Syst. - page 5

Figure 21 is a continuation from Figure 20. This is where we see the power variant from 29,264 kWh per day in July to 80,264 kWh in Summer.

Project: Malmesbury Farm

Variant: New simulation variant

PVsyst V7.2.17
VC0, Simulation date:
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with v7.2.17

Detailed User's needs

September and October

	Number	Power	Use	Energy	Number	Power	Use	Energy
		W	Hour/day	Wh/day		W	Hour/day	Wh/day
Lamps (LED or fluo)	10	6W/lamp	4.0	240	10	6W/lamp	4.0	240
TV / PC / Mobile	2	100W/app	3.5	700	2	100W/app	3.5	700
Fridge / Deep-freeze	2		24	4800	2		24	4800
Dish- and Cloth-washer	2		2	2000	2		2	2000
Pump	2	4000W tot	3.0	24000	2	4000W tot	6.5	52000
Borehole	1	5500W tot	1.5	8250	1	5500W tot	2.5	13750
Stand-by consumers			24.0	24			24.0	24
Total daily energy				40014Wh/day				73514Wh/day

November and December

	Number	Power	Use	Energy	Number	Power	Use	Energy
		W	Hour/day	Wh/day		W	Hour/day	Wh/day
Lamps (LED or fluo)	10	6W/lamp	4.0	240	10	6W/lamp	4.0	240
TV / PC / Mobile	2	100W/app	3.5	700	2	100W/app	3.5	700
Fridge / Deep-freeze	2		24	4800	2		24	4800
Dish- and Cloth-washer	2		2	2000	2		2	2000
Pump	2	4000W tot	7.0	56000	2	4000W tot	8.0	64000
Borehole	1	5500W tot	3.0	16500	1	5500W tot	4.0	22000
Stand-by consumers			24.0	24			24.0	24
Total daily energy				80264Wh/day				93764Wh/day

Hourly distribution

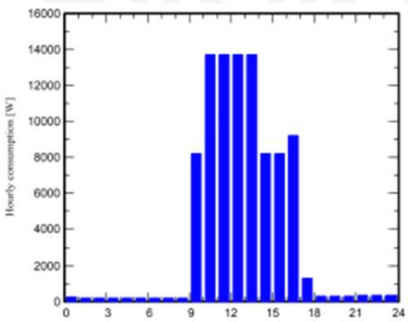

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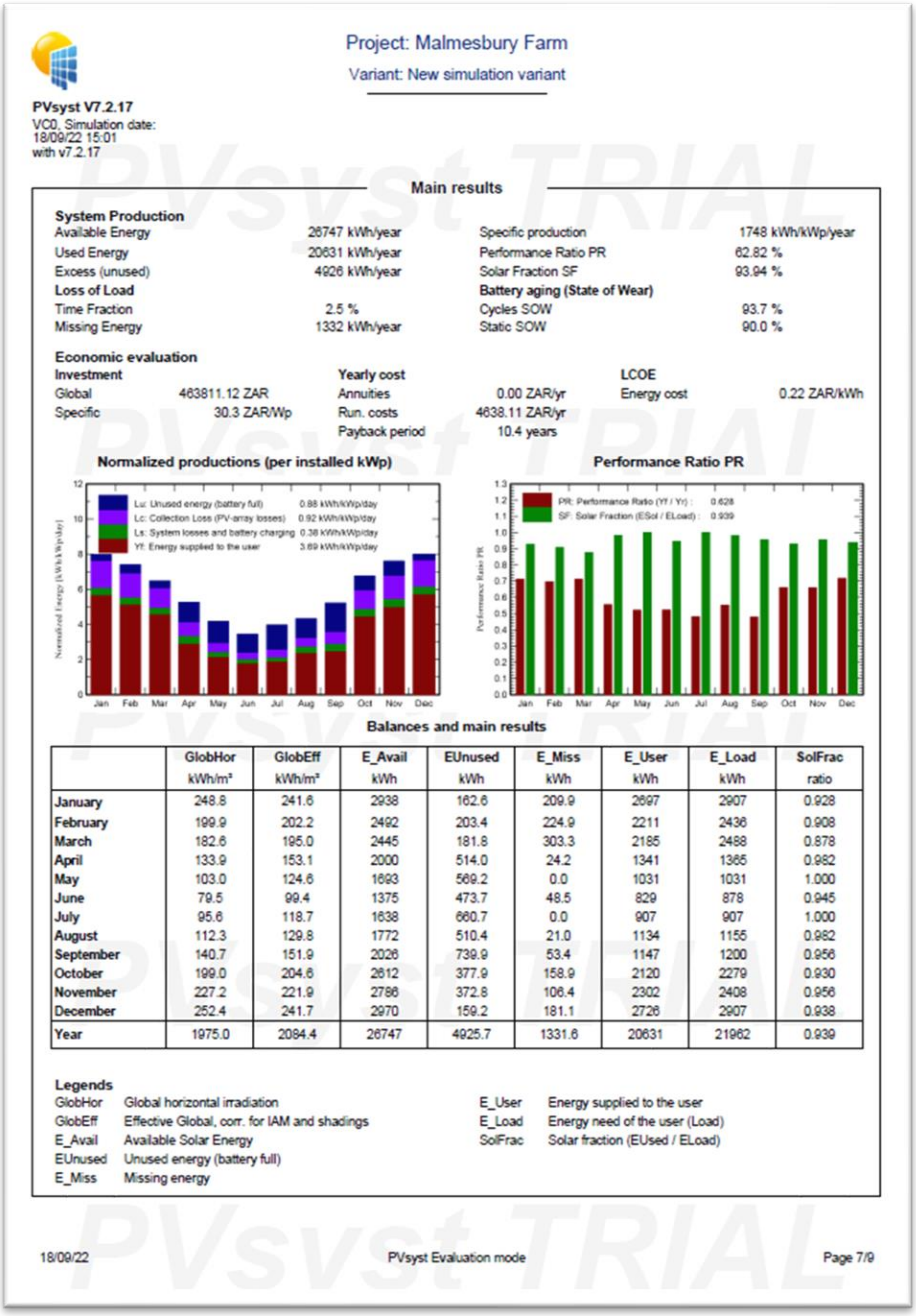
Figure 21: Malmesbury Farm - PV Syst. - page 6

Figure 22 is the main results of the simulation. The available energy has been calculated to be 26 747 kWh/year where the used energy is 20 631 kWh/year. If this facility connected to the local utility and was permitted to feed power back into the network they would have been able to export 4 926 kWh per year and save Eskom an equivelant amount of ‘carbon’ emissions. The total investment amount has been input with a calculated running or operating cost of R4 638.11 per year. With this data the simulation has calculated that the amortisation or paback period to be 10.4 years. The Levelised Cost of Energy (LCOE) has been calcuated at R 0.22 per kWh over the project lifecycle.


Project: Malmesbury Farm

Variant: New simulation variant

PVsyst V7.2.17
VC0, Simulation date:
18/09/22 15:01
with v7.2.17

Main results

System Production

Available Energy	26747 kWh/year	Specific production	1748 kWh/kWp/year
Used Energy	20631 kWh/year	Performance Ratio PR	62.82 %
Excess (unused)	4926 kWh/year	Solar Fraction SF	93.94 %
Loss of Load		**Battery aging (State of Wear)**	
Time Fraction	2.5 %	Cycles SOW	93.7 %
Missing Energy	1332 kWh/year	Static SOW	90.0 %

Economic evaluation

Investment		**Yearly cost**		**LCOE**	
Global	463811.12 ZAR	Annuities	0.00 ZAR/yr	Energy cost	0.22 ZAR/kWh
Specific	30.3 ZAR/Wp	Run. costs	4638.11 ZAR/yr		
		Payback period	10.4 years		

Balances and main results

	GlobHor kWh/m²	GlobEff kWh/m²	E_Avail kWh	EUnused kWh	E_Miss kWh	E_User kWh	E_Load kWh	SolFrac ratio
January	248.8	241.6	2938	162.6	209.9	2697	2907	0.928
February	199.9	202.2	2492	203.4	224.9	2211	2436	0.908
March	182.6	195.0	2445	181.8	303.3	2185	2488	0.878
April	133.9	153.1	2000	514.0	24.2	1341	1365	0.982
May	103.0	124.6	1693	569.2	0.0	1031	1031	1.000
June	79.5	99.4	1375	473.7	48.5	829	878	0.945
July	95.6	118.7	1638	660.7	0.0	907	907	1.000
August	112.3	129.8	1772	510.4	21.0	1134	1155	0.982
September	140.7	151.9	2026	739.9	53.4	1147	1200	0.956
October	199.0	204.6	2612	377.9	158.9	2120	2279	0.930
November	227.2	221.9	2786	372.8	106.4	2302	2408	0.956
December	252.4	241.7	2970	159.2	181.1	2726	2907	0.938
Year	1975.0	2084.4	26747	4925.7	1331.6	20631	21962	0.939

Legends

GlobHor Global horizontal irradiation
GlobEff Effective Global, corr. for IAM and shadings
E_Avail Available Solar Energy
EUnused Unused energy (battery full)
E_Miss Missing energy
E_User Energy supplied to the user
E_Load Energy need of the user (Load)
SolFrac Solar fraction (EUsed / ELoad)

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Figure 22: Malmesbury Farm - PV Syst. - page 7

Figure 23 is an indication of the losses within the system. All these loses are broken down on the righ hand side of the image.

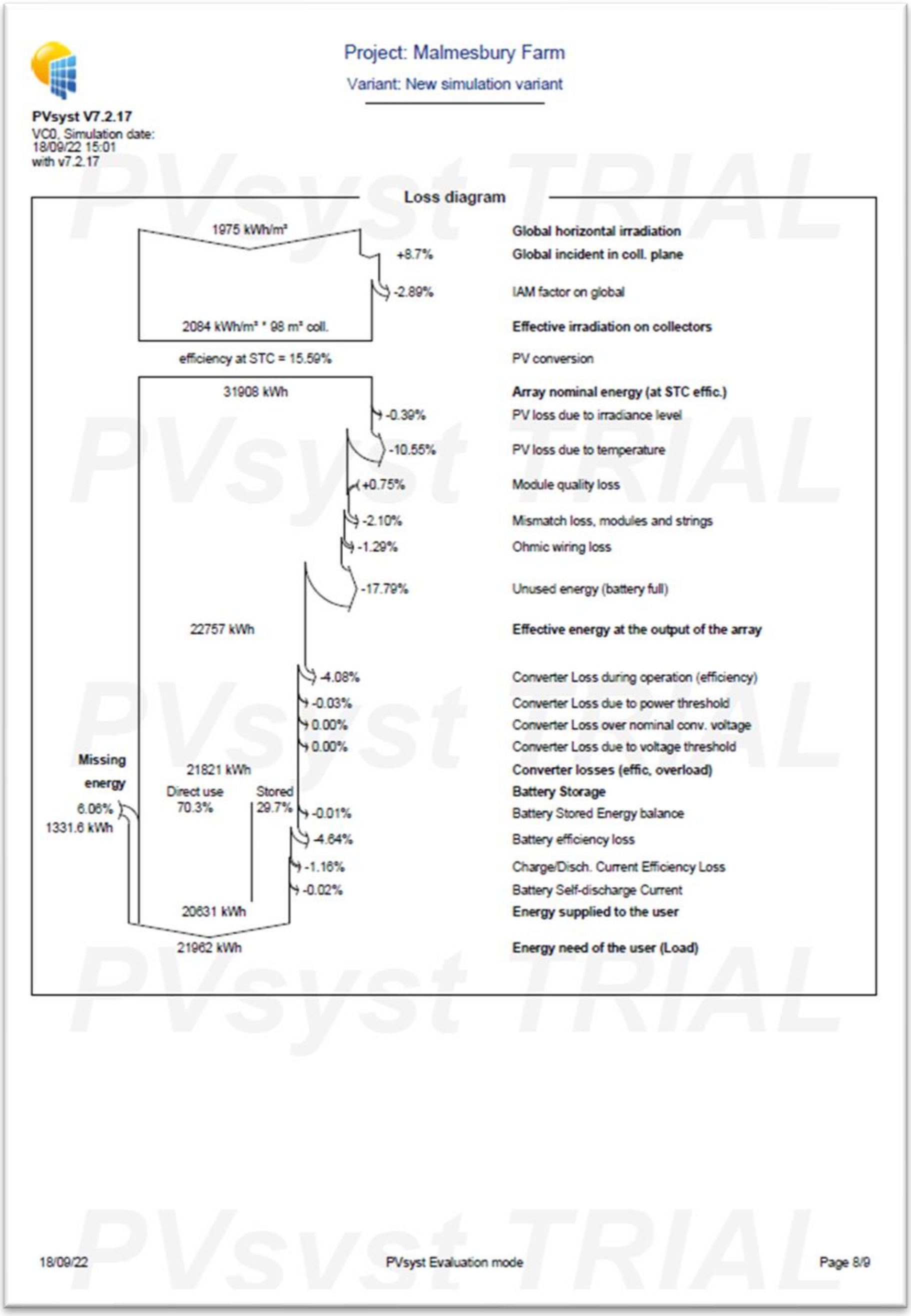

Figure 23: Malmesbury Farm - PV Syst. - page 8

Figure 24 is a table of the costs associated with the project.

Project: Malmesbury Farm

Variant: New simulation variant

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Cost of the system

Installation costs

Item	Quantity units	Cost ZAR	Total ZAR
PV modules			
JKM 255P-60	60	1657.50	99450.00
Supports for modules	60	282.72	16963.20
Batteries	3	80547.96	241643.89
Controllers			33410.54
Other components			
Accessories, fasteners	1	11846.39	11846.39
Taxes			
VAT	1	0.00	60497.10
Total			463811.12
Depreciable asset			403314.02

Operating costs

Item	Total ZAR/year
Maintenance	
Repairs	4638.11
Total (OPEX)	4638.11

System summary

Total installation cost	463811.12 ZAR
Operating costs	4638.11 ZAR/year
Excess energy (battery full)	4.9 MWh/year
Used solar energy	20.6 MWh/year
Used energy cost	1.349 ZAR/kWh

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Figure 24: Malmesbury Farm - PV Syst. - page 9

4.5.4 Summary for case study one

The Solar PV system was equipped with a power management and monitoring system. The monitoring system uses the Sunny Portal interface. All inverters and power meters communicate and upload their data to Sunny Portal. Sunny Portal then stores and displays this data in a graphical format.

This data has been downloaded as a CSV file and tabulated accordingly.

Table 4 to 5 is a tabulation of the data received from the CSV file, it indicates:

- The Total Energy Produced (from 10/04/2016 to 30/07/2022): 151 868.75 kWh
- When multiplied by the appropriate year electricity tariff the Total Electricity savings after 76 months is R243 758.52

Table 5 to 6 is a tabulated version of the saving due to the installation of the Solar PV System.

The system was installed in April 2016, but was only disconnected from the Eskom grid in June 2018

Total Service fee saving after 49 months: R103 948.78

Table 7 is the total savings as of end July 2022: R347 707.30

Therefore 75% of the asset has been recouped over the 76-month period.

Figure 25 is a graphical breakdown of the savings that have accumulated over the 76-month period.

Dark blue is indicating the electricity savings per month. Orange is indicating the availability charge savings per month. Light blue is the yearly combined savings.

Figure 25 is clearly indicating that there is more solar PV production over the summer months. As this farm cultivates crops, a significant amount of energy is used for water reticulation and irrigation. The farm pumps water from a borehole into a holding tank. This water is then pumped onto the fields to irrigate the crops. The majority of this pumping takes place over the summer months.

Sunny Design calculated a payback period of 13.9 years for the investment. PV Syst calculated a payback period of 10.4 years. Both had the same initial tariff, PV system and batteries. Only the consumption amounts differed due to the inability to add specific loads to Sunny Design.

It is evident that between the two software calculations there is a difference. This difference can be constituted to the use of power. The more power that is consumed during highly productive sunlight hours, the greater the reduction for the payback period.

Figure 26 takes into account the exact monies recouped. With the actual production data, we can calculate the revised payback period. This is done by adding the previous 12 months consumption and then dividing it by 12 to get an average monthly consumption. This average is then used for the next period until there is a tariff increase in the end of March. This increase is an average of the last 5 years. This average is = 10.69%. With this data we are able to calculate the amortisation date. When only the energy data is taken considered the amortisation time is 10 years and 5 months, this is graphically represented in Figure 26. When the energy data and service fee reduction is taken considered the amortisation time is 7 years and 9 months, this is graphically represented in Figure 27.

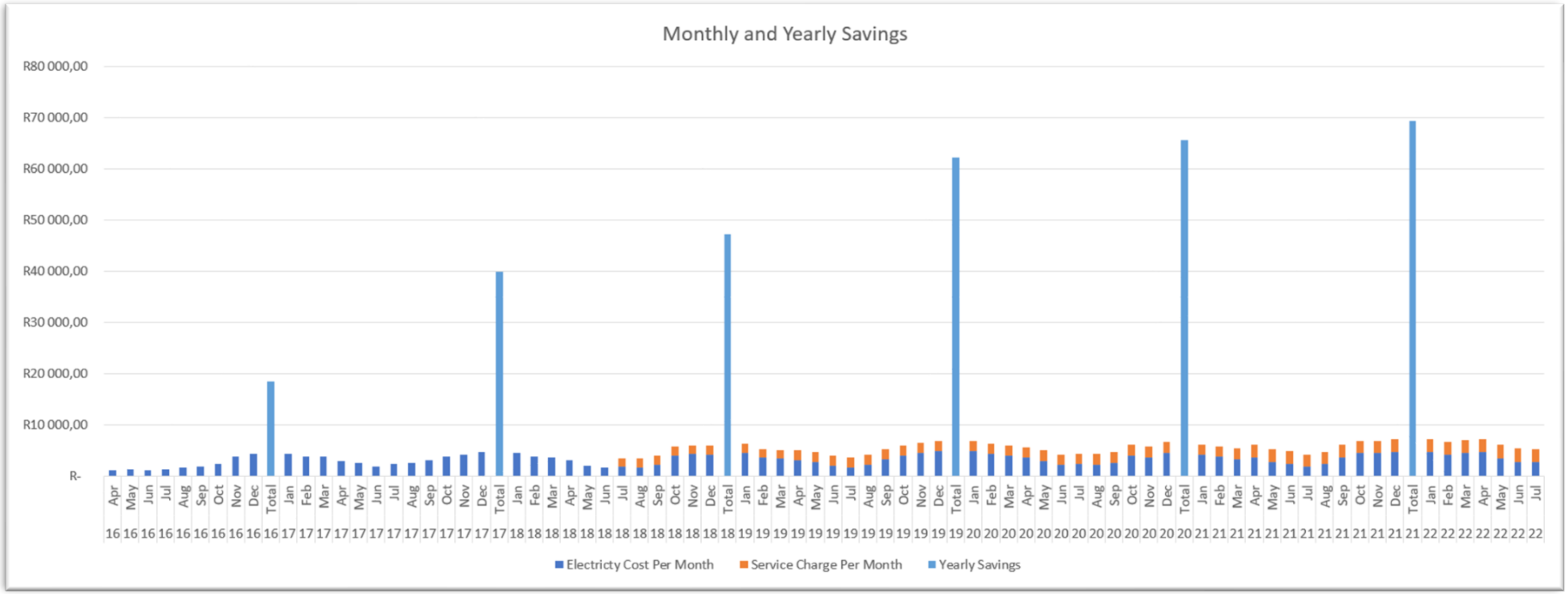


Figure 25: Malmesbury Farm - monthly and yearly savings

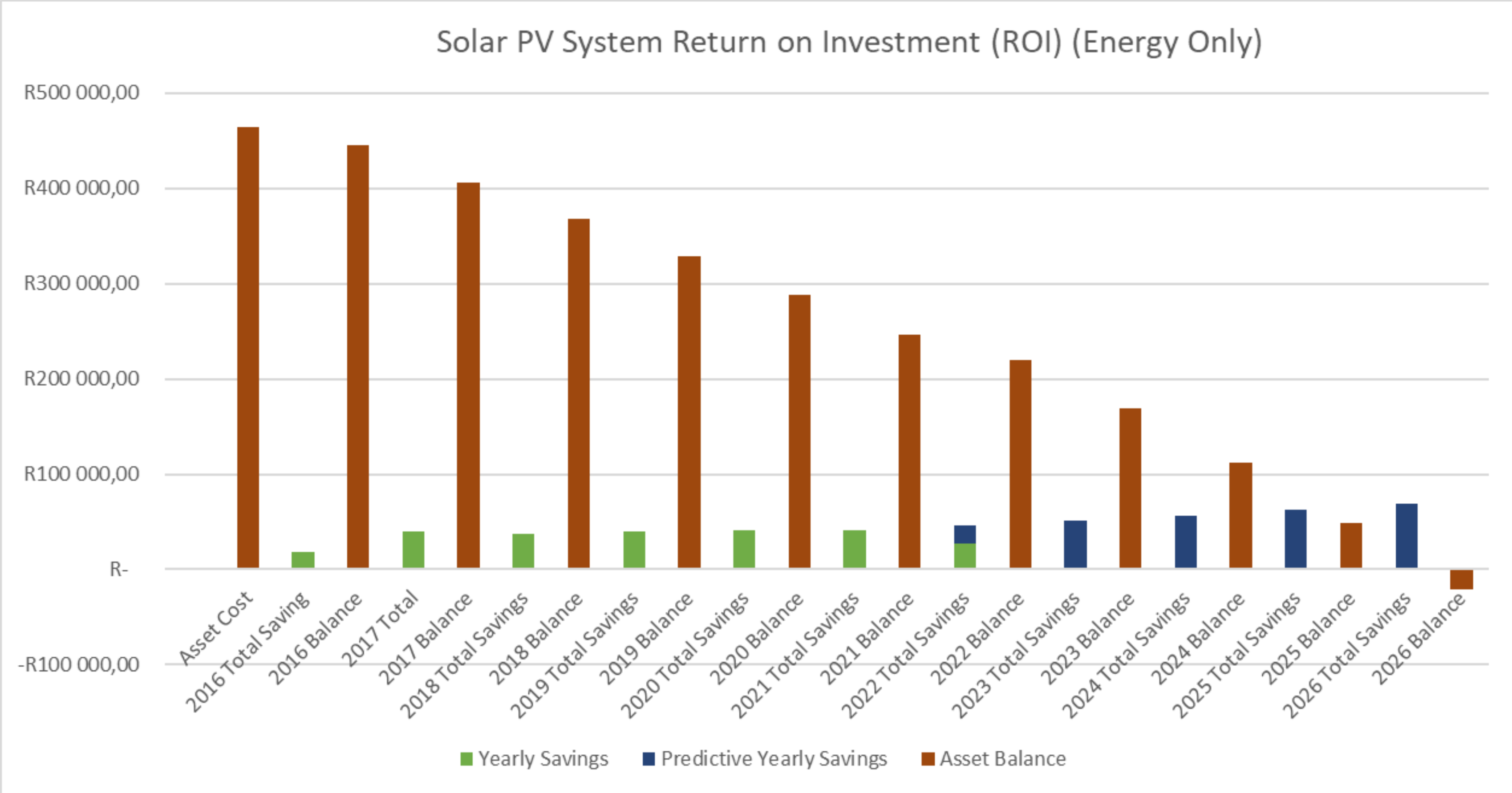


Figure 26: Malmesbury Farm - solar PV system return on investment (ROI) (energy only)

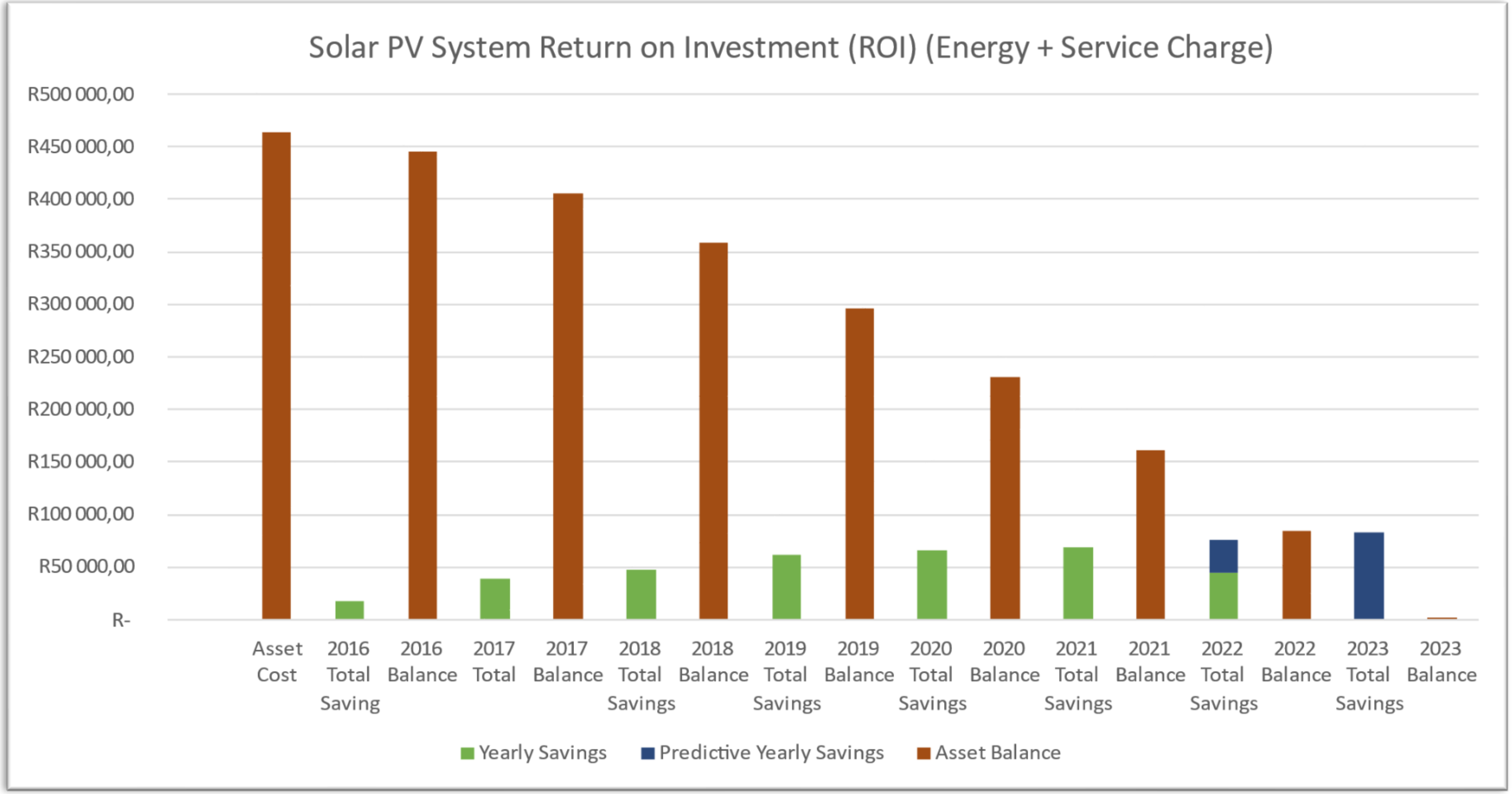


Figure 27: Malmesbury Farm - solar PV system return on investment (ROI) (energy + service charge)

Table 4: Malmesbury Farm - consumption data (2016 April to 2019 August)

Year	Month	Electricity Consumption	Rate Per kWh	% Increase In Electricity Cost Per kWh	Monthly Electricity Cost
2016	Apr	763,61 kWh	R 1,33		R 1 012,67
2016	May	983,29 kWh	R 1,33	0,00%	R 1 304,00
2016	Jun	786,44 kWh	R 1,33	0,00%	R 1 042,95
2016	Jul	913,99 kWh	R 1,33	0,00%	R 1 212,10
2016	Aug	1227,24 kWh	R 1,33	0,00%	R 1 627,52
2016	Sep	1394,60 kWh	R 1,33	0,00%	R 1 849,47
2016	Oct	1826,17 kWh	R 1,33	0,00%	R 2 421,80
2016	Nov	2790,97 kWh	R 1,33	0,00%	R 3 701,28
2016	Dec	3233,09 kWh	R 1,33	0,00%	R 4 287,60
2017	**Jan**	3296,00 kWh	R 1,33	0,00%	R 4 371,03
2017	Feb	2906,59 kWh	R 1,33	0,00%	R 3 854,61
2017	Mar	2800,84 kWh	R 1,33	0,00%	R 3 714,37
2017	Apr	2176,41 kWh	R 1,36	2,20%	R 2 949,79
2017	May	1862,44 kWh	R 1,36	0,00%	R 2 524,25
2017	Jun	1404,35 kWh	R 1,36	0,00%	R 1 903,38
2017	Jul	1716,82 kWh	R 1,36	0,00%	R 2 326,89
2017	Aug	1921,90 kWh	R 1,36	0,00%	R 2 604,84
2017	Sep	2223,88 kWh	R 1,36	0,00%	R 3 014,13
2017	Oct	2825,39 kWh	R 1,36	0,00%	R 3 829,38
2017	Nov	3028,19 kWh	R 1,36	0,00%	R 4 104,25
2017	Dec	3439,52 kWh	R 1,36	0,00%	R 4 661,74
2018	**Jan**	3356,79 kWh	R 1,36	0,00%	R 4 549,61
2018	Feb	2847,95 kWh	R 1,36	0,00%	R 3 859,96
2018	Mar	2595,76 kWh	R 1,36	0,00%	R 3 518,15
2018	Apr	2157,07 kWh	R 1,44	6,15%	R 3 103,52
2018	May	1433,74 kWh	R 1,44	0,00%	R 2 062,81
2018	Jun	1145,41 kWh	R 1,44	0,00%	R 1 647,98
2018	Jul	1251,73 kWh	R 1,44	0,00%	R 1 800,95
2018	Aug	1164,46 kWh	R 1,44	0,00%	R 1 675,38
2018	Sep	1567,54 kWh	R 1,44	0,00%	R 2 255,32
2018	Oct	2781,23 kWh	R 1,44	0,00%	R 4 001,54
2018	Nov	2990,83 kWh	R 1,44	0,00%	R 4 303,10
2018	Dec	2914,98 kWh	R 1,44	0,00%	R 4 193,97
2019	**Jan**	3176,30 kWh	R 1,44	0,00%	R 4 569,95
2019	Feb	2447,70 kWh	R 1,44	0,00%	R 3 521,67
2019	Mar	2364,64 kWh	R 1,44	0,00%	R 3 402,16
2019	Apr	1890,97 kWh	R 1,64	13,87%	R 3 097,96
2019	May	1617,82 kWh	R 1,64	0,00%	R 2 650,46
2019	Jun	1240,07 kWh	R 1,64	0,00%	R 2 031,59
2019	Jul	1010,33 kWh	R 1,64	0,00%	R 1 655,21
2019	Aug	1351,76 kWh	R 1,64	0,00%	R 2 214,57

Table 5: Malmesbury Farm - consumption data (2019 September to 2022 July)

Year	Month	Electriciy Consumption	Rate Per kWh	% Increase in electricity cost per kWh	Electricty Cost Per Month
2019	Jul	1010,33 kWh	R 1,64	0,00%	R 1 655,21
2019	Aug	1351,76 kWh	R 1,64	0,00%	R 2 214,57
2019	Sep	1943,28 kWh	R 1,64	0,00%	R 3 183,66
2019	Oct	2388,46 kWh	R 1,64	0,00%	R 3 912,99
2019	Nov	2771,25 kWh	R 1,64	0,00%	R 4 540,11
2019	Dec	2955,23 kWh	R 1,64	0,00%	R 4 841,52
2020	**Jan**	2925,41 kWh	R 1,64	0,00%	R 4 792,67
2020	Feb	2655,06 kWh	R 1,64	0,00%	R 4 349,76
2020	Mar	2470,33 kWh	R 1,64	0,00%	R 4 047,12
2020	Apr	1972,10 kWh	R 1,78	8,76%	R 3 513,91
2020	May	1605,42 kWh	R 1,78	0,00%	R 2 860,55
2020	Jun	1171,44 kWh	R 1,78	0,00%	R 2 087,28
2020	Jul	1278,53 kWh	R 1,78	0,00%	R 2 278,10
2020	Aug	1201,06 kWh	R 1,78	0,00%	R 2 140,06
2020	Sep	1441,74 kWh	R 1,78	0,00%	R 2 568,91
2020	Oct	2247,81 kWh	R 1,78	0,00%	R 4 005,17
2020	Nov	2039,97 kWh	R 1,78	0,00%	R 3 634,84
2020	Dec	2543,83 kWh	R 1,78	0,00%	R 4 532,62
2021	**Jan**	2283,97 kWh	R 1,78	0,00%	R 4 069,60
2021	Feb	2080,48 kWh	R 1,78	0,00%	R 3 707,02
2021	Mar	1843,74 kWh	R 1,78	0,00%	R 3 285,19
2021	Apr	1795,10 kWh	R 2,05	15,06%	R 3 680,14
2021	May	1355,79 kWh	R 2,05	0,00%	R 2 779,51
2021	Jun	1172,34 kWh	R 2,05	0,00%	R 2 403,42
2021	Jul	846,74 kWh	R 2,05	0,00%	R 1 735,91
2021	Aug	1119,33 kWh	R 2,05	0,00%	R 2 294,74
2021	Sep	1780,18 kWh	R 2,05	0,00%	R 3 649,56
2021	Oct	2155,60 kWh	R 2,05	0,00%	R 4 419,21
2021	Nov	2166,31 kWh	R 2,05	0,00%	R 4 441,16
2021	Dec	2298,40 kWh	R 2,05	0,00%	R 4 711,96
2022	**Jan**	2322,26 kWh	R 2,05	0,00%	R 4 760,88
2022	Feb	2047,12 kWh	R 2,05	0,00%	R 4 196,81
2022	Mar	2229,18 kWh	R 2,05	0,00%	R 4 570,05
2022	Apr	2046,97 kWh	R 2,25	9,60%	R 4 599,51
2022	May	1518,95 kWh	R 2,25	0,00%	R 3 413,06
2022	Jun	1195,53 kWh	R 2,25	0,00%	R 2 686,34
2022	Jul	1171,03 kWh	R 2,25	0,00%	R 2 631,29
Totals		151868,75 kWh			R 243 758,52
		Total Energy Consumption in 76 months			Total Energy Cost saved in 76 months

Table 6: Malmesbury Farm - Eskom service charges (2016 April to 2019 June)

Year	Month	Service Charge Per Month		% Increase In Service Charge Cost Per kWh
2016	Apr	R	1 578,10	
2016	May	R	1 578,10	0,00%
2016	Jun	R	1 578,10	0,00%
2016	Jul	R	1 578,10	0,00%
2016	Aug	R	1 578,10	0,00%
2016	Sep	R	1 578,10	0,00%
2016	Oct	R	1 578,10	0,00%
2016	Nov	R	1 578,10	0,00%
2016	Dec	R	1 578,10	0,00%
2017	**Jan**	R	1 578,10	0,00%
2017	Feb	R	1 578,10	0,00%
2017	Mar	R	1 578,10	0,00%
2017	Apr	R	1 608,63	1,93%
2017	May	R	1 608,63	0,00%
2017	Jun	R	1 608,63	0,00%
2017	Jul	R	1 608,63	0,00%
2017	Aug	R	1 608,63	0,00%
2017	Sep	R	1 608,63	0,00%
2017	Oct	R	1 608,63	0,00%
2017	Nov	R	1 608,63	0,00%
2017	Dec	R	1 608,63	0,00%
2018	**Jan**	R	1 608,63	0,00%
2018	Feb	R	1 608,63	0,00%
2018	Mar	R	1 608,63	0,00%
2018	Apr	R	1 707,45	6,14%
2018	May	R	1 707,45	0,00%
2018	Jun	R	1 707,45	0,00%
2018	Jul	R	1 707,45	0,00%
2018	Aug	R	1 707,45	0,00%
2018	Sep	R	1 707,45	0,00%
2018	Oct	R	1 707,45	0,00%
2018	Nov	R	1 707,45	0,00%
2018	Dec	R	1 707,45	0,00%
2019	**Jan**	R	1 707,45	0,00%
2019	Feb	R	1 707,45	0,00%
2019	Mar	R	1 707,45	0,00%
2019	Apr	R	1 944,42	13,88%
2019	May	R	1 944,42	0,00%
2019	Jun	R	1 944,42	0,00%

Table 7: Malmesbury Farm - Eskom service charges (2019 July to 2022 July)

Year	Month	Service Charge Per Month	% Increase in service charge cost per kWh
2019	Jul	R 1 944,42	0,00%
2019	Aug	R 1 944,42	0,00%
2019	Sep	R 1 944,42	0,00%
2019	Oct	R 1 944,42	0,00%
2019	Nov	R 1 944,42	0,00%
2019	Dec	R 1 944,42	0,00%
2020	**Jan**	R 1 944,42	0,00%
2020	Feb	R 1 944,42	0,00%
2020	Mar	R 1 944,42	0,00%
2020	Apr	R 2 114,89	8,77%
2020	May	R 2 114,89	0,00%
2020	Jun	R 2 114,89	0,00%
2020	Jul	R 2 114,89	0,00%
2020	Aug	R 2 114,89	0,00%
2020	Sep	R 2 114,89	0,00%
2020	Oct	R 2 114,89	0,00%
2020	Nov	R 2 114,89	0,00%
2020	Dec	R 2 114,89	0,00%
2021	**Jan**	R 2 114,89	0,00%
2021	Feb	R 2 114,89	0,00%
2021	Mar	R 2 114,89	0,00%
2021	Apr	R 2 433,42	15,06%
2021	May	R 2 433,42	0,00%
2021	Jun	R 2 433,42	0,00%
2021	Jul	R 2 433,42	0,00%
2021	Aug	R 2 433,42	0,00%
2021	Sep	R 2 433,42	0,00%
2021	Oct	R 2 433,42	0,00%
2021	Nov	R 2 433,42	0,00%
2021	Dec	R 2 433,42	0,00%
2022	**Jan**	R 2 433,42	0,00%
2022	Feb	R 2 433,42	0,00%
2022	Mar	R 2 433,42	0,00%
2022	Apr	R 2 667,24	9,61%
2022	May	R 2 667,24	0,00%
2022	Jun	R 2 667,24	0,00%
2022	Jul	R 2 667,24	0,00%
Totals		R 103 948,78	
		Total Service Charge saved in 49 months	

Table 8: Malmesbury Farm - total monthly savings (2016 April to 2019 August)

Year	Month	Electricity Cost Per Month	Service Charge Per Month	Total Monthly Electricity Savings
2016	Apr	R 1 012,67	R -	R 1 012,67
2016	May	R 1 304,00	R -	R 1 304,00
2016	Jun	R 1 042,95	R -	R 1 042,95
2016	Jul	R 1 212,10	R -	R 1 212,10
2016	Aug	R 1 627,52	R -	R 1 627,52
2016	Sep	R 1 849,47	R -	R 1 849,47
2016	Oct	R 2 421,80	R -	R 2 421,80
2016	Nov	R 3 701,28	R -	R 3 701,28
2016	Dec	R 4 287,60	R -	R 4 287,60
2017	**Jan**	R 4 371,03	R -	R 4 371,03
2017	Feb	R 3 854,61	R -	R 3 854,61
2017	Mar	R 3 714,37	R -	R 3 714,37
2017	Apr	R 2 949,79	R -	R 2 949,79
2017	May	R 2 524,25	R -	R 2 524,25
2017	Jun	R 1 903,38	R -	R 1 903,38
2017	Jul	R 2 326,89	R -	R 2 326,89
2017	Aug	R 2 604,84	R -	R 2 604,84
2017	Sep	R 3 014,13	R -	R 3 014,13
2017	Oct	R 3 829,38	R -	R 3 829,38
2017	Nov	R 4 104,25	R -	R 4 104,25
2017	Dec	R 4 661,74	R -	R 4 661,74
2018	**Jan**	R 4 549,61	R -	R 4 549,61
2018	Feb	R 3 859,96	R -	R 3 859,96
2018	Mar	R 3 518,15	R -	R 3 518,15
2018	Apr	R 3 103,52	R -	R 3 103,52
2018	May	R 2 062,81	R -	R 2 062,81
2018	Jun	R 1 647,98	R -	R 1 647,98
2018	Jul	R 1 800,95	R 1 707,45	R 3 508,40
2018	Aug	R 1 675,38	R 1 707,45	R 3 382,84
2018	Sep	R 2 255,32	R 1 707,45	R 3 962,77
2018	Oct	R 4 001,54	R 1 707,45	R 5 708,99
2018	Nov	R 4 303,10	R 1 707,45	R 6 010,55
2018	Dec	R 4 193,97	R 1 707,45	R 5 901,42
2019	**Jan**	R 4 569,95	R 1 707,45	R 6 277,40
2019	Feb	R 3 521,67	R 1 707,45	R 5 229,12
2019	Mar	R 3 402,16	R 1 707,45	R 5 109,61
2019	Apr	R 3 097,96	R 1 944,42	R 5 042,38
2019	May	R 2 650,46	R 1 944,42	R 4 594,88
2019	Jun	R 2 031,59	R 1 944,42	R 3 976,02
2019	Jul	R 1 655,21	R 1 944,42	R 3 599,64
2019	Aug	R 2 214,57	R 1 944,42	R 4 159,00

Table 9: Malmesbury Farm - total monthly savings (2019 September to 2022 July)

Year	Month	Electricty Cost Per Month	Service Charge Per Month	Total Monthly Electricity Savings
2019	Jul	R 1 655,21	R 1 944,42	R 3 599,64
2019	Aug	R 2 214,57	R 1 944,42	R 4 159,00
2019	Sep	R 3 183,66	R 1 944,42	R 5 128,08
2019	Oct	R 3 912,99	R 1 944,42	R 5 857,41
2019	Nov	R 4 540,11	R 1 944,42	R 6 484,53
2019	Dec	R 4 841,52	R 1 944,42	R 6 785,95
2020	**Jan**	R 4 792,67	R 1 944,42	R 6 737,09
2020	Feb	R 4 349,76	R 1 944,42	R 6 294,18
2020	Mar	R 4 047,12	R 1 944,42	R 5 991,54
2020	Apr	R 3 513,91	R 2 114,89	R 5 628,80
2020	May	R 2 860,55	R 2 114,89	R 4 975,44
2020	Jun	R 2 087,28	R 2 114,89	R 4 202,17
2020	Jul	R 2 278,10	R 2 114,89	R 4 392,99
2020	Aug	R 2 140,06	R 2 114,89	R 4 254,95
2020	Sep	R 2 568,91	R 2 114,89	R 4 683,80
2020	Oct	R 4 005,17	R 2 114,89	R 6 120,06
2020	Nov	R 3 634,84	R 2 114,89	R 5 749,73
2020	Dec	R 4 532,62	R 2 114,89	R 6 647,51
2021	**Jan**	R 4 069,60	R 2 114,89	R 6 184,49
2021	Feb	R 3 707,02	R 2 114,89	R 5 821,91
2021	Mar	R 3 285,19	R 2 114,89	R 5 400,08
2021	Apr	R 3 680,14	R 2 433,42	R 6 113,56
2021	May	R 2 779,51	R 2 433,42	R 5 212,93
2021	Jun	R 2 403,42	R 2 433,42	R 4 836,84
2021	Jul	R 1 735,91	R 2 433,42	R 4 169,32
2021	Aug	R 2 294,74	R 2 433,42	R 4 728,16
2021	Sep	R 3 649,56	R 2 433,42	R 6 082,97
2021	Oct	R 4 419,21	R 2 433,42	R 6 852,62
2021	Nov	R 4 441,16	R 2 433,42	R 6 874,58
2021	Dec	R 4 711,96	R 2 433,42	R 7 145,38
2022	**Jan**	R 4 760,88	R 2 433,42	R 7 194,29
2022	Feb	R 4 196,81	R 2 433,42	R 6 630,23
2022	Mar	R 4 570,05	R 2 433,42	R 7 003,47
2022	Apr	R 4 599,51	R 2 667,24	R 7 266,75
2022	May	R 3 413,06	R 2 667,24	R 6 080,30
2022	Jun	R 2 686,34	R 2 667,24	R 5 353,58
2022	Jul	R 2 631,29	R 2 667,24	R 5 298,52
Totals		R 243 758,52	R 103 948,78	R 347 707,30
		Total Energy Cost saved in 76 months	Total Service Charge saved in 49 months	Total Savings in 76 months

4.6 Case Study Two – Malmesbury Smallholding

In January 2018 a smallholding in Malmesbury was equipped with a complete off grid Solar PV system and a municipal Eskom connection that is used as a battery charger when the batteries are low.

This case study equipment and materials were designed and installed at the experimental phase of the project. The cost for all the equipment and materials was paid for by the owner of Malmesbury Farm.

4.6.1 Photovoltaic system details for case study two

- Installation date: 1/01/2018
- Total PV panels: 24x JKM270PP-60 = 6.48 kWp ('JKM270PP-60-Datasheet.pdf', 2015)
- Orientation – Northwest (10 ˚ West of North) at a 42˚ tilt angle.
- PV inverter: SMA Sunny Boy 5 kWp [SB5.0-1AV-40] (Henry, 2016)
- Battery inverter: 1x Sunny Island 8 kW [SMA Sunny Island 8.0H](Control, 2017)
- Batteries: 2x Solar MD 3.7 kWh (7.4 kWh usable)('SS4074', 2021)(Loggerv, no date)

Table 10 details the cost of the installed asset when it was installed in January 2018.

Table 10: Malmesbury Smallholding - PV system cost

Model	Description	Unit	Per Unit		Total	
SI8.0H	Sunny Island 8kW	1	R	34 175,04	R	34 175,04
SWDMSI-NR10	Speedwire	1	R	1 468,91	R	1 468,91
SRC20	Sunny Remote Control	1	R	2 939,12	R	2 939,12
HM BT-10	Home Manager	1	R	4 185,70	R	4 185,70
SS4037	Solar MD 3,7kWh Wall Mount	2	R	19 873,48	R	39 746,96
Logger	Solar MD smart Logger	1	R	3 163,40	R	3 163,40
SB5.0-1AV-40	SMA Sunny Boy 5kWp PV Inverter	1	R	18 139,90	R	18 139,90
	Electrical Accessories (Cable, CB's, Trunking, DB's etc)	1	R	5 234,68	R	5 234,68
JKM270PP-60	270 Solar Module	24	R	1 485,00	R	35 640,00
	Lizard Aluminium Profile 4,2m	12	R	280,00	R	3 360,00
	Lizard End Clamp 30-50mm	16	R	21,98	R	351,68
	Lizard Centre Clamp	40	R	21,98	R	879,20
	Lizard Profile Joiner	8	R	39,90	R	319,20
	Lizard 10x200mm Hanger Bolt	40	R	62,86	R	2 514,40
			Total		R	152 118,19
			VAT		R	22 817,73
			Total incl.		R	174 935,92

Figure 28 is an aerial view of the installed PV system. The system has been installed on two roof faces, both facing the same direction and at the same tilt angle. These panels are installed on a 42° roof. This allows for optimum energy production in the winter months and allows for adequate self-cleaning from the falling rain. This self-cleaning allows for any soiling that occurs on the panels to be removed without an abrasive brush. The PV inverter used has two independent MPPTs, this allows for the two strings of PV panels to be installed on different faces at different angles. With two independent MPPT's the panels can face different directions and do not affect each other. Each of the 12 panels in the string are connected in series, this adds the voltage produced by the PV panels. In this situation, during STC the voltage at each panel Vmp = 31.7 VDC multiplied by 12 = 380.4 VDC. As all of this is in series, the Imp current remains at 8.52 amps.

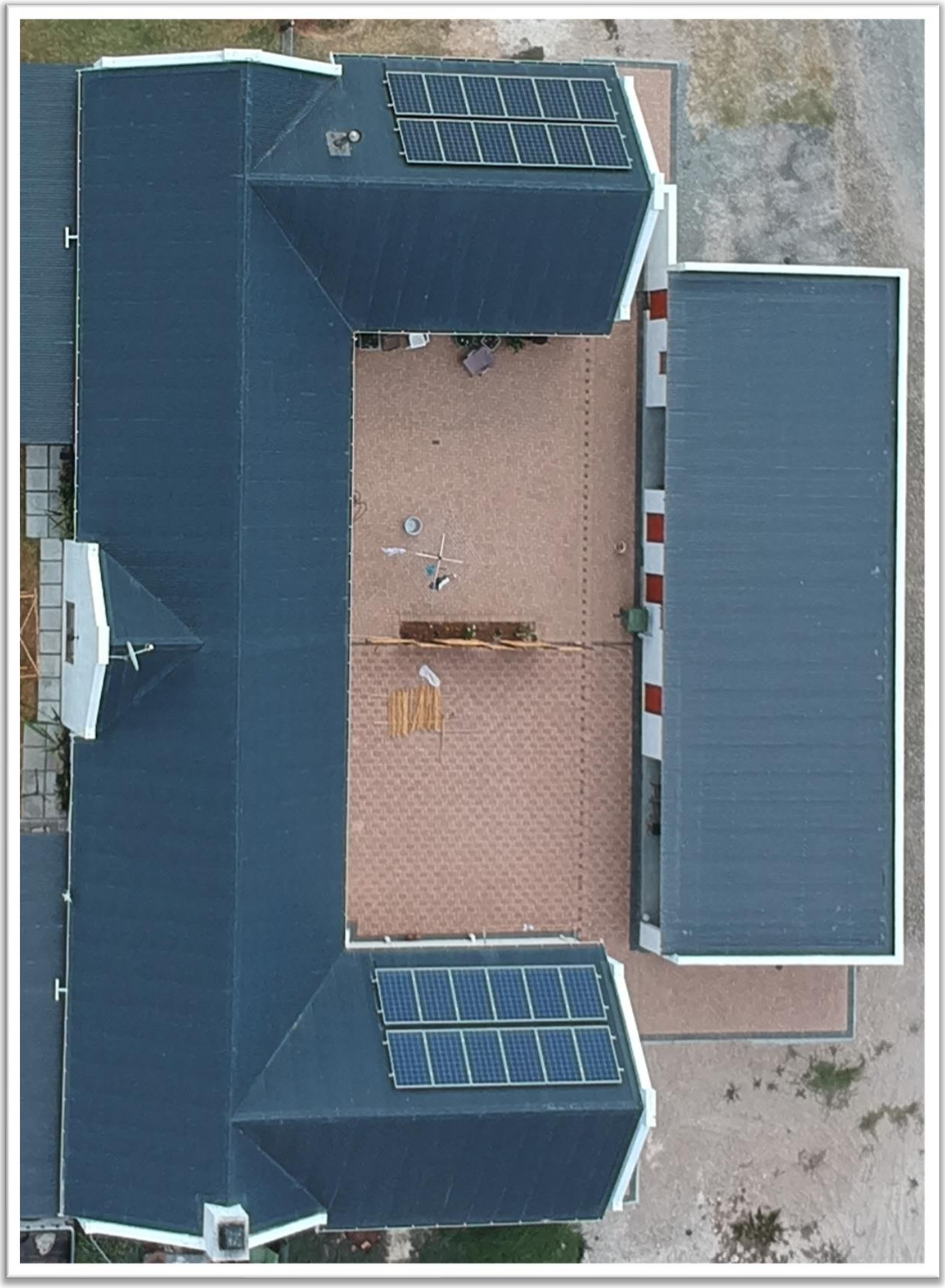


Figure 28: Malmesbury Smallholding - plan view of PV system

Figure 29 is a photo of the 5 kWp PV inverter. This inverter has two independent MPPT's. In the picture there are 3 DB boards installed closely to each other to the right of the inverter. The DB board closest to the PV inverter houses the DC isolator and the PV surge protection. This is an AC coupled grid tied inverter, it will therefore sync with the AC voltage and frequency. The power generated by the PV inverter will first be consumed by the loads within the house. Excess power, once the loads have been covered, will be transmitted back to the battery inverter (Sunny Island), where it will be rectified from 230 VAC to 48-55 V DC and stored in the battery for later use.

Figure 29: Malmesbury Smallholding - 5kWp PV inverter

Figure 30 (from left to right) is a photo of the main DB board for the Smallholding, the Sunny Island 8 kW battery inverter and the two 3.7 kWh Solar MD Lithium Ion battery packs. Below the battery on the right is the Solar MD logger, this device is used to communicate between the Lithium Ion batteries' battery management system and the Sunny Island. When using Lithium Ion batteries the controller sets the charge current for the Sunny Island, whereas when using lead acid batteries the charge current is determined by the batteries voltage.

This logger communicates to the battery and the Sunny Island via CAN bus. Controller Area Network (CAN) bus is a high speed serial communication bus protocol (Corrigan, 2002).

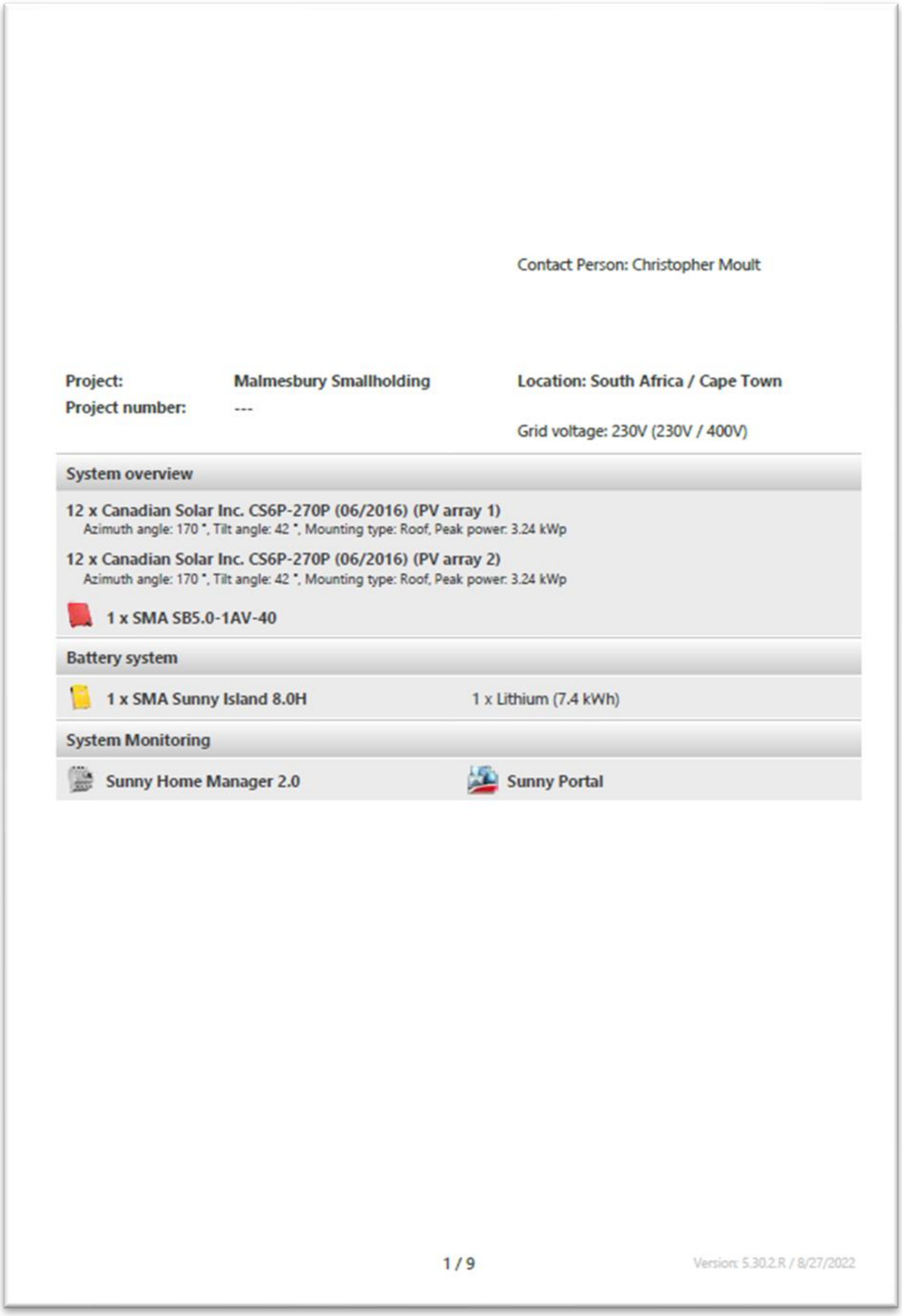
In addition to being the link between the inverter and the batteries it uploads all its data to a cloud server. This data can be viewed anywhere in the world that has an internet connection.

Figure 30: Malmesbury Smallholding - 8kW battery inverter, 2x 3.7kWh lithium batteries and distribution board

4.6.2 SMA Sunny Design simulation for case study two

Figure 31 to 39 is a simulation model from SMA Sunny Design and it only takes into account the electricity savings. It does not consider the reduction in service fee that Eskom charges. This model has indicated that the investment shall reach amortization in 14.1 years. A 10% year or year electricity increase was used for the SMA Sunny Design model. A 1% of total asset cost annual maintenance fee has been applied. The initial cost of electricity we set at R1.33 per kWh

Figure 31 is the first page of the Sunny Design report is a summary of the system, this summary details the grid voltage. South Africa has a nominal voltage of 400 V between the 3 phase and 230 V between any phase and neutral (This, 2017). As this facility has smaller loads it only has a 230 volt single phase supply. The PV system design data is a summary of the system performance after the size, orientation and quantity of panels has been inserted into the simulation software.



Contact Person: Christopher Moult

Project:	**Malmesbury Smallholding**	**Location: South Africa / Cape Town**
Project number:	---	Grid voltage: 230V (230V / 400V)

System overview

12 x Canadian Solar Inc. CS6P-270P (06/2016) (PV array 1)
Azimuth angle: 170 °, Tilt angle: 42 °, Mounting type: Roof, Peak power: 3.24 kWp

12 x Canadian Solar Inc. CS6P-270P (06/2016) (PV array 2)
Azimuth angle: 170 °, Tilt angle: 42 °, Mounting type: Roof, Peak power: 3.24 kWp

1 x SMA SB5.0-1AV-40

Battery system

1 x SMA Sunny Island 8.0H 1 x Lithium (7.4 kWh)

System Monitoring

Sunny Home Manager 2.0 **Sunny Portal**

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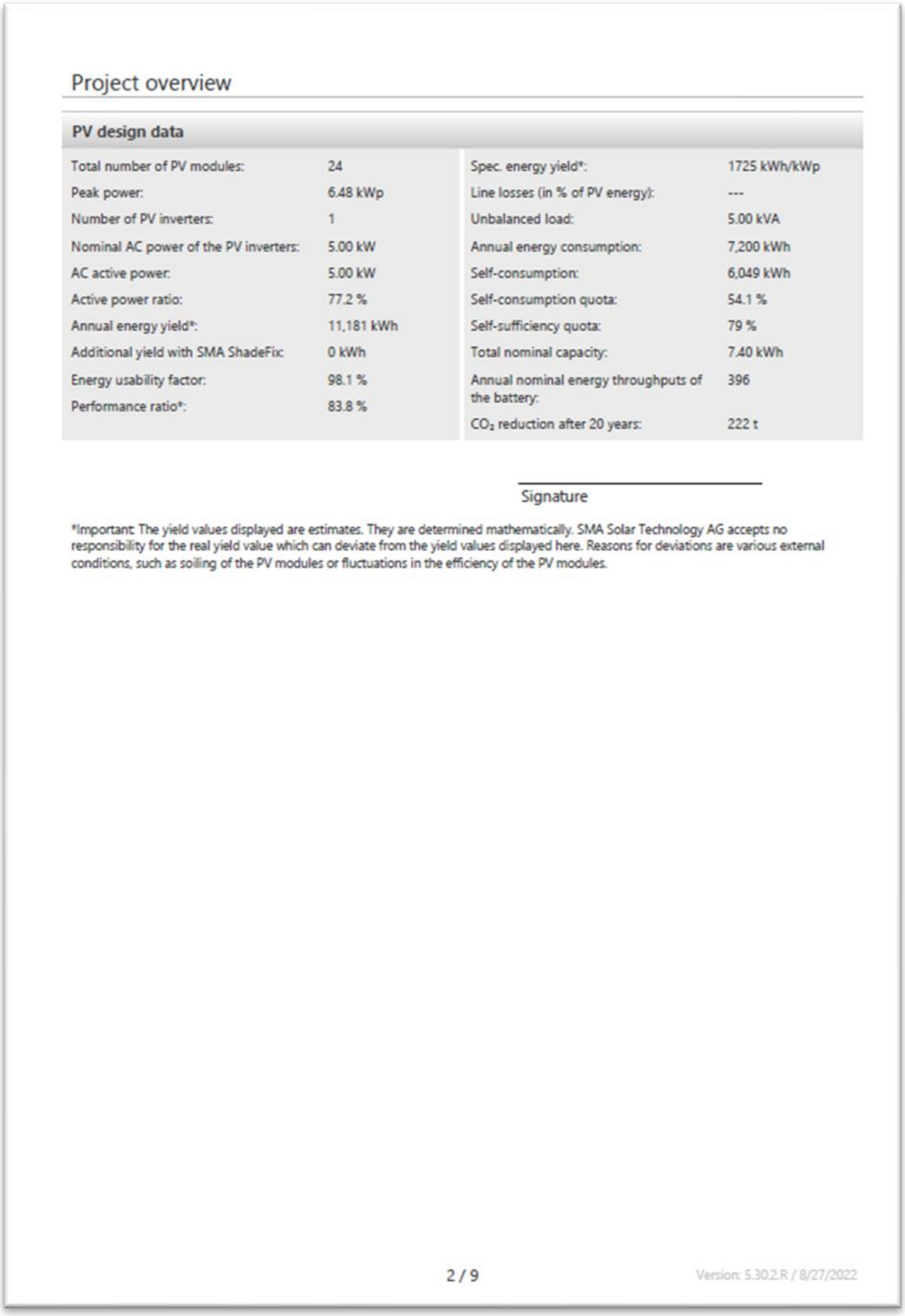
Figure 31: Malmesbury Smallholding – Sunny Design – page 1

Figure 32 is the PV system design data. This is a summary of the system performance after the size, orientation and quantity of panels has been input is a summary of the design.



Project overview

PV design data

Total number of PV modules:	24	Spec. energy yield*:	1725 kWh/kWp
Peak power:	6.48 kWp	Line losses (in % of PV energy):	---
Number of PV inverters:	1	Unbalanced load:	5.00 kVA
Nominal AC power of the PV inverters:	5.00 kW	Annual energy consumption:	7,200 kWh
AC active power:	5.00 kW	Self-consumption:	6,049 kWh
Active power ratio:	77.2 %	Self-consumption quota:	54.1 %
Annual energy yield*:	11,181 kWh	Self-sufficiency quota:	79 %
Additional yield with SMA ShadeFix:	0 kWh	Total nominal capacity:	7.40 kWh
Energy usability factor:	98.1 %	Annual nominal energy throughputs of the battery:	396
Performance ratio*:	83.8 %	CO_2 reduction after 20 years:	222 t

Signature

*Important: The yield values displayed are estimates. They are determined mathematically. SMA Solar Technology AG accepts no responsibility for the real yield value which can deviate from the yield values displayed here. Reasons for deviations are various external conditions, such as soiling of the PV modules or fluctuations in the efficiency of the PV modules.

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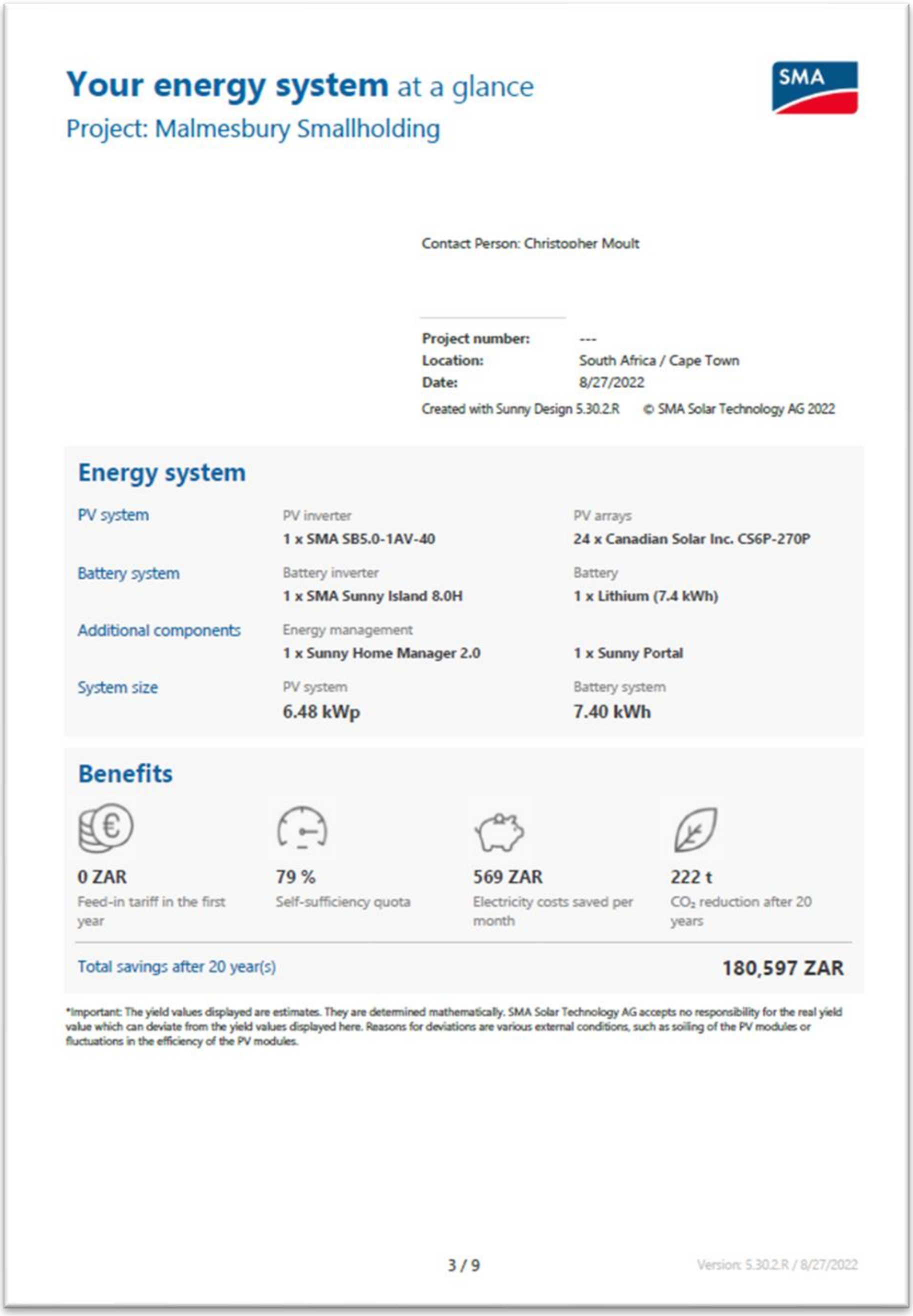
Figure 32: Malmesbury Smallholding – Sunny Design – page 2

Figure 33 is a summary of the design. The PV system that has been selected along with the panels, battery inverter and batteries have been summarised. The calculated CO_2 reduction over the 20 year period is 222 tones with a total monetary saving of R180 597.00.



Your energy system at a glance

Project: Malmesbury Smallholding

Contact Person: Christopher Moult

Project number:	---
Location:	South Africa / Cape Town
Date:	8/27/2022

Created with Sunny Design 5.30.2.R © SMA Solar Technology AG 2022

Energy system

PV system	PV inverter **1 x SMA SB5.0-1AV-40**	PV arrays **24 x Canadian Solar Inc. CS6P-270P**
Battery system	Battery inverter **1 x SMA Sunny Island 8.0H**	Battery **1 x Lithium (7.4 kWh)**
Additional components	Energy management **1 x Sunny Home Manager 2.0**	**1 x Sunny Portal**
System size	PV system **6.48 kWp**	Battery system **7.40 kWh**

Benefits

0 ZAR	**79 %**	**569 ZAR**	**222 t**
Feed-in tariff in the first year	Self-sufficiency quota	Electricity costs saved per month	CO_2 reduction after 20 years

Total savings after 20 year(s) **180,597 ZAR**

*Important: The yield values displayed are estimates. They are determined mathematically. SMA Solar Technology AG accepts no responsibility for the real yield value which can deviate from the yield values displayed here. Reasons for deviations are various external conditions, such as soiling of the PV modules or fluctuations in the efficiency of the PV modules.

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Figure 33: Malmesbury Smallholding – Sunny Design – page 3

Figure 33 highlights the details of the PV inverter in relation to the location. The peak power is the amount of PV that shall be connected to the inverter. Below this the total number of PV panels. The dimensioning factor is the total amount of PV connected to the inverter compared to the total maximum active power. The full load hours are a calculation as to how much time in a year the inverter will be at max output. The PV design data in Figure 34 is indicating the voltages and currents of the strings of panels under STC conditions. The maximum and minimum voltage for this specific inverter indicates the range in which the MPPT will operate.

Inverter designs

Project: Malmesbury Smallholding
Project number:

Subproject Subproject 1

Location: South Africa / Cape Town
Ambient temperature:
Annual extreme low temperature: 1 °C
Average high Temperature: 21 °C
Annual extreme high temperature: 33 °C

1 x SMA SB5.0-1AV-40 (PV system section 1)

Peak power:	6.48 kWp
Total number of PV modules:	24
Number of PV inverters:	1
Max. DC power (cos φ = 1):	5.25 kW
Max. AC active power (cos φ = 1):	5.00 kW
Grid voltage:	230V (230V / 400V)
Nominal power ratio:	81 %
Dimensioning factor:	129.6 %
Displacement power factor cos φ:	1
Full load hours:	2236.2 h

SMA SB5.0-1AV-40

PV design data

Input A: PV array 1
12 x Canadian Solar Inc. CS6P-270P (06/2016), Azimuth angle: 170 °, Tilt angle: 42 °, Mounting type: Roof

Input B: PV array 2
12 x Canadian Solar Inc. CS6P-270P (06/2016), Azimuth angle: 170 °, Tilt angle: 42 °, Mounting type: Roof

	Input A:	Input B:
Number of strings:	1	1
PV modules:	12	12
Peak power (input):	3.24 kWp	3.24 kWp
Inverter min. DC voltage (Grid voltage 230 V):	100 V	100 V
PV typical voltage:	✓ 341 V	✓ 341 V
Min. PV voltage:	316 V	316 V
Max. DC voltage (Inverter):	600 V	600 V
Max. PV voltage	✓ 489 V	✓ 489 V
Inverter max. operating input current per MPPT:	15 A	15 A
Max. MPP current of PV array:	✓ 8.8 A	✓ 8.8 A
Inverter max. input short-circuit current per MPPT:	20 A	20 A
PV max. circuit current	✓ 9.3 A	✓ 9.3 A

PV/Inverter partly compatible

PV array and inverter type are only conditionally compatible, since the inverter is undersized in this combination (< 86 %).

You get this inverter including SMA ShadeFix. SMA ShadeFix is a patented inverter software that automatically optimizes the yield of PV systems in any situation. Even under shading conditions.

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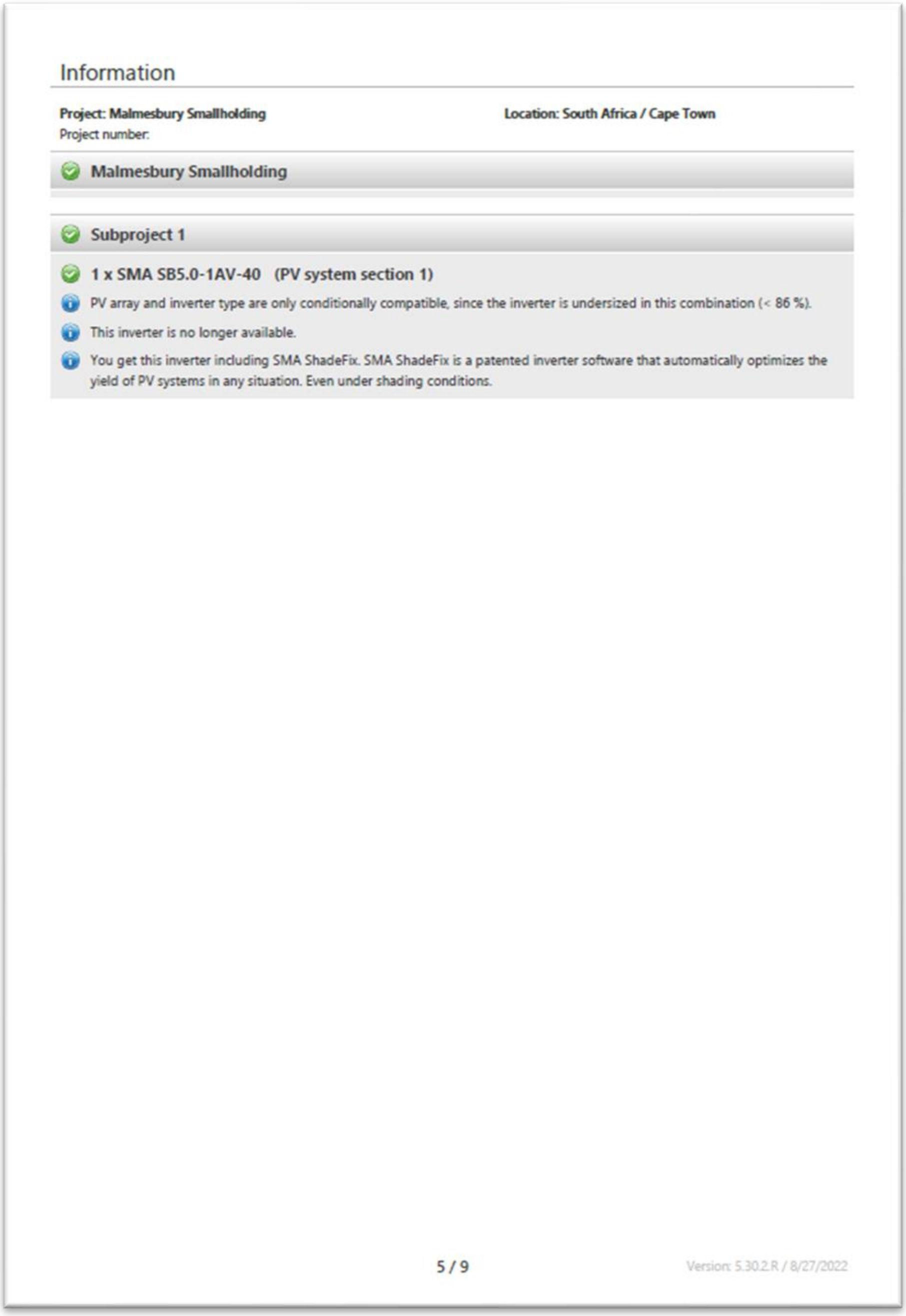
Figure 34: Malmesbury Smallholding – Sunny Design – page 4

Figure 35 is a check page that confirms the design is suitable and safe. If there are recommendations these shall be displayed towards the end of the paragraph in Figure 35.



Information

Project: Malmesbury Smallholding **Location: South Africa / Cape Town**

Project number:

Malmesbury Smallholding

Subproject 1

1 x SMA SB5.0-1AV-40 (PV system section 1)

- PV array and inverter type are only conditionally compatible, since the inverter is undersized in this combination (< 86 %).
- This inverter is no longer available.
- You get this inverter including SMA ShadeFix. SMA ShadeFix is a patented inverter software that automatically optimizes the yield of PV systems in any situation. Even under shading conditions.

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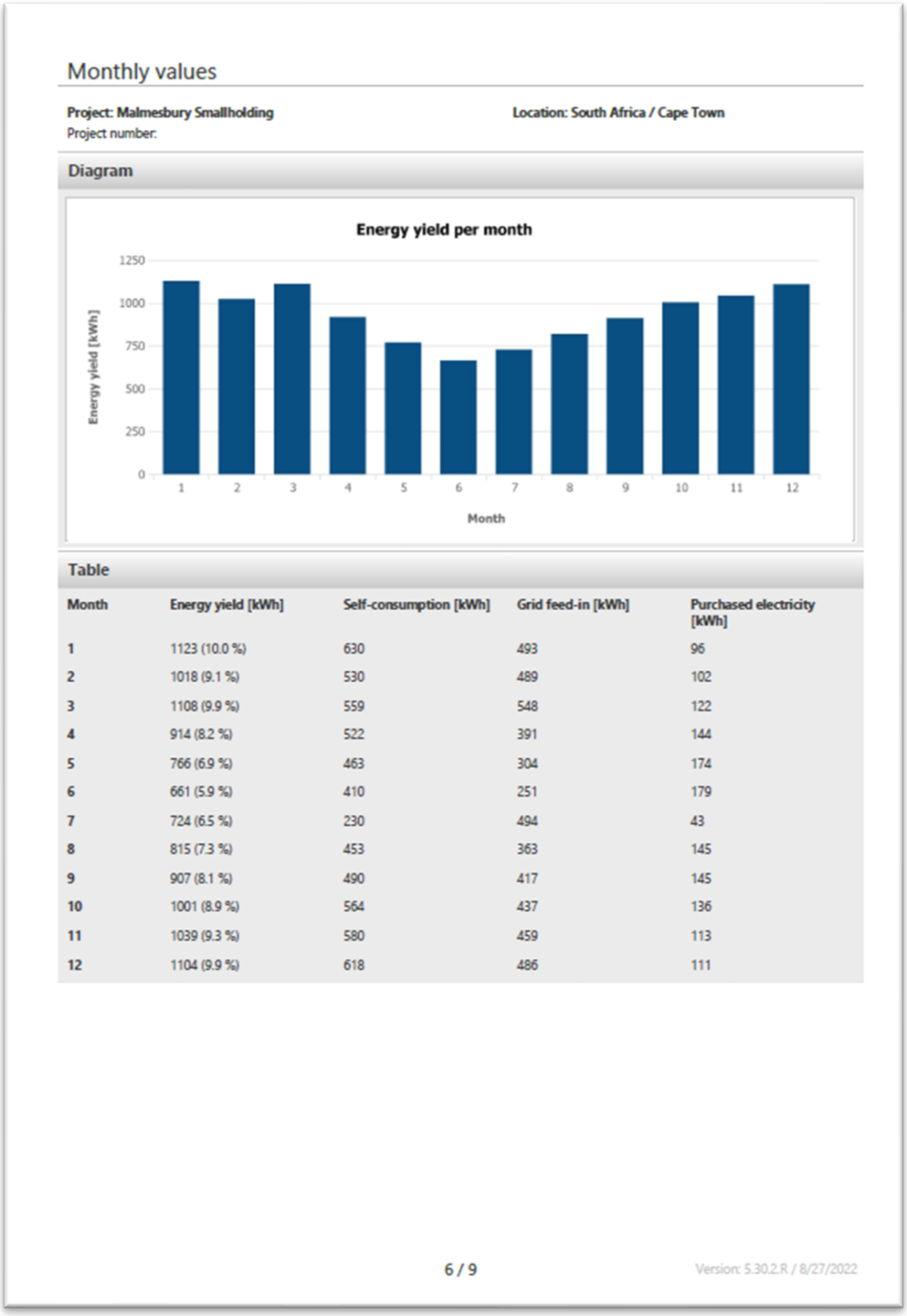
Figure 35: Malmesbury Smallholding – Sunny Design – page 5

The graph in Figure 36 indicates the expected monthly production throughout the year. As the location of the site is in the Southern Hemisphere and receives winter rains the expected yield over the middle months is considerably lower than the expected production over the summer months.



Monthly values

Project: Malmesbury Smallholding **Location: South Africa / Cape Town**
Project number:

Diagram

Table

Month	Energy yield [kWh]	Self-consumption [kWh]	Grid feed-in [kWh]	Purchased electricity [kWh]
1	1123 (10.0 %)	630	493	96
2	1018 (9.1 %)	530	489	102
3	1108 (9.9 %)	559	548	122
4	914 (8.2 %)	522	391	144
5	766 (6.9 %)	463	304	174
6	661 (5.9 %)	410	251	179
7	724 (6.5 %)	230	494	43
8	815 (7.3 %)	453	363	145
9	907 (8.1 %)	490	417	145
10	1001 (8.9 %)	564	437	136
11	1039 (9.3 %)	580	459	113
12	1104 (9.9 %)	618	486	111

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Figure 36: Malmesbury Smallholding – Sunny Design – page 6

The profitability analysis is possibly the most important page to investors and business owners this is shown in Figure 37. The electricity cost saved is a direct saving to the business once the investment and OPEX costs have been removed from this value the total savings can be deduced. The amortization period is a sum of the total investment value and the operating costs, minus the month on month electricity savings. The amortization value of 14.1 years is an indication of how many months it will take the savings to equal the costs. On the right side of Figure 37 is the lowest production or yield day, below this the average day and then below that the highest day of production. What this is indicating is that on the average or above average day the batteries will be fully charged by 12pm.

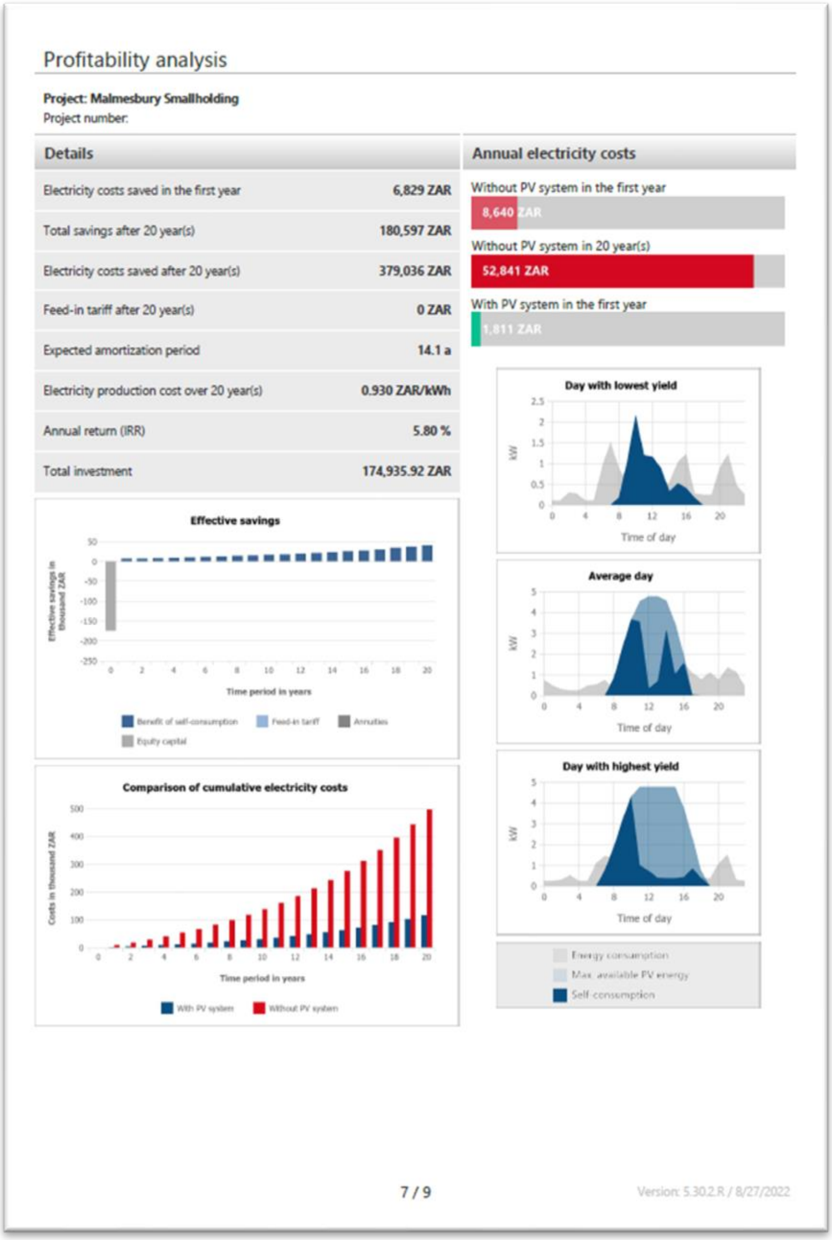
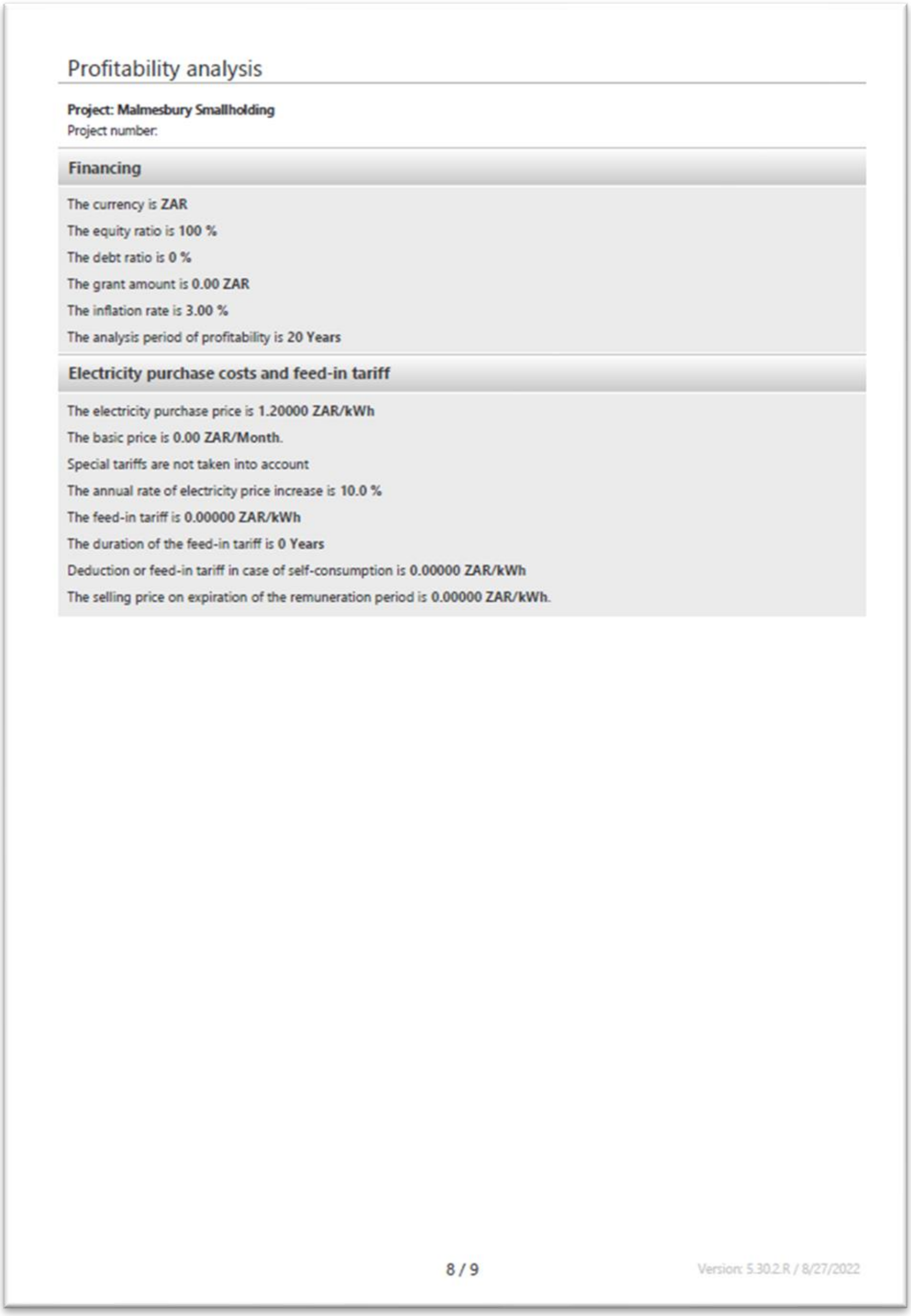


Figure 37: Malmesbury Smallholding – Sunny Design – page 7

Figure 38 is the profitability analysis; it is indicating all the financial figures and parameters that have been used to calculate payback periods and an amortization timeframe.



Profitability analysis

Project: Malmesbury Smallholding
Project number:

Financing

The currency is **ZAR**
The equity ratio is **100 %**
The debt ratio is **0 %**
The grant amount is **0.00 ZAR**
The inflation rate is **3.00 %**
The analysis period of profitability is **20 Years**

Electricity purchase costs and feed-in tariff

The electricity purchase price is **1.20000 ZAR/kWh**
The basic price is **0.00 ZAR/Month.**
Special tariffs are not taken into account
The annual rate of electricity price increase is **10.0 %**
The feed-in tariff is **0.00000 ZAR/kWh**
The duration of the feed-in tariff is **0 Years**
Deduction or feed-in tariff in case of self-consumption is **0.00000 ZAR/kWh**
The selling price on expiration of the remuneration period is **0.00000 ZAR/kWh.**

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Version: 5.30.2.R / 8/27/2022

Figure 38: Malmesbury Smallholding – Sunny Design – page 8

Figure 39 is specifically pertaining to the full project cost and fixed monthly costs.

Cost estimate (non binding)

Project: Malmesbury Smallholding | **Location: South Africa / Cape Town**
Project number:

Project costs		
PV system	0.00 ZAR/kWp x 6.48 kWp	0.00 ZAR
Battery system	0.00 ZAR/kWh x 7.40 kWh	0.00 ZAR
Other costs		174,935.92 ZAR
Total investment		**174,935.92 ZAR**
Fixed cost		
Annual fixed costs (as percentage of capital expenditure)	0.50 % of investment costs	874.68 ZAR

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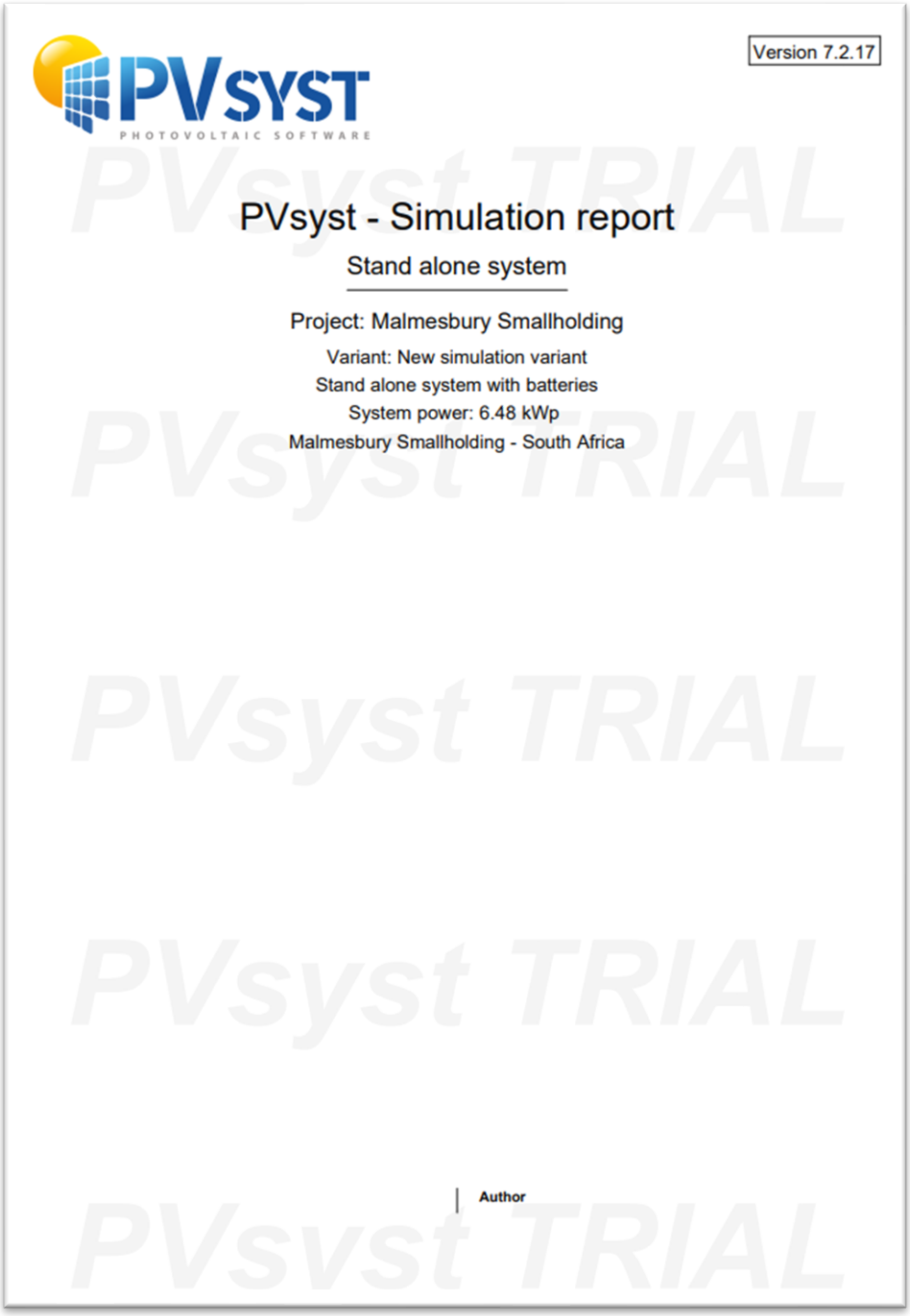
Figure 39: Malmesbury Smallholding – Sunny Design – page 9

4.6.3 PV Syst. simulation for case study two

The calculation done by PV Syst, Figure 39 to 46, is very similar to that of Sunny Design. This calculation has indicated that the payback period will be 12.4 years.

With PV Syst the actual loads are added for a more accurate calculation. The Malmesbury Smallholding does not conduct farming activities. As a result, the consumption throughout the year is consistent.

Figure 40 is the front page of the PV Syst simulation report. A summary of the system is given on this page.


Version 7.2.17

PVsyst - Simulation report

Stand alone system

Project: Malmesbury Smallholding

Variant: New simulation variant

Stand alone system with batteries

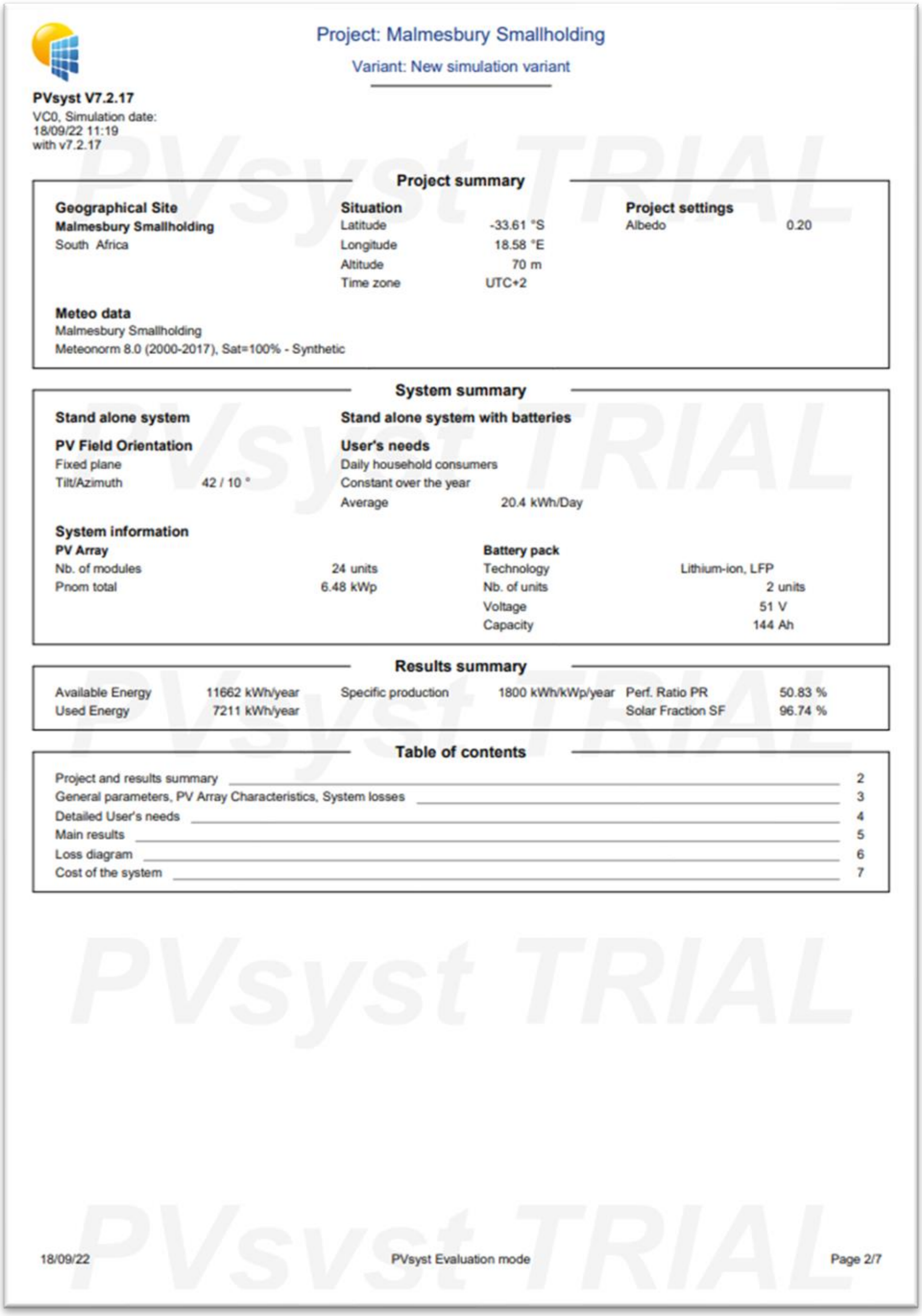
System power: 6.48 kWp

Malmesbury Smallholding - South Africa

Author

Figure 40: Malmesbury Smallholding - PV Syst. - page 1

Figure 41 begins with a project summary, this details the location of the site. The system summary highlights the main system criteria, such as the panel tilt angle, number of panels, total kWp, battery technology and size.



Project: Malmesbury Smallholding

Variant: New simulation variant

PVsyst V7.2.17
VC0, Simulation date:
18/09/22 11:19
with v7.2.17

Project summary

Geographical Site
Malmesbury Smallholding
South Africa

Situation

Latitude	-33.61 °S
Longitude	18.58 °E
Altitude	70 m
Time zone	UTC+2

Project settings

Albedo	0.20

Meteo data
Malmesbury Smallholding
Meteonorm 8.0 (2000-2017), Sat=100% - Synthetic

System summary

Stand alone system

Stand alone system with batteries

PV Field Orientation
Fixed plane
Tilt/Azimuth 42 / 10 °

User's needs
Daily household consumers
Constant over the year
Average 20.4 kWh/Day

System information

PV Array

Nb. of modules	24 units
Pnom total	6.48 kWp

Battery pack

Technology	Lithium-ion, LFP
Nb. of units	2 units
Voltage	51 V
Capacity	144 Ah

Results summary

Available Energy	11662 kWh/year	Specific production	1800 kWh/kWp/year	Perf. Ratio PR	50.83 %
Used Energy	7211 kWh/year			Solar Fraction SF	96.74 %

Table of contents

18/09/22 PVsyst Evaluation mode Page 2/7

Figure 41: Malmesbury Smallholding - PV Syst. - page 2

Figure 42 lists the general input parameters, important to note that the average consumption of the facility is 20.4 kWh per day. The PV array characteristics give a breakdown of the PV system design. There are 2 strings of 12 panels per string each, the panels are placed in series strings to increase the voltage, this reduces losses as the current remains the same. On the right-hand side of the PV array characteristics is the battery information, this facility is using 2 batteries with a total stored energy of 6.6 kWh. In the PV Syst software, the exact model number of the inverters is not used as this software caters for all manufacturers. The array losses are then summarised, these are further details in Figure 45.

Project: Malmesbury Smallholding

Variant: New simulation variant

PVsyst V7.2.17
VC0, Simulation date:
18/09/22 11:19
with v7.2.17

General parameters

Stand alone system — **Stand alone system with batteries**

PV Field Orientation

Orientation
Fixed plane
Tilt/Azimuth 42 / 10 °

Sheds configuration
No 3D scene defined

Models used
Transposition Perez
Diffuse Perez, Meteonorm
Circumsolar separate

User's needs
Daily household consumers
Constant over the year
Average 20.4 kWh/Day

PV Array Characteristics

PV module
Manufacturer Generic
Model CS6P - 270P
(Original PVsyst database)
Unit Nom. Power 270 Wp
Number of PV modules 24 units
Nominal (STC) 6.48 kWp
Modules 2 Strings x 12 In series
At operating cond. (50°C)
Pmpp 5.77 kWp
U mpp 326 V
I mpp 18 A

Battery
Manufacturer Generic
Model SS4037
Technology Lithium-ion, LFP
Nb. of units 2 in parallel
Discharging min. SOC 10.0 %
Stored energy 6.6 kWh
Battery Pack Characteristics
Voltage 51 V
Nominal Capacity 144 Ah (C10)
Temperature Fixed 20 °C

Controller
Universal controller
Technology MPPT converter
Temp coeff. -5.0 mV/°C/Elem.
Converter
Maxi and EURO efficiencies 97.0 / 95.0 %

Battery Management control
Threshold commands as SOC calculation
Charging SOC = 0.96 / 0.80
Discharging SOC = 0.10 / 0.35

Total PV power
Nominal (STC) 6 kWp
Total 24 modules
Module area 38.6 m²
Cell area 35.0 m²

Array losses

Thermal Loss factor
Module temperature according to irradiance
Uc (const) 20.0 W/m²K
Uv (wind) 0.0 W/m²K/m/s

DC wiring losses
Global array res. 316 mΩ
Loss Fraction 1.5 % at STC

Serie Diode Loss
Voltage drop 0.7 V
Loss Fraction 0.2 % at STC

Module Quality Loss
Loss Fraction -0.5 %

Module mismatch losses
Loss Fraction 2.0 % at MPP

Strings Mismatch loss
Loss Fraction 0.1 %

IAM loss factor
Incidence effect (IAM): User defined profile

10°	20°	30°	40°	50°	60°	70°	80°	90°
1.000	0.999	0.997	0.993	0.986	0.955	0.889	0.701	0.000

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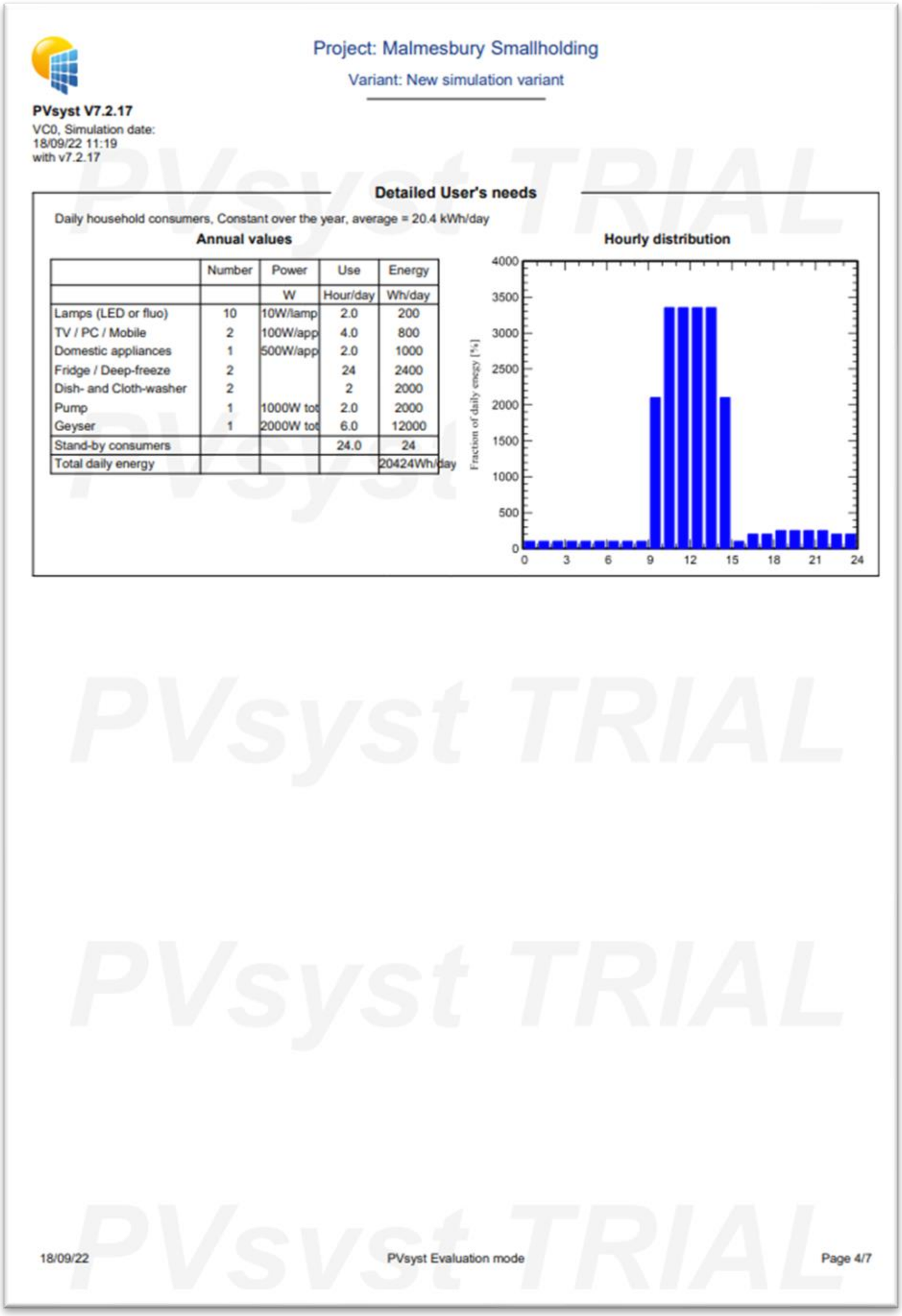
Figure 42: Malmesbury Smallholding - PV Syst. - page 3

Figure 43 is the detail of the loads seen at the facility; these loads are predominantly during the sunlight hours. The majority of the power is used for pump for livestock and heating of water. Other than pumping activities the facility is very power efficient. The daily consumption of the facility is 20.424 kWh.



Project: Malmesbury Smallholding

Variant: New simulation variant

PVsyst V7.2.17
VC0, Simulation date:
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with v7.2.17

Detailed User's needs

Daily household consumers, Constant over the year, average = 20.4 kWh/day

Annual values

	Number	Power	Use	Energy
		W	Hour/day	Wh/day
Lamps (LED or fluo)	10	10W/lamp	2.0	200
TV / PC / Mobile	2	100W/app	4.0	800
Domestic appliances	1	500W/app	2.0	1000
Fridge / Deep-freeze	2		24	2400
Dish- and Cloth-washer	2		2	2000
Pump	1	1000W tot	2.0	2000
Geyser	1	2000W tot	6.0	12000
Stand-by consumers			24.0	24
Total daily energy				20424Wh/day

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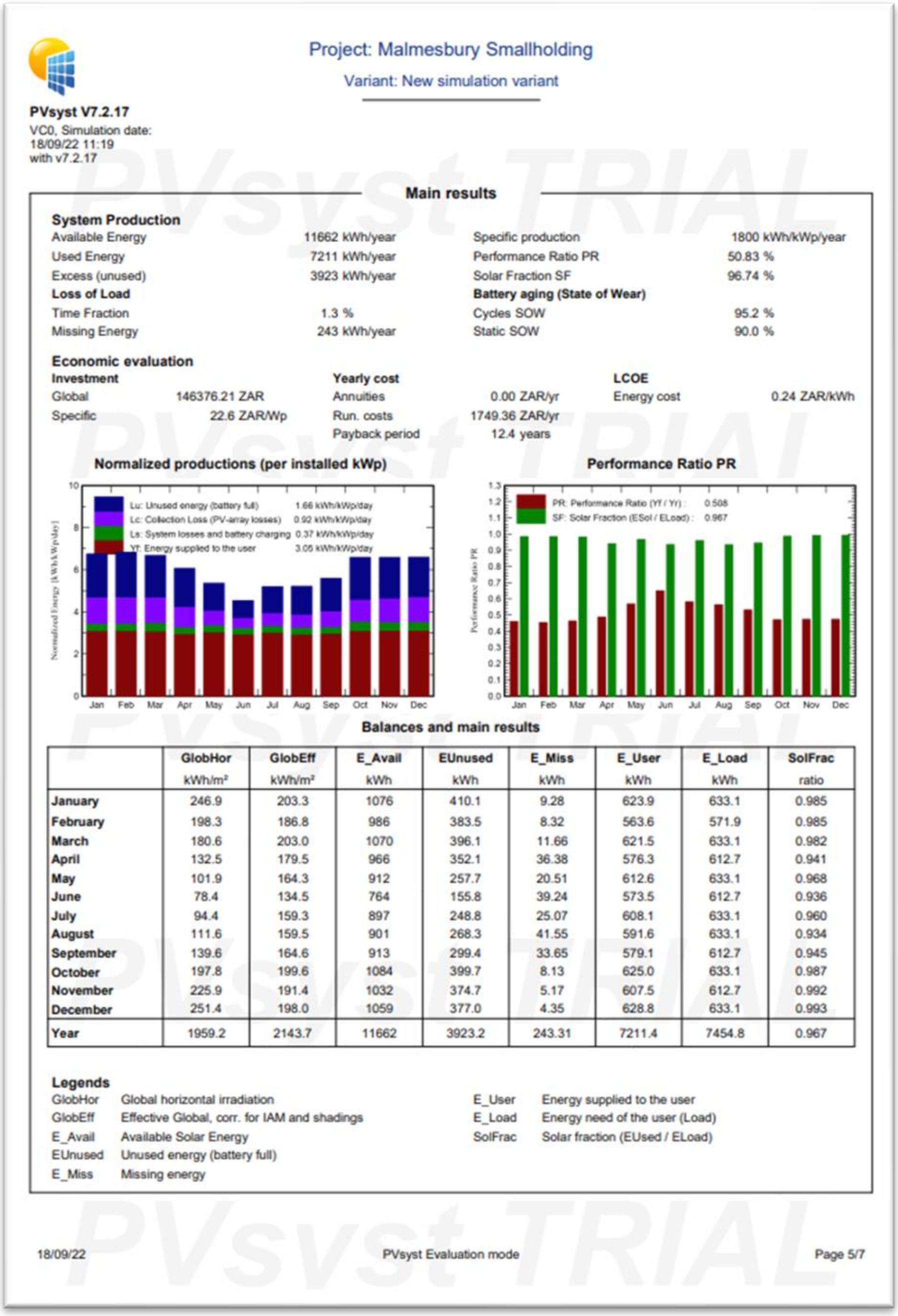
Figure 43: Malmesbury Smallholding - PV Syst. - page 4

Figure 44 is the main results of the simulation. The available energy has been calculated to be 11 662 kWh/year where the used energy is 7 211 kWh/year. If this facility connected to the local utility and was permitted to feed power back into the network they would have been able to export 3 923 kWh per year and save Eskom an equivelant amount of 'carbon' emissions. The total investment amount has been input with a calculated running or operating cost of R1 749.36 per year. With this data the simulation has calculated that the amortisation or paback period to be 12.4 years. The Levelised Cost of Energy (LCOE) has been calcuated at R 0.24 per kWh over the project lifecycle.


Project: Malmesbury Smallholding

Variant: New simulation variant

PVsyst V7.2.17
VC0, Simulation date:
18/09/22 11:19
with v7.2.17

Main results

System Production

Available Energy	11662 kWh/year	Specific production	1800 kWh/kWp/year
Used Energy	7211 kWh/year	Performance Ratio PR	50.83 %
Excess (unused)	3923 kWh/year	Solar Fraction SF	96.74 %
Loss of Load		**Battery aging (State of Wear)**	
Time Fraction	1.3 %	Cycles SOW	95.2 %
Missing Energy	243 kWh/year	Static SOW	90.0 %

Economic evaluation

Investment		**Yearly cost**		**LCOE**	
Global	146376.21 ZAR	Annuities	0.00 ZAR/yr	Energy cost	0.24 ZAR/kWh
Specific	22.6 ZAR/Wp	Run. costs	1749.36 ZAR/yr		
		Payback period	12.4 years		

Balances and main results

	GlobHor kWh/m²	GlobEff kWh/m²	E_Avail kWh	EUnused kWh	E_Miss kWh	E_User kWh	E_Load kWh	SolFrac ratio
January	246.9	203.3	1076	410.1	9.28	623.9	633.1	0.985
February	198.3	186.8	986	383.5	8.32	563.6	571.9	0.985
March	180.6	203.0	1070	396.1	11.66	621.5	633.1	0.982
April	132.5	179.5	966	352.1	36.38	576.3	612.7	0.941
May	101.9	164.3	912	257.7	20.51	612.6	633.1	0.968
June	78.4	134.5	764	155.8	39.24	573.5	612.7	0.936
July	94.4	159.3	897	248.8	25.07	608.1	633.1	0.960
August	111.6	159.5	901	268.3	41.55	591.6	633.1	0.934
September	139.6	164.6	913	299.4	33.65	579.1	612.7	0.945
October	197.8	199.6	1084	399.7	8.13	625.0	633.1	0.987
November	225.9	191.4	1032	374.7	5.17	607.5	612.7	0.992
December	251.4	198.0	1059	377.0	4.35	628.8	633.1	0.993
Year	1959.2	2143.7	11662	3923.2	243.31	7211.4	7454.8	0.967

Legends

GlobHor	Global horizontal irradiation	E_User	Energy supplied to the user
GlobEff	Effective Global, corr. for IAM and shadings	E_Load	Energy need of the user (Load)
E_Avail	Available Solar Energy	SolFrac	Solar fraction (EUsed / ELoad)
EUnused	Unused energy (battery full)		
E_Miss	Missing energy		

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Figure 44: Malmesbury Smallholding - PV Syst. - page 5

Figure 45 is an indication of the losses within the system. All these loses are broken down on the righ hand side of the image.

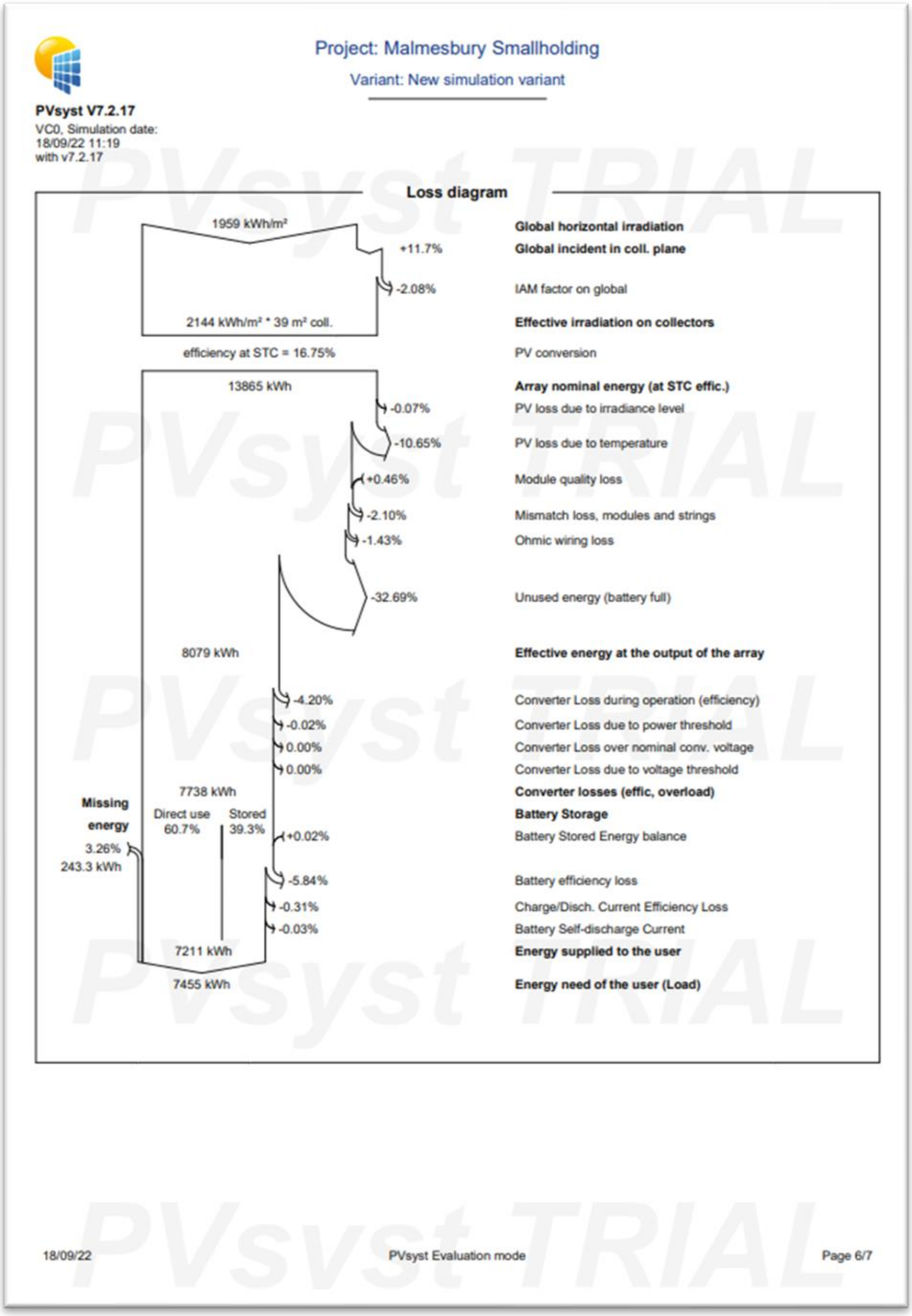

Figure 45: Malmesbury Smallholding - PV Syst. - page 6

Figure 46 is a table of the costs associated with the project.

Project: Malmesbury Smallholding

Variant: New simulation variant

PVsyst V7.2.17
VC0, Simulation date:
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with v7.2.17

Cost of the system

Installation costs

Item	Quantity units	Cost ZAR	Total ZAR
PV modules			
CS6P - 270P	24	2768.29	66439.06
Batteries	2	28559.71	57119.42
Taxes			
VAT	1	0.00	22817.73
Total			146376.21
Depreciable asset			123558.48

Operating costs

Item	Total ZAR/year
Maintenance	
Repairs	1749.36
Total (OPEX)	1749.36

System summary

Total installation cost	146376.21 ZAR
Operating costs	1749.36 ZAR/year
Excess energy (battery full)	3923 kWh/year
Used solar energy	7211 kWh/year
Used energy cost	1.257 ZAR/kWh

18/09/22 PVsyst Evaluation mode Page 7/7

Figure 46: Malmesbury Smallholding - PV Syst. - page 7

4.6.4 Summary for case study two

The Solar PV system was equipped with a power management and monitoring system. The monitoring system uses the Sunny Portal interface. All inverters and power meters communicate and upload their data to Sunny Portal. Sunny Portal then stores and displays this data in a graphical format.

This data has been downloaded as a CSV file and tabulated accordingly

Table 11 and 12 is a tabulation of the data received from the CSV file, it indicates:

- The Total Energy Produced (from 01/01/2018 to 30/07/2022): 29 157.27 kWh
- When multiplied by the appropriate year electricity tariff the Total Electricity savings after 55 months is: R60 361.21

Table 13 and 14 is a tabulated version of the total saving due to the installation of the Solar PV System.

The system was installed in January 2018. Therefore 35% of the asset has been recouped over a 55-month period. Figure 47 is a graphical breakdown of the savings that have accumulated over the 55-month period. Dark blue is indicating the electricity savings per month. Light blue is the yearly combined savings.

Figure 47 is showing that throughout the year the energy consumption is consistent. This smallholding does not farm crops. The energy consumed is mostly to heat water in the geyser and to pump water for domestic and livestock use.

With the actual production date, we can calculate the revised payback period. This is done by adding the previous 12 months consumption and then dividing it by 12 to get an average monthly consumption. This average is then used for the next period until there is a tariff increase in the end of March. This increase is an average of the last 5 years. This average is = 10.69% (Table 11 and 12). With this data we can calculate the amortisation date, this is graphically represented in Figure 48. This has been calculated to be within the 9th year, spec

ifically 9 years and 9 months.

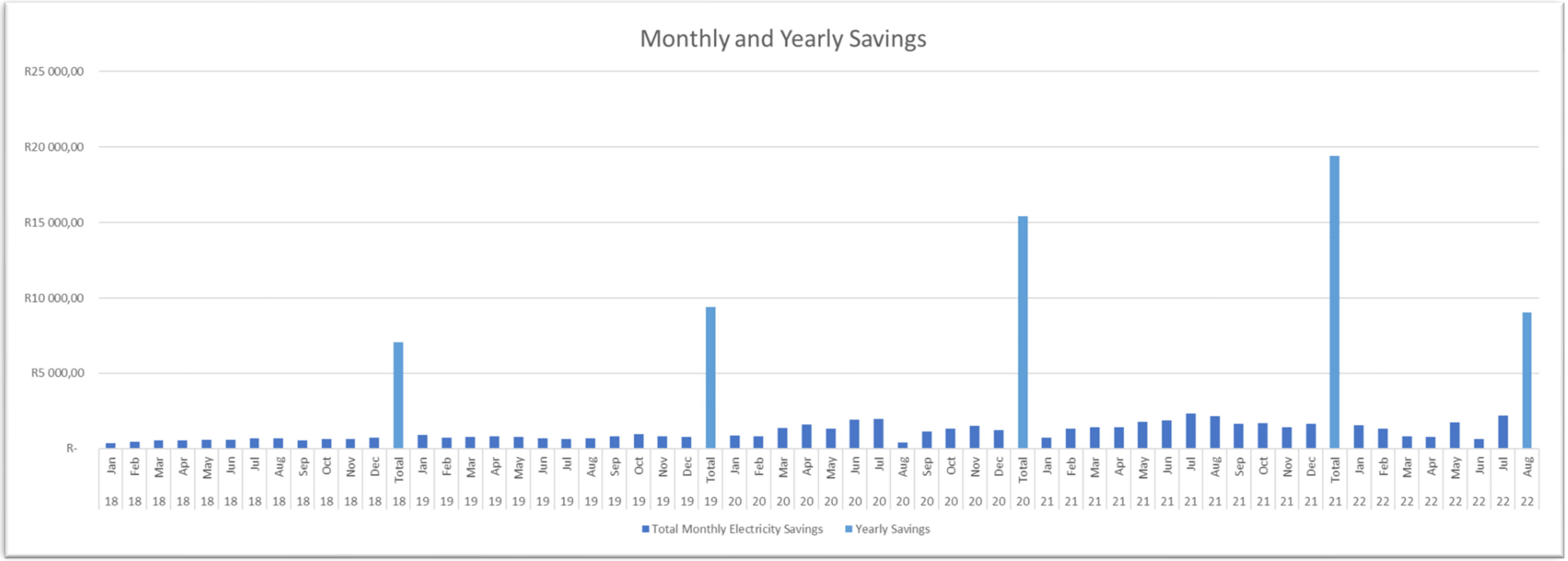

Figure 47: Malmesbury Smallholding - monthly and yearly savings

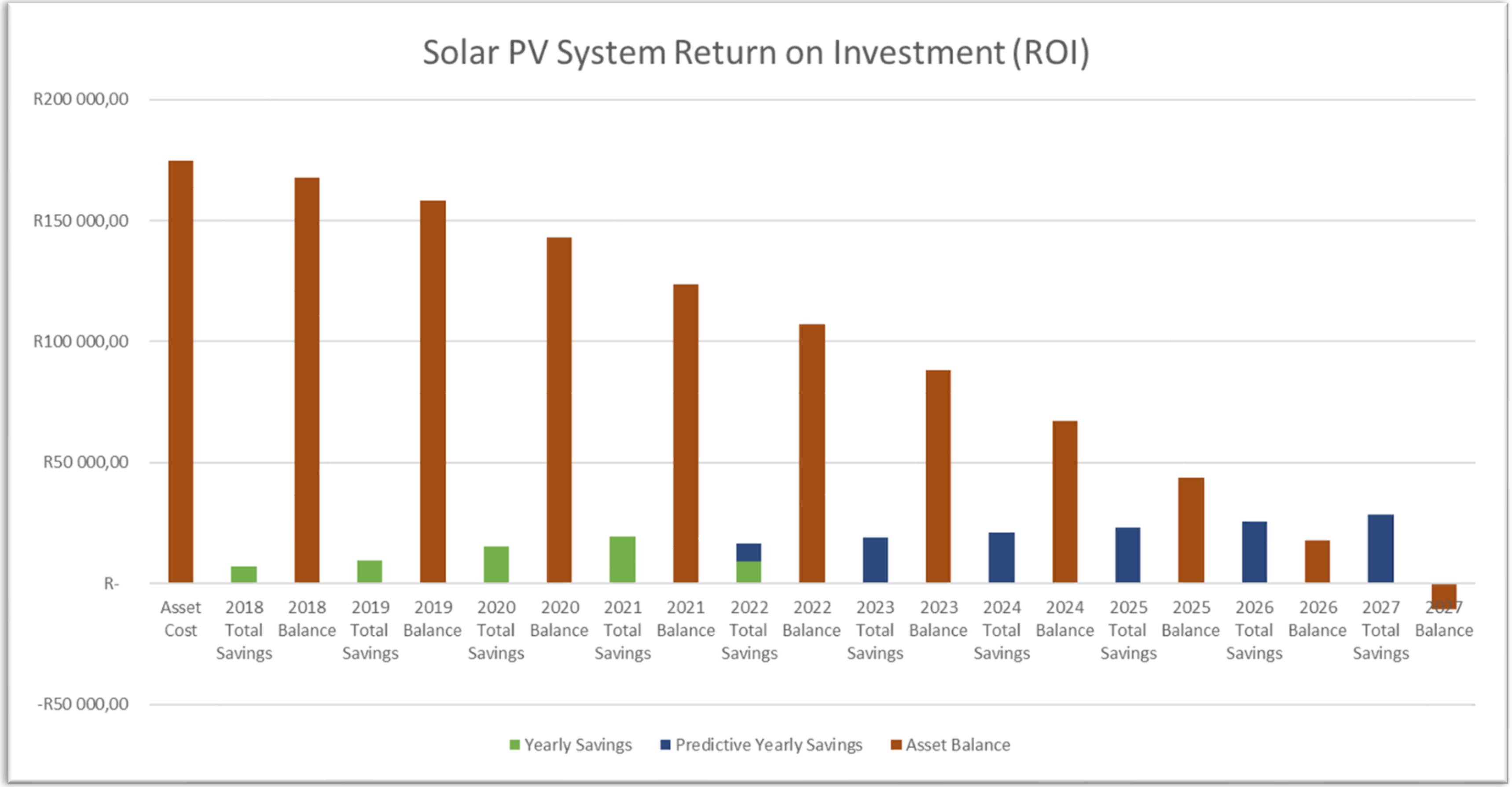

Figure 48: Malmesbury Smallholding - solar PV system return on investment (ROI)

Table 11: Malmesbury Smallholding - consumption data (2018 January to 2021 February)

Year	Month	External / Eskom Power Supplied	Electricity Consumption	Rate Per kWh [0-600 kWh]	Rate Per kWh [+600 kWh]	% Increase In Electricity Cost Per kWh
2018	**Jan**	0,00 kWh	283,44	R 1,20	R 2,05	0,00%
2018	Feb	0,00 kWh	382,19	R 1,20	R 2,05	0,00%
2018	Mar	0,00 kWh	461,39	R 1,20	R 2,05	0,00%
2018	Apr	0,00 kWh	434,9	R 1,28	R 2,17	6,16%
2018	May	0,00 kWh	467,18	R 1,28	R 2,17	0,00%
2018	Jun	0,00 kWh	466,07	R 1,28	R 2,17	0,00%
2018	Jul	0,00 kWh	534,94	R 1,28	R 2,17	0,00%
2018	Aug	0,00 kWh	536,11	R 1,28	R 2,17	0,00%
2018	Sep	0,00 kWh	431,82	R 1,28	R 2,17	0,00%
2018	Oct	0,00 kWh	513,09	R 1,28	R 2,17	0,00%
2018	Nov	0,00 kWh	501,06	R 1,28	R 2,17	0,00%
2018	Dec	0,00 kWh	584,36	R 1,28	R 2,17	0,00%
2019	**Jan**	0,00 kWh	661,84	R 1,28	R 2,17	0,00%
2019	Feb	0,00 kWh	583,44	R 1,28	R 2,17	0,00%
2019	Mar	0,00 kWh	595,37	R 1,28	R 2,17	0,00%
2019	Apr	0,00 kWh	558,41	R 1,46	R 2,47	13,87%
2019	May	0,00 kWh	529,34	R 1,46	R 2,47	0,00%
2019	Jun	0,00 kWh	474,81	R 1,46	R 2,47	0,00%
2019	Jul	0,00 kWh	450,35	R 1,46	R 2,47	0,00%
2019	Aug	0,00 kWh	472,06	R 1,46	R 2,47	0,00%
2019	Sep	0,00 kWh	552,65	R 1,46	R 2,47	0,00%
2019	Oct	0,00 kWh	640,84	R 1,46	R 2,47	0,00%
2019	Nov	0,00 kWh	570,76	R 1,46	R 2,47	0,00%
2019	Dec	0,00 kWh	538,79	R 1,46	R 2,47	0,00%
2020	**Jan**	0,00 kWh	601,91	R 1,46	R 2,47	0,00%
2020	Feb	5,55 kWh	553,26	R 1,46	R 2,47	0,00%
2020	Mar	101,46 kWh	692,45	R 1,46	R 2,47	0,00%
2020	Apr	182,80 kWh	652,36	R 1,58	R 2,69	8,76%
2020	May	197,94 kWh	546,18	R 1,58	R 2,69	0,00%
2020	Jun	425,26 kWh	530,18	R 1,58	R 2,69	0,00%
2020	Jul	323,62 kWh	646,81	R 1,58	R 2,69	0,00%
2020	Aug	102,65 kWh	245,04	R 1,58	R 2,69	0,00%
2020	Sep	182,15 kWh	489,08	R 1,58	R 2,69	0,00%
2020	Oct	205,32 kWh	530,88	R 1,58	R 2,69	0,00%
2020	Nov	170,98 kWh	630,8	R 1,58	R 2,69	0,00%
2020	Dec	144,89 kWh	562,83	R 1,58	R 2,69	0,00%
2021	**Jan**	97,61 kWh	445,68	R 1,58	R 2,69	0,00%
2021	Feb	137,48 kWh	604,7	R 1,58	R 2,69	0,00%

Table 12: Malmesbury Smallholding - consumption data (2021 March to 2022 July)

Year	Month	External / Eskom Power Supplied	Electriciy Consumption	Rate Per kWh [0-600kWh]	Rate Per kWh [+600kWh]	% Increase in electricity cost per kWh
2021	Mar	187,55 kWh	587,29	R 1,58	R 2,69	0,00%
2021	Apr	153,67 kWh	555,31	R 1,82	R 3,10	15,06%
2021	May	244,81 kWh	571,41	R 1,82	R 3,10	0,00%
2021	Jun	330,14 kWh	519,48	R 1,82	R 3,10	0,00%
2021	Jul	350,48 kWh	649,92	R 1,82	R 3,10	0,00%
2021	Aug	303,66 kWh	643,6	R 1,82	R 3,10	0,00%
2021	Sep	156,32 kWh	616,99	R 1,82	R 3,10	0,00%
2021	Oct	233,36 kWh	559,35	R 1,82	R 3,10	0,00%
2021	Nov	161,01 kWh	545,92	R 1,82	R 3,10	0,00%
2021	Dec	166,38 kWh	615,69	R 1,82	R 3,10	0,00%
2022	**Jan**	113,48 kWh	642,28	R 1,82	R 3,10	0,00%
2022	Feb	157,10 kWh	522,58	R 1,82	R 3,10	0,00%
2022	Mar	91,60 kWh	461,32	R 1,82	R 3,10	0,00%
2022	Apr	27,49 kWh	378,75	R 2,00	R 3,39	9,61%
2022	May	228,07 kWh	528,23	R 2,00	R 3,39	0,00%
2022	Jun	130,32 kWh	312,16	R 2,00	R 3,39	0,00%
2022	Jul	401,15 kWh	489,62	R 2,00	R 3,39	0,00%
Totals			29157,27 kWh			10,69%
			Total Energy Consumption in 55 months			Average Increase %

Table 13: Malmesbury Smallholding – total monthly savings (2018 January to 2021 May)

Year	Month	Electricity Cost Per Month [0-600 kWh]	Electricity Cost Per Month [+600 kWh]	Total Monthly Electricity Savings
2018	**Jan**	R 341,40	R -	R 341,40
2018	Feb	R 460,35	R -	R 460,35
2018	Mar	R 555,74	R -	R 555,74
2018	Apr	R 556,11	R -	R 556,11
2018	May	R 597,38	R -	R 597,38
2018	Jun	R 595,96	R -	R 595,96
2018	Jul	R 684,03	R -	R 684,03
2018	Aug	R 685,52	R -	R 685,52
2018	Sep	R 552,17	R -	R 552,17
2018	Oct	R 656,09	R -	R 656,09
2018	Nov	R 640,71	R -	R 640,71
2018	Dec	R 747,22	R -	R 747,22
2019	**Jan**	R 767,22	R 134,41	R 901,63
2019	Feb	R 746,04	R -	R 746,04
2019	Mar	R 761,30	R -	R 761,30
2019	Apr	R 813,04	R -	R 813,04
2019	May	R 770,72	R -	R 770,72
2019	Jun	R 691,32	R -	R 691,32
2019	Jul	R 655,71	R -	R 655,71
2019	Aug	R 687,32	R -	R 687,32
2019	Sep	R 804,66	R -	R 804,66
2019	Oct	R 873,60	R 101,07	R 974,67
2019	Nov	R 831,03	R -	R 831,03
2019	Dec	R 784,48	R -	R 784,48
2020	**Jan**	R 873,60	R 4,73	R 878,33
2020	Feb	R 805,55	R -	R 805,55
2020	Mar	R 873,60	R 479,91	R 1 353,51
2020	Apr	R 950,16	R 632,98	R 1 583,14
2020	May	R 950,16	R 387,93	R 1 338,09
2020	Jun	R 950,16	R 956,74	R 1 906,90
2020	Jul	R 950,16	R 997,09	R 1 947,25
2020	Aug	R 388,05	R -	R 388,05
2020	Sep	R 950,16	R 191,73	R 1 141,89
2020	Oct	R 950,16	R 366,61	R 1 316,77
2020	Nov	R 950,16	R 543,13	R 1 493,29
2020	Dec	R 950,16	R 289,95	R 1 240,11
2021	**Jan**	R 705,78	R -	R 705,78
2021	Feb	R 950,16	R 382,71	R 1 332,87
2021	Mar	R 950,16	R 470,62	R 1 420,78
2021	Apr	R 1 093,26	R 337,52	R 1 430,78
2021	May	R 1 093,26	R 669,65	R 1 762,91

Table 14: Malmesbury Smallholding – total monthly savings (2021 June to 2022 July)

Year	Month	Electricty Cost Per Month [0-600kWh]	Electricty Cost Per Month [+600kWh]	Total Monthly Electricity Savings
2021	Jun	R 1 093,26	R 773,10	R 1 866,36
2021	Jul	R 1 093,26	R 1 240,08	R 2 333,34
2021	Aug	R 1 093,26	R 1 075,50	R 2 168,76
2021	Sep	R 1 093,26	R 536,76	R 1 630,02
2021	Oct	R 1 093,26	R 596,84	R 1 690,10
2021	Nov	R 1 093,26	R 331,17	R 1 424,43
2021	Dec	R 1 093,26	R 563,89	R 1 657,15
2022	**Jan**	R 1 093,26	R 482,40	R 1 575,66
2022	Feb	R 1 093,26	R 246,78	R 1 340,04
2022	Mar	R 840,57	R -	R 840,57
2022	Apr	R 756,44	R -	R 756,44
2022	May	R 1 198,32	R 530,59	R 1 728,91
2022	Jun	R 623,45	R -	R 623,45
2022	Jul	R 1 198,32	R 987,08	R 2 185,40
Totals		R 46 050,25	R 14 310,96	R 60 361,21
		Total Energy Cost saved in 55 months	Total Energy Cost saved in 55 months	Total Savings in 55 months

4.7 Comparison between case study one and two

Malmesbury Farm (case one) and Malmesbury Smallholding (case two) are excelling in their energy production as seen in Table 15. In both case studies the actual energy production is above or inline with the average simulation. In the case of Malmesbury Farm when including the service fee to the ROI calculation the amortisation period reduces to 7 years and 9 months.

Table 15: Months to reach investment amortisation

Investment amortisation period or return on investment (ROI) [years, months]		
Software	**Malmesbury Farm**	**Malmesbury Smallholding**
Sunny Design	13,9	14,1
PV Syst.	10,4	12,4
Actual	10,5 (7,9)*	9,9

* 7 years & 9 months when the service fee is included in the payback period

Sunny Design seems to be the most conservative simulation, a consideration for this is that the loads of the facilities are not well defined. The software has a limited quantity of load profiles that the user has to select, this load profile is not optimised to a specific site. The only adjustment that can be made is the total yearly consumption, this raises or lowers the profile values accordingly. The user cannot however add specific loads like that of PV Syst. PV Syst on the other hand does have the ability to add specific loads, the user can add specific items to specific days. Both software's make use of the same meteorological and solar radiation data, the only delimiting factor is that of the consumption data.

Table 16 is a summary of the past 12 months energy consumption of the facilities. Without PV Malmesbury Farm and Malmesbury Smallholding would have consumed 22 050.86 kWh and 8 486.43 kWh respectively. This consumption would have resulted in a 22.93 tCO_2e and 8.83 tCO_2e respectively of emissions over the past year. Due to the installation of the PV system these two facilities have reduced their emissions by 100% and 74.43% respectively. This is a considerable reduction over this short period.

Malmesbury Farm has reduced their emissions by 22.93 tCO_2e whereas Malmesbury Smallholding has reduced theirs by 6.57 tCO_2e.

Table 16: Power and emissions reduction due to the installation of PV system over the past 12 months

Power and emissions reduction due to the installation of PV system over the past 12 months [August 2021 to July 2022]				
Power from Eskom	**Malmesbury Farm**		**Malmesbury Smallholding**	
Without PV	22050,86 kWh (pa)	22,93 tCO2e (pa)	8486,43 kWh (pa)	8,83 tCO2e (pa)
With PV	0,00 kWh (pa)	0,00 tCO2e (pa)	2169,94 kWh (pa)	2,26 tCO2e (pa)
Reduction (actual)	22050,86 kWh (pa)	22,93 tCO2e (pa)	6316,49 kWh (pa)	6,57 tCO2e (pa)
Reduction (%)	100%	100%	74,43%	74,43%

These case studies show that the installation of PV systems have both a favourable return on investment and considerably reduce the emissions of a facility.

CHAPTER FIVE:
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

South Africa is in an energy crisis. The state utilities' (Eskom) infrastructure is outdated, not maintained, and has insufficient capacity. This is clearly indicated by the loadshedding that began in South Africa in 2007 (Chettiar, Lakmeeharan & Koch, 2009). Each successive year it has worsened as the infrastructure grows older and deteriorates even further, aging infrastructure comes terrible inefficiencies. This results in a waste of resources and over consumption of fossil fuel to produce electricity throughout the country. This clear identifier is the emissions factor of 1036 grams of CO_2e per kWh produced, which in 2019 was one of the worst in the world, when compared to all European countries South Africa is the worst. In addition, in 2020 South Africa had the worst per capita emissions rate on the African continent. This is not something to be proud of.

Eskom have however since 2020 been reducing their CO_2e emissions. When we compare the Eskom GHG emissions for the months of April, May, June and July in 2021 to that of 2022 there has been an average GHG emissions decrease of 10.22%. This is exceptional given the circumstance.

Loadshedding is another critical identifier of how the state-owned Eskom is in trouble. There is however a positive aspect to loadshedding as more homeowners, businesses and facilities are looking into alternative options for electricity supply. In this research, the option and feasibility to reduce Scope 2 emissions has been evaluated in two case studies: Malmesbury Farm and Malmesbury Smallholding. It gives a positive ROI for the asset over a 10-year period. The actual ROI for these two sites is approximately 10,5 and 9,8 years respectively. Both sites are performing better than initially calculated from the PV Syst and Sunny Design software. This is a positive for potential investors to witness and have confidence in the technology. In addition to the favourable ROI, these sites shall reduce their Scope 2 emissions by 549 tCO_2e and 222 tCO_2e respectively over a 20-year period according to Sunny Design. They shall not be able to reduce their Scope 2 emissions below 0 as the Malmesbury Farm is not connected to the grid and the Malmesbury Smallholding does not have permission from the utility to export power. In both case studies a positive result has been achieved. Both facilities have considerably reduced their Scope 2 emissions. The

Malmesbury Farm has reduced their Scope 2 emissions by 100%, where they have consumed 0 kWh from Eskom over the last year. The Malmesbury Smallholding has reduced their Scope 2 emissions by 74.43%, where over the past 12 months their Scope 2 emissions have amounted to only 2.26 tCO_2e compared to 8.83 tCO_2e if no PV system was installed. This research proves that the installation of PV can considerably reduce a facilities carbon footprint and have a positive financial return on the investment.

The method followed in this study has proven to be beneficial to the two sites, namely Malmesbury Farm and Malmesbury Smallholding. The variables from site to site as well as the changes over time are not predictable or consistent. All Engineering designs should attempt to cater for flexibility and expansion.

5.2 Recommendations

The research and investigation for this study has been conducted over a 6-year period, throughout this period there have been many improvements to technologies as well as techniques and methods. Different needs and objectives have matured over this time. Many of these needs have been brought into the forefront due to the ever worsening loadshedding in South Africa. Below are recommendations for possible further studies:

- Revise the ROI calculations in 2026 once Malmesbury Farm reaches its expected ROI.
- This study has been limited to 2 case studies of varying size and complexity. It would add value to do an evaluation with a greater number of sites with different inverters and different installations / connection types.
- Include time and production loss due to South African loadshedding in the ROI calculation.
- High Voltage batteries have only reached market maturity in 2022. It would be very interesting to evaluate the losses between the currently low voltage batteries with these high voltage +400 V batteries.
- The trading of carbon credits. Further investigation as to how this can be managed and evaluated to ensure transparency is recommended. In addition, it can open up funding for developing countries that do have the space and the climate that is suitable for these renewable energy generators.

- Carbon Tax in South Africa is to be formalised in October 2022. An assessment of this process and how it aids in the reducing of GHG emissions of facilities would add value to future studies.
- Establishment of possible forest rehabilitation and increased oxygen levels when Carbon Neutral positively effects the environment and reduces global warming.
- Review Eskom's GHG emission status in 2030 after all the commitments are supposed to have materialised.

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Appendix A: Single Line Diagram of 3 Phase SMA Off-grid