Techno-Economic Investment Framework for REIPPPP Utility-Scale PV Plants in SA

By

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DECLARATION

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own original work, that I am the authorship owner thereof (unless to the extent explicitly otherwise stated) and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

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ABSTRACT

The South African department of energy forecasts generation capacity to reach 89.5GW by 2030, and the objective is to have 8.4GW generated from solar Photovoltaic (PV) renewable energy plants. The department created an enabling environment for the private sector to invest through the Renewable Energy Independent Power Producer Procurement Program (REIPPPP). The REIPPPP has been hailed as one of the best renewable energy programs world-wide and has stimulated investment in this sector in South Africa. The questions considered in this research were: how is project viability of PV utility power plants assessed? Are conventional capital budgeting and project financial evaluation parameters sufficient to perform a preliminary analysis? How should investors account for risk associated with PV plants in South Africa? And finally, how should the risk be calculated or what tools and or techniques should be considered applicable? The aim of this research was to propose and develop an investment framework and model that private investors could use during the preliminary phase of utility scale solar photovoltaic projects. The first focus of the study was the development of a financial model which employs the conventional capital budgeting parameters such as the net present value (NPV), the rate of return (IRR), the return on investment (ROI), and the Debt Service Coverage Ratio (DSCR). @Risk® simulation package was used to simulate financial uncertainty through varying some of the inputs randomly, to see the effect on required financial output and probability of viability. The second phase of the study expands on the NPV values that were calculated, through the use of real options analysis. The significance of real options is the fact that, the volatility factor which is incorporated in the formulae, best represents all risks which are not catered for in most project financial formulas. Real options analysis provides the decision makers of a project with the flexibility to actively evaluate the project's financial viability and undertake the risk based on all available information. The study uses project data obtained from REIPPPP window two PV project to evaluate the investment feasibility using conventional project finance evaluation parameters, an @Risk® analysis is performed and then expanded upon to do a real options analysis. A real options analysis (ROA) active mapping framework is adopted to map and analyse the viability of the project. This dynamic study of project financial evaluation in the form of the ROA of the case study, provided volatility and NPV ratios that yielded a 'maybe invest now' decision. The project used as a case study is already constructed and the volatility used in this study was based on risks experienced during the construction phase. The results support the decision made to invest in this project, as a good investment opportunity undertaken three years ago. The research objective proposing that three techniques; conventional capital budgeting methods, risk analysis and real option analysis should be combined in financial analysis of renewable energy utility scale PV projects was confirmed

through this study. The advantage of combining the three techniques is that the financial due diligence now incorporates the risks associated with such projects which conventional capital budgeting methods does not account for.

OPSOMMING

Die Suid Afrikaanse Departement van Energie voorspel dat Suid Afrika se opwekkingskapasiteit 89.5GW sal bereik teen 2030, met die doelwit om 8.4 GW hiervan met sonkrag photovoltaise (PV) energie projekte op te wek. Die departement het ‘n finansierings vriendelike omgewing geskep waarin die privaat sektor kan investeer deur die Hernubare Energie Onafhanklike Kragvoorsiener-program (REIPPPP). Die REIPPPP word wyd geloof as een van die beste hernubare energie programme ter wêreld en het aansienlike investering in Suid Afrika teweeggebring. Die vrae wat in hierdie navorsingstuk ondersoek is was: hoe word die projek lewensvatbaarheid van grootskaalse PV projekte geassesseer? Is konvensionele kapitale begrotings en projek finansiële evaluasie parameters voldoende om 'n voorlopige analise uit te voer? Hoe behoort beleggers voorsiening te maak vir die risikos wat met PV projekte in Suid Africa geassosieer word? En laastens hoe behoort die risiko bereken te word en watter tegnieke moet oorweeg word ten einde ’n ingeligte besluit te kan neem? Die doel van hierdie navorsing was om 'n finansiële model te ontwikkel en voor te stel wat privaat beleggers kan gebruik om die lewensvatbaarheid van grootskaalse PV projekte tydens die ontwikkeling fase te bepaal. Die eerste fase van die model het die tradisionele finansiële parameters in ag geneem, onder andere die netto huidige waarde (NPV), interne opbrengkoers (IRR), opbrengs op belegging (ROI) en die skuld vereffenings dekking verhouding (DSCR). Die @Risk® simulasie pakket is gebruik om die finansiële onsekerheid te simuleer deur die inset parameters lukraak te wysig en sodoende die effek op finansiële uitsette en die waarskynlikheid van lewensvatbaarheid te bepaal. Die tweede fase van die projek brei uit op die NPV waardes wat bereken is, deur die gebruik van die reële opsies benadering (ROA). Die waarde van reële opsies is die feit dat die formule 'n wisselvalligheids faktor bevat wat alle risikos assesseer, iets wat nie deur die meeste projek finansiële formules in ag geneem word nie. Reële opsies benaderings voorsien aan die besluitnemers van projekte die buigsaamheid om aktief die projek se lewensvatbaarheid te analiseer en die riskio te ontleed met alle moontlike informasie tot hulle beskikking. Projek data wat ingesamel is van 'n projek uit die tweede rondte van die REIPPPP is in 'n gevallestudie gebruik om die finansiële lewensvatbaarheid van die projek te bepaal. Dit is gedoen deur die gebruik van konvensionele projek finansierings evaluasie parameters. ‘n @Risk® analise is uitgevoer en daarna uitgebrei om die reële opsies benadering toe te pas. 'n Reële opsies benadering aktiewe kartering raamwerk is gebruik om die lewensvatbaarheid van die projek uit te beeld en te analiseer. Hierdie dinamiese studie van die projek se finansiële evaluasie deur middel van 'n ROA van die gevallestudie, het wisselvalligheid en NPV verhoudings opgelewer wat 'n "investeer moontlik nou" besluit teweeg gebring het. Konstruksie is reeds voltooi op die projek wat as gevallestudie gebruik is en die wisselvalligheid wat in hierdie studie gebruik is is

gebaseer op risikos en kwessies wat tydens die konstruksie fase ervaar is, en nie risikos wat bekend was tydens die ontwikkelings fase nie. Die resultate bevestig die besluit wat 3 jaar gelede gemaak is om in hierdie projek te belê as 'n goeie beleggingsgeleentheid. Die navorsings doelwit wat aanbeveel dat die drie tegnieke; die konvensionele kapitale begrotings metode, risiko analise en die reële opsies benadering metode gekombineer moet word tydens die finansiële analise van grootskaalse hernubare energie PV projekte is deur hierdie studie bevestig. Die voordeel teweeggebring deur die kombinering van hierdie drie tegnieke is dat die finansiële omsigtigheidsondersoek nou die risikos insluit wat met hierdie projekte geassosieer word, waar konvensionele kapitale begrotings metodes nie hierdie risikos in ag neem nie.

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LIST OF ABBREVIATIONS

AC	Alternating Current
AOI	Angle of Incidence
BIPV	Building Integrated Photovoltaics
BOO	Build, own and operate
BOOS	Build, own, operate and sell
BOOT	Build, own, operate and transfer
BOP	Balance of Plant
BOS	Balance of System
BOT	Build, operate and transfer
Capex	Project Capital Expenditure
CdTe	First Solar Cadmium Telluride
CIGS	copper indium gallium diselinide
CPV	Concentrating Photovoltaic
CSP	Concentrated Solar Power
CUOSA	Eskom Connection and Use of System Agreement
DC	Direct Current
DCF	Discounted Cash Flow
DNI	Direct Normal Radiation
DoE	Department of Energy
DSCR	Debt Service Coverage Ratio
EDO	Economic Development Obligations
EHV	Extra-high-voltage
EPC	Engineering, procurement and construction
EPIA	European Photovoltaic Industry Association
FCI	Fixed Capital Investment
FCI	Fixed Capital Investment
HV	High-voltage
IA	Implementation Agreement
IEA	International Energy Agency
IPP	Independent Power Producer
IRP	Integrated Resource Plan
IRR	Internal Rate of Return
JRC	European Joint Research Centre

LCOE	Levelised Cost of Energy
LLCR	Loan Life Coverage Ratio
LR	Learning Rate
LSR	Least Squares Regression
MPP	Maximum Power Point
NERSA	National Energy Regulator of South Africa
NPV	Net Present Value
NREL	National Renewable Energy Laboratory
O&M	Operations and Maintenance
OECD	Organisation for Economic Co-operation and Development
PLC	Programmable Logic Controller
PPA	Power Purchase Agreement
PR	Progress Ratio
PV	Photovoltaics
R&D	Research and Development
RE	Renewable Energy
REFIT	Renewable Energy Feed-In Tariffs
REIPPPP	Renewable Energy Independent Power Producers Procurement Program
ROA	Real options analysis
ROE	Return on equity
ROI	Return on investment
SPV	Special Purpose Vehicle
TLC	Technology Learning Curve

CHAPTER ONE: INTRODUCTION

1.1 INTRODUCTION

A 2009 Department of Energy (DoE) publication (Subramoney, et al., 2009), stated that the government was determined to reduce the country's reliance on high-carbon power generation sources. From years past up to 2015, the country's electricity generation is still over 90% coal-based, with the rest taken up mainly by nuclear, gas and hydro-scheme generation plants.

The DoE issued an Integrated Resource Plan (IRP) in 2011, which documented a roadmap for adding new capacity to the country's system of electricity power generation for the next 20 years. According to the IRP, the target for renewable energy generation is to reach a maximum of 42% of the entire new fleet of generation capacity built between 2010 and 2030. The forecast is that by 2030, overall generation capacity will be at 89.5GW, and of that, 17.8GW will be from renewable energy sources, with 8.4GW each from solar and wind energy (South Africa. Department of Energy, 2011).

The DoE, together with National Treasury, crafted and implemented a private investor friendly renewable energy policy which culminate in the Renewable Energy Independent Power Producers Procurement Program (REIPPPP) (Winkler, 2005). The government backed policy had the goal of stimulating private sector investment through public private partnership models and thereby created an enabling investor environment. The REIPPPP is a bidding process, through which, independent power producers that are able to propose technically sound projects to meet local economic content and local development requirements at the best-proposed tariff, are awarded projects by the DoE (Papapetrou, 2014). The bidding process is phased into what is referred to as bid windows, with each bidding window, there is a number of allocated MW per renewable energy technology type to be awarded based on specified criteria.

The private industry's appetite to enter any unexplored territory is solely driven by its potential profitability and associated risk.

> *"When we consider investing in a renewable energy project, we focus on two key factors. First, we only pursue investments that we believe make financial sense. South Africa's strong resources and supportive policies for renewable energy make it an attractive place to invest—which is why it had the highest growth in clean energy investment in the world last year. Second, we look for projects that have transformative potential—that is, projects*

*that will bolster the growth of the renewable energy industry and move the world closer to a clean energy future." (*Needham 2013)*.*

This statement was made by Google's director of Energy and Sustainability. It concisely captured the potential and lucrativeness of the market, as seen by prospective investors. However, with the renewable energy industry being in its infancy in South Africa, no academic research was found that relates to the techno-economic viability of investing in large-scale grid-connected photovoltaic systems. Some of the literature reviewed (Chidi, et al., 2012) presents models and a techno-economic evaluation of similar technologies in different parts of the world (Chowdhury, et al., 2010). One relevant study looked at the economic viability of solar PV electricity generation as compared to conventional energy sources in order to estimate when grid parity would be reached in South Africa (Minaar, 2011).

1.2 THE PROBLEM STATEMENT

South Africa's REIPPPP has been ranked in the top three globally, due to the achievements of the program over the last three years. The programme has been regarded as excellently regulated and implemented and has attracted investors from different sectors both locally and internationally. In addition to the goal of addressing the need for incorporating more renewable energy sources in SA's energy mix, it was equally important to develop a programme that would stimulate a market for this technology whilst driving the tariff to levels that could be at parity with conventional power generation technologies. By observing the tariffs from REIPPPP projects in 2011 to current, it is clear that the competitive nature of the programme has pushed the tariffs down. For the private equity investors or shareholders, the question regarding the profitability of the REIPPPP has gained stronger emphasis due to the dramatic decrease in tariffs in short period of time. The complementary problem related to the question of profitability is the aspect of risk associated with the renewable energy projects and industry within South Africa. Given the infancy of the industry in South Africa, there was no research work done for large scale renewable energy photovoltaic projects. The problem being investigated is how to development techno-economic model to evaluate profitability of PV projects in South Africa from a private equity investor perspective. The second and most critical problem is how conventional capital budgeting framework addresses project risk and its impact on project viability. Furthering this object is the use of @Risk® simulation to analyse probabilities of profitability and then lastly incorporating real options analysis in the study to evaluate viability of projects in lieu of associated risk.

1.3 AIMS AND OBJECTIVES

The aim of this research was to propose and develop a financial model that investors could use during the feasibility evaluation phase of utility scale photovoltaic projects. The first phase of the model considered the traditional financial parameters such as the net present value (NPV), the internal rate of return (IRR), the return on investment (ROI), and the debt service coverage ratio (DSCR). Recent developments that have led to further drastic decreases in tariffs for projects awarded under the REIPPPP due to how companies structure the financing of their large renewable energy projects. Therefore, the question on the profitability and sustainability of the programme for private investors has come to the surface as tariffs went down. This research and model developed is for projects under project financing structure funding. A technology learning curve model was also used to evaluate what could be expected in South Africa, and an attempt to incorporate the learning curve in the sensitivity analysis of the NPV, IRR, ROI and DSCR. @Risk® statistical simulation is performed with the specific focus of varying only three key inputs: energy output, inflation and loan interest. This simulation evaluation enhances the sensitivity analysis by randomly varying key input data.

The second phase of the project expanded on the NPV values that were calculated, through the real options analysis theory. A framework established by Luehrman (1998) and developed further by Campher (2012), called the real options analysis active mapping tool, was developed to conduct analyses on projects. Real options analysis (ROA) provides the decision makers of a project with the flexibility to actively evaluate the financial viability with risk volatility factored into the calculation. When the project risk is considered objectively, the decision could ultimately be to defer, abandon, or execute the project.

The use of real options analysis (ROA) for the current renewable energy programme was of particular interest because the procurement program have shown an increase in the number of projects submitted, while far fewer projects are awarded. Therefore, adopting a financial evaluation model that considers the project risk is critical for investors especially as the competition for winning the bid is high. The objective of this research was to show that the use of capital budgeting model should be enhanced through incorporation of project risks in order to realistically assess financial feasibility of renewable energy utility-scale PV projects.

1.4 RESEARCH QUESTIONS

The following research questions were posed in order to achieve the aim set out for the research project:

1. What factors influence the financial viability of renewable energy PV projects?

2. Is capital budgeting project financial evaluation sufficient to evaluate profitability in the South African renewable energy PV industry, given the current tariffs and economic climate?
3. How can risk in renewable energy projects be contemplated by investors?
4. Could the @Risk® tool provide required risk analysis complimentary enough to real options?
5. Could real options be considered for the evaluation of renewable energy PV projects?
6. How should the implementation of real options be considered for PV projects?
7. What value does real option analysis add to the traditional valuation of project economic feasibility in the renewable energy PV market?

1.5 METHOD OF RESEARCH

Literature was reviewed to understand the tools, techniques and models that have been developed to date and an assessment was made concerning their relevancy in the South African context. A technical and financial analysis of the requirements to develop a grid-connected PV system was performed. A financial spreadsheet model was developed, which had the following as inputs: capital expenditure to construct the plant, energy output of the plant, financial factors such as interest rates for loan repayment, tax rates, tariffs, inflation rate, loan tenure, and debt vs equity ratio. The model calculates the traditional discounted cash flows of the project, providing information regarding the net present value, rate of return, and return on investment and equity. The model was then expanded further by incorporating the real options analysis model, and the results of this were also mapped onto the active mapping tool.

To validate the relationship between the technical parameters and the economic yield of a theoretical project, a case study was evaluated. The case study was based on one of the projects that were selected under the REIPPPP preferred bidder window 2, and window 3 tariffs were also used in the model to measure the difference between the two bidding windows. The reason for the use of the phase 3 tariff was to demonstrate as under scenario analysis the financial viability of such low tariffs.

It was expected that the results obtained would match, or be very close to the figures obtained by the case study project developers during the bidding phase of the project. It was also expected that this model would confirm that, under the current South Africa DoE policy, these projects would be viable and profitable for independent power producers.

1.6 CHAPTER LAYOUT

This chapter has laid the general background as an introduction to the study, further raising the questions that will be answered as well as highlighting the study objective. Chapter Two discusses the literature surveyed for the study, and covers the theory and technical parameters that typically influence the energy generation of large-scale photovoltaic systems. A background on the South African Renewable Energy Independent Power Producer Procurement Program is also introduced and expounded upon. The third chapter gives a brief overview of project finance and the financial evaluation of projects. The theory of real options analysis is also discussed against the backdrop of discounted cash flows. Chapter Four discusses how the model was developed, the different parameters that were included and the assumptions that were made. The fifth chapter investigates the case study within the framework of the model that was developed, and it presents the results for the discussion of the thesis. The conclusions of the study are finally drawn in Chapter Six.

1.7 SUMMARY

In this chapter, the REIPPPP was introduced, which is a bidding process, through which independent power producers that are able to propose technically sound projects at the best-proposed tariffs, are awarded projects by the DoE. The aim of this research was introduced, along with the research questions and method of research. The chapter ended with the layout of the dissertation.

The next chapter presents a comprehensive literature review of the thesis, which includes a technical review of PV systems as well as a brief review of the renewable energy independent power producer program process.

CHAPTER TWO: PV TECHNICAL LITERATURE REVIEW

2.1 INTRODUCTION

This chapter provides a literature review on photovoltaics (PV). It begins with a discussion on the potential for solar energy, globally, and contemplates the amount of available solar energy in certain parts of the world, with a focus on the amount of electricity that could be generated from PV technology. The chapter then turns towards solar technologies by discussing the primary technologies that are available for generating electricity from solar radiation. It focuses on photovoltaic technology systems directly, the different types of PV technology, and how these systems are manufactured.

Balance of system (BOS) or balance of plant (BOP) components are then discussed, such as inverters, with a deliberation on central inverters and string inverters. The applications of PV systems are then presented, with each of the systems of off-grid or standalone, grid-connected distributed and grid-connected centralised being reviewed in detail.

The chapter explores the models and methodologies for determining the potential energy yield of a PV installation, and considers aspects such as irradiation on the PV module's plane, and other important site-specific characteristics. Concepts such as PV panel performance are also presented as factors that are important for discerning the potential energy yield, and therefore the financial feasibility of a PV project.

The chapter provides a brief introduction and discussion on South Africa's renewable energy policies, implementation status, as well as the Renewable Energy Feed-In Tariffs (REFIT) and Renewable Energy Independent Power Producer Procurement Program (REIPPPP).

2.2 THE SOLAR POTENTIAL

Researchers have sufficient statistical data on solar irradiation and energy availability collected globally to show that there is more than enough solar energy to supply the world's energy consumption (GreenPeace & EPIA, 2011). The US National Solar Radiation database has 30 years' worth of solar irradiation and meteorological data from 237 sites in the USA (GreenPeace & EPIA, 2011). The European Joint Research Centre (JRC) also collects and publishes solar irradiation data from 566 sites around Europe (GreenPeace & EPIA, 2011).

Green Peace & EPIA reported that about 60% of the total energy emitted by the sun (towards the Earth) reaches the earth's surface. Furthermore, the total solar energy that reaches the earth's surface could meet existing global energy demand more ten-thousand times, as shown in Figure 2.1 (GreenPeace & EPIA, 2011). In the year 2000, Jackson and Oliver (cited in Audenaert et al., 2010) stated that if all solar irradiation could be converted into a useful form of energy with an average efficiency of 5%, only 3% of land in the United Kingdom would be sufficient to supply its total electricity demand. Even if only 0.1% of the sun's available energy could be converted to usable energy, at an efficiency of 10%, it would be four times larger than the world's total electricity generating capacity of about 5,000 GW (GreenPeace & EPIA, 2011).

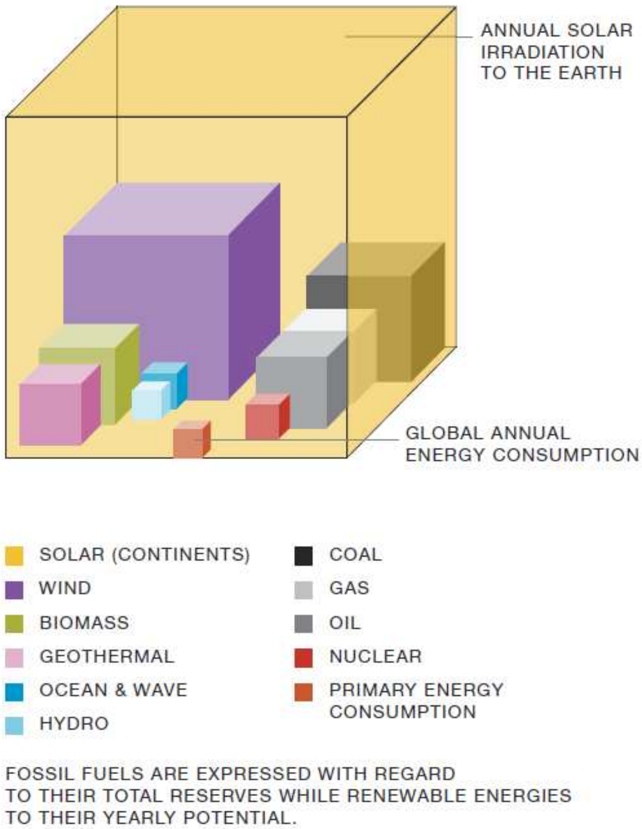

Figure 2.1 Comparison of available green energy sources compared to the global energy needs

Source: (GreenPeace & EPIA, 2011)

On average, each square metre of land on earth is exposed to enough sunlight to generate 1,700 kWh of energy every year using currently available technology (GreenPeace & EPIA, 2011). Where there is more sun, more power can be generated. The sub-tropical areas of the world offer some of the best locations for solar power generation. The average energy received in Europe is about 1,200 kWh/m^2 whereas the Middle East experiences between 1,800 and 2,300 kWh/m^2 per year (GreenPeace & EPIA, 2011). South Africa's annual solar irradiation is between 1600 and 2400 kWh/m^2 (South Africa. Department of Energy, 2011). The country is therefore well positioned to harness the energy from the sun.

There is enormous untapped potential, and vast areas such as roofs, building surfaces, fallow land and deserts could be used to support solar power generation. For example, the European Photovoltaic Industry Association (EPIA) has calculated that Europe's entire electricity consumption could be met if just 0.34% of the European land mass were covered with photovoltaic (PV) modules (an area equivalent to the Netherlands) (GreenPeace & EPIA, 2011). Furthermore, at least 40% of the European Union's total electricity demand could be met if all suitable roofs and facades were covered with solar panels (GreenPeace & EPIA, 2011). International Energy Agency (IEA) calculations show that if four percent of the world's very dry desert areas were used for PV installations, the world's total primary energy demand could be met (IRENA, 2012).

2.3 SOLAR TECHNOLOGIES

The use of solar energy is growing rapidly around the world, in part due to the fast-declining solar panel manufacturing costs. For instance, between 2008 and 2011, PV capacity increased in the United States from 1,168 MW to 5,171 MW, and in Germany from 5,877 MW to 25,039 MW (World Energy Council, 2013).

There are two main technologies for producing electricity from solar radiation that have gained traction around the world: concentrated solar power (CSP), also known as solar thermal energy; and solar photovoltaic (PV) technology (Bosatra, et al., 2010).

There are four different CSP technologies in use: the parabolic mirror trough, the linear Fresnel, the Dish Stirling and the Solar Tower (Dinter & van Niekerk, 2014). In these systems, mirrors are used to concentrate the thermal energy of the sun to heat a transfer fluid. The heat energy of the fluid is then used to produce steam, and electricity is generated when this steam is used to drive conventional turbines.

In contrast, PV technology uses silicon-based photovoltaics to convert the energy from solar radiation directly into electricity. PV technologies that have become commercialised are PV thin film and PV crystalline (Candelise, 2009). Another form of PV technology also available commercially, is concentrating photovoltaic (CPV) technology, which is based on the reflection of concentrated sunlight onto highly efficient photovoltaic cells, such as copper indium gallium diselinide (CIGS) and thin film amorphous silicon. Nowadays, CPV technology is used only in smaller or prototype PV installations and has not yet been considered as a viable alternative to other technologies for bigger utility-scale PV plant installations (Baker, et al., 2013).

2.3.1 Introduction to photovoltaic (PV) technology systems

A PV system is an integrated assembly of modules and other components designed to convert solar energy into electricity. The main component of a PV system is the photovoltaic panel, which contain cells that convert sunlight into electricity. A PV system does not need bright sunlight in order to operate. It can also generate electricity on cloudy and rainy days from reflected sunlight (Candelise, 2009). The basic element of photovoltaic panels, the cell, is comprised of layers of a semi-conducting material, and light falling on these cells generates an electric field across the layers, which causes electricity to flow. The intensity of the light determines the amount of electrical power that each cell generates (Candelise, 2009).

Each cell of a PV panel consists of a junction of two thin layers of dissimilar semiconducting material (see Figure 2.2): a positive 'p-type' semiconductor and a negative 'n-type' semiconductor, which creates an electric field in the region of the junction where negative and positive charges move in opposite directions (Markvart & Castaner, 2003).

As stated by Candelise (2009):

> *"Semiconductors have weakly bonded electrons occupying a band of energy called the valence band. Photons whose energy is greater than the band gap energy can excite electrons and make them free to move into the so-called conduction band where they can conduct electricity through the material. When an electron is stimulated by a photon to jump into the conduction band, it leaves behind a hole in the valence band. Therefore, two charge carriers are generated, one positive and one negative. The flow of electrons is by definition an electric current. If there is an external circuit for the current to flow through (e.g. the metallic contacts on top of the cell) the moving electrons will eventually flow out of the semiconductor".*

PV solar electricity generating systems produce direct current (DC). Most appliances, however, utilise alternating current (AC); therefore, an inverter is one of the key required components of a PV system. All other additional components needed to construct a PV system are called Balance of Plant (BOP) components (Candelise, 2009). Usually, the BOP refers to all of the PV system components and cost elements aside from the modules. It thus includes the cables and wiring, metering (for grid-connected applications) and the installation, design and commissioning costs (Baker, et al., 2013).

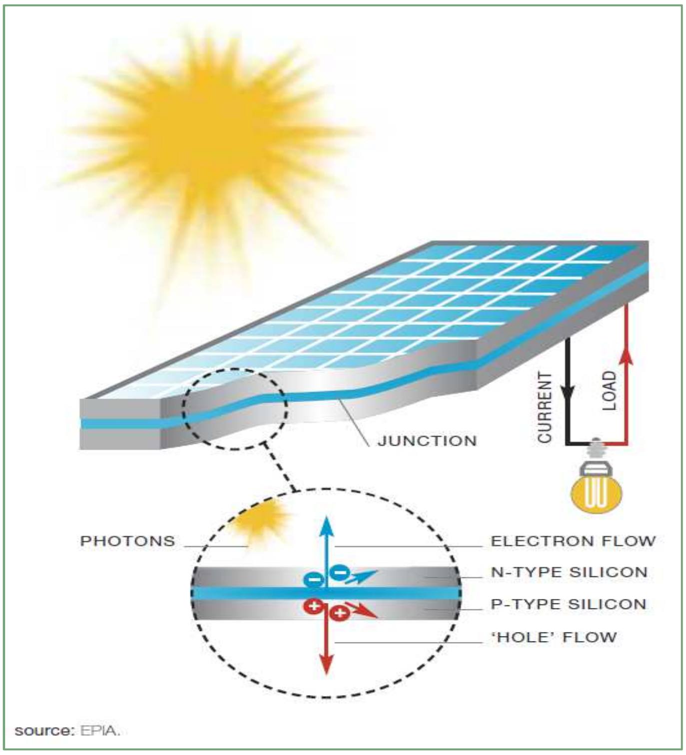

Figure 2.2 Diagram of the mechanism of electricity generation from a PV panel

Source: (Markvart & Castaner, 2003)

2.3.2 Types of PV technologies and their manufacture

It is important to have an appreciation of how PV modules are produced. There are various types of PV technologies, as shown in Figure 2.3, including crystalline silicone, thin film modules and third-generation technologies (Luckhurst, 2014).

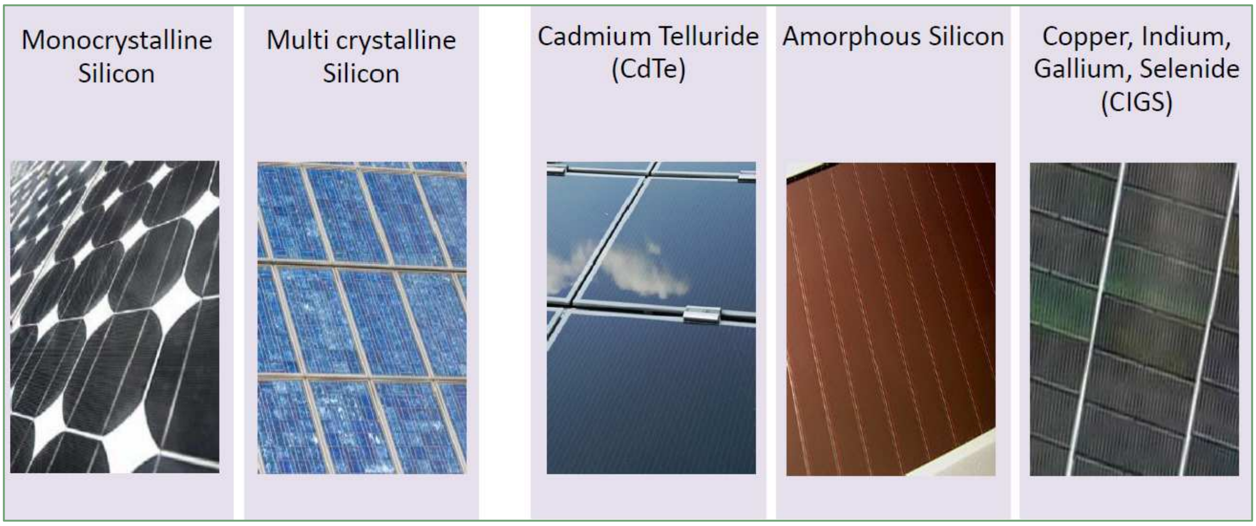

Figure 2.3: Different types of PV module technologies

Source: (Luckhurst, 2014)

Below is a summary of the processes of manufacture of each of these.

2.3.2.1 Crystalline silicone technology

Crystalline silicone module technology is the most widely used technology, whereby about 86% of current global photovoltaic production uses wafer based crystalline silicon technology (Photon International, 2009). This technology has reportedly been around for decades, since the 1970's, and was mainly used on electronic equipment and spacecraft (Candelise, 2009). As a result, it has matured as a technology, and currently produces highly reliable modules that are now guaranteed for 20-year lifespans (Candelise, 2009). Over the last two decades, following the need to consider more renewable energy resources, focused research and development (R&D), and support for this technology, the energy conversion efficiency has progressively improved, as shown in Figure 2.4 (Luckhurst, 2014).

Quartz sand is mined to produce silica, which is further processed in “super-high-heat furnaces” to melt the sand into silicon; and thereafter it is purified to required specifications. As shown in Figure 2.5, the silicon is then crystallised under carefully controlled conditions into large blocks of crystalline material, or ingots, which are then treated and cut into very thin slabs, or wafers. Silica can be processed into either monocrystalline or multi-crystalline variants, whereby the monocrystalline form is a more purified grade and therefore has better conversion efficiency than that the multi-crystalline form.

Multi-crystalline silicon is less energy intensive in the production process, and is therefore cheaper (Alsema & Nieuwlaar, 2000). The complete production line can also be bought, installed and prepared for production within a relatively short timeframe, making it an appealing and low-risk investment. This has historically been a significant advantage of multi-crystalline technologies, allowing a large number of new companies to enter the market in recent years, to meet the increasing demand for PV products (Candelise, 2009, p. 53).

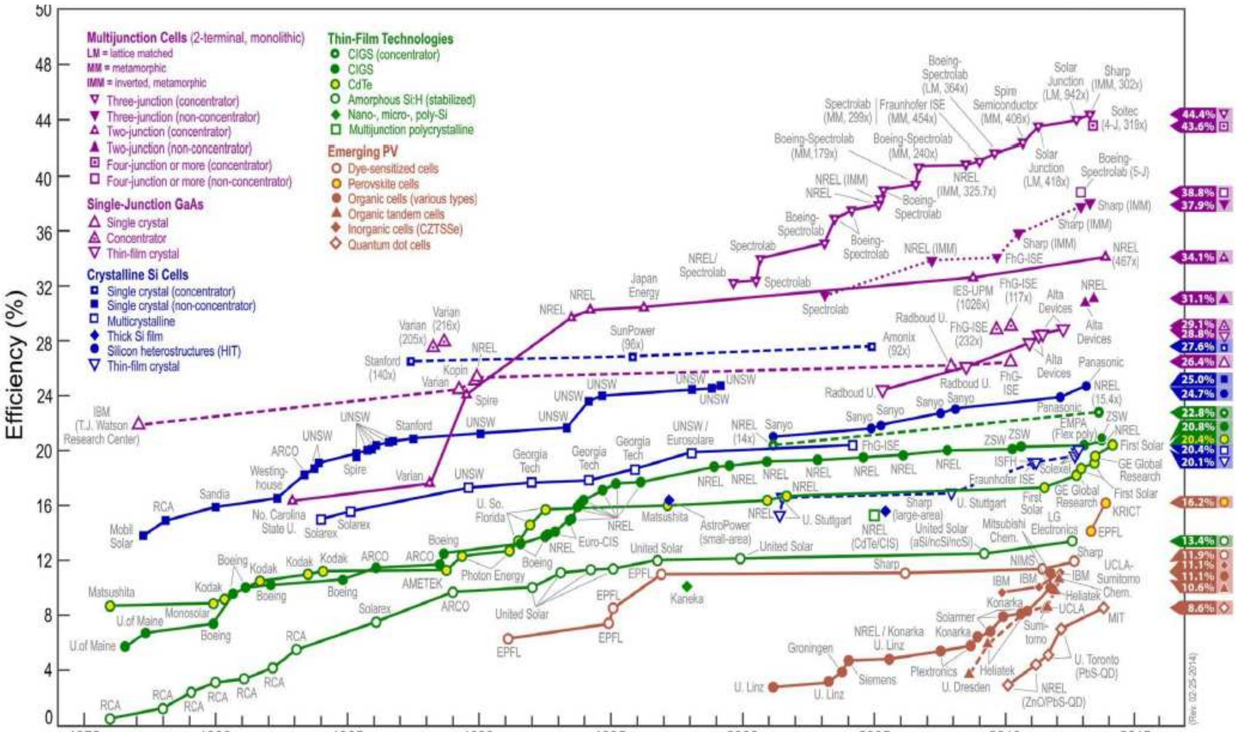

Figure 2.4 PV cell efficiencies between 1975 and 2014

Source: (Luckhurst, 2014)

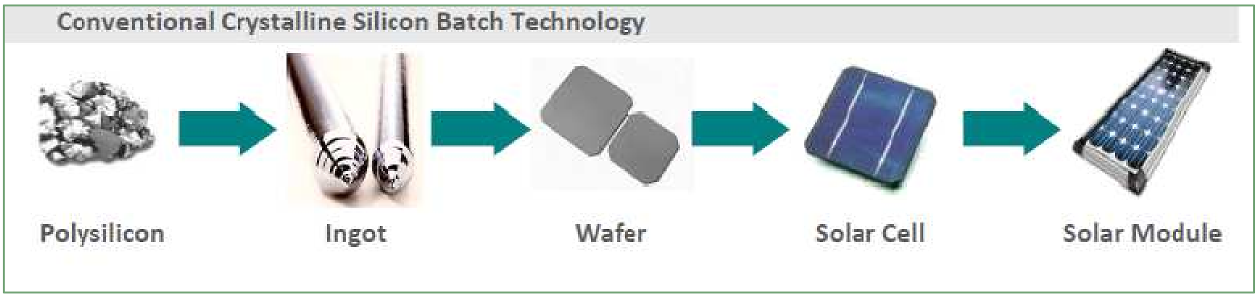

Figure 2.5: Crystalline silicone manufacturing process

Source: (Luckhurst, 2014)

National Renewable Energy Laboratory (NREL) research shows that in laboratory tests, crystalline technology is "pushing the limits", with a goal to reach the mid- to upper-twenty percentage efficiency range (Luckhurst, 2014).

Some of the thin film technologies are also reaching the early-twenty-percent range of efficiency. First Solar Cadmium Telluride (CdTe) technology has reached this target and is going into production already (Luckhurst, 2014). This level of efficiency is approaching the efficiencies of some of the more well-established crystalline technologies.

2.3.2.2 Thin film technology

Thin film technologies date back to the 1980s, but it is only recently that this technology has attracted significant interest in the PV sector, due to the increasing market and industry focus on cost reductions (Baker, et al., 2013).

Thin film modules are made by depositing thin (0.5 to 10 micrometre) layers of semiconductor material onto glass plates, or substrates. The depositing of semiconductor material onto a substrate can be done by various techniques: chemical vapour deposition, evaporation, electrolytic deposition and chemical bath deposition (Alsema & Nieuwlaar, 2000). The solar cells are created through a subsequent layer deposition process and are ‘defined’ by removing some of the previously deposited material. Contact layers are also deposited using similar techniques. When the final processing is done, the module is encapsulated and sealed off with a glass plate or polymer film (Alsema & Nieuwlaar, 2000).

Due to the boom in the silicon market (as a result of the demand for PV modules and other such technologies), there has been a shortage of silicon in recent years. This, together with the increasing need to reduce PV module cost, has resulted in a renewed interest to invest in thin film technologies (Candelise, 2009). Thin film is reportedly gaining market share, with reports noting an almost doubling in market share between 2005 and 2008 (First Solar, 2009).

2.3.2.3 Third generation technology

The third generation category of PV technologies incorporates various of the PV technologies, and while it is mostly still in R&D stage, it is seen by many as “the bright future for PV”, because it is likely to provide the breakthroughs that are needed to achieve cost reductions and an increased diversity of applications (Candelise, 2009).

2.4 INVERTERS

As discussed previously, PV solar panels produce DC electricity; however, grid electricity is based on AC, as are most electrical appliances and equipment that are available for commercial, industrial and residential use (Candelise, 2009). Therefore, there is a need to install a DC to AC converter, or inverter, to render the electricity usable for general applications. Inverters also perform a variety of other critical functions (Huang & Pai, 2001):

- Due to the variability and intermittency of energy produced by the sun, in cases where there may be clouds or other factors affecting power production, inverters optimise voltages by ensuring a ‘maximum power point’ at all times, so that maximum available power is delivered at all times.

- Inverters have the controlling function of switching off the power production where certain regulatory limits are not met, or in the case of faults, issue instructions to other items of the system to isolate the faulty section of the array.

Inverter efficiency is a measure of the losses experienced during the conversion of DC to AC power. Conversion efficiency is the ratio of the fundamental component of the inverter's AC power output, to its DC power input, as shown in Figure 2.6 (Miller & Lumby, 2012).

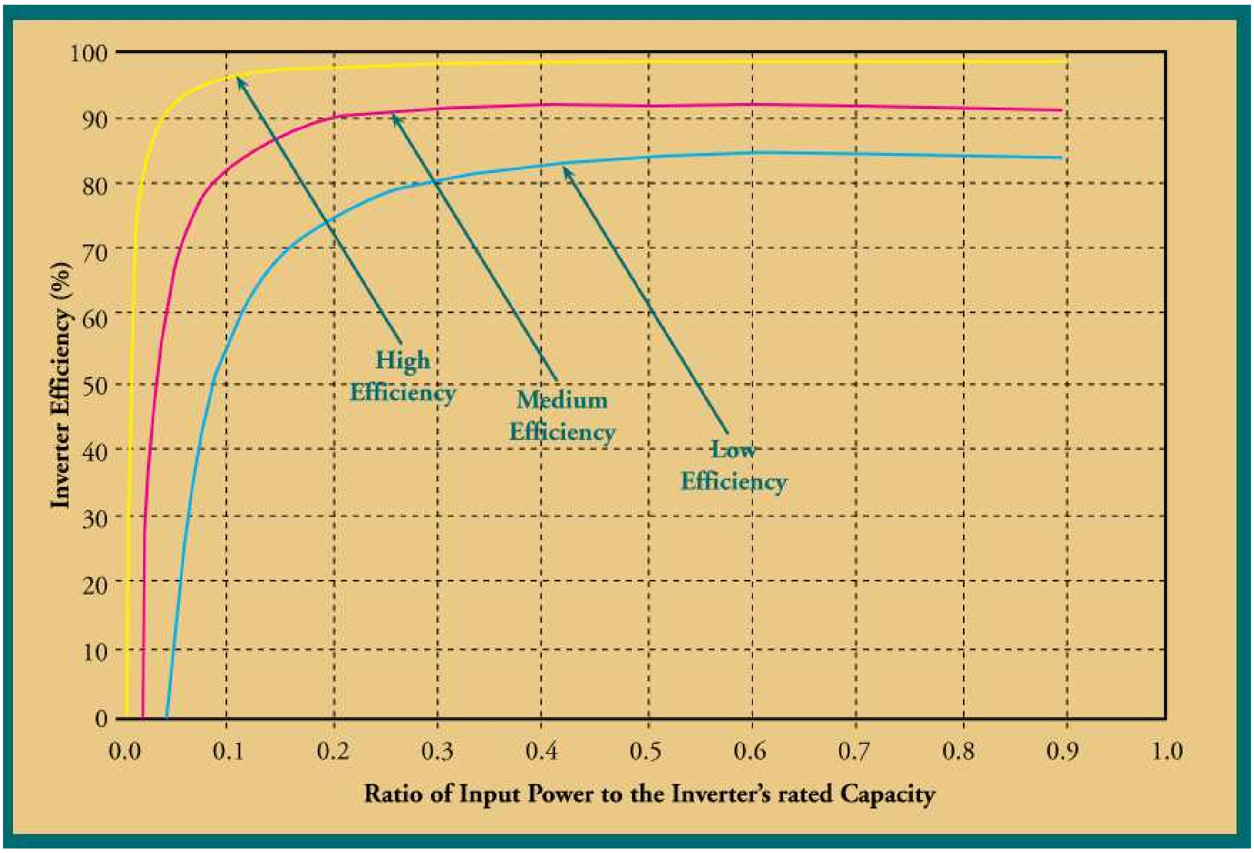

Figure 2.6 Efficiency curves of low, medium and high efficiency inverters

Source: (Miller & Lumby, 2012)

The conversion efficiency of an inverter is ultimately dependent on the DC input power, which in turn depends on the operating voltage, and this is related to the weather conditions, such as ambient temperature and irradiance. Changes in ambient temperature and irradiance lead to changes in the 'maximum power point' of the PV system; therefore, the output power from a PV array varies based on these factors (Miller & Lumby, 2012).

Two types of inverters exist: central and string inverters

2.4.1 Central inverters

Central inverters are used on large-scale PV plants. They offer a high level of reliability and are simple to install. They are designed for three-phase current, and incorporate both a frequency and voltage transformer (Miller & Lumby, 2012).

2.4.2 String inverters

String inverters consist of multiple inverters that are used for a number of 'strings' of modules. They can cover a wide power range and are cheaper to manufacture compared to central inverters (Zhang, et al., 2006). They are very useful in cases where PV module specifications are different, or where array orientations differ. They work well for small power plants, but are not preferred for utility scale installations because of the many logistical requirements necessary for their implementation (Miller & Lumby, 2012).

2.5 APPLICATIONS OF PV SYSTEMS

PV systems can have different applications, which may be divided into the following categories: off-grid or standalone, grid-connected distributed, and grid-connected centralised.

2.5.1 Off-grid or standalone

Off-grid or standalone PV systems operate independently of any grid network and are mainly used for remote power applications. Off-grid industrial systems provide a cost-effective way of bringing power to areas that are very remote from existing grids. The main implementation of this type of system is in the rural areas of developing countries, where people use the system for electricity supply to their own dwellings (Preiser, 2003). Non-domestic uses of such systems also include a wide range of commercial applications, in particular for telecommunications — such as repeater stations for mobile phones, marine navigational aids, remote lighting, highway signs, water pumps, and so forth — where small amounts of electricity can have high costs (Candelise, 2009). This makes PV relatively cost competitive with other small power-generating sources, while the high costs of constructing high-voltage power lines also makes the construction of off-grid solar power systems an economical alternative (Candelise, 2009). In most cases, off-grid systems require storage batteries to be installed as part of the system, to cater for periods of low or no irradiation.

2.5.2 Grid-connected distributed

Grid-connected distributed PV systems produce electricity using standard PV modules that are installed on homes and businesses in developed areas for their own use, as shown in Figure

2.7, but are connected to the public electricity grid via a suitable inverter to convert DC to AC (Preiser, 2003). By connecting to the local electricity network, normally on a low voltage network, and not on a large scale, the system installers can sell any excess power that is generated (and therefore not consumed by the installer) back to the electricity grid. When there is bad solar irradiation and the PV system cannot produce enough electricity, electricity can instead be drawn from the grid. These types of systems can be installed on the tops of roofs (in private, public or commercial premises), integrated into premises' façades as Building Integrated PVs (BIPV), or simply located in the built environment; for example, ground mounted in areas close to premises or on motorway sound barriers (Assi, et al., 2009).

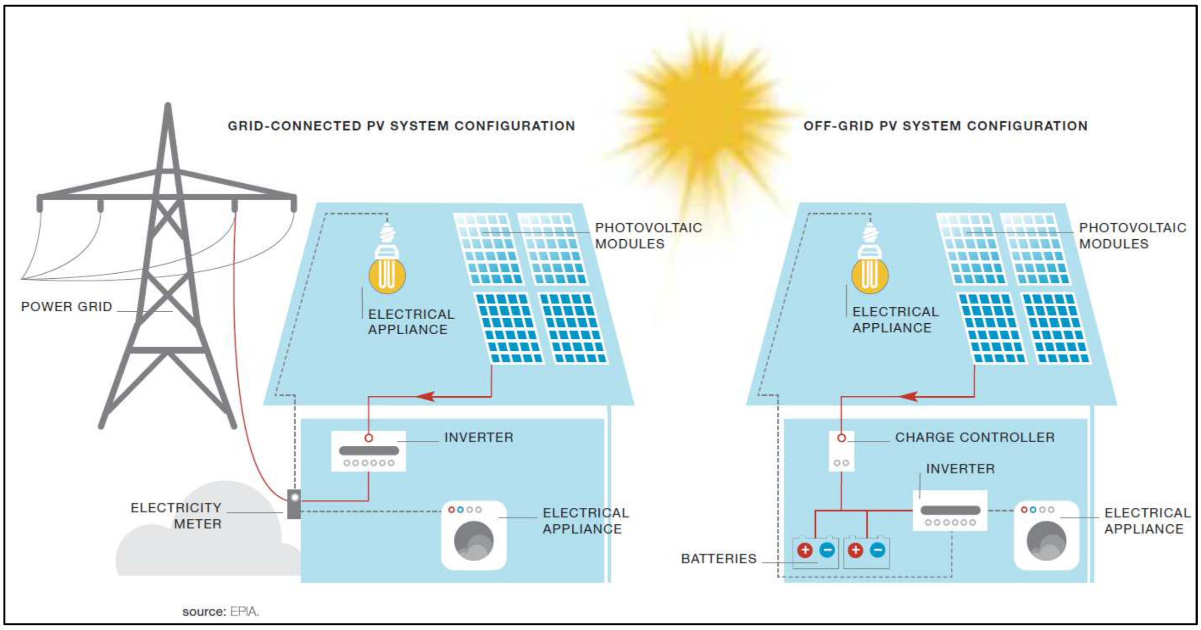

Figure 2.7 Diagram representing a grid-connected distributed PV system

Source: (GreenPeace & EPIA, 2011)

2.5.3 Grid-connected centralised:

A grid-connected centralised type of PV system is constructed on a large scale to perform the functions of a centralised power station. This type of PV system is referred to as either utility-scale grid-tied, or grid-connected (Candelise, 2009). The power produced by the system is not associated with a particular electricity customer and is simply supplied to the regional or national grid network as bulk power. Such systems are typically ground-mounted and vary in capacity and size, as shown in Figure 2.8 (Bakke, 2011).

Utility-scale PV systems are relatively new, and growing in popularity at a very fast pace. In 2009, some of the largest plants in the world produced between 40 and 60 MW, while to date, there are plants being built with capacities of hundreds of megawatts (Edkins, et al., 2010).

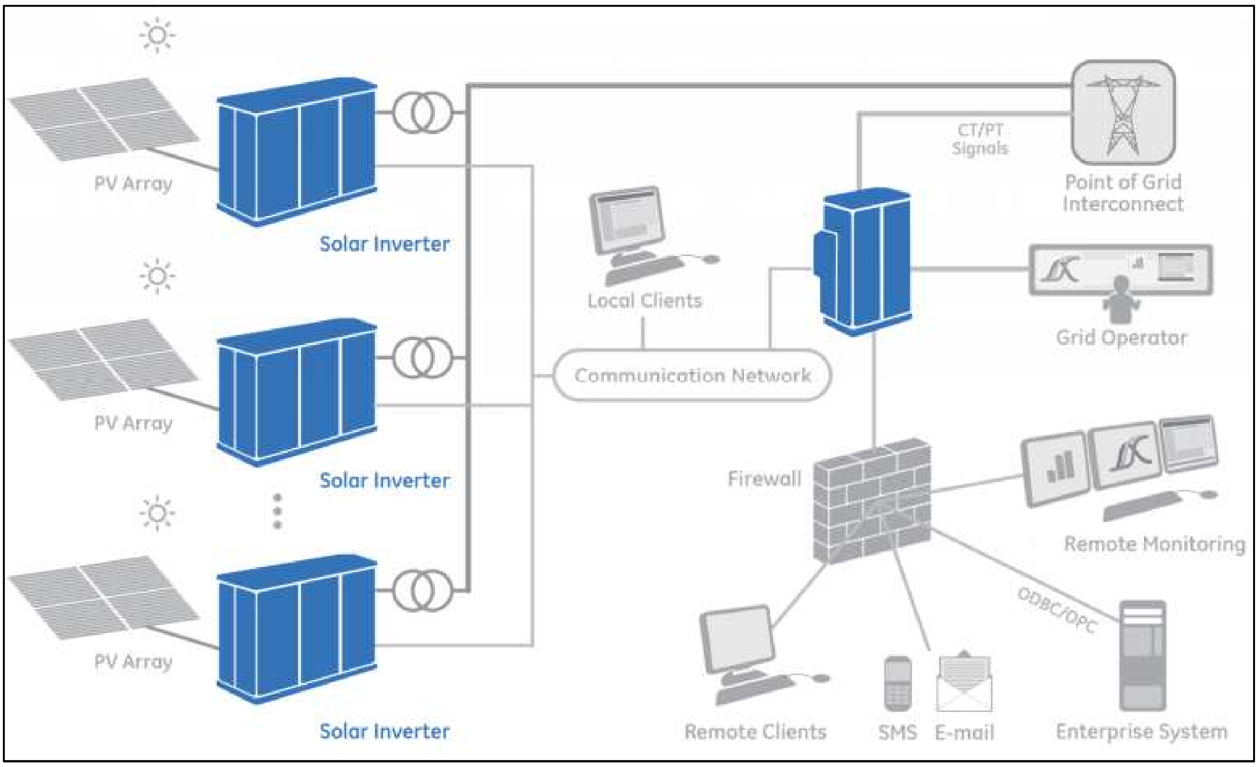

Figure 2.8 Diagram representing a grid-connected centralised PV system

Source: (Bakke, 2011)

In a grid-connected centralised type of PV system, the PV modules are electrically connected together in series and parallel, and connected by DC cabling to centralised inverters that convert the DC electricity into AC electricity. The inverters are then connected together, on the AC side, to a medium-voltage network, which in turn is delivered to a high-voltage (HV) or extra-high-voltage (EHV) grid by means of one or more step-up transformers (Bosatra, et al., 2010).

PV modules are installed on fixed metallic support structures that are arranged in long, adequately spaced rows, at an appropriate tilt. When installing a fixed PV array, the 'rule-of-thumb' is to select a tilt angle of approximately 15 degrees plus the sites' degree of latitude, with a bias factored for the change of season (Lakeou, et al., 2006). In the Northern Hemisphere, the PV array should be positioned to face true south and vice versa for locations in the Southern Hemisphere. As discussed next, PV systems may also be deployed on tracking devices to follow the sun.

2.5.3.1 Solar tracking systems

A solar tracking system is designed to follow the sun throughout the day and to adjust the angle of the solar panels in relation to the sun, thereby ensuring maximum irradiation catchment by the panels' area. More energy is collected by controlling the solar panel to follow the sun like a sunflower, and research has shown that up to 30% more solar energy can be harvested by use of solar tracker systems, or between 20% and 50% increase in harvest efficiency, when compared to fixed-position systems (Guo, et al., 2013). However, the cost of a PV tracking system is also usually greater than a fixed PV system.

According to Guo et al. (2013),

> *"The efficiency of the PV system depends on climatic conditions of the solar radiation, ambient temperature and wind speed, matching of the system with load, and appropriate placement of solar panels."*

A solar tracking system must have the following essential features:

1. Azimuth tracking for adjusting the tilt angle of the surface of the PV array during changing seasons; and
2. Daily solar tracking for maximum solar radiation incidence to the PV array.

The tilt angle (theta) of a PV array, which is required to follow the sun's path throughout the year, is a function of the sun's seasonal altitude, as shown in the following equation and in Figure 2.9 (Lakeou, et al., 2006):

$$(\boldsymbol{Tilt\ Angle})\boldsymbol{\theta} = \mathbf{90}^{\circ} - \emptyset \qquad \textbf{[2.1]}$$

For a simple single-tracking system, motors and gears rotate the array about the y-axis with equally angular steps per set time, depending on the season and hours of sunshine per day. A Programmable Logic Controller (PLC) is designed and built into the motor control system, and seasonal data is stored in the PLC to drive the tracker to the correct position at any given time of the day, month or year (Lakeou, et al., 2006).

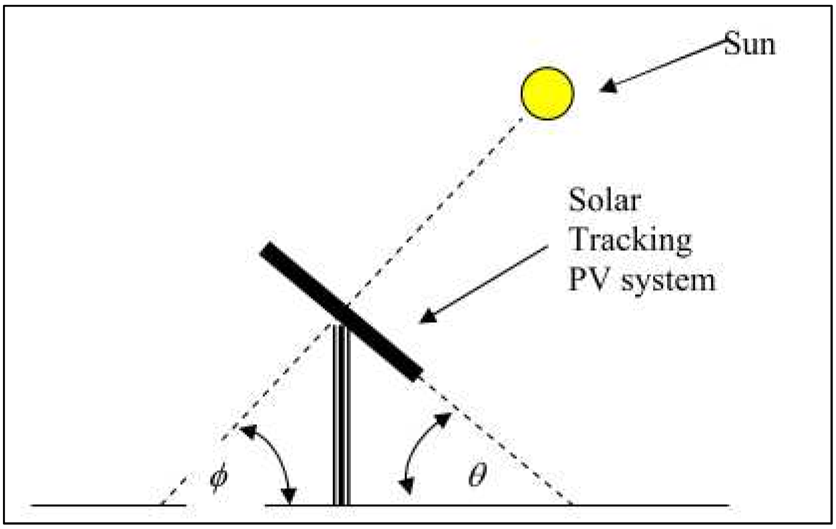

Figure 2.9 Tilt angle θ of a PV array

Source: (Lakeou, et al., 2006)

2.5.3.2 Grid integration

In order for a PV power plant to export electricity onto a grid and receive income, the plant must be appropriately connected to the grid. Critical to grid connection are three factors: capacity, availability and proximity to the grid. To determine grid capacity, a technical analysis of the overhead lines, cables and transformers must be performed (Papapetrou, 2014). Should the required capacity not be available, the option to upgrade the existing infrastructure may be needed. A major cost influence of the grid connection infrastructure is the distance from which a power plant is to be connected, including the length of the line and cable. Additionally, higher connection voltages require higher infrastructure costs.

2.6 ENERGY YIELD ANALYSIS

A critical step for assessing a project's feasibility, and therefore objectively assessing the possibility of attracting finance, is predicting the expected energy yield from a project. Based on the expected energy yield, modelling can be done. As can be expected, the estimated energy yield that is calculated by the model depends on the stage of the project's development. In the initial phase, the available solar resource data and equipment specification data can be used in a simplified model. As the project development advances, other more sophisticated simulation tools must be used for improved accuracy (Miller & Lumby, 2012).

The procedure for predicting PV plant energy yield using time-step simulation is as follows (Bizzarri, et al., 2013):

1. Obtain environmental data, including irradiance, wind speed, and average temperatures from land-based measuring stations;
2. Calculate incident irradiation on a tilted plane for certain time steps;
3. Model the plant performance with respect to varying irradiance and temperatures, to calculate energy yield in each time-step;
4. Apply losses by using specific equipment efficiencies;
5. Apply a statistical analysis of data to assess any uncertainty in input values, and evaluate its impact on the prediction of final energy yields.

2.6.1 Irradiation on a module plane

The financial revenue of PV project assumes a certain level of irradiation expected over the life of the plant. This energy output can only be estimated through the use of forecasting techniques in order to predict solar resource at a specific site over the lifetime of a project. This in turn relies on accessibility or availability of and analysis of historical data for that site. This data is typically given for a horizontal plane (Lorenzo, 2003). The assumption is that the future solar resource will follow the same pattern as the historical values, which is in and of itself a risk. This historic data may be obtained from land-based meteorological stations or satellite based measurements and imagery (Lorenzo, 2003).

2.6.2 Modelling

Appropriate simulation software can be used to predict the performance of a PV plant, based on available solar resource data. Typically, these simulations are detailed and evaluate the efficiency of a solar plant and its associated losses.

A system's energy efficiency and performance is based on a thorough accounting of its input and output energies. A utility PV energy plant's output is dependent on the following parameters: PV module efficiency and module design parameters, location irradiation, cable losses, inverter efficiencies, and transformer efficiencies. In practical applications, the efficiency of a system is affected by the system's losses, which are composed of equipment losses as well as the degradation of the equipment (Assi, et al., 2009). In the case of PV technology, PV module research shows that between 0.31% and 0.51% degradation is the accepted standard, per annum (Alsema & Nieuwlaar, 2000).

The total solar radiation reaching an inclined PV module is the sum of the direct normal radiation (DNI), diffused radiation and reflected radiation components, as shown in Figure 2.10 (Bouabdallah, et al., 2013).

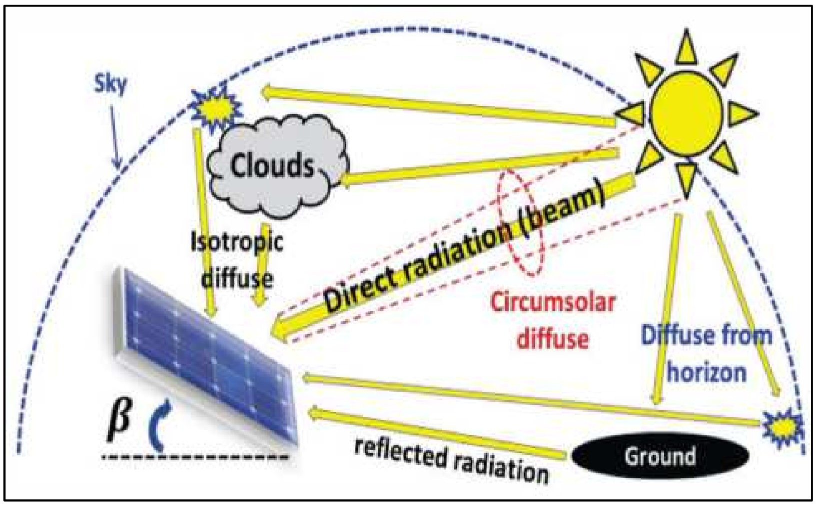

Figure 2.10: Components of solar radiation

Source: (Bouabdallah, et al., 2013)

The total solar radiation reaching an inclined PV module may be presented in the following equation:

$$R_{tot} = R_{dir} + R_{dif} + R_{ref} \qquad \textbf{[2.2]}$$

Where, R_{tot} *is Total Radiation*, R_{dir} *is Direct Radiation*, R_{dif} *is Diffused Radiation*, and R_{ref} *is reflected Radiation*

The output of solar tracked arrays (as discussed in Section 2.5.3.1) rises to its maximum potential power quicker, and maintains this output for longer during production hours, than on fixed array systems (Jeong, et al., 2013). Energy production is calculated as follows:

$$P_{pv} = \eta_{pv} A G_{tot} \qquad \textbf{[2.3]}$$

Where:

P_{pv} is the power output of the panel;

η_{pv} is the efficiency of the PV panel;

A is the surface area of the PV panel; and

G_{tot} is the overall solar radiation.

The efficiency of the PV module is dependent on the temperature of the PV cells (T_c), as defined below (Bouabdallah, et al., 2013):

$$\eta_{pv} = \eta_{manufacture}\eta_{ch}[1 - \beta_t(T_c - T_{NOCT})] \qquad \textbf{[2.4]}$$

$$T_c = T_a + [T_{NOCT} - (273 + 20)]\frac{G_{tot}}{G_{NOCT}} \qquad \textbf{[2.5]}$$

Where:

$\eta_{manufacturer}$ is the panel efficiency as provided by the manufacturer;

η_{ch} is the efficiency of the photovoltaic conversion chain with maximum power point tracking from the DC to AC converter;

β_t is the temperature coefficient, as provided by the panel's manufacturer;

T_{noct} is the cell temperature under normal operating conditions; and

T_a is the ambient temperature.

The efficiency of modules also differs from manufacturer to manufacturer, and this has an effect on the cost of the module and the overall project cost. The higher the efficiency the more expensive the module. Therefore, the project developer has to consider the type of PV module upfront with his design.

2.6.3 PV Array performance

A recent comprehensive study identified seven factors influencing the annual performance of PV modules (Bruckman, et al., 2013). These factors are:

- Cumulative solar irradiance: Long-term irradiance profiles depend on surface orientation and possible tracking. This factor depends on the location of the panel, and varies between a 25% reduction in irradiance for vertical surfaces — as compared to latitude-tilt fixed systems — to an over 30% increase in irradiance in the case of two-axis tracking systems (Meyer & van Dyk, 2004).
- Module power rating at standard test conditions: research on several PV technologies has shown that for the same power rating, all technologies' expected annual energy production is very much similar within a 5% error margin.
- Operating temperature: Operating module temperature can reduce annual energy production by a factor of between 2% and 10%, depending on the module design, wind speed, mounting technique and ambient temperature (Miller & Lumby, 2012).
- Maximum power point voltage dependence on irradiance level: A-Si and CdTe modules tend to have a larger maximum power point voltage value at lower irradiance levels than the standard '1-sun' conditions. This can result in an additional 10% increase in annual energy production.
- Soiling: Soiling may account for an up-to-10% reduction in annual energy production (Meyer & van Dyk, 2004).
- Variation in solar spectrum: It has been found that the effects of hourly variation on the solar spectrum almost cancel out on a yearly basis. Amorphous silicon technology has the highest sensitivity to this effect, but the observed changes usually remain below 3%.

Optical losses when the sun is at a high angle of incidence (AOI): Optical losses occur due to an increased reflectance of the cover glass of PV modules for AOI's greater than approximately 60 degrees. However, the effect on a long-term basis is relatively small (typically less than 5%) although it may have a larger effect on a seasonal basis (closer to 10% for a vertical inclination) (Meyer & van Dyk, 2004).

Most of the PV system design and simulation software tools require input parameters that are specific to the site for the project.

Table 2.1, below, provides a table of loss factors that influence the total plant yield. These should be considered for each plant design in order to arrive at a realistic yield (Miller & Lumby, 2012).

Table 2.1 Table of plant losses

Loss	Description
Module quality	PV modules do not exactly match their manufacturer's nominal specifications. Modules are sold with a nominal peak power and a guarantee of actual power, within a given tolerance range. The module quality loss quantifies the impact on the energy yield due to divergences in the actual module characteristics from their specifications.
Module mismatch	Losses due to 'mismatch' occur when modules in a string do not all present exactly the same current or voltage profiles and statistical variations between them give rise to power losses.
DC cable resistance	Every type of conductor has electrical resistance which results in what is termed "ohmic losses" and the conductor heats up. The DC cable between the module, combiner box and the input terminals of an inverter will give rise to 'ohmic losses' (I^2R). If the cable is correctly sized, the loss could be less than 3% annually.
Inverter performance	Inverters convert DC power to AC power with an efficiency that varies with the inverter load.
AC losses	This includes transformer performance and 'ohm losses' in the cable leading to the substation.
Downtime	Downtime is a period when the plant does not generate power, due to equipment failure. The downtime periods depend on the quality of the plant's components and its design, environmental conditions, and diagnostic and repair response times.
Grid availability and disruption	Once generated PV power has to be evacuated to where it is required and for that the availability of capacity or proximity of the distribution or transmission network comes to play. Typically, the owner of a PV power plant will not own the distribution network, but instead will rely on the distribution network operator to maintain service at high levels of availability. Unless detailed information is available, this loss is typically based on an assumption that the local grid will not be operational for a given number of hours or days in any one year, and that this lack of operation will occur during periods of average production.
Degradation	The performance of a PV module decreases with time. If no independent testing has been conducted on the modules being used, then a generic degradation rate — depending on the module technology — may be assumed. Alternatively, a maximum degradation rate that conforms to the module's performance warranty may be considered.

MPP tracking	Inverters constantly seek the maximum power point (MPP) of their array by shifting the inverter voltage to the MPP voltage. Different inverters do this with varying efficiency.
Curtailment of tracking	Yield loss due to high winds enforces the 'stow mode' of tracking systems.
Auxiliary power	Power is required for auxiliary electrical equipment on the plant. This may include security systems, tracking motors, monitoring equipment, and lighting. It is usually recommended to meter this auxiliary power requirement separately.
Grid compliance loss	This parameter is included to draw attention to the risk of a PV power plant losing energy through complying with grid code requirements.
Soiling losses	Dust and bird droppings accumulate on the glass substrate of the modules, thus obstructing some of the irradiation and causing loss of solar energy conversion. The operations and maintenance strategy for cleaning panels' deals with this, however, if not properly implemented, losses of up to 4% could be expected. Rain does help, though, with washing off some dust (Endecon Engineering, 2001).
Module efficiency at low irradiance levels	Energy conversion efficiency reduces at lower light intensities. This loss depends on the module design characteristics and the irradiation intensity.
Losses at temperatures about 25 degrees Celsius	Module efficiency characteristics are designed for standard temperature conditions of 25 degrees Celsius. When temperatures exceed this set standard, the efficiency performance of the modules reduces, whereby a one degree Celsius difference leads to about 0.5% drop in performance. Areas with high ambient temperature and strong irradiance cause increased module temperatures, which reduce PV module efficiencies. Wind can provide some cooling effects and should be factored into any models when accurate energy yield calculations are required.
Shading losses – (inter-row, horizontal)	Any structure or object that is in the way of the sun can lead to shade to be cast on the panel. This leads to parts of the panel cells either partially or incompletely producing electricity, thereby reducing the efficiency of the panels. Therefore, designs should consider the distance of the array rows from each other, especially at sunrise and sunset.

Source: (Miller & Lumby, 2012)

Losses are dependent on specific site characteristics as well as the plant design, and could come from any of the factors presented in the losses table above (Miller & Lumby, 2012).

The PV system designer has to consider all these factors during development phase of the project as they can affect the overall energy yield and therefore impact on financial ratios.

2.7 SOUTH AFRICAN ENERGY BACKGROUND

South Africa is blessed with rich deposits of minerals and fossil fuels in the form of coal, and is ranked among the top ten countries in the world, in terms of coal reserves. It has also been ranked the sixth largest coal producer in the world with total production estimated at 4% of world production (South Africa. Department of Minerals and Energy, 2007). The country's historic economic development was founded upon the extraction and processing of these mineral resources, of which coal inevitably emerged as the major source of primary energy. The abundant coal reserves and dominance of coal fired power stations contributed significantly towards an economic environment wherein the unit price of electricity is among the cheapest in the world (South Africa. Department of Energy, 2011).

A 2009 department of energy publication (South Africa. Department of Energy, 2011) stated that the government was determined to reduce the country's reliance on high-carbon power generation sources; however, in 2015 the country's electricity generation is still 91.7% coal-based, with the rest produced mainly by nuclear, gas and hydro-scheme generation plants.

The Department of Energy (DoE) issued an updated Integrated Resource Plan (IRP) in 2011, which documented a roadmap for adding new capacity to the country's system of electricity power generation for the next 20 years. According to the IRP, the target for renewable energy generation is to reach a maximum of 42% of the new generation capacity built between 2010 and 2030. The forecast is that by 2030, overall generation capacity will be at 89.5GW, and of that, 17.8GW will be from renewable energy sources, with 8.4GW from both solar PV and wind energy; the rest being concentrated solar power. The IRP provided the contribution detail plan per technology as presented in Figure 2.11 below (South Africa. Department of Energy, 2011).

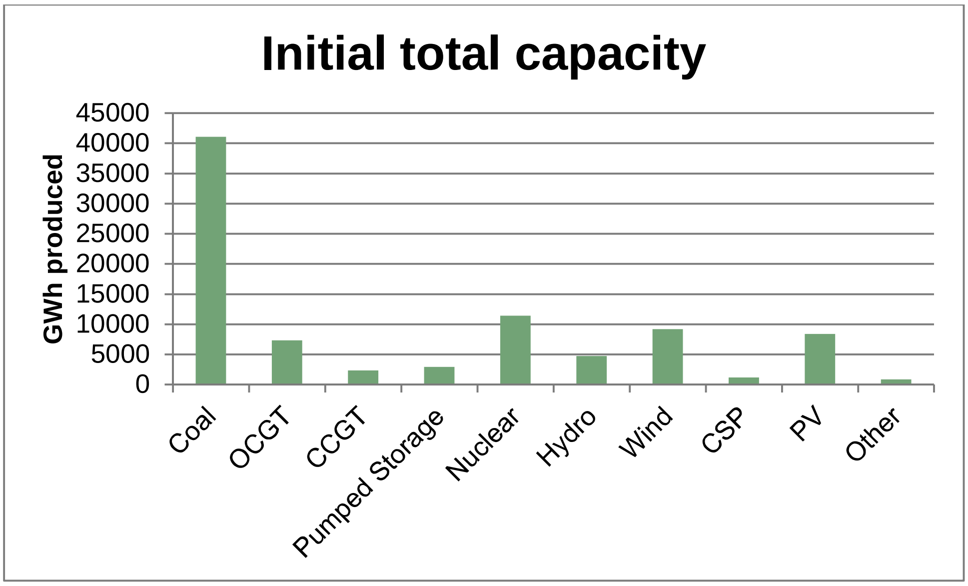

Figure 2.11 Initial total capacity estimates by 2030

Source: (South Africa. Department of Energy, 2011)

The DoE has resolved to reduce the high contribution of coal energy with the new generation capacity making up only 16.3% of capacity to be added by 2030 as shown in Figure 2.12. The renewable energy sources content, however, could increase by double the figure that was initially planned (South Africa. Department of Energy, 2011).

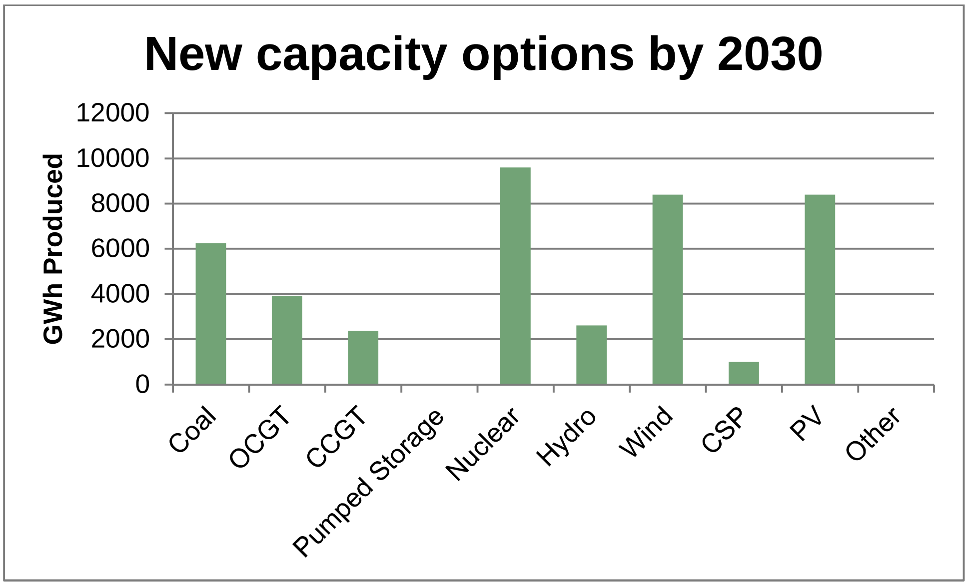

Figure 2.12 New Capacity as per IRP 2011

Source: (South Africa. Department of Energy, 2011)

Prior to the IRP of 2011, the white paper on renewable energy of 2003 by the Department of Minerals and Energy (South Africa. Department of Minerals & Energy, 2003) had set its target at 10,000 GWh of renewable energy contribution towards the total final energy consumption by 2013. This paper's approach in tackling the implementation of integrating renewable technology in South Africa's energy mix was broader than just utility scale renewable energy power plants.

2.7.1 Renewable energy policy

The renewable energy policy had a target of 10,000GWh by 2013 (South Africa. Department of Minerals & Energy, 2003), which was not achieved due to numerous issues; one of which was the lack of clarity regarding how it was to be measured (McDaid & Wood, 2013). Despite attempts to clarify the targets, there was little achieved by 2013. Eberhard et al. (2014) state that while the renewable energy policy did little to effect the required implementation of renewable energy (RE) strategies, the climate change policies had a profound impact in pushing the country forward, despite the fact that South Africa did not have any punitive commitments to reducing greenhouse emissions. At the 2009 Copenhagen Conference of Parties, South Africa made commitments to reduce carbon emissions by 34% by 2020 with the goal to reach 42% by 2025 (South Africa. Department of Energy, 2011). In order to achieve this, South Africa called on the developed world to support it with funding, technology development, deployment, and the required technology transfer. This emissions reduction policy informed the development of the IRP. Furthermore, at the 2011 COP17 meeting in Durban, there was further commitment to achieve the government's goal of creating 300,000 new jobs in the 'green economy' by 2020 (Eberhard, et al., 2014).

The challenge up to 2010 was that even though South Africa had plans in its white papers on renewable energy and policies to implement renewable energy, there were still obstacles. Eskom had been the main producer, transmitter and distributor of electricity, with the exception of a few municipalities and smaller private producers. Therefore, Eskom would have to purchase any electricity generated from private renewable energy plants; however, at what cost? Given that most of Eskom's generation fleet was very old and had already paid off their loans, their cost of generation compared to renewable energies, was low (Eberhard, et al., 2014). Therefore, purchasing electricity at exorbitant costs, at the time, did not make sense to Eskom. Furthermore, the National Energy Regulator needed to issue licenses to prospective producers, and there was no policy or regulatory framework to guide the National Energy Regulator or Eskom on how to deal with independent power producers on a large scale (Eberhard, et al., 2014).

2.7.2 Renewable energy status

The integration of renewable energy power plants into the electricity generation mix has become highly prevalent around the globe; the driving force behind this being the realisation that the renewable energy technology industry must be stimulated, while addressing the carbon emissions that result from conventional coal-based power generation. Many countries around the globe have implemented a 'feed-in-tariff' incentive as a support mechanism to accelerate private investment into the industry. This has worked well in stimulating technology development, particularly in Europe (Eberhard, et al., 2014).

2.7.3 Private investment

The developed world started their renewable energy industries up to two decades ahead of South Africa. This has advantaged South Africa, because the technologies had been established and matured somewhat by the time South Africa began its RE advancements. Furthermore, the developed world's market growth had reached a plateau, due to oversupply and increased competition. With the 2008 economic challenges, some of the Western countries' markets were declining, and as a result, developers and investors were looking towards the new emerging markets (Eberhard, et al., 2014).

Investments in private public infrastructure projects such as roads, energy, water, and so forth, require a clearly laid out regulatory framework that is fully supported by the government. Private investors want to have some certainty regarding the sovereign's support and commitment to such investment. Therefore, the government's commitment by setting a proper regulatory framework and policy eliminates the first and critical risk to investment, by creating political stability. (JP Morgan Asset Management, n.d.).

The private industry's appetite to enter any unexplored territory is solely driven by its potential profitability and associated risk. This is exemplified by a statement made by Needham (2013), Google's director of energy and sustainability that they only pursue investments that make financial sense. The statement concisely captured the potential and lucrativeness of the market, as seen by prospective investors. However, with the renewable energy industry being in its infancy in South Africa, no academic research was found that relates to the techno-economic viability of investing in large-scale grid-connected photovoltaic systems. Some of the literature reviewed (Chidi, et al., 2012) presents models and a techno-economic evaluation of similar technologies in different parts of the world, but in 2015 no academic literature could be found that dealt with this topic within the South African context.

2.8 FROM REFIT TO REIPPPP

The Renewable Energy Feed-In Tariffs (REFIT) policy for South Africa was approved in 2009 by the National Energy Regulator of South Africa (NERSA), but there was no clarity regarding the nature of procurement by the DoE or Eskom. At the time, Eskom was neither ready, nor prepared to deal with numerous private power producers, and had not clarified the internal standards and processes related to power purchase and grid connection agreements (McDaid & Wood, 2013). Further to this, NERSA called for a change to the original REFIT tariff, which confused any interested investors. Following on from that, the DoE and National Treasury issued a statement that REFIT was contravening the government's pubic finance and procurement regulations because it was a non-competitive procurement policy. Therefore, the National Treasury led the development of a renewable energy independent power producer procurement program by consulting local and international experts from relevant engineering, technical, legal, and financial backgrounds (South Africa. National Treasury, 2001). The program was officially announced in 2011 and REFIT was abandoned (Eberhard, et al., 2014).

The Renewable Energy Independent Power Producer Procurement Program (REIPPPP) was designed for the procurement of a maximum of 3,625 MW, in a program lasting five tendering phases. This capacity included the main solar technologies (PV and CSP), as well as wind, biomass, biogas, landfill and hydro technologies (South Africa. Department of Energy, 2011). The rationale for the five tendering phases was to facilitate the introduction of these technologies, while increasing tariff competition. A 100 MW allocation of capacity was reserved for small IPP program projects, which covered projects of less-than-five MW capacity. Large IPP capacity for PV was 75 MW; CSP 100 MW; and Wind 140 MW. The bid submission pack was supposed to consist of the project structure, legal documentation, land acquisition documents, environmental requirements, financial information, plant technical information and economic development documents — all indicating how the project was to meet the set criteria. The project selection criteria were 30% based on economic development and 70% on the tariffs presented (Eberhard, et al., 2014).

The REIPPPP, has already had four bid windows which has included additional awards in the window 4, called 4b and a further expedited allocation, 4c of which bids were submitted on 11 November 2015. The intention of the South African government to stimulate a price competitive renewable energy market has surely been achieved in these first three windows, since prices have dropped significantly since the first round, with solar PV tariffs decreasing by 68% and wind tariffs down by 42% (Eberhard, et al., 2014). This has further strengthened with bid window 4 prices falling even further. The question remains to be answered whether the prices are sustainable in the long term, and what type of investors or financing structures would be attracted to the market at such prices.

2.8.1 REIPPPP bid outcomes

The first bid window had 53 projects totalling 2,128 MW of generation capacity being submitted, as shown in Table 2.2. Out of these, only 28 projects were awarded 'preferred bidder' status, with a total capacity of 1,416 MW. 18 were based on PV technology, with 632 MW capacity, two were CSP technology with a total of 150 MW capacity, and eight were wind technology projects with a total capacity of 634 MW (Eberhard, et al., 2014).

Table 2.2 REIPPPP outcomes of windows 1, 2 and 3

	Wind	PV	CSP	Hydro	Biomass	Biogas	Landfill	Total
WINDOW 1								
Capacity offered (MW)	1850	1450	200	75	12.5	12.5	25	3625
Capacity awarded (MW)	634	631.5	150	0	0	0	0	1415.5
Projects awarded	8	18	2	0	0	0	0	28
Average tariff (SAc/kWh)	114	276	269	N/A	N/A	N/A	N/A	N/A
Average tariff (USc/kWh) ZAR8/$	14.3	34.5	33.6					
Total investment (ZAR mill)	13312	23115	11365	0	0	0	0	47792
Total investment (USD mill) ZAR8/$	1664	2889	1421					5974
WINDOW 2								
Capacity offered (MW)	650	450	50	75	12.5	12.5	25	1275
Capacity awarded (MW)	562.5	417.1	50	14.3	0	0	0	1043.9
Projects awarded	7	9	1	2	0	0	0	19
Average tariff (SAc/kWh)	90	165	251	103	N/A	N/A	N/A	N/A
Average tariff (USc/kWh) ZAR7.94/$	11.3	20.8	31.6	13				
Total investment (ZAR mill)	10897	12048	4483	631	0	0	0	28059
Total investment (USD mill) ZAR7.94/$	1372	1517	565	79	0	0	0	3534
WINDOW 3								
Capacity offered (MW)	654	401	200	121	60	12	25	1473
Capacity awarded (MW)	787	435	200	0	16	0	18	1456
Projects awarded	7	6	2	0	1	0	1	17
Average tariff (SAc/kWh)	74	99	164	N/A	140	N/A	94	N/A
Average tariff (USc/kWh) ZAR9.86/R	7.5	10	16.6		14.2		9.5	N/A
Total investment (ZAR mill)	16969	8145	17949	0	1061	0	288	44413
Total investment (USD mill) ZAR9.86/R	1721	826	1820		108		29	4504
TOTALS								
Capacity awarded (MW)	1984	1484	400	14	16	0	18	3915
Projects awarded	32	23	5	2	1	0	1	64
Total investment (ZAR mill)	40590	42130	33797	631	1061	0	288	120263
Total investment (USD mill)	4683	5085	3806	79	108	0	29	14011

Source: Constructed by the authors from DOE presentations and data provided by the DOE IPP Unit.

Note 1: ZAR/USD conversions calculated at date agreements were signed in each window.

Note 2: The above data is representative at the time of bidding. Contracted capacity and investment amounts changed slightly at the time of financial close. The investment data for bid Window 1 were provided by the DOE IPP Unit and differ slightly from data released in DOE presentations.

Source: (Eberhard, et al., 2014)

Bid window two was initiated in November 2011, with only 1,275 MW to be procured. The number of bids received was one and a half times that of window one, totalling about 3,233 MW. Out of the 79 submissions received, only 19 projects were allocated ‘preferred bidder’ status (Eberhard, et al., 2014). The wind and PV technology prices, however, fell by 20% and

40% respectively, as shown in Table 2.3. Furthermore, the local content under economic development rose from 38.4% to 53.4% for PV and from 27.4% to 48.1% for wind technology.

Bid window three allocations took place in August 2013, and out of the 6,023 MW submitted, only 1,456 MW was allocated to 17 'preferred bidders'. Prices dropped from an average of R1.65/kWh to an average of R0.99/kWh for PV and from R0.90/kWh to R0.74/kWh for wind technology (Eberhard, et al., 2014).

Bid window four submissions were made in August 2014, and the allocation announcements were made in April 2015. The estimated balance still to be allocated is set at 2,808 MW, which will consist of 1,041 MW from solar PV; 1,336 MW from wind; 200 MW from solar CSP; and 2,310 MW from the other technologies (Eberhard, et al., 2014).

Table 2.3 REIPPP average bid tariff awarded

	Round 1	Round 2	Round 3
Wind	114.3	89.7	65.6
Reduction from previous round		-21.5%	-26.9%
Total reduction from round 1			-42.6%
Solar PV	275.8	164.5	88.1
Reduction from previous round		-40.4%	-46.4%
Total reduction from round 1			-68.1%
Concentrated solar power	268.6	251.2	146.0*
Reduction from previous round		-6.5%	-41.9%
Reduction from previous round			-45.6%

**The price structure for CSP in Round 3 was different to Rounds 1 and 2 and included a peak tariff 270% of the base price.*
Source: Constructed by authors from Department of Energy presentations.

Source: (Eberhard, et al., 2014)

Considering the number of developers and the amount of potential projects submitted with each bid, it is acceptable to conclude that competition was a key driver in pushing the bidding prices down. A decline in renewable energy equipment costs due to manufacturing capacity increases, as well as technology advancement were also considered to have contributed to this decline in prices. Furthermore, familiarity with the REIPPPP requirements and specifications by lenders, project sponsors and other stakeholders also contributed to this decline (McDaid & Wood, 2013).

2.8.2 Economic development requirements

Globalisation and the increasing size of international trade have made developing countries more vulnerable to difficulties than their counterparts in the developed world (Padayachee & Morgan, 2013). For this reason, developing countries have established economic development policies as a measure to protect and drive economic developments. Thus, the REIPPPP has economic development obligations forming part of the bid submission process (South Africa. Department of Energy, 2011). The economic development requirements are designed to incentivise the participating companies to promote job creation; industry development; ownership by local communities; and enterprise and socio-economic development. Economic development obligations (EDO) are the 'non-price' criteria that account for 30% of the total bid score, while the rest is based on price. The EDO forms part of the documents to be submitted at the bidding stage (South Africa. Department of Energy, 2011).

The REIPPPP EDO target the creation of jobs, local content benefits through the procurement of local goods and services, and local community development. The intention is to stimulate local manufacturing and local enterprise participation in completely underdeveloped sectors of the country and in regions, and thereby promote economic development in areas that are far from the big cities, and where most of the renewable energy potential is densely distributed (Eberhard, et al., 2014).

While all of the potential economic development elements are important, critical elements include enterprise development and socio-economic development because a certain percentage of the revenue from operations is to be allocated to these elements. The first three bid windows have shown that little emphasis has been placed on these elements during construction phase, but they have been 'overloaded' for the operation phase (Eberhard, et al., 2014).

Therefore, bidders are required to submit different types of documentation to substantiate their economic development commitments. Some of the documents to be submitted are (Eberhard, et al., 2014):

- An economic development scorecard that shows the bidders' performance against government targets;
- Documents confirming their compliance;
- An economic development plan identifying the socio-economic needs of local communities and a strategy by the project to meet those needs; and

- A reporting plan indicating how the project will be reported on a quarterly basis for monitoring purposes.

The DoE's Implementation Agreement explains how, on a quarterly basis, calculation of performance should be evaluated, any rewards provided and penalties effected.

2.9 SUMMARY

This chapter discussed the solar potential of South Africa, PV technology, applications of PV systems, and factors for conducting a thorough energy yield analysis from the PV plant. The total area of high radiation in South Africa is estimated to be close to 194,000 km^2. Considering how Europe has harnessed its solar energy to power their grid with so little available sun, it can be said that South Africa is well positioned for solar energy wealth. The potential of solar energy to contribute towards South Africa's future energy needs is huge. This still requires meticulous planning and large investments in relevant solar power plant technologies and transmission lines from the areas of high radiation to integrate into the national grid.

This chapter also explored government policy and its relevance. The Department of Energy (DoE) has issued an Integrated Resource Plan for adding new capacity to the country's system of electricity power generation for the next 20 years. The Renewable Energy Independent Power Producer Procurement Program (REIPPPP) was designed for the phased procurement of a large supply of renewable energy, and economic development targets were included for the creation of jobs, local content benefits through the procurement of local goods and services, and local community development.

Aspects relating to the techno-economic viability of large-scale grid-connected PV systems in South Africa are discussed in the following chapter.

CHAPTER THREE
DEVELOPING A MODEL FOR ASSESSING THE TECHNO-ECONOMIC VIABILITY OF LARGE-SCALE GRID-CONNECTED PV SYSTEMS IN SOUTH AFRICA

3.1 INTRODUCTION

The aim of this second chapter of the literature study is to evaluate and consider current academic resources that can or should be used to perform a techno-economic feasibility assessment on utility-scale solar photovoltaic systems in South Africa. Aspects relating to the techno-economic viability of large-scale grid-connected PV systems in South Africa, and the efforts by the government for their implementation are also discussed in this chapter.

The chapter discusses the concept of financing a project. To do so, the types of project financing structures, financial feasibility assessment models, and financial feasibility criteria are all deliberated along with the financial profitability and debt ratios that would be needed to assess a project's viability. The chapter also explores the concept of real options analysis, which provides decision-makers with a framework for making financial choices in uncertain conditions.

3.2 PROJECT FINANCING

Project financing is a method of providing loan funding to a feasible project on the basis of future cash inflows expected from the project (Harvard Business School, 1999). This method is usually employed in capital-intensive projects as they require high leverage. The cash flows of a project are ring-fenced through the creation of a special purpose entity, created to separate the project funds from those of its sponsors.

This method of financing has the advantage of reducing risk of exposure to the sponsor's other business interest. Through the creation of a distinct legal project entity, its projected cash flows are used for motivation of the project's viability (Bjornsdottir, 2010). Furthermore, it necessitates that project-related contracts be concluded and signed off early on, thereby eliminating some of the major risks upfront. The major advantage for sponsors is that their debt capacity is expanded and they are able to explore more projects to invest in, due to the limited recourse (Groobey, et al., 2010).

The financing structure and terms are often different from project to project and among other things they also depend on the type of sector, market sentiment, the level of risk, government policy, and the credit rating of the project owner.

Figure 3.1 shows a typical project finance structure. Fabozzi and Peterson (2003) states that project finance structuring is a very important managerial decision, since the methods of financing a project obligate the project in many ways.

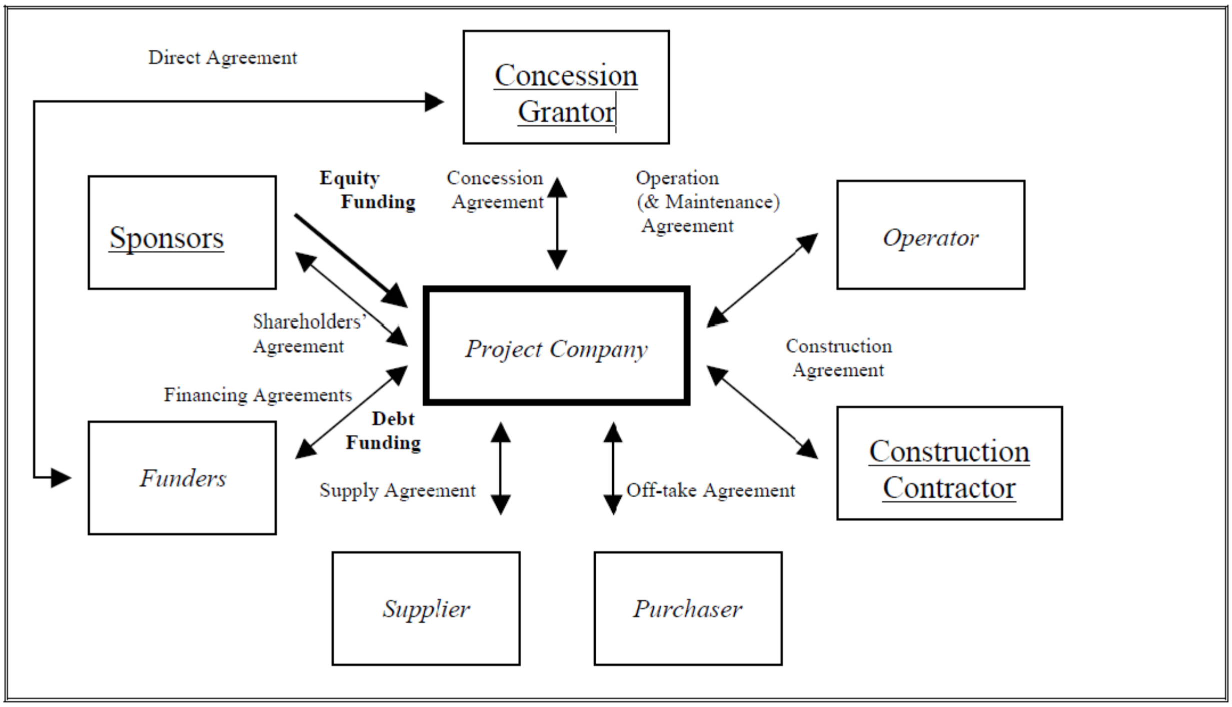

Figure 3.1 Typical project finance structure

Source: (United Nations, 2000)

The DoE, together with National Treasury, created an enabling environment welcoming and simulative to private sector investment in the energy sector through the REIPPPP. As discussed in Section 2.8, the REIPPPP is a bidding process, through which, private power producers that are able to propose technically sound projects to meet local economic content and local development requirements at the best-proposed tariff, are awarded projects by the DoE. Through the REIPPPP, key contracts are established enabling the independent power producers to have some security regarding revenue on any electricity generated. The following types of contracts are signed with key stakeholders (Papapetrou, 2014):

- Power Purchase Agreement (PPA): The PPA contract is signed between the Independent Power Producer (IPP) and Eskom. It is an agreement that the IPP is the seller, and Eskom the buyer of electricity. It captures the terms of construction and operation of the power plant, which both parties must abide by.
- Implementation Agreement (IA): The IA is signed by the DoE and the IPP. It is a contract capturing the terms and obligations upon which the IPP, as the seller, is required to uphold, it also captures Eskom's obligations.

- Eskom Distribution Connection and Use of System Agreement (DCUOSA): The DCUOSA is signed between Eskom and the seller, as the terms upon which the seller must comply, in order to use the Eskom electricity system. This is often because at times (such as when the renewable energy source is not available), the power plant must import power from Eskom's system for use by the facility.

3.2.1 Types of project financing structures

Different project financing strategies may be applied to fund private or public infrastructure projects, which are listed below (Kashani, 2012):

- Build, own and operate (BOO): The investor raises finance to build and operate a facility. The asset ownership belongs to that investor open-endedly;
- Build, operate and transfer (BOT): The investor raises finance, builds and operates a facility for an agreed duration. At the end of the agreed period, the asset ownership is transferred to the relevant authority;;
- Build, own, operate and transfer (BOOT): The investor raises finance, builds, owns and operates the facility. At the end of an agreed period the asset ownership get transferred to the relevant authority;
- Build, own, operate and sell (BOOS): The investor raises finance, builds, owns and operates a facility. At the end of an agreed period, the asset ownership get transferred to the relevant authority in exchange for the asset's residual value (Buljevich & Park, 1999).

The REIPPPP program is a BOO-strategy program with a twenty-year PPA agreement. There is no clarity, though, whether or not the government will extend the PPA after that period.

The ultimate objective of project financing is to strategically structure debt or loan finance, to the benefit of the sponsor's interest whilst also not affecting the sponsor's credit rating and balance sheet (Buljevich & Park, 1999). Buljevich and Park states:

> *"The key to a successful project financing is structuring the financing of a project with as little recourse as possible to the sponsor while at the same time providing sufficient credit support though guarantees or undertakings of a sponsor or third party, so that lenders will be satisfied with the credit risk."*

Projects from the first two REIPPPP bid windows were all financed through project finance, and according to Eberhard et al. (2014), a third of the phase three projects were done the same way.

3.3 FINANCIAL FEASIBILITY ASSESSMENT MODEL

3.3.1 Conceptual framework

An analysis and evaluation of capital investment feasibility of a project involves the study of a number of different financial parameters. In order to study these parameters, normally a financial assessment model is developed. The usual parameters studied are static and therefore require a model to be built in such a way that many different scenarios can be studied (Bjornsdottir, 2010). It is necessary to make the model as dynamic as possible so that changes in assumptions and project conditions can be implemented with ease. Using a model saves time and money, and reduces errors (Bjornsdottir, 2010).

Bjornsdottir (2010) stresses the importance of ensuring that a developer has a thorough understanding of the user's requirements. The objective of building a model is for it to meet the set criteria of those that wanted in the first place, and therefore the model developer must have this objective from design to implementation. Furthermore, assumptions should be factored into the model appropriately.

Mun (2002) proposes setting basic rules of engagement during the model building process, in order to make the model as user friendly as possible. Simple examples of some things that could be done are the colour coding of input parameters and creating separate sheets for inputs and outputs so that later on when conditions have changed, the model can still be used with ease (Mun, 2002). Protection against tampering is a must and changes to the model should be tracked formally (Bjornsdottir, 2010).

Clearly defined objectives makes the model development and implementation more streamlined. The model should be easily understood by the user. The calculations should be accurate and reliable so that the user can confidently use the results in the decision-making process (Sengupta, 2004).

Financial investment analysis models can be developed and built in many different ways using many different coding techniques, depending on the developer and on how dynamic or sophisticated one may require the model to be. When developing a model of any sort, there is a general rule to the architecture: that it will have four components to it, which are assumptions, inputs, calculations or algorithms and outputs. It also makes sense to modularise each component so that any changes — whether in data, calculations or formulae — can be easily made, and errors easily traced (Bjornsdottir, 2010).

In 2010 Groobey found out that most financial investment models were custom made, as there were no standard model solutions on the market. The main reason for this, was that investment projects are very different from one sector to another, and as a result the model would differ from one sector to another. Therefore it is very complex or near impossible to develop a model that can accurately estimate the financial feasibility of every project type (Groobey, et al., 2010).

3.3.2 Model building

A financial model is a mathematical representation of the relationship between the input and output variables of the problem being addressed. Depending of the problem or investment, some of the variables represents money, some could even be technical input an outputs of another model that becomes an input to the main model. A model should be able to be used to analyse different scenarios and make projections. A model should clearly and accurately quantify as much of the interdependencies of variables as possible. The model structure and setup should make it easy to vary input values in order to analyse how these changes affect key output metrics (Sengupta, 2004).

Investment feasibility evaluation is critical in making right an accurate decisions. In most cases investment feasibility analysis is done upfront in the decision-making process as a screening method, however, the analysis should be carried out throughout the project life and be updated when changes occur (Sengupta, 2004).

If the analysis results indicates that the proposed project does not meet set criteria of the investor, the business idea should be discarded. (Bjornsdottir, 2010). This could be easier said than done, though, because what happens if some of the assumption changes occur after the project has already begun? It is important, therefore, to have a type of model that at least incorporates some sensitivity analysis so that worst-case scenarios can be considered before they occur. Thus, even if they cannot be changed, the investment decision can be made with some foresight.

At feasibility analysis stage, a base case financial plan should be modelled and then a sensitivity assessment performed on the profitability of a project. Computer modelling is critical for analysing profitability for the investor's equity, sensitivity analysis is simpler through the use of a model to analyse effect of fluctuating inputs; changes in operating and maintenance cost; the effects of cost overruns and delays in completion; interruptions of project operations; and other significant factors (The African Development Bank, 2006).

At the beginning of an investment feasibility study, the analyst must make sure that all assumptions, whether technical, economic, financial or otherwise are clearly stated. As the project moves from conceptual to execution, the assumptions become more accurate and reliable, as does the investment analysis. Any assumption that could make the project change from successful to unsuccessful, should be considered as a key element requiring careful consideration. Facts should be clearly distinguished from assumptions, and the sources of the facts and rationale for the key assumptions noted (Bjornsdottir, 2010).

A proper due-diligence is critical as the first analysis step to eliminate projects that are not worth investing in. Different organisations have different approaches to how much effort, time and money should be invested in the early stage of a project. However, time that is invested early on in the feasibility analysis can save future effort and money (Helfert, 2001). Helfert emphasises that investment feasibility study shouldn't be undertaken until the following is considered:

- project characteristics and scope;
- key variables and relationships beneficial in the study;
- reliability and certainty of the available data;
- input data type and format (cash flow or accounting);
- limitations of applied tools and their effects on results;
- qualitative judgments or risks relevant to the project;
- use of results' estimates to determine critical data and steps; and
- Verifying accuracy during the analysis.

Helfert's argument is that by reviewing these will lead to the analyst having better understanding and knowledge of the area of study. This should contribute to well thought out and strategic approach to ensure that the model achieves its objectives. Therefore effort can be directed to areas where the most payoffs can be achieved (Helfert, 2001).

The output of an investment feasibility study can only be as reliable as the input data, assuming that the mathematical formulae are correct. Data can be collected from the similar projects, research institutions and specialists in the relevant fields. Often specialist researchers assist with relevant realistic estimates and forecasts required to achieve accurate assessment. The input data accuracy depends on the project circumstances as well as experience of the team, therefore, it is recommended that error margins are factored into the expected outcomes (Helfert, 2001).

3.4 CONVENTIONAL CAPITAL BUDGETING CRITERIA

The traditional capital budget methods used in most, if not all project feasibility analyses are based on the calculation of the cash flows' input and output. The cash flows are then used to model the payback period or discounted payback period, the rate of return on the investment, the net present value (NPV), the profitability index, and the rate of return (IRR).

3.4.1 Net present value

The net present value is the sum of all the cash inflows minus the sum of all the cash outflows. It is regarded as the amount of money an investment is worth over the lifetime of the project, and takes into account expenses or capital outlay and revenues — calculated in present value terms, as shown in the following equation (European Commission, 2008):

$$\boldsymbol{NPV} = \frac{\boldsymbol{CF^0}}{(\boldsymbol{1}+\boldsymbol{i})^{\circ}} + \frac{\boldsymbol{CF^1}}{(\boldsymbol{1}+\boldsymbol{i})^{\boldsymbol{1}}} + \cdots + \frac{\boldsymbol{CF_N}}{(\boldsymbol{1}+\boldsymbol{i})}$$

$$= \sum_{n=0}^{N} \frac{CF_n}{(1+i)^n} \qquad \textbf{[3.1]}$$

where:

CF_n is the net cash flow at the end of period n;
I is the internal rate of return or discount rate; and
N is the service life of the project.

Values for NPV should be treated as follows:

If NPV>0, accept the investment;
If NPV = 0, remain indifferent to the investment;
If NPV < 0, reject the investment.

3.4.2 Profitability index

The profitability index is calculated by dividing the net present value of cash inflows by the capital investment amount.

3.4.3 Internal rate of return

The IRR is the discount rate at which the net present value of the project is zero. It thus serves as the benchmark rate, whereby any rate less than this is not good for the project because the NPV will be negative, therefore implying a bad investment (Sengupta, 2004). This can be observed by the equation (European Commission, 2008):

$$NPV = \sum_{n=0}^{N} \frac{CF_n}{(1+i)^n} = 0 \qquad [3.2]$$

3.4.4 Payback period

The payback method measures the number of years taken to pay back the capital investment amount. It is therefore the period of time required to recover the investment without considering the time value of money (Firer, et al., 2008).

3.4.5 Deliberation on the financial feasibility criteria

While the financial feasibility methods have been accepted and are used widely in business, they have many shortcomings. For example, uncertainty and risk are not considered in the NPV model. Ward and Gittinger (1997) conclude that traditional tools for project evaluation, like IRR or NPV are thus inadequate for dealing with the uncertainties and risks that are prevalent in projects. This is true for rapidly changing industries, where shortly after calculating the models the set assumptions would have changed; thereby questioning whether or not the project would still be viable.

Bjornsdottir (2010) also argues that the traditional discounted cash flow (DCF) methods disregard uncertainty and risk in investment projects. This therefore underestimates the option value that is attached to growing profitability of the business. Conventional capital budgeting disregards investments that do not show a positive NPV in the short term and by so doing fails to recognise future growth opportunities.

Audenaert et al. (2010) argue that the classical evaluation techniques do not sufficiently capture the real value of PV installations because they do not account for externalities, financial risks, portfolio costs, and strategic and managerial options. Rather, these methods focus exclusively on direct costs while ignoring the cost of quality. The above statement therefore goes on to justify that if the classical method indicates a project to be viable, then it certainly should be very viable (Audenaert, et al., 2010). The question remains, however, why other methods that consider the limitations mentioned above are not considered.

3.5 FINANCIAL RATIOS

Financial ratios can be divided into five categories: liquidity, asset turnover, profitability, market trend ratios, and debt management ratios (Bjornsdottir, 2010). The study focused only on those ratios considered relevant to private investor’s interest. That is be summarised as liquidity ratios, profitability ratios, market trend ratios, and debt management ratios; which will be defined further in this section.

3.5.1 Profitability ratios

Profitability ratios are popularly considered financial metric as indicative of business capacity to earn more than its expenses through its operations. It considers the business' profit margins, asset turnover and return on equity for a set operating period (ICAP Group SA, 2006). The metrics measure an entity's capacity to generate profits based on its earnings, expenses, and debt obligations. Often higher ratios when compared to the same ratios from the previous year or to firms in the same industry, indicates good health.

3.5.2 Return on investment

The rate of return on investment (ROI) method calculates the net returns of a project, it takes the difference between the total gain from the investment and the initial capital outlay, and divided by the project cost. T

The formula for the return on investment ratio is:

$$ROI = \frac{\text{Earnings before interest and taxes}}{\text{Total Liabilities and shareholders equity}} \qquad [3.3\ ]$$

The ROI is a profitability ratio that, when taken over set period of time reflects efficiency of invested capital. It is a key investment indicator for decision making and can be used to compare performance of businesses across different economic sectors (Helfert, 2001).

3.5.3 Return on equity

ROE measures the rate of return of equity invested by the shareholders. The higher the ratio, the more efficient the use of the shareholders' equity has been, and the more return has been given back to investors (Helfert, 2001). The formula for the return on equity ratio is (Firer, et al., 2008):

$$ROE = \frac{Net\ profit\ after\ taxes}{Shareholders'\ equity} \qquad [3.4]$$

The ROE is a relevant and excellent performance indicator practice that summarizes efficient capital investment. However, it does not factor debt service, therefore this ratio should be viewed from a long term perspective approach (Bjornsdottir, 2010).

3.5.4 Debt ratios

Debt ratios are used as indicators of how a business employs debt financing, as well as the entity's capacity to service its debt obligations. Debt ratios are mostly used by the loan providers to amongst other things decide on relevant interest rate level for an entity or project (Bjornsdottir, 2010).

The loan providers use debt service coverage ratio (DSCR) to measure the prospective borrower or project's funds capacity to pay the debt. The indicator takes cash flow after operational expenses available to service loan debt (interest and principal repayments) compared to the debt service for the same period. The formula for the debt service coverage ratio is:

$$DSCR = \frac{\textbf{Cashflow after taxes}}{\textbf{Debt Service}} \qquad \textbf{[3.5]}$$

The higher the DSCR value, the easier it is for the entity to pay its debts and therefore the more likely for it to obtain loan (Mae, 2014).

3.5.4.1 Loan Life Cover Ratio

The loan life coverage ratio (LLCR) is commonly used debt ratios in project financing. The ratio is similar to the DSCR, but the difference being that it considers the full tenure duration of the loan. This ratio shows the number of times the cash flow can repay the outstanding loan debts, throughout the planning horizon. LLCR is formulated as:

$$LLCR = \frac{\textbf{NPV [Cash Flow Available for Debt Service]}}{\textbf{\textit{Outstanding principal}}} \qquad \textbf{[6]}$$

The period used in the NPV calculations is from the calculation year till the time loan maturity and the discount rate is the cost of borrowing (Navigator Project Finance, 2009).

The financial model, as discussed in section 3.3.2 will therefore consider and calculate a variety of the ratios, as summarised in Table 3.1 below.

Table 3.1 Financial feasibility ratios considered for financial modelling

Description	Formula	Definition
Profitability ratios		
ROE (before tax)	$= \frac{Net\ Income\ Before\ Taxes}{Average\ shareholder\ Equity}$	Indicator of gain or loss on shareholder investment.
ROI	$= \frac{Profits\ after\ Taxes + interest}{Total\ Investment}$	Measures the efficiency of the capital investment as compared to the effect of its returns. (Loth, 2014).
Operating Profit Margin	$= \frac{Profits\ before\ Taxes\ and\ Interest}{Net\ Sales/Revenue}$	Current operations profitability indicator without regard for interest charges due to capital investment.
Leverage ratios		
Debt to Asset Ratio	$= \frac{Total\ Debt}{Total\ Assets}$	Extend to which a company is in debt as compared to its assets (Loth, 2014).
Debt Service Cover Ratio	$= \frac{Operating\ Profit + Depreciation + Interest}{Interest + Principal\ Amount}$ $= \frac{Net\ operating\ income}{Total\ Debt\ Service}$	Ratio indicates the available cash flow to meet company or project's debt
Times Interest Cover Ratio	$= \frac{Operating\ Profit + Depreciation + Interest}{Interest + Principal\ Amount}$	Ratio indicating whether a company or project is able to service its debt interest (Loth, 2014).
Net Present Value	$= \sum_{n=0}^{N} \frac{CF_n}{(1+i)^n}$	Sum of all the cash in and out flows discounted to present value.
Internal Rate of Return	$= \sum_{n=0}^{N} \frac{CF_n}{(1+i)^n} = 0$	Rate of discount at which the sum of the cash inflows and outflows is zero.

For a comprehensive financial evaluation model study to be carried out, it is therefore required that in addition to classical capital budgeting methods, other financial ratios has to be considered. More especially since these type of projects are funded through commercial loans, it becomes critical to prove to the banking institutions that the project company would meet required liquidity ratio targets and able to service its debt. For the equity investors they will be interested in the profitability of such an investment.

However, these type of financial evaluation parameters are fundamental and good, however, they do not necessarily address the aspect of risk on the investment. Hence the study includes the theory of real options analysis.

3.6 REAL OPTIONS ANALYSIS

Real options analysis (ROA) provide a framework for making decisions in uncertain conditions, thereby enhancing the value of an investment. The flexibility of real options is realised through the option or right to take specific action in the future at some cost, depending on how the original risks pan out. Options theory is used to appraise physical assets, as opposed to financial assets, stocks or bonds.

Lack of knowledge and the complexity of real options have created obstacles in their uptake. Literature indicates that very few companies have considered using real options in evaluating projects. Over the years, research has been done to determine whether Fortune 1000 companies use real options and what percentage use real options. The literature indicates that a range between nine percent and 14 percent of the Fortune 1000 companies use real options and that about 14 percent of these are highly specialised and technical industries in the technology space, such as utilities and energy enterprises (Janse van Rensburg, 2010).

Luehrman (1998:1) argues that any capital investment opportunity is similar to a call option, based on the fact that enterprises have the right, but not the obligation, to invest in a new project or to expand their existing activities: "*If we can find a call option sufficiently similar to the investment opportunity, the value of the option would tell us something about the value of the opportunity*" Luehrman (1998:1). A correlation can be established between the project's specific investment parameter metrics and the variables that determine the value of a simple call option on a share of stock.

A model that combines the investment opportunity or project's characteristics with the structure of a call option can be developed by mapping the characteristics of that investment opportunity onto the template of a call option. The European call is considered the simplest of all the options because it is exercised on expiry date only.

According to Campher (2012), the three main attributes incorporated from original concept of real options are as follows:

1. Uncertainty of future cash flows;
2. Investment irreversibility (once a project is started, recovery of the entire investment can only be through its future cash flow); and

3. Timing of project commencement.

Real options analysis add value through their flexibility, as they allow critical decisions to be made throughout the life of a project.

3.6.1 Basic options pricing

Real options pricing theory is derived from financial option pricing theory. Therefore, to gain understanding of how real options add value, the fundamentals of financial option pricing theory must be understood.

3.6.1.1 Call option

A call option gives the right, but not the obligation, to purchase an associated asset at a fixed strike price any time before the option date expires. Therefore, a buyer pays a set price for that right. If, at expiration date, the value of the asset is less than the strike price, the option is not exercised and it expires worth nothing. However, should the value have exceeded the strike price, the option is executed putting the purchaser into profit. The purchaser buys the stock at the exercise price and the difference between the asset value and the exercise price consists of gross profit and unit price paid for the asset. Figure 3.2, below, indicates the relationships between time, value, and paid premium.

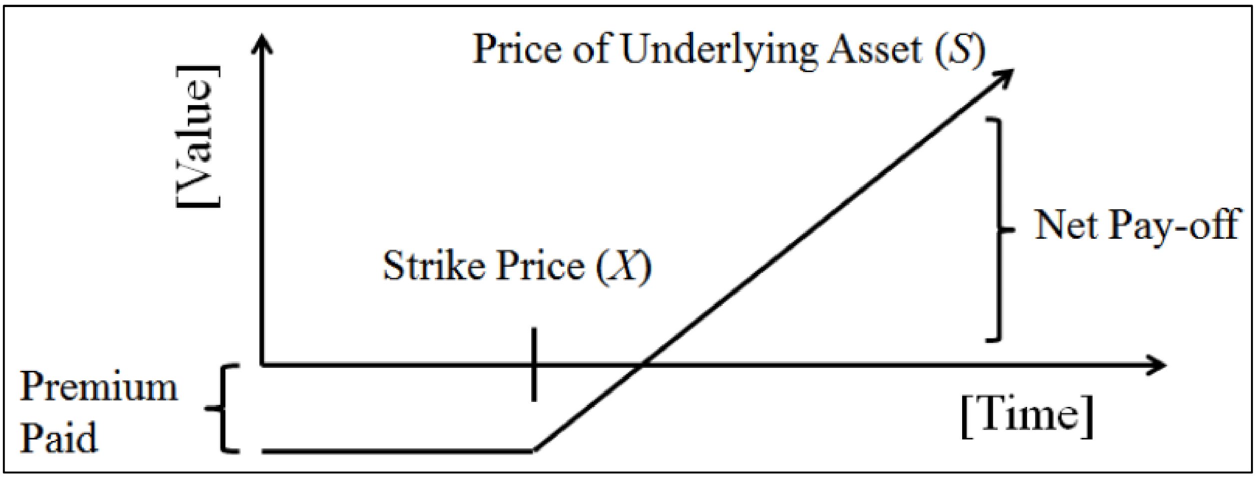

Figure 3.2: Call option pay off diagram

Source: (Campher, 2012)

Noting the value on Figure 3.2, the net amount paid could be negative or equal to the initial call price paid, if the value of the asset is less than the strike price. Should the value of the asset exceed the strike price, the gross amount paid is positive. Strike price is also referred to as exercise price.

The premium paid for the call option gives the purchaser of the option the right, to buy the associated asset at strike price (X). The value of the associated asset (S) is the present value of the asset which could be susceptible to change and can increase or decrease in value over time. A premium is paid to enable the purchaser the option to buy the asset or not. If the value of the underlying asset appreciates, then the buyer makes a profit; should it drop, then the buyer loses money.

3.6.1.2 Put option

The put option functions in exactly the same way as the buy option, except that it is in the opposite direction.

3.6.2 Real options in theory

The term ‘real options’ was coined in 1977 by Stewart Myers. Real options analysis is applied in cases where the investment opportunity are tangible assets such as large infrastructure capital projects, as opposed to financial instrument investments. Real options analysis within capital budgeting include the option to invest or not to invest, the option to abandon or to continue a project, and the option to delay or to carry on with the investment.

There has been a significant increase in interest in implementing real options analysis to appraise large capital investment. Real options analysis has the potential to provide more efficient ways to allocate capital and maximise shareholder value by leveraging uncertainty and limiting risk. This does not mean that they are flawless, but the mathematical formulation and option valuation tools provide a great deal more certainty in the calculation of project value (Janse van Rensburg, 2010).

Campher (2012) notes that real options analysis can provide strategic insight by guiding executives with the following:

- Identifying different investment decision paths that may require navigating when considering high uncertainty;
- qualitative and quantitative project prioritisation;
- strategic decision optimisation;
- optimal times for effective execution of investments;
- consideration and management of existing and new ‘options and

- strategic decision making for future opportunities.

Real options factor in the risk as well as the uncertainty of the investment. Since real options analysis was founded upon financial option theory, parameters used to valuate physical assets are matched to such financial option valuation parameters.

3.6.3 Real option analysis technique

Two primary modelling approaches are used in performing real options analysis: discrete and continuous time approaches. The discrete time approach includes multinomial lattices such as binomial lattice and the adjusted decision tree approach. The continuous-time approach consists of closed form equations, stochastic differential equations and simulation approaches, as shown in Table 2.12 below.

Table 3.2 Call modelling options

Optional Calculator	Advantages	Disadvantages
Discrete-Time Calculators		
Multinomial Lattice	Intuitively appealing	Cumbersome
	Flexible	Labour intensive
	Easy implementation	
Continuous-Time Calculators		
Closed Form	Simplified calculations	Limiting assumptions
	Straightforward	Limited applicability
Stochastic Differential Equations	Model flexibility	Approximate solutions
	Mathematically 'accurate'	Complicated
Simulation	Adaptable	Require special skills
	Broad applicability	Potential misuse

Source: (Campher, 2012)

3.6.3.1 Black-Scholes model

According to Luehrman (1998), the literature discusses a number of different closed form equations developed for real options analysis (ROA). He further alludes to the fact that most of the other equations were formulated out of the Black-Scholes model. The argument is that Black-Scholes equations are simplified and provide straightforward calculations. Black-Scholes equations can value options for growth, abandonment and also the suitability of delaying projects.

It is stated (Luehrman, 1998) that, when it is applied, the Black-Scholes model reflects an approximation to option value fundamentals in real options. It is therefore said to represent the closest best option value in real options analysis.

Luehrman furthermore states how it has been shown that the discrete time method calculation converges to that of a continuous time model as the number of time steps becomes infinitely small. This, therefore, supports the claim that the Black-Scholes model is a fairly reliable method for performing real options analysis.

Black-Scholes uses an option pricing formula. The Black-Scholes option pricing formula is considered fundamental in option pricing methodologies. This study therefore focused on this model, and the parameters used were based on the Black-Scholes option pricing formula.

The Black-Scholes equation is as follows (Wang & de Neufville, 2005):

Call option:
$$\mathbf{C = SN(d_1) - Xe^{rt}N(d_2)} \qquad [\,3.7\,]$$

Where:

$$d_1 = \frac{\ln\left(\frac{S}{X}\right) + \left(r + \frac{\sigma^2}{2}\right)t}{\sigma\sqrt{t}} \qquad [\,3.8\,]$$

$$d_2 = \frac{\ln\left(\frac{S}{X}\right) + (r - \sigma^2/2)t}{\sigma\sqrt{t}} = d_1 - \sigma\sqrt{t} \qquad [\,3.9\,]$$

And:

N(x) is the cumulative probability distribution function for a variable that is normally distributed with a mean of zero and a standard deviation of one.

The major assumptions underlying the Black-Scholes approach are:

- Existence of a market that values assets;
- The market is efficient, provides no riskless opportunities;
- Selling securities short has no limitations;
- transaction costs or taxes don’t exist;
- All securities are perfectly divisible;
- Security trading is continuous;
- The risk-free rate of interest is constant and the same for all securities; and
- The asset price follows Geometric Brownian Motion with μ and σ constant (Wang & de Neufville, 2005).

Generally speaking, most projects involve expenditure to acquire or construct some productive asset. Expecting to realise more value from an opportunity is similar to exercising an option. The money spent is like the option's exercise price (X); the present value of the asset built or acquired is like the stock price (S); and the length of time that the investment opportunity could be deferred without losing the opportunity is similar to the option's time to expiration (t). The uncertainty about the future value of the project's cash flows (that is, the riskiness of the project) corresponds to the standard deviation of returns on the stock (ρ), and the time value of money is like the risk-free rate of return (r_f). By pricing an option using values for these variables, one can learn more about the value of the project than a simple discounted cash flow analysis would reveal (Luehrman, 1998). Parameters are defined based on financial option pricing terminology.

3.6.3.2 Stock price (S)

Stock price is considered the present value of future cash flows obtained from the investment of an option. Present value is cash flow discounted at a predetermined discount rate. This rate could be based on an industry standard.

3.6.3.3 Risk & discount rate (r_f)

Financial options must use replicating portfolios consisting of either an underlying traded asset or a risk-free bond. This is used to hedge risks within an options value and is assumed to be a risk-free rate. An assumption, therefore, is that the underlying tradability of real option valuation should be treated like those of financial options. The risk-free rate should be used in all discounting calculations. In most cases, the risk-free rate comes from replicated portfolios with low risks, such as government bonds or savings plans.

3.6.3.4 Volatility (σ)

One of the major parameters affecting option value is volatility. Therefore, choosing or calculating volatility or standard deviation accurately is important. Calculating volatility or risk to a project or business can be very challenging. Volatility can be calculated with the use of historical data, educated guess work, and estimation or through some sophisticated simulation. The literature suggests the use of Monte Carlo simulation or closed form formulae. This metric also represents the uncertainty associated with an investment project. This study based its volatility the project risk analysis matrix provided as part of the project information.

3.6.3.5 Exercise price (X)

The exercise price represents the cost due to executing the next phase of an investment, whatever action the next phase may entail. Real options analysis costs may be instalments spread over a period of time or in one lump sum pay out. Calculations using lump sums are less complicated.

3.6.3.6 Exercise time (t)

As the actual date becomes difficult to establish in real options analysis, educated timeline estimations can be used instead. The factors to be considered when mapping an investment onto a call option are listed in Figure 3.3 below.

Figure 3.3 Mapping an investment onto a call option

Source: (Luehrman, 1998)

The advantages of deferring projects for industries such as real estate development are that they could lead to better material and building costs. The question then becomes how long should the wait be? Real options analysis can determine the value to cost, as well as uncertainty attributes of market conditions, which can indicate the optimal waiting period.

The financial tool most relied upon to estimate strategy value is normally discounted cash flow, which does not factor in project or business risks. An optimal approach should be for any valuation of an investment to factor in the uncertainty related to the investment opportunity and the active decision making required for the strategy a success.

Real options analysis provides insight into the potential future impact of risk on an investment and thereby encourages active management of strategy, rather than a passive approach (Campher, 2012).

3.6.3.7 Combining discounted cash flow and real options analysis

The literature demonstrates that real options analysis can provide flexibility and greater future valuation. Discounted cash flow (DCF) techniques are foundational for any capital budgeting process. Therefore, instead of settling for one technique, the strengths of each method can be combined. Then they complement each other thereby enhancing effective decision making. The reality of all investment opportunities, especially any lucrative opportunity, is that there are a great deal of potential risks and uncertainties that affect markets or projects. These uncertainties could lead to losses of returns, and this presents an opportunity to apply real options analysis. Below, Figure 3.34 illustrates the area of overlap between DCF and ROA.

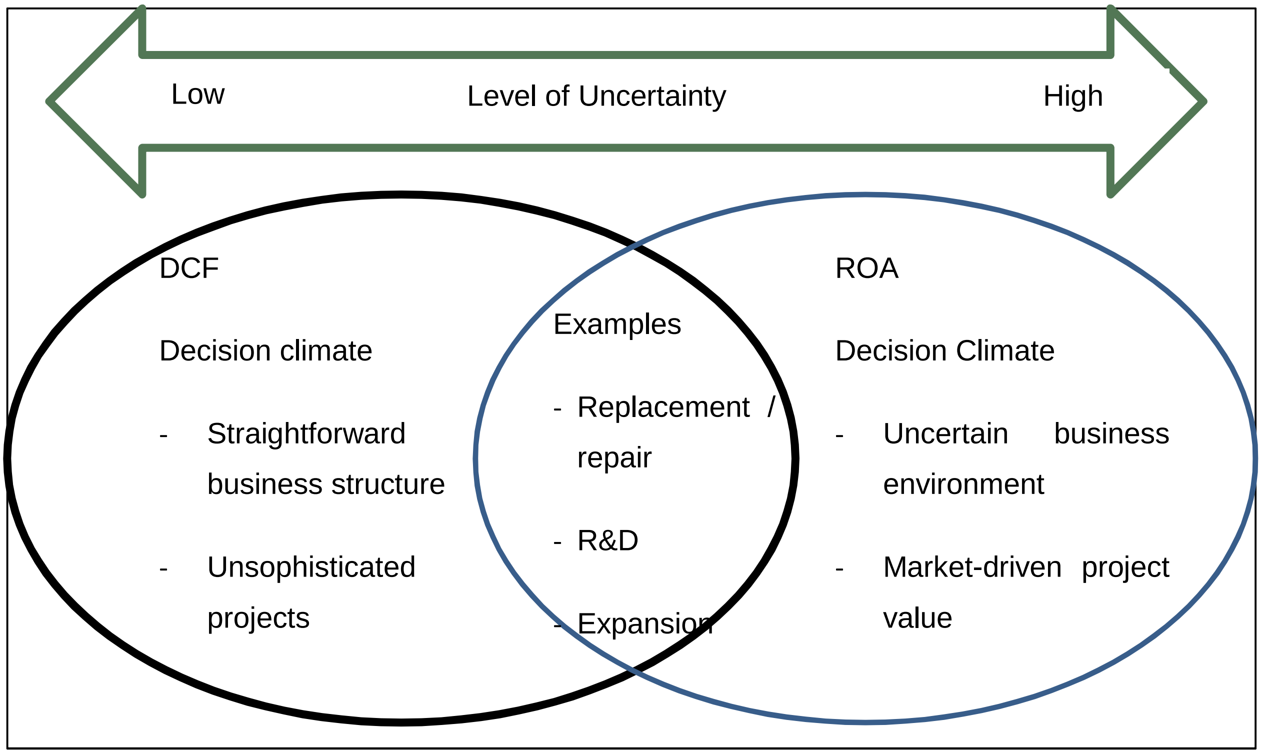

Figure 3.4 DCF and ROA complement area

Source: (Campher, 2012)

Campher (2012) explains the method of combining DCF and ROA as combining the sum of traditional NPV and the expected value of any future options made possible by the initial investment. He further claims that, in the majority of cases, ROA requires information obtained in DCF methods and calculations. Therefore, DCF calculations should be performed first and then expanded upon using real option analysis, thereby creating an overlap between discounted cash flow and real option analysis. The included options can then leverage strategic flexibility for project implementation, deferral or abandonment. If the real options analysis yields a favourable value, the investment can be implemented. If the value is not favourable, the project can be deferred, after which an analysis review can be performed and, if it becomes clear that the value and the uncertainty or risk is unavoidable, the investment can then be abandoned. Figure 3.5 provides a visual depiction of the various quadrants used to calculate investment choices.

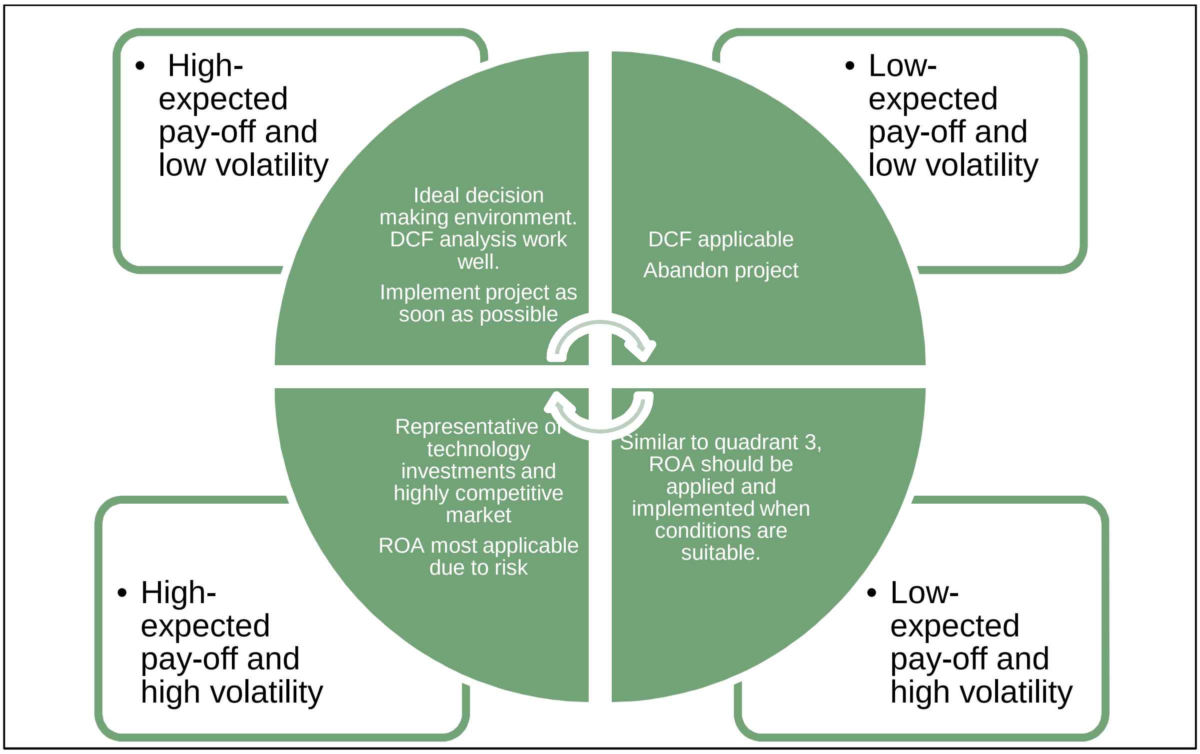

Figure 3.5 Investment analysis according to quadrant classification

Source: (Campher, 2012)

"The higher the case of uncertainty, the more ROA decision criteria and technique impact the final decision".

Companies that rely on conventional capital budgeting analysis alone often underestimate the value of their projects, and may fail to invest in high reward high risk opportunities. Far from being a replacement for DCF analysis, real options are an essential complement, and projects' total values should encompass both. DCF captures a base estimation of value, while real options take into account the potential for gains (van Putten & Macmillan, 2004).

Real options analysis facilitates value realisation through active managerial decision-making flexibility under uncertain conditions. ROA can, however, also lead to overvaluation of investments, especially in cases of high uncertainty and longer time spans. This can be combated through a combination of the traditionally trusted DCF method and the more flexible ROA technique.

3.6.3.8 Linking NPV and option value

The traditional DCF method assesses investment opportunities by calculating net present values. In short, NPV stands for how much the operating assets are worth in relation to their actual costs:

$$NPV = present\ value\ of\ assets - required\ capital\ expenditure \quad [7\ ]$$

A positive NPV means the project is worth investing in. A negative NPV, on the other hand, means the project will lose money, and therefore is not worth investing in. A project NPV and option value can only be the same when the project cannot be deferred any longer because, at that stage, the option has reached its expiration date. At that stage, either:

$$C = S - X \text{ or } C = 0; \text{ thus } NPV = S - X \qquad [3.11]$$

If an option value is similar to NPV, it may be negative, zero, or positive. An option value that is negative is the same as a negative NPV. An option value that is positive has the same effect as a positive NPV and the same applies if the option value is zero.

This commonality between NPV and option value means that corporate financial spreadsheets set up to evaluate projects' NPVs are relevant and can also be adjusted to consider option pricing. Any spreadsheet that computes NPV already has the required information to compute S and X.

Luehrman (1998) states that NPV and option price diverge when the investment decision may be deferred. In actual fact, the deferral of a project can add value to the project:

- By paying later rather than sooner, assuming that all factors stay the same, deferred expenditure can be invested to earn interest on a risk-free rate of return; and
- Change could occur that affects the value of the operating assets to either go up or go down. If the value goes up, the decision to invest (exercise the option) can be made. However, should the value decline, that would also be good, because a poor decision would be avoided.

These two examples illustrate the importance of real options analysis in project evaluation. The conventional NPV method, on the other hand, does not provide such insight into the opportunities of an investment. Therefore, to value an investment, new metrics must be developed to quantify the value of deferring an investment.

3.6.3.9 Quantifying extra value NPV_q

Assuming that, when deferring an investment, the required capital expenditure is put in an interest earning vehicle, thereby adding more value to the initial funds by not undertaking the investment opportunity, the invested initial capital expenditure (X) would then be discounted to present value employing the discount rate, PV(X) (Luehrman, 1998):

$$PV(X) = \frac{X}{(1+r_f)^t} \qquad \textbf{[3.12]}$$

In order to include the extra value to the original NPV, the equation NPV = S - X is modified to the following (Luehrman, 1998):

$$NPVmodified = S - PV(X) \qquad \textbf{[3.13]}$$

This modified NPV includes the earned interest during the deferral period of the investment, which is valuable information not provided by the conventional NPV method. This value can be negative, zero or positive. In order to gain more information from this new calculation, the relationship between the initial capital expenditure and the new present value cost of operating assets must be adjusted in such a way that the outcome value cannot be negative or zero (Luehrman 1998). Therefore, a new metric should be created by converting the difference between S and NPV(X) into a ratio. This changes the negative values into decimals between zero and one. This new metric is called NPV_q, with q standing for quotient (Luehrman, 1998):

$$NPV_q = \frac{S}{PV(X)} \qquad \textbf{[3.14]}$$

When modified NPV is positive, NPV_q will be greater than one. When modified NPV is zero, NPV_q will be one, and when modified NPV is negative, NPV_q will be less than one, as shown in Figure 3.6.

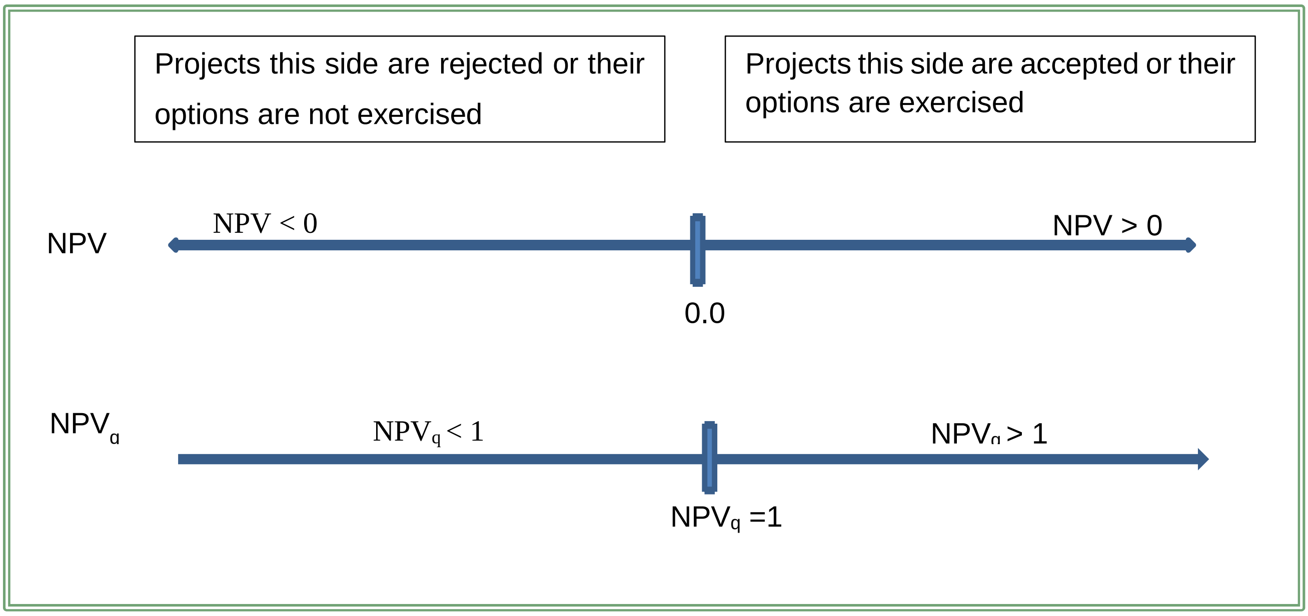

Figure 3.6 Substituting NPVq for NPV

Source: (Luehrman, 1998)

3.6.3.10 Quantifying extra value: Cumulative volatility

The uncertainty of what might happen in the future to cause a change to the value of an asset is a significant concern when considering any project or investment opportunity. The challenge is to determine whether the asset value will change or not and what future value the asset may have if it changes. In order to estimate potential asset value change, an investment opportunity should be quantified for uncertainty. The only way to measure uncertainty is by assessing probabilities.

The simplest approach to quantifying uncertainty is to consider the range of all possible values, from lowest to highest, and then take into account the likelihood of all those possibilities occurring. The most common probability measure of dispersion is the variance, which is the likelihood of having a value furthest from the average value within a sample. The higher the variance, the more likely it is that other values within the sample will be far from the average, either on the high or low side.

Variance is a good measure of uncertainty; however, time also has to be considered. How long one can afford to wait while things change is a serious consideration. Markets and external factors can change remarkably over a two- to five-year period when compared to a two- to five-month period.

Uncertainty is variance per period multiplied by the number of periods, or σt. Cumulative variance, as it is called, is a good measure of business investment uncertainty; however, it has to measure project returns instead of variance of project values. This make it possible to work with rates of returns in percentage gained, rather than in currency terms. Return is the future value as a percentage of the present value. Furthermore, it is easier to understand uncertainty as standard deviation rather than as variance. This makes it possible to account for uncertainty in the same units being measured, be they currencies or percentages. The symbol σ^2 denotes variance of returns per unit of time on the project, and the formula for cumulative variance is thus as follows (Luehrman, 1998):

$$\textbf{Cumulative variance} = \sigma^2 t \qquad [\ 3.15\ ]$$

The formula for cumulative volatility (C_v) is as follows:

$$C_v = \sigma\sqrt{t} \qquad [\ 3.16\ ]$$

3.6.3.11 Valuing options

The new metrics for using real options together with DCF are NPV_q and C_v. These metrics contain all the information required to value a project using European call option theory, based on Black-Scholes model (Luehrman, 1998).

When mapping projects into options, five variables are defined, four of which are S, X, r_f and t, which NPV_q is comprised of; and cumulative volatility, C_v is the fifth. While all the variables are employed in the model, only two metrics are focussed on, thereby simplifying options analysis in project investment analysis.

These two main metrics have natural business significance, which makes option analysis a great deal more comprehensible to non-finance professionals. Based on these metrics, Luehrman (1998) developed a two-dimensional space graph, on which calculated values could be positioned (see Figure 3.7).

NPV_q is on the horizontal axis, increasing from left to right, so that as NPV_q rises, the value of the call option rises too. The higher the project present value (S), or lower capital expenditure (X), the higher the NPV_q. On the vertical axis is the cumulative volatility, increasing from top to bottom. The higher the uncertainty of a project's future value and ability to defer the project, the higher its cumulative volatility.

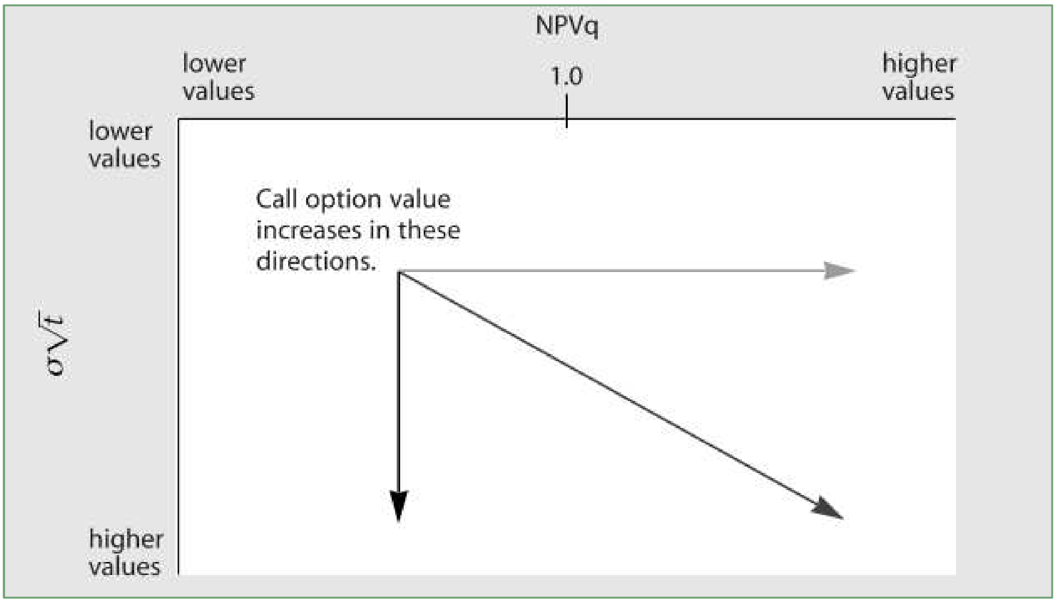

Figure 3.7 Option value in two-dimensional space

Source: (Luehrman, 1998)

3.6.3.12 Mapping the metrics on a two-dimensional space:

Adopted from Campher's (2012) study and active mapping tool method, linking NPV to an option value as one metric and then quantifying risk or uncertain conditions allows for option valuation of the investment. Campher expanded on Luehrman's (1998) two-dimensional space mapping of the two metrics with a 'visual active' mapping tool (see Figure 3.8). The active map is based on a rectangle that is subdivided into four quadrants, of which the top two are further subdivided into two each, in order to capture the unique value associated with a relevant decision regarding the investment opportunity. The volatility metric is measured along the vertical axis and NPV_q is measured along the horizontal.

The active map tool takes the options analysis method as presented by Luehrman (1998) further, to make decision making easier. The NPV_q is also referred to as value to cost, because it represents the value gained through earned interest during the deferred period. The capital expenditure would be invested in government bonds. Furthermore, the NPV_q contains all the information that a conventional NPV analysis has as well. This value refers to the asset under scrutiny, and it is not the option on an investment.

As previously discussed, if the NPV_q value is between zero and one, then the investment is worth less than it costs. This is equivalent to the NPV being less than zero. A value above one indicates an investment that is worth more than its present value cost and is equivalent to an NPV above zero.

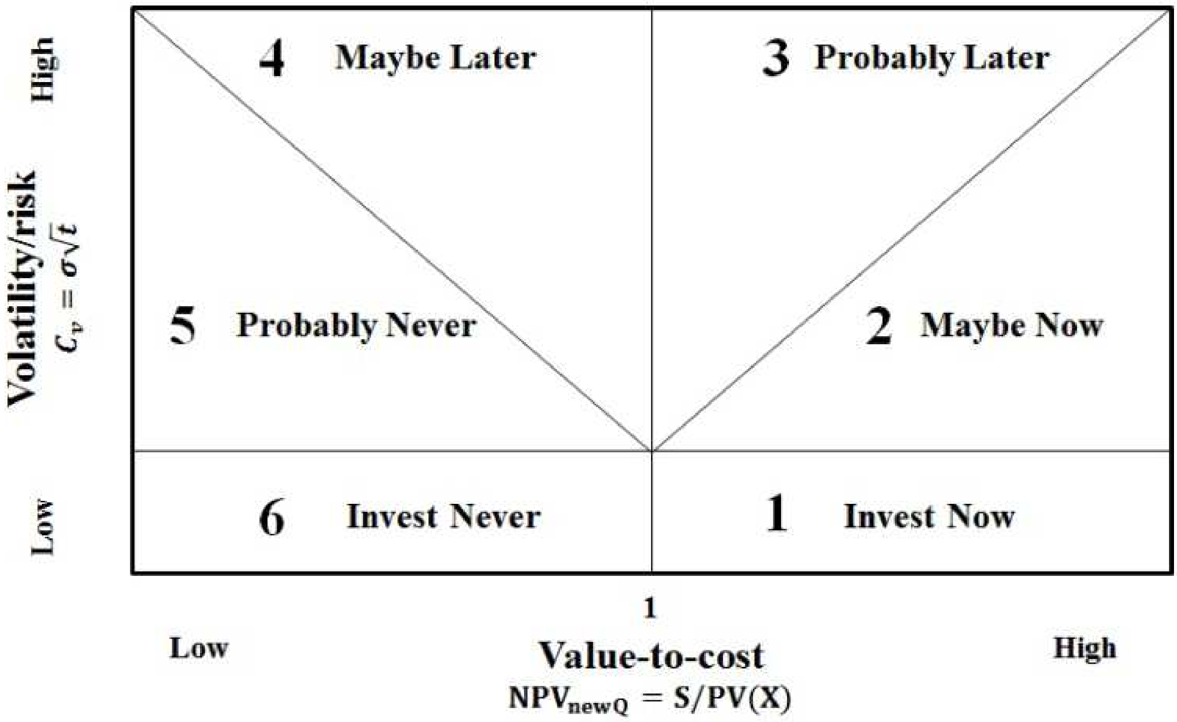

Figure 3.8 Active mapping tool with decisional criteria diagram

Source: (Campher, 2012)

The second metric, cumulative volatility, represents market risk conditions before the decision is taken and how those risk conditions would affect the performance of the investment.

3.7 SUMMARY

This concludes the literature review chapters. While the intention is to stimulate local manufacturing in completely underdeveloped sectors of the country, and thereby promote economic development in areas that are far from the large cities, considerable financial resources are needed for this undertaking. Analysing an investment feasibility of a project is an essential part of the decision-making process and investment framework.

Classical evaluation techniques do not sufficiently capture the real value of PV installations because they do not account for externalities, financial risks, portfolio costs, and strategic and managerial options. Financial ratios are therefore necessary for calculating the value of prospective investments, and ratios from four categories have been considered in this study. Real options analysis provides a framework for making financial decisions in uncertain conditions. The next chapter provides the details of the framework for model development and its structure.

CHAPTER FOUR: MODEL DEVELOPMENT AND STRUCTURE

4.1 INTRODUCTION

This chapter presents the model development and structure of the study. It begins with a discussion of the objectives of the study, and the analysis framework upon which it was based. This includes a review of the study's proposed investment analysis framework. Next in the chapter, the plan of development is deliberated, which includes the scope and limitations of the study.

The chapter then discusses the methodology in detail, considering aspects such as the technical input, capital cost, operational input, main calculations, real options analysis, volatility and management of uncertainty. The chapter ends with a discussion of the key assumptions that were made for the study, including assumptions relating to the energy output, tariffs, revenues, expenses and financing.

4.2 OBJECTIVES

The objective of this thesis was to develop an investment analysis framework based on the conventional methods of NPV and ROI, among others, to evaluate the feasibility of any proposed PV generation plant. The proposed investment analysis framework consisted of seven functional components:

1. The energy resource and finance input data;
2. The DCF calculation model;
3. The sensitivity simulation modelling;
4. @Risk® analysis;
5. Real options analysis and
6. The technology learning curve modelling;

4.3 PLAN OF DEVELOPMENT

The technical project cost and other main inputs were set up in a Microsoft Excel spreadsheet and used in the calculation of operating profit, depreciation, interest payments and corporate income tax, which was in turn used to determine the income statement, balance sheet and cash flow statement. The impact of the variation in inputs was then obtained from these original values and a sensitivity analysis of the key outputs was carried out.

A schematic diagram of the model algorithm representing the modelling approach used is shown in Figure 4.1. Each block in the figure represents a separate sub-model, which was developed on separate but interlinked sheets in MS Excel.

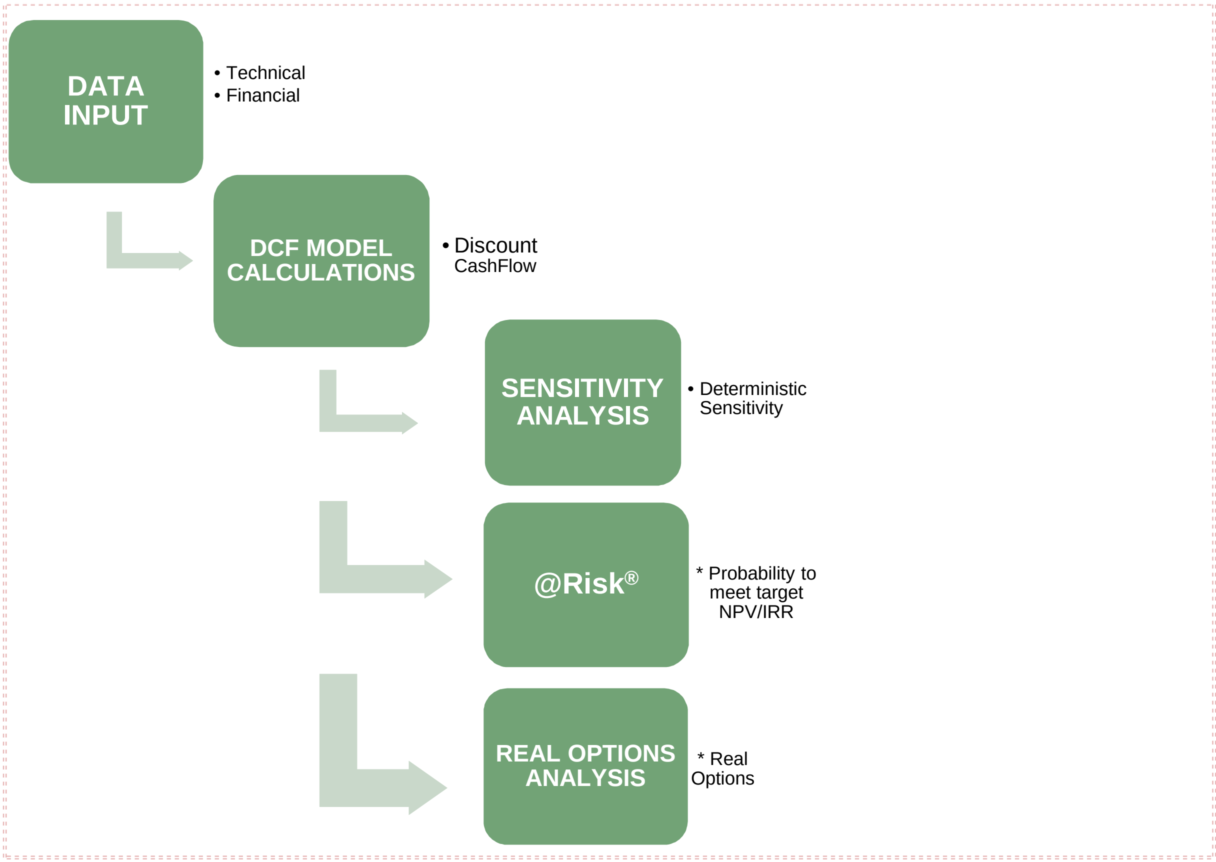

Figure 4.1 Flow diagram of the developed model

4.3.1 Scope and limitations

Data from an existing project was used to provide information on the viability of investing in a theoretical project that would be of a similar nature. The valuation metrics used were the NPV, IRR, ROE and DSCR. In addition, inclusion of the energy industry-specific levelised cost of energy (LCOE) metric provided a range of indicators that would be expected to offer valuable information for investment decision-making on a proposed project, at a preliminary level.

4.4 METHODOLOGY

Figure 4.1 presents an overview of the combined capital investment and real option analysis framework for the theoretical utility scale PV project. An investment valuation model based on NPV, IRR, ROI, and DSCR was at the core of this framework. It received input from external modelling components, which generated the input information that proper financial analysis of a theoretical energy retrofit solution would require.

4.4.1 Technical input

The first component was the energy output estimations based on the case study project. The model determines the energy output potential of the theoretical PV generation plant by the empirical energy forecast, factoring module efficiency, solar field area and the losses of the plant.

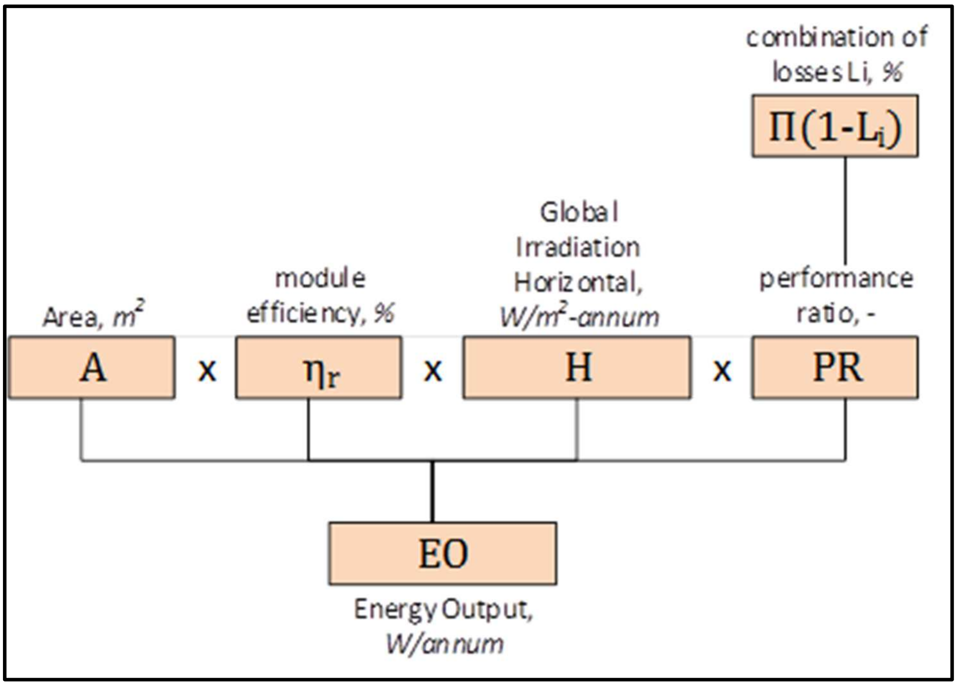

Figure 4.2 Energy Output Model

This project data and some of the information used is based on the REIPPPP window 2 project, solar Facility. The data used includes estimated and approved energy outputs for the site. The project site satellite data set drawn from www.soda-is.com was considered and analysed, however, due to uncertainty of this data it was decided to rather use data that was vetted by independent professional sources.

Table 4.1 Model Technical Inputs Interface

PV Module Type	JKM255PP	JKM270PP	JKM300PP	JKM315PP	
Module specific energy yield, EO_m	356	373	427	641	kWh / annum
EO_m	40.7	42.6	48.8	73.1	W
Module power capacity	15.9	15.8	16.3	23.2	
Total system energy yield, EO	125.2	131.1	150.1	225.3	GWh / annum

P50 & P90

P50 & P90 values represent the likelihood of exceedence.

	JKM255PP		JKM315PP	
P50	125.2	GWh / annum	225.3	GWh / annum
P90	119.6	GWh / annum	215.1	GWh / annum

For example, the Jinko-JKM255PP module P90 value indicates that the energy yield is greater than 119.6 GWh /annum 90% of the time.

The data is used to calculate energy output based on panel efficiency, and all required technical inputs which the model calculates as provided in chapter 2. It is practice to calculate the solar energy probabilities of exceedance, P50 and P90 for the proposed project site. The energy production is a critical determinant to the revenues that will be realized, it is therefore important to estimate a level of production that is most likely to be realized with probability of even exceeding such level, that is what is called the P50, meaning that there is 50% chance of exceeding. The other level which is also normally calculated is the P90, this by its nature implies, that if you want higher level of certain to achieve such energy production, it must be a bit more conservation in order to achieve. The project being analysed in this study will use P50, this element of the model could be dictated by the lenders.

4.4.2 Capital cost

The capital cost, which formed part of the input, was also based on the Solar Facility project data, as shown below.

Total Project Cost (FCI)	**R**	**2,062,333,568**

The assumption is that this cost was linked to a single axis tracker system consisting of direct costs to the plant and indirect costs such as project management fees, legal and administration management fees. Some of the direct costs as listed in Table 4.2 below, are for the PV modules, tracking system, inverter stations, and balance of plant items: DC and AC cables, trenching for cables, interconnection system including metering, monitoring and control systems, and associated labour component.

Table 4.2 Model Capital Cost Inputs

Direct Capital Costs

Modules	319600	*units*	0.255	*kWdc/unit*	81498	*kWdc*	7.73	*R / Wdc*	R 630,089,957	*38%*
Inverters	237	*units*	333	*kWac/unit*	79053	*kWac*	2.08	*R / Wac*	R 164,527,318	*10%*
								Tracking system	R 240,395,446	*15%*
								String boxes, LV cables, MV cables	R 70,086,771	*4%*
								Total direct costs	**R 1,105,099,492**	***67%***

Indirect Capital Costs

Electro-mechanical installation	R 38,809,485	*2%*	Miscellaneous (spare parts, preliminary, logistics)	R 35,908,878	*2%*
Grid interconnection	R 73,842,077	*4%*	Contingency	R 95,106,362	*6%*
Civil works	R 186,443,513	*11%*	Construction management	R 64,232,614	*4%*
Ancillary systems	R 15,028,028	*1%*	Legal and administrative	R 0	*0%*
Project engineering services	R 29,609,245	*2%*			
			Total indirect costs	**R 538,980,202**	***33%***

Administrative and Research and Development Costs

EPC	R 197,289,563	12%	SPV Development & Admin	R 220,964,311	12%

This component was used to estimate the capital cost of the project and characterises the cost of a PV generation plant. The cost used in the model is as based on the case study project.

4.4.3 Operational input

The third component incorporated the assumptions about the project operations and maintenance (O&M) expenses, project duration, financing options, discount rate, inflation rate, and energy retail tariff. The data for the loan terms and related financial requirements by the banks were factored on this sheet.

Table 4.3 Model Operations Costs Inputs

Operation and Maintenance Costs

	First year cost		Escalation rate (above inflation)	
Fixed annual cost	n/a	R/yr	n/a	Model applies both inflation and escalation to the first 1 year cost to calculate out-year costs.
Fixed cost by capacity	n/a	R/kW-yr	n/a	
Variable cost by generation	n/a	R/MWh	n/a	

Subtitle

		(% of revenue)			(% of revenue)
O&M agreement	R 43,884,690	10.42%	SPV personnel	R 3,345,951	0.79%
SPV insurance	R 4,247,576	1.01%	Project management fee	R 1,422,997	0.34%
PPA charges / farm tax	R 341,879	0.08%	Other	R 1,293,634	0.31%
Regulatory inspections	R 216,818	0.05%	SED & ED costs	R 8,844,803	2.10%

Above are the input operational costs based on the available project data. The operational costs of the plant are far minimal compared to the capital outlay of developing and constructing the plant. All these costs are annual with CPI related increases.

Table 4.4 Model Financial Inputs

Analysis Parameters

Infaltion rate	5.70%		Analysis period	20	*years*
JIBAR	6.32%		Corporate income tax rate	28%	

The 20-year nominal discount rate taken to be the logarithmically extrapolated (speculation) risk-free RSA retail servings bond rates (secure.rsaretailbonds.gov.za)

Power Purchase Agreement Tariff and Escalation

Specify PPA tariff	PPA tariff	R 1,712	R / MWh	PPA tariff escalation rate	1.00%	*/ annum*

Inflation does not apply to the PPA tariff. Will have agreed upon PPA escalation.

Salvage Rate and Value

Net salvage rate	0%	of installed cost	End of analysis period value	R 0

Unsure how end of analysis period value is calculated?

Construction Term and Drawdown

Construction Period	1	Drawdown	12%

Drawdown - funds for the1 year of construction

Project Debt

Debt percent	75%	Tenor / Loan term	20	*years*
Leverage / Debt-to-Equity ratio	3	Annual interest rate	6.32%	

A combination of owner's equity and debt to finance operations. The leverage ratio (debt-to-equity ratio) assesses the project's ability to meet debt obligations. Ceteris paribus, projects with lower leverage considered safest. Debt-to-equity ratio above 2 indicates relatively risky scenario.

For protection against inflation, regulated assets like electricity can count on periodic re-adjustments or revisions to revenue figures, based mainly on the cost of maintaining the infrastructure itself and on making planned investments. For infrastructure assets once belonging to the public but transferred to private ownership, rates are often indexed for inflation and intended to compensate for maintenance costs (JP Morgan Asset Management, n.d.).

4.4.4 DCF calculations

The proposed investment valuation framework model required inputs from a fourth component, energy tariff modelling, which showed future projected paths for the energy tariff. The financial benefit of the theoretical PV generation solution was calculated based on these energy tariff models. This model calculated all the discounted cash flows, NPV, IRR, ROI and DSCR. The calculations were done on a semi-annual basis rather than on a monthly basis to minimise the size of the spreadsheet.

A full financial cash flow spreadsheet calculates the following:

- Revenues: This is calculated when the energy output is multiplied by the tariff and the inflation indexation.
- Expenses: the expenses are provided as consisting of 13% of the revenues. Additional contribution is from the economic development associated cost, which is 2.1% of the revenue dedicated towards the enterprise development and socio-economic development objectives.
- Earnings: earnings are also calculated to reflect the profit before and after tax.
- Debt calculations: These calculations are done, assuming a constant fixed rate over the life of the project. The debt service interest and principal amounts are also reflected together with the debt service cover ratio.

4.4.5 Sensitivity analysis:

This study analyses the impact of certain variations, to establish their impact on the outcomes and whether the risks are worth taking. The main inputs are tariff, discount rate, inflation rate, capex, energy output, and loan terms. The analysis is done to see how varying each of these factors affects the NPV and IRR.

4.4.6 @Risk® simulation

@Risk® is an excel add-on tool which performs Monte Carlo simulations based on set variable inputs used to evaluate financial outputs. This is performed as a way to best reflect the risk that accompanies most projects and provides the project's probability to attain set financial metrics.

4.4.7 Technology learning curve

In order to model the reduction in PV installation cost per kilowatt, the REIPPPP round one to round three capital costs, together with the related awarded project capacity per round, is used to calculate the estimated learning rate. Thereafter, this rate is also used in making assumptions regarding the reduction in installation costs for the sensitivity analysis.

The definitions of the equations and formulae were covered under the literature review in Chapter 3.

4.4.8 Real Options Analysis

The study built on the already calculated discounted cash flows mentioned previously. The ROA expanded on the NPV that had been calculated to determine the NPV_q, and then based on the project data, other variables were also determined in order to start mapping the project's real options performance, such as on the active mapping tool developed by Campher (2012). The rest of the parameters and variables have already been expounded upon in the literature review, specifically Section 3.6.1.1, which related to the mapping of an investment onto a call option. For detailed case study definitions, the risk free rate table is listed below, in Table 4.5 together with the related period for fixing the investment. Therefore, the rates used should be linked to the fixed period as the length of deferment for simplicity.

Table 4.5 South African National Treasury risk free retail bond rate, considering current (2014) interest rates

FIXED RATES		INFLATION LINKED RATES	
2 Year Fixed Rate	7.25%	3 Year Inflation	1.00%
3 Year Fixed Rate	7.75%	5 Year Inflation	1.25%
5 Year Fixed Rate	8.25%	10 Year Inflation	2.25%

Source: (South African National Treasury, 2014)

The data in Table 4.5 provides the option to link the investment to inflation plus a certain percentage for three to ten year periods. The calculations for this study model used fixed rates.

4.5 VOLATILITY

Economic analysis is concerned with the present and future consequences of investment alternatives. It is, however, not easy to perform and it is sometimes impossible to foresee and estimate the future consequences or benefits of a decision made in the present. The accuracy of such estimates is purely based on available data, and the accuracy of the model used (Adedeji, 2013).

The impact of uncertain future events can be either positive or negative. This depends on the type of risk that occurs. ISO 31000 further defines risk as "the effect of uncertainty on objectives" (AIRMIC, Alarm & IRM, 2010). This definition links the risks to the objectives of an organisation or project.

4.5.1 Management of uncertainty

In risk management, the process is first to perform risk assessment, which involves identifying all the risks by listing them on a risk register. After identifying the risks, they are analysed by indicating the potential causes of the risks, their potential consequences and their probabilities of occurrence. Thereafter, the risks are evaluated and prioritised, and the last phase is introduced, which is the mitigation strategy and plan (AIRMIC, Alarm & IRM, 2010).

Risk is a measure of the probability and consequence of an event on the defined organisational or project goals. When risk is considered, the consequence or damage associated with its occurrence must also be considered. Risk is not always easy to assess, since the probability of occurrence and the consequence of occurrence are usually not directly measurable parameters and must be estimated by statistical tools or other procedures (Kerzner, 2001).

Risk has two primary components for any given event (van Heerden, 2013):

- Probability of occurrence; and
- Impact of occurrence.

Therefore, risk can be mathematically defined as follows (Kerzner, 2001):

$$\textbf{Risk} = \textbf{f (likelihood/probability, impact/severity)} \qquad [\,8\,]$$

As either the likelihood/probability and or impact/severity increases, so also risk increases (Kerzner, 2001). The notion of risk has in concept, the fact that one does not have the capability to know all that could happen. It has to do with not knowing, what one does not know could happen, referred to as uncertainty. While the project plan is known, and certain seasonal events or requirements might be known and planned for in the project schedule, there are still unknowns because humans do not know everything that could happen in life. The unknowns that pose an unfavourable outcome are called risks, and the unknowns that present a favourable outcome are called opportunities.

According to a JP Morgan Asset Management report (JP Morgan Asset Management, n.d.), investments in infrastructure outside the countries of the Organisation for Economic Co-operation and Development (OECD) are generally considered more risky for two principal reasons:

- The legal, regulatory and political environment poses higher risks of uncertainty in dealing with authorities than in the OECD countries;
- There is a greater difficulty in forecasting demand than in OECD countries because of surging economic and population growth in the emerging economies.

Sources of risk or uncertainty in the renewable energy industry of South Africa can be identified under two categories: internal and external risk. These are further classified as shown in Figure 4..

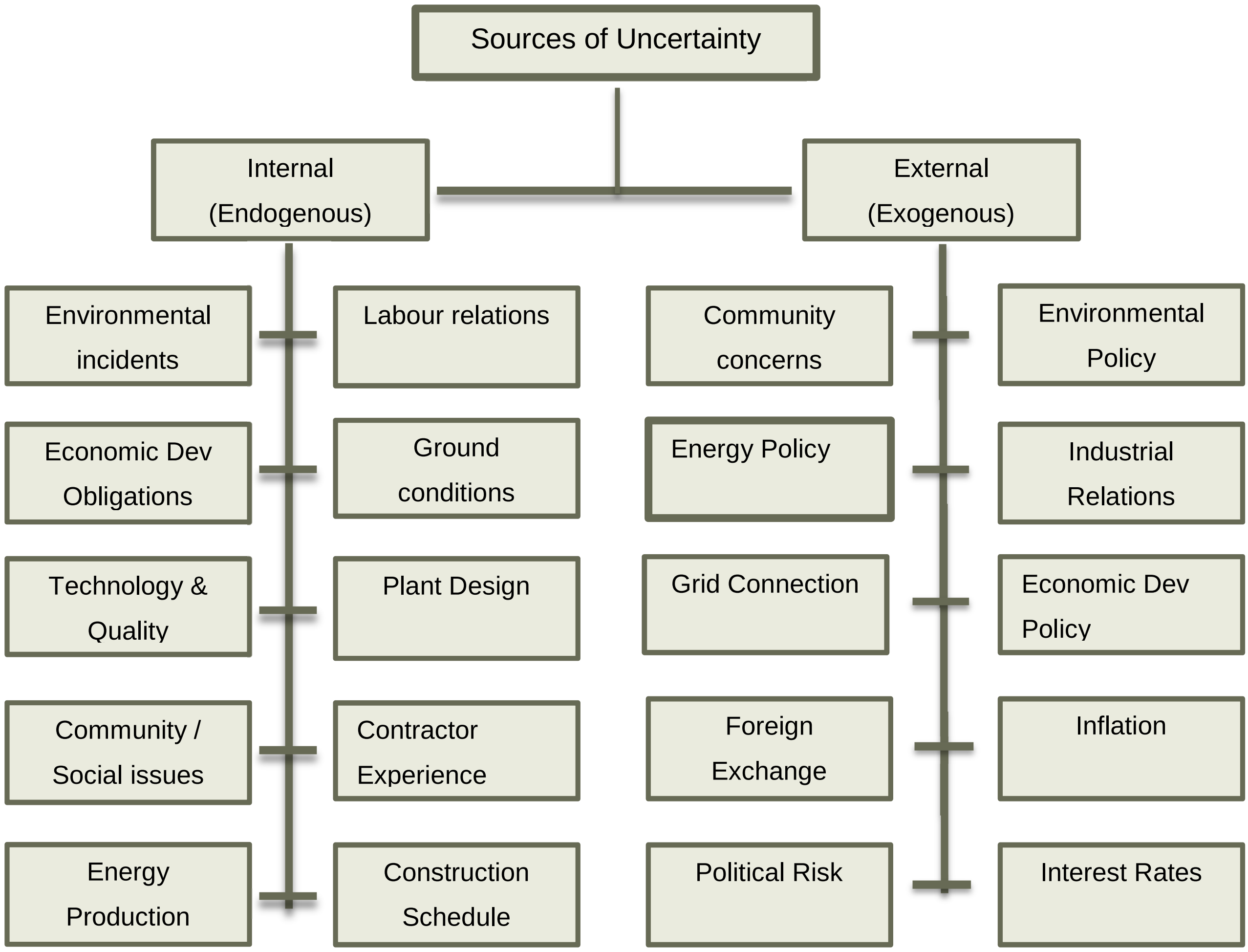

Figure 4.3 Sources of uncertainty in renewable energy projects

Source: Adapted from (Janse van Rensburg, 2010) and (Ward & Gittinger, 1997)

The risks shown in Figure 4. can lead to events that could affect returns, and should be quantified into a metric that can be used in the calculation of volatility.

Table 4.6 Risk prioritisation matrix

Consequence Type	Risk Rating				
Likelihood	**1 Insignificant**	**2 Minor**	**3 Moderate**	**4 High**	**Major**
5 Certain	11	16	20	23	25
4 Likely	7	12	17	21	24
3 Possible	4	8	13	18	22
2 Unlikely	2	5	9	14	19
1 Rare	1	3	6	10	15

Source: (South African National Treasury, 2014)

Generally accepted industry practice is to create a risk matrix in order to assess and prioritise the risks (van Heerden, 2013). Table 4.6 above shows the scores assigned to either the likelihood and the consequence or severity. In this study, a risk matrix from the case study project was used in an attempt to quantify the volatility of the project. A project register was created during the project life cycle, and was used in calculating the volatility of the project.

Campher's (2012) study put forward the notion that once a prioritisation score has been assigned to the risk matrix, the best way to link the risk to the financial impact would be through the generally accepted fact that the higher the risk the higher the option value. However, this relationship links the risk to the ultimate option value and not the quantified financial impact of the risk. In addition, the relationship between the risk event and the financial risk is an inversely proportional correlation. An example of this is that the safety risk impact is inversely proportional in relation to the financial risk of a project (or any operation). Therefore, it can be assumed that a physical risk event would be inversely proportional to the financial risk of a project (Campher, 2012).

Therefore, if a risk is assigned a score of 40%, then its financial risk, according to options theory is as follows:

$$\sigma = 100\% - 40\% = 60\% \quad [4.2]$$

In Table 4.7 below, risks were identified and evaluated in order to arrive at a risk levels in the case study project. This study takes this information further by using it to estimate the project volatility.

Table 4.7 Calculation of the volatility of the project

Project Category	Identified Risk	Consequence	Probability	Severity	Risk Level
Construction Schedule	Material damage	Delay COD	1	4	4
	Foundations piling	Delay COD	3	4	12
	Industrial protest	Delay COD	4	4	16
	Local enterprise procurement	Delay COD	3	5	15
	Safety / health incidents	Delay COD	3	4	12
Contractor Experience	Lack of experience	Delay COD			
Social Issues	Theft	Delay COD	5	3	15
Technology	Eskom testing and commissioning requirements	Delay COD	3	5	15
Environmental Issues	Permit expired	COD delay	1	3	3
	Unauthorised activity	COD delay	2	4	8
Management / Operations team	Plant performance	Plant Performance not optimal	1	4	4
	Plant failure	Plant Performance not optimal	2	4	8
DoE Policy	Change of policy		1	5	5
Average					**11.21**
Risk standard deviation σ_r					**0.45**
Financial risk standard deviation σ = (100%-σ_r)					**0.55**

The project risk level scores are averaged and then converted to standard deviation to be used in calculating the volatility of the project, as shown above.

4.6 KEY ASSUMPTIONS

The validation of the theoretical investment analysis framework was carried out by applying the framework to a valuation of the investment in a PV generation plant similar to an existing plant. The initial cost of the PV generation plant was considered to be R2.06 billion, as shown in section 4.4.2, including direct costs; indirect costs; engineering, procurement and construction (EPC); Special Purpose Vehicle (SPV) development; and administration.

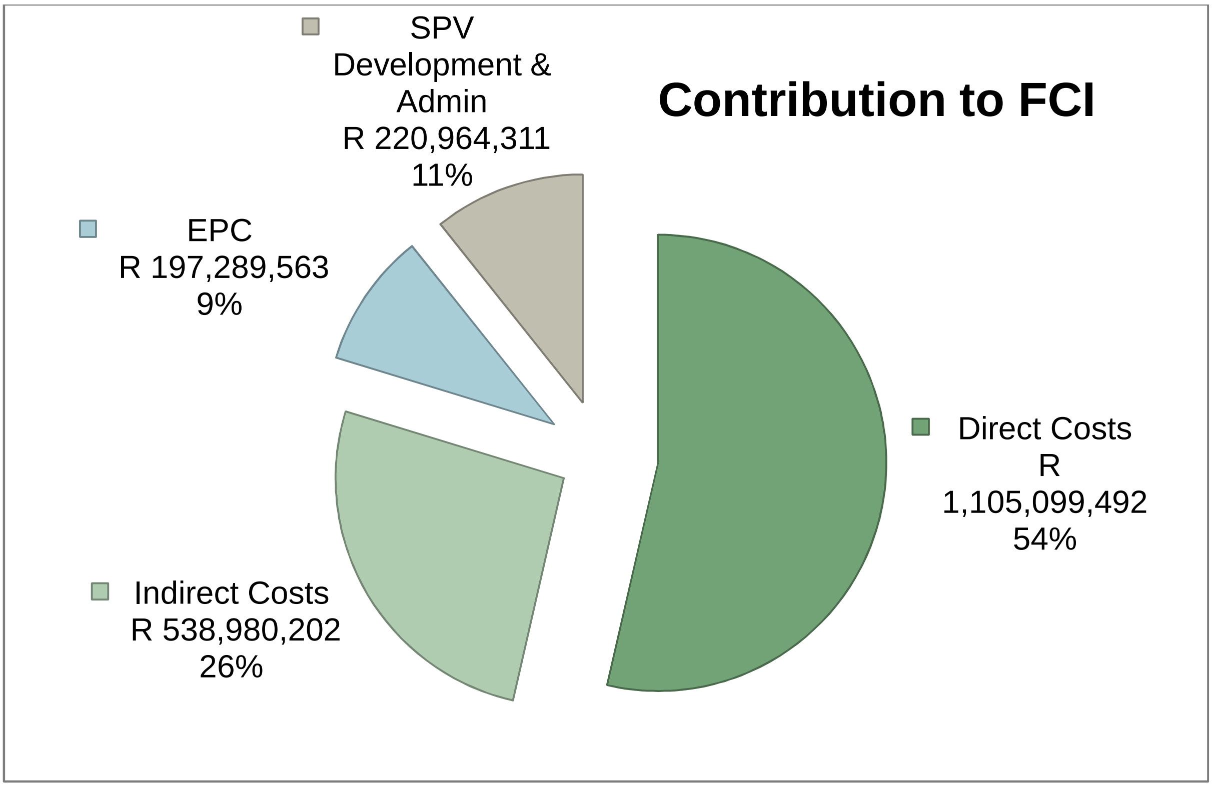

Figure 4.2 Total project cost breakdown of PV generation plant

The following assumptions were made for the project:

- Capex, TLC and plant life: It was supposed that the installed PV cost with a service life of 20 years would currently be R25,305 per kW and it was anticipated to decrease every year, due to the 'experience curve effect' (LR=20.0%). This means that when the cumulative production of the PV modules was doubled, the installed PV cost (R/kW) would be reduced by 62.2% of its 2012 cost.
- Energy output: The PV generation plant was expected to generate 225,000 MWh per year. It was expected that the performance of the installed PV panels would decrease by a magnitude of 0.51% on an annual basis due to degradation.
- PPA tariff: The initial energy tariff was assumed to be R1, 712 per MWh; however, this unit price would change over time with an expected annual inflation rate of 5.71% and a volatility of 50%, indicating a potential drop to R800 per MWh. These values were used to model the electricity tariff variations.
- Revenue: Financial benefits of the PV plant were considered in terms of energy output sold under a PPA.
- Expenses: The operational and maintenance costs of the plant were assumed to be 13% of the annual revenues.

- Financing: The total capital required for the project was assumed to be provided at a debt-to-equity ratio of 25% from equity investment and 75% from debt, at an interest rate of 9.85% per year with a loan term of 20 years.

Under these circumstances, the NPV, IRR, ROE and DSCR analysis was applied and the financial performance of the PV generation plant was evaluated under the investment analysis framework.

Uncertainty about the electricity tariff, project cost, energy output, discount rate, and inflation rate along with any variation in the debt-equity leverage and loan term were evaluated using a sensitivity analysis methodology.

4.7 SUMMARY

This summarizes the discussion on the model development and structure of the study. The proposed investment analysis framework consisted of five functional components. Data from an existing project was used to provide information on the viability of a theoretical project that would be similar in nature, whereby the NPV, IRR, ROE, DSCR, and LCOE valuation metrics were used.

In terms of the methodology, the data used and capital cost values for the analysis were from a case study on the Solar Facility in the Northern Cape. For the real options analysis, the study built on the already calculated discounted cash flows, and used fixed rates, based on the South African National Treasury risk free retail bond rate.

In order to consider the volatility of the theoretical PV project in this study, a risk matrix from the case study project was used in an attempt to quantify the volatility of the project. Finally, the assumptions of the study supposed that the initial cost would be R2.06 billion; the installed PV cost would decrease every year, due to the ‘experience curve effect’; the performance of the installed PV panels would decrease by 0.51% on an annual basis due to degradation; and the tariff unit price would drop over time to R800 per MWh. Furthermore, the energy output would be sold through a 20 year PPA; operational and maintenance costs would be 13% of annual revenues; and the ratio of the capital invested for the project would be 25% equity and 75% debt, at 12.4% interest per year over 20 years.

CHAPTER FIVE: MODEL RESULTS ANALYSIS

5.1 INTRODUCTION

This chapter covers the results analysis of the dissertation. It begins with a presentation of the results of the cash flow evaluation, followed by the results on the sensitivity analysis. Each of the results on the aspects of net present value (NPV), internal rate of return (IRR), and return on investment (ROI), return on equity (ROE), and debt service cover ratio (DSCR) are then each presented in turn. The @Risk® excel add-on package is used to analyse the probabilities of realizing good returns and ratios. The chapter continues with a depiction of the technology learning curve (TLC) analysis, and the real options analysis (ROA). The results of the real options analysis are also discussed. Finally, a validation is presented of the investment analysis frameworks.

5.2 DISCOUNTED CASH FLOW VALUATION

The attached model yields the results as per the technical input, project cost, input data and assumptions that were made, as stated in Chapter 4. The assumptions together with the project data provided the base case study that was analysed in relation to what was currently known.

Table 5.1 Output metrics for PV generator plant investment valuation

Metrics and Timeline					
	Timeline			Metrics	
Current Year	2014		NPV	5420	million R
Desired Operations Start Year	2015		IRR	12.54%	
Number of Years of Operations	20		ROI	13.14%	
Loan Term	20		ROE	52.56%	
LCOE	0.963	ZAR R / kWh	Average EBITDA	581.97	million R
			Average CFADS	296.77	million R
			Minimum DSCR	3.24	

The results shown in Table 5.1 yielded all that face value analysis would be expected to provide. A good positive NPV was observed, along with a supporting IRR and an excellent ROE. For the funders of such a project, the debt service ratio would be even better at significantly above one. The above results should give the project investors the ‘green light’ to proceed with their investment.

5.3 SENSITIVITY ANALYSIS

The discounted cash flow analysis ensures that projected expenses and revenues from future time periods are assessed using their present values. Discounted cash flow (DCF) calculations incorporates the ‘opportunity cost’ of investing in a PV generation project using the inflation and discounted interest rates that counteract the risk of monetary depreciation over a 20-year power purchase agreement period.

As discussed in the literature review, discounted cash flow does not consider other critical project risks. Sensitivity analysis of the base case is performed to add value to the deterministic DCF valuation. This tests the sensitivity of the expected profitability to any assumptions that are made about the key input factors.

The seven factors that were found to have the largest impact on profitability of a PV generation project were utilised as input parameters to be varied in the sensitivity analysis of this study. These were:

- Fixed Capital Investment (FCI) or Project Capital Expenditure (Capex);
- PPA tariff;
- Discount rate;
- Inflation rate;
- PV Plant Energy Output;
- Debt-to-Equity leverage ratio; and
- Loan term.

The key profitability and valuation indicators whose sensitivity to the input parameters monitored were:

- NPV;
- IRR;
- ROI;
- ROE;
- DSCR; and
- LCOE.

The results of this sensitivity analysis are presented and discussed in the following subsections.

5.3.1 Net present value (NPV)

The sensitivity tests for the NPV are shown in Figure 5.1. In the worst case, the base case NPV of ZAR 5.43 billion was found to decrease to ZAR 0.82 billion due to a corresponding 50% decrease in tariffs (*ceteris paribus*). It must be highlighted that this tariff was dropped to this level in order to evaluate the viability of this REIPPPP window 2 project at window 3 prices. This value was still above zero and according to the NPV investment criteria, the PV project would still be viable.

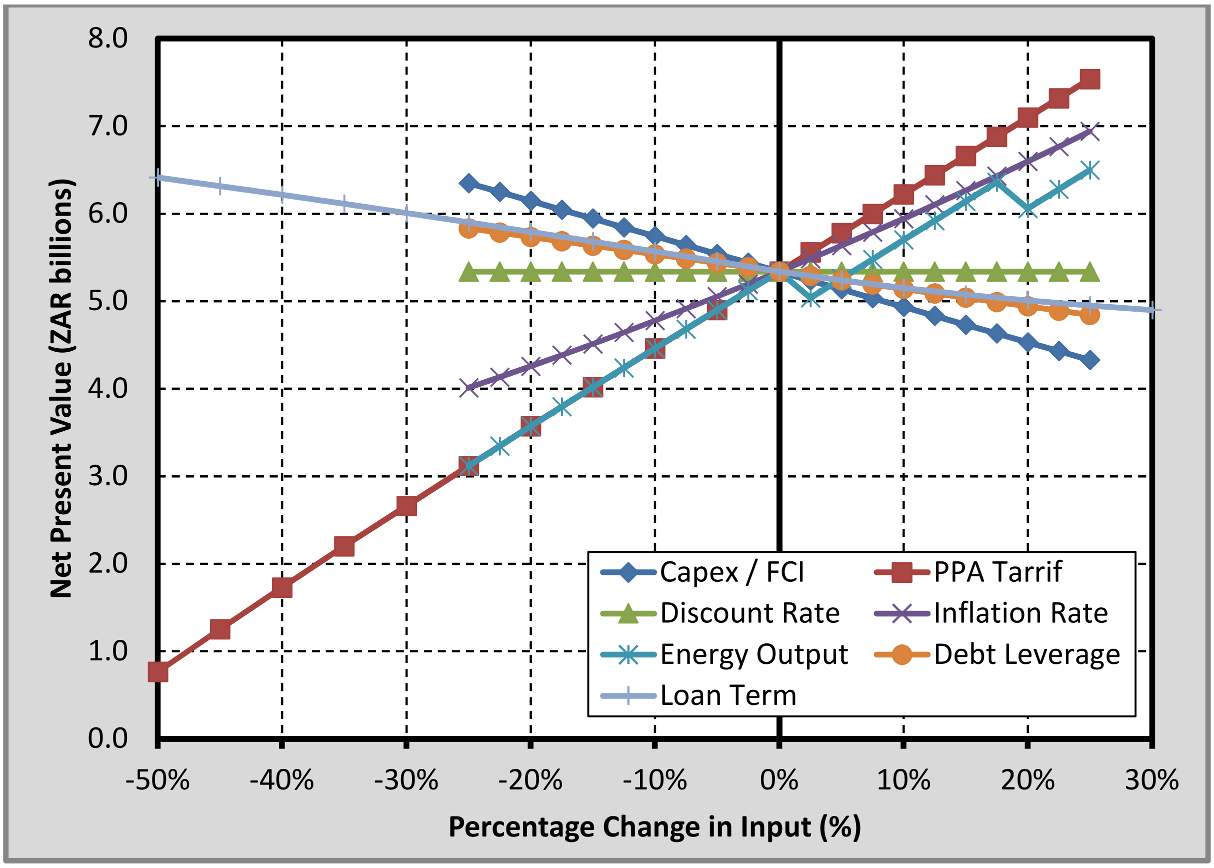

Figure 5.1 Sensitivity of NPV to inputs

In the best-case scenario, the base case NPV of ZAR 5.4 billion was found to increase to ZAR 7.65 billion due to a corresponding 25% increase in tariffs (*ceteris paribus*). In conclusion, this value was still above zero and according to the NPV investment criteria, the PV project would still have been viable. However, in comparing the best and worst-case scenarios for the project, the highest NPV would be chosen.

In Figure 5.1, the PV project NPV was shown to be most sensitive to energy output and the inflation rate, followed by Capex/FCI and the loan term. NPV was less sensitive to percentage-debt or equity leverage and was insensitive to the discount rate. The reason for this is that the inflation was incorporated in the revenue calculation and it was not necessary to discount the free cash flows again at the end. It must be noted that the discontinuity (steps) in the energy output sensitivity were due to the different Capex costs that are associated with solar energy, as the output moves out of the operating range of the specific technology (tracking system). For example, a 0% change in input (Figure 5.1) signified the maximum energy output capability of the fixed-axis PV system that was modelled, such that a further increase in energy output would have required a change in technology to the single axis modules, which would have been capable of this new energy output. The single-axis module technology would come with a corresponding change in Capex (*ceteris paribus*).

5.3.2 Internal rate of return (IRR)

While the NPV showed the PV project to be viable at all considered sensitivity scenarios, more insight into the value of the PV project was derived from the IRR sensitivity (see Figure 5.2).

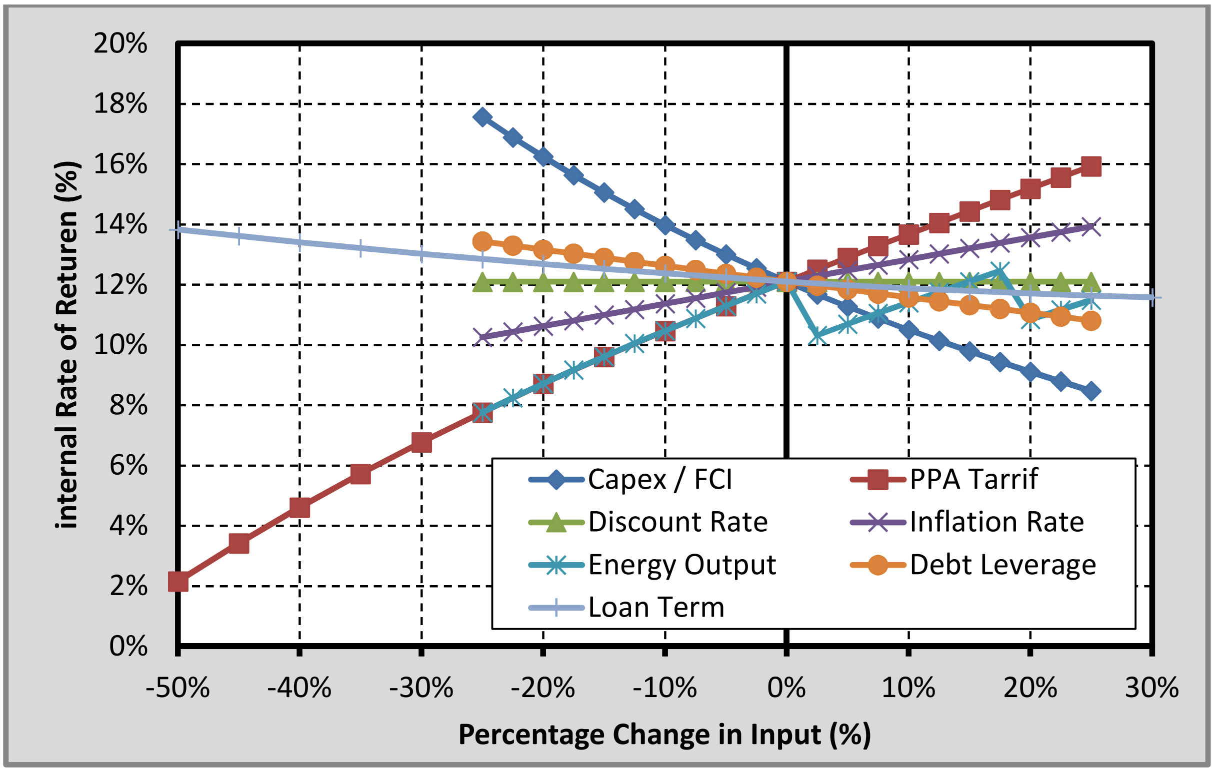

Figure 5.2 Sensitivity of IRR to inputs

In the worst case scenario, the base case IRR of 12.5% was found to decrease to 2% due to a corresponding 50% decrease in tariffs (*ceteris paribus*), such that the IRR was now lower than the risk-free 'two-year South African government retail savings bonds (7.25%)'. This indicated that the project ceased to be viable at this stage, once levelled against the two-year risk-free government bond.

In the best case scenario, the base case IRR of 12.3% was found to increase to 17.8% due to a corresponding 25% decrease in Capex or FCI. At this new value, the project would have remained viable.

The IRR was seen to be most sensitive to the tariffs, Capex, and energy output, followed by the inflation rate as shown by Figure 5.2. However, the IRR was less sensitive to the debt leverage and loan term; and was also unaffected by the discount rate, as found with the NPV. The energy input-output representing the different technologies (fixed, single and multi-axis) at each step was seen to maintain the base case IRR somewhat, while all of the other variables remained the same.

5.4 @RISK® ANALYSIS

5.4.1 Inputs

@Risk® requires certain inputs that would be varied based on a specific frequency distribution to be used for the calculation of required outputs. @Risk® would then perform random simulations given the inputs to calculate outputs and their probability of occurrence. A number of key inputs were used to model variation and impact of such variation to the profitability of the project. The mean value and standard deviation has to be defined for @Risk® to perform the calculations. For our model, Table 5.2 provides the input parameters.

Table 5.2 Output metrics for PV generator plant investment valuation

Varried Input Parameters

	Distribution	Mean Value	Standard Deviation	COV
Energy yield	Normal	225.252	13.7404	0.06100
Interest rate	Normal	0.09840	0.00500	0.05081
CPI Inflation	Normal	0.05700	0.03320	0.58237

These inputs typically represent aspects of the project that remain uncertain over the life of the project which can affect the profitability significantly.

5.4.2 Outputs

The outputs of interest are the key financial parameters such as NPV, IRR, EBITDA and DSCR which is what private investors would be interested in evaluating on the project on.

5.4.2.1 Net Present Value (NPV)

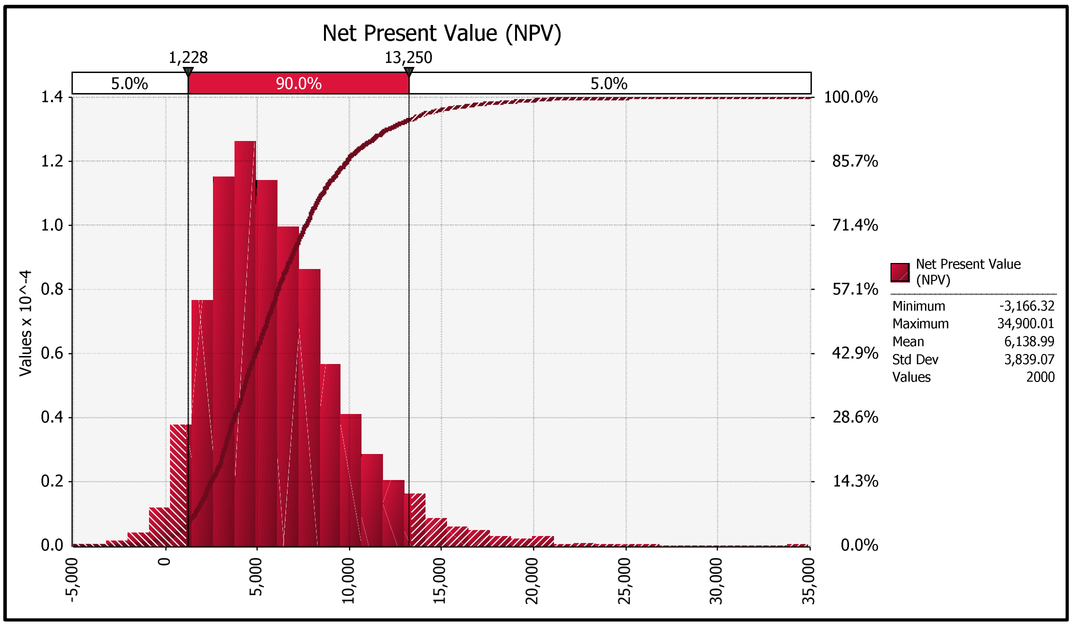

Figure 5.3 NPV at risk Probability Analysis

Based on the above it is clear that the probability of achieving an NPV ranging between R1, 228 billion and R13, 250 billion is about 90%. The range of values lying within the 90% probability of occurrence will change due to the random @Risk® simulations. This analysis provides very good insight into the potential of the project whilst factoring the inherent risks.

5.4.2.2 Internal rate of return (IRR)

@Risk® simulation indicates very high profitability for an IRR between 3.9% and 34%. This IRR range has a probability of 90% as per Figure 5.4. An investor could streamline the analysis by setting a target IRR required and the probability thereof can be determined. Based on such probability, the investor can decide to invest or not to invest.

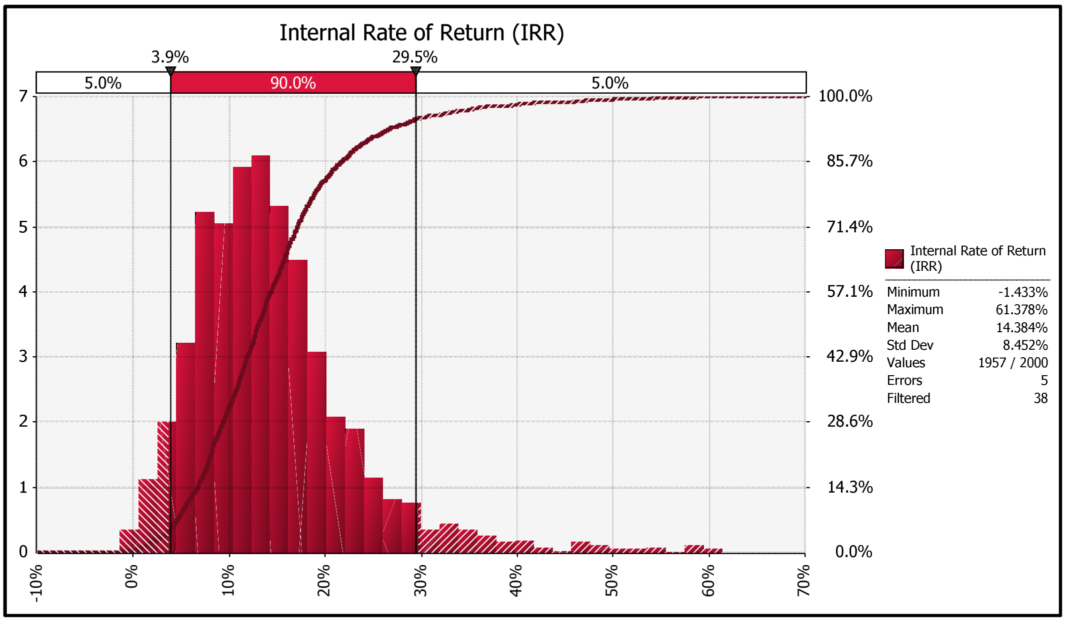

Figure 5.4 IRR @Risk® **Probability Analysis**

5.4.2.3 Return on Investment (ROI)

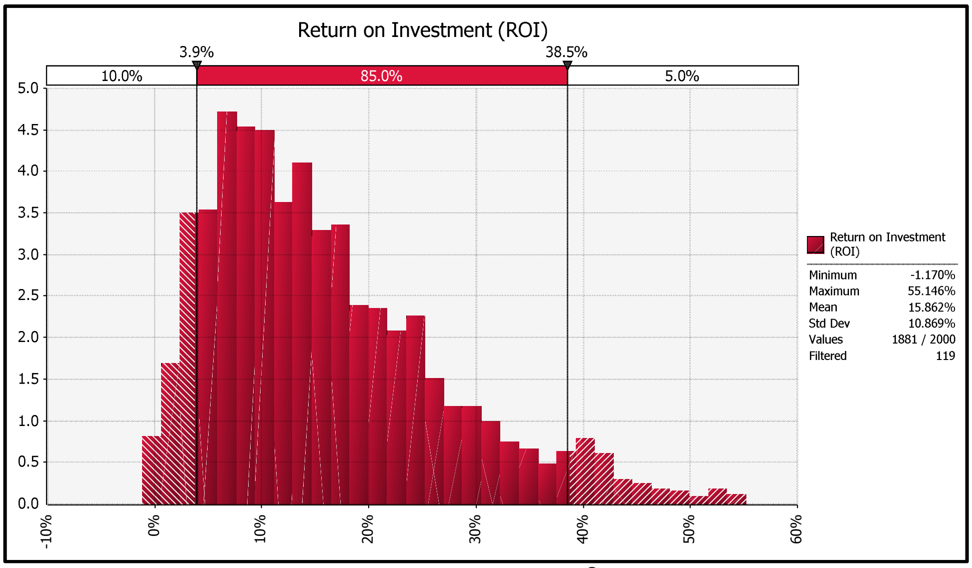

Figure 5.5 ROI @Risk® **Probability Analysis**

This specific simulation provides an 85% probability of realising an ROI between 3.9% and 38.5%. An investor could set a required minimum target ROI as base line to compare to at risk analysis above. Then based on the probability thereof conclude whether it's a worthwhile investment or not.

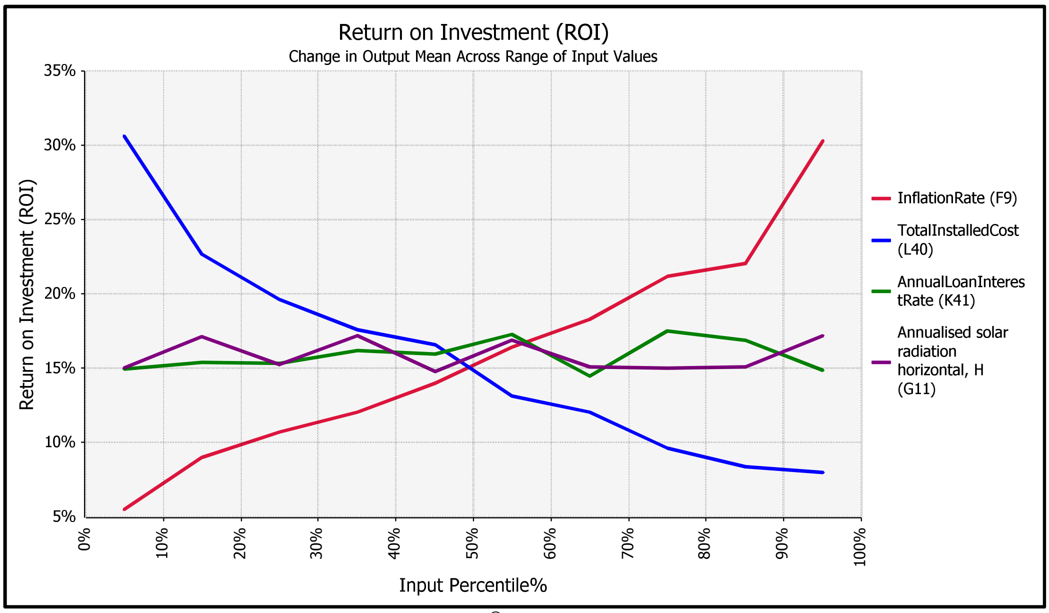

Figure 5.7 ROI @Risk®**Sensitivity Analysis**

The sensitivity analysis also confirms the ranking analysis from @Risk®. To realise improvement in ROI, either increase inflation so that the revenues could increase or decrease the capital cost. What is interesting is the fact that, increase in annual solar irradiation does not lead to significant improvement in ROI.

5.4.2.4 Debt service cover ratio (DSCR)

In order to determine the change in debt servicing ability with varying input conditions, the minimum DSCR simulation, and results of this are presented in **Error! Reference source not found.**

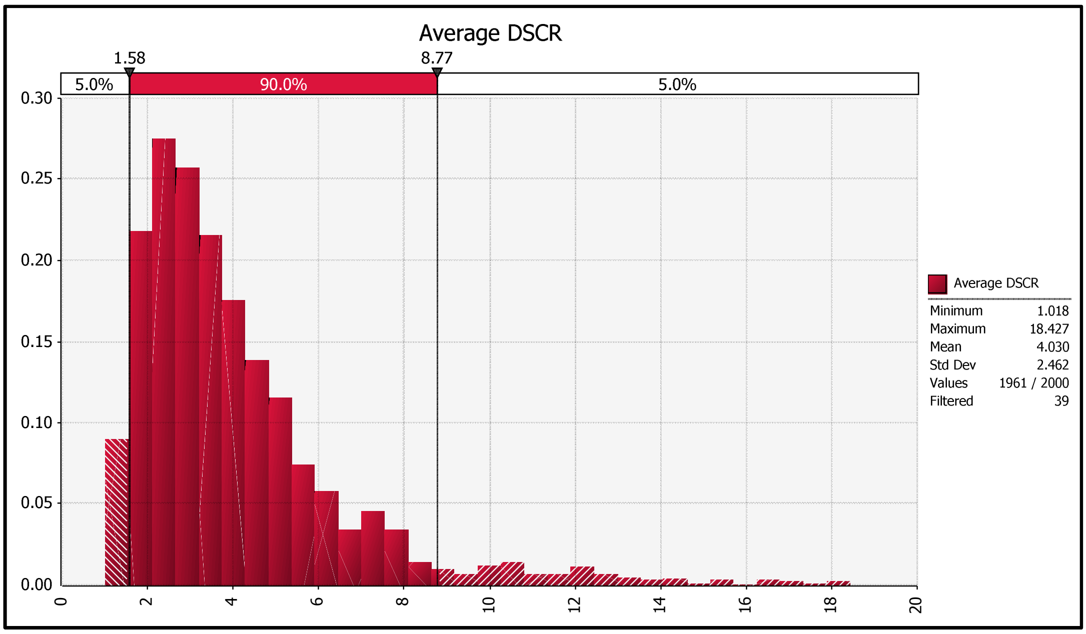

Figure 5.8 Average DSCR @Risk® **Probability Analysis**

The average DSCR was found to be mostly impacted by the capital costs and inflation rate above the other two main variable inputs to the simulation. The explanation thereof can be that this capital expenditure is the fundamental component to the debt principal and interest payable, therefore significant variation is compounded over 20 years.

In this model inflation mainly affects the tariff directly, thereby the increase in the potential to payback debt. The model did not build in the impact of inflation on interest rates which could be an area of improvement.

The average DSCR sensitivity analysis in Figure 5.10 below, further indicates how the project's capacity to service its debt can be enhanced or affected by change in these four variable inputs. On the whole the average DSCR is well above 1 indicating that the project can service its debt fairly well.

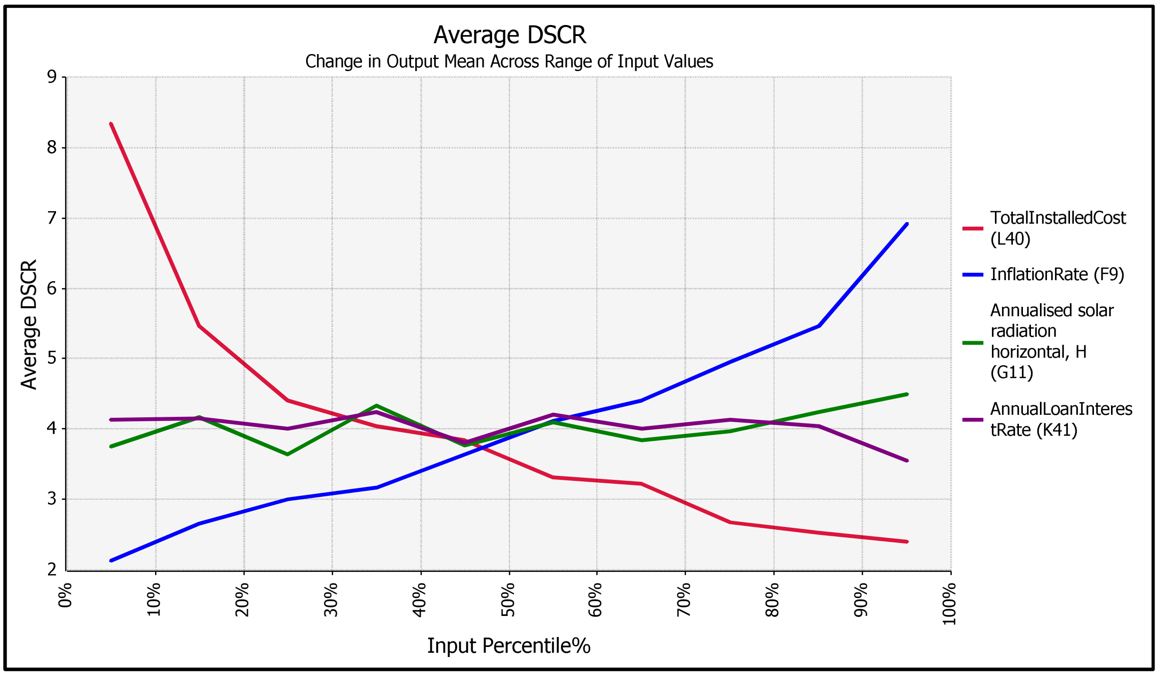

Figure 5.10 Average DSCR @Risk® Sensitivity Analysis

5.5 TECHNOLOGY LEARNING CURVE (TLC)

The concept of technology learning curve (TLC) describes how the marginal PV installed costs would decrease in relation to the cumulative installed production capacity over time. This correlation is generally characterised by empirically determined power laws such as those presented by Ayompe et al. (2010) and Kobos et al. (2006), in equations [5.1] and [5.2] respectively (Ayompe, et al., 2010), (Kobos, et al., 2006):

$$\boldsymbol{C(x_t) = C(x_0)\left(\frac{x_t}{x_0}\right)^b} \quad \textbf{[9]}$$

Where: x_t is the cumulative installed PV module capacity at year *t*; *b* is the learning parameter or learning elasticity parameter; *C* (x_t) PV module cost per KWp at year *t*; $C(x_0)$ the PV module cost at an arbitrary starting year; x_0 the cumulative installed PV module capacity at an arbitrary starting point.

$$\boldsymbol{Cost_{ti}(CC_i) = Y_i CC_{ti}^{-ai}} \quad \textbf{[5.2]}$$

Where: CC_i = Cumulative Capacity of Technology I; $Cost_{ti}$ = Cost per unit; Y_i = capital cost at initial levels of installed energy capacity and a_i is an estimate for technology specific elasticity.

Herein, the outcome of creating a TLC for the proposed PV generation plant in this research was detailed. The TLC was obtained by regression of the actual installation data that was reported (Eberhard, et al., 2014), in order to find the learning elasticity parameters, a_i for the respective correlations or models applied.

The progress ratio (PR) could thus be determined from the learning elasticity parameters and equation [5.3] below, while the learning rate (LR) was obtained from equation [5.4].

$$\boldsymbol{PR_i = 2^{-ai}} \quad \textbf{[5.3]}$$

$$\boldsymbol{LR_i = 1 - PR_i} \quad \textbf{[10]}$$

In equation [5.3], $-ai$, from the Ayompe et al. (2010) model, is replaced by b, from the Kobos et al (2006) model. The learning rate is the relative cost reduction in percentage after doubling the cumulative production as defined in equation [5.4].

The results of the regression are reported in Table 5.3.

Table 5.3 Early stage South African Learning Rate and Progress Ratio from regression of historical bidding window data

Model:	**Ayompe et al. (2010) Model**	**Kobos et al. (2006) Model**
Learning Rate, LR	35.5 %	41.0 %
Progress Ratio, PR	64.5 %	59.0 %
Learning elasticity parameters	b = -0.6320	$-ai$ = 0.761

The initial (2012 to 2014) bidding window data was inserted into each of the two models considered by Ayompe et al. (2010) and Kobos et al. (2006). These models were linearised by taking logarithms on each side of equations [5.1] and [5.2] and linear least squares fit was applied to determine the learning elasticity parameter for each model.

After fitting a linear model using least squares regression (LSR) analysis, it was essential to determine how well each model fitted the data, thus the R-squared (R^2) statistic was used in conjunction with the model's residual plots.

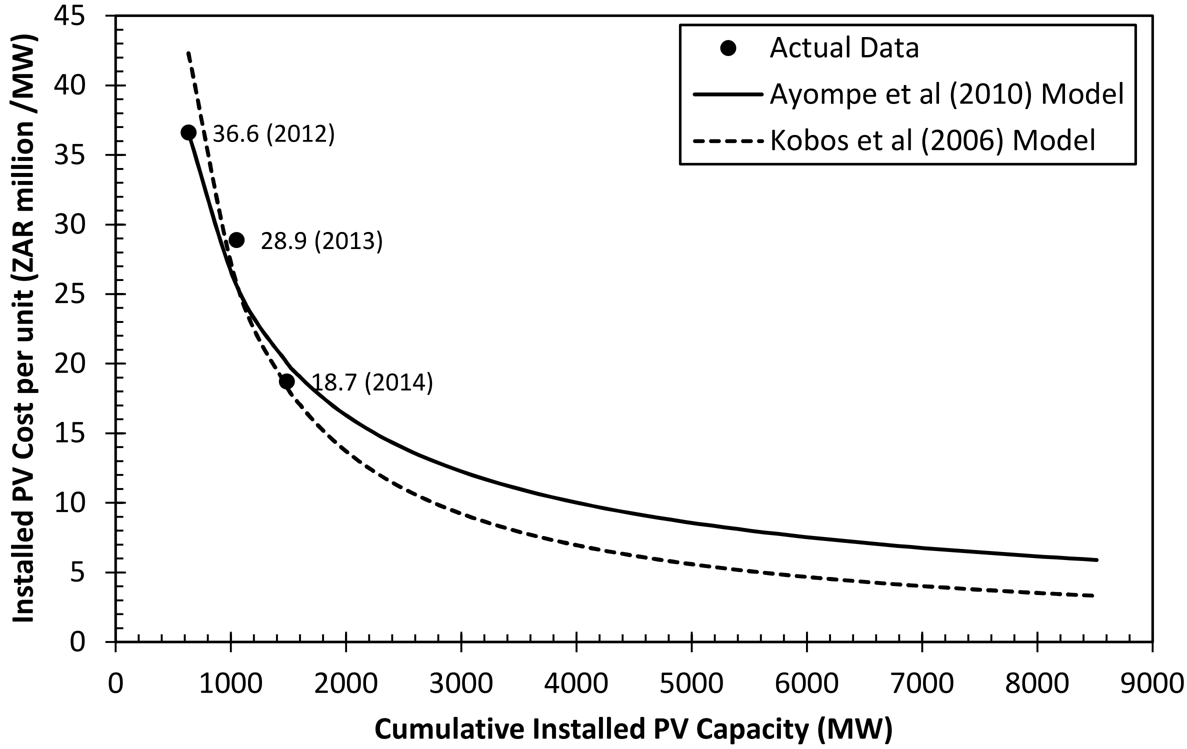

Figure 5.11 The Technology Learning Curve (TLC) as estimated by the Ayompe et al. (2010) regression model of actual reported data

Due to the few data points available for regression, patterns in the residual plots (rather than the randomness necessary to validate the fit) were more difficult to identify — if indeed they were present.

At this early stage of PV technology adoption in South Africa, the more generalised (non-PV specific) Ayompe et al. (2006) model was found to produce a closer fit (R-square = 0.923) than the PV technology specialised Kobos et al. (2006) model (R-squared = 0.876).

Figure 5.11 demonstrates that as the cumulative installed PV capacity was doubled, so the installed PV cost per unit would decrease. This decrease in installed PV costs is suggested to be as a result of factors, including the "process innovation, learning-by-doing, economies of scale, R&D expenditures, product innovation/redesign, input price declines, etc." noted by Ashuri et al. (2011).

Although modelling generally requires a large data set for definitive or more conclusive results, such data was not available for the South African case study. Thus, the few data points that were available were used tentatively to derive all the early stage indicators of the PV technology leaning rate in South Africa.

In addition, it must be noted that although this research forecasted that the learning elasticity parameters, $-ai$ and b, would be constant, determining whether these parameters would actually remain constant or change over time was found to be difficult. Current research is focused on developments that would incorporate these uncertainties (Ashuri, et al., 2011).

In such cases, and in the case of two differing models for the change in installed PV over time, “the best engineering judgment can be used to characterise the cost trend of [the] emerging technology” (Ashuri, et al., 2011).

5.6 REAL OPTIONS ANALYSIS

This section presents the results of valuing the flexibility of investment decisions in large-scale PV infrastructure projects using the real options analysis (ROA) approach.

Changing market conditions over time could give rise to advancements that would result in improved technologies being adopted for PV plants in such a way that the project’s profitability would be affected to the point of changing the investment decision. Providing a right without an obligation to delay, abandon or invest in a PV generation project, depending on the actual market realisations, would provide potential investors with a real option flexibility that could increase the value of the entire project (Koo, 2013). Market realisations here, refers to conditions such as “the technology becomes available at a lower price, or stricter environmental regulations are put in place”, making renewable energy installations a necessity (Koo, 2013).

The real options of the PV generation project were valued by drawing parallels with the European-type financial options, which could only be exercised on the date of expiration of these options. The Black-Scholes option pricing model was used as the typically model for pricing European-type options. Some details on the models are provided in chapter three and four of this report.

5.6.1 Investment Valuation Modelling based on real options analysis

This research focused on the expiration date of the real option, the potential change in tariffs, the TLC modelled change in exercise prices and the analysis to determine whether the different PV project scenarios considered should be delayed, abandoned or implemented when uncertainties in the projected revenues and capital expenses had changed (increased or decreased). The focus of the analysis in this section was to use real options to allow for decision-making flexibility, based on the changing market conditions in the years leading up to the expiration date of the real option.

The total number of real options scenarios determined was 45. A selection of representative scenarios are given in Table 5.4 and presented graphically in Figure 5.12.

Table 5.4 Selection of Real Options Scenarios

	Formulas used for Cv and NPVq analysis					
	NPVq	**Cv**	**Tariff** (R/kWh)	**σ**	**t** (years)	**rf** (%)
Basecase	3.172801	0.955363	1,712	0.5516	3	7.75%
Case 1	3.172801	1.388375	1,712	0.8016	3	7.75%
Case 2	3.769906	1.233368	1,712	0.5516	5	8.25%
Case 3	0.694795	0.955363	880	0.5516	3	7.75%
Case 4	0.694795	1.388375	880	0.8016	3	7.75%
Case 5	0.825552	1.233368	880	0.5516	5	8.25%

Results of the ROA were found to be somewhat sensitive to some of the parameters. In some cases, this resulted in a change to the investment decision. The ROA metrics, C_v and NPV_q were found to be sensitive to the tariff, exercise time and uncertainty or risk. The $NPVq$ was primarily found to be sensitive to tariff, exercise time and its corresponding risk-free rate. In addition to exercise time, the C_v was also found to be sensitive to changes in uncertainty, σ.

Figure 5.12 shows that higher rewards (a higher NPV_q) would have been obtained at higher risks, which is consistent with the 'higher risk, higher potential reward, higher option value' trends observed for financial option valuation.

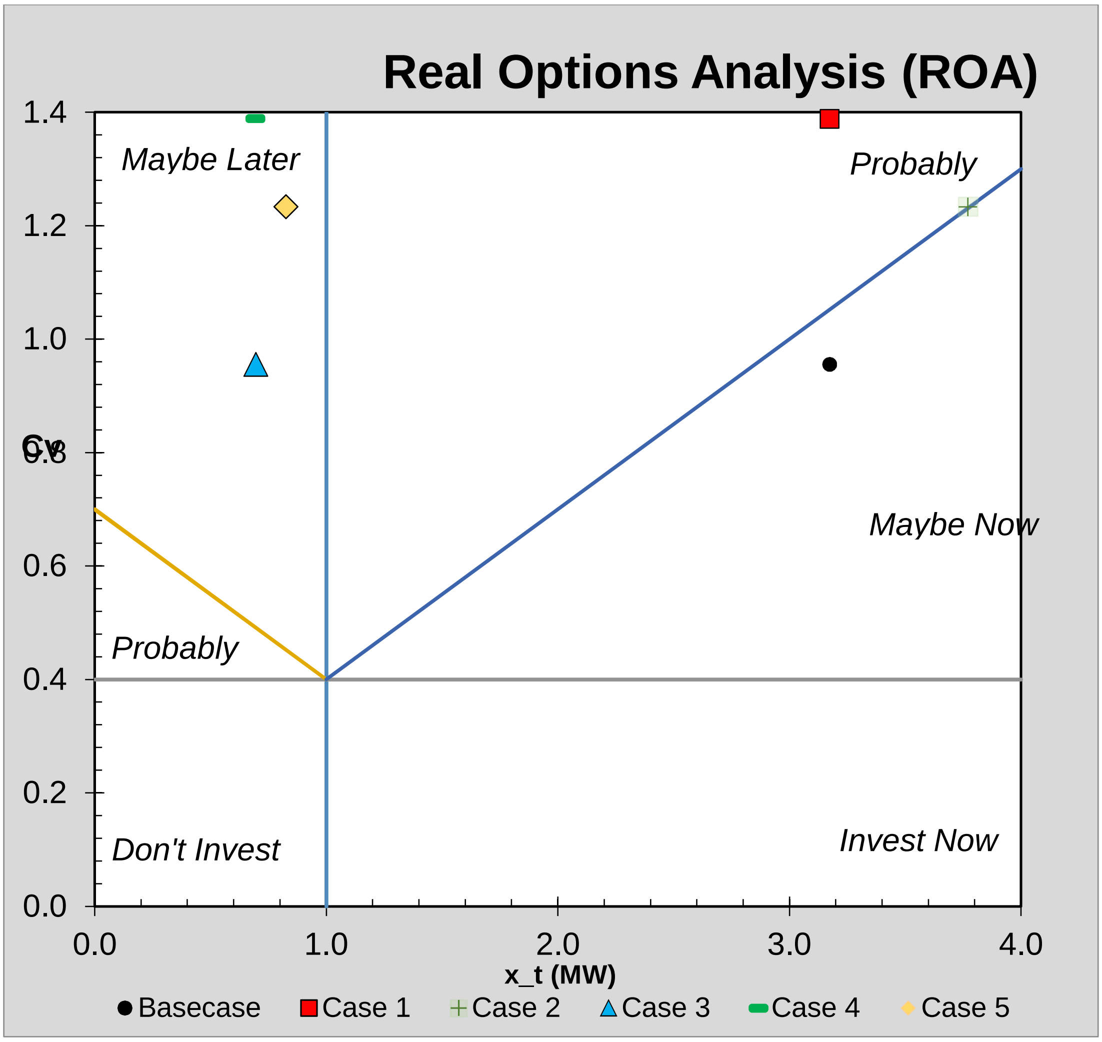

Figure 5.12 Real Options Analysis (ROA) Scenarios

In Figure 5.12 the base case scenario was in the 'maybe now' section, indicating that the investment was a potentially viable one. A change (case 2) in exercise time from the original three years (from valuation point) to the five year plan had the effect of increasing both the C_v (from 0.955 to 1.233) and the $NPVq$ (from 3.172 to 3.769), however, the investment decision did not change based on the criteria for ROA.

The next scenario of note was the change in tariffs from the base case. In scenario case 3, the tariff was increased from the base case (ZAR 1 712 per MW) to ZAR 880 MW, as indicated by Table 5.3. While the risk, C_v, remained the same (0.9553), the NPVq significantly decreased from 3.172 to 0.6947, thereby forcing the investment decision into the 'maybe later' section, suggesting that the investment should rather be delayed.

5.7 VALIDATION OF INVESTMENT ANALYSIS FRAMEWORK

The validation of these calculations could not be validated with the project due to the project financial data and information being confidential. The deterministic model provided financial parameters that seem reasonable and perhaps more conservative. This could be attributed to the fact that the model used an average interest rate over a 20 year period as compared to varying interest rates over that same period as would be the case in real life.

The @Risk® simulation excellently complement the deterministic model through incorporation of probabilistic variation in key input factors. The gap in @Risk® simulation is that, it only factors the risk within the direct inputs to the project costs, other project risk not factored in the costs are not necessarily included. This is where ROA provides an excellent opportunity and advantage in this analysis framework.

The ROA on the base case scenario provided a potential support to invest, however it also indicated some high volatility associated with the project risk. Due to the fact that the volatility in this case could have changed over time, it was still a worthwhile investment and yielded a very high call option value.

The results of the ROA seemed to support the pure DCF results for scenario S16 in the sense that at this tariff level (*ceteris paribus*), the returns would have been much lower and it may instead have made sense to defer the investment to a later date.

5.8 SUMMARY

The analysis provides insight into the need for more dynamic study when performing project financial evaluation. In this study, at risk performed some probabilistic analysis by incorporating random changes to key inputs in the model.

The deterministic model provided a positive NPV, along with a supporting IRR and an excellent ROE, indicating that project investors should perceive a ‘green light’ to proceed with their investment of such a project. @Risk® took this further by providing insight into probability of being profitable and how the inputs could be varied to increase profitability.

The average DSCR over the project life was determined to be at its minimum at a value of 1.92 and averaging at 3.24, which are well above required ratio of 1:00. This implies that the project income would be more than enough to service its debt and operational expenses.

It was demonstrated that as the cumulative installed PV capacity was doubled, so the installed PV cost per unit would decreased confirming the view that the more a technology is accepted and adopted within an economy, the more affordable such technology will be.

The ROA scenario analysis results were found to be somewhat sensitive to some of the parameters; in some cases, resulting in a change to the investment decision. The base case scenario was found to be in the 'maybe now' section, indicating that the investment was a potentially viable one.

The ROA on the base case scenario provided a potential support to invest, however it also indicated some high volatility associated with the project risk. Due to the fact that the volatility in this case could have changed over time, it was still a worthwhile investment and yielded a very high call option value. The results of the ROA thus supported the pure DCF results in the sense that the returns may have been much lower, and it may instead have made sense to defer the investment to a later date.

The analysis in this chapter confirms the importance of thorough risk analysis during the feasibility phase of projects. It can therefore be concluded @Risk® considers the project risks by randomly varying certain model input parameters over a set number of iterations. This simulation enhances the model analysis because it provides a probability range of realising some profitability or some other key output parameter metric. Despite this, ROA is still required because of the volatility factor which incorporates risks which may not be financial in nature, i.e. technology failure, contractor issues, engineering errors, schedule delay and labour issues.

CHAPTER SIX: CONCLUSION

6.1 INTRODUCTION

This final chapter of the dissertation presents the conclusions of the study. It begins with a deliberation of the findings from the previous chapter, and what the implications of the results are.

The chapter concludes with the recommendations of the study, with an indication of future possible research that may be conducted to boost, or further support the findings of this study. The chapter continues, next, with the conclusions of the study.

6.2 CONCLUSIONS OF THE STUDY

The study's goal was to develop a techno-economic model to evaluate the viability of renewable energy projects in the South African REIPPPP. A literature survey was carried out on PV technologies, which provided some insight into the technical aspects of the technology. A background to the REIPPPP was also presented in chapter two.

Through the literature review, the critical factors that must be considered in large scale projects were observed to include the technology type and efficiency of the PV modules, which significantly impact the output of a plant as well as its capital costs. Other observations included whether a fixed or motion tracking system should be implemented, which can lead to significant revenue increases; the project site location, which is important since the different regions in South Africa have different climatic conditions and seasons; and the overall plant efficiency, which can lead to better output and therefore higher revenues. These items were noted to be the primary factors that dictate the financial outputs of a plant. Once these have been carefully considered, the secondary factors of importance are the tariffs and the financial terms and conditions of the project, as dictated or agreed upon with the capital lenders.

The most critical financial factor affecting the NPV is the inflation increase since it affects the tariff thereby pushing the revenues higher, in reality this would not be the case due to impact of inflation on interest rates and everything else. Secondly, the capital cost affects the project NPV due to debt costs. The next important factor IRR is also affected by these two factors above any other, thereafter, interest rate hikes starts impacting the IRR.

For the lenders, interests earned on their loans should increase, which affects the debt service cover ratio as well as the loan life cover ratio. However, the investors can often negotiate with the lenders to structure their loan servicing agreements such that the interest rates are serviced, while the principal amount is paid off later. However, in the case study that was presented for this study, both the DSCR and LLCR indicated that sufficient revenues would be available to service the debt obligations. It was therefore concluded that the financial performance of a project would be dependent on the technical performance, geographic location and design specifications of any prospective plant.

The third chapter provided an overview into the background of the structure of project financing, as well as an evaluation framework that included both the traditional capital budgeting as well the real options analysis platforms. The literature that was discussed supported the notion that, while discounted cash flow evaluation techniques provide a good indication of the potential of returns, the calculations are static and do not factor the dynamic nature of infrastructure project risks in projects. Hence, there is a need to consider the effect of risks on project returns and for that real options analysis (ROA) techniques were used.

Chapter Four discussed how the model was developed, and considered all the technical plant energy outputs that would provide an input to the financial calculations. The capital cost as well as the operational financial data put into the calculations. The main calculation spreadsheet provided all the expected cash flows, returns on investment, and internal rates of return on the projects.

As part of the main calculations, sensitivity analysis and @Risk® analysis was done to evaluate potential variation in some of the inputs and to evaluate their impact on the key outputs. @Risk® provides a dynamic simulation, however, it still mainly only considers risks of price movement within the financial input parameters. Other risks that are endogenic to the project, as listed in chapter 4, are not necessarily factored into this because of the nature of the risks not being financial, but mainly related to events which could happen during construction.

The final evaluation was done using the ROA framework developed by Luehrman (1998) and which was further purported by other authors for consideration in physical assets financial evaluations. This dynamic study in the project financial evaluation in the form of the ROA of the case study — considered under chapter five — provided volatility and NPV ratios that yielded a ‘maybe invest now’ decision. This could be interpreted as good, since the result supports the decision to invest in the project. Real options structure and formulation provides for endogenous non-financial in nature, risks to be assessed and factored into the financial calculation. It therefore closes the gap not addressed by other methods of financial evaluation including @Risk®. It also supports the hypothesis from the first chapter that the two techniques should be combined in all financial analysis of renewable energy utility scale PV projects.

The results of the calculations as discussed in chapter five, confirmed the viability of the case study project when using traditional evaluation techniques. The ROA evaluation provided an interesting scenario, which indicated that the project could be viable depending on the overall risks. When mapping the base case results on the active mapping tool, the ROA indicated a very high volatility and an NPV_q above three. The NPV_q was acceptable; however, the volatility pushed it into the “maybe now” region. Considering that the base case scenario was already an accepted and executed project, the active mapping tool confirmed the profitability of the project. This therefore reaffirmed the results yielded by the conventional NPV and IRR as well as @Risk®.

It can thus be concluded that the ROA active mapping tool is an excellent complementary technique to the traditional discounted cash flow evaluation techniques. Therefore, while the developed model results have not been matched to the actual financial figures that were approved by the case study project owner, due to issues of confidentiality, they do confirm the overall viability of the project.

Conclusions drawn above further illustrate the importance of including ROA within the traditional capital budgeting financial evaluation techniques, as it incorporates the risk factor into the calculations. Risk is dynamic in nature and its quantification in project financial evaluations is critical in order to have a fair and realistic appraisal of the financial performance of risky or ground-breaking investments.

It can further be concluded that, for projects to be profitable, the investor may have to:

- Settle for higher than normal equity-to-debt ratio in order to make sure the debt is minimized.
- Find alternative ways of driving the initial capital costs down
- Negotiate very favourable interest rates and or even longer payback periods.

The REIPPPP market in South Africa has driven the PV technology tariffs down and thereby making it a very competitive industry. South Africa has provided a stable renewable energy investment environment which is still appealing to especially investors.

6.3 RECOMMENDATIONS FOR FUTURE STUDY

In a future study, a scientific and more quantitative approach could be performed to generate an estimation of the physical risks that would be involved to undertake such PV projects.

6.4 CONCLUSION

This concludes the final chapter of the dissertation. In the case study that was presented, both the DSCR and LLCR indicated that sufficient revenues would be available to service the debt obligations. It was therefore concluded that the financial performance of a project would be dependent on the technical performance, geographic location and design specifications of any prospective plant.

Various financial evaluations were performed. The final evaluation was done using the ROA framework, which provided volatility and NPV ratios that yielded a 'maybe invest now' decision, which was good, since it supported the decision to invest in the project. The result also supported the hypothesis from the first chapter that the ROA techniques should be combined in all financial analysis of renewable energy utility scale PV projects. The results also confirmed the viability of the case study project when using traditional evaluation techniques. It could thus be confirmed that an ROA active mapping tool would be an excellent complementary technique to the traditional discounted cash flow evaluation techniques for project viability studies.

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