INVESTIGATING ALTERNATIVE POWER GENERATION STRATEGIES FOR LOCAL MUNICIPALITIES THAT ARE TIED TO THE NATIONAL GRID

BONOLO PATRICIA TSHETLHE

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Supervisor: Prof. A.J Swart

Co-supervisor: Dr. S.P Koko

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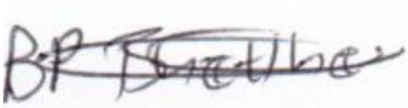
Declaration

I, Bonolo Patricia Tshetlhe (Student number:) hereby declare that this research project which has been submitted to the Central University of Technology, Free State for the degree of MASTER OF ENGINEERING IN ELECTRICAL ENGINEERING, is my own independent work; complies with the Code of Academic Integrity, as well as other relevant policies, procedures, rules and regulations of the Central University of Technology, Free State, and has not been submitted before by any person in fulfilment (or partial fulfilment) of the requirements for the attainment of any qualification.



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Abstract

The demand for electricity keeps on increasing every year, and this puts pressure on municipalities that are supplying electricity to their communities. Once the demand for electricity goes up, municipalities consume a lot of electricity from national energy suppliers, putting a lot of pressure on the National Grid. Furthermore, some municipalities are struggling to pay off debt owed to national energy suppliers, such as Eskom, due to low revenue collection from electricity, because of non-paying customers, faulty meters and electricity theft. Under this condition, local municipalities may have to consider alternative power generation strategies to continue functioning to a limited degree.

The challenge exists in identifying viable alternative power generation strategies for local municipalities to reduce pressure on the National Grid during the months of high energy demand and to provide limited power to their communities when disconnected from the National Grid, due to load-shedding. The first objective of this research was to conduct an energy audit of two towns in the Free State Province of South Africa, which is Koffiefontein and Petrusburg and correlate it to their electrical bill. Secondly, it was to identify various alternative power generation strategies, based on the energy audit and weather data for the two towns. Thirdly, it was to apply the HOMER simulation tool to evaluate the viability of the proposed strategies and then recommend the most appropriate strategy for the two identified towns. The payback period for the alternative power generation systems was also determined.

The results of the audit indicated that Koffiefontein consists of a total of 2 038 houses, with 1 246 in the township and 792 in town. This town also has 113 businesses, with 36 in the township and 77 in town. Electricity sale statistics from the municipality indicated that Koffiefontein houses consume more electricity than businesses, with June 2016 having the highest electricity consumption of 1 135 572.98 kWh. For Petrusburg, the audit was conducted in town only, as the township is being supplied directly by Eskom. Petrusburg consists of 606 houses and 63 businesses in town. Businesses in Petrusburg town consume more electricity than houses, with August 2016 having the highest electricity consumption of 1 002 048 kWh.

After conducting an energy audit, the HOMER program was used to simulate the output of the two identified potential strategies, which is solar and wind. HOMER indicated that solar energy is the best renewable energy strategy to supplement the current energy source of both Koffiefontein and Petrusburg town, due to it being cost effective and having high yearly energy production. The cost of energy for the battery-based solar PV system, suggested for

Koffiefontein houses is R 6.10 /kWh, while the cost of energy for the battery-based wind turbine system is R 776.490 /kWh. For Petrusburg town, the cost of energy for the battery-based solar PV system suggested for Petrusburg businesses is R 4.04 /kWh, while the cost of energy for the battery-based wind turbine system is R 840.4 /kWh. The results revealed that the utilization of a battery-based solar PV system may lead to a payback period of 11.5 years and 7.6 years, for Koffiefontein and Petrusburg respectively.

Municipalities should consider doing an energy audit at least every two years to make sure that they are aware of any energy loses, due to tampered meters and faulty meters so that it can be addressed before it affects revenue collection of the municipality. Towns in the Western Free State should consider installing battery-based solar PV systems for businesses and houses so that they can have access to electricity during load-shedding and reduce the pressure placed on the National Grid during high energy demanding hours. The battery-based wind turbine system is more expensive than the battery-based solar PV system and has a longer payback period. Furthermore, wind speed data collected at Fauresmith indicates that a battery-based wind turbine system would suffer poor performance, due to the low annual wind speed.

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Abbreviations

COE	Cost of Energy
HOMER	Hybrid Optimization Model for Electric Renewable
NPC	Net Present Cost
PV	Photovoltaic
TV	Television
O&M	Operation and Maintenance
IRP	Integrated Resource Plan
DoE	Department of Energy
ESKOM	Electricity Supply Commission
c/kWh	Cents per kilowatt-hour
kWh	Per kilowatt-hour
kVA	kilovolt-ampere
NMD	Notified maximum demand
MW	Megawatts
NERSA	National Electricity Regulator of South Africa
MH	Micro hydro
A	Current
AC	Alternating Current
COE	Cost of Energy
DC	Direct Current
ADMD	After Diversity Maximum Demand
HPA	Highveld Priority Area
LV	Low Voltage

VTAPA	Vaal Triangle shed Priority Area
WBPA	Waterberg Bojanala Priority
kV	kilovolt
W	Watts
GWh	Gigawatt hour
MWh	Megawatt hour

CHAPTER 1: INTRODUCTION

1.1 Introduction

The supply of electricity involves three phases: generation, transmission and distribution [1]. In South Africa, 93% of electricity is generated from coal [2]. Eskom generates 96% of electricity, which includes 5% of imported electricity. As the only transmission licensee, Eskom is responsible for all transmitted electricity. In South Africa, Eskom and municipalities both distribute electricity to consumers, thus the distribution function is shared between municipalities and Eskom. No district municipality is authorised to distribute electricity [1]. For municipalities that supply electricity to households and businesses, revenue collected from electricity sales is a major source of income for the municipality [1]. Eskom holdings SOC LTD is under statutory obligations to generate and supply electricity to the municipalities nationally on a financial sustainable basis [3].

Eskom supplies the licensed municipalities in bulk at a pre-determined tariff, where after the municipality re-sells electricity to the end users within their municipal borders at a mark-up price. The terms on which electricity is supplied by Eskom to municipalities are recorded in an electricity supply agreement. Eskom invoices municipalities monthly for the supply of the electricity in terms of the supply agreement, concluded with each municipality. Municipalities are obliged to effect payment of all owed amounts in terms of section 41 of the local government [4].

At all times there must be sufficient supply to meet the electricity demand. The demand is not consistent, because of peak periods and continuous growth in the number of customers requiring electricity services [3]. Since 2007, Eskom has experienced lack of capacity in the generation and reticulation of electricity. As a result, in the first quarter of 2008, blackouts became common place in the country with damaging effects on South Africa's economy [5]. Load reduction is done countrywide as a controlled option to respond to unplanned events to protect the electricity power system from a total blackout [3].

Eskom follows the following protocol to implement load reduction to keep the power system balanced at 50Hz as per international standards. Load curtailment; an agreement with some of Eskom's large industrial customers, which means Eskom can instruct them to reduce electricity consumption when it is urgent to balance the system [3]. They are able to reduce their load by up to 20%, significantly easing capacity on the grid, and it takes a minimum of two hours to implement. If after load curtailment the demand on the system is still greater than available supply, a process of load-shedding is implemented [3].

With load-shedding, as a last resort and preventative measure, consumers are cut off on a rotational basis for two to four hours to protect the electricity grid from collapse. Depending on the stage, the national system operator instructs the regional distribution centres, 126 municipalities and key industrial customers to implement load-shedding according to their schedule. Figure 1 outlines when load shedding occurs [6]:

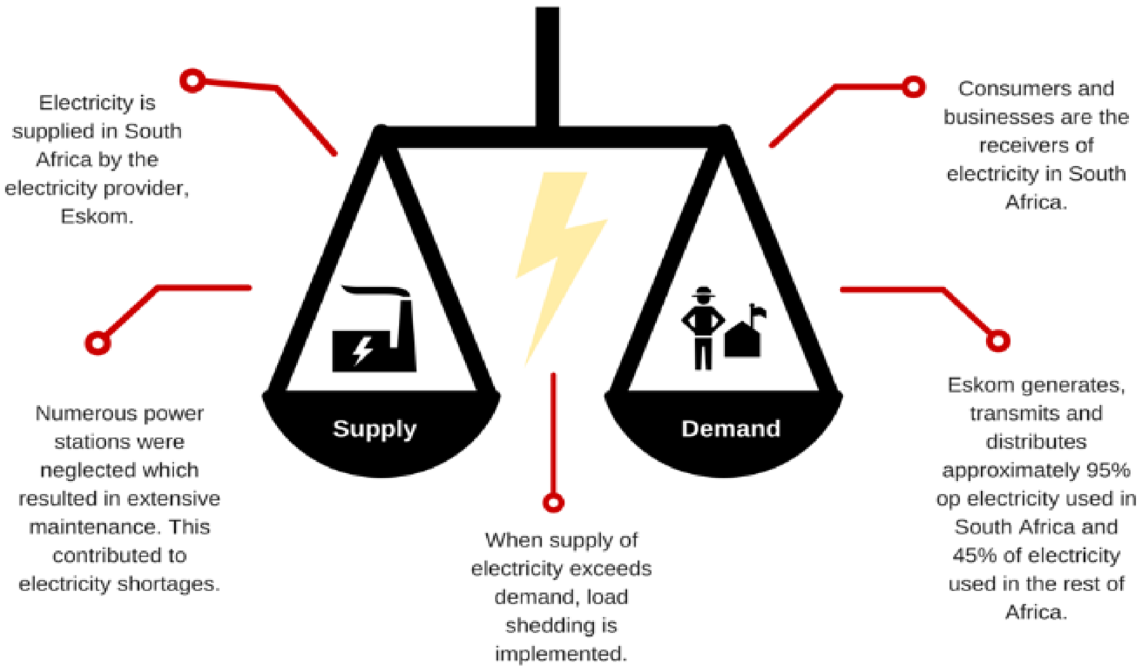


Figure 1: Steps of load-shedding [7].

The main reason provided by Eskom for the energy crisis was the imbalance between electricity supply and demand. Figure 2 shows Eskom's long-term demand forecast as presented to Parliament [5]. The demand is expected to be between 56 710 MW and 77 960 MW in 2025, depending on the economic growth in the country [5]. On average, South African electricity demand is around 29 000 MW with production capacity at 42 800 MW [8]. This is the average consumption, but it might peak higher on some days [8]. Furthermore, this century would witness unprecedented growth and challenges in power generation, delivery and usage [9].

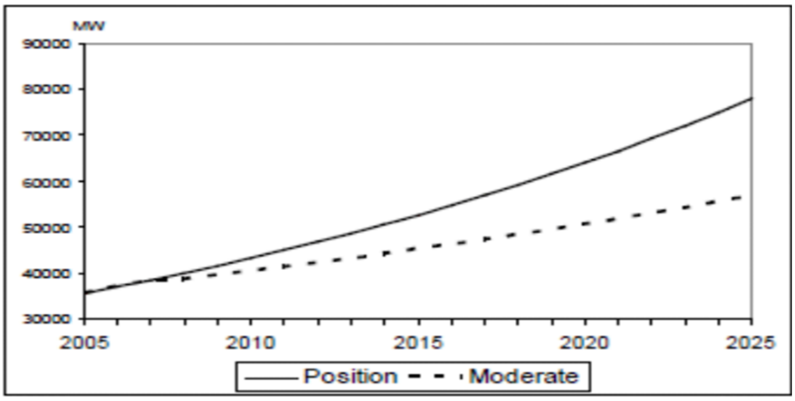


Figure 2: Eskom's long-term demand forecast [5].

Government and Eskom has started planning for stage 5 and stage 6 load-shedding. There is a race against time to ensure that a national blackout and grid collapse does not happen [10]. NERSA (National Electricity Regulator of South Africa) has approved City Power to implement a residential time-of-use tariff system. The introduction of this system by City Power is informed by its commitment to provide service to its hard-pressed consumers by incentivising and rewarding them for changing their usage pattern while at the same time ensuring security of supply by lessening the pressure on the grid [11].

Renewable and clean alternative power generation technologies can play an important role in future power supply, due to increased global public awareness on the need for environmental protection and the desire for less dependence on fossil fuels for energy production [9]. It may also help to ease the pressure on the National Grid. The government of South Africa has responded with action to increase generation capacity and reliability, including investment in renewable and alternative energy sources and to enhance energy efficiency [12].

These technologies include power generation from renewable energy sources such as Wind, Photovoltaic (PV), Micro Hydro (MH), biomass, geothermal, ocean waves and tides and clean alternative energy power generation technologies [9]. These renewable energy and alternative energy generation sources often come in the form of customized distributed energy systems in grid connected or standalone configurations [9].

1.2 Problem statement

Escalating electrical energy usage has resulted in large utility bill expenses that municipalities are struggling to pay-off to Eskom, along with load-shedding. The challenge exists in identifying viable alternative power generation strategies for local municipalities to reduce pressure on the National Grid during the months of high energy demand and to provide limited power to their communities when disconnected from the National Grid.

1.3 Research aim and objectives

The main aim is to investigate alternative power generation strategies for local municipalities, in order to enable more autonomy that can help to reduce the pressure placed on the National Gird. The objectives of this research is to:

- Conduct an energy audit of the two towns, which is Koffiefontein and Petrusburg and correlate it to their electrical bill.
- Identify various alternative power generation strategies, based on the energy audit and weather data for the two towns.
- Apply the HOMER program to evaluate the viability of the proposed strategies.
- Recommend the most appropriate strategy for the two identified towns.
- Determine the payback period for the selected renewable energy system.
- Verify the regulator code on the technical requirements for municipalities to have renewable energy systems.

1.4 Importance of the research

This research is based on helping local municipalities reduce the pressure on the National Grid during months of high energy demands by using alternative power strategies. During the municipal high energy demand months, an environmentally friendly renewable energy strategy method could be used to supplement the current energy source of the municipality. The environmentally friendly method that could be used, may further help reduce the current carbon footprint, which is the amount of a carbon dioxide released into the atmosphere as a result of activities of a particular individual, organisation or community that can impact on climate change [13].

A suitable renewable energy method could be identified to supplement the municipal current energy source during municipal high energy demand months, which could help reduce pressure on the National Grid and provide a measure of autonomy on local municipalities. This research could also assist municipalities to identify their area of energy losses during the energy audit, as the objectives of the energy audit is to detect and assess saving opportunities and improve energy efficiency [14]. The audit could also assist with analysing the possibility of using renewable energy [14].

This research could further provide knowledge of the use of renewable energy for generating electricity to local municipalities. This research could also show municipalities the importance of doing an energy audit at least every two years to make sure that they are aware of any energy losses so that it can be addressed before it affects revenue collection of the municipality.

1.5 Methodology

This research is focussed on the two towns in the Letsemeng Local Municipality region, which is Koffiefontein and Petrusburg, this towns are selected because they are owing Eskom a lot of money hence a need exists to minimize their bills. This towns will not present the average scenario of South Africa. Municipalities buy electricity from Eskom on a time-of-use tariff and then sell that electricity to residential consumers at a flat rate. The time-of-use applies different charges per kWh at different times of the day and year, whereas a flat tariff charges the same rate per kWh, regardless of the time of the day [15]. Eskom invoices municipalities monthly for the supply of the electricity in terms of the supply agreement concluded with each municipality. Figure 3 outlines the steps of the research:

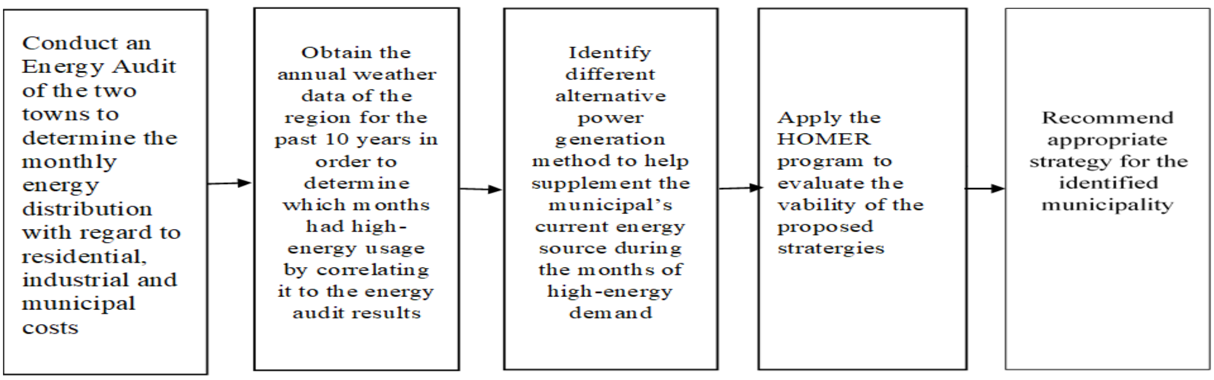


Figure 3: Steps of the research

The researcher will conduct an energy audit of the two towns within the Letsemeng Local Municipality, which is Koffiefontein and Petrusburg. Audit levels clearly differ in respect of their set of objectives, scope of tasks and powers and the related tools [16]. The objective is to determine the number of households and businesses within Koffiefontein and Petrusburg. A novel approach involves using Google Maps as the tool to determine these values. This then forms a basic level audit.

Household's neighbourhoods will be identified by swimming pools, sports grounds and schools. Businesses will be identified by the nearby presence of government departments of public buildings. This will then be correlated to the amount of electrical energy that was sold to residential and industrial businesses for the past year. This information will help to identify months of high energy usage for businesses, as well as for households. A suitable supplementary method will be suggested according to the information obtained from Google Maps, as well as the correct size of solar farm or wind farm for either households or businesses to supplement the current energy source during months of high energy demand.

This data will then be correlated to the weather data that has been obtained for the past 10 years for the two towns. The researcher checked during high energy consumption months, whether there was high solar radiation or high wind speed. The energy data from the municipality will help identify months of high energy usage, and months during which a supplement to the current energy source is really required.

After comparing the annual weather data with the monthly energy consumption from the municipality, an alternative power generation method will be suggested. The two main alternative strategies to focus on, are wind farms and solar farms. They are the most widely used renewable energy resources around the globe and there is an existing potential of utilizing them at the studies site.

The weather data will also be used to select the most appropriate strategy to cover the months that have the highest electrical energy demand. Supplementary energy could be provided during high demanding hours of businesses and when government departments and schools are operative.

The HOMER program will be used for simulating the output power of the two strategies with given weather data. Hybrid Optimization Model for Electric Renewable (HOMER) is a free software application developed by the National Renewable Energy Laboratory in the United States [17]. This software application is used to design and evaluate the technical and financial the options of off-grid and on-grid power systems for remote, standalone and distributed generation applications [17]. It allows you to consider a large number of technology options to account for energy resources' availability and other variables [17].

The strategy that provides the output power requirements for the houses or the businesses will be selected as the preferred alternative power generation method for the municipality. A cost analysis and payback period for the municipality will be conducted. After conducting an energy audit, comparing the annual weather data with the monthly energy consumption and evaluating two primary alternative power generation strategies, a recommendation will be made. A suitable appropriate strategy to supplement the current energy source of the municipality will be given.

1.6 Definition of terms

Blackouts: No lights or load-shedding [3].

Reticulation: A pattern or arrangement of interlacing lines, resembling a net [3].

Bulk: The mass or size of something large [4].

Tariff: A tax or duty to be paid [4].

Capacity: The maximum amount that something can contain [12].

Forecast: Estimate (A future event or trend) [5].

Peak: The highest level [8]

Load curtailment: The action of reducing [3].

Collapse: Fall down [10].

Time of use tariffs: New concept or design to incentivise customers to use more energy at off-peak times, in order to balance demand [15].

1.7 Delimitation

This research does not include other alternative sources, such as hydro power systems, biomass and geothermal renewable energies. This research only focuses on the electricity sales of the municipality, and it does not include electricity losses due to tampered meters. This research only considers the residential and business districts of the two selected towns of the south western part of the Free State Province of South Africa.

1.8 Overviews of the research

Chapter 1 is an introduction of the background and current challenges being faced by Eskom and municipalities with regards to the supply of electricity in South Africa. It also highlights the problem statement to be investigated (researched), which focuses on finding alternative power generation strategies for local municipalities to supplement the current energy source, which may help reduce the pressure on the National Grid.

Chapter 2 is a discussion of literature reviews from previous research. Chapter 2 looks at the history of energy supply in South Africa, causes of load-shedding and how load-shedding is implemented by Eskom. Chapter 2 also looks at researches that were done on ways to help reduce pressure on the National Grid. The history of renewable energy, such as wind farms and solar farms in South Africa, and the forecasted growth of renewable energy resources are discussed, as well as methods of audits, the importance of energy audit. The importance of using HOMER as a simulation tool and where it has been used, are highlighted. Chapter 2 also considers the regulator code on the technical requirements for municipalities to have renewable energy systems.

Chapter 3 explains how the research was conducted. An energy audit was conducted in the two towns of Letsemeng, which is Koffiefontein and Petrusburg. Quantitative data of the municipal energy usage was collected for the two towns under the research, along with the annual weather data of the two towns for the past 10 years. The results of the energy audit were compared to the annual weather data, in order to suggest a suitable renewable energy method, based on either a wind farm or solar farm. The HOMER program was used for simulating the output power of the two strategies, using the given weather data.

Chapter 4 focuses on data analyses. Electricity sales from the municipality and annual weather data of solar radiation and wind speed for Petrusburg and Koffiefontein town are analysed in this chapter. Results of the simulations conducted, using the HOMER software, were analysed.

Chapter 5 draws from the previous four chapters. This chapter offers a comprehensive summary of how the researcher responded to the research problem statement, aim and methodology. It takes into consideration the findings and what they mean for the research and lessons to be learned in addressing the problem statement. The lessons to be learned from this research offer recommendations of what can be done going forward to have a sustainable energy supply for Petrusburg and Koffiefontein towns.

1.9 Summary

The demand for electricity keeps on increasing every year. This puts pressure on the National Grid. This research was based on helping municipalities reduce the pressure on the National Grid by supplementing their current energy source with a suitable alternative power generation strategy during their months of high energy demand. An energy audit of the two identified towns, which is Koffiefontein and Petrusburg, was conducted. The results of the audit were correlated to the weather annual data for the past 10 years and then a suitable alternative power generation method was suggested.

The next chapter is a discussion of literature reviews from previous research. Chapter 2 looks at the history of energy supply in South Africa, causes of load-shedding and how load-shedding is implemented by Eskom. The next chapter also considers ways of helping reduce pressure on a National Grid.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Chapter 1 introduced the research, highlighting the problem statement to be investigated and methodology that will be followed. Chapter 1 introduced the main aim of the research, which was to investigate alternative power generation strategies for local municipalities, in order to enable more autonomy that can help to reduce the pressure placed on the National Gird.

Chapter 2 is a discussion of literature reviews from previous researchers. Chapter 2 looks at the history of energy supply in South Africa, causes of load-shedding and how load-shedding is implemented by Eskom. It also considers methods to reduce pressure on a National Grid and describes the value of the HOMER software program that was applied in this research.

2.2 History and impact of energy supply in South Africa

Electricity supply in South Africa has long been the domain of Eskom [18]. Eskom was established in 1923 in terms of the Electricity Act following an amalgamation of several private enterprises [18]. Eskom supplies 96% of electricity in South Africa [19]. 92% of the electricity produced by Eskom is from coal with the remainder generated from nuclear energy (5%) and other sources (3%) [20].

Eskom's baseload generation capacity comprises of several large coal-fired power stations, situated in the north east of the country and a single nuclear power station on the West coast [21]. Diesel-fired gas turbines and pumped storage schemes are also used by Eskom. Figure 4 illustrate four major Eskom power plants, which are Koeberg nuclear plant, Camden power plant, Lehabo and Arnot power plants, as discussed in the next paragraph [21].

Nuclear energy currently provides approximately 11% of the world's electricity. The Koeberg nuclear power station near Cape Town, which is labelled number 4 on Figure 4, powers most of the western region and supplies approximately 4.4% of South Africa's total electricity needs since 1984 [22]. The second plant, the Camden power plant, which is number 1 on figure 4, is located in the Mpumalanga Province and was officially reopened by the national power utility, Eskom, on 21 October, after it has been decommissioned in 1988. The coal-fired Camden was initially commissioned in 1967 and adds 1520 MW power to the National Grid [22] .

Eskom's third major plant is the Lethabo power station, labelled number 2 on figure 4, which first went into commercial operation in December 1985 [22]. The plant is located in Sasolburg in the Free State Province and has an operating capacity of 3558 MW. The fourth major plant of Eskom is the Arnot power station, labelled number 3 on Figure 4. This plant is often described as Eskom's most scenic station [22]. It is situated about 220 km east of Johannesburg on the Mpumalanga Highveld and has an operating capacity of 2232 MW. South Africa relies on coal-fired plants for more than 80% of its electricity generation, while renewable sources contribute around 7% [23].

Figure 4: Location of four major power generation plants of Eskom

Figure 5 illustrates two solar farms: the De Aar solar plant and Kathu solar plant, which forms part of renewable energy in South Africa [21]. The De Aar solar power, labelled number 1 on Figure 5 is a 50 MW PV facility and is one of the first utility scale solar plants on the continent [24]. The plant is located near the town of De Aar in the Northern Cape on approximately 100 hectares of land, owned by the Emthanjeni Municipality. The plant uses 167 580 PV panels to generate electricity, which is exported into the Eskom distribution system under a 20 year power purchase agreement. De Aar solar generates approximately 85 GWh per year, supplying enough clean, renewable electrical energy to meet the annual energy needs of 19 000 average South African homes [24].

The second solar plant, the Kathu solar plant, labelled number 2 on Figure 5, is located in the Northern Cape Province. The 100 MW Kathu solar power plant accomplished its first synchronisation to the National Grid in November 2018 [25]. Kathu solar has an installed capacity of 100 MW, allowing clean energy to be supplied to 179 000 homes in the Northern Cape Province. The use of solar energy is growing at a fast rate in South Africa [25]. In 2016 solar energy contributed 2 151 GWh to the National Grid; this indicates that the use of solar energy is becoming popular in South Africa [23].

Figure 5: Location of two solar plants

Figure 6 illustrates the locations of two wind farms, which is the Amakhala Emoyeni wind farm, which is number 1 on the figure, and the Cookhouse wind farm, which is number 2 on the figure [21]. The Amakhala Emoyeni wind farm is a 134.4 MW wind farm comprising of 56 Nordex N117 P91 turbines [26]. It is situated on farmland between the towns of Cookhouse and Bedford in the Eastern Cape Province and has been operational since June 2015. The Cookhouse wind farm is one of South Africa's largest wind farms, with 66 Suzlon S88 wind turbines situated on a high ridge to the east of the Great Fish River. It does not only supply South Africa with 341 000 MWh of much needed green energy per year, it also benefits the local communities of Adelaide, Bedford, Cookhouse and Somerset East in the Eastern Cape, through its many socio-economic development programmes [26].

South Africa's first commercial wind farm to contribute directly to the National Power Grid went on line in July 2008, operating from a Western Cape region that has the potential to become the wind powerhouse of Africa [27]. The Darling wind farm, which is number 3 on figure 6, is situated near the peaceful town of Darling in the Western Cape, about 70 km north of Cape Town. This wind farm consists of four Siemens wind power turbines of 1.3 MW capacity, which together generate 5.2 MW of environment-friendly energy. The region was chosen, because it lies on the western edge of the Swartland, where ferocious winds constantly blow over the hills, building up to the Cedarberg mountain range in the north [27]. The use of wind as a source to generate electricity has been increasing rapidly, with wind power producing 18 GWh of electricity in 2013 and 2126 GWh in 2016 [23].

Figure 6: Location of wind farms

South Africa's dependence on coal to generate electricity has made it the biggest carbon emitter in Africa [28]. The department of energy (DoE) states that at present the electricity sector is responsible for 45% of the country's greenhouse gas emissions [28]. This contributed to the country's high carbon emissions intensity and has to be reduced to meet international commitments [20]. Reducing South Africa's dependence on coal for generating electricity and increasing the percentage of renewable energy sources in the country's energy mix, is a so-called low hanging fruit, a goal that must be achieved [28]. The minister of environmental affairs has to date declared three national priority areas in terms of section 18(1) of the National Environmental Management: Air Quality Act, 2004 namely [29]:

- The first priority area, the Vaal Triangle Air-Shed Priority Area (VTAPA), which covers parts of Gauteng and Free State Provinces, was declared in 2006 [29].
- This was followed by the declaration of the Highveld Priority Area (HPA), which covers parts of Mpumalanga and Gauteng Provinces in 2007 [29].
- The Waterberg Bojanala Priority (WBPA) was the third to be declared in 2012 and it compasses parts of Limpopo and the North West [29].

The Vaal Triangle is home to various large industrial companies and a number of informal settlements [30]. The declaration of the Vaal Triangle as a priority area was published in the Government Gazette of 2006 in terms of section 18(1) of the National Environmental Management: Air Quality Act of 2004. It was the first priority area in South Africa, which was declared, due to the concern of elevated pollutant concentrations within the area, being specifically particulates [30].

The declaration of the HPA came about as a results of poor air quality, due to industrial activities, domestic fuel burning, waste burning and mining activities in these areas [29]. The air pollution on the Mpumalanga Highveld has been a feature of the South African landscape since the 1950s [31]. Major towns like eMalahleni, Middelburg, Secunda, Standerton, Edenvale, Boksburg and Benoni are well known for their poor air quality. Home to Eskom's 15 coal-fired power station, petrochemical plants like Sasol's giant refinery in Secunda and other small additional industrial operations, the Highveld is one of South Africa's industrial heartlands [31].

The Minister of Water and Environmental Affairs declared the Waterberg-Bojanala priority area on 15 June 2012, as the third national priority area. The WBPA covers an area of 67 837, bordering with Botswana [32]. It includes the Waterberg District Municipality in Limpopo Province and parts of Bojanala Platinum District Municipality in the North West Province with nine local municipalities. The energy-based development initiatives in South Africa and Botswana pose a threat to the current state of ambient air quality in the region [32].

The potential of renewable energy sources to mitigate climate change was highlighted in the national climate change responses white paper, which pointed out that investments in renewable energy programmes are one of the most promising options of climate change mitigation in the electricity sector [28]. Investment in electricity generation capacity is largely motivated through the anticipated long term need for electricity [33], which should include more renewables in an effort to curb air pollution. South Africa can reach the level of 70% renewable energy share in the energy mix by the year 2040 [34].

Electricity is vital to households, businesses and municipalities [35]. South Africa has a growing population, which creates an increasing need for housing and services [33]. Over the past 10 years, global electricity generation grew at an average of 2.8% per year and totalled 24 100 terawatt hours in 2015 [36]. By far the largest consumer of power in 2015 was industry at 42%. The residential and commercial and public services sectors took 27% and 22% respectively as illustrated in Figure 7 [36].

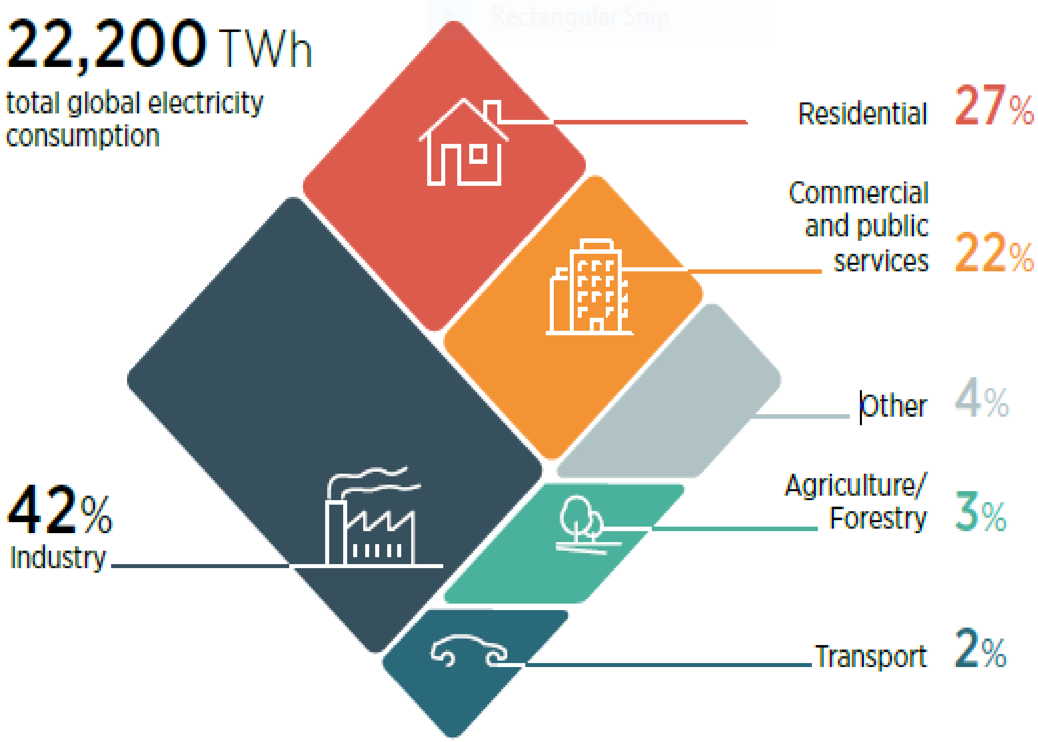


Figure 7: Global power consumption by sector [36].

In 2013, electrification rates in South Africa were reported to be 90% in urban areas and 77% in rural areas, leading to an overall electrification rate of 85%. Eskom reports that 158 016 households were electrified during the year 2015 / 2016, reaching almost 90% of all households nationwide [37]. South Africa has to consider alternative power generation strategies, such as solar and wind energies to keep up with the growing demand and to enable a better level of sustainability [38].

2.3 History and impact of load-shedding

The demand for power keeps growing at an alarming rate while supply trails behind [39]. This leads to the implementation of load-shedding initiatives to keep the country illuminated [39]. When there is not enough electricity available to meet the demand from all Eskom customers, it could be necessary to interrupt supply to certain areas; this is called load-shedding [39]. Load-shedding is defined as a coordinated set of controls that decreases the electric load in one part of the system to restore the overall system back to its normal operation conditions [40]. Frequent incidents of load-shedding remain a possibility, as much of the national electricity generation infrastructure is approaching an age at which it will need to be replaced [41].

For decades, Uganda has suffered from inadequate supply [42]. A disruptive civil war from 1971 to 1986 and decreasing water levels in Lake Victoria, the main reservoir for the country's hydro dominated electric power systems, exacerbated this problem and led to a 60% decrease in the country's available generation capacity. In 2011 the country entered a new period of prolonged and widespread load-shedding when the government, which had hitherto subsidised the cost of power from thermal generators, ceased to do so, leading to the withdrawal of thermal generation capacity. This lasted until the much-awaited Bujagali power station was commissioned in June 2012 [42].

Historically, India has relied on thermal and hydro power plants to balance the supply with demand, turning these plants up and down in response to varying demand [43]. When flexibility demands were too high for the power plants to cover, power quality dipped and outages were forced across the system. In recent years, India has reduced unplanned outages through load-shedding where system operators have planned reduced services and curtailments to groups of customers, in order to improve power quality [43].

In South Africa, when the electricity crisis first arose late in 2007, Eskom informed all municipal supply authorities and consumers that it required a 10% saving in electricity consumption [44]. In 2008, Eskom introduced load-shedding or planned rolling blackouts, based on a pre-determined rotating schedule in phases where short supply threatens the integrity of the Grid [44]. In November 2007- January 2008 load-shedding hit the country for the first time, disrupting businesses, closing mining operations and affecting households [45]. The power grid came under severe constrains during the 2013 / 2014 summer maintenance programme and Eskom implemented load-shedding in March 2014 for the first time since

2008. Eskom implemented 99 days of load-shedding in 2015, causing a decrease in manufacturing and mining output, dragging down economic growth [45].

This century should witness unprecedented growth and challenges in power generation, delivery and usage [9]. Renewable and clean alternative power generation technologies may play an important role in future power supply, due to increased global public awareness of the need for environmental protection and desire for less dependence on fossil fuels for energy production [38]. Government's plans for meeting South Africa's growing electricity demand needs are outlined in the Integrated Resource Plan for electricity (IRP) of 2010 [46]. The plan contains a long term electricity demand projection and details of how demand should be met in terms of generation sources, capacity, timing and cost [46]. The IRP (Integrated Resource Plan) foresees 42% of electricity generation, coming from renewables by 2030 [47].

2.4 Method to reduce pressure on the National Grid

South Africa's National Grid provides access to electricity for 85% of South Africa, but suffers from capacity and connection constrains [48]. South Africa currently has an aging transmission grid infrastructure and there are challenges associated with grid congestion [48]. Problems began in December 2005 when damage to the Koeberg nuclear power station resulted in power cuts in the Western and Northern Cape [49]. Methods to reduce pressure on the National Grid must be implemented, as has been done in other countries.

Mozambique has the highest electricity consumption growth in Southern Africa with demand growing to 12 % in the last five years, well above the 3 % regional average [50]. With national consumption levels at 850 MW, electricity production and supply systems are now operating at their limit [50]. Peak electricity demand of Mozambique was 530 MW in 2010 with an energy consumption of approximately 3 032 GWh [51]. The Mozambique-based assembling unit of Pico solar PV system shows local production to help solve the problem [52]. Renewable energy investment projects approved by Mozambique are large-scale biofuel projects with the aim of exporting the bulk of the biofuels produced from Europe and America [52].

Another country with high electricity demand is India, starting its journey from commissioning its first major electricity generation station in Karnataka in the year 1902 to being the 5th largest power generating country in the world [53]. India has witnessed a tremendous growth in the power sector. As the number of consumers rose, the electrical demand increased proportionately, which further led to a rise in complexity of the type of electrical loads [53]. To meet the electricity demand, India will require an assured supply of three to four times more energy than the total energy consumed [54]. Renewable energy is one of the options to meet this requirement. To date, renewable energy accounts for about 33% of India's primary energy consumption [54]. The Kamuthi solar facility in Tamil Nadu, India has a total generation capacity of 648 MW [55]. Covering 2 500 acres and consisting of 2.5 million solar panels, the site is estimated to make enough power for 750 000 people [55]. Completed in September 2016, at a cost of approximately $ 679 m, the station was built in just eight months; this is a motivation for South Africa to start investing in solar energy [55].

South Africa is endowed with some of the best solar and wind resources in the world [28]. South Africa has some of the highest solar irradiance in the world and experiences some of the highest levels of yearly horizontal solar irradiation globally. The average daily solar radiation in South Africa is between 4.5 and 6.5kWh//day ,as illustrated in Figure 8 [28].

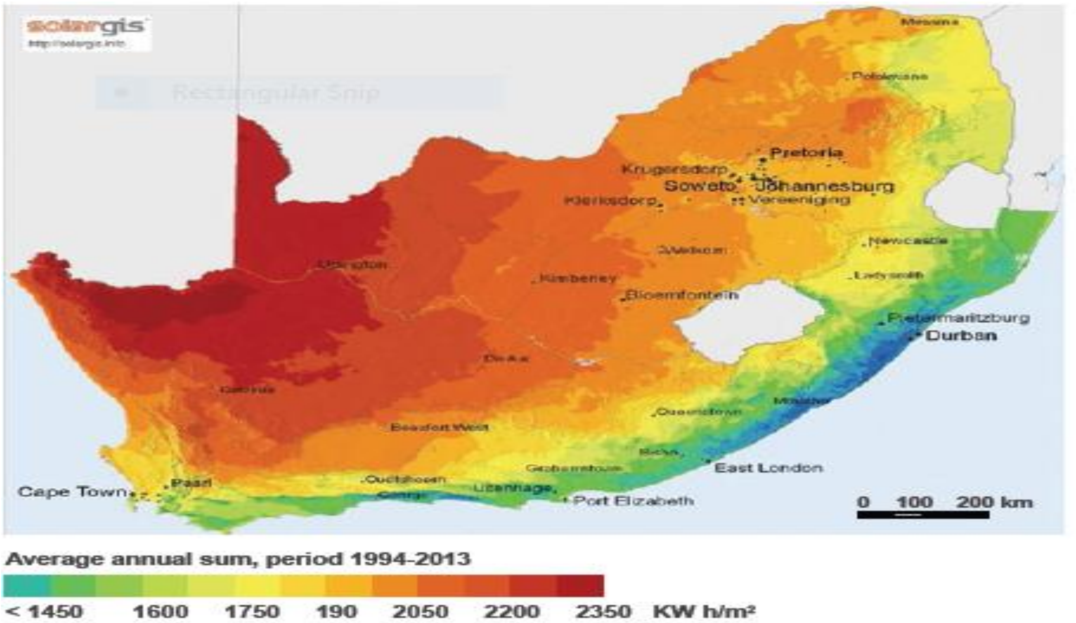


Figure 8: Global horizontal irradiation for South Africa [28].

China's wind energy industry has experienced a rapid growth over the last decade [56]. China is the world leader in wind power generation with the largest installed capacity of any nation and continued rapid growth in new wind facilities. With its largest land mass and long coastline, China has exceptional wind power resources. It is estimated that China has about 2 380 GW of exploitable capacity on land and 200 GW on the sea. In 2016 China added 19.3 GW of wind power generation capacity to reach a total capacity of 149 GW and generated 241 TWh of electricity, representing 4% of total national electricity consumption [56].

Wind power in the United States is a branch of the energy industry that has expanded quickly over the latest several years [57]. As of January 2017, the total installed wind power nameplate generating capacity in the United States, was 82.183 MW of wind power that was installed, representing 26.5% of new power capacity. Thus far, wind power's largest growth in capacity was in 2012, when 11 895 MW of wind power was installed, representing 26.5% of new power capacity [57].

In terms of South Africa's theoretical wind potential, research from the council for scientific and industrial research suggests that to generate the equivalent of South Africa's current electricity demand, only 0.6% of the available South African land mass would have to be dedicated to wind farms [28]. Figure 9 illustrates the technical theoretical potential for wind power in the southern parts of the country where red indicates the highest and blue the lowest mean wind speed [28].

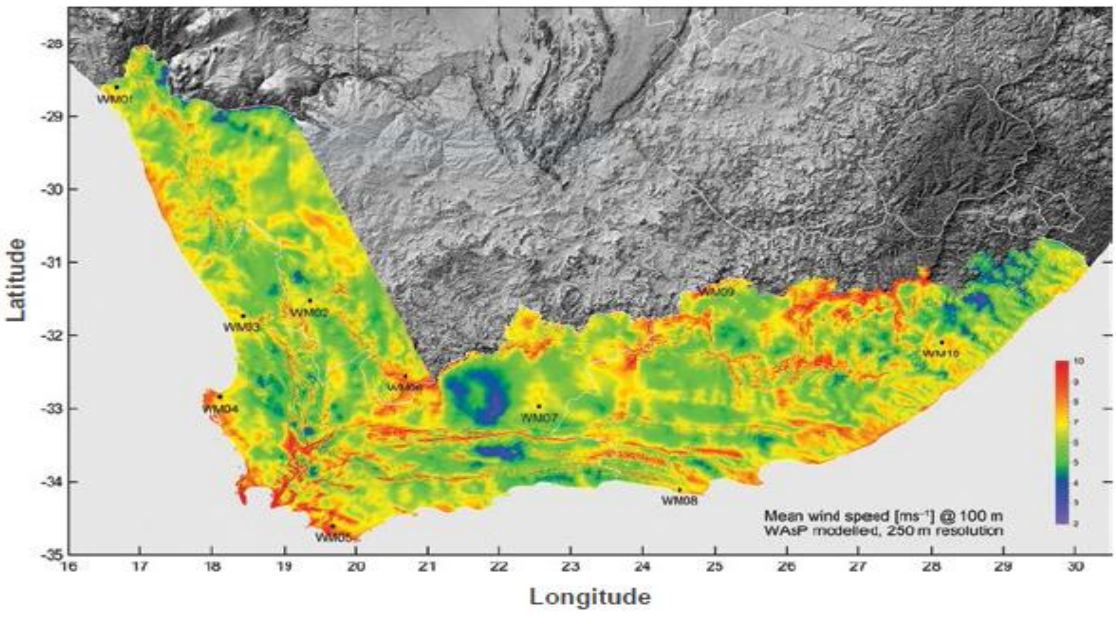


Figure 9: The theoretical potential for wind power in the southern parts of the country [28].

Renewable energy is in various ways more efficient and less challenging to utilise than fossil fuel [58]. Renewable energy sources increased at an annual average rate of 6.4% between 2009 and 2014 [36]. In 2015, renewables provided about 23.5% of all electricity generated globally, the bulk of which came from hydropower followed by wind, bioenergy and solar photovoltaic, as illustrated in Figure 10 [36].

People depend on energy for almost everything in their lives [59]. However, energy loss in any industrial process or plant is inevitable [60]. Its economic and environmental impacts are not to be taken lightly, thus explaining the need for industrial energy efficiency [60]. Energy efficiency is key to ensuring a safe, reliable, affordable and sustainable energy system for the future [61]. Wind and solar energy, in this study, were considered as possible alternative energy generation strategies to try and reduce pressure on the National Grid. However, before this can be done, an energy audit of the two towns that are considered in this research was required.

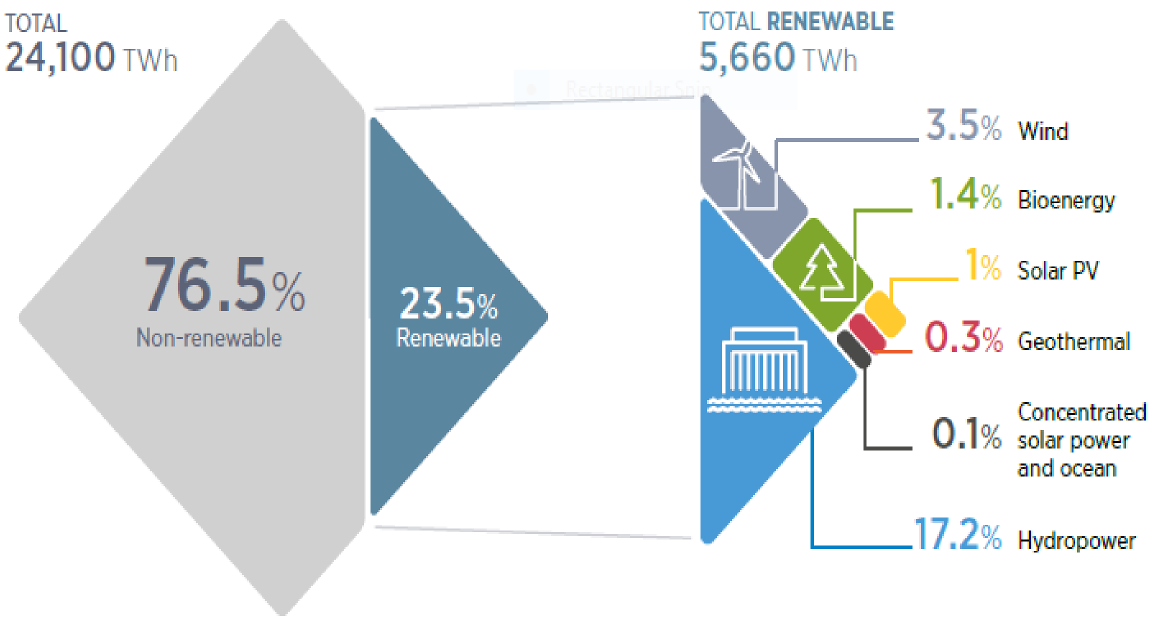


Figure 10: Global electricity generation [36].

2.5 Types of energy audits

An energy audit is defined as the verification, monitoring and analysis of use of energy, including submission of technical reports containing recommendations for improving energy efficiency with a cost benefit analysis and action plan to reduce energy consumption, as illustrated in Figure 11 [62]. An important part of energy auditing is energy accounting / bill auditing. Energy accounting is a process of collecting, organising and analysing energy data [63].

Figure 11: Energy audit [63].

For electricity accounts, usage data is normally tracked and should include metered kilowatt-hour consumption, metered peak demand and rate schedules [63]. All of this information can be obtained by analysing typical energy bills. Creating energy accounting records and performing bill audits can be done internally without hiring outside consulting firms. Energy audits assist in identifying errors in utility company bills and are for beneficial rate and service options [63].

There are three types of energy audits: preliminary energy audits, general energy audits and detailed energy audits. Preliminary energy audits are also called simple audits or screening audits or walk-through audits. This is the simplest and the quickest type of audit [64]**.** It is carried out in a limited span of time and it focuses on major energy supplies and demand. The general energy audit is called a mini audit or site energy audit or complete site energy audit. It collects more detailed information about facility operation and enables a more detailed evaluation of energy conservation measures that are identified. During a general energy audit, utility bills can be collected for a 12 to 36 months period, to allow the auditor to evaluate the facility energy / demand rate structure and energy usage profiles. A detailed energy audit is also called a comprehensive audit or investment grader audit. It expands on the general energy audit. It covers estimation of energy input for different processes, collection of past data on production levels and specific energy consumption [64].

An audit that was conducted during this research was a general energy audit where the utility bills of two towns in the Letsemeng Local will Municipality were collected and analysed that covered two years of data. The number of households and businesses were determined using Google Map and were then correlated to the monthly energy consumption or electricity sale statistics from the municipality; this helped identify which one (either households or business) consumed the most energy that has a bearing on the time of day in which the energy was used.

In determining energy demand / requirements, seasonal differences and daily peaks in electricity usage need to be considered [65]. Between 7 am and 17:00 pm there is a constant demand for electricity. The small dip at around 12 pm and 13:00 pm is probably due to a decrease in use of equipment during lunchtime. Demand peak at the end of the working day is between 18:00 pm and 21:00 pm, when electricity consumption is at its maximum in the form of lighting, stoves and television. In terms of seasons, electricity usage is approximately high in the winter season between June and August [65].

Annual weather data will also be obtained and be correlated to the monthly energy consumption data from the municipality. This will help to identify months of high energy usage when a supplement to the current energy source is really required. After compering the annual weather data with the monthly energy consumption from the municipality, an alternative power generation method will be suggested, based on the results obtained from the HOMER simulation software.

2.6 Simulation modelling using HOMER

Research related to renewable energy systems often involves different types of simulations. Simulation modelling is used in various fields to allow developers and users to present a system and examine its operations, using different possible scenarios and conditions [66]. This allows developers to determine optimal operating conditions and also to provide tools that allow them to explore various possibilities by changing procedures or conditions without actually disturbing the actual operational system [66]. With simulation software, you can minimize the need for measurements, overcome the limitations of spread sheets, run variation calculations in no time and early on ensure the functionality of your design [67]. System simulation helps one increase performance and energy efficiency of a product, optimize vibration behaviour, reduce potential risk to health and safety and back up planned investments [67].

Hybrid Optimization Model for Electric Renewable (HOMER) is a free software application developed by the National Renewable Energy Laboratory in the United States [68]. HOMER is used to simulate the operation of a system by making energy balance calculations for each of the 8 760 hours in a year, calculating the flow of energy to and from each component of the system [69]. This software can assist in the design of micro power systems and to facilitate the comparison of a generation technology across a wide range of applications [70]. HOMER allows the modeller to compare many different design options, based on their technical and economic merits. It also assists in understanding and quantifying the effects of uncertainty or change in inputs [70].

In Perlis, northern Malaysia, a study was conducted using HOMER to evaluate the performance and economic effects of a 5 MWp solar PV plant [71]. A comparison of the energy yield of solar power plant systems in Malaysia, with other global systems, shows a higher energy yield for Malaysia. The comparative study confirms the suitability of Malaysia as a solar power plant location. The solar plant, with an energy capacity of 5 MWp, began selling energy to Tenaga Nasional Berhad in January 2013 [71].

A study was conducted at Sri Lanka by an international resource group, using HOMER software to explore the role of generator sets in small solar power systems [72]. This study used HOMER to explore the threshold load size at which it is more cost effective to include a diesel generator than to increase the size of the battery bank or array. By performing multiple sensitivity analyses, the economic crossover point between these two system types was determined over a range of system sizes, solar resources, fuel prices and reliability requirements. Depending on these factors, the crossover varied from 3-13 kWh per day [72].

The successful evaluation of any renewable energy project requires appropriate criteria to be applied in the selected area to ensure that the operational behaviour of different scenarios can be analysed accurately [73]. Standalone Solar Photovoltaic (PV) systems offer a cost-effective alternative to expensive grid extensions in remote areas of the world [72]. In such applications, solar home systems provide power for a few small fluorescent lights and other small appliances. According to the survey conducted, most of the solar home systems may be quite cost effective when compared to the operation, maintenance and fuel cost of electricity from diesel generators [72].

This study explored the role of backup generators to reduce overall system costs [72]. The survey focused on Sri Lanka, because it has an extensive program of small solar home systems with continuing efforts to electrify rural areas. HOMER software simulated the operation of thousands of different system designs with and without a backup generator. It was then able to identify the least cost system as a function of load size and other variables. This survey used the results from HOMER to analyse the load threshold above which a hybrid PV / diesel / battery system becomes more cost effective than a simpler PV / battery system. HOMER made clear the sensitivity of this threshold to several factors [72].

HOMER performed three principal tasks: simulation, optimization and sensitivity analysis [70]. HOMER accepted multiple values for a particular input variable, such as the average load; the load profile is based on a hypothetical single home. Solar resources, diesel fuel prices and reliability constraints also served as input variables. Parameters for generators, converters, batteries and PV panels also served as input variables. Figure 12 illustrates a typical load profile for a home. A small base load of a 5 W occurs throughout the day. A small peak of 20 W occurs in the morning and at noon while the majority of the load occurs in the evening. This evening load with a peak of 40 W would likely include compact fluorescent lighting and a radio. The total daily load averages 305 Wh per day [72].

After running the simulation, HOMER sorted the feasible cases in order of increasing net present cost [72]. This cost is the present value of the initial, component replacement, operation, maintenance and fuel costs. HOMER listed the optimal system configuration, defined as the one with the least net present cost for each type. HOMER’s sensitivity analysis then repeated this optimization as user-defined factors, such as fuel prices, load size, reliability requirement and resource quality, which are varied [72].

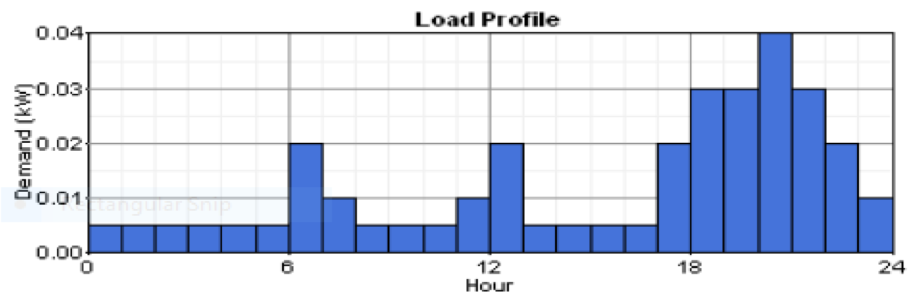


Figure 12: Hourly load profile [72].

HOMER could perform sensitivity analysis by accepting multiple values for particular input variables, such as the average load. By scaling the annual average value of kWh/d (kilowatt-hour per day), HOMER modelled the impact of increasing loads [72]. This analysis determined how changes in the input variables affected the performance of the system and the relative ranking of different systems. HOMER can be used to perform a sensitivity analysis over a large range of load sizes from a single home to a large community [72].

A solar resource was used for a site in Sir Lanka at a location of 7°30´N and 81°30´E longitude. Solar radiation data for this region was obtained from the NASA surface meteorology and solar energy web site and used as input data to HOMER. This data helped to identify which months had the highest and lowest solar radiation, which was used to help size an appropriate solar PV system. The annual average solar radiation for this area is 5.43kWh/m²/d. Figure 13 shows the solar resource profile over a one-year period. This provides insights into the effects of high solar radiation on the system type [72].

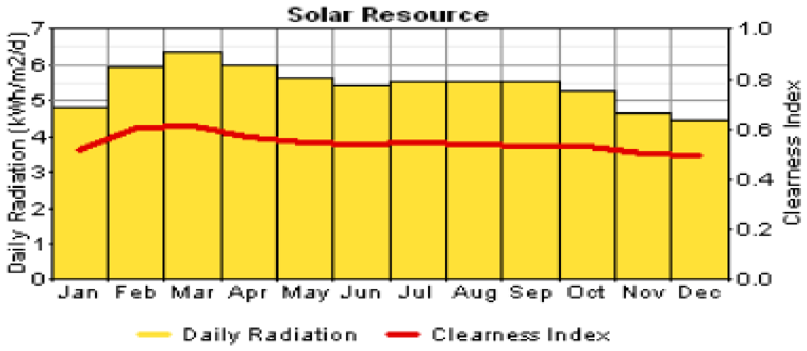


Figure 13: Solar radiation profile for Sri Lanka [72].

This study included a sensitivity analysis on the price of diesel fuel. This price can vary considering factors based on region, transportation costs and current market price [72]. Price information from both the World Bank and the international energy agency shows that average diesel prices ranged from $0.40/L to $0.70/L in 2000. Prices of $0.30L to $0.80L were evaluated in increments of $0.10L. A real annual interest rate of 6% was assumed. The search space, list of system component sizes that HOMER considered for this analysis, is outlined in Table 1 [72].

Table 1: System components considered [72].

Component	Size	Capital cost ($)	Replacement cost	O&M Cost ($)	Lifetime
PV Panels	0.05 -5.0kW	$7 500/kW	$7 500/kW	0.00	20 years
Trojan T-105 Batteries	225Ah/6 volt (bank size: 1-54 batteries)	$ 75/battery	$ 75/battery	$2.00/year	845 kWh of throughput per battery
Converter	0.1- 0.4kW	$ 1 000/kW	$ 1 000/kW	$100/year	15 years
Generator	4.25kW	$2 550	$2 550	$0.15/hour	5000 hours

PV panels were specified with capital at a replacement cost of $7.50/W. A derating factor of 90% was applied to the electric production from each panel. This factor reduced the PV production by 10% to approximate the varying effects of temperature and dust on the panels. The panels were modelled as fixed and tilted south at an angle equal to the latitude of the site [72].

HOMER simulated each system with power switched between inverter and the generator as illustrated in Figure 14. These devices were not allowed to operate in parallel. The generators were not allowed to operate at a less than 30% capacity [72].

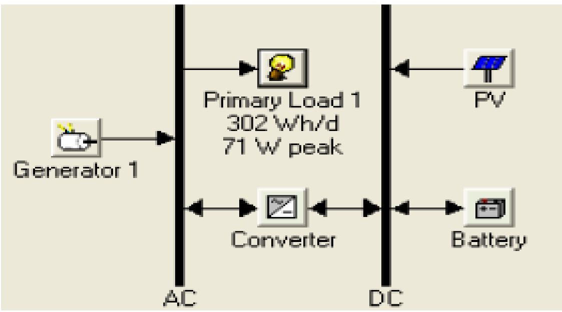


Figure 14: Equipment considered for the study [72].

As the system load increases, the cost of energy identifies specific load thresholds for different system types. Figure 15 shows the results for a system with 100% reliability, and a global solar radiation of 0.50L. The PV / battery system has the lowest cost of energy for small loads up to about 3.5kWh/d at a cost of energy of $0.85/kWh. The hybrid system is less expensive than either technology on its own, and this indicates that the HOMER programme was able to provide power for the area of Sri Lanka at affordable costs. The same principle may be applied to identifying viable alternative power generation systems to help reduce pressure on the National Grid [72].

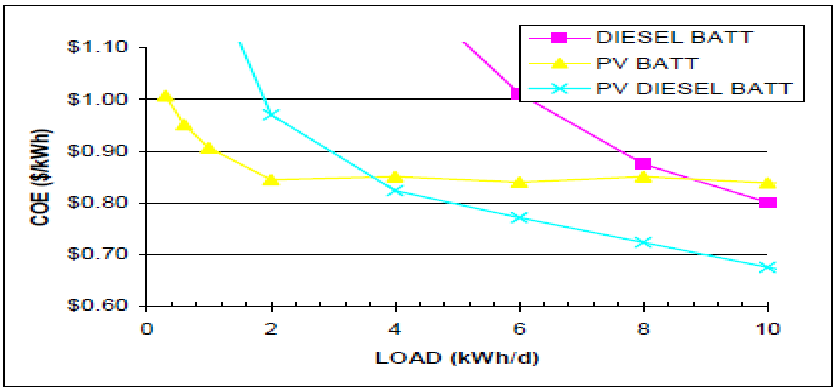


Figure 15: Cost of energy for three different system types over increasing load

2.7 The regulator code in South Africa

In South Africa, utilities (Electricity Distribution Supply Authority) are receiving an increasing number of requests from customers to allow small-scale embedded generation [74]. As given in the South African distribution network code, the utility is obligated to provide an offer to connect the embedded generator under the conditions in application for connection. Renewable electricity generation equipment, such as PV modules, small wind turbines and micro-hydro turbines has typically been considered as an off-grid technology [74].

Low voltage (LV) (400 V / 230 V) connected generators are required to follow a simpler connection process that does not require detailed network studies before connecting or using wind or solar PV energy sources [75]. The South African regulator code classifies two types of feeders to be applied for before connecting any renewable energy sources: dedicated and shared network feeders. A dedicated network is a section of the utility network that exclusively supplies single customer / generator, (a dedicated network can be a dedicated LV feeder or dedicated MV / LV feeder transformer). A shared network is a section of the utility network that supplies more than one customer / generator [75].

For the shared LV feeders, the maximum individual generating limit is approximately 25% of the customer’s NMD up to a maximum of 20 kVA (generators greater than 20 kVA should be connected through a dedicated LV feeder) [75]. The notified maximum demand (NMD) is the maximum capacity in kVA, as measured over a 30-minute integrating period per point of delivery / premises that the customer will contact Eskom for, to make it available during the time period [76]. Table 2 summarises the resulting maximum generator sizes for common domestic supply sizes. The individual limit is only dependent on the service circuit breaker rating and not the feeder After Diversity Maximum Demand (ADMD) [75].

Table 2: Maximum individual generation limit in a shared LV (400 V/230 V) feeder [75]

Number of phases	Service circuit breaker size	NMD	Maximum individual generation limit kVA
1	20A	4.6	1.2
1	60A	13.8	3.68
1	80A	18.4	4.6
3	60A and 80A	41.4	13.8 (4.6 per phase)

In shared LV feeders, any generator greater than 4.6 kVA should be balanced across phases [75]. For example, an LV customer with a 100 kVA NMD supplied through a shared LV feeder could connect up to 100 × 25% = 25 kVA of generation. Since 25 kVA is greater than the 20 kVA (maximum individual generation limit in a shared LV feeder), the maximum size to be connected is 20 kVA. Since we have three phases which are red, yellow / white and blue, each phase can connect / generate up to 4.6 kVA. This means that the 20 kVA maximum generation limit has to be three-phase connected. In addition, the total generation supplied by a shared LV feeder should be limited to 25% of the MV / LV transformer rating. For example, a 200 kVA MV / LV transformer can supply up to 50 kVA of generation supplied through LV feeders, connected to that transformer [75].

In dedicated LV feeders, the maximum individual generation limit is a function of the NMD [75]. The maximum generator size is limited to 75 % of the NMD. Generators greater than 4.6 kVA should be balanced across the available phases. Customers with dedicated single-phase supplies, supplied by a dedicated MV / LV transformer (e.g. 16 kVA MV/LV dedicated supplies in rural area) should be allowed to connect up to 13.8 kVA on that single phase, but should not exceed 75% of their NMD. The dedicated feeder cable size is limited so that the voltage rise between the point of supply and transformer busbar is limited [75].

Internationally, the grid connected market for renewable electricity generation technologies has become far more important than the off-grid market. In 2007 the global installed base of grid connected PV, was estimated to be 7.8 GW, more than twice the off-grid installed capacity [74]. The NRS-097-2 series of specification specify the minimum technical requirements for low voltage generators connected to the South African grid as aligned to the requirements of the grid connection code for renewable power plants connected to the electricity transmission system or the distribution system in South Africa [75].

Requirements given in this section should be used to evaluate low voltage generator grid interconnection application. Low voltage (400 V / 230 V) connected generators that fall within these criteria are proposed to follow a simplified connection process that will not require detailed network studies [75]. All low voltage, grid connected, generator interconnections equipment should be type test certified, complying with the minimum technical requirements of NRS 097-2-1. Simplified connection of generator sizes should be limited to 350 kVA [75].

The maximum permissible generator size of an individual, low voltage customer is dependent on the type of low voltage network and on whether the low voltage network that supplies the customer is shared or dedicated. The customer's NMD in many cases, is determined by the low voltage services connection circuit breaker. The low voltage fault level at the customer point of supply should be greater than 210 A. If the criteria in the NRS-097-2-3 standard are not met, it does not imply that the proposed generator cannot be connected, thus more detailed studies are required to access if the generator can be connected [75].

Most municipalities step down voltage from 22 kV/11 kV to 400 V. They supply their customers with a single-phase voltage of 230 V / 240 V and some of the customers using a three-phase, are supplied with 380 V / 400 V. When installing a solar PV or wind energy source to supplement the current energy source, municipalities need to install a solar PV or wind energy system that will generate a medium voltage of 400 V to be able to cater for both three-phase and single-phase customers. Municipalities are on the shared network feeder; therefore, they are allowed to connect 25 % of their NMD. Communication should be done with Eskom before installing any off-grid and on-grid energy supply to ensure that the applicant (customer) follows the regulator code [75].

2.8 Summary

Chapter 2 discussed causes of load-shedding and how Eskom is implementing it. It also discussed methods to reduce pressure on the National Grid by considering renewable energy sources. A general energy audit has to be conducted to determine the number of households and businesses within Koffiefontein and Petrusburg town, so as to correlate this to the power consumption for various months of the year. This chapter also discussed a simulation software package that can be used for this study, namely HOMER. Finally, the regulation codes from Eskom that municipalities need to follow when using renewable energy to supplement their current energy source, was given.

Chapter 3 explains how the research was to be conducted. An energy audit of the two towns, which is Koffiefontein and Petrusburg, was analysed along with the annual weather data for the past 10 years.

CHAPTER 3: METHODOLOGY

3.1 Introduction

Chapter 2 discussed the history of energy supply in South Africa, causes of load-shedding and how load-shedding is implemented by Eskom. It also considered methods to reduce pressure on the National Grid and described the value of the HOMER software program that was applied in this research.

Chapter 3 explains how the research was conducted. An energy audit was conducted in the two towns of the Letsemeng Local Municipality, which is Koffiefontein and Petrusburg. Quantitative data of the municipal energy usage for the two towns, together with the annual weather data were considered. The results of the energy audit were compared to the annual weather data in order to suggest a suitable alternative renewable energy method, based on either a wind farm or solar farm. Municipal sales statistics and weather data were used as input data for HOMER.

3.2 Location of the two towns under research

Koffiefontein is a small farming town in the Motheo and Xhariep region of the Free State Province, as indicated in Figure 16 [77]. Koffiefontein lies on the R 48, 140 km southwest of Bloemfontein. The small town of Koffiefontein is located in the Southern Free State. The town started off as a stopover spot for transport riders in the 1800's, as they travelled between the coast and burgeoning diamond fields and gold mines up north. Koffiefontein consists a population of 10 403, with a town size of 36.85 km² [78]. Koffiefontein is a major social, administrative and economic hub of Letsemeng Local Municipality. It houses the regional agricultural services centre, diamond mining operation and regional social services centre [77].

The second town under research was Petrusburg, a small mixed farming town in the Free State Province of South Africa (see Figure 16). Petrusburg lies on the N 8 between Bloemfontein and Kimberly and is connected to Koffiefontein by the R 48 road [79]. It started out as a Dutch reform church, serving the farms in 1891 [80]. When it became a town, it was originally started on a farm close to "Emmaus", a railway station on the line between Bloemfontein and Kimberly [80]. The town of Petrusburg has a population of 8 435, with a town size of 19.00 km² [78].

Koffiefontein and Petruburg's main economic activities are farming. Koffiefontein's farming activities are predominantly cattle and sheep farming, while for Petrusburg it is mixed farming, which describes a preference for sheep farming supplemented with potatoes, maize, corn and sunflower [81]. Table 3 indicates the distance of the nearest site where solar radiation data and wind speed data for these locations can be obtained.

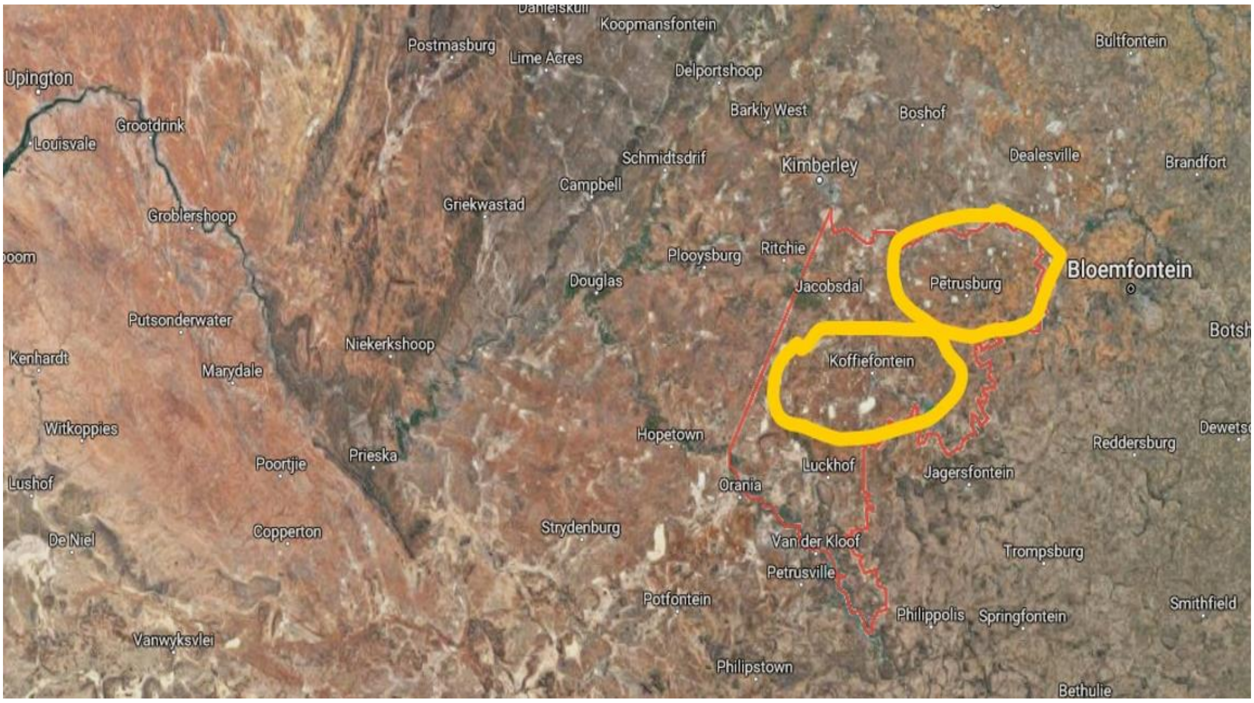


Figure 16: Location of Koffiefontein and Petrusburg town in South Africa [79].

Table 3: Sites where data was collected

Sites	Purpose of these towns	Longitude (E)	Latitude (S)	Koffiefontein (km)	Petrusburg (km)	Jacobsdal (km)	Fauresmith (km)
Koffiefontein	Area of the study	25°00'60.00"	-29°23'59.99"	-	59.2	52.8	54.5
Petrusburg	Area of the study	25°24'59.99"	-29°06'60.00"	59.2	-	82.2	76.9
Jacobsdal	Solar radiation data	24°46'13.67"	-29°07'25.99"	52.8	82.2	-	98.1
Fauresmith	Wind speed data	25°18'54.00"	29°44'56.00"	54.5	76.9	98.1	-

Figure 17 indicates sites where wind speed and solar radiation data were collected. Solar radiation data was collected from Pulida solar farm in Jacobsdal town, which is 52.8 km away from Koffiefontein and 82.2 km away from Petrusburg town. The wind speed data were collected from one of the South African weather services stations in Fauresmith town, which is 54.5 km away from Koffiefontein and 76.9 km away from Petrusburg town.

Figure 17: Site where data is collected [79].

3.3 Energy audit

A novel approach, involving Google Maps, was used to complete a basic energy audit of Koffiefontein and Petrusburg (See Figure 18). For Koffiefontein, the audit was conducted in the township and town. Indicated in Figure 18 is a section that helps to identify houses by the presence of a school in the area (see Table 4). For Petrusburg, the audit was conducted in town only, as the township is being supplied directly by Eskom. A township is a division of a country, while a town is a populated area with less people than a city, but more than a village [82]. Townships are generally much larger than towns and usually contain many towns and villages within their geographical limits [82]. The objective of the audit was to determine the number of houses and businesses within Koffiefontein and Petrusburg; this will then be correlated to the amount of electrical energy that was sold to residential and industrial businesses for the past year. A suitable supplementary method was suggested according to the information obtained from Google-Maps. The correct size of a solar farm or wind farm for either households or businesses to supplement the current energy source during months of high energy demand was then be determined.

Figure 18: Map of Koffiefontein households and businesses [79].

Koffiefontein consists of 1 246 houses in the township that were identified by the presence of a school. Schools can be identified by the presence of a sports ground or shape of the building, as indicated in Figure 19. Table 4 indicates the criteria that was used to identify houses, businesses and schools. Koffiefontein consists of a total of four schools, one located in town and three in the township. Schools are classified as businesses that run during the day only. They operate at night during school meetings and functions.

Figure 19: Identification of houses in Koffiefontein [79].

Koffiefontein consist of 33 small businesses in the township, which can be classified as businesses that run throughout the day and night, because their fridges have to be on throughout the night. The total number of businesses in Koffiefontein location is taken at 36, where three is the number of schools in the location and 33 is the number of small businesses. Table 5 indicates the results obtained after the audit.

Table 4: Identification criteria for Koffiefontein

	Criteria for identification
Houses	Schools in the vicinity
Schools	Sports ground / Shape of the building
Businesses	The presences of government buildings

Businesses were identified by the nearby presence of government departments of public buildings, as indicated in Figure 20 (Municipality). Koffiefontein consists of 76 business, which are guesthouses, butcheries, supermarkets, etc., which are classified as businesses that runs throughout the night and day, because their fridges have to be on all the time. Koffiefontein consists of 792 houses in town. Table 5 indicates the results of the audit, where the houses where counted systematically per block, with each block being crossed off the map when completed.

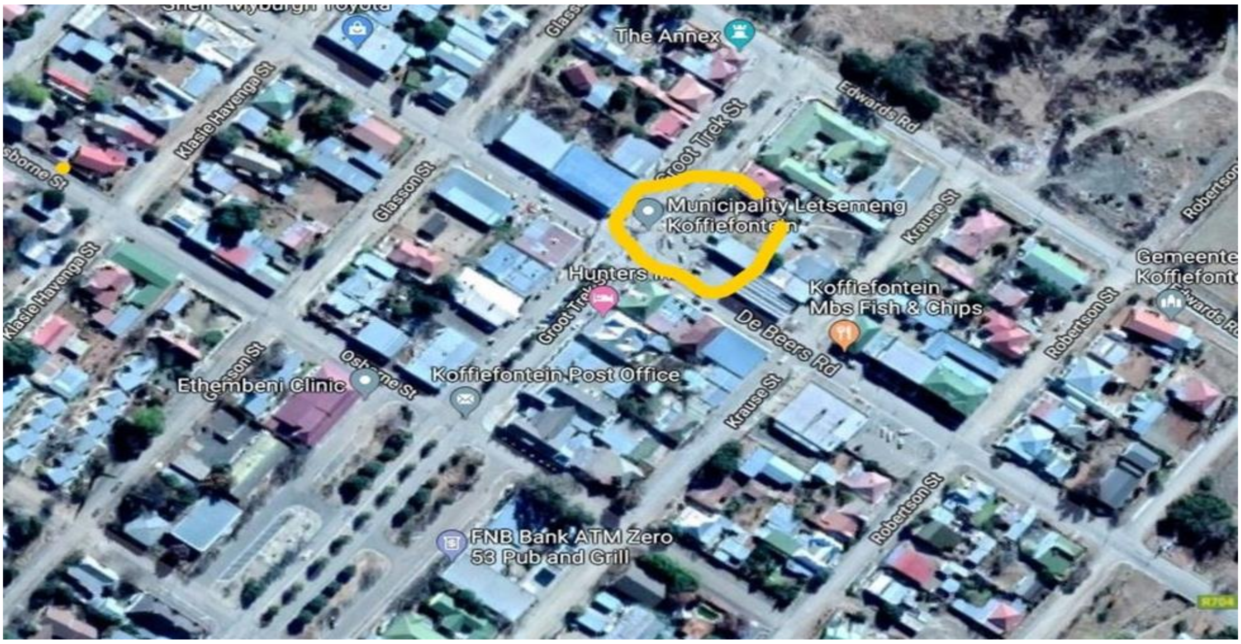


Figure 20: Identification of businesses in Koffiefontein town [79].

Table 5: Number of businesses and houses in Koffiefontein

Description	Township	Town	Total
Houses	1246	792	2038
Businesses	36	77	113

After obtaining the total number of houses and businesses in Koffiefontein from Google Map, the results of the audit were compared to the list of total number of businesses and houses that are registered on the municipal system (Syntell). The list from the municipal system indicate the meter number of each house/business with its location as indicated in Annexure A and B. Annexure A indicates businesses for both Petrusburg and Koffiefontein while Annexure B indicates houses in Petrusburg and Koffiefontein.

During the site visit, 1 house and 1 small business was chosen in Koffiefontein township in order to complete a walk-through energy audit. The aim of the energy audit was to determine the energy requirements of the house/business. During the audit, electrical equipment that are used often in the house were captured along with their power rating as indicated in Annexure C. Figure 21 indicates some of the electrical equipment that are used in a house.

Figure 21: Different electrical equipment used in an averaged sized Home in Koffiefontein

Annexure D indicates the results of the walk-through energy audit for a small business in Koffiefontein township. Indicated in Figure 22 is an example of a refrigerator that is used by a small business in Koffiefontein township.

Figure 22: Example of electrical equipment that are used by businesses.

Petrusburg consists of one school which has two hostels (boys and girls); the school is identified by the presence of a sports ground in Figure 21. The town of Petrusburg consists of 606 houses, the houses are identified by means of the schools in the area, as indicated in Figure 21. The same criteria indicated in Table 4 was followed to identify houses, businesses and schools in Petrusburg town.

Figure 23: Identification of households in Petrusburg town [79].

Businesses were identified by the nearby presence of a government department of public buildings, as indicated in Figure 22 (Magistrate). Petrusburg consists of 62 businesses in town, which are factories, supermarkets, guest houses and agricultural silos, which require electricity to run throughout the day and night. The total number of businesses is taken as 63, where one is a school and 62 are businesses in town. Table 6 indicates results obtained from Google Maps.

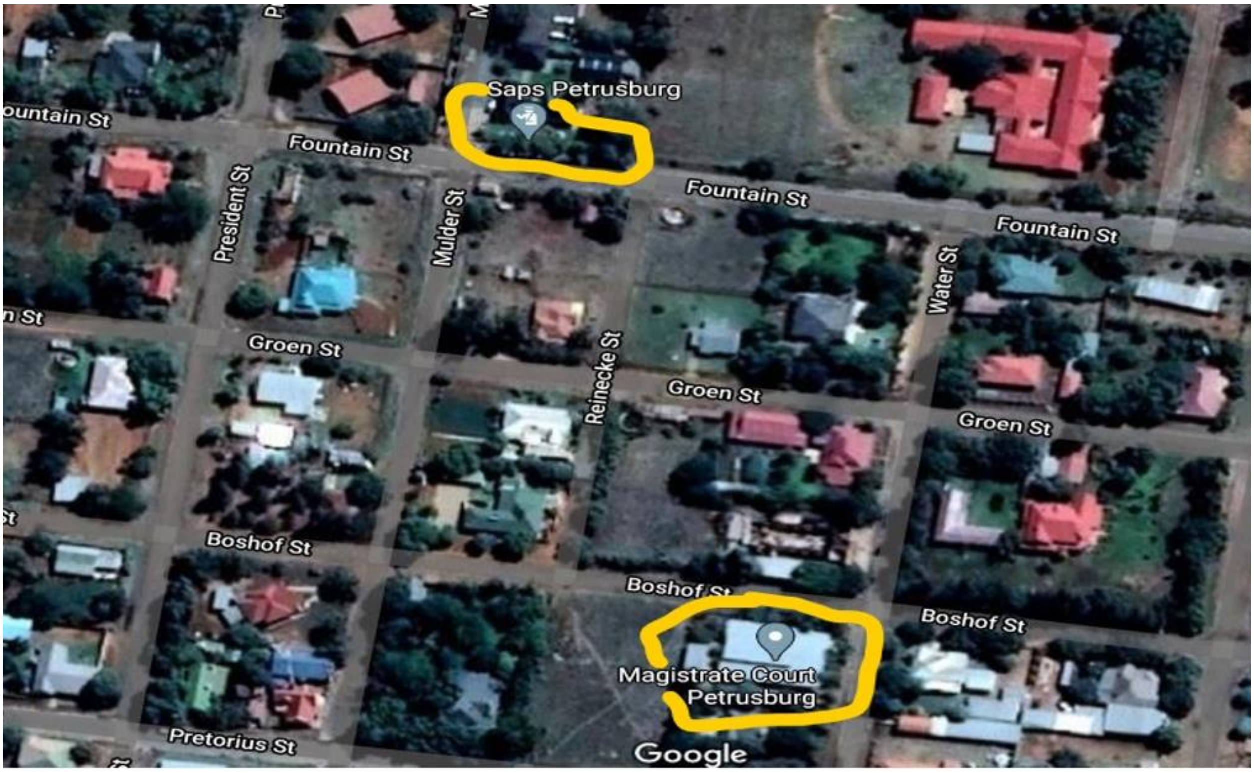


Figure 24: Identification of businesses in Petrusburg town [79].

Table 6: Number of businesses and households in Petrusburg town

Description	Township	Town	Total
Houses	NA	606	606
Businesses	NA	63	63

After obtaining the total number of houses and businesses again in Petrusburg town, the results were compared to the list of all businesses and houses that are registered on the municipal system indicated in Annexure A and B. A walk-through energy audit was conducted to determine the energy requirements of the different businesses. Business owners signed a consent form that was used during the walk-through energy audit. Indicated in Annexure E is the results of the audit. Figure 25 indicates examples of the electrical appliances that were found in the building during the audit.

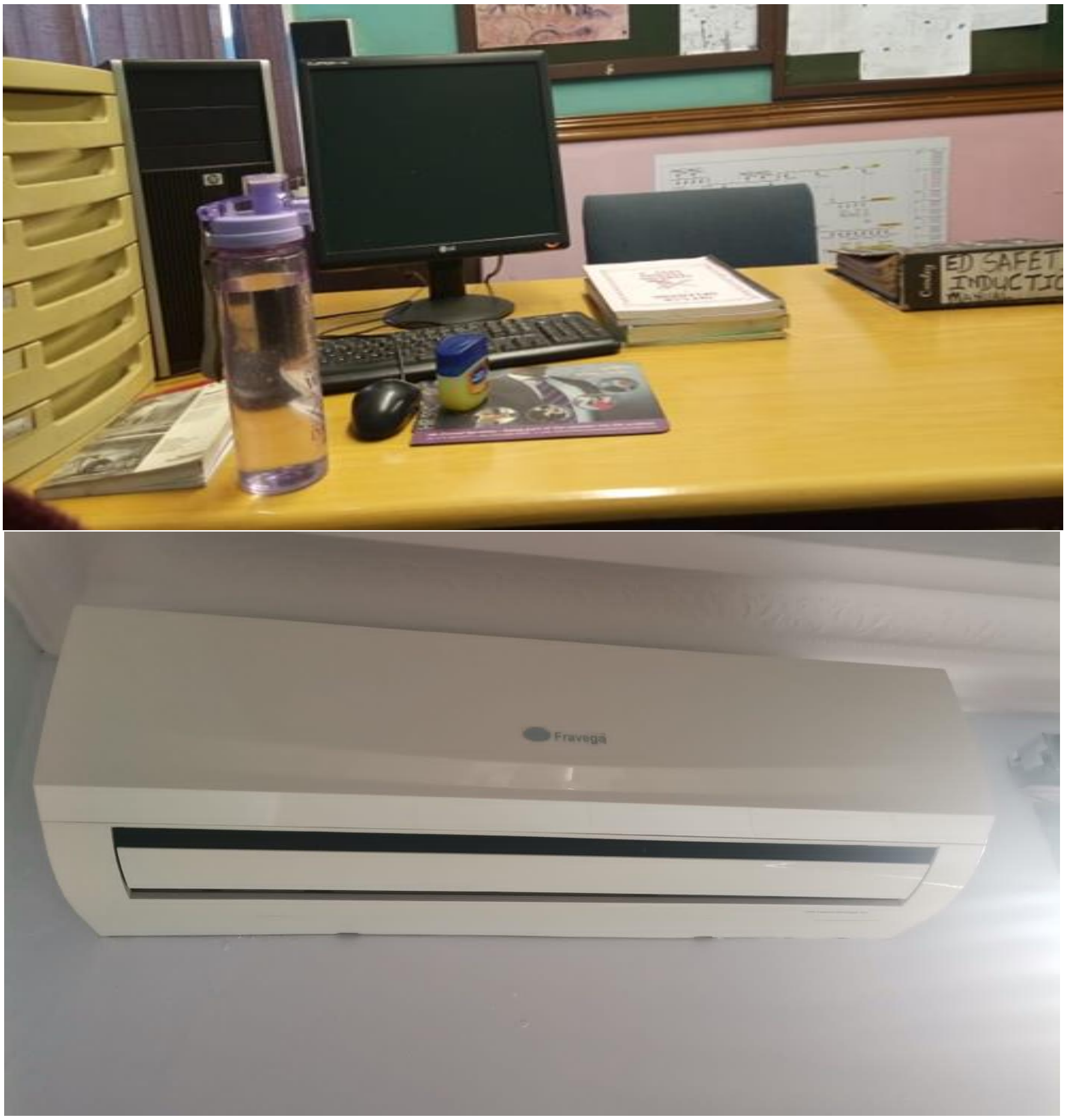


Figure 25: Example of electrical equipment found in businesses

During the energy audit, there were some Type A and Type B uncertainties that were found. Type A and Type B uncertainty are two elements that are commonly discussed in estimating measurement uncertainty [83]. Table 7 indicates the 2 types of uncertainties that were found during the energy audit.

Table 7: Type A and Type B uncertainty

Type A uncertainty	Type B uncertainty
During the walk-through energy audit, some buildings were closed therefore the researcher had to assumed that the building is still in operation.	The customer list obtained from the municipality include all municipal customers, even areas that are not part of the research e.g. Luckoff
	Some customers are registered as unknown in the system, therefore they had to be confirmed physically.
	Some buildings in the list were vandalised but still had to be counted as part of the customer list as they still have electricity meters that were registered.

3.4 Energy and cost analysis

The electricity sector is regulated by the National Energy Regulator of South Africa (NERSA), which was established in terms of the National Energy Regulator Act of 2004 [84]. Electricity generation is a dominion of Eskom, which owns and operates the national electricity grid. Eskom is a wholly owned public enterprise and although it does not have exclusive generation rights, it has a practical monopoly on bulk electricity [84].

Eskom supplies electricity to licensed municipalities in bulk at a pre-determined tariff, then the municipality re-sells electricity to the end users within their municipal borders at a mark-up [85]. The terms on which electricity is supplied by Eskom to municipalities are recorded in an electricity supply agreement. Eskom invoices municipalities monthly for the supply of the electricity in terms of the supply agreement concluded with each municipality. Figure 26 and 27 are examples of electricity bills from Eskom to a municipality. Municipalities are obligated to effect payment of all amounts owing, in terms of Section 41 of the local government [85].

Figures 26 and 27 are obtained from the main meters of Eskom at each town. Figure 26 indicates that the municipality consumed an energy worth R 3 993 953.50 for the month of June 2017. Figure 27 indicates the NMD of the municipality, which is 3300.00 kVA, as well as the energy consumption. For winter months, the energy is classified into two groups: the low and high energy season. The low and high energy season tariffs differ as indicated in the Figure 27. The low energy season is 281 588 kWh and high energy season is 1 024 721 kWh. If the municipality exceeds their NMD, they pay a penalty to Eskom and they have to apply for an NMD increase.

ACCOUNT TRANSACTION SUMMARY

ADMINISTRATION CHARGE		R	2,472.25
TRANSMISSION NETWORK CAPACITY		R	27,531.27
DIST. NETWORK CAPACITY CHARGE		R	54,639.58
DX EXCESS NETWORK CAPACITY CHA		R	18,052.73
NETWORK DEMAND CHARGE		R	94,556.35
ANCILLARY SERVICE (ALL)		R	4,572.05
ENERGY CHARGE (STD)	1,306,300.00	R	828,379.43
ELECTRIFICATION AND RURAL SUBS (ALL)		R	90,004.07
DEMAND CHARGE	3,511.19	R	568,723.30
SERVICE CHARGE		R	5,484.83
TOTAL CHARGES FOR BILLING PERIOD		R	**1,694,415.86**

ACCOUNT SUMMARY FOR JUNE 2017

BALANCE BROUGHT FORWARD	(Due Date 2017-06-10)	R	2,037,741.92
TOTAL CHARGES FOR BILLING PERIOD		R	1,694,415.86
ADJUSTMENT	Interest on overdue account	R	24,577.50
VAT RAISED ON ITEMS AT 14%		R	237,218.22

ARREARS						
>90 DAYS	61-90 DAYS	31-60 DAYS	16-30 DAYS	CURRENT		
0.00	978,951.07	1,058,790.85	0.00	1,956,211.58	TOTAL DUE R	3,993,953.50

Account OVERDUE - Subject to Disconnection

Figure 26: Amount due for monthly energy consumption

ATT CHIEF FINANCIAL OFFICER
P O BOX [redacted]
KOFFIEFONTEIN
9986

TAX INVOICE NO	982372530301
ACCOUNT MONTH	JUNE 2017
CURRENT DUE DATE	2017-07-11
VAT REG NO	4000846396
NOTIFIED MAX DEMAND	3,300.00
UTILISED CAPACITY	3,845.15

CONSUMPTION DETAILS (2017-05-25 - 2017-06-24)

ENERGY CONSUMPTION STD kWh	1,306,299.68
ENERGY CONSUMPTION ALL kWh	1,306,299.68
DEMAND CONSUMPTION - OFF PEAK	2,967.16
DEMAND CONSUMPTION - PEAK	3,511.19
DEMAND READING - KW/KVA	3,511.19
LOAD FACTOR	51.00

PREMISE ID NUMBER 9823754348 **TARIFF NAME:** Nightsave Urban kVa Interval

BULKFED KOFFIEFONTEIN 3200 KVA NIGHTSAVE URBAN

Administration Charge @ R79.75 per day for 31 days	R	2,472.25
TX Network Capacity Charge 3,845.15 kVa @ R7.16 : = R7.16/kVA	R	27,531.27
Network Capacity Charge 3,845.15 kVA @ R14.21 : = R14.21/kVA	R	54,639.58
Number of Events: 4	R	0.00
NMD Exceeded by 211.19 kVA	R	0.00
Excess Network Capacity Charge 844.77 kVa @ R21.37 : = R21.37/kVA	R	18,052.73
Network Demand Charge 3,511.19 kVA @ R26.93 : = R26.93/kVA	R	94,556.35
Ancillary Service Charge 1,306,300 kWh @ R0.0035 /kWh	R	4,572.05
Low Season Energy Charge 281,588 kWh @ R0.5193 /kWh	R	146,228.65
High Season Energy Charge 1,024,712 kWh @ R0.6657 /kWh	R	682,150.78
Electrification and Rural Network Subsidy 1,306,300 kWh @ R0.0689 /kWh	R	90,004.07
Energy Demand Charge 3,511.19 kVA @ R201.03 :(for 24 of 31 days) = R155.636129 /	R	546,468.02
Energy Demand Charge 3,511.19 kVA @ R28.07 :(for 7 of 31 days) = R6.3383871 /kVA	R	22,255.28
SERVICE CHARGE	R	5,484.83
TOTAL CHARGES	R	1,694,415.86

Figure 27: NMD and energy consumption

Figure 28 and 29 indicate the energy consumption bill for Koffiefontein and Petrusburg town respectively; the energy consumption is for businesses and houses. There are two methods of charging for energy, either by means of a metered supply or by means of a monthly energy charge [76]. The supply may be metered on either the home power or the business rate tariff. The choice of tariff depends on the consumption of the supply [76]. The total energy consumption of the two towns was collected from 2016 to 2017, using such bills. This data were obtained from the municipal sales statistics and were used to obtain the highest electricity consuming area between households and businesses and the months of high energy consumption. Figure 26 and 27 indicate the total energy that the municipality consumed from Eskom, including energy losses, due to faulty meters and electricity theft (Low and high season energy charge).

Figure 26 indicates that for June 2017, the low energy season consumed by Koffiefontein was 281 588 kWh and the high energy season consumption was 1 024 721 kWh for the same town, and this gives a total of 1 306 300 kWh energy consumption for Koffiefontein. This amount includes power losses. This value can be derived from Figure 28 by summing the energy consumption for businesses, which was 435 436.33 kWh and houses, which was 870 498.67 kWh during the month of June 2017. Values of energy consumption for both houses and businesses were obtained from Syntel, which is a municipal system used to a generate resets code, sell electricity and generate sales statistics reports. Figure 29 indicates that for the month of June 2017, Petrusburg businesses consumed 337 735.33 kWh energy, while houses consumed 169 045.67 kWh energy, and this led to a total of 506 781 kWh energy consumption for the month of June 2017.

From the municipal system (Syntel), the municipality can see how much energy was sold and how much turned into energy losses. The municipality can also see if what they bought from Eskom equals what they sold to their consumers. Results obtained were to be compared to the annual weather data to determine a suitable renewable alternative strategy that will be able to provide for the energy needs of these two towns.

Figure 29 indicates that there was low energy consumption in 2017 in the Petrusburg town from January 2017 onwards. This may be due to some of the businesses / buildings not being in operation, due to the place being on sale, guest houses not attracting enough guests, factories not producing a high number of products, due to an economic downturn and some of the businesses being disconnected from the supply, due to their accounts not being paid.

From Figure 28 and 29 the researcher wanted to obtain months of high energy consumption for houses and businesses. Electricity losses due to faulty meters and electricity theft were not considered. Table 8 indicates months of high energy consumption for Koffiefontein and Petrusburg town.

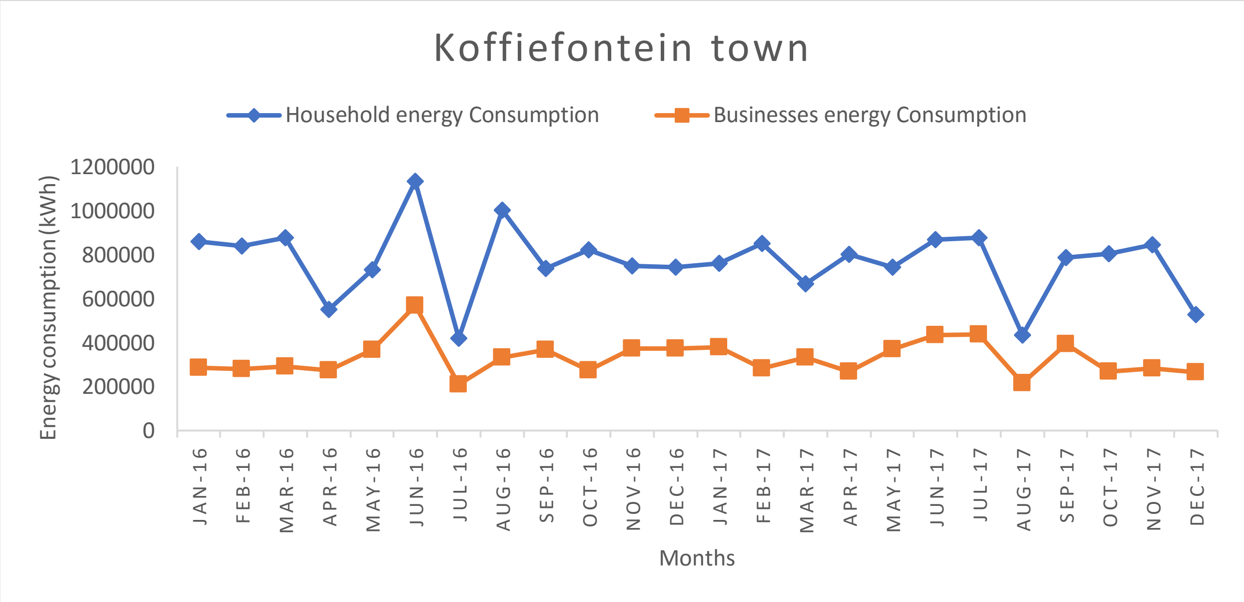


Figure 28: Total energy consumption of Koffiefontein town which has a population of 10 403

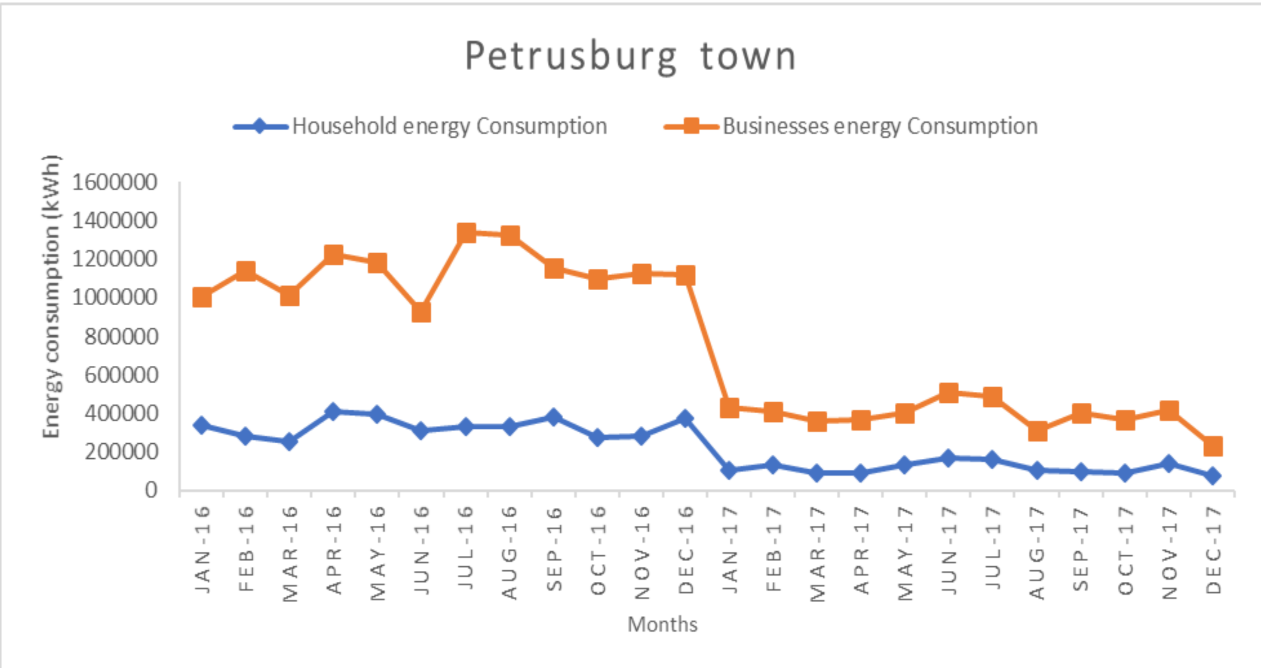


Figure 29: Total energy consumption of Petrusburg town, which has a population of 8 435

From Table 8, June 2016 had the highest electricity consumption of 1 135 572.98 kWh for Koffiefontein houses. This may be due to the June month being very cold, where people use heaters for long hours, and electric blankets, etc. to keep warm. August 2016 was the highest electricity consuming month for Petrusburg businesses with a value of 1 002 048 kWh. This may be due to heaters being used at the offices, electric kettles being used from time to time for making tea, as well as keeping geysers on for a long time to ensure that the water is warm enough for bathing at guest houses. The size of the alternative energy system should consider the month of June 2016, which was the highest electricity consuming month of Koffiefontein and the month of August 2016 which was the highest electricity consuming month for Petrusburg town.

Table 8: Months of high energy consumption for Koffiefontein and Petrusburg town

Location	Number of people, houses and businesses	Months of high energy consumption	Year	Households or businesses	Energy consumption (kWh)
Koffiefontein	People = 10 403 Houses = 2038 Businesses = 113	March	2016	Households	877 627.5
		June	2016	Households	1 135 572.94
		August	2016	Households	1 002 308.75
		February	2017	Households	851 685.25
		April	2017	Households	803 310.25
		July	2017	Households	877 041
		November	2017	Households	845 753.5
	Total	7			6 393 299.46
Petrusburg	People = 8435 Houses = 606 Businesses = 63	February	2016	Businesses	855 985.25
		July	2016	Businesses	990 892.25
		August	2016	Businesses	1 002 048.75
		November	2016	Businesses	843 143.25
		June	2017	Businesses	337 735.33
		July	2017	Businesses	323 987.33
		September	2017	Businesses	303 572.25
	Total	7			4 657 363.91

3.5 Temperature analysis

The most important variables in a solar energy are solar irradiance and surface air temperature, compared with other climatic and environmental factors [86]. The changes of solar radiation intensity are proportionally related to PV power output, whereas increasing air ambient temperature negatively affects PV energy output. A good understanding of climate changes and projected trends of these two variables is very important for policy-makers and / or industry managers to undertake planning projects of installing solar cells in a considered locality [86]. Therefore, temperature fluctuations need to be known before suggesting a variable alternative power generation strategy to the municipality. The research needed to keep in mind a change in temperature, because it is one of the factors that may affect the PV energy output.

Figure 27 presents the maximum average temperatures over a period of 10 years. This data were obtained from 2008 to 2017. To obtain the average temperature for each month, data for each month of January in the 10-year period were summed-up and then divided by the total number of the months. Figure 30 presents the results of the following equation used:

$$\text{Month} = \frac{2008+2009+2010+2011+2012+2013+2014+2015+2016+2017}{10} \quad (1)$$

$$\text{January} = \frac{29.8+31.8+28.3+28.4+33.3+33+33+32.9+32.6+29.5}{10}$$

$$= 31.26^{\circ}\text{C}$$

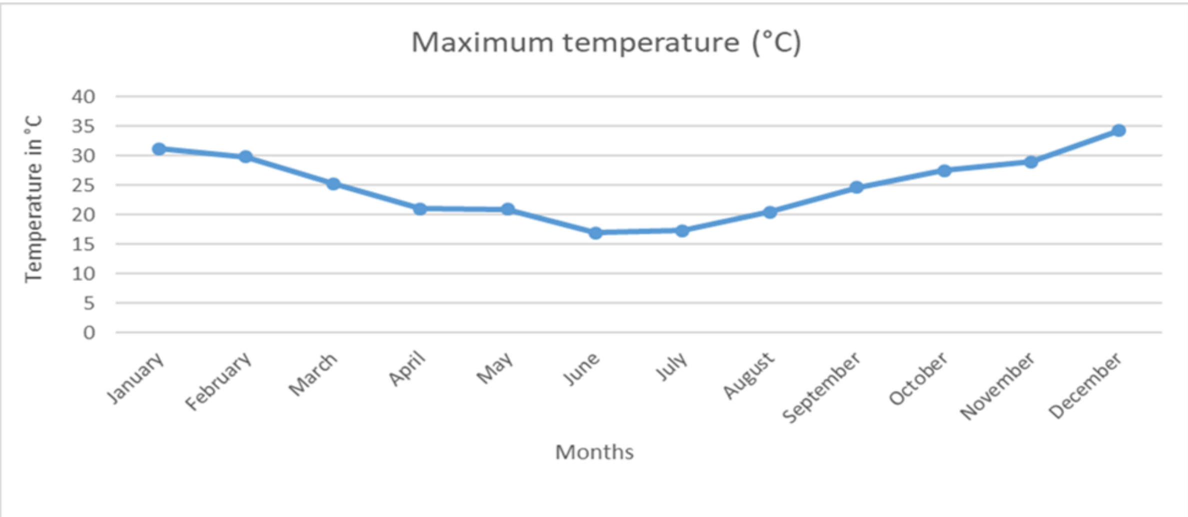


Figure 30: Maximum average temperature for the past 10 years (2008-2017) from Fauresmith

3.6 Wind analysis

Wind energy development has been thriving both in India and around the world [87]. Wind speed is a crucial element in projecting turbine performance and a site's wind speed is measured through wind resource assessment prior to a wind system's construction [88]. Generally, annual average wind speed greater than 4 m/s (9 mph) are required for small electric wind turbines (less wind is required for water-pumping operations). Utility scale wind power plants require a minimum average wind speed of 6 m/s (13 mph). The power available in the wind is proportional to the cube of its speed, which means that doubling the wind speed increases the available power by a factor of 8. Thus a turbine operating at a site with an average wind speed of 12 mph, will generate about 29 % more electricity than one at an 11 mph site [88].

Figures 31, 32 and 33 indicate the average wind speed for a 10-year period (2008 through 2017), representing different times of the day. This data can help to suggest if a wind renewable energy system would be able to supplement the current energy needs of the two towns. Figure 31 indicates the average wind speed data obtained at 08:00 am. Equation 1 is used to calculate the average wind speed.

$$\text{January} = \frac{3.2+2.9+2.8+3.2+3.5+3.8+3.2+2.9+3.1+3}{10}$$

$$= 3.6 \text{ m/s}$$

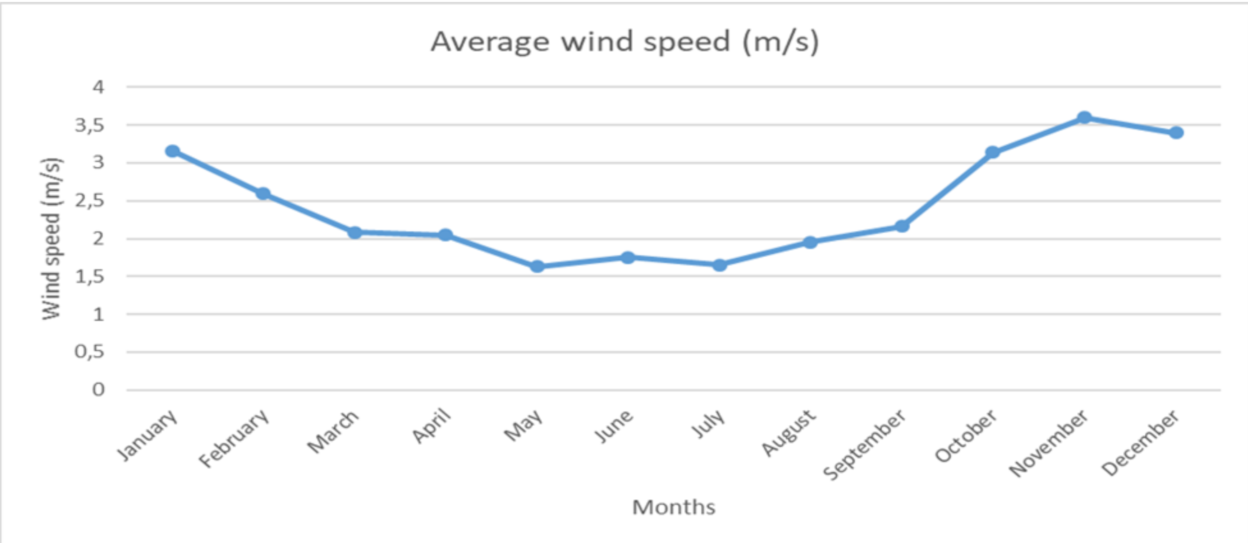


Figure 31: Average wind speed at 08:00 am from Fauresmith

Figure 32 indicates the average wind speed obtained at 14:00 pm during the day. This data were also collected for the same time periods stated in Figure 28. To obtain the average wind speed, equation 1 was used for each month of the year.

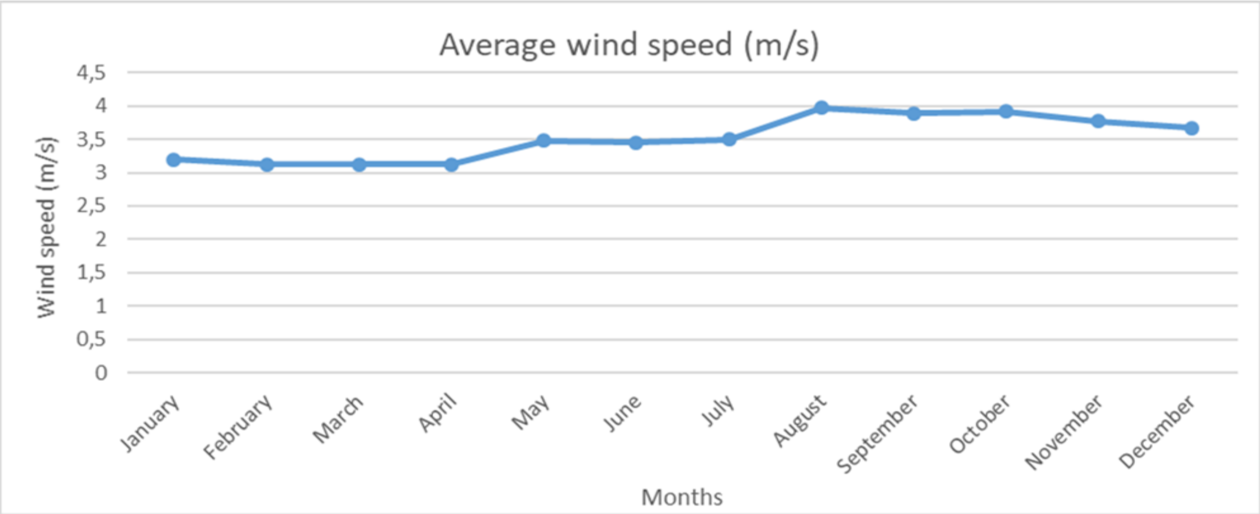


Figure 32: Average wind speed at 14:00 pm from Fauresmith

Figure 33 indicates the average wind speed obtained at 20:00 pm. To obtain the average wind speed data, equation 1 was used again to calculate the values for this figure.

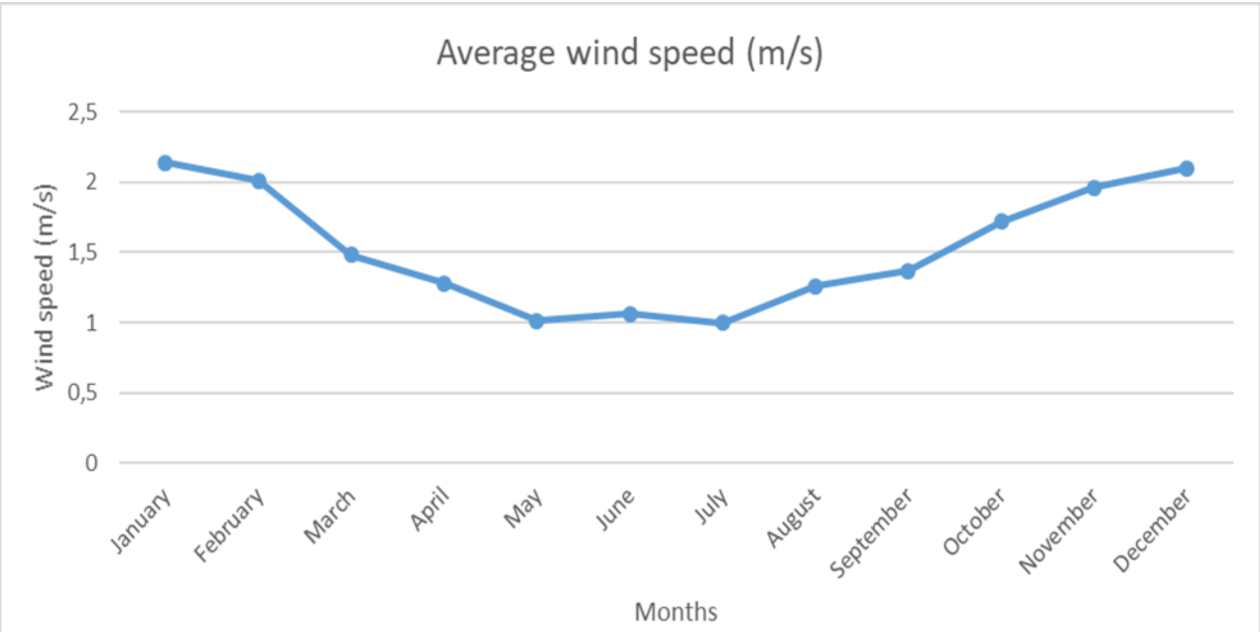


Figure 33: Average wind speed at 20:00 pm from Fauresmith

3.7 Solar radiation analysis

Solar energy is a promising renewable energy resource and an economical alternative to fossil fuels that can play a critical role in achieving green policy objectives and resolving energy crisis issues [89]. The importance of solar energy is marked by the fact that the current global installed capacity of solar PV generation is around 505 GW [89]. Figure 34 indicates the solar radiation data, both incline and horizontal data for the past two years (2017-2018) that was obtained from the Pulida solar plant, located about 20 minutes' drive outside Jacobsdal, a small rural village in the Free State Province of South Africa. The Pulida plant serves as an economic growth and tourism development node and is situated approximately 45 km northwest of Koffiefontein.

Access to the town is gained from the R 12 route between Koffiefontein and De Aar [90]. This plant is in a vast and isolated area, which has always been home to a few farms and several animal breeders. The plant is near the Kalahari Desert, a complex environment, which is certainly very appropriate for hosting a solar plant [90]. To obtain the average horizontal and incline irradiation for January, data from 2017 and 2018 were added and then divided by two.

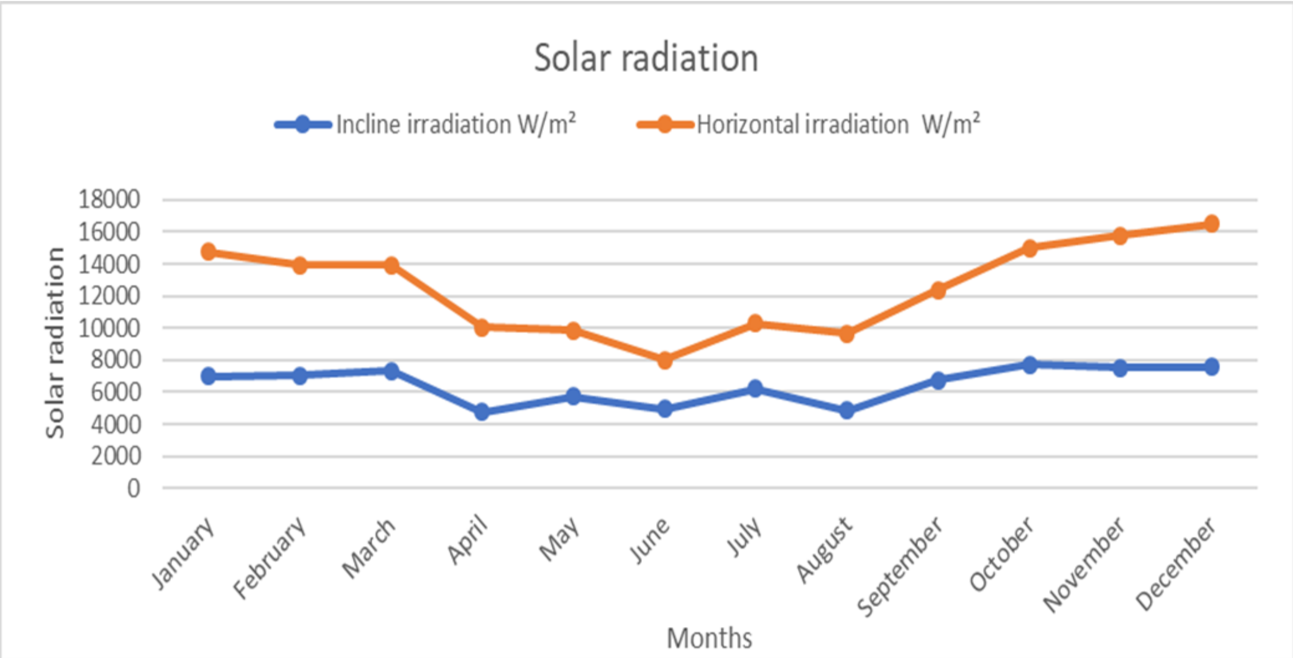


Figure 34: Solar radiation data from Jacobsdal

In chapter 2, it was stated that the notified maximum demand (NMD) is the maximum capacity in kVA, as measured over a 30 minute integrating period per point of delivery / premise, that a customer has to contract Eskom with to make available all the time [76]. The NMD for Koffiefontein town is 3300.00 kVA from January 2016 till December 2017 with an utilised capacity of 3 845.15 kVA. The utilised capacity was higher than the NMD, because the municipality had exceeded their NMD and needed to make an application of NMD increase to Eskom. The NMD for Petrusburg town was 1600.00 kVA from January 2016 till December 2017 with an utilised capacity of 1600.00 kVA.

Before connecting any renewable electricity generation equipment, such as PV modules or small wind turbines, the municipality needs to make an application to the electricity distribution supply authority [74]. It was stated in chapter 2, for the shared LV feeders the maximum individual generating limit is approximately 25 % of the customer's NMD, up to a maximum of 20 kVA. It was also stated that a generator greater than 20 kVA should be connected through a dedicated LV feeder.

In the dedicated LV feeder, the maximum generator size is limited to 75 % of the NMD [75]. Therefore, HOMER was used to determine the size of the solar or wind turbine needed to meet the electricity demand of Koffiefontein and Petrusburg during their high electricity demand months, and then apply the regulator code. Table 9 indicates the current NMD and the proposed renewable energy system size that needs to be used in HOMER. The renewable energy size was proposed based on the high consuming areas between households and businesses in both towns.

Table 9: HOMER proposed renewable energy system size

	NMD (kVA)	Proposed renewable energy size (kVA)
Koffiefontein	3300	1420
Petrusburg	1600	1200

3.8 Input data for HOMER

The HOMER software can simulate, analyse and model renewable energy or hybrid power systems that can include generation, cogeneration, solar / PV systems, batteries, wind turbines, micro turbines, hydropower and fuel cells among other inputs [91]. The software can be used to design, analyse and model micro-power and hybrid power system configurations with various energy resources for economic and sizing to determine the optional combination of them to meet the load demand and the user requirement.

The HOMER program was used for simulating the output power of the two strategies (solar and wind) with the given weather data from the previous sections. The proposed system was either battery-based solar PV system or battery-based wind turbine system. The battery was employed as energy storage system, in order to ensure uninterrupted power and to maintain the desired power quality at the load point, because of unpredictable variations if the climatic condition affects nature of the renewable source [92].

Figure 35 shows the basic architecture of the HOMER software package. It shows the calculation results of the number of cases of different renewable energy sources under weather conditions, load demand, capacity ranges, fuel costs and carbon emission constraints to select the optimum system [91].

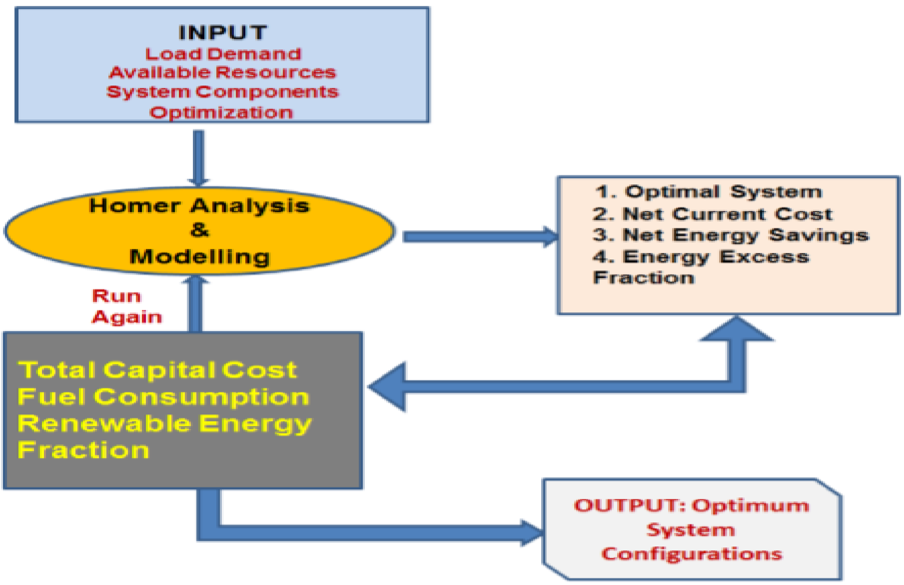


Figure 35: HOMER software package architecture [91].

3.8.1 Load profile for Koffiefontein town

An important consideration of any power generation system is load requirements and characteristics, not only for the load itself, but also for the efficiency and reliability of power transmission. The load factor for the project is important in the design process. The peak load requirement decides the size, structure and architecture of the proposed system [91].

Load profiling also plays a vital role in the design of profitable demand programs by providing necessary information about individual customers, such as their electrical consumption pattern [93]. Many people work 7 days a week so as to support themselves, therefore it is assumed that the electricity consumption during the week and on weekends will remain the same

To obtain data needed to design the systems in HOMER, an energy audit was conducted in Koffiefontein. The energy audit revealed that households consume a lot more energy than businesses in Koffiefontein as indicated in Figure 28. The determination of residential load profiles and electric power consumption has an effect on the accuracy of demand response studies [94]. Table 10 indicates typical appliances to be supplied for an average sized home in Koffiefontein. This information was obtained during the walk-through energy audit indicated in Annexure A. The microwave was not included in Table 10 because not all houses in the township has a microwave.

HOMER compared the electric demand in an hour to the energy that the system can supply in that hour and then calculated the flow of energy to and from each component of the system [91]. June 2016 had the highest energy consumption for Koffiefontein households, therefore the results obtained for June 2016 (total energy consumption of 1 135 572.98 kWh from Table 5) were used to create a daily load profile for HOMER. Electricity consumption data obtained from the municipality were in months. To convert the energy consumption to daily consumption it was firstly converted to weekly consumption using equation 2.

$$\text{Weekly energy consumption} = \frac{Monthly\ energy\ consumption\ (kWh)}{4\ Weeks} \qquad (2)$$

$$= \frac{1\ 135\ 572.98}{4}$$

$$= 283\ 893.245 \text{ kWh}$$

$$\text{Daily energy consumption} = \frac{Weekly\ energy\ consumption\ (kWh)}{7\ days}$$

$$= \frac{283\ 893.245}{7}$$

$$= 40\ 556.\ 171 \text{ kWh}$$

The daily energy consumption was then divided by the total number of houses in Koffiefontein town to obtain the daily energy consumption of an average sized house as indicated in Table 10.

Daily energy consumption of an average sized home= $\frac{40\ 556.171}{2038}$

=19.9 kWh

In the mornings from 06:00 am to 08:00 am, when people start preparing for work and children start preparing for school, the energy usage increased. During the day when most of the consumers were at work, the usage decreased. Energy usage is likely to increase again between 14:00 pm and 15:00 pm during the day when most people start preparing for lunch. When most of the people are back from work and school (between 17:00 pm and 21:00 pm), televisions are on, cooking takes place and laundry is being done and the energy consumption increases again. Figure 36 illustrates energy usage of an averaged house in Koffiefontein township.

From Table 5, Koffiefontein consist of 2038 houses, of which 792 are houses in town and 1 246 are houses in the township. The daily usage of an average household in Koffiefontein town was used to design a 24-hour electricity consumption required as input data for HOMER and is illustrated in Figure 36. The load peak demand for the average house in Koffiefontein township is 2 kW. When summing-up the hourly usage for 24 hours as indicated in Figure 36, then a total daily energy consumption of 19.9 kWh was obtained

Table 10: Typical load profile for an averaged sized home in Koffiefontein.

Appliances	Wattage	Hours assumed that the appliance will be on	Watt-hour
Television	300	5	1500
Fridge	100	24	2400
Hot plate stove	1200	3	3600
Lights (Incandescent)	100	6	600
Electric kettle	1200	0.5	600
Iron	1200	0.5	600
Fan	800	2	1600
Heater	3000	3	9000
Total			19 900

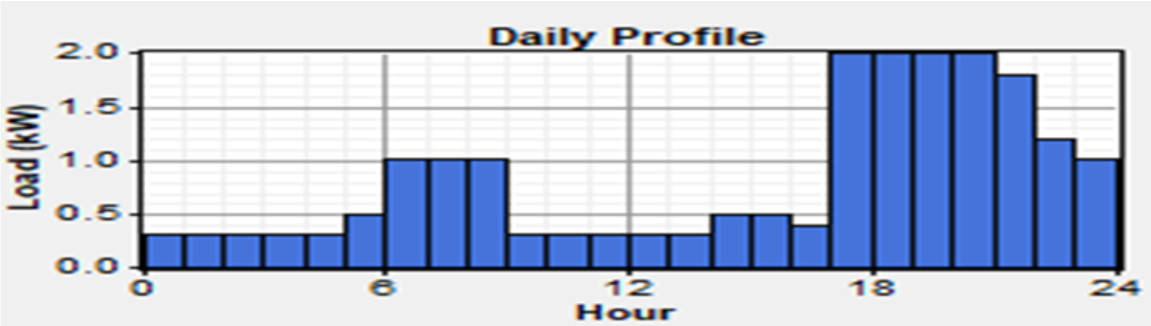


Figure 36: Hourly energy consumption of an average sized home in Koffiefontein township

3.8.2 Load profile for Petrusburg town

Table 11 shows detailed information of typical appliances to be supplied for different businesses in Petrusburg town, where the daily load profile was generated for different appliances assumed to consume power for different businesses in town. The information in Table 11 was obtained during the walk-through energy audit. These businesses include businesses such as salons, guest houses, factories, municipal offices, etc. From Table 8, it is indicated that August 2016 was the month in which Petrusburg had the highest energy consumption. The energy consumption for businesses during this month was 1 002 048.75 kWh. The HOMER program required daily electricity consumption; therefore, equation 2 was again used to convert the energy consumption to daily consumption.

$$\text{Weekly energy consumption} = \frac{1\ 002\ 048.75}{4}$$

$$= 250\ 512.2 \text{ kWh}$$

$$\text{Daily energy consumption} = \frac{250\ 512.2}{7}$$

$$= 35\ 787.5 \text{ kWh}$$

To obtain an example of daily energy usage, Table 11 indicates typical appliances to be supplied over a 24 hour period for one business. The daily energy usage was divided by the total number of businesses in this town.

$$\text{Example of daily usage for one business in Petrusburg town} = \frac{35\ 787.5}{63}$$

$$= 568.1 \text{ kWh}$$

The daily energy consumption of one business in Petrusburg town was then divided into 24 hours, in order to obtain the daily profile, as indicated in Figure 37. To keep the stock fresh, refrigerators are kept on for 24 hours. At the guesthouses they are likely to use fridges in the guest rooms. At the factories where they keep the onions, the air conditioner is kept on for 24 hours to ensure that the onions stay fresh. To supply water to the community, the municipality requires a water pump motor, which will operate during some hours of the day and some hours of the night in order to supply water to the community.

Some people may use their laptops at work, some at home to do their schoolwork or finish up their work after hours, hence it will be in operation for longer hours. The heater is used for long hours, because it may be switched on from 08:00 am till 17:00 pm in the office to keep warm. At guest houses some may use it to keep warm while watching television or to keep the room warm while bathing. The energy consumption is likely to be high from 07:00 am till 17:00 pm when most of the businesses are in operation, as computers will be on, food will be prepared at guest houses, salons will be using hair dryers, etc. The load peak demand for businesses in Petrusburg town is 36.2 kWh, and the load peak demand is obtained during high energy demand hours, which should be from 09:00 am when most of the businesses are in operation. When summing-up the hourly usage for 24 hours, as indicated in Figure 37, a total daily energy consumption of 568.1 kWh is obtained for one business in Petrusburg town.

Table 11: Example of typical appliances to be supplied for different businesses over a 24 hour period in Petrusburg town.

Appliances	Wattage	Hours assumed that the appliance will be on	Watt-hour
Computer	500	10	5000
Laptop	175	15	2625
Printer	100	14	1400
Electric Kettle	2000	3	6000
Heater	3000	18	54 000
Lights	100	8	800
Furnace 3/5 HP fan	875	12	10 500

Swimming pool motor (Guesthouses)	1200	5	6000
Geyser (Guesthouses)	4500	6	27 000
Hair dryer (Guesthouses and salon)	1500	16	24 000
Vacuum cleaner	1500	4	6000
Washing machine (Guesthouses)	1150	12	13 800
Clothes dryer (Guesthouses)	5750	13	74 750
Iron (Guesthouses)	1400	1	1400
Television (Guesthouses)	350	8	2800
Electric blanket (Guesthouses)	200	10	2000
Coffee maker (Guesthouses)	1500	4	6000
Toaster (Guesthouses)	1600	4	6400
Blender (Guesthouses)	500	4	2000
Microwave (Guesthouses and offices)	1723	3	5169
Dish washer (Guesthouses)	1500	6	9000
Fridge (Guesthouses)	1200	18	21 600
Stove (Guesthouses)	3300	8	26 400
Hydro boil (Guesthouses)	2400	20	48 000
Garage door opener	550	20	11 000
Security systems	180	24	4320
Electric sensor door	100	24	2400
Refrigerator	1200	24	28 800
Air conditioner (Central AC 4000BTU)	6000	24	144 000
Sewing machine	180	10	1800
Water pump motor (Municipal water plant)	1100	12	13 200
Total			568 164

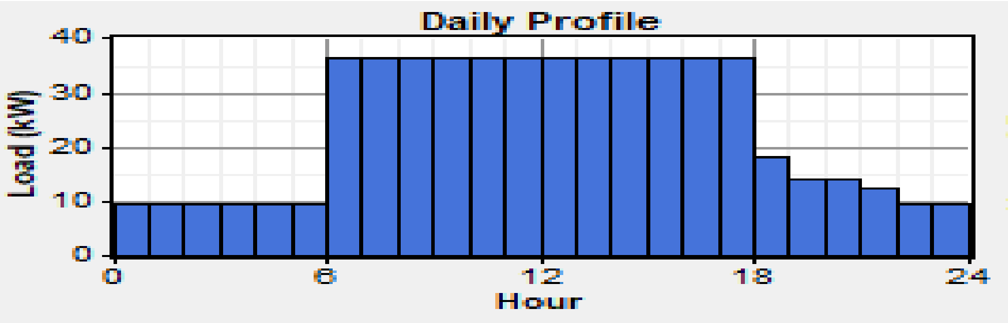


Figure 37: Average daily energy consumption for one business in Petrusburg town

3.9 Summary

Chapter 3 used HOMER software to simulate the results, and high energy consuming areas of the municipality were identified for both towns. Temperature data, wind speed data and solar energy data were analysed and applied in the HOMER software. Daily energy consumption for both Petrusburg and Koffiefontein were obtained from HOMER.

Chapter 4 focuses on HOMER simulation results. Solar PV and wind systems to supply the load of Koffiefontein and Petrusburg town are provided. Cost of both solar PV and wind system are compared.

CHAPTER 4: RESULTS

4.1 Introduction

Chapter 3 explained the methodology of the research. An energy audit was conducted in Koffiefontein and Petrusburg towns. The results of the audit indicated that Koffiefontein consists of a total of 2 038 houses and 113 businesses for both the township and town. Petrusburg consists of 606 houses and 63 businesses in town. A daily load profile for both Koffiefontein and Petrusburg towns were provided.

Chapter 4 focuses on the HOMER simulation analyses. Costs for both solar PV and wind turbine systems are provided and compared. An affordable renewable energy method is selected to supplement the current energy source during high demanding months for both Koffiefontein and Petrusburg towns.

4.2 HOMER simulations software

Municipal electricity distributors are bound by strict regulations to ensure that the distribution of a grid's power, quality and safety standards are maintained [95]. The municipality distributes electricity to their customers, either by prepaid or conversional meters, and these meters can either be single phase or three phases. Both businesses and houses require electricity on a daily basis, as indicated in Table 12.

The expected daily energy consumption for an averaged sized home in Koffiefontein is around 19.9 kWh and the total daily energy consumption of the 2 038 houses is 40 556.171 kWh. For Petrusburg town, the daily energy consumption for one business is around 568.1 kWh and the total daily energy consumption for 63 businesses is 35 787.5 kWh. HOMER software was used to design a system for one house in Koffiefontein and one business in Petrusburg town.

The results can then be scaled to cover all 2 038 houses in Koffiefontein and 63 businesses in Petrusburg. This software can also be used to determine the best optimal sizing and pre-feasibility study of the system. Sensitivity analysis was considered when designing the system [96].

Table 12: Energy consumption to consider

	Description	Total	Highest consuming area	Expected daily energy per house/business (kWh)	Total daily energy per day (kWh)
Koffiefon-tein	Houses	2038	Houses	19.9	40 556.171
	Businesses	113			
Petrusburg	Houses	606	Businesses	568.1	35 787.5
	Businesses	63			

4.3 Results for Koffiefontein

4.3.1 Solar as a source of energy for Koffiefontein

The type and size of the load used and its characteristics is one of the most important inputs, since it determines the system energy demand and is critical for system optimization, architecture size and cost [97]. HOMER software can handle a large set of technologies (including PV, wind hydro, fuel cells and boilers), loads (AC/DC, thermal and hydrogen) and can perform hourly simulations [98].

HOMER requires several inputs in order to perform any simulations. To determine the size of the PV required to meet the load demand of an average sized home in Koffiefontein, solar radiation was used as one of the inputs required by HOMER. Figure 38 indicate solar radiation data as collected from Jacobsdal Pulida solar plant. Data were collected from the Jacobsdal area, since both Koffiefontein and Petrusburg do not have an existing solar plant. Hence, Jacobsdal is the nearest town to both Koffiefontein and Petrusburg, with an existing solar plant.

The Pulida solar plant is located about 20 minutes' drive outside Jacobsdal, a small rural village in the Free State Province of South Africa. The scaled annual average is indicated to be 6.06 kWh/m²/d, and this value was calculated automatically by HOMER.

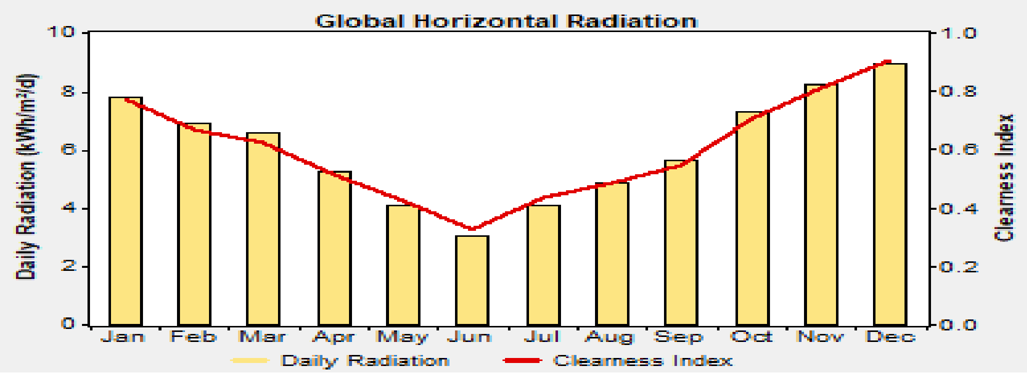


Figure 38: Solar radiation graph from HOMER based on the solar radiation data from Jacobsdal

Figure 39 shows the proposed battery-based solar PV system to be used to supply an averaged sized home in Koffiefontein. The PV panels have no tracking device and they were modelled with a slope of 30 degrees. The following individual PV panel sizes were considered in integer steps of one kW from 1-20 kW. The price of a 1 kW PV panel was considered to be R 7 592. The operation and maintenance (O&M) cost of the solar PV panels was assumed to be 1.56 % of the capital cost [99]. For the Trojan T-105 battery, the individual sizes were considered in integer steps of one Ah from 1-40 Ah. The price of the battery was taken to be R 2 894.02 ($ 189) with the O&M cost assumed to be 2% of the capital cost of the battery per year [100].

A 5-kW inverter was considered to meet the peak demand of the load. The price of the pure sine wave inverter, which is a Bi-Directional designed to obtain optimum inverter AC power from an installed DC battery system, was found to be R 29 599. The operation and maintenance cost was assumed to be 1% of the capital cost [100]. The typical lifespan of the converter was considered to be 15 years [98]. The load demand of the studied averaged sized home was found to be 20 kWh/day, as obtained from the municipality. During the HOMER simulation, the daily random variation of 10 % was considered, since it is impossible for the daily load demand to be constant throughout the year.

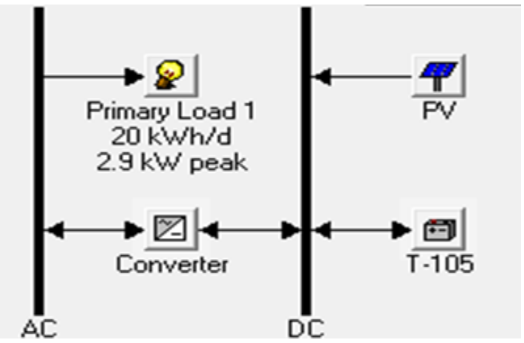


Figure 39: Battery-based solar to supply one house in Koffiefontein

Figure 40 indicates the optimal size of the proposed battery-based solar PV system, as suggested by HOMER to supply the load demand of one averaged sized home in Koffiefontein town. The load demand is met at no capacity shortage. This system consists of a PV of size 16 kW, 58 Trojan T- 105 battery, which are connected in series (two batteries per string). The system consists of an initial capital of R 318 883.00, and the cost of energy for this system is R 6.10/kWh.

				PV (kW)	T-105	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Batt. Lf. (yr)
				16	58	5	$ 318,883	17,586	$ 520,593	6.100	1.00	8.5

Figure 40: Optimization results

Figure 41 indicates the generated output power of the PV panels. This Figure indicates that from 00:00 am to 06:00 am, the PV output power was 0 kW as there was no solar radiation. After 06:00 am the PV panels can produce an output of at least 1.8 to 12.6 kW from January to April. From May to July, the maximum output of around 9 kW can be reached. It is indicated in the Figure that a maximum of between 16.2 and 18 kW can be reached during December month, due to high solar radiation level.

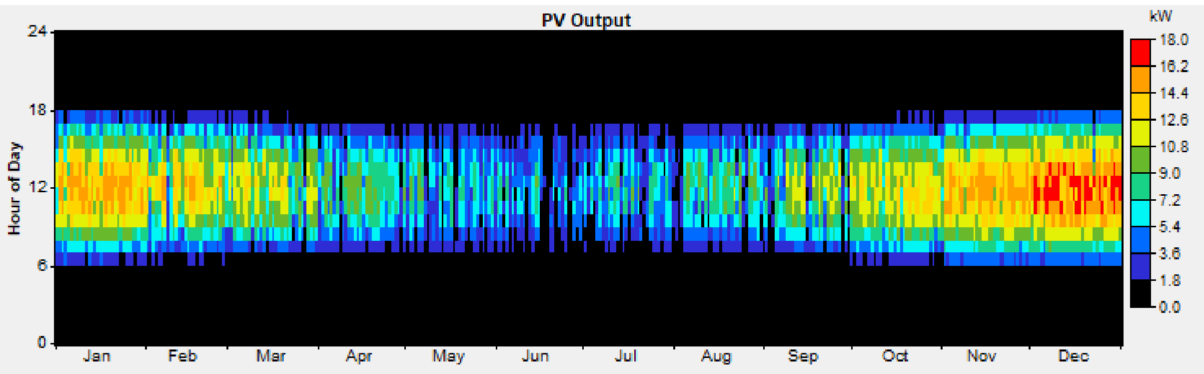


Figure 41: Output power of the PV panels

Figure 42 shows the state of charge of the battery. It can be noticed that from 07:00 am till 19:00 pm, the battery reached the fully charged state (100%), since the PV panels were able to solely meet the overall household energy demand. After 19:00 pm the state of charge of the battery was not 100%, because it had to supply energy to the house. It can be seen that the state of charge of the battery did not reach 100% during some days of the winter season in June.

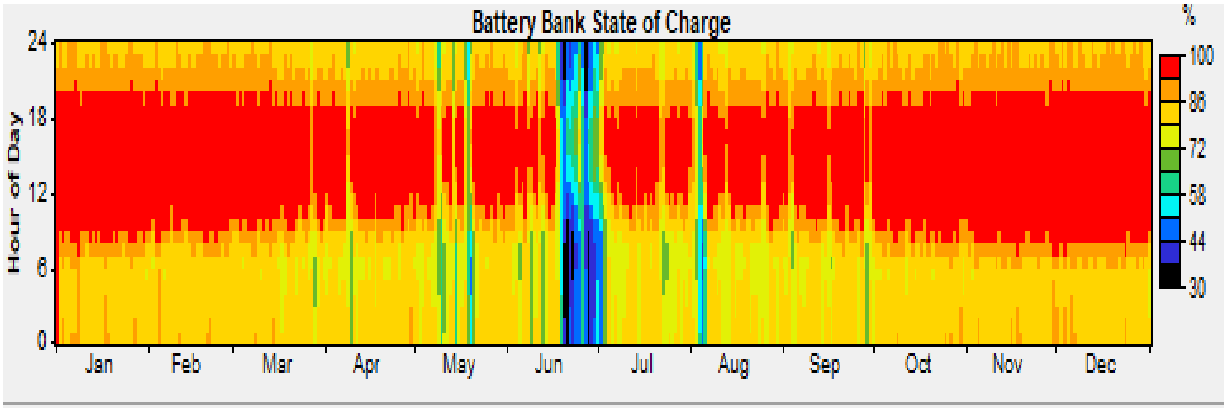


Figure 42: State of charge of the battery

The system indicated in Figure 39 had an electricity production of 27 661 kWh/year as indicated in Figure 43. Excess electricity for this system is 18 817 kWh/year as indicated in Figure 44. This is found to be 68% of the overall generated PV electrical energy. Hence, only 32% of the generated PV electrical energy had been utilized. Since this excess electricity is not utilized for the load demand, the municipality can sell it into the Eskom utility grid to generate more revenue. Results obtained for Koffiefontein town was used to write the paper attached in annexure E.

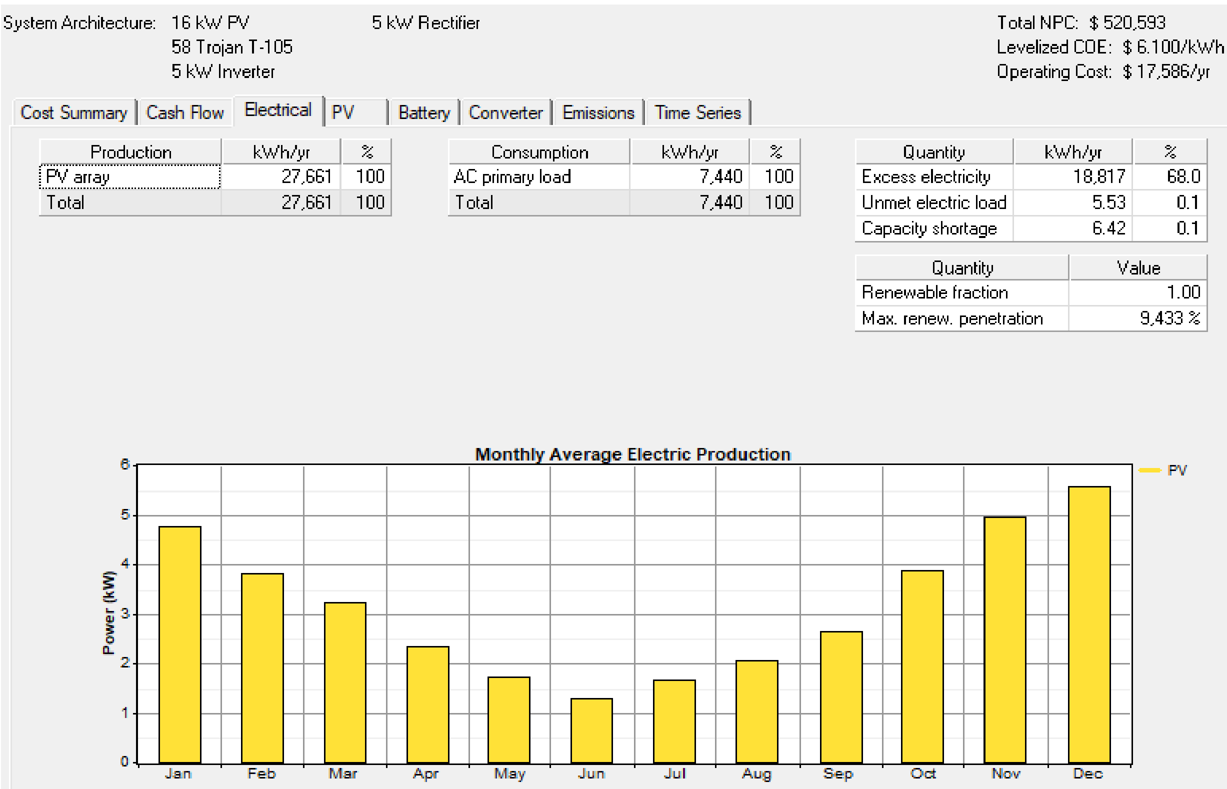


Figure 43: Yearly electricity production of the solar PV system

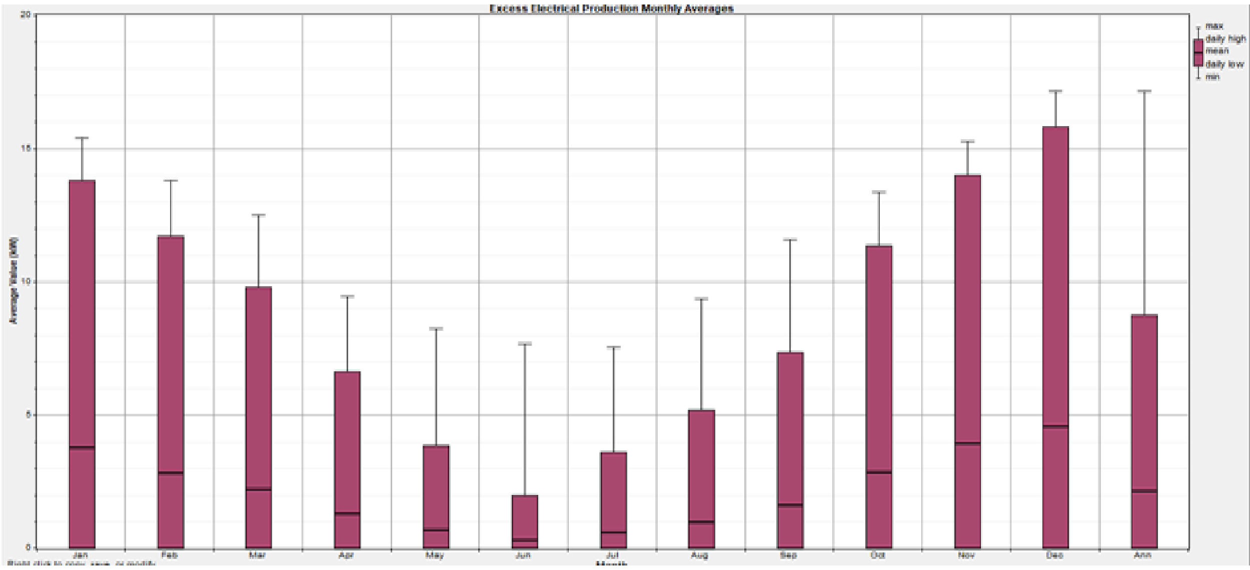


Figure 44: Excess electricity

4.3.2 Wind as a source of energy for Koffiefontein

For this study, the wind data was collected from one of the South African Weather Services Station in Fauresmith (Free State). The wind speed data was collected at different times of the day, and this data would help to suggest if a wind renewable energy system would be able to supplement the current energy needs of the two towns. Figure 45 indicates the wind speed data obtained at 20:00 pm. Data collected at 20:00 pm were chosen, because when most of the people are back from work and school (between 17:00 pm and 21:00 pm), the peak load demand took place. The annual average wind speed was 1.53 m/s at an anemometer height of 10 m.

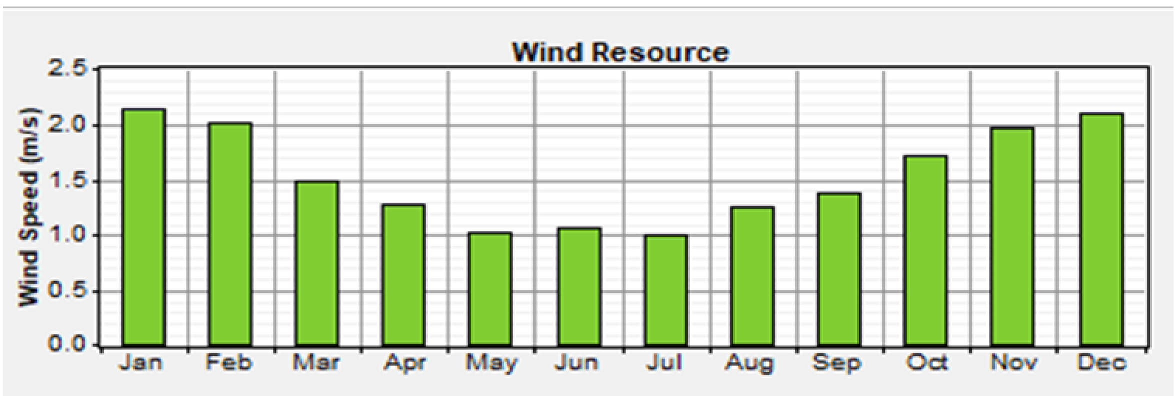


Figure 45: Wind speed data obtained at 20:00 pm from Fauresmith

Figure 46 shows the proposed battery-based wind turbine system to be used to supply an averaged sized home in Koffiefontein. This system indicates the primary load of 20 kWh/d, which could be used as the electricity consumption input for an average house in Koffiefontein. During HOMER simulation, wind turbine system sizes were considered in steps of 10 kW integer values, ranging from 1 to 23 wind turbines.

The capital cost of the generic 10 kW was assumed to be R 465 320 and the operation and maintenance of the system was taken as 2% of the capital [100]. The lifetime of the system was assumed to be 25 years. The following individual sizes were considered for the Trojan T-105 battery: steps of one Ah integers from 3501-3520 Ah. The same capital cost of the battery used for the PV system was considered.

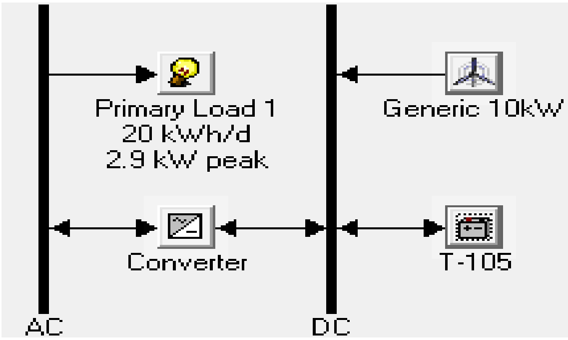


Figure 46: Batter-based wind system to supply one house in Koffiefontein

Figure 47 indicates an optimal size of the proposed battery-based wind turbine system as suggested by HOMER to supply the load demand of one averaged sized home in Koffiefontein. The load demand is met at no capacity shortage. This system has an initial capital of R 28 232 728, cost of energy for this system is R 776.490/kWh. This system will require 7012 Trojan T-105 batteries, which are connected in series (two batteries per string).

				G10	T-105	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.
				17	7012	5	$ 28,232,728	3,316,240	$ 66,269,736	776....	1.00

Figure 47: Optimization results

Figure 48 indicates the generated output power of the selected wind turbine system. The system is a 170 kW wind turbine system. HOMER selected a combination of 17 wind turbines whereby each turbine was 10 kW, so the system is a 170 kW wind turbine system. From April to August, the selected wind turbine system had no power production. During January and March, the system could reach a maximum of 18 kW power production. The highest power production of between 27 kW-30 kW could be reached around December months for a short period of time during the day.

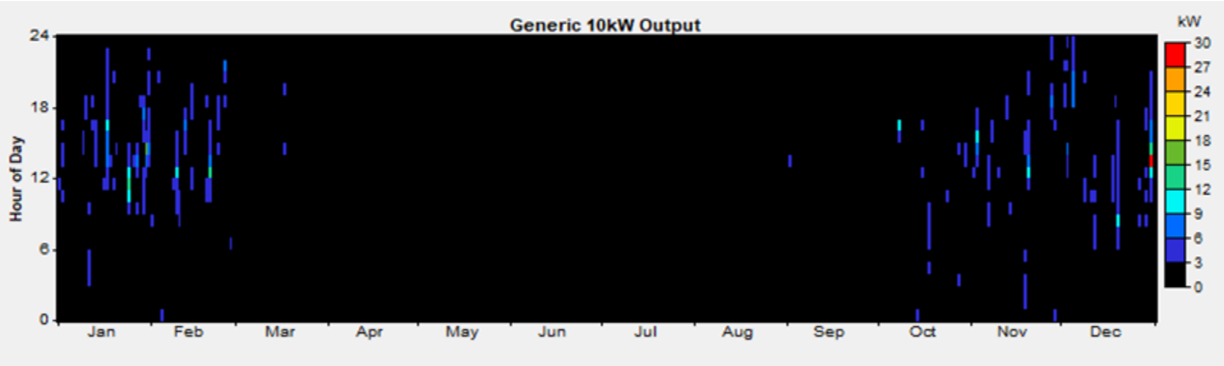


Figure 48: Output power of the selected wind turbine system

In January and February, the state of charge of the battery was between 93 and 100 %, because there was enough wind to supply the demand throughout the day and night as indicated in Figure 49. From March to October, the state of charge of the battery did not reach 100 %. Instead, the state of charge of the battery decreased, since the battery was used as the only source of electricity.

From the beginning of November month, the state of charge of the battery had reached 37 % and discharged up until it reached 30 % by the end of December. This simply means that HOMER had sized the battery storage unit, such that the load demand was met until the end of the year since the minimum allowable state of charge (30%) had been reached. This had led to a very expensive battery storage unit.

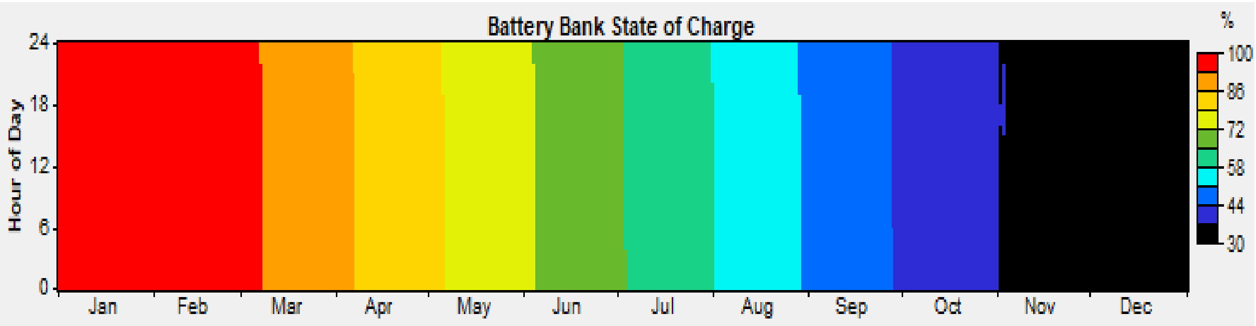


Figure 49: State of charge of the battery

Figure 50 indicates the yearly electricity production results of the battery-based wind turbine system. This system had an electricity production of 1 907 kWh/year. This had resulted in an excess electricity of 3.26 kWh/year (0.171%) with an unmet electricity load of 5.21 kWh/year.

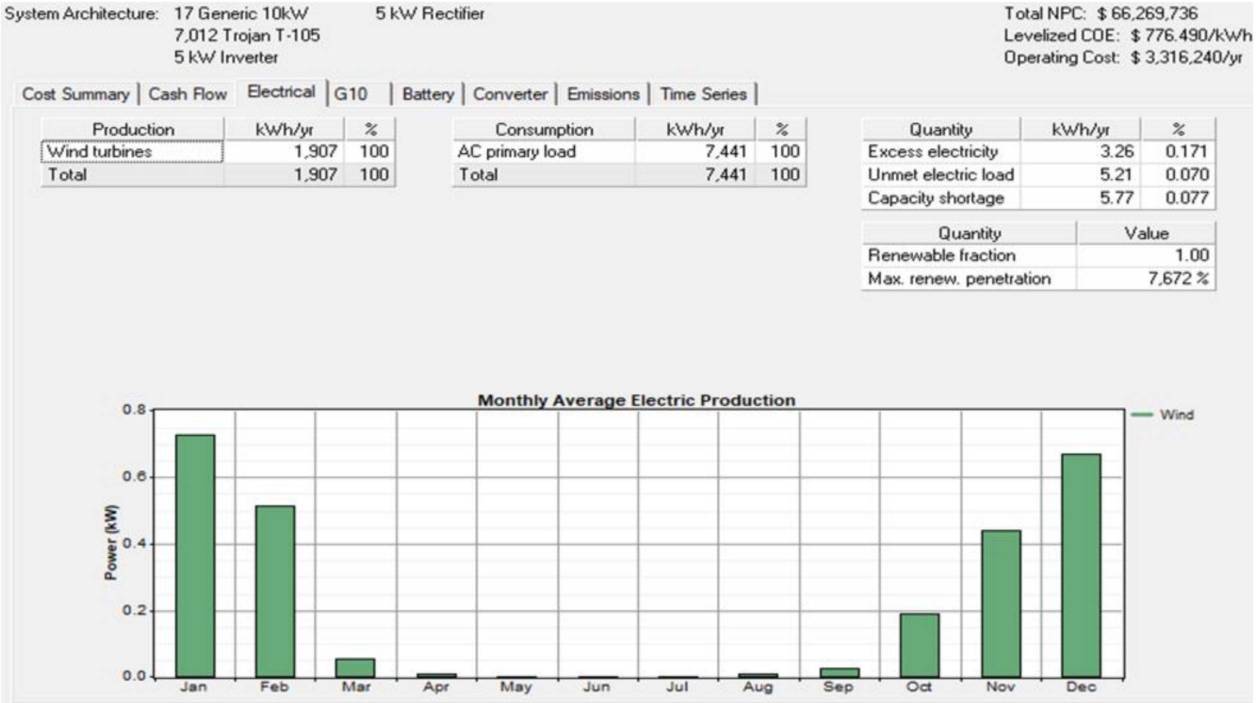


Figure 50: Yearly electricity production of the wind turbine system

4.4 Results for Petrusburg town

4.4.1 Solar as a source of energy for Petrusburg

The battery-based solar PV system indicated in Figure 51 was modelled using HOMER. Solar radiation data indicated in Figure 38 were used again as input data to HOMER to obtain the system to supply the load of one business in Petrusburg town. Data from Jacobsdal Palida solar plant were used as Petrusburg does not have an existing solar plant. Jacobsdal was the nearest town with an existing solar plant.

Load input from the municipality was 568.1 kWh/day. Prices considered for the PV and battery in Figure 39 were considered again. A 60-kW converter was considered to meet the peak demand of the load. This converter had a capital cost of R 188 796, and the operation and maintenance cost was taken as 1 % of the capital [100]. The following individual sizes were considered for the PV panels: steps of one kW integer values from 1-500 kW. The following individual sizes were also considered for the Trojan T-105 battery: steps of one Ah integer values from 460-470 Ah.

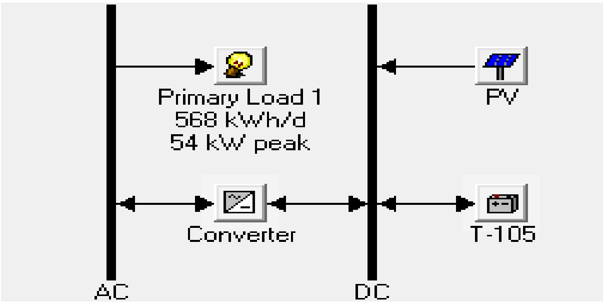


Figure 51: Battery-based solar PV to supply businesses 1 in Petrusburg

Figure 52 indicates the optimal size of the proposed battery-based solar PV system, suggested to supply one business in Petrusburg town. The load demand was met at no capacity shortage. Based on HOMER's optimal configuration results, the system consisted of a solar PV size of 496 kW and 928 Trojan T-105 battery, which were connected in series (two batteries per string). The initial cost of this system was indicated to be R 6 640 061, and the cost of energy for this system was indicated to be R 4.042/kWh.

PV (kW)	T-105	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.
496	928	60	$ 6,640,061	317,861	$ 10,703,385	4.042	1.00

Figure 52: Optimization results

Figure 53 indicates the generated output power of the PV panels. From January to June, the PV panels could reach an output power of 488 kW during the day. From 00:00 am to 06:30 am, the PV panels had no output power as there was no sun radiation to charge the panels. During December, the PV panels could reach a maximum of between 486 kW and 540 kW during the day.

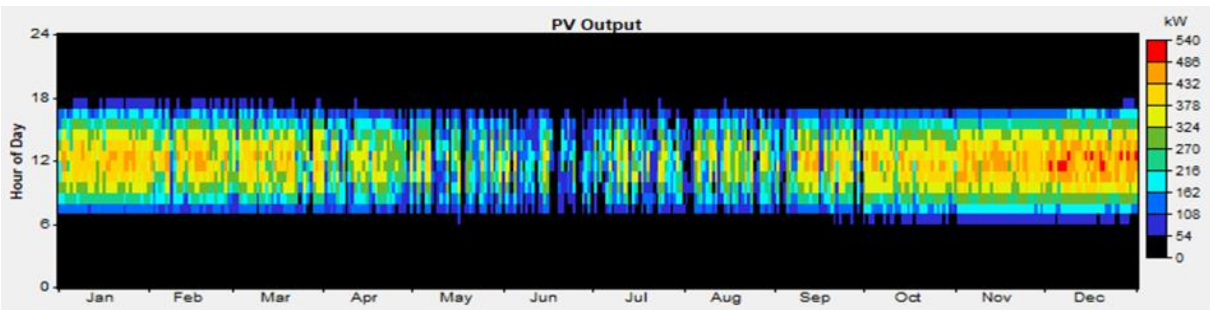


Figure 53: Output power of the solar PV panels

Figure 54 indicates the state of charge of the battery. From January to March, the state of charge of the battery was 100 % from 6:30 am to 00:00 am. After 00:00 am, the battery had to start supplying the load as there was not enough solar radiation for the PV panels to supply the load. Therefore, the state of charge of the battery started to decrease, ranging between 88 to 95 %.

In June and August, there were some days where the battery did not reach 100 %, thus the maximum state of charge of the battery is 58 %. From mid-August to December, the state of charge of the battery was able to reach 100 % from 6:30 am to 00:00 am again.

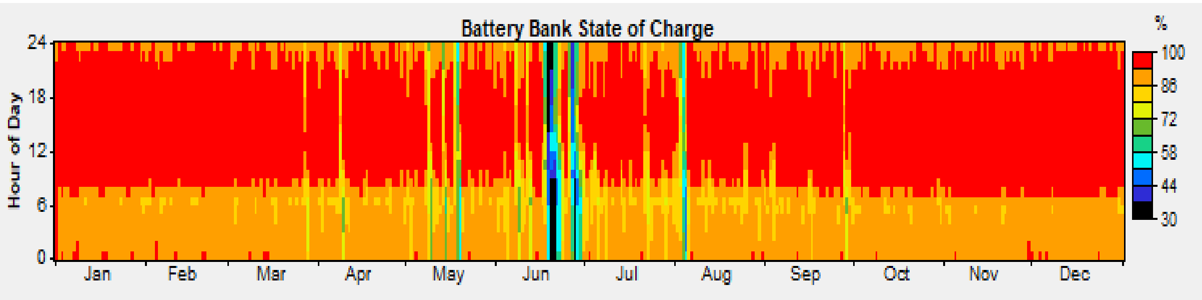


Figure 54: State of charge of the battery

The yearly electricity production of the system indicated in Figure 51 was 874 689 kWh/year as indicated in Figure 55. This electricity was produced by the PV array. This system consists of 928 Trojan T-105 battery, 496 kW PV, 60 kW converter. Excess electricity for this system is 643 492 kW/year as indicated in Figure 56. This system has an unmet load of 168 kWh/year.

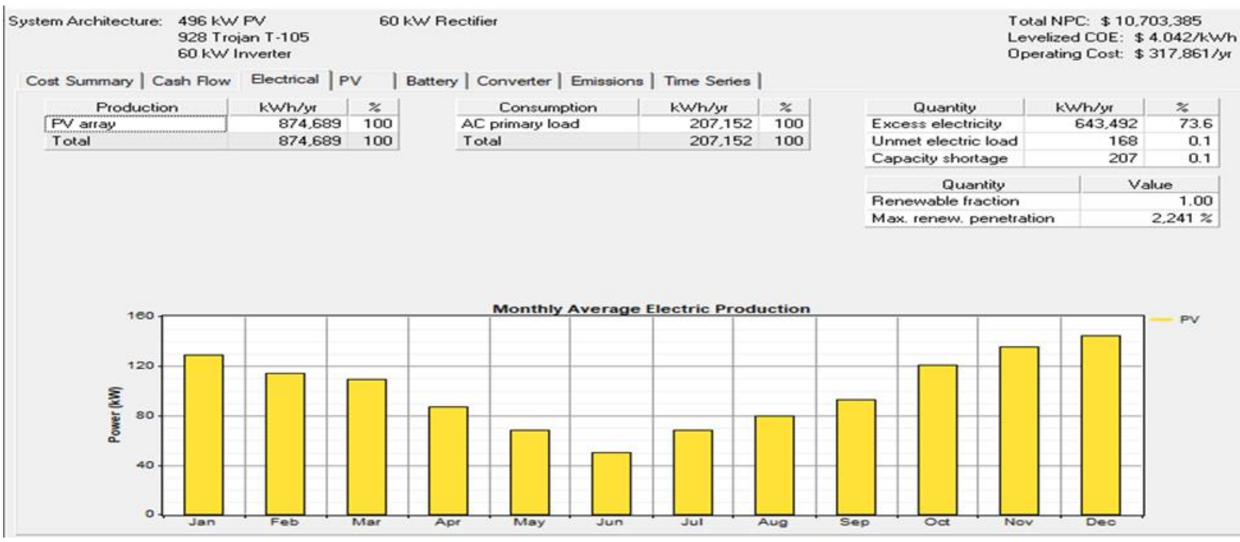


Figure 55: Yearly electricity production of the solar PV system

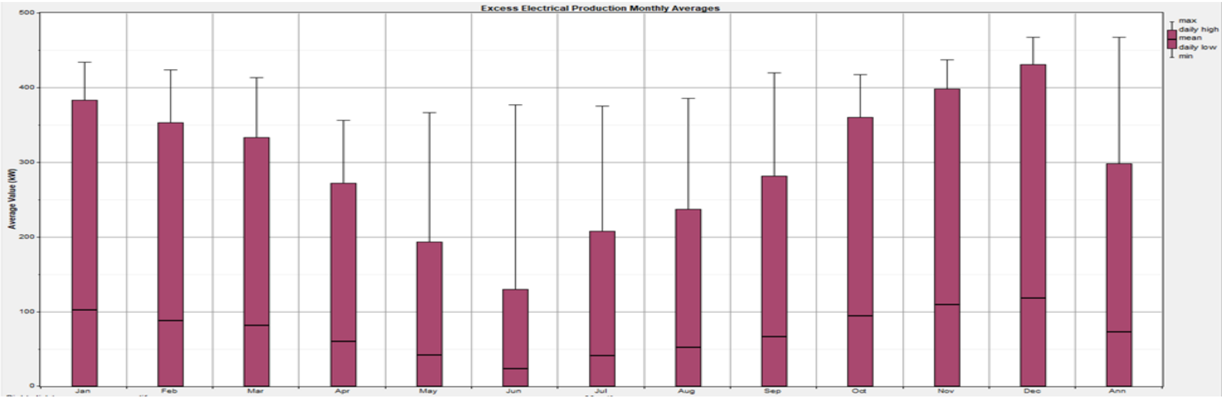


Figure 56: Excess electricity

4.4.2 Wind as a source of energy for Petrusburg

Most of the businesses start their operations at 07:30 am or 08:00 am, therefore wind speed data, collected at 08:00 am were used. This data were also collected from Fauresmith town, which is the nearest town to both Koffiefontein and Petrusburg with a wind satellite station. Indicated in Figure 57 is the wind speed graph from HOMER. The annual average wind speed is 2.43 m/s at an anemometer height of 10 m.

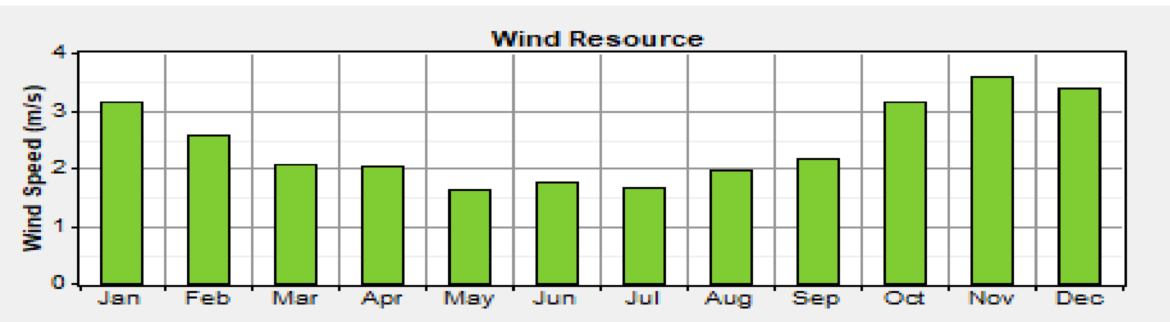


Figure 57: Wind speed data obtained at 08:00 am from Fauresmith

Indicated in Figure 58 is the proposed battery-based wind turbine system to be used to supply one business in Petrusburg town. This system indicates the primary load of 568 kWh/d, which is used as daily electricity consumption input for one business in Petrusburg town. The price of the generic 10 kW wind turbine system considered in Figure 46 was considered again for this system. The same battery cost and converter size and cost used in Figure 51, were used again for this Figure. The following individual sizes were considered for the wind turbine system: steps of one kW integer values from 2791-2805 kW. For the battery, the following individual sizes were considered: steps of one Ah integer values from 841-855 Ah.

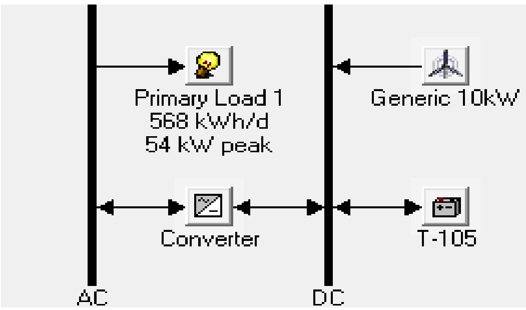


Figure 58: Battery-based wind turbine system to supply businesses in Petrusburg town

Figure 59 indicates the optimal size of the proposed battery-based wind turbine system suggested by HOMER to meet the load demand of one business in Petrusburg town. The load demand was met at no capacity shortage. This system has an initial cost of R 1 352 86. The cost of energy for this system is R840.4/kWh.

	G10	T-105	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.
	2800	17200	60	$ 1,352,86...	68,284,864	$ 2,225,771...	840....	1.00

Figure 59: Optimization results

Figure 60 indicates the output power of the selected wind turbine system. HOMER selected a combination of 2 800 wind turbines whereby each turbine is 10 kW, so the system is 28 000 kW. From April to August, the output of the selected wind turbine system was 0, and this means that there was not enough wind for the system to generate any power.

In January the output reached between 8 100 to 10 800 kW. During February and March, the output power reached a maximum of between 2 700 and 5 400 kW during the day. In November, a maximum of 27 000 kW was reached during the day for a short period during the day.

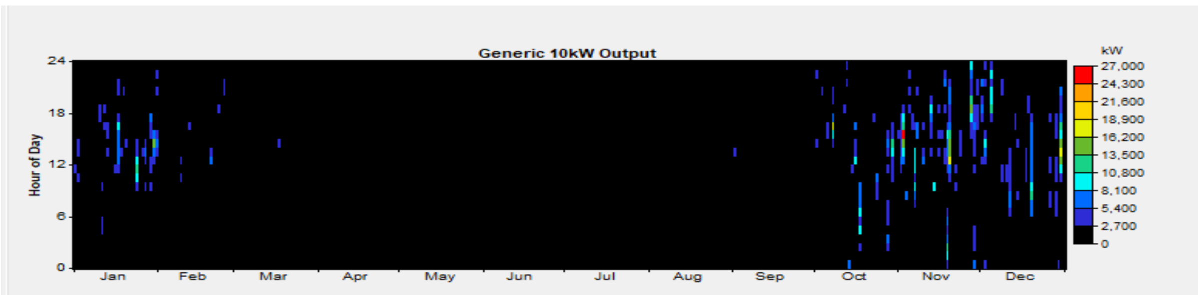


Figure 60: Output power of the wind turbine system

Figure 61 indicates the state of charge of the battery. From January to early March, the state of charge of the battery was 100 % throughout the day and night. From May to July, the battery did not reach 100 % of the charging rate. From late September to December, the state of charge of the battery remained 100 % throughout the day and night again.

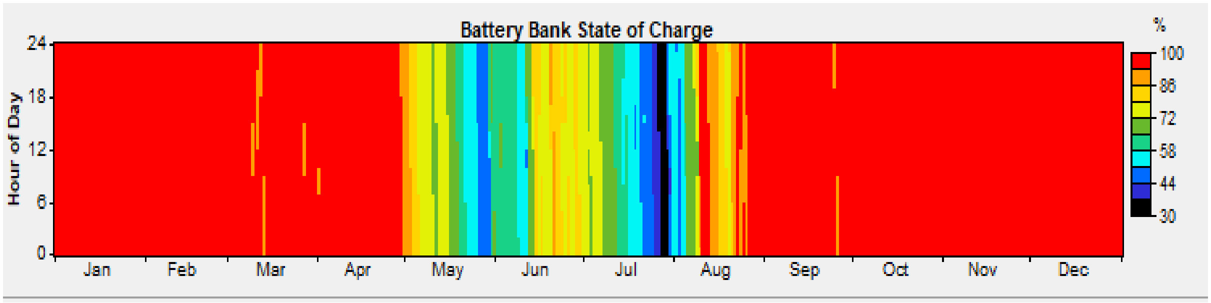


Figure 61: State of charge of the battery

Figure 62 indicates the electricity production of the wind turbine system indicated in Figure 58, which is 3 408 145 kWh/year. Excess electricity for this system is 3 164 265 kWh/year. This system consists of an unmet electric load of 139 kWh/year.

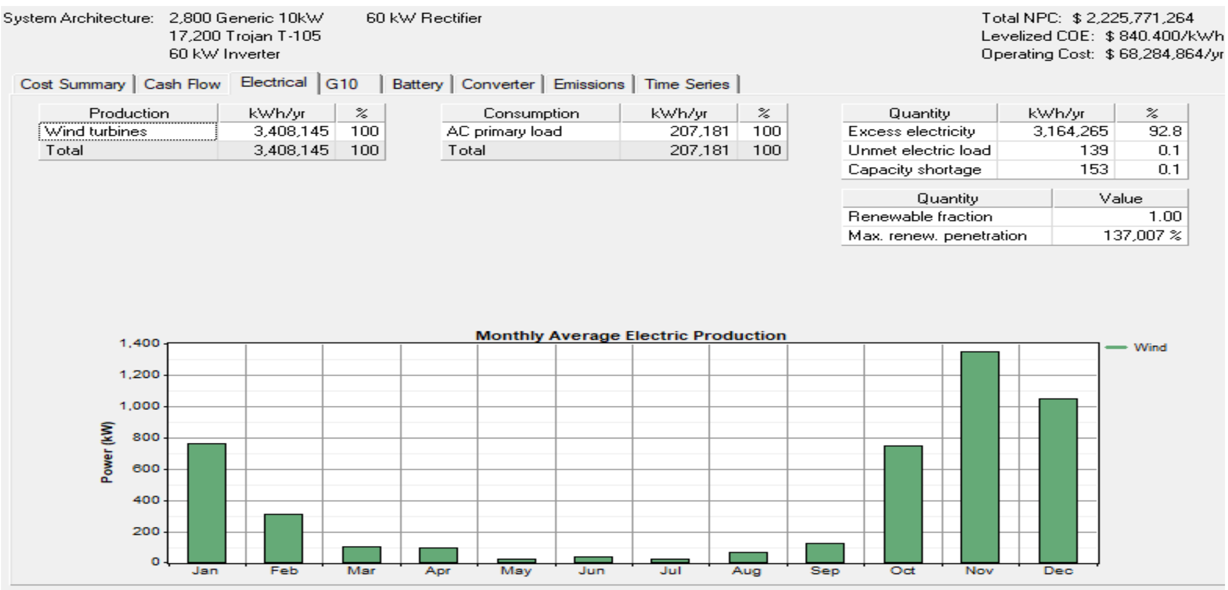


Figure 62: Yearly electricity production of the wind turbine system

4.5 Cost analysis for system implementation

HOMER simulated the operation of a system by making energy balance calculations for each of the 8 760 hours in a year [101]. The NPC denotes the total cost for a proposed design [102].

This software estimated four major costs as indicated in Figure 63. It also made it possible to compare the various results obtained. This allows the user to select the feasible design in terms of cost, space availability, etc. [102].

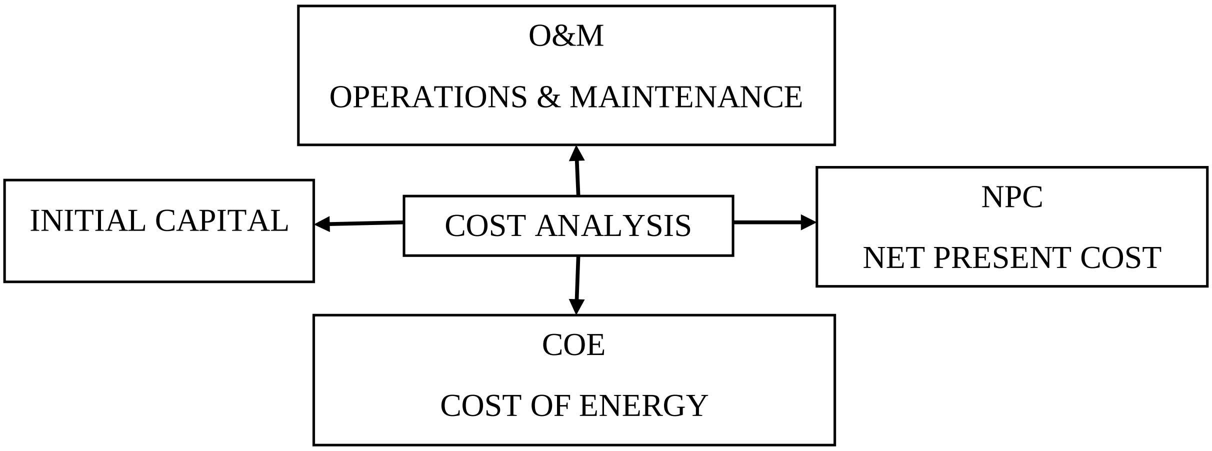
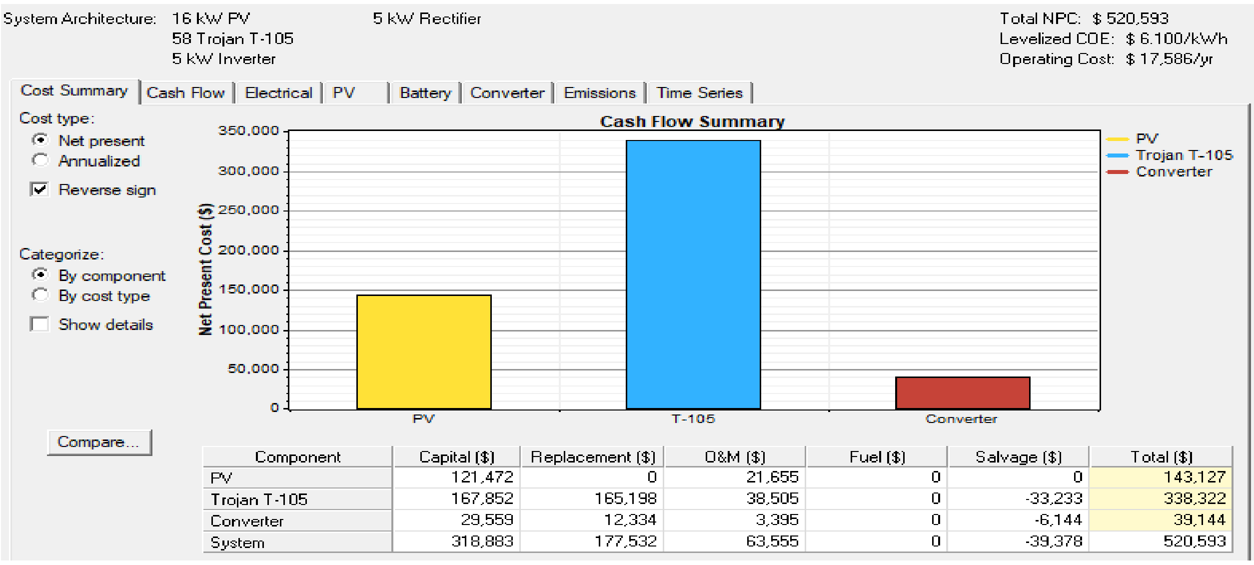


Figure 63: Four major costs estimated by HOMER [102].

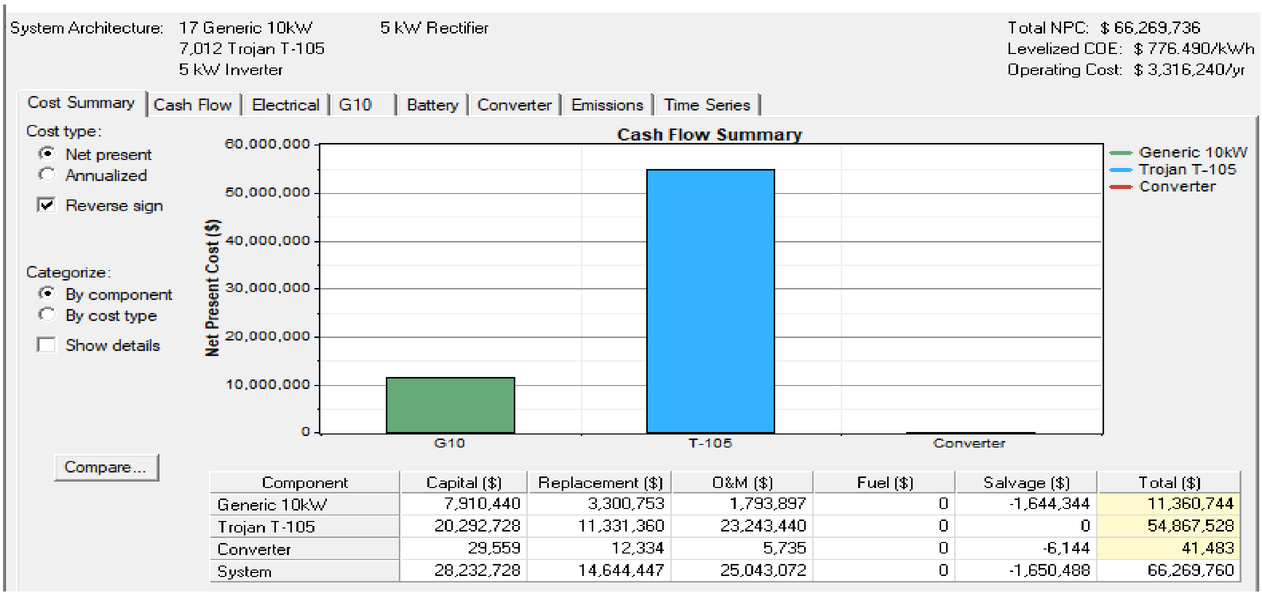
Figure 64 indicates the cost analysis for the configuration of the solar PV suggested to supply the load of an averaged size home in Koffiefontein. As the Figure shows a symbol of $, it was considered to be the South African Rand. The total NPC of the system is indicated to be R 520 593. This system consists of a PV array with a total size of 16 kW, 58 Trojan T-105 batteries, and a 5 kW converter. The total replacement cost is R 177 532, and the total costs of the operation and maintenance for the system is R 63 555.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	121,472	0	21,655	0	0	143,127
Trojan T-105	167,852	165,198	38,505	0	-33,233	338,322
Converter	29,559	12,334	3,395	0	-6,144	39,144
System	318,883	177,532	63,555	0	-39,378	520,593

Figure 64: Net present cost for the solar PV system (Koffiefontein)

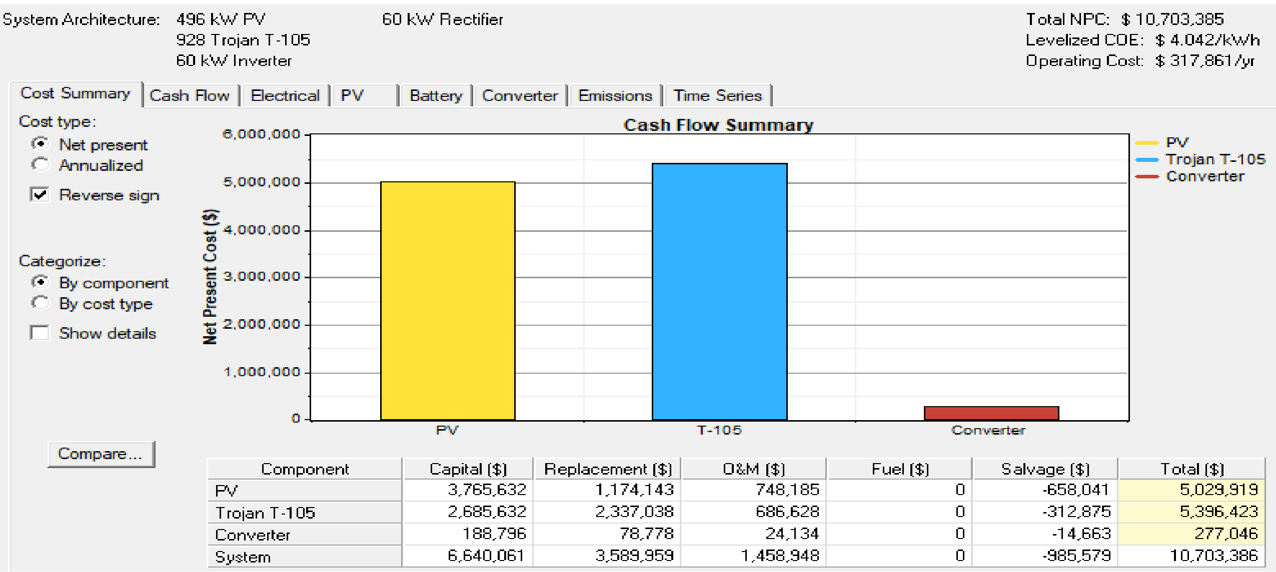
For the wind turbine systems suggested to supply the load of an averaged sized home in Koffiefontein, costs for each component that makes up the system is being obtained and analysed. Figure 65 indicates an NPC of R 66 269 736, which is the total cost of the system. The system requires R 14 644 447 to replace all components that makes up the system. For the system to operate and be maintained, the municipality needs R 25 043 072.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Generic 10kW	7,910,440	3,300,753	1,793,897	0	-1,644,344	11,360,744
Trojan T-105	20,292,728	11,331,360	23,243,440	0	0	54,867,528
Converter	29,559	12,334	5,735	0	-6,144	41,483
System	28,232,728	14,644,447	25,043,072	0	-1,650,488	66,269,760

Figure 65: Net present cost of the wind system (Koffiefontein)

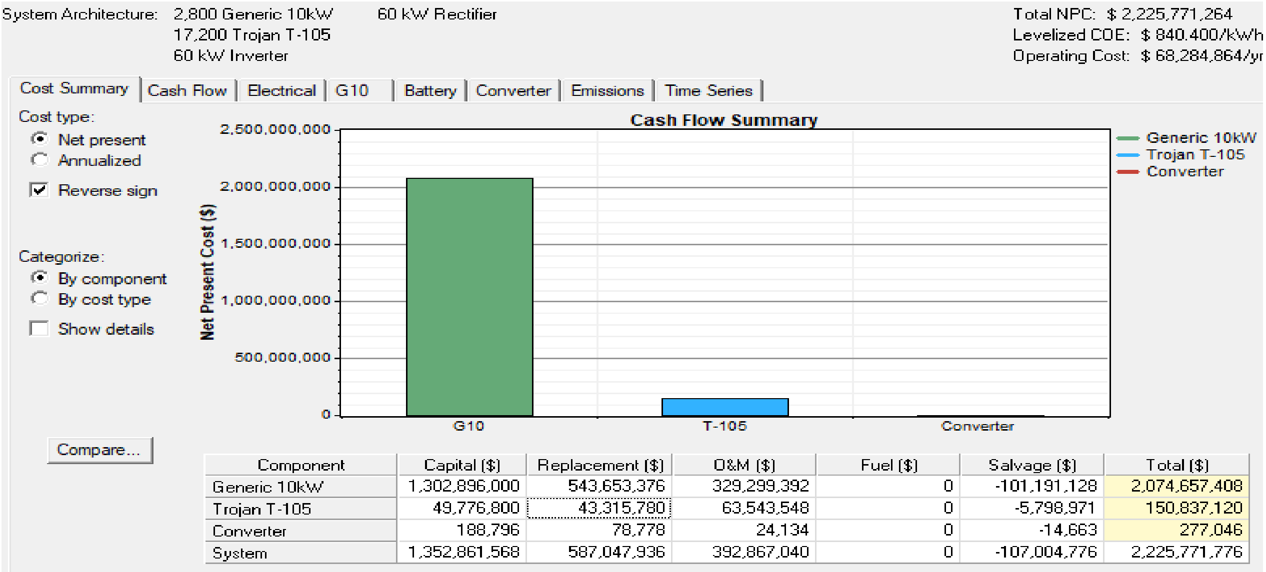
Figure 66 indicates the configuration of the solar PV to supply businesses in Petrusburg town. This system consists of 496 kW PV arrays, 928 x T-105 batteries, and a 60 kW converter. The NPC of this system is R 10 703 385.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	3,765,632	1,174,143	748,185	0	-658,041	5,029,919
Trojan T-105	2,685,632	2,337,038	686,628	0	-312,875	5,396,423
Converter	188,796	78,778	24,134	0	-14,663	277,046
System	6,640,061	3,589,959	1,458,948	0	-985,579	10,703,386

Figure 66: Net present cost of the solar PV (Petrusburg)

Figure 67 indicates the configuration of the wind turbine system to supply one business in Petrusburg town. This system consists of a 28 000 generic 10 kW wind turbine, 17 200 Trojan T-105 batteries and a 60 kW converter. The NPC of this system is R 2 225 771.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Generic 10kW	1,302,896,000	543,653,376	329,299,392	0	-101,191,128	2,074,657,408
Trojan T-105	49,776,800	43,315,780	63,543,548	0	-5,798,971	150,837,120
Converter	188,796	78,778	24,134	0	-14,663	277,046
System	1,352,861,568	587,047,936	392,867,040	0	-107,004,776	2,225,771,776

Figure 67: Net present cost for the wind turbine system (Petrusburg)

4.6 Anticipated revenue for both towns

Payback period is the period of the time required to be able to recoup the expenditures made through the profits derived from a project that has been run or operated [103]. This calculation is simply the number of years it would take for the project’s cash flows to pay back the initial investment. The theory is that after the original cost of investment is recuperated, the remaining cash flows goes towards creating shareholder value [103].

Figure 68 and 69 indicate the total revenue of the municipality from January 2016 to December 2017 for Koffiefontein and Petrusburg town respectfully. This information will help in determining how long it will take the municipality to pay off the chosen system with the collected revenue from houses in Koffiefontein and businesses in Petrusburg. Excess energy of the battery-based solar PV system suggested for both Koffiefontein and Petrusburg may be sold to Eskom to reduce the payback period of the municipality

Figure 43 indicates that the battery-based solar PV system suggested to supply houses in Koffiefontein has an excess energy of 18 817 kWh/year, which maybe be sold into the Eskom grid to help reduce the payback period of the system. The average standard Eskom tariff is R 1.2824 /kWh as indicated in Figure 68 [104].

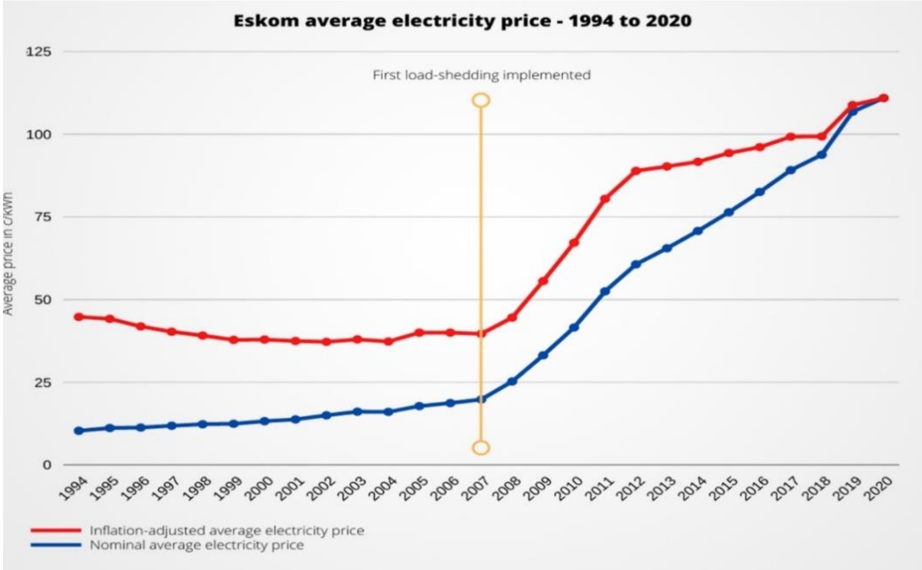


Figure 68: Eskom average electricity price [105]

This means that excess electricity from the battery-based solar PV system suggested for Koffifontein houses may be sold for 18 817 kWh /year × R 1.2824 /kWh ×2023 household = R 49 178 816.1 /kWh. For Petrusburg town, excess energy for the battery-based solar PV system suggested for Petrusburg businesses will be sold for 643 492 kWh/year × R 1.2824 /kWh ×63 businesses = R 51 988 490.87 /kWh. Revenue collected from excess energy sold will be used as the cash inflow of the municipality. During the payback period calculations, the power consumption pattern and energy prices are assumed to be constant for worst case scenario.

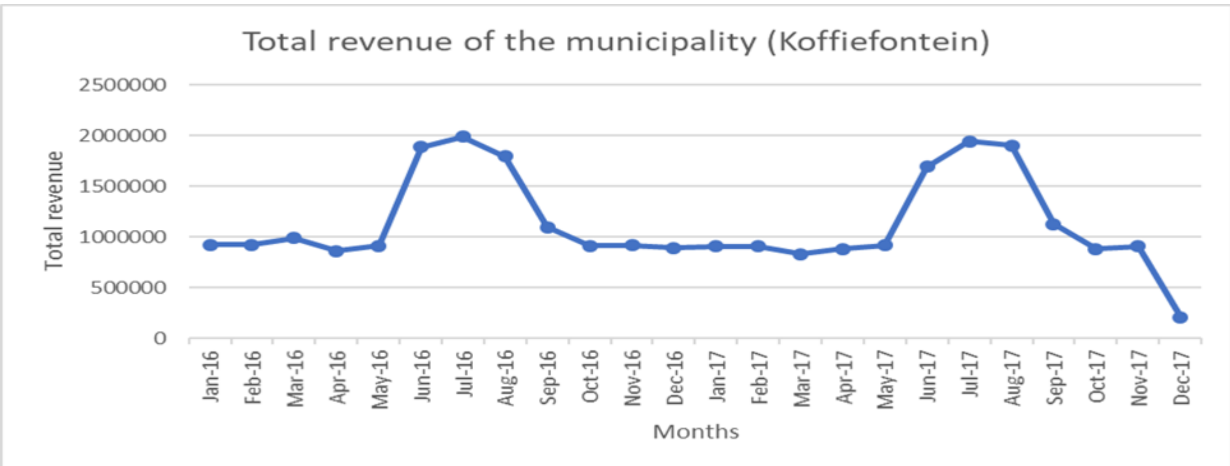


Figure 69: Total revenue of the municipality in Koffiefontein town

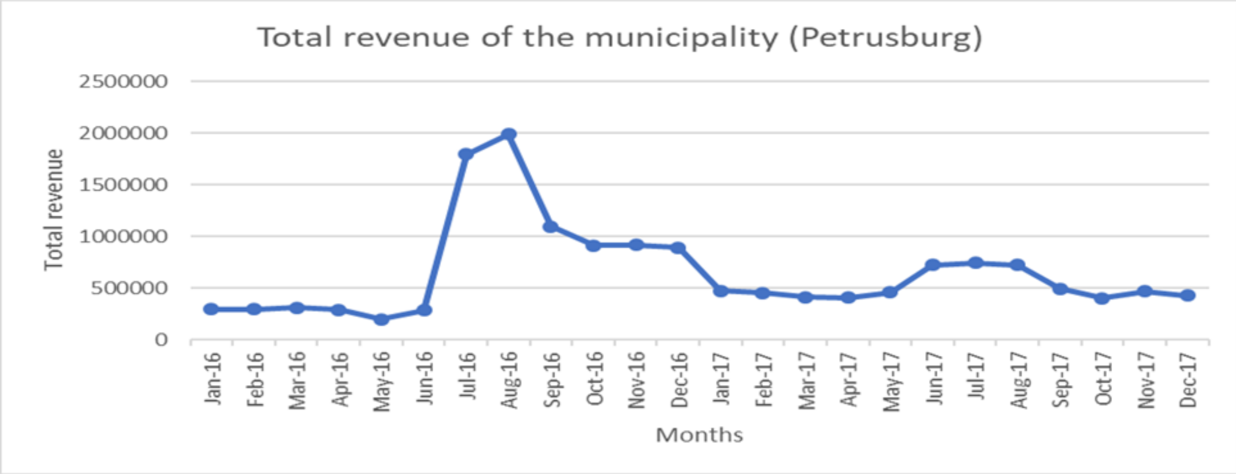


Figure 70: Total revenue of the municipality in Petrusburg town

To determine how long it will take the municipality to pay off the system suggested, to supply houses in Koffiefontein with the revenue they collect from household electricity sales, the total cost of the PV system, which is R 649 883 554 for 2038 houses, is used. Table 13 indicates the payback period for the battery-based solar PV system for 2038 houses in Koffiefontein. An averaged sized home in Koffiefontein requires 16 kW PV panels to meet its load demand. To determine the size of the PV panels required to meet the load demand of the total number of houses, which is 2038, the total number of houses, which is 2038, is multiplied by the 16 kW PV panels, and this gives a total of 32 608 kW PV panels.

Equation 3 is used to calculate the payback period of the municipality for the battery-based solar PV system for 2038 houses in Koffiefontein. The cost of the system, which for the battery-based solar PV system is R 649 883 554, is taken as the initial investment. Revenue collected in 2017, which was R 7 437 498.10 and revenue collected from excess energy sold to Eskom, which is R 49 178 816.59, is combined and taken as the cash inflow of the municipality.

$$\text{Payback period} = \frac{Initial\ Investment}{Cash\ inflow\ per\ period} \quad (3)$$

$$= \frac{Initial\ Investment\ for\ 2038\ household}{Revenue\ for\ supplying\ load/year + Excess\ \ energy\ sales/year}$$

$$= \frac{R\ 318\ 883 \times 2038}{7\ 437\ 498.1 + (R\ 1.2824 \times 18\ 817 \times 2038)}$$

$$\text{Payback period (solar PV)} = \frac{649\ 883\ 554}{56\ 616\ 314.6}$$

$$= 11.5 \text{ years}$$

Table 13: Payback period for the battery-based solar PV system for 2038 houses in Koffiefontein

	Battery-based solar PV system
System size (kW)	32 608
Total cost of the system (R)	649 883 554
Total revenue for 2016 (R)	6 893 384.83
Total revenue for 2017 (R)	7 437 498.1
Excess energy sold to Eskom (R)	49 178 816.59
Payback period	11.5 years

Table 14 indicates the size of the battery-based solar PV system required to meet the load demand of 63 businesses in Petrusburg town. One business requires 496 kW PV system to meet the load demand. To determine the size of the PV system required to meet the load demand of 63 businesses in Petrusburg, the size of the PV system, which is 496 kW is multiplied by the total number of businesses in Petrusburg town, which is 63. This gives a size of 31 248 kW PV system required to meet the load demand of 63 businesses in Petrusburg town.

Equation 3 is used again to determine how long the municipality will take to pay off the battery-based solar PV system chosen to meet the load demand of 63 businesses in Petrusburg town. The cost of the battery-based solar PV system, which is R 418 323 843, is taken as the initial investment. The yearly excess energy amounting to 40 539 996 kWh generates a revenue of R 51 988 490.87 when sold to Eskom at a fit-in-tariff of R 1.2824 per kWh. The revenue collected in 2017, which is R 3 182 331.40, is combined with the revenue collected from excess energy sold to Eskom. This amount to an overall annual cash inflow of R 55 170 822.27. The reason is because in 2017, the revenue was affected by factors such as some businesses being closed, factories not operating full time due to low production of onions. Hence, the 2017 data is used to calculate the payback period as a last year data obtained from the municipality.

$$\text{Payback period} = \frac{Initial\ Investment\ for\ 63\ businesses}{Revenue\ for\ supplying\ load/year + Excess\ \ energy\ sales/year}$$

$$\text{Payback period (solar PV)} = \frac{6\ 640\ 061 \times 63}{3\ 182\ 331.40 + (\ R\ 1.2824 \times 643\ 492 \times 63)}$$

$$= \frac{418\ 323\ 843}{55\ 170\ 822.27}$$

= 7.6 years

Table 14: Payback period for the battery-based solar PV system for 63 businesses in Petrusburg

	PV
System size (kW)	31 249
Total cost of the system (R)	418 323 843
Total revenue for 2016 (R)	6 282 391.36
Total revenue for 2017 (R)	3 182 331.4
Excess energy sold to Eskom (R)	51 988 490.87
Payback period	7.6 years

4.7 Preferred alternative energy generation system for both towns

The cost of energy for the PV system suggested for Koffiefontein houses is R 6.10 /kWh, with the yearly electricity production of 27 661 kWh. The wind turbine system has the cost of energy of R 776.490 /kWh with the yearly electricity production of 1 907 kWh. The PV system has an initial cost of R 649 883 554 for 2038 houses, while the wind turbine system has an initial cost of R 57 538 299 664. The payback period of the solar PV system is 11.5 years. The PV system has high excess electricity of 18 817 kWh, while the wind turbine system has an excess electricity of 326 kWh. The cost of energy of the battery-based solar PV system is cost effective and the initial cost of the system is much lower than the wind turbine system, therefore the preferred alternative energy generation system for Koffiefontein is the battery-based solar PV system.

The cost of energy for the PV system suggested for Petrusburg businesses is R 4.042 /kWh with the yearly electricity production of 847 689 kWh. The cost of energy for the wind turbine system is R 840.4 /kWh, with the yearly electricity production of 3 480 145 kWh. The PV system has an initial cost of R 418 323 842, while the wind turbine system has an initial cost of R 85 230 278 784. The PV system has an electricity excess of 643 492 kWh/year, while the wind turbine system has an electricity excess of 3 164 265 kWh/year. The payback period of the solar PV system is 7.6 years. This means that the municipality will be able to gain profit in a shorter period with the battery-based solar PV system. The cost of energy for the PV system is cost effective for municipal customers. The cost of energy for the wind turbine system is expensive. Therefore, the preferred alternative energy system for Petrusburg businesses is the battery-based solar PV system.

For the new developments of both Koffiefontein and Petrusburg town, the municipality will need to make a new application to Eskom in order to connect the new load. A research will be done on how much loads needs to be connected and either it needs to be connected to wind or solar energy.

4.8 Summary

In chapter 4, the results of the simulations conducted using the HOMER software was provided and analysed. Electricity production of each system for the two towns was analysed and compared with the cost of energy for each system. The payback period for each system suggested by HOMER for each town, was determined. The system that has an energy production that meets the load demand, affordable cost of energy and shorter payback period, was suggested for each town.

Chapter 5 takes into consideration the findings and what they mean for the research and lessons to be learned in addressing the problem statement. The lessons to be learned from this research offer recommendations of what can be done going forward to have a sustainable energy supply for Petrusburg and Koffiefontein towns.

CHAPTER 5: CONCLUSION

5.1 Introduction

In chapter 4, results of the simulations conducted using HOMER software were discussed. The net present cost of each system suggested by HOMER, was also provided. The optimal size of the battery-based solar PV system and battery-based wind turbine system suggested for houses in Koffiefontein and businesses in Petrusburg, were presented. Calculations of the payback period for each system suggested for houses in Koffiefontein and businesses in Petrusburg town, were also covered.

Chapter 5 focuses on the findings of the research. This chapter also offers recommendations based on the findings of the research.

5.2 Research objectives reviewed

The main aim was to investigate alternative power generation strategies for local municipalities, in order to enable more autonomy that can help to reduce the pressure placed on the National Gird. The objectives of this research were to:

- Conduct an energy audit of the two towns, which are Koffiefontein and Petrusburg and correlate it to their electrical bill

The results of the audit indicated that Koffiefontein consists of a total of 2 038 houses, with 1 246 in the township and 792 in town. This town also has 113 businesses, with 36 in the township and 77 in town. Electricity sale statistics from the municipality indicated that Koffiefontein houses consume more electricity than businesses. For Petrusburg, the audit is conducted in town only, as the township is being supplied directly by Eskom. Petrusburg consists of 606 houses and 63 businesses in town. Sale statistics from the municipality indicated that businesses in Petrusburg town consume more electricity than houses.

- Identify various alternative power generation strategies, based on the energy audit and weather data for the two towns

The two main alternative strategies for this study focused on the use of wind and solar farms as possible supplements to the current energy needs of the two towns of the Letsemeng Local Municipality. Solar radiation data and wind speed data were used to determine which system between a wind turbine system and solar PV system will be the best renewable energy strategy to supplement the current energy source. Since the results of the audit indicated that Koffiefontein houses consume more energy than businesses, a supplement was proposed for houses in Koffiefontein, and a supplement was proposed for businesses in Petrusburg.

- Apply the HOMER program to evaluate the viability of the proposed strategies

HOMER required daily energy consumption, therefore the monthly energy consumption obtained from the municipality, was converted to daily energy consumption. June 2016 had the highest energy consumption for Koffiefontein households, which was 1 135 572.98 kWh. This was used to create a daily load profile for an averaged sized home in Koffiefontein. For Petrusburg town, August 2016 was the highest consuming month for businesses with an energy consumption of 1 002 048.75 kWh. This was used to create a daily energy consumption for one business in Petrusburg. When conducting simulations for the solar PV system, solar radiation data from the Jacobsdal Pulida solar plant was used as one of the inputs required by HOMER. For the wind turbine system simulations, wind speed data collected from the South African Weather Services station in Fauresmith were used as input data in HOMER.

- Recommend the most appropriate strategy for the two identified towns

HOMER indicated that the battery-based solar PV system was the best renewable energy strategy to supplement the current energy source of houses in Koffiefontein town and businesses in Petrusburg town. This system was indicated to have the cost of energy that is affordable for municipal customers and the initial cost of the system is much lower than that of the battery-based wind turbine system. The battery-based solar PV system was indicated to have the highest yearly electricity production in both towns.

The cost of energy for the battery-based solar PV system suggested for Koffiefontein houses is R 6.10 /kWh, with the yearly electricity production of 27 661 kWh, while the battery-based wind turbine system has the cost of energy of R 776.490 /kWh, with the yearly electricity production of 1 907 kWh. The battery-based solar PV system has an initial cost of R 649 883 554 for 2038 houses, while the battery-based wind turbine system has an initial cost of R 57 538 299 664.

The cost of energy for the battery-based solar PV system suggested for Petrusburg businesses is R 4.042 /kWh, with the yearly electricity production of 847 689 kWh, while the cost of energy for the battery-based wind turbine system is R 840.4 /kWh, with the yearly electricity production of 3 480 145 /kWh. The battery-based solar PV system has an initial cost of R 418 323 842 for 63 businesses in Petrusburg, while the battery-based wind turbine system has an initial cost of R 85 230 278 784.

- Determine the payback period for an installed renewable energy system

The battery-based solar PV system has the shorter payback period on both towns. Koffiefontein has a payback period of 11.5 years and Petrusburg has a payback period of 7.6 years.

- Verify the regulator code on the technical requirements for municipalities to have renewable energy systems

As stated in chapter 3, before connecting any renewable electricity generation equipment, such as PV modules or small wind turbines, the municipality needs to make an application to Eskom. The municipality may be connected through the shared LV feeders or the dedicated LV feeder. For the shared LV feeder, the maximum individual generating limit is approximately 25 % of the customer's NMD up to a maximum of 20 kVA. A generator greater than 20 kVA should be connected through a dedicated LV feeder. In the dedicated LV feeder, the maximum generator size is limited to 75 % of the NMD.

The municipality will have to connect through the dedicated LV feeder, since they will require a generator greater than 20 kVA. The NMD for Koffiefontein is 3300 kVA and the 2 038 houses in Koffiefontein requires 32 608 kW PV. The regulator codes states that the embedded generator shall not inject reactive power into the utility network, while the drain of reactive power shall be limited to a power factor of 0.9. These limits apply, unless otherwise agreed upon with the utility.

When using the 0.9 power factor to convert the 32 608 kW panel to kVA, an answer of 36 231 kVA is obtained for 2 038 houses in Koffiefontein. Only 2 475 kVA which is 75% of the NMD, will be connected for Koffiefontein houses. This makes up only 15 % of the battery-based solar PV system, which means that the municipality will have to reach an agreement with Eskom in order to allow them to connect at least 90 % of the battery-based solar PV systems.

The NMD for Petrusburg town is 1 600 kVA and the 63 businesses in Petrusburg require 31 248 kV PV panels, which is 34 720 kVA when using the 0.9 power factor to convert to kVA.

Only 1 200 kVA of the NMD in Petrusburg town will be connected, which is 29 % of the battery-based solar PV system. This again means that the municipality will have to reach an agreement with Eskom, in order to connect at least 90 % of the battery-based solar PV system.

5.3 Problem statement reviewed

The original problem statement given in chapter 1 stated: Escalating electrical energy usage has resulted in large utility bill expenses that municipalities are struggling to pay-off to Eskom along with load-shedding. The challenge exists in identifying viable alternative power generation strategies for local municipalities to reduce pressure on the National Grid during their months of high energy demand and to provide limited power to their communities when disconnected from the National Grid.

HOMER software was used to design a system for an averaged sized home in Koffiefontein and one business in Petrusburg towns, in order to supplement the current energy source during high demanding months of the year. Daily energy consumption of an averaged sized home and business was used as the primary load input required by HOMER. To determine the size of the battery-based solar PV system and battery-based wind turbine system required to meet the load demand, wind speed data collected at one of the South African Weather service satellite were used, as wind resource inputs and solar radiation data collected from the Pulida solar plant were used as solar resource inputs. Different sizes of batteries were used as inputs to determine the required size of batteries for each simulation. For the solar PV simulation, different sizes of the panels were used and for the wind turbine simulations different sizes of wind turbines were also used as inputs.

A battery-based solar PV system of size 16 kW with 58 Trojan T-105 battery, which are connected with two batteries per string, were suggested for an averaged sized home in Koffiefontein. The PV panels were indicated to reach a maximum generated output power of between 16.2 -18 kW during December month only, due to high solar radiation levels. The state of charge of the battery suggested for an averaged sized home in Koffiefontein, indicated that from 07:00 am till 19:00 pm, the battery reaches the fully charged state (100%), since the PV panels are able to solely meet the overall household energy demand. After 19:00 pm the state of charge of the battery is not 100%, because it has to supply energy to the house. This system had an initial capital of R 318 883, while the cost of energy for this system was indicated to be R 6.10 /kWh. This system was indicated to have an electricity production of 27 661 kWh/year with excess electricity of 18 817 kWh/year.

The battery-based wind turbine system suggested for an averaged size home in Koffiefontein had a size of 170 kW wind turbines, whereby each turbine is 10 kW and 7012 Trojan T- 105 batteries, which are connected with two batteries per string. Figure 46 in chapter 4 indicated that the generated output power of the selected wind turbine system can reach the highest power production of between 27 kW -30 kW in December month only, for a short period of time during the day. The state of charge of the selected batteries indicated that in January and February, the state of charge of the battery was between 93 and 100 %, because there was enough wind to supply the demand throughout the day and night. From the beginning of November month, the state of charge of the battery had reached 37 % and would discharge up until it reached 30 % by the end of December. This system had an initial capital of R 28 232 728, and the cost of energy for this system was indicated to be R 776.490 /kWh. The yearly electricity production of this system was indicated to be 1 907 kWh.

A battery-based solar PV system of size of 496 kW with 928 Trojan T-105 battery, which are connected with two batteries per string was suggested for one business in Petrusburg town. The output power of the PV panels indicated that from January to June, the PV panels could reach an output power of 488 kW during the day. From 00:00 am to 06:30 am, the PV panels had no output power as there was no sun radiation to charge the panels. During December, the PV panels reached a maximum of between 486 kW and 540 kW during the day. The state of charge of the battery indicated that from January to March, the state of charge of the battery was 100 % from 6:30 am to 00:00 am. After 00:00 am, the battery had to start supplying the load, as there was not enough solar radiation for the PV panels to supply the load. Therefore, the state of charge of the battery started to decrease ranging between 88 to 95 %. The initial cost of the system was indicated to be R 6 640 061, and the cost of energy for the system was indicated to be R 4.042 /kWh. The yearly electricity production of the system was indicated to be 874 689 kWh.

A battery-based wind turbine system of size 28 000 kW with 17 200 Trojan T-105 batteries was suggested for one business in Petrusburg town. The output power of the wind turbine system indicated that from April to August, the output of the selected wind turbine system was 0, and this meant that there was not enough wind for the system to generate any power. In

January the output reached between 8, 100 to 10, 800 kW. The state of charge of the battery indicated that from January to early March, was 100 % throughout the day and night. From May to July, the battery did not reach 100 % of the charging rate. This system had an initial cost of R 1 352 86, and the cost of energy for this system was indicated to be R840.4 /kWh. This system has an electricity production of 3 408 145 kWh/year. Excess electricity for this system was indicated to be 3 164 265 kWh/year.

The preferred renewable energy strategy for both Koffiefontein and Petrusburg towns is solar energy. The cost of energy for the battery-based solar PV system suggested for Koffiefontein houses is R 6.10 /kWh, with the yearly electricity production of 27 661 kWh, while the battery-based wind turbine system has a cost of energy of R 776.490 /kWh, with the yearly electricity production of 1 907 kWh. This system has an initial cost of R 649 883 554 for 2 038 houses, and the battery-based solar PV system has high excess electricity of 18 817 kWh/year per system, while the wind turbine system has an excess electricity of 326 kWh/year. The payback period of the solar PV system is 11.5 years. Results from chapter 4 also indicated that the battery-based wind turbine system will not be able to function throughout the year as there is not enough wind.

For Petrusburg town, the cost of energy for the battery-based solar PV system suggested for Petrusburg businesses is R 4.042 /kWh, with the yearly electricity production of 847 689 kWh, while the wind turbine has a cost of energy of R 840.4 /kWh, with the yearly electricity production of 3 480 145 kWh. The battery-based solar PV system has an initial cost of R 418 323 842 and electricity excess of 643 492 kWh/yearly. The payback period of the battery-based solar PV system is 7.6 years. The battery-based wind turbine system will not be able to function throughout the year also in Petrusburg town as there is not enough wind.

The municipality is going to supply this clean and renewable source of energy to their consumers at the same flat tariff rate as Eskom. The customers will be encouraged to move to this clean and renewable source of energy because this system will not be affected by load shedding which is currently affecting businesses and households. This system won’t be producing any carbon emission and will have sustainable renewable energy. Results from this study do not take into account electricity theft or losses that would impact on the cost of electricity.

5.4 Future work that can still be done

More research should be done on hydro, solar and wind energy to motivate the government to invest in installing hydro, solar or wind energy in areas that have the potential to use either of the renewable energies to meet the future electricity demand in the country. Hydro energy should be undertaken for municipalities situated close to water resources. This will further help in reducing air pollution when producing electricity. Researchers could look at proposing a policy for the inclusion of alternative energy sources for all new homes in major residential areas.

With the current state of power shortage in South Africa, more research could be done for businesses in big cities so that they can make hybrid wind and solar electric systems more sustainable. This will avoid businesses running at a loss, due to load-shedding or power failure.

Instead of focusing only on the high demanding months of businesses and houses, research could focus on worst-case scenarios, e.g. should a certain area have power failure of three to four days. There could be a hybrid system that can supply power for a longer period without any failures, and the use of solar during the day and wind during the night to ensure that there is always power supply, could be considered during the research.

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Annexure A

Customer Total Units Received

Velaphi/2-6-17_11-25AM

District: All Districts

Meter No	Name	Acc #	Location	Tariff	Units Purchased	Free Units	Value	VAT	Refund Amount	Refund Units	Refund VAT	Last Purchase
07126766968	OTTO, S	07126766968	Erf# 326, RIEMVASMAAK, LUCKHOFF, LUCKHOFF	DIAMANTHOOGTE BESIGHED	2721.8	0.0	4806.10	673.90	0.00	0.0	0.00	01-06-2017
07081765179	OLIFANT, LE		Erf# 25, KOEDOE STR, DIAMANTHOOGTE, KOFFIEFONTEIN	DIAMANTHOOGTE BESIGHED	6366.7	0.0	11359.75	1590.25	0.00	0.0	0.00	01-06-2017
07123854767	NORTJE, P		Erf# 53, GEMSBOK STR, DIAMANTHOOGTE, KOFFIEFONTEIN	DIAMANTHOOGTE BESIGHED	986.6	0.0	1728.08	241.92	0.00	0.0	0.00	09-02-2017
07083273230	SHAIKH, 1BILAL SHAIKH		Erf# 934, 72 GROTTREK STR, DIAMANTHOOGTE, KOFFIEFONTEIN	DIAMANTHOOGTE BESIGHED	14997.9	0.0	26735.30	3742.70	0.00	0.0	0.00	01-06-2017
07060936916	MADEBE, ANDRIES		15 BOTHALAAN ST, KOFFIEFONTEIN, KOFFIEFONTEIN	DIAMANTHOOGTE BESIGHED	5313.8	0.0	9177.22	1284.78	0.00	0.0	0.00	01-06-2017
07081766417	JOHANNES, AS		Erf# 145, BOTHA LAAN, DIAMANTHOOGTE, KOFFIEFONTEIN	DIAMANTHOOGTE BESIGHED	11537.5	0.0	19109.75	2675.25	0.00	0.0	0.00	03-04-2017
07126622765	KEMP, PR	07126622765	Erf# 30, tompson, PETRUSBURG, PETRUSBURG	DIAMANTHOOGTE BESIGHED	1782.0	0.0	3052.65	427.35	0.00	0.0	0.00	15-07-2016
07081952264	VAN DER BERG, H J		Erf# 22, , PETRUSBURG, PETRUSBURG	DIAMANTHOOGTE BESIGHED	11970.7	0.0	21228.04	2971.96	0.00	0.0	0.00	02-06-2017
07083272109	STRAMPE, HJ		Erf# 15, GORDON, KOFFIEFONTEIN, KOFFIEFONTEIN	DIAMANTHOOGTE BESIGHED	2375.4	0.0	4210.56	589.44	0.00	0.0	0.00	04-05-2017
07083272224	Saikh, Bilal		Erf# 7(839), Glasson, KOFFIEFONTEIN, KOFFIEFONTEIN	DIAMANTHOOGTE BESIGHED	1638.2	0.0	2900.89	406.11	0.00	0.0	0.00	09-05-2017
07083273271	BILAL, BILAL SHAIKH		Erf# 72/839, GROOTTREK STR, DIAMANTHOOGTE, KOFFIEFONTEIN	DIAMANTHOOGTE BESIGHED	1067.0	0.0	1894.75	265.25	0.00	0.0	0.00	13-03-2017
07072105153	ERF110 PETRUS(BK,		Erf# 706, , KOFFIEFONTEIN, KOFFIEFONTEIN	DIAMANTHOOGTE BESIGHED	15833.6	0.0	28070.24	3929.76	0.00	0.0	0.00	25-05-2017
07081952413	MOTERS, PHILLIP		Erf# 706, PRETORUIS STR, PETRUSBURG, PETRUSBURG	DIAMANTHOOGTE BESIGHED	1283.3	0.0	2280.72	319.28	0.00	0.0	0.00	19-05-2017
07126622641	MATLHAPE, PATRICK	07126622641	Erf# H0493, PRINCE STR, DITLHAKE, KOFFIEFONTEIN	DIAMANTHOOGTE BESIGHED	7907.2	0.0	14063.27	1968.73	0.00	0.0	0.00	01-06-2017
07084726194	THOMAS, METER FOUTIEF	07084726194	Erf# EXTENTION 3, , LUCKHOFF, LUCKHOFF	DIAMANTHOOGTE BESIGHED	13.9	0.0	23.68	3.32	0.00	0.0	0.00	22-01-2016
07073869492	., Unknown		Erf# 00001, , KOFFIEFONTEIN, KOFFIEFONTEIN	DIAMANTHOOGTE BESIGHED	2364.4	0.0	4210.56	589.44	0.00	0.0	0.00	02-05-2017
00000000000	., Unknown		Erf# 1, , DIAMANTHOOGTE, KOFFIEFONTEIN	DIAMANTHOOGTE BESIGHED	16.7	0.0	28.94	4.06	0.00	0.0	0.00	21-09-2016
07126623938	RAADT, OWEN	07126623938	Erf# 44, koedoe str, DIAMANTHOOGTE, KOFFIEFONTEIN	DIAMANTHOOGTE BESIGHED	7224.6	0.0	12982.56	1817.44	0.00	0.0	0.00	29-05-2017

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Annexure B

Customer Total Units Received

Velaphi/2-6-17_11-37AM

District: All Districts

Meter No	Name	Acc #	Location	Tariff	Units Purchased	Free Units	Value	VAT	Refund Amount	Refund Units	Refund VAT	Last Purchase
07083271812	MOKGWETSI, JIMMY		Erf# H0396, MATHIBELA, KOFFIEFONTEIN, KOFFIEFONTEIN	DITLHAKE HUISHOUDELIK	5681.0	50.0	5780.75	809.25	0.00	0.0	0.00	01-06-2017
TA5FB137	LEFOKOTSANE, METER		Erf# H1560, , DITLHAKE, KOFFIEFONTEIN	DITLHAKE HUISHOUDELIK	3771.6	50.0	3539.24	495.76	0.00	0.0	0.00	25-01-2016
07031667558	MAY, N J		Erf# h1135, , DITLHAKE, KOFFIEFONTEIN	DITLHAKE HUISHOUDELIK	2154.9	50.0	1920.96	269.04	0.00	0.0	0.00	22-05-2017
TA5EV302	SWAKAMISA, A		Erf# H1372, , DITLHAKE, KOFFIEFONTEIN	DITLHAKE HUISHOUDELIK	329.8	50.0	254.37	35.63	0.00	0.0	0.00	31-12-2015
07031668309	MATHETSA, MARIA		* H1298 CHRISHANI PARK, ,	DITLHAKE HUISHOUDELIK	3170.3	0.0	2881.54	403.46	0.00	0.0	0.00	25-05-2017
07047637173	ENKELD, JULY		Erf# H2576, DONKERHOEK, DITLHAKE, KOFFIEFONTEIN	DITLHAKE HUISHOUDELIK	586.0	50.0	473.63	66.37	0.00	0.0	0.00	12-05-2017
07031667863	RAAD, JAN		Erf# H1378, , DITLHAKE, KOFFIEFONTEIN	DITLHAKE HUISHOUDELIK	986.6	300.0	829.65	116.35	0.00	0.0	0.00	31-05-2017
07073869583	BRAND, EJ		Erf# 11, VOORTREKER STR, PETRUSBURG, PETRUSBURG	DITLHAKE HUISHOUDELIK	6175.0	0.0	7289.49	1020.51	0.00	0.0	0.00	31-05-2017
07043434070	MOGADE, M G		Erf# H0660, MOROANYANE, DITLHAKE, KOFFIEFONTEIN	DITLHAKE HUISHOUDELIK	2030.4	0.0	1802.61	252.39	0.00	0.0	0.00	31-05-2017
07038014374	MATTHYS, AGNES		Erf# H0663, , DITLHAKE, KOFFIEFONTEIN	DITLHAKE HUISHOUDELIK	3234.9	50.0	2938.58	411.42	0.00	0.0	0.00	26-04-2017
07081766300	MPATSETLA, L		Erf# H0268, ROSE LOVE STREET, DITLHAKE, KOFFIEFONTEIN	DITLHAKE HUISHOUDELIK	3423.7	0.0	3131.59	438.41	0.00	0.0	0.00	18-05-2017
07045205304	MAYEKISO, KS		Erf# H0724, , DITLHAKE, KOFFIEFONTEIN	DITLHAKE HUISHOUDELIK	2199.1	50.0	1964.82	275.18	0.00	0.0	0.00	31-05-2017
07046153248	PIETERSE, D		Erf# H1466, , DITLHAKE, KOFFIEFONTEIN	DITLHAKE HUISHOUDELIK	3373.6	0.0	3114.05	435.95	0.00	0.0	0.00	01-06-2017
07045175770	SENTI, MP		* H2189 EXT 4, ,	DITLHAKE HUISHOUDELIK	2157.9	0.0	1925.43	269.57	0.00	0.0	0.00	30-05-2017
07045174500	BIKO, M W		* H2286 EXT 4, ,	DITLHAKE HUISHOUDELIK	944.0	0.0	789.37	110.63	0.00	0.0	0.00	02-06-2017
07035568406	NDARA, JAN		Erf# H1369, , DITLHAKE, KOFFIEFONTEIN	DITLHAKE HUISHOUDELIK	2352.2	50.0	2109.58	295.42	0.00	0.0	0.00	01-06-2017
07041719217	RAMOHLABA, M L		Erf# h1647, , DITLHAKE, KOFFIEFONTEIN	DITLHAKE HUISHOUDELIK	3306.2	0.0	2992.58	419.42	0.00	0.0	0.00	01-06-2017
07031668242	MODUPE, MARTHA		Erf# H1227, , DITLHAKE, KOFFIEFONTEIN	DITLHAKE HUISHOUDELIK	338.8	50.0	257.84	36.16	0.00	0.0	0.00	20-05-2017
07083271838	QALINGE, L		Erf# h1627, THABONG STR, DITLHAKE, KOFFIEFONTEIN	DITLHAKE HUISHOUDELIK	3892.7	50.0	3588.61	502.39	0.00	0.0	0.00	29-05-2017
07047173187	LOUW, P N		Erf# H0728, BONANI STR, DITLHAKE, KOFFIEFONTEIN	DITLHAKE HUISHOUDELIK	3362.9	0.0	3052.67	427.33	0.00	0.0	0.00	01-06-2017
07035568307	MOKGALAGADI, NTOSANG		Erf# H0468, , DITLHAKE, KOFFIEFONTEIN	DITLHAKE HUISHOUDELIK	2016.8	50.0	1789.47	250.53	0.00	0.0	0.00	02-06-2017

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Annexure C

PROJECT TITLE : INVESTIGATING ALTERNATIVE POWER GENERATION STRATEGIES FOR LOCAL MUNICIPALITIES THAT ARE TIED TO THE NATIONAL GRID.

DESIGNED BY : B. P TSHETLHE

CLIENT NAME : MPUBI EDDIE

HOUSE NUMBER : 558 BAHUMI STREET

LOCATION : KOFFIEFONTEIN

OBJECTIVE OF THE ENERGY AUDIT: To determine the residential/business energy flow. Determine which electrical appliance consume more energy in the house/business then identify energy saving methods.

ASSUMED MONTHLY ENERGY USAGE: 179 kWh

Appliances	Wattage	Hours assumed that the appliance will be on
Fridge	100	00:00am - 23:00p.m
Iron	1200	21:30pm - 22:00pm
Television	300	17:00 - 22:00
Electric kettle	1200	06:00am - 06:30am
Lights	100	06:00am - 07:00am, 18:00pm - 23:00
Fan	800	16:30pm - 18:30pm
Heater	3000	06:00am - 07:00am, 19:00 - 21:00
Stove (Hot plate)	1200	17:00pm - 20:00pm
Microwave	1200	5 minutes

Signature of the owner: Mpubi

Annexure D

PROJECT TITLE : INVESTIGATING ALTERNATIVE POWER GENERATION STRATEGIES FOR LOCAL MUNICIPALITIES THAT ARE TIED TO THE NATIONAL GRID.

DESIGNED BY : B. P TSHETLHE

CLIENT NAME : Groente Winkel

HOUSE NUMBER : 0005 Tshwaraganang street

LOCATION : Koffiefontein

OBJECTIVE OF THE ENERGY AUDIT: To determine the residential/business energy flow. Determine which electrical appliance consume more energy in the house/business then identify energy saving methods.

ASSUMED MONTHLY ENERGY USAGE: 2552.39 Units

Appliances	Wattage	Hours assumed that the appliance will be on
Computer	100	07:30am – 17:30pm
Refrigerator	1200	00:00am – 23:00pm
Lights	17	18:30pm – 23:00pm
Television	350	10:00am – 16:00pm

Signature of the owner: G Winkel

Annexure E

PROJECT TITLE : INVESTIGATING ALTERNATIVE POWER GENERATION STRATEGIES FOR LOCAL MUNICIPALITIES THAT ARE TIED TO THE NATIONAL GRID.

DESIGNED BY : B. P TSHETLHE

CLIENT NAME : Stander AJA

HOUSE NUMBER : 27 Ossewa street

LOCATION : Petrusburg

OBJECTIVE OF THE ENERGY AUDIT: To determine the residential/business energy flow. Determine which electrical appliance consume more energy in the house/business then identify energy saving methods.

ASSUMED MONTHLY ENERGY USAGE: 4807.04 Units

Appliances	Wattage	Hours assumed that the appliance will be on
Computer	500	08:00am – 18:00 pm
Laptop	175	07:30am – 16:30pm; 17:00pm – 23:00 pm
Lights	100	18:00 pm – 23:00pm; 04:00am – 07:00am
Furnace fan	875	07:30am – 19:30 pm
Vacuum cleaner	1500	06:30am – 08:30am; 17:00pm – 19:00pm
Microwave	1723	06:00 – 07:00am; 13:00pm – 14:00pm; 18:00pm – 19:00pm
Fridge	1200	07:00am – 02:00am
Security systems	180	00:00 – 23:00
Electric Kettle	2000	05:30 – 07:30am; 13:00pm – 14:00pm
Heater	3000	05:30 – 07:30 am; 07:30am – 18:30pm; 19:30pm – 23:30
Printer	100	07:30am – 20:30pm
Electric door sensor	100	00:00 – 23:00pm
Hair dryer	1500	07:00am – 24:00pm
Iron	1400	05:30am – 06:30am
Television	350	18:00pm – 23:00pm; 14:30pm – 16:00; 6:30 – 08:00
Coffeemaker	1500	06:00 – 09:00am; 19:00pm – 20:00pm
Dish washer	1500	10:00am – 12:00pm; 15:00 – 17:00pm; 22:00pm – 00:00am

Signature of the owner: ____________

PROJECT TITLE : INVESTIGATING ALTERNATIVE POWER GENERATION STRATEGIES FOR LOCAL MUNICIPALITIES THAT ARE TIED TO THE NATIONAL GRID.

DESIGNED BY : B. P TSHETLHE

CLIENT NAME :

HOUSE NUMBER :

LOCATION :

OBJECTIVE OF THE ENERGY AUDIT: To determine the residential/business energy flow. Determine which electrical appliance consume more energy in the house/business then identify energy saving methods.

ASSUMED MONTHLY ENERGY USAGE:

Appliances	Wattage	Hours assumed that the appliance will be on
Swimming pool motor	1200	16:00pm - 22:00pm
Geyser	1500	04:00 - 07:00am; 19:00pm - 22:00
Washing machine	1150	05:00am - 18:00 pm
Stove	3300	04:00 - 06:00; 12:00 - 14:00pm; 18:00pm - 20:00
Clothes dryer	5750	05:00am - 19:00 pm
Electric blanket	200	20:00pm - 06:00am
Toaster	1600	06:00am - 10:00 am
Blender	500	06:00am - 08:00am; 13:00pm - 15:00pm
Dish washer	1500	10:00am - 12:00pm; 15:00 - 17:00pm; 21:00 - 23:00pm
Hydro boil	2400	04:00am - 10:00am; 17:00 - 23:00pm
Garage door opener	550	04:00 am - 08:00am
Air conditioner	6000	00:00am - 23:00pm
Sewing machine	180	07:30 am - 17:30pm
Water pump motor	1100	03:00am - 08:00am; 14:00 - 17:00pm; 19:00 - 23:00pm

Annexure D

Link: https://ojs.3ciencias.com/index.php/3c-tecnologia/article/view/1211

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ABSTRACT

Escalating electrical energy usage and costs over the past few years has resulted in large utility bill expenses that municipalities are struggling to pay-off to National Energy Suppliers. Furthermore, some energy suppliers are struggling to meet the demand for more energy due to a variety of factors. The challenge therefore exists in identifying viable alternative power generation strategies for local municipalities to reduce their current electrical energy expenses or to provide limited power to their community when disconnected from the National Grid. An environmentally friendly renewable energy strategy method could be used to supplement the current energy requirements of a municipality during months of high energy demand. The main focus of this study will be on a small town in the Free State province of South Africa, called Koffiefontein. A battery-based solar PV system was designed in the Homer software and chosen as the renewable energy strategy to supplement the current energy needs of Koffiefontein due to its performance and cost effectiveness. The initial implementation cost of the system is $ 42 995 649.95. The cost of energy for the PV system suggested for Koffiefontein houses is $ 0.40/kWh with the yearly electricity production of 27 661 kWh. The payback period of the system is 45.3 years. The municipality needs to consider installing battery-based solar PV system to supply businesses in Koffiefontein during their high demanding hours and during load shedding as the system indicates an affordable cost of energy with high yearly production.

KEYWORDS

Solar PV Systems, Wind Turbine Systems, Load Shedding, Energy Audit.

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