A Case Study on the Viability of Electricity Generated from a Solar PV Installation as an Alternative or Supplement to Traditional Electricity Supply in Existing Buildings

By

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JSTFRE001

October 2020

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A research report for a minor dissertation presented to the Department of Construction Economics and Management in partial fulfilment of the requirements for the Masters of Science degree in Property Studies (Course Code CON5037Z).

Abstract

This research study emphasizes the global responsibility and the importance of employing alternative sources of energy that are climate-friendly. It argues against coal-based energy creation and explains why it is not a long-term sustainable solution to the global energy demand. Many countries have embraced green energy initiatives and are adopting progressive strategies to limit its carbon footprint. The research explores and compares various methods of generating renewable energy and motivates the identification of solar energy as a suitable candidate to contribute on a much larger scale to the energy demand for South Africa and abroad. The paper further researches the history of solar energy, barriers preventing large scale implementation and the solutions to bridge those barriers.

The aim of this paper is to determine to what extent technology has developed for small scale property owners to generate its own electricity supply from solar energy resources in South Africa and whether the supply generated would be sufficient to warrant consistent and uninterrupted flow compared to traditional coal-based energy resources. The cost of installation and maintenance of solar PV technology together with its financial return is investigated as well as the possibility to generate excess electricity that can be fed back into the grid. The result of the research sheds light on whether it makes financial sense to small scale building owners or managers to install a rooftop solar PV system to either generate its own stream of electricity supply or to merely supplement the traditional electricity supply from Eskom, the national electricity supplier.

The research study chose to analyse a single case study and conducted semi-structured interviews with a number of stakeholders. The case study comprised a solar PV system that has been mounted on a rooftop of a building tenanted by a private school. The financial data from the installation in addition to qualitative data arrived at the conclusion that it is financially viable for building owners or managers to install a suitably sized PV system to supplement traditional electricity supply in existing buildings.

Acknowledgements

The researcher would like to thank his supervisors, Karen Le Jeune and Saul Nurick for their patience with the researcher during the previous 2 years. The research was done under challenging circumstances.

The project is dedicated to my 2 sons born during the previous 2 years, Rael and Daniel Jooste who created the challenging circumstances.

Lastly, a special thanks to my wife Anneli for coping with me over this period. Also, thanks to my father who inspired me to keep going.

Plagiarism Declaration

I know that plagiarism is wrong. Plagiarism is the use of other's work and pretending that is my own.

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This research is my own work.

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Signed by candidate

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Abbreviations:

AC-DC	Alternate current – Direct current
BOD	Balance of System Costs
CAPEX	Capital Expenditure
CDM	Clean Development Mechanism
COCT	City of Cape Town
DCF	Discount Cashflow
DSSC	Dye Sensitised Solar Cell
EDRC	Energy and Development Research Centre
EI	Energy Intelligence
FDI	Foreign Direct Investment
FIT	Feed in Tariff
GHG	Green House Gas
GP	Grid Parity
GW	Gigawatt
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IPP	Independent Power Producer
IRP	Integrated Resource Plan
kW	Kilowatt
LCOE	Levelised Cost of Electricity
LED	Light Emitting Diode
LSC	Luminescent Solar Concentrator
MVA	Manufacturing value added
MW	Megawatt
NERSA	National Energy Regulator of South Africa
NPV	Net Present Value
PPA	Power Purchase Agreement
PV	Photovoltaic
RE	Renewable Energy
REFIT	Renewable Energy Feed in Tariff
REIPPP	Renewable Energy Independent Power Producers
REPS	Renewable Energy Portfolio Standards
RET	Renewable Energy Technology
ROI	Return on Investment
UNEP	United Nations Environmental Program
WMO	World Meteorological Organisation
Wp	Watt Peak

Chapter 1 Introduction

1.1 Introduction

This chapter establishes the foundation of the research topic. It starts with the background to the research from a global perspective, outlining the need and urgency to explore renewable energy resources as oppose to coal based energy resources that leaves behind a devastating footprint on the natural world. It motivates to what extent solar energy technologies has the potential to contribute to global energy demand and more particularly to the South African energy demand and economy. Solar energy is investigated as a potential solution globally and for the South African context. The financial model and affordability of employing solar technologies are investigated in order for it to be measured as a potential solution.

The relevant research problem, question, proposition and focus derived from literature are stated, before the objectives, methodology and limitations are defined.

1.2 Background to the study

The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 by the World Meteorological Organisation (WMO) and the United Nations Environment Program (UNEP) and has since provided policy makers with the most authoritative and objective scientific reports on climate change (Stocker *et al.*, 2013). The IPCC's Fifth Assessment Report presents unequivocal conclusions on the assessment of climate change science, in particular that there is a 95% certainty that the dominant cause of global warming since the mid-20th century can be attributed to human activity. Global efforts to mitigate climate change are rationalised by the projections of future temperatures, but the eventual equilibrium global mean temperature associated with a given stabilization level of atmospheric greenhouse gas concentrations remains uncertain (Allen *et al.*, 2009).

There are further warnings of a 50% probability of a temperature increase of 2% as a result of the warming of the atmosphere and oceans, diminishing snow and iceberg concentrations, rising sea levels and increasing concentrations of greenhouse gasses (Stocker *et al.*, 2013). A growing number of countries around the world have recorded its commitment to reduce its Carbon Dioxide (CO_2) emissions, yet despite decades of climate change discussion platforms, conventions and commitments emerging from multinational negotiations, CO_2 emissions continues to rise (IEA, 2012).

If one takes all the new developments and policies into account, the world is still failing to put the global energy system on a more sustainable path (IEA, 2012). Global energy demand is predicted to grow with more than one-third over the period up to 2035. Despite the growth in low-carbon emission sources of energy production, fossil fuels remain dominant in the global energy mix. The International Energy Agency (IEA) is satisfied that solar power has cemented its position as a renewable source of energy indispensable to the global energy mix and already grows more rapidly than any other renewable technology (IEA, 2012).

The IEA is of the view that the types of energy technology currently being developed and deployed will affect investment decisions, the cost of supply of different forms of energy and the level and composition of future energy demand. The question remains how fast existing and new technologies could be rolled out and fully used. New technologies are approaching the commercialisation phase and further cost reductions could be achieved as a result of increased learning and deployment. Production techniques are also expected to improve which lead to lower unit production costs and create new opportunities for developing resources (IEA, 2012).

The IEA's "New Policies Scenario" assumes that existing renewable energy policies and protocols that governments committed to as a result of multinational agreements are adhered to and effectively implemented. In terms of the "New Policies Scenario", coal is expected to remain the primary source of energy generation, however its share in the global energy mix is estimated to fall from 41% in 2010 to 33% in 2035, while energy generation from renewable recourses increase from 20% in 2010 to 31% in 2035 (IEA, 2012).

Renewable energy is viewed as a critical component to combat climate change and therefore most Nationally Determined Contributions (NDC's) submitted by member countries under the Paris Agreement include renewable energy as a fundamental measure to address climate change (Irena 2017). The implementation of NDC's will add at least 1.3 terawatts to the global renewable installed capacity at an investment cost of 1700 billion USD by 2030, according to the IRENA estimate.

The high upfront expense for installation of renewable technologies is one of the factors that hinder the deployment of renewable energy, however, the capital costs of energy technologies are known to decline over time due to cost-reducing technological changes, usually referred to as "learning"(Lafond F, 2017). Cost savings brought up by technological learning are especially attractive for developing countries, which are still facing rapid growths of electricity demand while also in the process of pledging their NDCs (Lafond F, 2017).

There are still technical, economic and institutional barriers hampering the contribution of renewable energy sources and more in particular, solar energy, to the global energy mix. As the awareness of global warming and other detrimental consequences of GHG grows in developed and developing countries, solutions to these barriers have been discovered and continues to develop (Aanesen *et al.*, 2012)

The South African context

South Africa, a country largely dependent on coal based energy from its abundant coal deposits, is a major contributor of GHG being emitted into the atmosphere (Banks and Schaffler, 2006). As the seventh largest coal producer in the world, approximately 77% of South Africa's electricity is generated from coal. In 2014, 232 Twh of electricity was generated from coal (2.3% if the world's coal power generation), making South Africa sixth largest producer of electricity from coal (Jain S, 2017). Coal mining impacts negatively on all three elements of environmental degradation namely land, water and air. At 437.37 Mt of CO_2 emissions annually, or 8.10t CO_2 per capita per annum, South Africa's greenhouse emissions are the highest in Africa (CRSES, 2017).

Despite having the highest electrification rate in Sub-Saharan Africa, only 55% of the rural population has access to electricity, compared to 88% of the population in urban areas. The lack of access to electricity in some parts has resulted in industrial development being restricted, this in turn resulted in the lack of opportunities for employment, low education levels and persistent poverty in rural and historically disadvantaged areas (DOE, 2015). Towards the end of 2007, South Africa endured a severe power crisis and could not produce enough electricity to meet its demand. The factors that contributed towards the crises included an increase in the internal demand from the increased population, increased economic activity, growth in construction for the disadvantaged communities by the Government, the lack of investment by the Government for maintaining the aging power grid infrastructure and failure to plan for sufficient generation capacity to meet the growing demand (Jain S, 2017).

During the three decades between 1978 and 2008, real inflation adjusted electricity prices in South Africa were allowed gradually fall to artificially low levels as the Government sought a market for Eskom's surplus generation capacity (Jesse, 2018). By 2004 electricity prices in South Africa in particular industrial consumers were among the lowest in the world. From 2008 onwards the price for electricity took a dramatic turn as the supply side crises reached a critical point forcing Eskom to introduce loadshedding. As a result, Eskom had to embark on a massive build programme to increase generation capacity. However, at this point in time the parastatal's tariffs was still relatively low with no cash reserves or the future revenue stream to finance the construction to increase generation capacity (Jesse, 2018).

In response the National Energy Regulator (NERSA) approved several sharp increases in tariffs and in the 5 years between 2008 and 2013, electricity prices more than doubled in real terms rising by a cumulative 114% while nominal prices rose by 191% over the same period. NERSA could no longer afford to comply with the extravagant price increase demands from Eskom as the public resistance to price increases continued to grow (Jesse, 2018).

South Africa found itself at a pivotal point in its evolution of energy generation and is forced to look at alternative and more importantly renewable sources of energy generation as the country faced its worst electricity supply side crises in 40 years. Regular load shedding has been implemented since 2014 and although occurring less frequently since 2016, it is predicted that the risk of load shedding will remain a grave concern for consumers. (Baker and Wlokas, 2015).

South Africa has large potential for solar and wind energy generation (Odendal N, 2017). With an average of 2 500 hours of sunshine per year, and 4.5 to 6.6 kWh/m^2 of radiation level, South Africa is among the top three in the world (Odendal N, 2017). Centrally generated power is also not successful enough in reaching remote areas because of a lack of distribution infrastructure. As a result of this, the Government of South Africa, the DOE and NERSA has developed policies and projects for the procurement and implementation of renewable energy to supplement fossil fuel-based production for greater sustainability and diversification in energy sourcing (Jain S, 2017).

The Renewable Energy Independent Power Producers Procurement Programme (REIPPPP) initiative has allocated to 92 Power Producers the potential to contribute 6 300 MW of power into the power grid mainly from solar and wind generation. The government support of green energy initiatives has led to a reduction in energy production costs, job creation, foreign investment and the support of local stakeholders. However, a number of impediments must first be bridged before South Africa will reap the benefits from assimilating this new industry (Jesse, 2018).

The DOE introduced the Integrated Resource Plan (IRP) in 2010 which initially presented a breakthrough for electricity planning in South Africa. For the first time the proses involved extensive stakeholder involvement and it introduced greenhouse gas emissions constraints (Mccall B, 2019). It is however out of date as since 2010 renewable energy costs have fallen significantly in South Africa and abroad, national electricity demand has been stagnant for a decade and South Africa is committed to doing its part under the Paris Agreement (Mccall B, 2019). The draft IRP 2018 which addressed in part the shortcomings of the earlier IRP is discussed in the following chapter together with impediments the renewable energy sector face currently in South Africa.

There are several renewable energy sources in existence that can benefit South Africa. These sources include amongst others, solar energy, wind, biomass, hydropower, wave power and geothermal. Solar can be broken down further into solar thermal (for heating), solar thermal electricity generation and solar photovoltaic (PV) electricity generation (Winkler, 2005).

An evaluation to determine which source has the most potential, must consider the technical, economic and market potential for capturing energy and match this with qualities unique to South Africa's topography, climate and socio economic conditions (Winkler, 2005). As the DOE (2015) have identified solar energy as the largest source of renewable energy due to South Africa's topography and climate, the research study focuses on solar PV electricity generation.

Kurokawa *et al.* (2007) estimated that PV cells installed in 4% of the world's desert surface areas would produce sufficient electricity to satisfy the demand for global energy consumption. For example, in China, if 1% (26 300 square meters) of its wasteland located in the dimly populated western and northern regions is covered with solar voltaic cells, it could generate 1300 GW of electricity. This is approximately double the electricity demand projected for China for the year 2020 (Hang *et al.*, 2007). Similarly, if an area of 23 418 square meters of the sunny south west of the United States was covered, it could match its present generation capacity (Mills and Morgan, 2008).

Figure 1 compares the technically feasible potential of various renewable energy options using the present conversion efficiencies of available technologies. In most regions in the world and South Africa in particular, the technical potential of solar energy far outweighs the current total primary energy consumption (Timilsina *et al.*, 2012). It remains the largest source of renewable energy supply. Solar energy is the most suitable candidate to satisfy South Africa's growing electricity demand. South Africa being a sub Saharan country has a suitable climate all year around producing an unending supply of solar energy to be harnessed in the form of electricity from PV cells (Winkler, 2005).

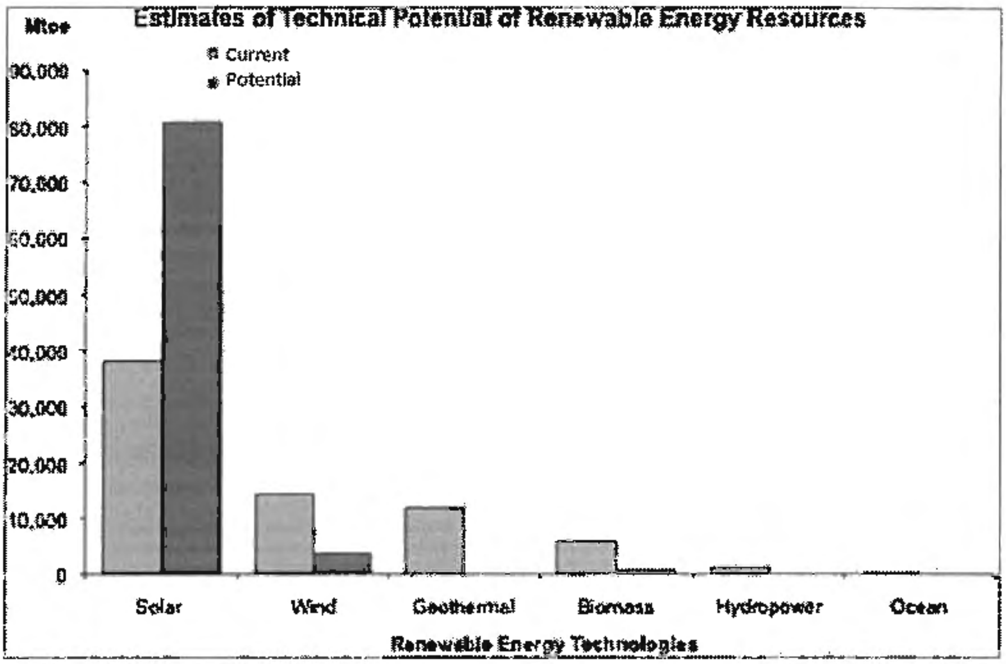

Figure 1 Estimates of Technical Potential of Renewable Energy Resources (Winkler, 2005)

The decision whether to roll out a solar PV installation project is first and foremost going to depend on whether the product and installation costs is financially justifiable from the perspective of a small-scale property owner. The study is going to investigate whether the existing economic climate in South Africa is conducive towards renewable energy initiatives like a rooftop PV installation. The question whether it is more beneficial to the owner of an installation to merely supplement electricity flow compared to replacing the full energy demand with solar power is answered and the economic consequences of doing so is discussed. It is further discussed at which point a solar PV installation becomes beneficial to its owner within the larger framework of emerging South African energy politics and South Africa's responsibility to the environment.

To investigate these issues, the study has focused on actual data from a sample rooftop PV model that has been factored into a discounted cash flow calculation to arrive at a conclusion from an investment point of view from the perspective of a small-scale property owner.

1.3 Problem Statement

The problem to be examined in this study can be described as follows:

Little is known about at what point does it become more feasible from the perspective of a small-scale property owner to install a rooftop PV system to supplement electricity flow from Eskom or whether to install a system capable of producing total power to meet its particular electricity demand.

1.4 Research Questions

The research questions to be answered in this study can be phrased as follows:

Question 1:

To what extent has solar technology advanced to the extent that it can provide uninterrupted electricity flow to meet the demand in Kilowatt output as required by an existing building during loadshedding?

Question 2:

To what extent can a building owner/tenant be completely reliant on the energy generated from a solar PV system or is it more feasible to only employ the solar PV system as a supplement to Eskom's electricity supply?

Question 3:

At which point does it become worthwhile for building owner/tenant to install a solar PV system to provide total power independently from Eskom.

Question 4:

At which point does it become financially justifiable for a building owner/tenant to install a solar PV system?

Question 5:

What is the payback period in order for the building owner/manager to finance the rooftop PV system purely in electricity savings?

1.5 Research Proposition

The research proposition to be tested in this study is as follows:

Installing a rooftop solar PV system in a grid connected area is more beneficial to a building owner/tenant to supplement centralised electricity supply as opposed to complete reliance on a solar PV system to meet the required electricity demand.

1.6 The Research Aim of the study

The research aim of the study may be stated as follows:

To establish the viability of installing a rooftop PV system on an existing building from an investment perspective by comparing the levelised cost of electricity generated from a PV system as a supplement to electricity supply from Eskom as opposed to complete reliance on electricity generated by the solar PV system.

1.7 Research Objectives

The research objectives to be achieved by the study are:

i) Investigate whether solar technology has developed to the extent where it not only serves a niche market, but is accessible and affordable to most small-scale property owners.

ii) Investigate the barriers to large scale deployment of solar energy and solutions in South Africa.
iii) Determine whether South Africa's social and environmental responsibility to comply with the Paris agreement regarding producing green energy is being followed.
iv) Determine the costs and affordability for building owners or managers to install and maintain a solar PV system.
v) Investigate the municipal savings yielded by a rooftop PV system
vi) Determine whether it is possible and feasible to feed excess electricity generated back into the national grid and whether it is cost effective to set up a system to allow for this option

1.8 Methodology

The research project is based on a single case study of a small scale solar PV installation of a private school in the Western Cape. The outcomes of the main focus and objectives of this research have been achieved through the following:

i) Literature review of recent articles, initiatives and legislation
ii) A single case study with resulting data unique to this research project
iii) Multiple semi structured interviews with industry stakeholders
iv) Detailed interpretation of qualitative and quantitative data
v) Conclusions and recommendations presented in support of hypothesis

1.9 Delimitations

The following limitations apply to the research study.

i) The research employs a single case study approach to test the proposition and therefore places limits on the reliability and replicability of the study. The parameters are relatively small and more observations to test the hypothesis is generally preferable, but due to the unique nature of the study and scarcity of comparable commercial data, the researcher had to work with the available data on offer.
ii) The type of tenancy could have a significant influence on the level of electricity demanded by the building. The reader must consider that the size of the solar PV system which ties with the installation costs is limited to serve the electricity demand of the tenant, which in this study is a private school.
iii) The solar PV system with resultant data has been running since January 2014 which means the data is less than 3 years old at the stage of conducting research. The length of the project is ultimately 30 years and currently still in its infancy stages. Certain projections were used regarding inflation rates and tariff increases that is subject to change during the life of the project.
iv) The reader must consider that the data from the solar PV installation is unique to its location being in the Cape Town City Centre, Western Cape Province. This location experience seasonal weather

patterns typical to the Western Cape climate. Data interpretation from a different region might yield different results.

v) The case study commenced in 2014 and is still operational. During the last 5 years solar PV technology advanced significantly leading to a decrease in cost parameters with regard to parts, maintenance and the overall installation. The decrease in price as a result of changes in production technology and the sector learning curve is not factored into the case study model, it is limited to the price parameters available in 2014.

vi) The building size, rooftop space and kW power output demand for the particular tenant justifies a solar system size of 10 KW. Under different parameters the size of the solar PV system and resultant data might differ.

vii) The study is undertaken from the perspective of a small-scale private property owner requiring uninterrupted electricity flow. A model is developed to serve this purpose.

1.10 Structure of Report

The research report has been structured as follows:

Chapter 2 comprises of a critical review of research relating to the study, in particular a background to the development of solar energy technology, it's potential to contribute and the barriers faced by the solar energy industry limiting its potential. The literature also reviews the solutions to historical barriers encouraging the large-scale deployment of solar energy technologies.

Chapter 3 is dedicated to the research methodology employed in the study. The research methodology selected was designed to provide answers to the research proposition, problem statement, research question and research objectives in a practical manner and not just in theory. It was selected in order for the research to be followed and understood by regular building owners/managers faced with the decision whether it is justifiable to invest in a rooftop PV system.

Chapter 4 presents the findings of a single case study, semi-structured interviews and case study analysis with the purpose to support or refute the research proposition and research objectives.

Chapter 5 provides conclusions, with specific focus on the aims and objectives stated in Chapter 1. The proposition is readdressed. This chapter closes with thought for future research.

Chapter 2 Literature Review

2.1 Introduction

This chapter serves to present literature related to the energy transition the world is facing and South Africa in particular. The importance of renewable sources of energy is highlighted and the focus shifts to solar energy as the solution with the most potential. The literature in this chapter highlights barriers to large scale deployment of this energy resource as well as the solutions to those barriers. It furthermore briefly reviews technical aspects of solar energy together with its historical contribution to world markets including the "boom-bust cycle" experienced by the industry. Recent trends in adoption of solar energy is discussed from a global perspective followed by a comprehensive analysis of the South African context. A logical argument is formed why this study is required from a South African perspective.

2.2 The case for renewable energy

Sorenson (2008) regards renewable energy as the product of matter being converted from earthly resources at a rate no faster than that at which the resources are replenished. According to Winkler (2005), energy is a vital component to the survival and development of South Africa's economic and social infrastructure. Providing a reliable energy supply that is affordable to most South Africans remains a challenge, especially because access to electricity has increased from one-third to two thirds of the population since 1994 (Winkler, 2005).

Besides growth in demand that has increased rapidly over the last two decades, the fact remains that the existing reliance on fossil fuels is not sustainable in the long term for the following reasons:

- <u>Finite Resources</u>

  The main source of energy supply in South Africa is coal based. Although South Africa has sufficient coal deposits to last for another century (Jeffrey, 2005), the source remains finite, deteriorating in quality and the government is struggling to maintain existing power plants in addition to bringing new plants on line (Banks and Schaffler, 2006).

- <u>Unsustainable extraction costs</u>

  Coal has various alternative uses that must be preserved for future generations. Carbon resources may have a far greater value in future, and should not be burned unnecessarily while other resources are available to fulfil the same purpose (Banks and Schaffler, 2006).

- <u>Green House Gas (GHG) effect</u>

  The burning of carbon-based fossil fuels like oil and coal result in the emission of carbon dioxide that is responsible for the GHG effect. This is the predominant contributor to manmade global warming that is having a devastating impact on global weather conditions, agriculture and sea levels. South Africa is one of the top 20 GHG producers in the world and emits 379 million tonnes of carbon dioxide equivalent GHG per year (World Energy Council, 2003).

- Energy price volatility

  Unpredictable fluctuations in energy prices and significant economic and social consequences (Banks and Schaffler, 2006).

- Negative knock on effect

  Fossil fuel use has a negative impact on other valuable natural resources. For example, every MWh of electricity generated from coal requires an average of 1 270 litres of water that is unjustifiable for a water scarce country. Coal mining leads to air pollution and environmental degradation from acid mine drainage (Stocker *et al.*, 2013).

- Nuclear power technology outdated

  It has been argued that nuclear energy might be the answer to reduce South Africa's reliance on fossil fuels. Nuclear power stations have low greenhouse gas emissions and there are sufficient nuclear fuel resources available in South Africa (Adam *et al.*, 2011).

However, the idea of nuclear electricity caused outrage from various non-governmental organisations (NGO's) and environmental groups. The organisation Greenpeace, launched compelling arguments based in fact in their 2011 report called "The True Cost of Nuclear Power in South Africa" in relation to the current government that appears to be willing to find any excuse to build nuclear reactors.

The Greenpeace report states that the ANC, at the time still in exile, denounced the apartheid regime's decision to acquire nuclear technology. South Africa has one nuclear reactor built in 1984 and 1985 in Koeberg, the Western Cape. It was designed to generate a total capacity of 1.844 MW, about 6% of South Africa's electricity needs. The ANC, while never committed to dismantle South Africa's nuclear power industry, publicly vowed it would never again allow any decisions about nuclear power to be taken behind closed doors. Despite the aforementioned, 6 days after the Fukushima nuclear catastrophe in Japan, March 2011, the Minister of Energy at the time, announced the country's intention to add 9.600 MW of nuclear electricity in the form of six new nuclear reactors (Adam *et al.*, 2011). The nuclear programme has since been a topic of controversy as various independent studies described it as being unaffordable to the South African economy and providing a breeding ground for political corruption (Paton, 2015).

Nicks (2013) believes that despite the risks involved in producing energy from nuclear reactors, it does make financial sense. He compared the cost per kwh generated from a new Finnish nuclear plant over the next 20 years compared to a comparable solar plant in Germany and found that solar electricity will cost almost five times more for every kwh of electricity compared to electricity produced by Finland's nuclear plant.

According to Adam *et al.* (2011), nuclear power plants have aside from financial requirements, a long verifiable history of performance that reflects poorly on it as a sustainable option to create energy. The nuclear disasters in Japan and Russia are widely known and constitutes the worst-case scenario to deploy this type of technology. From a practical perspective, nuclear reactors produce radioactive nuclear waste that must be treated at considerable cost and dumped in designated areas.

Radioactive effluent creates a significant health hazard to humans, animals and the environment. It is described by the Executive Director of Greenpeace International as expensive, dangerous, polluting and non-democratic. There is a growing aversion in the modern world of nuclear power generation. It is viewed as an outdated and dangerous source of energy for its consumers (Adam *et al.*, 2011)

2.3 Barriers to the development and large-scale deployment of solar energy in national energy systems

Solar energy technologies are not yet competitive with conventional technologies despite a large drop in capital costs and a dramatic increase in price for fossil fuels in addition to the detrimental environmental externalities caused by fossil fuels (Timilsina *et al.*, 2012).

The minimum values of levelised cost of any solar technology is higher than the maximum values of levelised costs of conventional technologies for the generation of power, even if capital costs of solar technologies were reduced by 25%. This remains the primary barrier to the large-scale deployment of solar energy technologies. The industry is furthermore constrained by technical, economic and institutional barriers (Timilsina *et al.*, 2012). Pegels (2010) agrees with this statement and concludes that South Africa in particular is mainly constrained by its present and historical reliance on coal-based energy and the comparative economies of scale faced by the renewable energy industry.

A well-established body of published research exists regarding the engineering dimensions of solar energy, yet literature dealing with economics and policies influencing the solar industry is relatively scarce (Neij, 2008). The following section identifies the major technological, economical and institutional barriers inhibiting the advancement of the solar industry.

2.3.1 Economic barriers

Cost comparisons between conventional electricity technologies and solar energy technology is the primary economic barrier for the PV industry (Wamukonya, 2007). BOS equipment costs (parts excluding PV panels such as wires, switches, inverters and labour for installation) represents more than 50% of the cost of a PV system (Aanesen *et al.*, 2012). The high upfront capital investment required for a PV system has steadily been decreasing as new technology came to the forefront (Timilsina *et al.*, 2012).

It is still an uneven playing field as conventional technologies have a long history of accumulated industry experience with a tried and tested track record of structuring economies of scale to its significant advantage, without calculating the costs of harmful social and environmental externalities. This is why the relatively high initial cost and lack of simple and consistent financing options remains of the largest barriers particularly in developing countries (Beck and Martinot, 2004).

Financial institutions are cautious about financing solar energy programmes. Compared to conventional technologies, solar energy technology is regarded as high risk as a result of its short history, long payback periods and relatively small revenue stream. If finance is granted, it is usually at high interest rates that adds additional pressure on the economic feasibility of a solar energy project (Margolis and Suboy, 2011).

According to Rickerson *et al.* (2007), the cost of BOS equipment is not declining proportional to the decline in module price.

2.3.2 Technological barriers

Barriers from a technological perspective include low conversion efficiencies of PV models. For example, the efficiency constraint for thin film is around 4 -12% and under 22% for crystalline (EPIA/Greenpeace, 2011).

Studies performed by Hernandez-Moro and Martinez-Duart (2013) found the inverter efficiency during AC-DC conversion to be 85%. PV modules are also exposed to ultra violet radiation and deteriorates on a yearly basis leading to reduced efficiency of PV modules over time. Hernandez-Moro and Martinez-Duart (2013) calculates the degradation factor on a yearly basis to be 0.6%.

Performance limitations of system components have been a factor for some time. This includes batteries, inverters and other power conditioning equipment (O'Rourke *et al.*, 2009). The lack of technical support for installation and maintenance poses a further barrier (Wamukonya, 2007).

Storage facilities for generated energy is one of the most expensive parts especially with off-grid PV systems. The electricity generated from rooftop panels is the highest during midday and available for use immediately, however the peak hours for electricity demand in residential areas is often during the morning or after sundown. This means the electricity generated has to be used or sold immediately or stored at great expense (Bazilian *et al.*, 2013).

Furthermore, the supply of certain raw materials required for the manufacture of essential components became problematic (Timilsina *et al.*, 2012). Heavy demand for solar energy outpaced supply in 2005 and the supply for cadmium and tellurium in thin film cells became scarce as they are by-products of zinc mining and copper processing industries.

Finally, there are constraints regarding system design and integration as well as operating experience for system optimisation. For the system to work property, it requires adequate infrastructure to interconnect for problem free metering and billing (Florida Solar Energy Centre, 2000).

2.3.3 Institutional/Legislative barriers

The lack of effective and appropriate policy or policy making instruments such as enforceable regulations or legislation to advance wider adoption is restraining the advancement of the solar energy industry (Timilsina *et al.*, 2012).

South Africa in particular has made vast progress in this respect, but policies do not yet adequately encourage small-scale PV based energy generation. The lack of incentives for small scale electricity producers poses a significant barrier in South Africa (Ndanga and Gorn, 2012). Sebitosi and Pillay (2008) is of the view that the political climate in South Africa has not been conducive to the promotion of renewable energy.

Net metering for example refers to the credit received for feeding excess electricity back into the grid. It has been employed very successfully in other countries to justify private investment in residential solar

PV systems. This potential has not been harnessed in South Africa as result of policy constraints (Ndanga and Gorn, 2012).

Most countries lack the enthusiasm to train an adequate number of technicians to effectively work on a new solar energy infrastructure. It is a well-known fact that only a very small percentage of the workforce is trained to install and maintain solar energy systems. Unless new policies are adopted in this regard, the industry will advance at a very slow pace (Timilsina *et al.*, 2012).

2.4 Solutions to barriers

Solutions to bridge the aforementioned technological, economic and institutional/legislative barriers to encourage large scale deployment of solar energy technologies internationally and South Africa in particular is discussed below.

2.4.1 Bridging Technological barriers

Low conversion PV efficiencies have improved significantly during the last decade. Dr. Neil Robertson of the Department of Chemistry in the University of Edinburgh, a renowned expert in solar PV economics, is working on two low cost devices called "dye-sensitised solar cell" or DSSC, and a light collecting device called a "luminescent solar concentrator" or LSC. Both technologies are more efficient at absorbing lower levels of sunlight, including diffuse light which passes through clouds (Barr, 2016).

Dr. Robertson is excited by the prospects of DSSC in developing countries as it is a highly cost-effective alternative to existing PV devices. DSSC units can also be manufactured very thin and flexible enough to be attached to clothes or rucksacks (Barr, 2016). Wamukonya (2007) is of the view that technical support for installation and maintenance can be bridged by training of technicians and user-friendly manuals. PV technology development should be supported by common standards and regulations being enforced by government.

Solutions to technological barriers have been forthcoming during the past few years to overcome historic challenges has been invented. The storage of electricity after being generated used to be problematic as this particular component was disproportionally expensive compared to other components. Technology entrepreneur and the founder of the American group Tesla, Elon Musk, has announced that his PowerWall battery technology is already on the market (Williams, 2016). This battery and converter system, linked to a rooftop solar PV installation, is capable to capture and store electricity generated during the day for use during hours of peak electricity demand. This technology is aesthetically pleasing to look at, claims to save up to 70% of the standard monthly electricity bill and can be purchased for approximately 170 000 ZAR in South Africa (Williams, 2016).

2.4.2 Bridging economical barriers

According to Aanesen *et al.* (2012) manufacturers should examine every operational step to identify opportunities to reduce costs. Consider lean productions approaches, implementing category-based procurement processes, develop strategic relationships with suppliers and streamline supply chains. BOS equipment costs may be reduced by implementing techniques such as modularisation, preassembly, standardisation and automation which is common in mature industries. Manufacturers in the solar industry are already developing components with durability in excess of 20 years (Aanesen *et al.*, 2012).

Wamukonya (2007) suggests that large upfront capital investment problem be solved by the removal of levies and taxes that might be required as a result of the installation of the system. Countries must consider micro credit facilities, loan schemes and subsidies to support the industry of rooftop solar PV systems.

In California, the PV market is being transformed as a result of the option to lease a PV system from the supplier, instead of purchasing a PV system. The high upfront costs can be eliminated by leasing the PV system on an instalment basis. This method is gaining momentum as it offers the PV system to a larger segment of the market (Drury *et al.*, 2012).

In the effort to make solar technology companies more competitive from an economical perspective, solar technology companies should attempt to understand their customers and their particular electricity demands. Companies ought to understand solar conditions in the area where customers are located, the space required and available for solar application and the level of power required during different times of day throughout the year (Aanesen *et al.*, 2012).

Securing low cost financing for solar projects is critical. Companies could explore strategic partnerships with organisations to gain access to low cost financing. As the solar investment pool is boosted, financial institutions, asset managers and professional investors will be drawn to the sector. Industry players that manage to reduce costs, develop value propositions to target the needs of particular segments and succeed to strategically navigate the evolving regulatory landscape, are bound to reap significant rewards (Aanesen *et al.*, 2012).

Affordable financing options are vital to develop solar energy and various countries has embarked on programmes in conjunction with their financial institutions to develop renewable energy financing portfolios. For example, the Spanish government has launched an initiative of low-interest loans for solar applications (Winkler, 2005)

2.4.3 Policy instruments to support solar energy development

The most effective way to grow the renewable energy industry in a particular country, is for the government to get involved and play an active part in promoting renewable energy in the electricity sector. The first item on the government's agenda ought to be to set a realistic target and make it a requirement that a small but growing percentage of electricity supply must come from renewable resources (Winkler, 2005).

Recent studies on energy and climate change have shown that a combination of the aforementioned two strategies are likely to be the most effective in realising the greatest environmental and economic benefits (Krause *et al.*, 2002). A significant deployment of renewable energy in South Africa will not be possible unless major policy incentives are introduced by government. Policy instruments to implement such a target usually include either regulating the quantity of renewable electricity or fixing prices through regulating tariffs (Winkler, 2005).

Recent studies on energy and climate change have shown that a combination of policy tools is likely to be the most effective in realising the greatest environmental and economic benefits (Weitzman, 1974).

2.4.3.1 Feed-in tariffs (FIT) for renewable energy

A Feed-in-Tariff (FIT) refers to a premium or tariff payment made to renewable energy technologies which are normally more expensive to produce than conventional technologies for the generation of electricity. The idea is to compensate the producer for the cost of the electricity produced plus a reasonable profit on top of that. A FIT is designed to drive investor confidence in new and innovative technologies that would ultimately contribute in driving down the costs of these technologies (Winkler, 2005).

FIT's has been implemented in over 75 countries around the world including South Africa. It is widely known as one of most effective policy instruments to boost solar, wind and biogas technologies (Commission of European Communities, 2008). A FIT is an example where price is used as a policy instrument. A price is set for renewable electricity usually differentiating tariffs between different technologies. Tariffs are set by an electricity feed-in law and guaranteed for a specific period of time (Winkler, 2005).

2.4.3.2 Renewable energy portfolio standards (REPS)

Many countries have introduced targets for renewable energy in total electricity supply mix on national and provincial levels. To meet these targets, suppliers are obliged to add a certain percentage of electricity generated from renewable electricity technologies to the mix. These standards are known as renewable energy portfolio standards (REPS). In effect, utilities with no or limited levels of renewable energy are required to buy from those utilities with high renewable electricity content, stimulating a healthy trading regime (Winkler, 2005).

2.4.3.3 Income tax incentives and subsidies

Several types of investment tax credits and subsidies have been implemented around the world to promote solar energy technologies. Government subsidies have had the most significant influence on solar energy development. It can take the form of investment grants or capacity payments, production or output based payments or soft loans (Commission of European Communities, 2008).

2.4.3.4 Net metering

This is the system where households or commercial establishments are allowed to sell excess electricity generated from solar technology back into the grid. It has been implemented successfully in several countries. The idea is to receive the same price for generation as the retail tariff. The amount that can be fed back into the grid is usually capped to the customer's total annual consumption (Winkler, 2005). Net metering has been implemented successfully in Australia, USA, Canada and various European countries (Timilsina *et al.*, 2012).

2.4.3.5 Creating enabling environment for renewable electricity

Winkler (2005) argues that an enabling environment for renewable electricity can be created by allowing non-discriminatory access to the grid, offering Power Purchase Agreements (PPA's) to Independent Power Producers (IPP's) and by providing funding for research and development on renewable energy. More

PPA's offered to IPP's would result in the grid being supplied with green energy to be fed back to consumers.

2.5 Trends unfolding in PV technology

2.5.1 Brief History

Around the 1860's a range of technologies were developed to generate steam by capturing the sun's heat. This was used predominantly to run engines and irrigation pumps (Smith, 1995). In 1954, Solar PV cells were invented at the Bell Labs in the United States and has originally been used to generate electricity for space satellites (Hoogwijk, 2004).

2.5.2 PV technology

PV technology converts radiant energy in the light quanta (elementary particle of light and other electromagnetic radiation) into electrical energy when light falls upon semi-conductor material, causing electron vibration and strongly enhancing conductivity. Two types of PV technology are common on the market: (a) crystalline silicon-based PV cells and (b) thin film technologies consisting of a range of various semi-conductor materials, including amorphous silicon, cadmium-telluride and copper gallium diselenide. A photovoltaic module has no moving parts and existing manufacturers guarantee their products for 20 years (Hoogwijk, 2004).

A PV installation consists of PV modules and Balance of System (BOS) equipment, including inverters, cables, installation equipment and mounting structures. The BOS equipment refers to materials not essential to the actual generation of solar energy but contribute to more than half the cost of the PV system (Aanesen *et al.*, 2012). Inverters perform the function of converting alternate electricity current into direct electricity current in order for it to be absorbed into the electricity grid. Installation equipment and mounting structures refers to the parts and materials used to mount the PV installation on the roof of a building or in a suitable open space from where the PV system would receive the optimum amount of sunlight. These parts or materials can be sourced locally or from international sources at varying prices. It is the BOS equipment that traditionally drove the capital cost portion of a PV system to the extent that it compared unfavourably with the cost of coal based electricity generation (Timilsina *et al.*, 2012).

The electricity produced from a PV system can be expressed as follows (Photovoltaic-software.com, 2016):

E = A x r x H x PR

E: the annual electricity production in kWh

A: the total area PV

r: the solar panel yield (kWp/area of 1 panel)

H: the solar irradiation (kWh/m2/year)

PR: is the performance ratio (%)

2.5.3 Boom-bust cycle and cost trends – a brief history

Solar energy technology became known after the 1970 oil shock and countries seemed interested in the development and commercialisation of this technology. The initial momentum carried forward during the 1970 and 1980's collapsed as a result of a sharp decline in the price of oil and a lack of sustained policy support (Bradford, 2006) .

In the year 2000, the industry experienced a renewed interest for growth and development. It was initially nurtured in Germany, Japan and the United States and later in Italy where government support led to a boost in demand and assisted manufacturers to increase capacity, reduce costs and improve technologies (Aanesen *et al.*, 2012).

The price for residential customers to install a PV installation dropped from about 100 US dollars per watt peak (Wp) in 1975 to 8 US dollars per Wp by the end of 2007. Soon after, other countries including Canada, France, South Korea, Australia, India, China and South Africa developed support programmes to foster and encourage growth of national solar sectors within their borders (Aanesen *et al.*, 2012) further states that as result of this recent promising energy venture, Chinese manufactures started to target other foreign countries where demand was driven to a large extent by government subsidies. With cheap equipment and inexpensive labour, the Chinese manufacturers managed to steer prices down from 4 US dollar per Wp in 2008 to about 1 US dollar per Wp in 2012 (Bazilian *et al.*, 2013).

Government subsidies in the end laid the foundation for the boom of the solar industry from 2005 to 2008. This period saw technology development advance and the pace of innovation accelerated, making solar PV economically attractive for many consumers. However this also created the foundations for a "bust" scenario from 2009 to 2011 where large scale, low cost Chinese manufacturers entered the market space, manufacturing capacity increased significantly and the market became oversupplied (Aanesen *et al.*, 2012).

Prices dropped significantly increasing pressure on margins and government subsidies steadily decreased as the world entered a global economic crisis. The shale-gas boom also had an influence to a minor extent and the industry briefly appeared to have run its course. But according to Aanesen *et al.* (2012) page 4:

"... these are natural growing pains, not death throws. The industry is entering a period of maturation that is likely to set the conditions for a more stable and expansive growth after 2015. To succeed in this environment, companies must turn their attention to the relatively prosaic objective of reducing costs without giving up on the imperative to innovate, which has been critical to success thus far".

It was estimated that the cost of a commercial-scale rooftop system could be reduced by 40% by 2015. More particularly, 1.70 USD per Wp, and another 30% by 2020 to nearly 1.20 USD per Wp (Aanesen *et al.*, 2012).

The cost of solar energy technology has dropped substantially over the last 30 years. Bazilian *et al.* (2013) predicts that prices will continue to drop as a result of the global supply of PV cells and modules, estimated to be greater than 50GW, currently outweighing global demand, estimated to be between 26GW and 35GW.

Despite the boom-bust cycle between 2005 and 2011, the solar energy market expanded significantly during the past decade and this growth can be attributed to various policy instruments including the Kyoto Protocol adopted in 1997 and the Paris Agreement of 2015.These international agreement reflects the volatility of fossil fuel prices and the national responsibility of all countries to limit GHG emissions into the atmosphere (Stocker *et al.*, 2013). Kurokawa *et al.* (2007) is of the view that solar energy has the resource potential to far exceed global energy demand, yet despite the industry's impressive growth statistics, the contribution to the global energy supply mix is still negligible.

2.6 Recent Trends regarding the rapid adoption of renewable power globally

The upward global market trend for renewable energy technologies remained relatively stable between to 2019 (REN21, 2019). Total renewable power capacity in 2018 grew at a consistent pace compared to 2017 and the amount of countries integrating high shares of variable renewable energy (VRE) continues to expand (Motyka M, 2018).

Renewable energy has been established as a mainstream source of electricity generation worldwide for several years. According to REN21 (2019), the estimated share of renewables in global electricity generation was more than 26% by the end of 2018. Net capacity additions for renewable power were higher than for fossil fuels and nuclear combined for a fourth consecutive year, and renewables now make up more than one-third of global installed power capacity. This is due to stable policy initiatives and targets that sends positive signals to the industry, along with decreasing costs and technological advancements (REN21, 2019).

Renewable power has become more cost-competitive than conventional fossil-fuel fired power plants. By the end 2018, electricity generated from new solar PV plants and wind farms had become more economical in many countries. Record low bids in tenders for renewable power, especially for solar and wind were recorded in several countries all over the world (Froese M, 2018).

Renewable energy targets are in place in nearly every country and several has made their targets more ambitious in 2018 in line with their commitments under the Paris Agreement. The signatory states of the United Nations Framework Convention on Climate Change (UNFCCC) agreed on the first document with legally binding obligations for limits of reductions of GHG emissions in 1997, called the "Kyoto Protocol". The period of applicability was set for the years 2008 to 2012 and 2013 to 2020. In order to maintain international climate protection after 2020, a new climate agreement was adopted in 2015 called the "Paris Agreement". For the first time, a specific target was included to limit global warming at a level of at least 2 degrees Celsius below the pre-industrial level of 1750 (Jacobsen M, 2018).

In developing and emerging economies, distributed renewable energy systems continue to play a vital role in connection communities in rural and remote areas to electricity services. An estimated 5% of the population in Africa and 2% of the population in Asia has access to electricity via off-grid solar PV installations. In 2017, the global population with no access to electricity decreased to below 1 billion, with approximately 122 million people worldwide gaining access since 2016 (REN21, 2019). In the power sector, renewables are increasingly preferred for new electricity generation. It is estimated that 181 GW of renewable power capacity was added in 2018. Overall, renewable energy now accounts for around one-third of total installed power generation worldwide. Nearly 64% of net installations in 2018 were from renewable sources of energy, making it the fourth consecutive year that net additions of renewable power were above 50% (REN21, 2019).

Despite the success curve renewable energy has shown the last 10 years, many countries continue to invest and develop new coal-fired power plants 2018, turning a blind eye towards multiple benefits, such as improved public health through reduced pollution, increased reliability and job creation (Carbon Brief, 2019).

2.7 Initial trends in the South African renewable energy sector

South Africa is fortunate to have coal deposits sufficient to last for another 300 years (Tsikata and Sebitosi, 2010). It is even more fortunate for the country to have unlimited Renewable Energy (RE) resources available notably in the form of solar and wind (DOE, 2015). According to a report issued on the state of renewable energy in South Africa by the Department of Energy, South Africa receives more than 2500 hours of sunshine per year at an average solar radiation level of between 4.5 and 6.5 kWh/m^2, placing it in the top three countries in the world for renewable energy generation (DOE, 2015).

The report reviews the policy framework within which South Africa's commitment to renewable energy technologies (RET's) was set out and paved the way to South Africa's existing RE status. South Africa ratified the United Nations Framework Convention on Climate Change in 1997 as well as the Kyoto Protocol in 2002, however the noteworthy developments in South Africa's commitment to RET programs came many years later.

White Paper on Energy Policy (WPEP) of 1998

The adoption and publication of this policy led to the recognition in the early 1990's of opportunities in the development of RET's. The team formulating the policy consisted of collaboration between policy makers and research institutions including the Energy and Development Research Centre (EDRC). It was recognised that RET's would eventually become cost competitive and cost effective over time (Department of Minerals and Energy, 1998). The exploitation of South Africa's vast RE resources would furthermore create valuable opportunities for the South African economy and this policy laid the initial foundation for development of the RE industry (DOE, 2015).

White Paper on Renewable Energy (WPRE) of 2003

The adoption and publication of this policy formulated the first targets to promote RET's in South Africa. It identified financial instruments, legal instruments, technology development, governance and awareness raising, capacity building and education as the five key facilitation areas to enable large scale deployment of RET's (Department of Energy, 2003).

As a result of this policy being implemented, South Africa's RE market gained significant momentum and was recognised internationally for its ambitious targets and achievements for progress made with RET's. It gave South Africa's president the confidence in Copenhagen 2009 to provide an undertaking, that South

Africa is committed to reduce its carbon dioxide emissions by 34% by the year 2020 progressing to 42% by the year 2025 (compared to its past average yearly emissions baseline) (DOE, 2015).

National Climate Change Response White Paper (NCCRWP)

This policy and adopted and published in 2011 and its main focus was to motivate and monitor the implementation of climate change mitigation programmes across various sectors of the South African economy (Department of Energy, 2011). The Electricity Regulations Act promulgated in 2006 and the New Generation Capacity Regulations issued have been vital as key legal instruments for the South African government to capture the potential for RET advancement under the Renewable Energy Independent Power Producers Programme (REIPPP), launched August 2011 (DOE, 2015).

The Integrated Resource Plan (IRP) 2010-2030, as contained in the Government Gazette of 6 May 2011, reflects the government's energy strategy for the next period until 2030. The IRP recorded a target of 17800 MW new generation capacity set aside for renewable energy sources (DOE, 2015).

Renewable Energy Feed-In-Tariffs (REFIT)

In order to facilitate the introduction of RE into the national power grid, South Africa approved the process of a renewable energy feed-in-tariff (REFIT). It was regarded as the "tipping point" launching the development of RET's in South Africa on an unstoppable course (Baker and Wlokas, 2015).

The effect of REFITs was accelerated as a result of the electricity supply crises resulting in rolling black outs endured by South Africa. The National Energy Regulator of South Africa (NERSA), declared the REFIT schedule in 2009. The rate suggested aimed to cover generation costs plus an after tax return of 17% fully indexed for inflation (DOE, 2015).

The actual implementation was facilitated through a competitive bidding system in terms of which the REIPPP captures the REFIT rate. The bidding process is a useful tool to unlock the potential for lower prices while still providing adequate incentives for market entry by new RE investors (DOE, 2015).

Progress made by South Africa through Renewable Energy innovations

A UNEP 2014 Report placed South Africa in the top 10 countries in respect of RE investments (DOE, 2015). Thus far, a total of ninety-two Independent Power Producers have secured contracts with the government of produce RE with a combined capacity of 6327 MW.

According the DoE's report, more REIPPP projects will be directed to poor and rural areas labouring under high unemployment numbers in order to stimulate the local economy. REIPPP has attracted in excess of R53.2 billion in foreign investment up to 2015. Foreign equity in REIPPP amounts to R35 billion or the equivalent to 34% of the total foreign direct investment (FDI) attracted into South Africa during 2013 and has furthermore created 109 443 employment opportunities in the RE industry over the same period (DOE, 2015).

South Africa made significant strides in a very short period of time in increasing the share in RE in the national energy mix. An enabling environment has been created to assist the transformation from a single public utility to multiple energy generators and to adhere to the national objective of contributing 30% renewable energy in 2025 (DOE, 2015).

The contribution of small-scale rooftop installations

According to the DOE (2015), the solar PV rooftop market has been steadily growing within convincing market incentives. A voluntary database of small-scale rooftop PV installations established in 2011 suggested that by May 2015, these installations ought to have reached a combined capacity of 43.8 MW. The rooftop PV installations are mostly found in the commercial, agriculture and industrial sectors. This area requires policy refinement on a national level to harness the potential offered by PV rooftop installations.

2.8 Latest trends in the renewable energy sector and a debate on its future in South Africa

In 2014, a bidding process of 5 rounds commenced that led to 92 power producers being appointed in terms of the REIPPP program with the potential to generate 6323MW mainly from solar and wind technology (Sager M, 2017). Regrettably, most of the allocations made have not been awarded by the DOE to the power producers as promised. Only 1860MW generation capacity had commenced commercial operation by mid-2015 (Jain S, 2017).

A further 20 bids relating to small scale REIPPP projects (the Smalls programme) account for a further 99MW, that brings the total procured supply to 6422 MW. As at June 2018, 3801 MW of the total procured capacity was operational that represents only 54% of the 2020 target for renewable energy capacity in South Africa and 21% of the 2030 target, as per the 2010 Integrated Resource Plan (Deloitte, 2019). The REIPPP programme did not come to fruition as intended and political instability and challenges at Eskom led to significant delays resulting in the expiration of a number of bids and the programme being delayed by at least 2 years (Deloitte, 2019).

Jeff Radebe, the Minister of Energy has made public the draft Integrated Resource Plan of 2018. It was released for comment in 2016 and provides a necessary update to the 2010 IRP. The draft report acknowledged that a least-cost electricity future for South Africa is now comprised primarily of renewable energy and it does not feature new investment in nuclear or coal-fired power (Department of Energy, 2018). Surprisingly, the draft report indicates that the DOE is persisting in procuring coal-fired power from the proposed Thabametsi and Khanyisa power plants. Eskom is furthermore continuing with the construction of Medupi and Kusile and no explicit plans exist for decommissioning its oldest coal stations. It is simply placed in cold storage. The draft report continues to assume that existing coal-fired power plants will continue to be competitive until it reaches the age of 50 years and it shall keep running until that time (Department of Energy, 2018).

According to Mccall B (2019), artificial and arbitrary constraints on the investment in renewable energy in the draft report will have the effect of raising costs and limiting the sector's contribution to meeting

South Africa's future energy requirements and its climate change mitigation commitments. Eskom is furthermore in crises considering its outstanding debt, runaway capital and operating costs. The national power utility is heading to a death spiral as a growing number of its customers are investing in on-site distributed energy generation, resulting in a stagnating demand for electricity from the central power grid. The draft report does not consider this in context of its assessment of future technology roll out or the global energy technology shifts taking place all around the world that will significantly affect the viability of the current fleet, either because of economics or from a global climate change perspective (Mccall B, 2019).

Energy Minister Jeff Radebe recently signed a R56 billion contract with 27 independent power producers, but the National Union of Mineworkers had threatened to end its support for the ANC if the project is allowed to continue, stating that it would cost 40 000 jobs in the coal sector (Engineering News, 2018). In response the South African Photovoltaic Industry Association welcomed the signing of the IPP contracts arguing that it will boost and revitalise long-term investor confidence and create more than 61 000 jobs (Engineering News, 2018).

Although the increase in decentralised solar PV is viewed as progressive for sustainable development, it is not without dire financial implications for electricity utilities. There is a concern that solar PV connection to the grid will reduce electricity sales for local governments and their revenue streams from electricity sales (Korsten *et al.*, 2017). It is therefore a major concern for municipalities, that the loss of income due to decentralised energy generation, is going to cause that other underfunded services cannot be supplemented (REN21, 2019). As revenue from electricity sales is a major source of income for municipalities, the problem lies in the fact that costs incurred by utilities do not decrease in proportion to decrease in electricity demand. This is because the fixed costs utilities pay towards the distribution infrastructure are so high, that it needs to be recovered over a long period (Cai *et al.*, 2013).

As a result of decreases in electricity demand, overall electricity tariffs must increase so that utilities can continue to recover fixed costs, failing which the grid cannot adequately be maintained or serviced (Korsten *et al.*, 2017). A further increase in electricity tariffs will incentivise the public to invest in self-generation initiatives. Again this process may result in a death spiral from the utilities perspective, representing an unstable dynamic process that threatens the prospects for its financial survival (Cai *et al.*, 2013). It furthermore depletes the traditional income stream from electricity sales that use to supplement the municipal coffer to be utilised for cross-subsidisation within the municipality (Korsten *et al.*, 2017).

Another school of thought exists that despite claims of grid parity, wind and solar farms are still more expensive than fossil fuels. According to Ritchie EJ (2017), the fact that wind and solar energy has reached grid parity in some areas, does not necessarily mean it is cheaper than fossil fuels, because there is a number of definitions of grid parity. He argues that the rapid growth rate of renewable energy is primarily due to subsidies and national mandates. Mathiesen K (2016) argues that although manufacturing costs for solar technology has dropped by 10% a year since the 1980's, the main impediment that lies ahead for solar power is grid infrastructure. The central electricity grid was built to carry fairly consistent levels of generation and it will struggle to cope with the variability of solar and wind energy. Solar is held back its "capacity factor", essentially how often it produces electricity. A coal power station runs at 70 -80% capacity. The capacity factor of solar is around 15%.

As opposed the above, Kilian Hagemann of G7 Renewable Energies (Engineering News, 2019) stated that traditionally the renewables debate in South Africa was about environmental considerations and to introduce cleaner forms of electricity generation, whereas now the motivation has shifted more towards economic considerations. Through economies of scale, efficiency improvements and competitiveness in the sector, the tariff for energy produced by solar and wind is down to 60c per kWh as opposed to 95c per kWh from Eskom. Coal based electricity continues to increase in price, resulting in national energy tariffs that is not globally competitive, and much needed direct foreign investment in all power intensive sectors is driven away. Climate conscious countries may also stop importing goods and services from South Africa if we do not comply with our commitments to the Paris Agreement.

He continues by arguing that the social upheaval around job losses in the coal industry, can be mitigated through the efficient transitioning to renewables. The technical nature of renewables presents significant opportunities for the youth employment industry.

David Chown of the South African Photovoltaic Industry Association (Engineering News, 2018) is of the view that PV grid installation is expected to double in 2019. He admits that job losses in the coal mining industry is a concern, but the adoption of renewable energy systems poses no immediate or significant threat to workers in local coal industry. South Africa is still heavily dependent on coal as an energy resource and it will continue for the foreseeable future. When renewables do begin to play a more significant role in the energy mix as outlined in the Integrated Resource Plan, it will create emergent job opportunities as the energy transition takes shape. Coal workers will have the opportunity to gradually upskill to PV panel suppliers, transporters and installers and other skilled jobs the new clean energy economy, which will likely be better paying and safer.

2.9 Importance of feasibility studies for solar PV installations

Performing feasibility studies and learning how to conduct feasibility studies correctly is critical to the promotion of solar PV installations as a preferred renewable energy technology worthy of being explored (Javier *et al.*, 2017). To promote this type of technology, one needs to identify when PV systems are an option for a building, learn how to calculate the feasibility of specifying PV systems for a building and to calculate the return on investment for alternative-energy PV systems (Javier *et al.*, 2017).

A feasibility study is the first step towards development and installation of a technically and financially sound solar PV system. In order to achieve this goal, the following important aspects must be investigated to develop a solar feasibility study (Associated Renewable, 2017):

- Potential for solar PV energy generation potential on site
- Risks associated with the project
- Planned installations
- Region and country specific assessments of financial incentives & regulations
- Operational costs assessment

- Technology design and cost calculations
- Simulations and Modeling for all scales (small, medium and utility)
- Long terms yield and ROI calculations
- Projected payback on the project
- Uncertainty assessment on yield generation
- Technical and economic feasibility and field-mounted, grid-connected solar PV systems

The correct research and fact-finding efforts are important functions to contribute to a successful feasibility study. The return on investment is usually the deciding factor as it is where the date comes together to give a true picture of the possible outcome (Abarca J, 2017). As this study will show in the chapters to follow, the ROI part of the feasibility study is the deciding factor in the process to determine whether it is economically viable to install a PV system.

2.10 Key Findings

The key findings in this chapter relative to the research objectives is as follows:

i) Solar PV technology has developed to the extent where it is accessible and affordable to most small scale property owners in South Africa and internationally. It is no longer an expensive source of energy only relevant to a niche market or for developments off the grid.

ii) The barriers to large scale deployment of solar energy has been discussed from a South African and international perspective as well as the solutions to it. The problems that this energy component face in South Africa is largely political in nature. Plans (IRP) have been drawn to support the renewable energy sector in South Africa, however the political will is absent to execute those plans.

iii) South Africa is poised to comply with its responsibilities in terms of the Paris Agreement through its Integrated Resource Plan and REIPPP program, but the process is being stifled to protect Eskom's monopoly.

2.11 Chapter Summary

This chapter reviewed literature relating to the global trend towards the support for renewable energy and focused on energy generated from solar PV as the source with the most potential. The history, technology and cost trends of energy from solar PV are investigated as well as the barriers restricting large scale deployment of this particular source. Solutions to these barriers have been researched and the method of implementation of solutions and the state of renewable energy in the South African context is discussed. The chapter focusses on the adoption of renewable energy technologies from a global perspective and thereafter compares the rate of adoption from a South African context. The chapter ends in a debate about whether renewable energy initiatives are more attractive than fossil fuels from an economic perspective in South Africa.

Chapter 3 Research Methodology

3.1 Introduction

This chapter describes the methodology and research methods used in the study. The research design is explained and use of a single case study as the most appropriate method to investigate the problem is justified. The focus of the chapter is to justify and explain the findings reached in Chapter 4 and to strengthen the reliability and validity of the research. An overview of the research methods is provided followed by the justification for the use of qualitative and quantitative data as the overarching methodology.

3.2 Research design

Research design is about organising research activity and the collection of data in a manner which is most likely to achieve the intended research aims for a particular project (Easterby-Smith *et al.*, 2002). Research methodology is driven by ontological and epistemological assumptions and consists of research questions or hypothesis, a conceptual approach to a topic, the methods to be used in the study including its justifications, and consequently the data source. Methodology is therefore concerned with the manner in which a particular piece of research is undertaken and can be understood as the critical study of research methods and their use (Easterby-Smith *et al.*, 2002). In essence, it provides answers to the what, the how and the why rooted in the particular type of empirical research undertaken in this research project. It is based on a positivism type of methodology in terms of which the world is viewed as external and objective, the observer is independent and the study is focused on facts to be formulated in order to test the assumption recorded in Chapter 1.

As the problem statement relates to insufficient information being available in the public domain regarding the feasibility of electricity produced from a rooftop PV system compared to Eskom's electricity flow from the perspective of a small-scale property owner, the writer has identified a project to investigate the problem. A rooftop PV installation was identified and employed in a single case study as data from such installations in the private sector is very difficult to obtain and the results from this project is highly likely to be the same for similar projects. The PV system is installed on the rooftop of a building in Hope Street, Cape Town and it is tenanted by a private school. The writer obtained special permission to use the data from the installation in this study to provide insight into the research problem, research questions and the research proposition.

This research study consists of five distinct stages being, the define stage, the design phase, the data collection phase, the data analysis phase and finally the evaluation and conclusion phase. Chapter 1 and 2 of the research is relevant to the "define phase" in terms of which the basis of academic theory and the body of knowledge was established. During this phase the research question developed and the methodology undertaken to test the research question and hypothesis. The "design phase" refers to Chapter 3 and includes the research method and data collection techniques envisaged to answer the research question posed during the "define stage". The "data collection phase" is thereafter carried out as defined in this chapter and the results of the data recorded is reflected in Chapter 4 in the form of impact assessments and interview results. The "data analysis phase" is thereafter carried out which finally leads to the "evaluation and conclusion phase" in Chapter 5. Conclusions are drawn in the final chapter with particular reference to the research question posed in Chapter 1.

3.3 Research Methodology

Methodology refers to the procedural framework within which research is conducted and the method refers to the various ways in which data can be collected and analysed (Petre and Rugg, 2007). Bryman and Bell (2015) is of the view that a clear understanding of research methods is bound to assist in matching research questions to research methods, being ethically responsible in undertaking research, and critically evaluating other's research.

According to Petre and Rugg (2007) research is defined as finding things out in a systematic fashion. It is about designing a map or adding detail to an existing map leading to a particular outcome. To decide on an applicable research design, one must determine 'what size of effect is relevant to the question?' To determine this, one must identify the relevant aspects for study and for exclusion from the study (Petre and Rugg, 2007). There are four basic designs; case study, surveys, field experiments and controlled experiments.

3.3.1 Research Method

Leedy and Ormrod (2010) believes that research methods and data are intricately intertwined. There are two approaches available, namely qualitative and quantitative strategies; the choice of method adopted is dependent on the availability of information and the type of data that best suits the research and problem statement (Ahmed *et al.*, 2016).

Qualitative research relies on what is seen in field or naturalistic setting more than on statistical data while in contrast, quantitative research collects and reports data primarily in numerical form (Leedy and Ormrod, 2010). Qualitative methods are more concerned with the understanding of causes and people's behaviours and is more subjective in nature, while quantitative research is more objective, rigid and reliable in nature. It measures objects that are tangible and able to be counted (Naoum, 2007).

This research project has extracted quantitative data from the analysis of a single case study and qualitative data from multiple interviews. Both research strategies have been used in order to improve the validity and reliability of the data presented in order for informed conclusions to be drawn in Chapter 5.

The method whereby two or more methods are incorporated to investigate a research problem is called the triangulation method (Fellows and Lui, 2007). Quantitative information from an experiment blended with qualitative data extracted from interviews has the ability to increase the credibility of results. This leads to potentially increasing the reliability of data collected to support or reject the assumption of the research report (Babby and Mouton, 2005).

As the research relates to the question at what point in time does it become beneficial to a small-scale property owner to install a rooftop PV system from a feasibility point of view and whether the installation should be large enough to generate total power supply or alternatively only supplement electricity supply from the national grid. can be answered by observing quantitative data from a case study designed to produce such data.

The research question can further be illuminated by qualitative data extracted during interviews with solar PV industry specialists that has already identified solar technology as a solution to South Africa's existing electricity security problems.

3.3.2 Case study approach

Strengths and limitations

The case study method as suggested by Petre and Rugg (2007) has been selected to investigate the research question and hypothesis as the appropriate model under the circumstances.

The case study is the most flexible of all research designs, allowing the researcher to retain the holistic characters of real life events while investigating empirical events (Schnell, 1992). Yin (2013) is of the view that case study approach to research applies most effectively to situations where the focus is on contemporary, rather than historical information.

The information obtained relates to an already well-formulated theory and provides insight into a solar PV rooftop installation that is unique under the circumstances. This is furthermore the rationale behind electing the single case study analyses approach to be most applicable under the circumstances to study quantitative data. As the data from a privately-owned rooftop PV installation is very difficult to obtain, the study can be viewed as unique under the circumstances. Data from similar small-scale private PV installations are scarce and the model as contained in this thesis to analyse the PV installations performance, qualifies as a special case. Conclusions drawn from the data presented in this study, is likely also to be true for PV installations of a similar nature.

The case study approach has in the past been criticized to lack reliability compared to quantitative procedures, as it can be prone to biases of the researcher, lack scientific rigour and labours under the suspicion of generalisability not adequately addressed (Schnell, 1992). Yin (2013) agrees that case studies in the past has been criticised for being less rigorous due to the level of subjectivity involved and that researchers view it as adequate only during the exploratory phase of research. Yin (2013) also stated that case studies have in the past viewed as unreliable when making generalisations and that the data cannot be trusted beyond the scope of the investigation.

However, Yin (2013) further describes this view as being outdated and that case studies has the potential to produce rigorous and trustworthy data without the need for other methods to be employed in addition to case studies to strengthen the perceived result. As long as the researcher is conscious of the limitations of case studies and guards against it, reliable data can be produced. According to Yin (2013) the researcher can address any inadequacies in case study research and maintain the credibility of research methodology by observing constructive validity, internal validity, external validity and reliability.

Constructive validity aims to ensure that inferences made from data adequately relates to the study (Brown, 1996). Data collection and analyses by nature can be subjective to the investigator, which is why it is critical that the design and the operation is performed in such a way that it yields unbiased results in terms of which the research question is connected to the source and analysis of data (Yin, 2013). This research project attempts to achieve this by observing qualitative data from interviews with PV industry specialists blended with quantitative data forthcoming from a case study yielding actual financial results involving rooftop PV system.

Internal validity is relevant to explanatory case studies and of minor importance to this study. It concerns the connection between relationships under study in such a way that the effect that has been identified in one party can be directly attributable to the defined cause (Yin, 2013).

External validity guards against findings being generalized (Yin, 2013). As case studies are not statistical generalisations, the theories formulated from observing samples cannot always be applied to the universe. The question remains whether the trend that emerges from the sample data can be inferred upon a greater trend that goes beyond the sample data. This research project guards against findings being generalized by describing the boundaries within which the findings can be applied.

Reliability of case studies refers to the ability of research to be replicated with the same results (Yin, 2013). It is the answer to the question whether another researcher employing the same methods within the same distinct parameters would yield similar results and provide the same answer to the research question and hypothesis formulated in Chapter 1. The quantitative data observed from a case study derived from a PV system installed on rooftop as a commercial investment is not ambiguous or open to a different interpretation. The data gathered cannot be influenced by the researcher's perceived bias or tampered with in a manner which could lead to a different outcome.

The quantitative data forthcoming from the PV rooftop installation is the same as that provided to the building owner or manager. This data is blended with qualitative data derived from interviews on the research question. Although more susceptible to manipulation or subjectivity from the researcher, the safeguards mentioned in this chapter has been enforced to ensure that reliable data was produced from which informed conclusions can be drawn in Chapter 5.

3.4 .1 Determining the feasibility of PV installations

In order to assess the feasibility of PV installations and other green building features, it is critical to discuss the tools in terms of which financial implications of such features can be demonstrated (Le Jeune *et al.*, 2013). According to Buys *et al.* (2011), the use of Life Cycle Cost Analysis (LCCA) is an appropriate financial tool to promote green building features. LCCA is defined as a tool that uses discounted cashflows to evaluate a project within a given set of parameters, including a time period and cash flow.

Clift and Bourke (1998) define LCCA as the systematic consideration of all relevant costs and revenues associated with the acquisition and ownership of an asset. Paumgartten (2003) states that LCCA estimates the nett present value of all relevant costs during the assessment period including construction costs, maintenance, repair, energy savings and residual values. LCCA are of the most commonly used financial tools and is generally used to determine if future operational savings justify higher initial capital expenditure (Kneiffel, 2009).

The NPV is the main financial indicator employed to determine the viability of the LCCA, while the IRR indicates the overall return for the given holding period. A feasible NPA must be greater than zero, while a viable IRR should be greater than returns of other asset classes with similar risk profiles (Le Jeune *et al.*, 2013).

In order for the LCCA to be conducted one must assume a range of projected figures affected by underlying variables, the most prominent of which is going to be the discount rate. The discount rate needs to be verified by the market with specific focus on the investment type and location (Le Jeune *et al.*, 2013). In this research project the investment type is a PV system mounted on a rooftop of a private school. A comparison of sensitivity analyses will result in different payback periods for the PV system relating to the range of discount figures suggested by the market for an investment type of this nature.

According to Le Jeune *et al.* (2013), a LCCA is an appropriate tool to employ to independently test the data from the case study. A LCCA is one of the most commonly used tools to determine the NPV and IRR of an asset in order to determine the value of future operational savings (Kneiffel, 2009).

This method allows the researcher to independently test and verify the data sourced from a single case study. As the case study reveals financial data of only a fraction of the PV installation's life span, future operational savings can only be assumed by using a projected discount rate. The discount rate is determined by comparing the risk profile of the PV installation with similar investment types and locations in the market (Le Jeune *et al.*, 2013).

As variations in a projected discount rate can be expected, a sensitivity analysis plays a vital role in predicting the NPV and IRR values of the PV installation as an investment. A sensitivity analysis to determine the value of the PV installation as an asset has been performed with a discount rate ranging between 10% and 16%.

3.4.2 Levelised Cost of Electricity (LCOE)

Reichelstein and Yorston (2013) defines the levelised cost of electricity (LCOE) as the minimum price that an electricity producer would need to be compensated for in order to break even for producing electricity. This value is measured in R/kWh and incorporates a discount rate to indicate the cost per unit of electricity produced. LCOE can therefore be used as a measure to determine the financial viability of solar PV. It is simply expressed as the Net Present Value (NPV) per unit energy produced (kWh).

The perception exists that the LCOE generated from solar PV systems is relatively expensive and not yet competitive with traditional sources of energy generation (Bazilian *et al.*, 2013). From an historical point of view, this perception appears to be accurate, however the solar PV industry is changing and constantly improving as the development of new solar PV technology advances, the industry matures and the costs of modules and equipment parts is steadily decreasing (Mills and Morgan, 2008). This phenomenon drives down the LCOE to the point of Grid Parity (GP). GP is the point of which the cost of producing energy from solar PV is roughly the same as producing electricity from traditional sources (Bazilian *et al.*, 2013).

Bazilian *et al.* (2013) explains that it can be complicated to determine LCOE as it is site specific and depends on local factors such as solar insulation, the quality and type of components used in installation, the system design and the cost of maintenance. Timilsina *et al.* (2012) calculated a solar PV installation's LCOE as low as 0.19 USD/kWh with 90% capital cost and 10% operation and maintenance costs. According to the Integrated Resource Plan (IRP) for the period 2010 to 2030, South Africa aims to reach the point where LCOE of solar PV technologies is equal or less to the costs of municipal rates by 2015 (DOE, 2015).

As Eskom's price for electricity from coal-fired plants has increased significantly since the 2008 electricity supply crises, despite South Africa's abundant coal resources, the price for solar PV modules dropped by 40% in 2011 (Ndanga and Gorn, 2012). Ndanga and Gorn (2012) predicted that South Africa would reach GP in 2015, which it did.

3.5 Data Collection Methods

3.5.1 Interviews

"The purpose of interviewing is to find out what is in and on someone else's mind. We interview people to find out from them those things we cannot directly observe" (Patton, 1990).

Kvale (1996) describes qualitative research interviews as attempts to understand the world from the subject's point of view, to unfold the meaning of people's experiences, to uncover their lived world prior to scientific explanations. In general, interviews are one of the basic tools to acquire evidence relevant to research questions and research objectives.

Fellows and Lui (2007) identified three basic types of interviews: structured, unstructured and semi-structured. Structured interviews refer to conversations with the interviewee based on pre-planned questions where the interviewer does not deviate from the preconceived program. Unstructured interviews make use of general open-ended questions where the interviewee is allowed the discretion to lead the conversation in a direction, he/she deems fit within the appropriate context. Semi-structured interviews fit in between the two in the sense that the basis for a particular question is identified but leaves space for the interviewee to elaborate beyond the question which might also set the tone for follow-up questions (Naoum, 2007).

This research project identified that semi-structured interviews with two PV specialists would be appropriate to discuss the Solar PV rooftop installation on the building in Cape Town in order to test the research question and project hypothesis. The interviews were conducted in an informal fashion at the offices of a prominent Solar PV contractor in the Cape Town Waterfront without a time frame and recorded in writing.

The strengths of this approach can be summarized as follows:

- There are no existing standardized questionnaires or outcomes measures available to accomplish the research object;
- The interviewer is in a position to obtain large amounts of relevant data in a short period of time;
- The interviewer is at liberty to probe for more details and in a position to make sure the questions are interpreted as intended; and
- Interviewers has the flexibility to use their own knowledge and interpersonal skills to explore interesting and unexpected ideas raised by participants (Sewell, 1998).

The limitations of the interview approach can be summarized as follows:

- It may be experienced as more intrusive than quantitative approaches;
- The interviewee might be reactive to personality, moods or interpersonal dynamics with the interviewer;
- Conducting interviews can be expensive and time-consuming; and
- Requires considerable skill and experience (Sewell, 1998).

The following table represents the link between interview questions and the source or section in the literature review where the question is grounded.

Table 1 Linkage between interview questions and literature review

Interview question	**Literature source/sections**
Under what circumstances would a landlord consider installing a Solar PV system in general?	2.2 Case for renewable energy, 2.3 Case for solar energy
Explain energy efficiency measures	2.5.2 Technological barriers
What time of day is electricity demand the highest and what is the demand?	2.5.2 Technological barriers
What can one expect the installation costs to be?	2.5.1. Economic barriers
Is it necessary to get permission from the local municipality to install a Solar PV system?	2.4.3 Legislative barriers
What types of PV systems are available and how does one choose the appropriate system?	2.5.2 Technological barriers
Which technology is more suitable for the South African market and why?	2.6 Trends
Please explain the cost implications regarding maintenance and installation of a PV system.	2.5.1. Economic barriers
What is the function of the inverter and why is this component so important?	2.6 Trends
Once the energy has been generated, please discuss the storage capacity and new technology on the horizon on this particular aspect	2.6 Trends
Has the development of new Solar PV technology caused a significant decrease in the pricing of the unit installation in general? Do you foresee that installation might become even more affordable in the near future?	2.6 Trends
Discuss technical barriers limiting solar energy technology in general beyond that already mentioned in this research.	2.6 Trends

Is it more cost effective to install a PV system to supply the total electricity demand for a building; or only as a supplement to Eskom's power supply?	2.6 Trends

3.5.2 Solar PV System Data

The advantages for this quantitative research design are that it is an ideal way of finalizing results and proving or disproving an assumption. The structure has remained the same for centuries and is standard across many scientific fields and disciplines (Shuttleworth, 2016). Quantitative data gathered from a case study, if properly designed, can be viewed as real and unbiased.

The PV system installed on the rooftop of a building in Hope Street, Cape Town is tenanted by a private school. The researcher obtained permission from the chairman of the school board of the private school to study the system and for commercial data to be made available by the contractor and PV specialist instructed to install and maintain the system. Quantitative data relating to the product specifications, capital outlay and maintenance of the system in the form of yearly assessments and reports have been shared with the researcher in order to investigate the research question and test the research assumption.

The researcher has interviewed the chief executive officer and the operational manager of Energy Intelligence, an industry leader in the installation and management of solar PV systems regarding the PV system on the rooftop of the private school in Cape Town. It was agreed with the school board to release information pertaining to:

- Costs of the installation of PV system
- Electricity demand and electricity produced in kWh
- Net present value of the installation
- Return on Investment
- Payback period for the installation
- Municipal savings

To enhance the credibility of the research undertaken, the study focused on qualitative data extracted during interviews from a case study on the suitability of solar PV to completely replace or merely supplement traditional electricity supply in the South African context. The purpose of the interviews was to provide background information relating to rooftop PV installations in general in order to create a context for the data to be analysed from a single case study. The interviews explored various factors a landlord or building manager must consider before making the decision to install a solar PV system. These factors include amongst others, location of the system, space requirements, types of PV systems, various components, storage capacity and technical barriers.

The research study furthermore analysed quantitative data extracted from a single case study reflecting actual values of an existing solar PV installation to test whether the capital costs for installing and maintaining the PV system is justified. Due the nature of the information gathered, it would have been impractical to adopt an approach of multiple case study analysis, as the single case study is unique in the sense that actual financial information of this variety is not freely available.

3.5.3 Ethical risks and methods of mitigation of ethical risks

Ethics are broadly defined as a set of rules that govern our expectations of our own and other's behaviour. It includes publishing findings in a transparent way, not plagiarising other's work and not falsifying work (Guillemain M and L, 2004). The ethical risks in this research project involved obtaining financial information from the Solar PV contractor and permission from the school board to analyse the data and present it in a manner that is objective, transparent and accurate. The writer met with chairman of the school board to explain the purpose behind the research project and the audience likely to review the findings of the research. The chairman could not find a reason how financial information pertaining to the rooftop PV system could damage the reputation of the private school. The school's main function is to educate French speaking pupils which is far removed from the findings of the writer's research.

In the year 2016, the relationship between the solar PV contractor and the school board deteriorated for reasons unknown to the writer and unrelated to this research project. The writer has permission to utilise the data as provided up until 2015 but could not obtain further data relating to the PV installation post 2016.

3.6 Conclusion

This Chapter has evaluated and justified the chosen research methodology, being quantitative and qualitative data based on a case study approach as the most relevant and applicable method to answer the research question and test the research hypothesis posed by the study. The strength and weaknesses of the approach has been considered and the data collection techniques explained. The chapter ends with an explanation of the tools recognised to test the data gathered from the case study.

Chapter 4 Data Presentation and Analysis

4.1 Introduction

This chapter serves to present the findings gathered from two semi-structured interviews and a single case study. The information generated from the aforementioned data collection techniques will be assessed based on its relevance to the research question and objectives. The Chapter begins with two semi-structured interviews with specialists in the solar PV technology industry. Relevant questions pertaining to the problem statement and research questions are asked. It is followed by a brief description of a single case study that relates to a rooftop installed solar PV system. The electricity demand for the building is discussed together with the solar PV technology specifications relevant to the project. The chapter concludes with an analysis of the data extracted from the interviews and the single case study as it relates to the problem statement of the research project.

4.2 Case Study

4.2.1Interview with Solar PV contractor and technical specialist

The following questions were posed to an experienced and well-established Solar PV specialist from the perspective of a property owner in order to decide whether the installation of a Solar PV system is justified in general.

Under what circumstances would a landlord consider installing a Solar PV system in general?

> *"Before 2007, landlords mostly considered Solar PV systems in rural areas with no electricity supply. In more recent times, the Solar PV industry received much interest predominantly because it can deliver power during load shedding protocols and to counter the rising costs of electricity form Eskom. The expectation exists that the industry will continue to grow in the long term mainly because it serves to reduce monthly electricity costs (Interviewee 1)*

Explain energy efficiency measures.

> *"Energy efficiency is usually the most cost-effective way to reduce electricity costs. Always put energy efficiency initiatives in place first. For example, replace all conventional light bulbs with energy efficient light bulbs (LED lights)." (Interviewee 1)*

What time of day is electricity demand the highest and what is the demand?

> *"Understanding your load profile is key in designing an optimal PV installation. The following needs to be established:*
>
> *When do you need electricity? – Summer, winter, every day, only weekends, day time or night time? PV panels only generate electricity when the sun is shining and the system requires batteries to store electricity if it's not intended for use when it is produced.*
>
> *How much electricity do you need? The average South African household uses approximately 4 600 kWh per year, therefore a 3-kW installation (10 panels; 25 sqm) would be sufficient to cover 80% of this consumption." (Interviewee 1)*

What is the space requirement to install a Solar PV installation?

An open area (roof or ground) is required without shading or obstruction for the PV panels. For a 3 to 6 kW installation approximately 25 to 50 sqm is required. For a 10-kW installation approximately 90 to 110 sqm is required. North facing areas are ideal for maximizing electricity production. (Interviewee 1)

What can one expect the installation costs to be?

"As a guideline, the price of an installed PV system, including panels, inverter and cables without batteries ranges between R22/W and R25/W. For example, a 3-kW system, installation costs would range between R54 000 and R75 000 including VAT. A system with batteries is likely to range between R36/W and R50/W and would expect to pay for a 3-kW system between R108 000 and R150 000 including VAT."

"For a 10-kW system one can expect to pay between R250 000 and R280 000 including VAT depending on the materials used and one would expect to pay between R18 and R20/W. A system with batteries would range between R500 000 and R600 000." (Interviewee 1)

Is it necessary to get permission from the local municipality to install a Solar PV system?

"Each Municipality has its own regulations. The landlord must make enquiries before the system is installed. In order to feed electricity back into the grid, the City of Cape Town Municipality is very strict in this regard and insists on an inspection and approval of the premises. A qualified engineer is required to sign off the installation design and a bi-directional meter must be installed (enabling electricity to flow both ways) before the Municipality is willing to pay for excess solar generated electricity to be sold back to the City." (Interviewee 1)

What types of PV systems are available and how does one choose the appropriate system?

"Off-Grid system: Found mostly in a home or business that does not have a grid connection. Usually far from grid connection points namely, farms, holiday homes, telecom repeaters or lighthouses. This system consists of PV panels, inverter and a battery pack. The sizing of batteries depends on the required workload (kWh used) and solar resource in the area. The more shade or cloudy days expected, the bigger the battery would have to be."

"Batteries require regular maintenance and the system should be serviced yearly. The system has a lifespan of approximately 20 years, but the inverter would probably need to be replaced after 10 years. Batteries lasts between 2 and 10 years depending on the usage profile and maintenance record."

"Grid-Tied system: This system can reduce your carbon footprint and electricity bill by providing part of the electricity consumed from the PV system. Electricity from this PV installation is consumed directly at home or business. There are no batteries which means no electricity from the installation when very cloudy or at night."

"Very low maintenance required with a lifespan of approximately 25 – 30 years. Inverter may also have to be replaced after 10 years."

"Hybrid system: Hybrid systems with a battery back-up has the same advantages as a grid-tied system. In addition, this system allows the use of solar energy in the evenings and on cloudy days as well as during load shedding. It consists of PV panels, inverter, grid connection and battery pack. Back-up power is limited to the capacity of the battery bank. The system requires regular maintenance and batteries must be checked on a weekly basis in additional to the entire system being serviced yearly. It also has a lifespan of approximately 20 years with the batteries lasting between 2 – 10 years and the inverter that might need replacement after approximately 10 years. It is furthermore significantly more expensive than a grid-tied system as it includes storage for power." (Interviewee 2)

Two types of Solar PV technology are currently available on the market: (a) crystalline silicon-based PV cells and (b) thin film technologies made from a range of different semi-conductor materials, including amorphous silicon, cadmium-telluride and copper indium gallium diselenide. Which technology is more suitable for the South African market and why?

"Both technologies are used in PV installations in the South African market. Thin film technologies are a superior product, it is more practical to use and it generates more power per square meter than crystalline silicon-based PV cells. However, it is also proportionally more expensive and not always more cost effective."

"The rationale behind which technology to use depends on the particular circumstances in each case. If the property owner has only limited space available to generate electricity from PV panels, the decision would probably lean towards thin film technologies. If the owner has a large area or roof space available, it would be more cost effective to elect a more affordable technology." (Interviewee 2)

Please explain the cost implications regarding maintenance and installation of a PV system.

"There are basically 3 components that is going to determine the overall cost of the PV installation which are:

1) *The mounting system*
2) *Panels*
3) *Inverter*

The pricing depends on the quality and origin of the materials used in the installation. One can use cheaper parts made in China with a lower prospect of durability or one can import German or other European equipment at a higher price which are generally better quality.

With regards to maintenance, the operating expenses ("OPEX") is relatively minor compared to the size of capital investment ("CAPEX"). Systems close to the ocean tends to yield higher maintenance costs as salt deposits or bird droppings necessitate more regular maintenance compared to PV systems installed inland. Dust accumulation can also justify panels to be cleaned regularly. Compromised panels effected by amongst other things, dirt, dust, salt or bird droppings havet a lower generation capacity." (Interviewee 2)

What is the function of the inverter and why is this component so important?

> *PV panels deliver direct power or direct current ("DC"). Most appliances utilised in everyday life requires alternate power or alternate current ("AC"). The inverter transforms DC to AC. The inverter also controls the power output in kWp from the PV installation to the grid, households or business. It is necessary to regulate this power output to the amount of power required or more often to "trim down" the power output to satisfy the required power demand. (Interviewee 2)*

Once the energy has been generated, please discuss the storage capacity and new technology on the horizon on this particular aspect.

> *"The technology to store electricity has improved significantly over the last decade and even more so in the last few years with reference to the battery designed by Elon Musk from Tesla. However, this particular battery technology is still more expensive than that which can be found currently in the South African market. Although storage capacity technology keeps improving and the prices keeps decreasing steadily, it is still not cost effective in South Africa as it still responsible for about 50% to 60% of overall costs. These batteries at the moment are manufactured abroad and is still relatively unaffordable considering the weak South African rand currency." (Interviewee 2)*

Has the development of new Solar PV technology caused a significant decrease in the pricing of the unit installation in general? Do you foresee that installation might become even more affordable in the near future?

> *"The cost of solar technology has decreased significantly since the early 2000's as the industry matured and new technology replaced earlier inventions. It is however not likely that solar technology pricing would continue to decrease much further. It is close to the point of the saturation where further price decreasing would result in the manufacturing process to be no longer attractive. Certain European countries have already placed a ban on importing cheaper parts from China for example, as local manufacturing companies struggle to remain competitive and run the risk of going out of business." (Interviewee 2)*

Discuss technical barriers limiting solar energy technology in general beyond that already mentioned in this research.

> *"A major factor limiting solar installations is asbestos roofing. The rules and regulations around working on or altering an asbestos roof is strict and very inflexible. Most of the time the roof would need to be replaced at considerable cost. The asbestos would thereafter need to disposed of in an environmentally friendly manner that further drives up costs." (Interviewee 2)*

Is it more cost effective to install a PV system to supply the total electricity demand for a building; or only as a supplement to Eskom's power supply?

The following graph (Figure 2) serves to illustrate this argument. It is an example of the pattern of electricity consumption on a daily basis during a typical week.

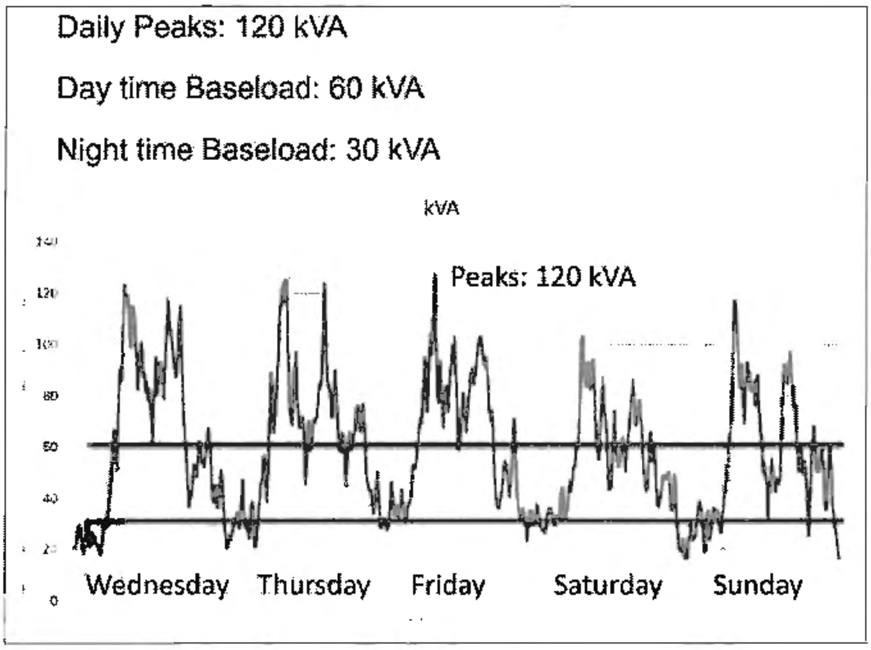

Figure 2 Pattern of electricity consumption during a typical week

> *"The picture reflects the day time baseload as 60 kWh and the night time baseload as 30 kWh which is close to the pattern in reality for most buildings. In order to supply the total of the electricity required with a PV system, a 120-kW system would have to be installed at a considerable cost. As a result of economies of scale, it would cost approximately R13 Wp – R14 Wp to produce electricity from a 120 kW PV system compared to approximately R16 Wp to R18 Wp from a 60 kW PV system. However, the installation costs for a 60kW system can be around R1.2 million. Installation costs for a 120 kW PV system can be around R2.6 million. In order for the system to provide electricity for the night baseload it would have to also be supplied with a storage facility (battery pack) at 50% of the cost, driving the price potentially to R5.2 million. It is therefore more cost effective to install a smaller and more affordable PV system to provide electricity supply for the daytime baseload and be reliant on Eskom for the night time baseload at standard Eskom rates as opposed to installing a large and expensive PV system responsible for the total electricity demand." (Interviewee 2)*

4.3 Single Case Study

The research project has identified a building situated in Cape Town, tenanted by a private school ("the School"). The School experienced problems with its electricity supply during hot days which resulted in power shortages.

4.3.1 Power requirements for School

A representative of the building owner decided to employ an industry specialist to conduct an energy assessment at the School with the overall purpose to:

- Assist the school to quantify their significant energy users
- Identify potential opportunities for reduction in energy usage
- Identify inefficiencies within the school

4.3.2 School solar PV installation specifications

After the assessment by the energy specialist the following issues was discovered:

1) The main circuit breaker trips due to high load required by running all 20 air conditioning units at the same time
2) The school was supplied by an 80A circuit breaker from the municipality that appeared insufficient for its purpose
3) For lighting, the school was making use of over 200 inefficient 58W fluorescent tubes
4) The roof of the school was ideal for the installation of solar PV panels

The energy specialist recommended to resolve the energy inefficiency obstacles by:

1) Installation of a 10-kW photovoltaic system that would enable the school to generate a portion of its own electrical requirements, thereby reducing the load by 15 Amps per phase.
2) A Refusol lightweight and compact 3phase string converter to supply the school with 3phase power supply
3) Lighting retrofit: replacement of all inefficient light fittings by LED lights to reduce the load by 12 kW of 18 Amps per phase.
4) Upgrading the circuit breaker from an 80A to 100A to eliminate the power outage at the school even when all loads are used at once.

4.3.3 Solar PV installation: specifications

Twenty 250 Wp panels were installed within four days on the roof of the school in order to establish a 10 kWp system. It was decided to install a grid-tied system without batteries as adding storage capacity would increase the cost of the system with approximately 40% in initial start-up costs and maintenance. A Schletter mounting system was used, Solaire Direct Solar panels manufactured in South Africa with a Fronius inverter imported from Europe and 3 phase string converters in the 8.25 to 20kW power classes.

The choice of the size and particulars of the system installed was based on the information and estimates reflected in Table 2 below. Table 2 indicates the energy specialist's prediction of the electricity that is going to be generated from the PV panels. The first column (1) reflects the month of the year, the second column (2) an estimate of electricity that will be produced in that particular month and the third column is a daily estimate of electricity in kWh. The third column (3) is equal to the monthly estimate divided by the amount of days in that particular month.

The fourth column (4) reflects the tariff that applies to 1 kWh produced and sold to the public by South Africa's national electricity provider, Eskom. There is a yearly tariff increase in July clarifying the increase of R1.27 per kWh to R1.29 kWh. The fifth column (5) represents the monthly saving the PV system would be responsible for should it be installed.

The amount of electricity estimated to be produced fluctuates from month to month. These values are based on the angle of sun, shade and typical weather patterns recorded historically in that particular month in the Western Cape region. It explains why the estimate of electricity produced is lowest around June/July and the highest around January/December.

Table 2 Solar PV Power Estimate

1	2	3	4	5
Months	**kWh Estimate**	**kWh Daily**	**Tariff per kWh (exclusive of VAT)**	**Monthly Cost saving**
Jan	1780	57.4	R1.27	R2 260.60
Feb	1530	54.50	R1.27	R1 943.10
Mar	1490	48	R1.27	R1 892.30
Apr	1150	38.4	R1.27	R1 460.50
May	982	31.7	R1.27	R1 247.14
June	849	28.3	R1.27	R1 078.23
Jul	920	29.7	R1.29	R1 186.80
Aug	1090	35.2	R1.29	R1 406.10
Sep	1260	42.1	R1.29	R1 625.40
Oct	1560	50.4	R1.29	R2 012.40
Nov	1650	55.1	R1.29	R2 128.50
Dec	1770	57.2	R1.29	R2 283.30
Total	**16031**	**528**		**R20 524**

The solar PV system was installed in June 2014 and the actual production data is represented in Table 3 above. The installations performance is tracked by comparing actual data (kWh produced by the system) against production estimates for the year 2014. In the months between June and October, the amount of electricity produced in kWh was less than estimated and the discrepancy is reflected in the Performance column. For example, Measure 1 on the 18th of June recorded 1030 kWh of electricity produced as opposed to the estimate of 1175.10 kWh over the same period. Performance therefore is 12.3% below the estimated values. The rationale for this phenomenon is rooted in unexpected weather patterns over this period where the PV panels were exposed to more overcast weather conditions than expected and therefore generated less electricity.

During the months February to March 2015, the PV panels generated more electricity than expected as a result of improved weather patterns compared against original predictions. After 306 days, the system produced 14200 kWh of electricity which is 4% above production estimates. This production represents a cost saving of R17 044.26 as displayed in table 3.

Table 3 PV Production Performance Measure

Comment	Date	Cumulative kWh Produced	Cumulative kWh Production estimates	Performance	Cumulative Savings (ZAR)
Installation	10-May				
Measure 1	18-Jun	1030	1175.10	-12.3%	R1,236.31
Measure 2	15-Jul	1800	1960.2	-8.2%	R2,160.54
Measure 3	27-Oct	5890	6145.5	-4.2%	R7,069.77
Measure 4	23-Feb	13200	12798.2	3.1%	R15,843.96
Measure 5	12-Mar	14200	13650.7	4.0%	R17,044.26

SOLAR PV ACTUAL IMPACT ON MUNICIPAL BILL

Table 4 below reflects the City of Cape Town (COCT) municipal account in total for the School over the relevant period:

- Column A: the relevant month the observation was made.
- Column B: the exact starting date the observation was recorded.
- Column C: the exact end date the observation was recorded.
- Column D: the amount of days in question.
- Column E: the amount of electricity consumed in kWh by the School according to the COCT's invoice for the relevant period.
- Column F: the amount of electricity produced by the Solar PV installation over the relevant period.
- Column G: the amount of electricity in kWh that would have been consumed if LED lighting was not introduced in March 2015. The value in Column G multiplied by the tariff in Column I calculates the saving in rand from introducing LED lighting as reflected in Column L.
- Column H: total in kWh
- Column I: tariff per kWh in rand steadily increasing between 2013 and 2015.
- Column J: COCT municipal bill for the relevant month. This value is calculated by multiplying Column E with Column I.
- Column K: the electricity produced by the PV system in Rand value for a particular month. This value is calculated by multiplying Column F with Column I and represents the amount saved.

- Column L: the electricity in rand value saved by introducing LED lighting in March 2015. This value is calculated by multiplying Column G with Column I.
- Column M: total electricity bill in Rand value from the COCT for a particular month. This value is calculated by adding the values in Column J, Column K and Column L.

The table was created in order to track the influence of the PV system on actual municipal data. Observations start in January 2013, approximately 17 months before the PV system was installed, in order to compare the data with the period from June 2014 onwards.

The quantity of electricity consumed within a typical year fluctuates according to seasonal weather patterns. It is also influenced by occupation patters or usage to a minor extent, however the pattern of electricity consumption on a yearly basis remains relatively consistent.

To illustrate the purpose of the table 4, compare the total amount of electricity (Column H) consumed in row 25 (4934 kWh), row 13 (4260 kWh) and row 1 (4260) with each other. In December 2013 (row 25), the School was invoiced R5 502 by the COCT for electricity consumed. In December 2014 (row 13), 4260 kWh of electricity would have cost the School R5 113. However, the Solar PV system generated 1770 kWh of electricity (Column F) at a cost of R2 125 (Column K). The amount of R2 125 is a direct saving on the monthly electricity bill resulting in the School only being liable to the COCT for R2 989 (Column J).

In December 2015 (row 1), 4260 kWh of electricity would have cost the School R5 727. With the PV system generating 1770 kWh of electricity valued at R2 379 (Column K) and the LED lighting saving electricity in the amount of R2 689 (Column L), the School is only liable to pay R659 to the COCT. The LED lighting introduced in the 2015 saves the School the equivalent of paying for 2000 kWh per month. Column G (2000 kWh) multiplied with the tariff in Column I calculates to the value in Column L that represents the saving in rand as a result of the LED lighting. The LED lighting is not factored into the model determining the feasibility of the solar PV installation. It is presented in this project as an additional power saving method.

Table 4 City of Cape Town ("COCT") municipal account in total for the French School

	A	B	C	D	E	F	G	H	I	J	K	L	M
	Month	**Start**	**End**	**Days**	**CoCT**	**Solar PV**	**LED**	**Total**	**Tariff**	**CoCT**	**Solar PV**	**LED**	**Total**
1	Dec-15				490	1770	2000	4260	1.344	R659	R2,379	R2,689	R5,727
2	Nov-15				470	1650	2000	4120	1.344	R632	R2,218	R2,689	R5,539
3	Oct-15				2201	1560	2000	5761	1.344	R2,959	R2,097	R2,689	R7,745
4	Sep-15				2489	1260	2000	5749	1.344	R3,346	R1,694	R2,689	R7,729
5	Aug-15				1720	1090	2000	4810	1.344	R2,312	R1,465	R2,689	R6,466
6	Jul-15				3426	920	2000	6346	1.344	R4,606	R1,237	R2,689	R8,531
7	Jun-15				5134	566	2000	7700	1.2003	R6,162	R679	R2,401	R9,242
8	May-15				3551	982	2000	6533	1.2003	R4,262	R1,179	R2,401	R7,842
9	Apr-15				2153	1150	2000	5303	1.2003	R2,584	R1,380	R2,401	R6,365
10	Mar-15	2015-02-14	2015-03-12	26	2696	1490	0	4186	1.2003	R3,236	R1,788	R0	R5,024
11	Feb-15	2015-01-20	2015-02-13	24	3759	1530	0	5289	1.2003	R4,512	R1,836	R0	R6,348
12	Jan-15	2014-11-14	2015-01-19	66	2490	1780	0	4270	1.2003	R2,989	R2,137	R0	R5,125
13	Dec-14				2490	1770	0	4260	1.2003	R2,989	R2,125	R0	R5,113
14	Nov-14	2014-10-16	2014-11-13	28	2470	1650	0	4120	1.2003	R2,965	R1,980	R0	R4,945
15	Oct-14	2014-09-13	2014-10-15	32	4201	1560	0	5761	1.2003	R5,042	R1,872	R0	R6,915
16	Sep-14	2014-08-14	2014-09-12	29	4489	1260	0	5749	1.2003	R5,388	R1,512	R0	R6,901
17	Aug-14	2014-07-16	2014-08-13	28	3720	1090	0	4810	1.2003	R4,465	R1,308	R0	R5,773
18	Jul-14	2014-06-18	2014-07-15	27	5426	920	0	6346	1.1152	R6,051	R1,026	R0	R7,077
19	Jun-14	2014-05-20	2014-06-17	28	7134	566	0	7700	1.1152	R7,956	R631	R0	R8,587
20	May-14	2014-04-15	2014-05-19	34	6533	0		6533	1.1152	R7,286	R0	R0	R7,286
21	Apr-14	2014-03-14	2014-04-14	31	5303	0		5303	1.1152	R5,914	R0	R0	R5,914
22	Mar-14	2014-02-15	2014-03-13	26	4152	0		4152	1.1152	R4,630	R0	R0	R4,630
23	Feb-14	2014-01-17	2014-02-14	28	6380	0		6380	1.1152	R7,115	R0	R0	R7,115
24	Jan-14	2013-12-11	2014-01-16	36	5068	0		5068	1.1152	R5,652	R0	R0	R5,652
25	Dec-13	2013-11-14	2013-12-10	26	4934	0		4934	1.1152	R5,502	R0	R0	R5,502
26	Nov-13	2013-10-15	2013-11-13	29	4928	0		4928	1.1152	R5,496	R0	R0	R5,496
27	Oct-13	2013-09-13	2013-10-14	31	6586	0		6586	1.1152	R7,345	R0	R0	R7,345
28	Sep-13	2013-08-15	2013-09-12	28	5613	0		5613	1.1152	R6,260	R0	R0	R6,260
29	Aug-13	2013-07-17	2013-08-14	28	3019	0		3019	1.1152	R3,367	R0	R0	R3,367
30	Jul-13	2013-06-19	2013-07-16	27	5845	0		5845	1.034	R6,044	R0	R0	R6,044
31	Jun-13	2013-05-18	2013-06-18	31	7119	0		7119	1.034	R7,361	R0	R0	R7,361
32	May-13	2013-04-18	2013-05-17	29	4865	0		4865	1.034	R5,030	R0	R0	R5,030
33	Apr-13	2013-03-15	2013-04-17	33	5635	0		5635	1.034	R5,827	R0	R0	R5,827
34	Mar-13		2013-03-14	54	4766	0		4766	1.034	R4,928	R0	R0	R4,928
35	Feb-13	2013-01-19			4766	0		4766	1.034	R4,928	R0	R0	R4,928
36	Jan-13	2012-12-14	2013-01-17	34	4918	0		4918	1.034	R5,085	R0	R0	R5,085

To graphically illustrate the data represented in the Table 4, Figure 3 reflects the power consumption profile of the School for the period between June 2013 and May 2014 before the PV system was installed. Figure 4 shows the power consumption profile for the period between June 2014 and May 2015 after the PV system was installed and highlights the impact of the PV system and the LED lighting on the power consumption profile of the School.

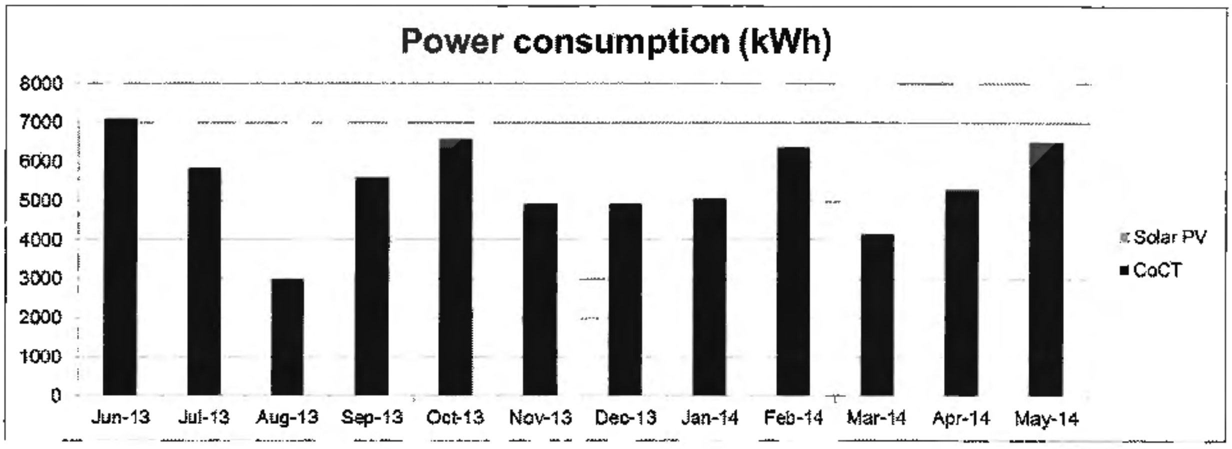

Figure 3 Power consumption for the School (2013-2014)

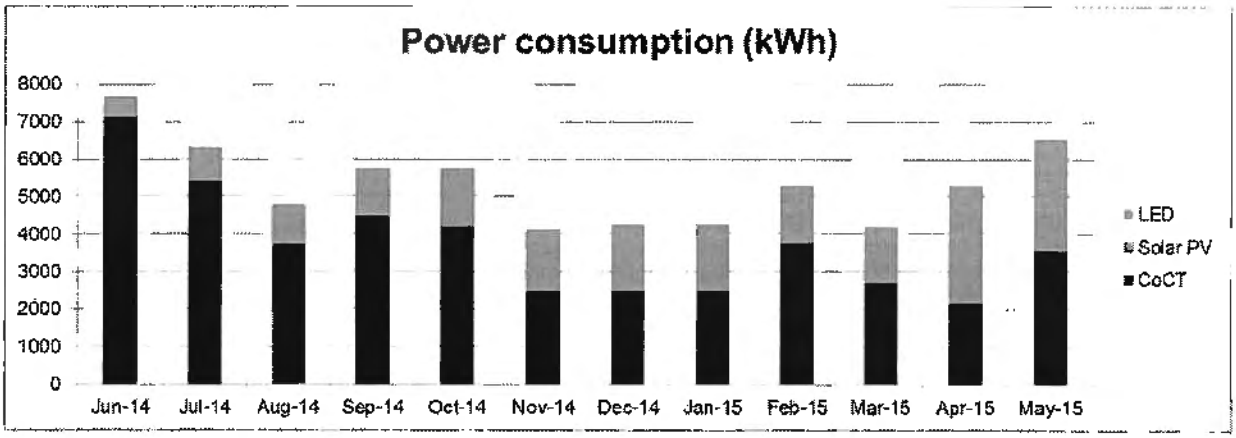

Figure 4 Power consumption for the School (2014-2015)

Figure 5 illustrates the influence of the PV system and LED lighting on the quantity of electricity consumed in kWh over the entire observation period being from January 2013 to December 2015.

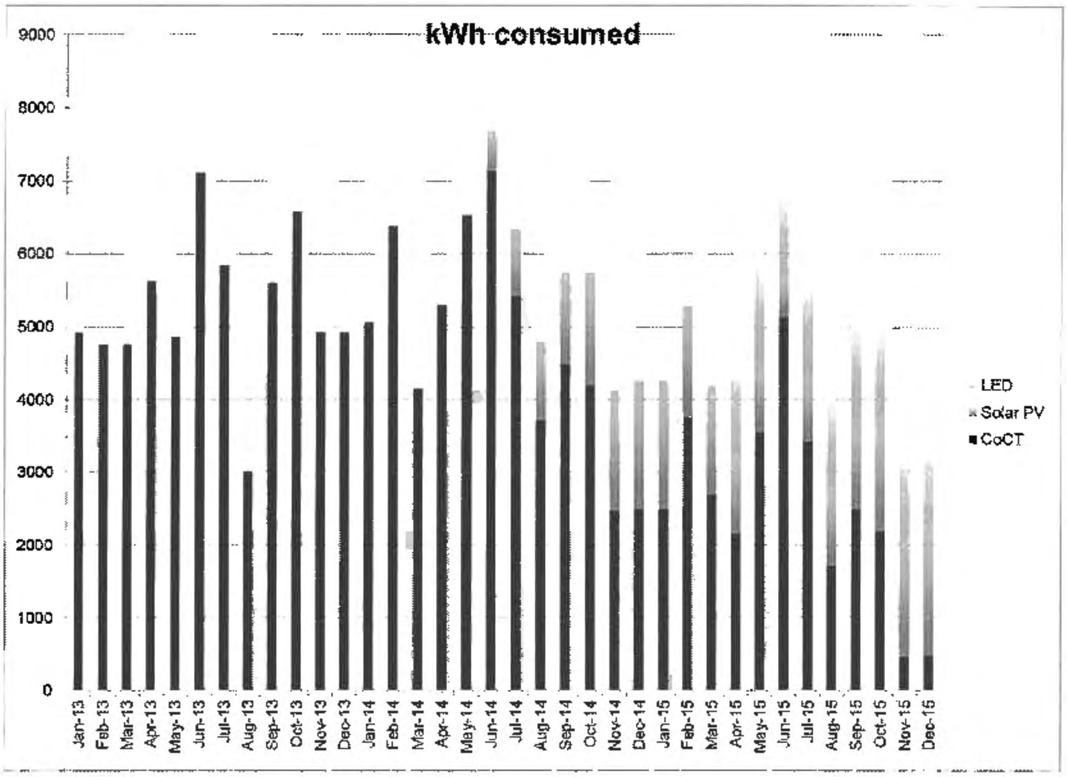

Figure 5 Power consumption for the School (2013-2015)

Figure 5 reflects the positive effect the introduction of the PV system and LED lighting had on the School's finances.

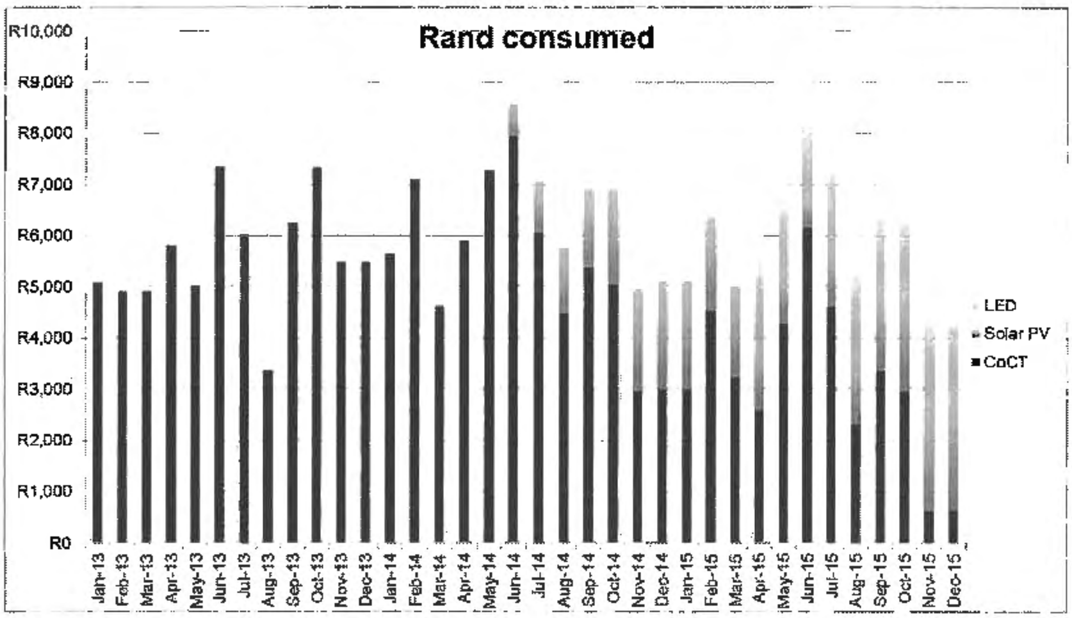

Figure 6 Power expense for the School (2013-2015)

It is important to note that as the tariff for units of electricity increases over time, and electricity in general for reasons discussed in Chapter 2 becomes more expensive for the consumer, the amount of savings increases proportionally. The cost of purchasing and installing a PV system will eventually be redeemed purely in electricity savings over a particular period. This period will be established later in this Chapter. The true value of the PV system to the consumer does not have to pay for the quantity of electricity produced by the PV system. As the tariff and costs of electricity increases, so also does the savings by not having to pay for the electricity at COCT rates. Therefore, the increase in tariff and costs is equal to an increase in savings. This presents a compounded benefit for the consumer and has the effect of paying off the PV system in a shorter period of time and increasing the consumer's return on investment.

4.3.4 The Budget and Financial Model

The research information presented in this section justifies the decision made to install a PV system on the roof of the building. After a thorough assessment by the energy specialist of the solar PV project's potential, the representative of the building owner was presented with the following budget.

The school's monthly electricity demand was conservatively estimated to be 6000 kWh. A solar PV system could contribute at least 22% of the demand at an average of 1333 kWh per month which is a yearly contribution of 16 000 kWh. The energy specialist recommended a 10 kWp installation generating 3 phase electricity with a yield of 18,26%. The roof space was suitable for 40 panels of 250 Wp strength to establish a 10 kWp system at the cost of R255 730 inclusive of VAT in May 2014.

The size of the PV system is 10 kWp which at its peak has a generation capacity of 10 000 kWh. The financial model below in Table 6 reflects the purchase price as R255 730 with a depreciation cost estimate of R10 229.20 per year. It was therefore predicted that the system's intrinsic worth would deteriorate at a rate of R10 229.20 per year over a period of 25 years. The estimated electricity production per year was estimated at 16 000 kWh or 1333 kWh per month as a portion of the total electricity demand of 6000 kWh per month. At the time the assessment was made, inflation was assumed to be 5.5%. The panel efficiency decrease was estimated to be 0.4% per year which means the panels are expected to operate 99.6% as efficient as the year before. The panel efficiency residual value was estimated to be 15% after a 30-year period.

Table 5 Financial Model of the PV system

Installed cap (Wp)	10,000
Rand Total	R 255,730
Depreciation (25yrs)	R10,229.20
Available CF	R 255,730
Loan	R 0
Yearly Yield (kWh)	16,000
Monthly yield (kWh)	1,333
Monthly usage (kWh)	6,000
Inflation	5.50%
Panel eff decrease	99.6%
Panel Residual value	15%

Depreciation period:	25 years
Inflation:	5.5%
Tariff increase:	7% year on year
Residual PV efficiency After 30 years:	15%
NPV of investment:	R645,808
ROI:	252.5%
PayBack period:	9 years

Tariff Increases

Year	1	2	3	4	5	6	7	8	9	10	20	30
kWh generated	16000	15936	15872	15809	15746	15683	15620	15557	15495	15433	14827	14244
kWh week	11429	11383	11337	11292	11247	11202	11157	11112	11068	11024	10591	10174
kWh weekend	4571	4553	4535	4517	4499	4481	4463	4445	4427	4409	4236	4070
Revenue week	R 20,290	R 21,858	R 23,547	R 25,367	R 27,075	R 28,898	R 30,844	R 32,921	R 35,137	R 37,504	R 71,979	R 138,200
Revenue weekend	R 12,643	R 13,632	R 14,699	R 15,849	R 16,932	R 18,088	R 19,323	R 20,643	R 22,053	R 23,559	R 45,626	R 88,396
Revenue Total	**R 32,932**	**R 35,490**	**R 38,246**	**R 41,217**	**R 44,007**	**R 46,986**	**R 50,167**	**R 53,564**	**R 57,190**	**R 61,063**	**R 117,606**	**R 226,596**
Depreciation	R 10,229	R 10,229	R 10,229	R 10,229	R 10,229	R 10,229	R 10,229	R 10,229	R 10,229	R 10,229	R 10,229	
Maintenance	R 2,925	R 3,086	R 3,256	R 3,435	R 3,624	R 3,823	R 4,033	R 4,255	R 4,489	R 4,736	R 8,090	R 13,818
GM	**R 19,778**	**R 22,175**	**R 24,761**	**R 27,553**	**R 30,154**	**R 32,934**	**R 35,905**	**R 39,079**	**R 42,472**	**R 46,098**	**R 99,287**	**R 212,778**
Cumulative CF	-R 235,952	-R 213,777	-R 189,016	-R 161,463	-R 131,309	-R 98,376	-R 62,471	-R 23,392	R 19,081	R 65,179	R 789,788	R 2,345,656

CoCT Tariff increase		**8%**	**8%**	**8%**	**7%**	**7%**	**7%**	**7%**	**7%**	**7%**	**7%**	**7%**
CoCT Tariff (Rand / kWh)	1.12	1.20	1.30	1.40	1.50	1.61	1.72	1.84	1.97	2.11	4.15	8.16
CoCT Tariff (Rand / day)	20.67	22.32	24.11	26.04	27.86	29.81	31.90	34.13	36.52	39.08	76.87	151.21

The discount cash flow model is calculated over a 30-year period at an inflation rate of 5.5% and 7% yearly tariff increase. As Table 5 illustrates, the NPV of the PV installation as an investment was predicted to be R645 808 with a ROI of 252%. If these values materialise as predicted, the PV system would pay for itself in municipal savings in year 9 after installation.

One of the values not included in the model is the funds generated from selling excess generated electricity back to COCT. The tariff at which COCT purchases excess electricity back from private electricity producers (FIT) is ZAR R0.49 per kWh. Private electricity producers like the School must weigh the costs of setting up the system to sell electricity back to the municipality against the income that can be generated at ZAR R0.49 per kWh. The costs involve the time and effort committed to inspections and approvals from the COCT, paying an engineer at approximately R1500 to R1800 per hour to sign off the installation design and purchasing a bi-directional meter to allow electricity to flow to and from the COCT.

According to the energy specialist, the cost to the School to allow for electricity to be fed back into the grid was estimated between R15 000 and R20 000. Over weekends the PV system keeps generating electricity without a demand for it from the school that resulted in an excess that could be sold back to the municipality. It was decided that the system would produce enough electricity over weekends and outside peak demand hours to justify the cost of establishing a FIT system.

The value of income generated from the FIT was not factored into the financial model. If it was, the NPV and ROI would have increased proportionally and the payback period shortened. A further incentive from an environmental point of view, is that the COCT is ending up with green electricity generated by private producers in its system. This energy leaves no carbon footprint and is what the South African government should be aspiring to in terms of its responsibilities under the Kyoto Protocol and Paris Agreement.

4.4 LCCA

The financial model presented in Table 5 is a projection by the PV contractor for a 30-year period. The rise in the cost of electricity over the holding period is influenced by variables such as inflation projections, tariff increases, efficiency decreases and discount rates to account for the time value of money at the end of the holding period.

The actual values yielded by the PV installation for the first year is known (Table 4) and it was important to build a model to test the LCCA of the project and compare the IRR, NPA and payback period to the projected data received from the PV contractor. With reference to Table 4, the energy savings earned by the PV installation was recorded from 1 of June 2014 until the 1st of May 2015.

The LCCA model marked appendix 1 considered the data recorded from the 1st of June 2014 until the 1 of May 2015 on a monthly basis and merged afterwards into the yearly income of R15 748. This is the amount of money that would otherwise have been paid to the COCT for electricity and constitutes the savings or the income generated by the PV installation. The average tariff increase recording for the period between 2013 and 2015 amounts to 9.15% and accounts for the growth in income for the PV installation over the holding period of 30 years.

With the initial capital expenditure of R255 730, the model calculates the IRR of the investment over the holding period of 30 years as 14.7%.

The LCCA model has tested the NPV on discount rates between 10% and 16%.

1. Discount rate of 10% = R174 680 NPV and ROI = 68.31%
2. Discount rate of 11% = R123 026 NPV and ROI = 48.11%
3. Discount rate of 12% = R80 742 NPV and ROI = 31.57%
4. Discount rate of 13% = R45 938 NPV and ROI = 17.96%
5. Discount rate of 14% = R17 138 NPV and ROI = 6.70%

Above a discount rate of 14% the NPV and ROI becomes negative and will have the effect that the project is no longer viable.

A sensitivity analysis was conducted to determine the payback period of the initial capital expenditure over a 30-year period also at discount rates between 10% and 16%. At a 10% discount rate, the PV installation has been projected to pay for itself in electricity savings after 16 years. At a discount rate of 11%, the payback period is projected to be in the 17th year; at a discount rate of 12% the payback period is projected to be 20 years and 23 years at a discount rate of 13%. At a discount rate of 14%, the payback period is projected to be in the 27th year and any discount rate higher than 14% has been projected to be outside the holding period which makes the PV installation no longer viable or attractive as an investment.

To understand when the project has a positive net asset (or at which point it reaches break-even), the writer has built a financial projection model (last section under the LCCA model). In this model it is assumed that the investor borrows the initial investment and pays interest on the outstanding amount periodically. All income received is used to offset the outstanding loan amount. The interest rate is assumed at 10% (the current prime interest rate). The projection model illustrates that the project will have a positive net asset value in year X at a borrowing cost of 10% per annum.

With reference to the Financial Projection illustration at the end of the LCCA model, the following observations was made:

- The net cashflow is plotted on the primary axis. This indicates the initial outlay, the amount in years during which the loan interest exceeds the income, the subsequent years where the income exceeds the loan interest (the point which the loan capital is starting to be repaid), and the point at which the loan capital has been paid off (break-even point).
- The net asset value is plotted on the secondary axis. The graph illustrates that the net asset value of the project becomes positive in year 17 if the average tariff increase is assumed at 9.15%. If the tariff increase is assumed at 7%, the nett asset value of the project becomes positive in year 19.

4.5 Summary of the main findings

Analysing the results from the interviews and the rooftop solar PV model, the research shows that it is beneficial to a small-scale property owner to install a 10 kWp grid-tied PV system on the rooftop of the school in this particular location. Installing an off-grid or hybrid system with storage capacity will be 40%

more expensive in initial outlay and maintenance costs and unnecessary considering the fact that the school is located in an area well connected to the national grid. The 10 kWp PV installation that operates without batteries combined with the centralised power grid connection is sufficient to warrant uninterrupted electricity flow during the daytime when the school is operational, even during day time periods of loadshedding.

The LCCA shows that the payback period for the PV installation as investment in pure electricity savings occurs between 16 and 18 years. The financial projection model indicates that the project will have a positive net asset value in year 17 at an assume tariff increase of 9.15% and ad borrowing cost of 10% per annum. If the tariff increase is assumed at 7%, the project will have a positive net asset value in the 19. As the lifespan of the project is 30 years, the research shows that the installation is feasible from the perspective of a small-scale property owner.

If the school was in a remote area with limited or no access to the national grid, an off-grid or hybrid system would have been more appropriate despite it being 40% more costly. In areas where there is a constant reliable power grid, the solar power installation system without a battery backup system is ideal. It is simpler and cheaper to install and easier to maintain. It can always be expanded to include battery storage at a later stage. The negative impact on municipal finances is also restricted by continuing to pay a portion of electricity costs to the government that in turn can continue to maintain the national grid.

Coal-fired electricity generation continues to rise in South Africa as a result of poor financial planning and corruption at Eskom over the last decade. Electricity sales remains the chief source of income for municipalities and a large scale roll out of off-grid PV systems would cease to protect Eskom from a death spiral situation. Considering that solar PV technology will continue to decrease, a small-scale property owner can enjoy the benefits thereof while still making a contribution to local municipal finances.

4.6 Conclusion

Chapter 4 presented data to respond to the question whether solar power is a viable alternative to traditional carbon-based power supply to existing building owners or managers. The installation of a rooftop PV system has been investigated including the circumstances under which such a project could be successfully implemented, the equipment involved and the capital outlay to finance such a project. The Chapter started with interviews from industry specialists regarding PV systems in general and the parameters within which it could operate in order to add value to a building owner or manager.

A particular PV project was identified, a single case study undertaken and the observations presented in the second half of the chapter. The electricity demand for the particular project and the costs of installation was investigated. These values culminated into the NPV, ROI, payback period and breakeven point for the installation as an investment.

The data as presented by the PV contractor was independently analysed with a LCCA and a sensitivity analysis which demonstrates how assumed values for a range of variables can affect the NPA, IRR and payback period. The model provides an indication for the reader to gauge at which assumed levels of risk the PV installation would no longer serve as a sustainable investment.

Chapter 5 Conclusion

5.1 Structure of Chapter

This chapter starts with a revision of the research questions to be answered by the study and the proposition to be validated or rejected. It explores the overall objectives of the study and presents the findings and results the researcher sought to discover including recommendations for future research.

5.2 Introduction

The purpose of this research was to establish whether electricity generated from a solar PV installation is a viable alternative to traditional electricity supply from Eskom or whether it is more effective as a supplement to existing Eskom power supply. It is researched at which point in time does it becomes beneficial to a small-scale property owner to acquire a rooftop PV system from an investment point of view. The research focused in particular on the installation and maintenance costs of such a PV system and whether the funds committed to a PV project is justified from an economic and environmental point of view. The research also investigated to what extent technology has developed to replace coal-based electricity supply completely with solar energy and the affordability of this solar technology.

5.3 The research problem statement

The research problem statement was:

Little is known about at what point does it become more feasible from the perspective of a small-scale property owner to install a rooftop PV system to supplement electricity flow from Eskom or whether to install a system capable of producing total power to meet its particular electricity demand.

5.4 The research questions

The research questions guiding the study were:

Question 1:

Has solar technology advanced to the extent that it can provide uninterrupted electricity flow to meet the demand in Kilowatt output as required by an existing building during loadshedding?

Question 2:

Can a building owner/tenant be completely reliant on the energy generated from a solar PV system or is it more feasible to only employ the solar PV system as a supplement to Eskom's electricity supply?

Question 3:

At which point does it become worthwhile for building owner/tenant to install a solar PV system to provide total power independently from Eskom.

Question 4:

At which point does it become financially justifiable for a building owner/tenant to install a solar PV system?

Question 5:

What is the payback period in order for the building owner/manager to finance the rooftop PV system purely in electricity savings?

5.5 The research proposition

The proposition to be validated or rejected, as presented in Chapter 1, was stated as:

Installing a rooftop solar PV system in a grid connected area is more beneficial to a building owner/tenant to supplement centralised electricity supply as opposed to complete reliance on a solar PV system to meet the required electricity demand.

The research method employed in this project included a review of the latest and most relevant literature, interviews with solar technology experts and a single case study.

5.6 Achievement of Research Objectives

The research objectives were to:

i) Investigate whether solar technology has developed to the extent where it not only serves a niche market, but is accessible and affordable to most small-scale property owners.
ii) Investigate the barriers to large scale deployment of solar energy and solutions in South Africa.
iii) Determine whether South Africa's social and environmental responsibility to comply with the Paris agreement regarding producing green energy is being followed.
iv) Determine the costs and affordability for building owners or managers to install and maintain a solar PV system.
v) Investigate the municipal savings yielded by a rooftop PV system.
vi) Determine whether it is possible and feasible to feed excess electricity generated back into the national grid and whether it is cost effective to set up a system to allow for this option.

Objective (i) and (ii) was examined through the analysis of the literature review. It can be concluded that solar energy provides the most potential to produce green energy. It is an unending and limitless source of renewable energy that has up to date been only partially exploited.

Literature has indicated that the solar technology industry is entering a period of maturation and through experience has adapted to be more accessible and affordable to the average property owner (Banks and Schaffler, 2006). Pricing has come down significantly during the last 10 years in general and the source and quality of component materials has developed and improved as well. Technical and economic barriers restraining the industry have largely been bridged. The challenge that remains is finding and implementing solutions to institutional barriers. These solutions are mostly within the hands of national governments and it is the responsibility of the consumer community to lobby government to create a space wherein solar technology can function at an optimal level. In South Africa it is imperative that the initiatives agreed to under the Integrated Resource Plan be implemented without further delay. From a political perspective, South Africa cannot afford to privatise Eskom. The media recently reported that Eskom will be broken up into three units – generation, transmission and distribution without it being privatised. It would prevent the labour unions representing the workforce in the coal industry from costly national strikes while renewable energy is added to the national energy mix by finally giving the go-ahead to the chosen independent power producers to generate renewable energy.

Objective (iii) was also examined through analysis of the literature review. Key sources state why renewable energy and why solar energy as a renewable energy resource in particular is preferred. It was pointed out that there is no long-term future in producing coal-based energy on a national level. The literature review pointed out that South Africa has promulgated the appropriate policies under the draft 2018 Integrated Resource Plan to comply with the Kyoto and Paris Agreement. The issue became the readiness to implement policies relating to renewable energy and whether the political will exists to push forward with the policies. It is also noticeable that South Africa has not disregarded coal fired energy generation, it is still a large portion of the energy mix and will remain so for the foreseeable future. The answer from a South African perspective lies in finding the correct balance between coal and renewable energy initiatives. It would be naïve to expect a developing country like South Africa with abundant coal resources to embrace renewable energy to the same extent as certain developed countries.

Objective (iv) goes to the core of any property owner or manager's basic considerations of whether a PV installation is financially viable. The interviews with solar PV experts provided clarification and motivations to this objective during empirical research.

Research indicated that the three most expensive components in a grid-tied PV system are the panels, the inverter and the mounting system. The answer whether the cost to roll out a PV system for a building with a particular electricity demand is justified, is influenced to a large extent by the competency and experience of the solar energy contractor in recommending a suitable size for the system, recommending the appropriate materials and equipment to be used as well as the mounting system. These components differ in quality and price and must be curtailed to fit within the owner's budget.

The size of the system is a crucial decision as larger systems are proportionally more expensive and would produce electricity at a higher cost per watt. Electricity demand fluctuates during day, during week and seasons. An energy specialist suggested using a data logger at particular site to observe electricity demand patterns during weekdays and weekends and factoring in the relevant season in order to arrive at an informed decision regarding recommending the size of the PV system to be installed. If the system is too small in context, it will not generate enough electricity to rendering it financially viable. Should the system be too large, it would be disproportionally expensive to install and generate too much excess electricity for which the landlord would only receive 49 cents per kWh.

The answer lies in finding a suitable balance for the project as the actual value of the PV system is saving the landlord to pay R1.29 per kWh for electricity rather than earning R0.49 per kWh for electricity sold back into the grid. An energy specialist recommends a 10 Wp system at a cost of R255 730. The financial model in Chapter 4 predicted the NPV to be R645 808 with a ROI of 252%. This information was sufficient to convince the School to proceed with the project.

In hindsight, it is now known from the results of the LCCA that the initial figures projected relating the financial viability of the PV system as an asset might have been over estimated. Considering the LCCA and sensitivity analysis, the PV system is still a viable investment, however at a slightly reduced IRR, a more realistic NPV and a longer payback period.

In conclusion, the PV system has a lifespan of 30 years. It requires a large initial capital outlay with relatively low maintenance costs. The payback period for the system in electricity savings, excluding additional revenue from selling excess electricity back into the grid, is between 16 and 18 years. The evidence has shown that the initial capital investment to install the PV is justified for this particular project. As the PV system installed dates back to 2014, the writer determined that a similar 10kWp grid-tied system in 2019 would cost approximately R200 000. It would include only 32 panels with 16 optimisers to generate the same 3 phase power supply. It would result in a proportionally shorter payback period and breakeven point for system from an investment point of view.

Objective (v) was examined and analysed in Chapter 4 and more particularly Table 5. It reflects the savings the PV system is responsible for by tracking actual data supplied by the School.

Objective (vi) was examined and analysed towards the end of Chapter 4. Despite the cost involved to enable the School to sell electricity back to COCT, it was decided that that it was still justified under the circumstances. The School will reap the benefits of excess electricity generated outside peak hours and weekends. In turn, the COCT will be supplied with green environmentally friendly energy to disburse again back to the City of COCT.

5.7 Findings of the Research Questions

This report aimed to address the aforementioned five research questions:

Solar technology has advanced to the extent that it is able to provide the demand in Kilowatt output as required by a particular building. An owner or building manager must simply install a system large enough to provide the required output. The logic behind committing the costs involved to set up such a system is questionable; however, it is certainly possible.

The analysis of data in Chapter 4 indicates that the initial costs committed to install a PV system on the roof of the School were justified. It would actually have been a liability to the School if the decision to install the PV system was not taken in 2014. The question remains whether the School and other landlords in general would be able to install a PV system large enough to generate electricity sufficient to feed the entire demand of the building. Consequently, can the building operate completely separate from the municipality or go completely off the grid by generating all of its electricity demands?

Solar PV experts indicated that the technology does exist for a building within acceptable parameters to install an off-grid system with a battery pack to store generated electricity for use also at night or during cloudy days. This type of system however is relatively expensive and does not allow the energy producer to sell excess electricity back into the grid.

The alternative is to install a grid-tied system, with a larger sized PV system capable of producing enough electricity so as to prevent the need to purchase electricity from the municipality. This system would still be capable to feeding electricity back into the grid at ZAR R0.49 per kWh. It is possible to install such a system; however, it must be compared to installing a smaller sized and more affordable grid-tied system where approximately 80% of the electricity demand is generated by the PV system and the balance of the demand during night time or cloudy days is purchased from the municipality.

Although theoretically possible, it is not cost effective to go completely off the grid in circumstances where one could still be connected to the grid. The only justification to go completely off the grid would be in remote areas where there is no option to connect to the grid. These PV installations are also comparatively more expensive than grid tied systems.

The research has shown that it is more cost effective to employ electricity generated from PV panels as a supplement to Eskom's power supply. The financial model would have failed if the PV installation on the School was sized to supply the total electricity demand to the building. The ideal sized system to install would be one that generates sufficient power to feed daytime peak demand and excess electricity sold back to the municipality. Electricity required after dark can be purchased from the municipality to ensure uninterrupted electricity supply. If upon review it is found that too much electricity is fed back into the system at ZAR R0.49 kWh, it could be argued that it would have been more cost effective to install a smaller PV system at a lower cost. As stated before, the actual value of the PV system is in saving the owner from payment to the municipality for electricity at ZAR R1.29 kWh, as opposed to income generated from selling electricity back to the grid at a rate of ZAR 0.49 cents kWh.

The LCCA has indicated that the payback period for the PV system in electricity savings according to model is between year 16 to 18. The break-even point according to the financial projection on the LCCA is in the year 17 at the assumed tariff increase of 9.15%. If the tariff increase is assumed at 7%, the break-even point shall occur in year 19. Certain variables have changed since 2014 that would affect this result. The cost of PV technology has steadily decreased and will continue to do so through increased competition, economies of scale and technology learning. The cost of coal fired electricity has also increased and will continue to do so to keep Eskom operational. It therefore makes more sense than ever before to install a suitably sized PV installation on the rooftop of existing buildings from an investment point of view for small-scale property owners.

5.8 Validation/Rejection of the Proposition

The proposition of this research stated:

"Installing a rooftop solar PV system in a grid connected area is more beneficial to a building owner/tenant to supplement centralised electricity supply as opposed to complete reliance on a solar PV system to meet the required electricity demand"

The research has shown that the proposition is supported based on the findings of the data supplied by the energy specialists relating to the case study and the independent feasibility predictions resulting from the LCCA.

5.9 Conclusion

The findings of the research and in particular the field experiment has shown that the technology does exist in South Africa and that it is affordable to the general market to produce a portion of your own electricity demand to supplement the harmful and coal-based energy supply from Eskom.

5.10 Recommendations for future research

The solar PV industry as a renewable energy solution is maturing and growing in exposure towards stakeholders and investors, as the dangers of climate change continues to make headlines and the production of green energy is being prioritised. The LCOE from a solar PV installation is also going to decline as new technology advances. PV modules and BOS equipment are becoming more freely available with a wider range of products to match the demand of a wider range of clients and installation or maintenance contractors are becoming more experienced. The solar industry needs more research case studies to track the performance of medium and smaller scale solar PV installations as an investment opportunity. Financial information on this topic is fairly scarce and mostly confidential.

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