The application of real options to renewable energy investments in South Africa: the case of solar energy technology for small businesses and individual homeowners

by

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Declaration

I, Paul Markham, hereby declare that the work on which this dissertation/thesis is based is my original work (except where acknowledgements indicate otherwise) and that neither the whole work nor part of it has been, is being, or is to be submitted for another degree in this or any other university.

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Paul Markham
February 2018

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Abstract

There is a growing interest in renewable energy generation projects due to environmental and sustainability concerns. However, initial costs and uncertainties caused by a number of factors can render renewable energy projects unattractive when subject to conventional financial assessment. The overall benefits of renewable energy technologies are often not well understood and consequently are often evaluated to be less effective than traditional technologies. From the moment that the energy sector abroad started a deregulation process, with a high level of competitiveness and associated increased market uncertainty, traditional evaluation techniques became insufficient to properly deal with these additional risk and uncertainty factors. Consequently, the way investors evaluate their investments require more sophisticated evaluation techniques. Initial research suggests that the value of renewable energy projects can be enhanced by the application of real options theory. In addition to revealing the benefits that renewable energy projects provide when employing real options, analytical results indicate that real option analysis is a highly effective means of quantifying how policy planning uncertainty, including managerial flexibility, influences renewable energy development. However, real option literature regarding renewable energy generation projects is limited and the theory requires further development to take advantage of more flexibility value within renewable energy projects. Literature is particularly limited in terms of small businesses and individual homeowners and worthy of analysis. This study attempts to address this issue.

This study shows that real option analysis is useful, in the face of numerous uncertainties, in assisting South African homeowners and small businesses in the six largest metros and Eskom when considering an investment in a solar PV system. Within these six metros and Eskom three different tariff structures are offered, some of which encourage such investments while others don't, thus forcing the latter to purchase expensive battery systems and consequently making the investment somewhat ineffective. Investments in solar PV systems are relatively costly and so, before committing, one needs to be certain that the system will be cost effective. In this study, it is shown that there is strong evidence that real option analysis is, not only useful in determining whether such an investment is cost effective, but also in assisting with the timing of such investments. This could be crucial for success. The findings of this study have theoretical implications in terms of the efficiency of real option analysis in the South African

energy sector, and thus provide a contribution to real option literature in this sector. They also have practical insights for investors, both homeowners and small businesses in the South African context, who are looking to invest in a solar PV system.

The study starts with an introduction and background to energy generation and then presents a literature review concentrating on the use of real options as an appropriate valuation method for renewables. Thereafter, the hypothesis is stated and the data sample and research methodology discussed. One of the limitations of this study was the unreliable data and the difficulty finding it, which could give rise to self-selection bias. Finally, the results and a brief analysis are presented and then, in conclusion, there is a discussion on the limitations of the study and suggestions for further research.

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1. Introduction and background

1.1 Introduction

Historically, Eskom has been the sole provider of electricity in South Africa. It has made extensive use of its coal-fired power stations, mostly situated close to the coal fields of Mpumalanga, the Free State/Gauteng and north-western KwaZulu-Natal[1]. Currently the majority of the country's electricity is coal-fired thermal generation due to the abundance and low cost of coal. The balance is generated by nuclear, hydroelectric and pumped storage, gas turbines and wind (Eskom, 2017). Recently independent power producers (IPP) have been invited to participate through a renewable energy programme run by the Department of Energy. They will ostensibly supply energy into the national grid owned by Eskom and will be compensated for at a predetermined rate. The two energy sources that are most attractive to these IPPs are wind and solar. This study will concentrate on solar power since it is the one most readily available to all consumers and since it is the one that will be most important in providing the world's future energy needs. However, the process and results of this study could be adapted reasonably easily to other renewable energy sources as well.

Renewable energy development is constrained by high development costs, difficulty of investment recovery, long and deferrable planning processes, high investment risks and uncertain returns. The ability to use real option analysis to assess the benefits of renewable energy investments provides the ability to, not only quantify managerial flexibility neglected by conventional assessment methods, but also the opportunity to minimise the possibility of underestimating the value of the investment. Therefore, investors are able to capitalise on the options concept to generate value derived from "waiting" in order to reduce any uncertainty in planning. Investors in the past have been deterred from investing because investment risks were difficult to assess, ultimately reducing cost effectiveness in power generation (Lee, 2011).

The aim of this study then is to determine whether or not the use of the real options approach is valuable in assisting both small businesses and individual homeowners in their quest to

[1] L.S. Jeffrey provides a comprehensive analysis of South Africa's coal resources and reserves (Jeffrey, 2005). This should be read in conjunction with a study done by Stephan Schmidt to obtain an appreciation of South Africa's coal deposits (Schmidt, 2008).

decide if and when an investment in a solar energy infrastructure would be cost effective. Not only is the cost of the investment an issue here, but equally so is the timing of such an investment. The study will start with a background to the renewables industry and then look at it in the South African context. This is an attempt to familiarise the reader with the dynamism of the industry and its potential. A review of the relevant literature will then be presented as will a discussion on the data used and the methods employed to analyse this data. Conclusions will be drawn and the findings communicated providing a number of recommendations. Finally, the study will discuss whether, or not, it would be useful from a scholarly point of view to pursue any areas of research in the future.

1.2 Background

1.2.1 The need to obtain energy from renewables

Civilized society has been almost completely reliant on fossil fuels for all its energy needs. Fossil fuels, however, are a finite resource and in time will become too expensive as supplies start becoming depleted[2]. Consequently, there is a need to seek alternatives, like renewable energy sources, that are constantly replenished naturally and will never be exhausted. However, to develop the infrastructure needed for these alternatives takes time and funding, and changes in societal attitudes.

A further reason to seek alternatives is that the climate around the world is changing and that fossil fuels contribute greatly to that change[3]. When fossil fuels are burned carbon dioxide, accounting for over 80% of greenhouse gases, and other pollutants are released into the atmosphere. Together they are responsible for a large amount of land, water and air pollution and consequently are a health hazard. In contrast, renewables like solar or wind energy generate little or no emissions and are thus generally better for the environment. Renewable energy sources are not without their environmental impacts, though, but still far outweigh fossil fuels in terms of pollution, climate change and the impact on biodiversity.

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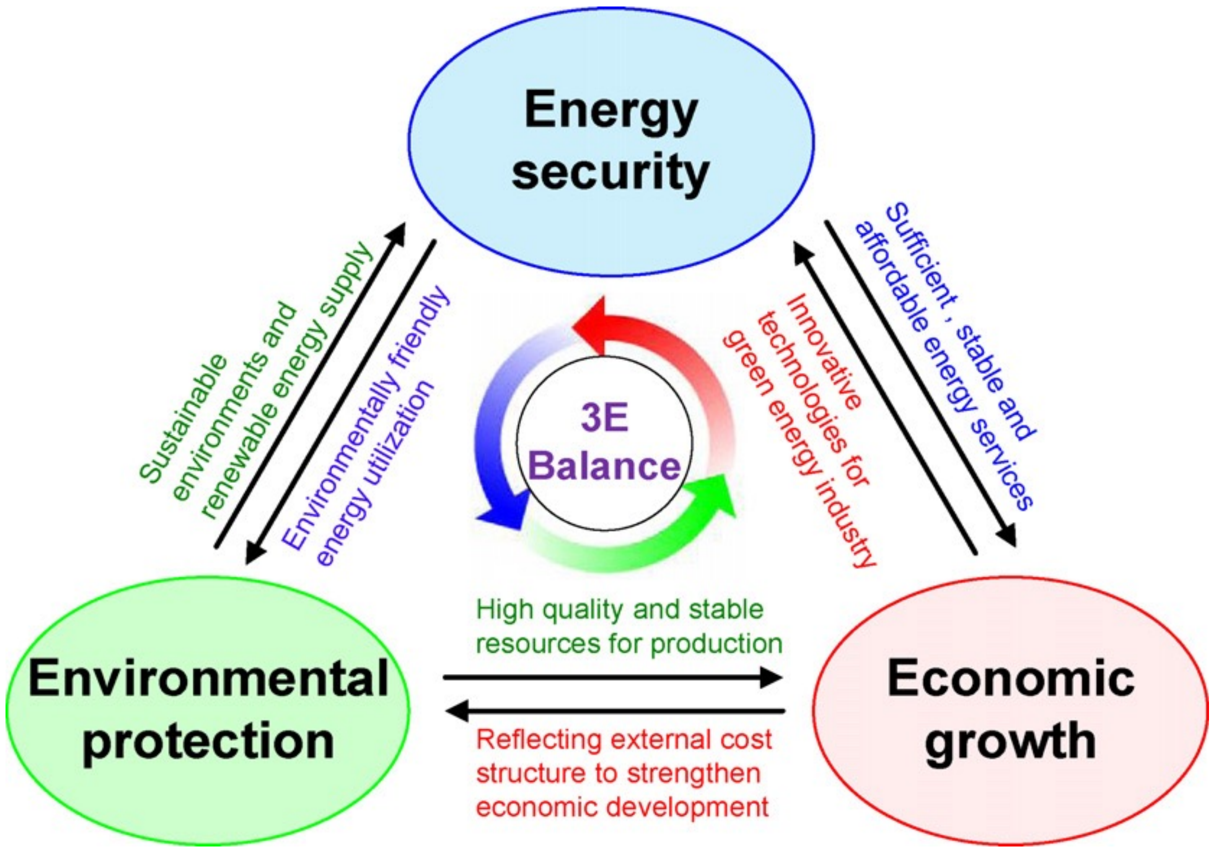
[2] If world usage continues at the current rate oil will be exhausted in around 50 years' time, as will gas, and coal will be exhausted in around 100 years' time.

[3] In Paris on 12 December 2015 an accord was signed by 195 nations approving a plan to combat climate change (Tollefson & Weiss, 2015). The document contains provisions to accelerate the world's transition from fossil fuels to renewable and other clean energy sources.

Renewable energy is available to all unlike fossil fuels, allowing for scalability. The average person has access to solar and, if able to afford a small solar system, won't need to rely on one or a few providers who control prices and distribution. The average person is also given more control over both ensuring their energy needs are met and seeking options that are more economically and environmentally sound. Not only will they be able to obtain energy from their own system but will also be able to sell any excess they produce back to the grid. Defined as sustainable and relatively clean, renewable energy can potentially overcome the gradual depletion of fossil-fuelled energies and their adverse environmental impact, while simultaneously addressing energy sustainability, economic development and environmental protection-related issues (Figure 1).

Figure 1: The relationship of 3E.



Source: Lee, 2011.

To accelerate development of the renewables industry, especially in the early stages of its development, governments need to provide policy support and make any necessary legislative changes to accommodate renewables more favourably. This will assist with reducing uncertainties during the early stages of development, attracting investment, lowering investment costs to increase installed capacity, and providing investment equipment subsidies and tax rebates. They can also implement incentives like feed-in tariffs, investment grants, fixed premium systems and use other promotional efforts like public-private sector collaboration (Lee & Shih, 2010). In the absence of adequate support policies renewables tend to be less competitive than other generation technologies. This suggests that additional economic drivers might be necessary to promote investment in renewable energy generation projects (Martinez-Cesena & Mutale, 2011). Investment firms might adopt innovative utilisation methods and technologies, and capacity expansion to achieve economies of scale. A potential and unexploited economic driver is the value of flexibility, flexibility in investment timing and design. This refers to the capability of managers to modify projects according to the evolution of uncertainty, uncertainty of electricity prices, renewable energy source and technology. This flexibility can enhance the project's worth yet is typically disregarded in the planning process of renewable energy generation projects. These economic drivers will ultimately enable renewables to compete with the non-renewables in the open market.

1.2.2 The potential to achieve 100% of energy needs from renewables

There are many forms of renewable energy (Twidell & Weir, 2015). They include solar, wind, hydroelectric, biomass from plants, bioenergy from liquid biofuels, hydrogen, geothermal and wave/tidal. On their own they cannot be relied upon to replace fossil fuels but combined in an appropriate mix they have the potential to solve any future crisis. Some countries have adopted plans to obtain 100% of their energy needs from renewables and have already integrated renewable energy into their existing infrastructure with the view to ultimately reaching a 100% mix (Heard, Brook, Wigley & Bradshaw, 2017).

Those countries that have recently had success in their quest to achieve a 100% mix are Iceland, Norway, Germany, Paraguay, Portugal and Denmark. Others have mandates to achieve a 100% mix by a certain date, e.g. Scotland (2020). In the US advocates believe they could replace 80% of their existing energy with renewables by 2030 and 100% by 2050 (Stanford, 2015). The mixes would be different from state to state but would concentrate on solar, wind, tidal, hydro and geothermal. An analysis of the feasibility of such a transition in terms of barriers, requirements, resources, market availability and cost, concludes that it is possible both technically and economically. The only barriers are social and political! Technical challenges would include developing a smart grid that would integrate storage facilities and that would accommodate small producers like homeowners, while economic challenges would include the substantial investments required for implementing renewable energy projects of production, storage and distribution on a large scale (Ecofys, 2011).

In five years' time, in 2022, renewables will account for a third of world power generation (Greentech Media, 2017). Renewables accounted for two-thirds of new power added to the world's grid in 2016. Competition and new technologies are driving prices down. No longer is cost a limiting factor, instead it's now system integration that has become the major challenge. Solar is the one source that is dominant surpassing growth from all other sources including coal for the first time in 2016. The shift was driven by falling prices and government policies, particularly in China, which accounted for more than half the solar panels installed. This suggests that solar technology will dominate renewables in the years ahead and its capacity growth will be higher than any other renewable technology. By 2022 growth in renewable energy will, in order, come from China, US (despite President Trump's vow to bolster coal's position in the energy sector in order to preserve jobs), India and then Europe. Also, by 2022 renewables will produce much more electricity than gas and will close the gap with coal. Renewables would increase even further if it weren't for policy barriers, tardy and inflexible grid integration by utilities and power suppliers (like Eskom), lack of storage facilities and inconsistent national policies on renewable targets (International Energy Agency, 2017).

Renewable energy is essentially a technology business with rapid change and innovation delivering ever decreasing prices and constant improvement in performance. It is already driving developments including electric vehicles, storage, demand-side management and customer involvement. It is democratising the power sector in the same way that the smartphone has enabled people to break out of the constraints of yesterday's society. As with the smartphone the next range of customer benefits will come, not just from continued cost reduction in hardware, but from the ancillary services designed by customers themselves. Like Airbnb and Uber, similar businesses will develop in the electricity industry and these will drive the next wave of innovation and customer choice (Mainstream Renewable Power, 2017).

1.2.3 The costs associated with renewables

Each method of power generation has its pros and cons and associated costs, be they direct costs like capital/maintenance or indirect like environmental/reliability/accessibility. Over the years the direct costs of renewables have been falling rapidly as technology advances and economies of scale take their affect.

One of the disadvantages of renewables is that they are not always available when and where needed (Menegaki, 2008). Some like hydropower require the installation of expensive infrastructure and others like solar/wind require some form of storage because, by nature, their delivery of power is intermittent (*Ibid*). While renewables generally don't produce nearly as much emissions as fossils do, they too have their negative impact on the environment, e.g. wind energy has to face concerns over being unsightly and spoiling scenic vistas, being destructive to bird and bat life and causing loss of habitat to certain species, and being noisy; while solar energy has to face concerns over how the systems are manufactured, installed and disposed of (*Ibid*). Regarding preferences for different types of renewable energy, hydro is preferred to wind because of the environmental impacts of wind farms and the significant social costs with wind farm development (*Ibid*).

In terms of direct costs there are those relating to the equipment and materials needed to collect, process, store and transport the energy to the users. Currently these costs associated with new renewables are higher than those for existing fossils (i.e. excluding any external costs like emissions and physical damages) and nuclear. When comparing two different forms of energy technology it is necessary to look at the total cost to build and operate a new power plant over its life. This would involve analysing all the costs including initial capital, cost of capital, continuous operational costs, fuel and maintenance costs, time required to build the plant and its expected life. For new plants commissioned in 2017 in the US the total cost of producing per kilowatt hour would see wind being the cheapest followed by hydro and then solar. Nuclear would be the most expensive! Since no new coal-fired plants are being commissioned a similar comparison cannot be made but existing coal still remains the cheapest[4] (US Energy

[4] In the US in 2017 new wind is priced at \$0.056 per kilowatt hour, new hydro at \$0.064, new solar at \$0.074 and new nuclear at \$0.096. These figures are without any subsidies. New coal in 2015 was priced at \$0.095 but existing coal is less than \$0.04 per kilowatt hour! The price of wind is down by 63% over the period 2010 to 2017 and solar 81%. It is estimated that in the

Information Administration, 2017). As a comparison in South Africa, both new wind and new solar are the cheapest at R0.61 per kilowatt hour with new coal at R1.03 per kilowatt hour. Once complete it is estimated that the Medupi power station will produce at R1.05 and Kusile at R1.16 per kilowatt hour. It is also conservatively estimated that new nuclear power using Russia's Rosatom reactors will produce power at R1.17 per kilowatt hour (CSIR, 2017).

1.2.4 The importance of energy storage where renewables are employed

Storage technologies can bridge gaps between supply and demand and allow for improved management. They can be implemented on small and large scales throughout the energy system. Storage technologies can be connected to a larger energy system, e.g. electricity grid, or can be applied to smaller off-grid storage facilities like homes. They are valuable components in most energy systems, especially where renewables are being employed, to ensure electricity grid stability, reliability and resilience. They allow for seasonal storage where energy is stored in summer to be used in winter, storage trades where energy is stored during low priced low demand periods and sold during higher priced high demand periods, load and congestion relief when and where required, and off-grid consumers who rely mostly on renewables for their energy needs. The best location for individual storage technology deployment depends on the services these technologies will supply to specific locations in the energy system. They will be deployed across the supply, transmission and distribution infrastructure with varying scales and types of storage depending on what is appropriate.

Some of the more popular storage technologies include pumped storage hydropower where water is pumped from a lower reservoir to a higher one during off-peak periods and reversed during peak periods[5], underground thermal energy storage where heated or cooled water is pumped underground into aquifers or man-made boreholes for later use as a heating or cooling resource, compressed air energy storage where off-peak energy is used to compress air underground or in tanks and then reversed during peak periods, various types of batteries,

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next 20 years wind will be down a further 11% and solar a further 18%. It is important to differentiate between new and existing plants. Current prices are based on existing installations while new-build prices compare the costs of different technologies if their operating lives started today (US Energy Information Administration, 2017).

[5] Pumped storage hydropower makes up more than 95% of global energy storage with a storage capacity of 150 GW. There are a further 100 planned projects around the world that will come on line between 2018 and 2030 and that will increase this capacity by 75 GW.

hydrogen storage where electricity is converted into hydrogen and stored and then converted back when required, flywheels, supercapacitors, magnetic energy storage, and hot and cold water storage in tanks to be used to meet heating or cooling demand. These storage technologies can be grouped into three main categories – short-term, long-term and battery – depending on how, when and where they will be required. The two technologies that are of most interest currently are battery and hydrogen.

1.2.5 Eskom's position regarding renewables

The positive spin-off from Eskom's load shedding between 2008 and 2014 led to many consumers reducing their demand and increasing efficiency. This, however, has not benefitted Eskom who is clearly worse off[6]. The question that arises then is whether, or not, solutions exist for Eskom to turn their business around.

In 2010 the South African government created a legislative and practical environment in which the Department of Energy could procure power generated by private entrants to the market. Then in 2011 the Renewable Energy Independent Power Producer (IPP) Procurement Programme was created. At the time, it was celebrated as a huge success at directing private capital into public infrastructure. Institutional investors include the likes of Old Mutual (the largest funder), commercial banks, foreign private equity firms and power utilities[7]. The programme operated under a competitive auction model thus forcing IPPs to achieve the most competitive rates in order to secure a Power Purchase Agreement (PPA). Eskom's role in this programme was to facilitate connection into the grid and sign the associated agreements to buy the power from the IPPs. However, Eskom refused to sign the second round of renewable PPAs in 2016[8]. Renewables obviously pose a threat to their plans for coal and nuclear. The pricing of both wind and solar globally is steadily shrinking as more renewables are deployed and the

[6] In 2007 Eskom sold 218 terawatt hours of electricity for 18.33 cents per kilowatt hour at a 16.11% profit margin. Ten years later in 2017 Eskom sold less power, 214 terawatt hours of electricity for 82.66 cents per kilowatt hour at a 0.5% profit margin (Eskom, 2017). Eskom is selling less power for higher tariffs at a lower profit margin.

[7] The renewable energy programme has attracted R194 billion in new investment of which 28% represents the share of foreign direct investment. The balance was secured from South African financial institutions.

[8] Eskom needs to sign the PPAs so that construction of new projects can start. Eskom has already signed PPAs with the first round of bids in the programme but now needs to sign off on the second round of bids.

systems become more efficient. This coupled with South Africa's extensive wind and solar resources present huge potential benefits.

In September 2017, the Energy Minister announced that Eskom must sign the IPP purchase power agreements by the end of October with the 26 preferred bidders[9]. A tariff of 77 cents per kilowatt hour had been negotiated. Despite this tariff not satisfying all IPPs, this is a positive signal by the South African government that they are committed to ensuring renewable energy plays a part in the future energy mix. However, the Minister also said that all future programs will be put on hold until a proper energy review has been completed for South Africa. Eskom currently has excess capacity and this situation is expected to remain until 2021! The reason for this is twofold – the first being the decline in energy demand due to a stagnating economy and the second being the additional generating capacity with four newly commissioned units. To further complicate matters this energy surplus will increase further as the remaining eight units are commissioned and brought online[10]. It makes no sense then that the government is even considering an investment in nuclear!

What is interesting is that the only energy projects coming online both on time and within budget are those undertaken by the IPPs. These wind and solar projects have been hugely successful. Not only do they satisfy emission criteria, but their costs are diminishing rapidly, they are relatively simple to install, can be widely distributed across the country allowing for more flexibility and giving many the opportunity to participate and benefit, corruption is kept in check and they can be commissioned as and when required. The latter is most important in an economy that has modest growth prospects (Fin24, 2017).

Eskom, plagued by debt, corruption scandals and weak governance, and having spent billions on new power plants that are years behind schedule and over budget, has the opportunity to turn their business around by following the lead of other economies like China, US, India and

[9] Once these agreements are signed the producers are guaranteed their income for 20 years. The end of October came and went without any being signed. A further date of 20 November was then set.

[10] Eskom commissioned two new coal-fired power plants, those of Medupi and Kusile, when it was evident that electricity demand had increased during the economic boom up to the financial crisis of 2008. These two plants consist of a total of 12 units that will produce roughly 6 200 MW of power once all have been commissioned. On average daily electricity demand in SA is 30 000 MW but peaks higher than that on some days. Eskom generating capacity is 42 800 MW and with these 12 new units will increase to 49 000 MW (Eskom, 2017).

Europe who are focussing on low-cost renewables and storage technologies. Renewables offer Eskom the least risk and most affordable option that would benefit a wider population and keep emissions in check. If Eskom's prices continue increasing the way they have done since 2007 (more than quadrupled), they will start to lose the support of the public with more customers seeking other sources of power[11].

1.2.6 A case for renewables in South Africa's energy mix

Eskom is believed to be the biggest contributor to air pollution in South Africa, particularly in the Highveld, where the dirty air is making people ill and causing environmental damage[12]. Air pollution from Eskom's coal-fired power stations causes 2 239 deaths per year and a large number of illnesses at a total cost of R32 billion per year (Centre for Environmental Rights, 2017). Quite ironically this report claims that one of Eskom's newest power stations, Medupi in the province of Limpopo, will be the deadliest yet. This is at a time when Eskom could have elected to adopt renewables instead! The report was commissioned because in 2007 the government promised to clean up air pollution on the Highveld by declaring it a priority area under the Air Quality Act. Clearly it has failed to do so in favour of more polluting coal-fired power stations when other cleaner options were available! The report was followed by a protest by environmental activists claiming that the government was not doing enough about air quality and needed to introduce renewable energy programmes using solar power (Fin24, 2017).

The CSIR Energy Centre conducted a study on re-optimising the South African power capacity and energy mix from 2016 to 2040 (CSIR, 2017). The study considers the low demand forecast for the years ahead, the reduced cost of producing electricity from wind and solar, and South Africa's commitment to reduce emissions. The study shows the need for new coal and new nuclear power is completely removed for the years ahead to 2040. Solar, wind and gas will

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[11] The City of Cape Town has made a court application challenging the designation of Eskom as the single buyer of generated electrical energy. This is being closely watched by other municipalities who want to reduce their electricity costs by installing their own generation capacity and/or procuring cheaper electricity from IPPs and industrial, commercial and domestic consumers that are equipped to also produce electricity (GreenCape, 2017).

[12] Mpumalanga Highveld towns of eMalahleni, Middleburg, Secunda, Standerton, Edenvale, Boksburg and Benoni are home to 12 of Eskom's 15 coal-fired power stations. As a result, the towns have ongoing problems with air pollution.

assume increased roles in place of coal and nuclear as Eskom's old plants are retired. This will result in emissions that are 60% lower and water usage that is some 60% lower[13]. This study also showed that there would be a saving of some R330 billion over this period and some R87 billion per year thereafter compared to a scenario where coal and nuclear is pursued. The study concluded by saying that solar, wind and natural gas now provide the cheapest mix for the South African power system and that the aim should be to achieve a 70% renewable mix by 2040.

Ben Heard, a South Australian energy researcher and director of environmental lobby group, Bright New World, is not convinced that solar and wind can provide the stability and reliability to drive the economy. They believe South Africa needs a more reliable source as the base load and that should be nuclear, followed by solar and wind to meet variable demand and gas as a back-up for the renewables. Nuclear is more expensive than renewables but more reliable, they claim. They agree that the risks with nuclear, though, are the capital costs and the potential time delays in the building process. There would need to be an open, competitive and transparent tender process and proper controls during the building process to ensure these risks are kept to a minimum. Despite what these proponents might believe most other countries who are committed have made plans to achieve high levels of renewables in their mixes that are similar, and are confident that their plans will be successful. New nuclear stations aren't even considered as an option! In fact, Germany has taken a decision to retire all of its nuclear plants by 2022[14] (TechCentral, 2017)!

In terms of the renewable energy IPP procurement programme the first independent power was procured in 2012. Since then the amount of renewable energy capacity added is around as much as the Medupi coal-fired power station will add once complete, and that is in about half the time! Renewables, therefore, currently represent around 5% of South Africa's generating capacity. The plan was to increase this to around 10% by 2020 and 20% by 2025. However,

[13] This will result in a saving of 40 billion litres of water per year (CSIR, 2017).
[14] The German approach has seen a total disruption to the role of traditional baseload suppliers, which are effectively now relegated to being top-up suppliers for when renewable companies cannot meet demand due to low solar irradiance or calm winds. The addition of renewable power generation systems, including the large number of domestic rooftop systems, has resulted in traditional large utility business models suddenly becoming outdated. This is reflected in the more than 50% reduction in share prices over the last two years for the two largest utilities in Germany.

this no longer looks the case given Eskom's current status. The programme has provided many benefits like creating fiscal space for National Treasury[15], employment spread over a wide geographical area, competition amongst investors and developers thus forcing pricing down below that of new coal and new nuclear power, transparency and discipline, and delivery within budget. If the government is looking for good governance combined with competitive enterprise to produce a public good that will deliver well into the future, they need look no further that South Africa's renewable energy IPP programme. There's no doubt that there is a case for renewables in the energy mix, ultimately achieving a more dominant role once the coal stations and South Africa's single nuclear station are decommissioned. There has to be some state involvement in the supply of power in South Africa, but where it should be, is debatable. The trend internationally is for the supply networks to be publicly owned and for generation to be privately owned.

[15] Recent data released by Stats SA shows that investment in electricity in 2016 was the biggest of public-sector capital expenditure. Eskom's share was 25.7% (R73 billion) focused mainly on the continued construction of Medupi and Kusile power stations (Stats SA, 2017)!

2. Literature review

2.1 Introduction

For the literature review a number of journals were identified that contained articles that were relevant to this study. It was important to make sure that each article had been subject to peer review and that they supported/refuted my claims in some way. The articles were studied in more detail and themes and issues associated with this study extracted and incorporated into a theoretical framework of themes. This helped me understand my research topic in more detail and enabled me to distinguish between an opinion and a discovery. It was important in my readings that I noted whether the knowledge was confirmed beyond doubt, that I noted the theories put forward and the methodologies adopted, that I examined to what extent the findings could be generalised, and that I ascertained the areas where gaps exist in the body of knowledge. As I went through the readings I realised that they dealt with a number of aspects that have a direct and indirect bearing on my research topic. Some information was universal while other information was more specific to my topic. The literature has been confined to the last 10 years except for one paper (Table 1).

I identified the following themes:

- real options considered a more appropriate valuation method for renewables
- financial options theory
- real options theory
- where real options fit into finance
- economics of renewable investments
- investment timing of renewables and capacity choice
- applications of real options to renewable projects
- research methodologies employed.

These themes are discussed in more detail under the various headings below. The reader will notice that references have been made to a large number of papers other than those listed in Table 1. These I have perused on a more limited scale, sometimes only reading the abstract, but was able to glean very valuable information from them and felt it necessary to include them in my literary review.

Table 1: List of those articles studied in detail.

Year	Reference	Title
2003	Davis and Owens	Optimising the level of renewable electric R&D expenditures using real options analysis.
2007	Menegaki	Valuation for renewable energy: a comparative review.
2009	Medez et al.	Real options valuation of a wind farm.
2010	Lee and Shih	Renewable energy policy evaluation using real option model I the case of Taiwan.
2011	Cunha and Ferreira	The use of real options approach in energy sector investments.
2011	Lee	Using real option analysis for highly uncertain technology investments: the case of wind energy technology.
2011	Martinez-Cesena and Mutale	Application of an advanced real options approach for renewable energy generation projects planning.
2012	Boomsma et al.	Renewable energy investments under different support schemes: a real options approach.
2013	Detert and Kotani	Real options approach to renewable energy investments in Mongolia.

2.2 Real options: a more appropriate valuation method for renewables

Wrong investment decisions could lead to situations that become unsustainable and eventually lead to business failure. The renewable energy industry in South Africa is at a critical point right now with Eskom appearing to renege on decisions taken years ago and also adopting a hard line in favour of coal and nuclear. Therefore, good financial management combined with good capital investment decision making are critical to survival and long-term success of the renewable firms (Fernandes, Cunha & Ferreira, 2011). As an energy industry becomes more and more deregulated the use of financial theory and methods become increasingly important. Financial theory is used for hedging against risk and uncertainty caused by fossil fuel price volatility (fossil energy is vulnerable to political uncertainties, trade disputes, embargoes and other disruptions), environmental regulation changes, demand/supply, and technology and market structure changes (Menegaki, 2008).

The benefits of renewable energy technologies are often not well understood and consequently they are often regarded as less cost-effective options than traditional technologies. In order for renewables to become competitive and to encourage investments in this field, valuation models that take risk and future uncertainties into account are necessary. Traditional valuation models relying mainly on discounted cash flows, where projects with positive net present values (NPV) or that yield a higher IRR than the capital cost are simply accepted and those with negative NPV or that yield a lower IRR than the capital cost are regarded as uneconomic and simply rejected without further analysis, fail to assess the strategic dimension of the investments and are inappropriate for a rapidly changing investment climate (Dixit & Pindyck, 1995; Herath & Park, 1999). (Table 2 summarises the merits and limitations of these two valuation methods.) They also don't allow for properly dealing with the risk and uncertainty of these projects and are inherently limited in valuing flexibility in decision making, possibly underestimating the opportunity and actual values of an investment (Badders, Clark & Wright, 2007). Furthermore, they make implicit assumptions like the reversibility of investments where the investment can be undone and the expenditures recovered. Also, if the firm does not make the investment now it will not be able to do so in the future and this will become irrecoverable. The way investors evaluate investments in renewables thus calls for more sophisticated valuation techniques.

Table 2: Merits and limitations of two traditional valuation methods (NPV and IRR).

Method	Merits	Limitations
Net present value NPV	Time possesses value and reflects all cash flows. The magnitude of economic benefits from an investment plan considered. NPV represents how an investment plan directly contributes to corporate value, and can accurately represent how it influences stockholder wealth. The principle of value additivity is compliant, implying that the sum total of a company's value equals the sum of the contributions of its individual independent investment plans. Only the NPV method can obtain the optimal decision when an exclusive plan is selected.	Owing to potentially high uncertainty of the cash flow and discount rate forecasts, forecasting errors lead to erroneous results, and decision-making risk is relatively high. When different investment cases entail varying amounts of risk, the NPV method's use of the same lowest rate of return on investment to discount cash flow tends to lead to a bias; different discount rates should thus be adopted. The NPV method does not reflect high- or low-cost effectiveness.
Internal rate of return IRR	Time also possesses value and reflects all cash flows. The magnitude of economic benefit from an investment plan is considered. The profitability of an investment plan is expressed as a single rate	Since the IRR is a rate, this method does not consider the amount of investment and magnitude of cash flow. It does not consider the various compensations of individual investment cases. Because IRR is unknown, analysis may be difficult when an investment plan exceeds

	(IRR), which can be compared with other rates. Profitability is expressed as a rate of return, and can be easily compared with the cost of funds.	two periods in duration, while net cash inflow may occasionally be positive and occasionally negative. It may yield an erroneous decision when evaluating an exclusive investment plan. It makes unreasonable assumptions about the rate of return on investment. Under circumstances of abnormal cash flow, this method may calculate one or more IRR values that are not consistent with value additivity.

Source: Lee, 2011.

The ability to delay an investment in order to obtain more information, and thus reducing uncertainty, provides management with a valuable opportunity to modify investment plans, provide better opportunities and reduce future losses. This can be seen as an "option" – an option to invest or to not invest – with characteristics similar to those of a financial call option whose foundations lie in option pricing theory developed by Black, Merton and Scholes (Black & Scholes, 1973). These options give the investor the ability to account for the value inherent in the flexibility to delay an irreversible investment in real assets such as plants, property or equipment in the future. This managerial flexibility has value and represents the "real options" associated with the investment (Brandao & Dyer, 2005). Real options can quantify this managerial flexibility neglected by conventional pricing methods and can minimise the possibility of underestimating value (Lee & Shih, 2010).

Real options pricing is one tool that accurately measures the value of a project (Herath & Park, 1999). It is a concept that was adopted from finance by Myers (1977), who argued that profits created by cash flow generated from an investment arise from the use of currently owned assets in addition to an option for future investment opportunities. Hence, the option pricing strategies of Black and Scholes (1973) were applied to value real assets with managerial flexibility. Trigeorgis and Mason (1987) referred to the value of an investment with option value and managerial flexibility as "expanded" or "strategic" NPV, where the value is the sum of the traditional NPV and the value of managerial flexibility.

2.3 A simple explanation of financial options

Black and Scholes stated that "an option is a security giving the right to buy or sell an asset, subject to certain conditions, within a specified period of time" (Black & Scholes, 1973).

There are two types of basic options, the ones that give the right, but not the obligation, to buy an asset (a call) at a predetermined price (exercise price) within a specified period (time to maturity) and those that give you the right, but not the obligation, to sell an asset (a put) in exchange for receiving an exercise price within a specified time. When the current price of the underlying asset is above the option exercise price (for a call option) or below the option exercise price (for a put option), it is said that the option is "in the money". Otherwise it is "out of the money". Options are either European or American. An option that can be exercised only on a specified future date is designated a "European option" while an option that can be exercised at any time up to the date the option expires is designated an "American option".

Each option has a buyer, the holder, and a seller, the writer. If the option is exercised the seller is responsible for fulfilling the terms of the contract by delivering the asset to the appropriate party. For the holder, the potential loss is limited to the price (premium) paid to acquire the option but the upside is unlimited. For the writer, the upside is limited to the premium but the potential loss is unlimited. The premium of an option is dependent on the volatility of the price of the underlying asset, the greater that volatility the greater the value of the option because of increased potential gains. When an option is not exercised it expires.

2.4 An introduction to real options

In competitive markets, no one expects to formulate detailed long-term plans and follow them mindlessly. As soon as one starts with a project/investment, one learns about business conditions, competitors' actions and the use of technology and one responds to what is learnt. Unfortunately, as already mentioned, the financial tool most widely relied upon to estimate the value of a strategy is NPV, which assumes that one follows a predetermined plan regardless of how events unfold. A better approach to valuing strategic alternatives would be to incorporate both the uncertainty inherent in business and the active decision making required for strategy to succeed (Luehrman, 1998).

When undertaking an investment there is value that derives from having the flexibility/option to abandon, delay or modify when new information becomes available. Management flexibility is the ability to affect the uncertain future cash flows of an investment in a way that enhances its expected returns or reduces its expected losses (Brandao & Dyer, 2005). Typical investment flexibilities include the option to expand operations in response to positive market conditions or to abandon an investment that is performing poorly. Management may also have the option to defer the investment for a period of time, to temporarily suspend operations, to switch inputs or outputs, to reduce the scale or to resume operations after a temporary shutdown. (There are seven common types of real options. Table 3 introduces the definition of each and identifies the options appropriate for solar energy projects.) All of these opportunities represent options on real assets that allow management to enhance the value of the investment. Thus, they are called real options, the value of which can be determined through option pricing or decision analysis methods.

Table 3: Definition of common types of real options.

Types	General definition	Definition for this study
Option to defer	Management hold a lease on, or an option to purchase, land or resources. The lease can wait x years without exercise.	Management can defer the plant construction until demand level and/or prices justify developing. Time works in favour of this method because production costs decrease and the process becomes more competitive over time.
Time-to-build option	Staging investments as a series of outlays creates the option to abandon the enterprise in midstream if new information is unfavourable. Each stage can be viewed as an option on the value of subsequent stages and valued as a compound option.	Solar can be developed in stages (modular) thus allowing for review of the decision to continue with the next stage or not. It is a convenient means of determining whether changes in demand or price levels are permanent and responding to the new market conditions with a relevant certainty.
Option to alter operating scale	If market conditions are more favourable than expected, the firm can either expand the production scale or accelerate resource utilisation and, conversely, if conditions are less favourable. Under extreme conditions production may be ceased and restarted.	If market conditions are more favourable than expected, a solar energy plant can be expanded to take advantage of the real market conditions. If expectations do not measure up there is the option of reducing the scale of operations or partially decommissioning.
Option to abandon	If market conditions decline severely, management can abandon current operations permanently and realise the resale value of capital equipment and other assets on second hand markets.	If market conditions decline severely, or if the capital equipment becomes obsolete due to technological changes, management can abandon the solar energy plant to permanently resume any residual value.
Option to switch	If prices or demand change, management can adjust the output mix of the facility (product flexibility). Alternatively, the same outputs can be produced by using different inputs (process flexibility).	If prices or demand change, the flexibility of the project/plant would be useful to optimise production.
Option to grow	An early investment is a prerequisite of interrelated projects, subsequently creating future growth opportunities, e.g. new product or process.	If the electricity market enters a new era of increasing deregulation, growth options are considerable and should be considered during the appraisal process of the projects, e.g. with environmental

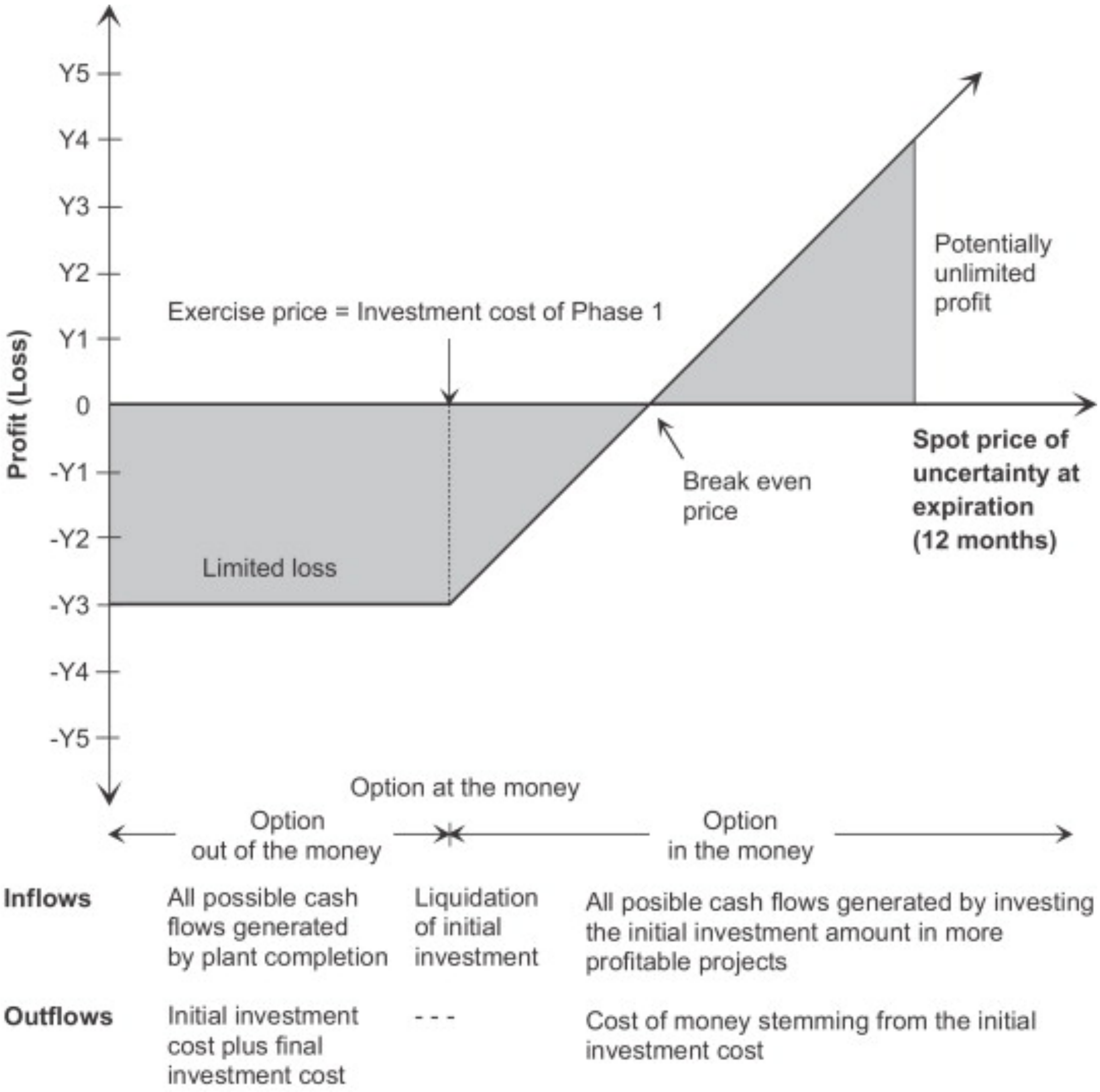
		issues solar energy is a valuable alternative and environment friendly energy source. Therefore, this market can be expected to expand rapidly if promoted above coal and nuclear.
Interaction among multiple real options	Real-life projects often involve a collection of various options. Their combined value may differ from the sum of their separate values, i.e. they interact with each other.	Management might be faced with a number of different options simultaneously the combination of which might be more efficient than dealing with each independently.

Source: Kjaerland, 2007.

A real option may be defined as “the right, but not the obligation, to take an action (e.g. deferring, expanding, contracting or abandoning) at a predetermined cost, called the exercise price, for a predetermined period of time – the life of the option” (Copeland & Antikarov, 2003) or may be defined as “an investment decision that is characterised by uncertainty, the provision of future managerial discretion to exercise at the appropriate time, and irreversibility” (Kogut & Kulatilaka, 2001). An opportunity to invest is, therefore, similar to a call option. If a firm with an opportunity to invest has the option to spend money (exercise price) now or in the future, in return for an asset (e.g. a project) of some value, the firm would invest if the option were “in the money”, and receive a positive net payoff. The firm would not invest if the option were “out of the money” to avoid a negative payoff. The irreversible investment cost that is committed at the initiation of the investment project plays the role of the exercise price and the real asset is the project once this starts producing cash flows. The applicability of option theory in renewable energy evaluation stems from the modularity characterising renewable energy projects (Menegaki, 2008). (The analogy of the financial option and the real option is shown schematically in Figure 2 where an energy firm is building a new plant in two phases that will be completed in 12 months.)

Real options create alternative choices for decisions regarding investments in real assets at a lower cost for a firm. Decisions can be based on actual circumstances that may occur in the future. Deferring choices can greatly reduce the risk that investments will lose part of or their entire value. Real options give the holder both the rights to real assets without making the full investment in the present time period, and the rights to keep the opportunities for future investments open (Badders, Clark & Wright, 2007). The challenge is to understand which set of options should be exercised right now and which set should be delayed. Since exercising one set of options leads to a series of other options most projects/investments can be viewed as a portfolio of strategic options which are dynamic in nature and whose pricing is changing continuously. This portfolio of options can, in turn, be broken down into simple portfolios of calls and puts. It is important at this stage, then, that one gain an understanding of how the value/price/premium of these options is determined.

Figure 2: Profit from a real option for various spot prices of uncertainty.



Source: Shapiro, 1996.

2.5 Pricing of real options

Initially, it is necessary to identify the main variables/inputs that influence the value of real options. Essentially there are six variables, namely, the value of the underlying asset/investment, the exercise price, the time to expiration, the uncertainty about the value (volatility), the risk-free rate of interest, and the dividends that must be paid out by the underlying asset (Copeland & Antikarov, 2003). (Table 4 compares financial options to real options.) If any of these variables increase so will the value of the real option. Also, a real option has a value at a particular time and this value will change as time changes. In general, most real options are American styled allowing for exercise at any point in the project's life, the reason being that they are best suited to most real-life problems that allow for adjustments at any time.

Table 4: Comparison of financial options to real options.

Description	Financial option	Real option
Underlying price	Current value of stock	The value of the expected PV of the stream of profits and/or losses the project would generate.
Exercise price	A fixed share price	The cost of converting the investment opportunity into the option's underlying asset.
Time to maturity	Time until expiration date	The length of time the investment can be deferred without losing an opportunity.
Risk-free rate	Risk-free rate corresponding to time to maturity	The risk-free rate of return, normally the rate of return of the 10-year government bond.
Volatility	The uncertainty of stock price	The uncertainty with respect to the future value of the project's cash flows.

Source: Lee, 2011.

A number of methods have been developed for real option valuation of which the binomial lattice, Monte Carlo and partial differential equation methods are the most widely used. This study will concentrate on the lattice-based model which is most suited to American-styled options and allows for flexibility to exercise when it is relevant to do so (Cox, Ross & Rubinstein, 1979). Binomial lattices are based on the description of an underlying asset over a period of time rather than at a single point. They consider expected changes in various parameters over an option's life, thereby producing a more accurate estimate of option prices than created by models that consider only one point in time. These models trace the evolution of the option's key underlying variables in discrete time. This is done by means of a binomial lattice "tree" for a number of time steps between the valuation and expiration dates[16].

The period leading up to option expiration is split into sub-periods or nodes. Each node in the lattice represents a possible price of the underlying at a given point in time. The investment then either rises or falls by a specific amount depending on its return volatility. Valuation is performed iteratively starting at each of the final nodes (those that may be reached at the time of expiration) and then working backwards through the tree towards the first node (valuation date). The value computed at each stage is the value of the option at that point in time. Option valuation using this method is a three-step process – creation of the binomial price tree, calculation of the option value at each final node, and calculation of the option value at each preceding node. The same six variables mentioned above play a role in valuing the option. In fact, as the binomial lattice is geared with smaller and smaller time increments, the option price will converge to the Black-Scholes value. What has been discussed above is best illustrated by way of a simple example (Appendix 1).

2.6 Economics of renewable investments

The value of a renewable energy project depends on the flexibility of the investment. Once a licence is granted to develop and operate, the investor owns an exclusive right, or option, to proceed with the project. The investor then has the ability to postpone investment until the economic environment justifies a commitment of funds (Boomsma et al., 2012).

Most renewable energy projects are more capital intensive than conventional energy technologies. For example, capital costs of wind power projects account for 75% of total costs. These are dominated by the costs of the turbines, where the prices of raw materials like steel can be uncertain. The other main cost components are grid connection, foundations and land rent. The timing of the investment then is crucial. Ideally investments should be undertaken when capital costs are low and electricity prices are high. Capital costs are typically paid

[16] Trees map out price movements of the underlying security. These price movements are represented by a grid of equally spaced time steps with a series of nodes at each step indicating the price of the security and of the option. At each node, the security moves up or down by a certain amount according to a pre-specified probability. The price of the option is evaluated at each node and then discounted back to obtain the price at the first node, representing present time.

upfront while profits are earned over a long period of time during which time electricity prices remain uncertain. Variable costs of renewable electricity generation are generally small comprising the costs of operation and maintenance. For wind power projects these represent the remaining 25% of total costs and include the costs of repairs, spare parts, administration and insurance (Boomsma et al, 2012).

With the sale of renewable electricity production, a power purchase agreement usually specifies the terms of delivery. These agreements can be fixed or index-priced with power purchasers, including retailers, industrial and institutional users or the transmission system operator, like Eskom, or may simply allow for access to the electricity spot market. The profitability of many renewable electricity investments relies heavily on the renewable energy support scheme employed.

Unlike conventional power production, renewable electricity generation is intermittent and hence largely uncontrollable, since the weather conditions directly determine production. In the short to medium term this makes production only partly predictable but in the long term, e.g. on yearly time scales, production is more predictable and less variable. Intermittency therefore does not itself affect the investment timing and expected yearly production is fairly constant. For wind power projects, one must consider a number of factors, namely wind speeds, grid losses, turbine maintenance and failure, and wake effects (Boomsma et al., 2012). Wake effects result from turbulence and, in some cases, can account for losses of between 5% and 10% of generation capability.

As far as indirect costs in the energy industry are concerned, which should be factored into valuations or pricing in some way to facilitate more realistic comparisons, consideration should be given to the replacement costs of non-renewables, as should the imposition of royalty rates on revenues from the mined (non-renewable) product. These could then be invested back to society (Menegaki, 2008). Other indirect costs to be considered are the external costs produced by non-renewables in the form of emissions and environmental damage. These physical damages could be attributed to actual power plants and converted to damage costs using available monetary estimates on damages caused by pollutants. The value of an environmental impact can also be measured by estimating the cost of replacing or reproducing the environmental service or benefits lost (Menegaki, 2008).

2.7 Investment timing of renewables and capacity choice

The investor has the flexibility to decide on the capacity of a project either before or after applying for a licence. This decision will depend on the balance between any economies of scale in capital costs and the property that production increases (marginal production will decrease with increasing capacity). Any support schemes implemented by the government can have a considerable impact on both the timing of investments and the capacities of projects[17]. There are incentives for investors to wait until the type of support scheme and the level of support is sufficiently attractive (Boomsma et al., 2012).

When the authorities grant a licence to develop and operate a renewable energy project, and negotiations with the local authority, the transmission company (Eskom in this case) and property owners have been finalised, the investor has the exclusive right to proceed with the project. However, because of the comparatively short construction times for such projects (i.e. a number of months compared with a number of years for conventional power plants), the investor may defer the investment until the relevant prices justify a commitment of funds. This ability to postpone the investment is valued as an option. In addition to this flexibility in investment timing, many renewable projects offer a choice of scale. With the possibility of capacity choice, the investor gains additional value by waiting since different scales may be optimal when prices evolve over time (Boomsma et al., 2012). Restrictions to capacity would include demand, the relevant prices, subsidies, geography and capital.

2.8 Applications of real options to renewable projects

In the last 15 years real options have been adopted as the tool for valuation of renewable investment projects. One of the first applications of real options theory to the renewable energy field dates back to 2002 by Venetsanos et al. They used them for valuing wind power investment projects and for assessing the profitability of wind power plants. Firstly, they considered the uncertainties which are inherent in energy production, then they identified the

[17] Investments in renewable energy are either encouraged indirectly through attempts to internalize external costs like emissions or by direct renewable energy support schemes – feed-in tariffs, certificates, tax credits, portfolio standards and quotas. Governments occasionally alter the choice of support schemes which can cause uncertainty among investors (Boomsma et al., 2012).

real options embedded in a wind energy project, and finally evaluated the project according to real options theory. They compared their results with those from the traditional DCF technique and found that the option value was positive and the NPV was negative! Kjaerland (2007) then used real options to analyse investment opportunities in hydropower in Norway, and to find the relationship between the price level of electricity and optimal timing of investment decisions. Following the same line of research, Bockman et al. (2008) presented a real options-based method for assessing small hydropower projects. In 2009 Munoz et al. developed a model to evaluate wind energy investments using a real options model to evaluate the probabilities to invest, wait or abandon the project. Martinez-Cesena and Mutale (2011) showed that projects planned using real options show higher expected profits than projects using other methods. They also developed an advanced real options methodology for renewable energy generation projects using a hydropower case study. Other studies have also used real options to assess renewable investment decisions (Botterud & Korpas, 2004; Rothwell, 2006; Wang & Min, 2006). Some real option studies have focussed on evaluating the overall benefits of renewable development planning. Using real options in the US, Davis and Owens (2003) estimated the option value of wind power given uncertain fossil fuel prices. Analytical results demonstrate that the DCF method significantly underestimates the PV of renewable technology whereas real options reflect the actual value of renewable technology. Siddiqui et al. (2007) evaluated the real option value of renewable R&D projects under various market risks. The proposed model considers renewable costs, non-renewable costs, R&D expenditure of renewables, abandonment, maintenance costs and demand for renewables. They used a binomial lattice structure arguing that a binomial lattice reveals the economic intuition underlying the decision-making process. Kumbaroglu et al. (2008) proposed a policy planning model while considering renewable and non-renewable costs, availability, capacity, learning rates and construction lead times. The study, based on the Turkish electricity supply industry, discussed a number of different energy allocation policies and provided some valuable insights into the impact of uncertainty on emerging renewable technologies.

The above studies noted that many factors affecting renewable development include non-renewable costs, renewable costs, R&D expenditure, technological advancement and demand for renewables. They also demonstrated that real options are appropriate for evaluating the investment value of renewable technological development. Real options allow the evaluation of uncertainty in policy planning and determining accurately managerial flexibility in a constantly fluctuating investment environment. They also provide decision makers with an approach for effectively responding to changing circumstances and making correct decisions.

3. Data and sampling

3.1 Formulation of hypothesis

The objective of this study is to consider whether the application of a real options model to investments in renewable energy infrastructures will assist with effective decision making in terms of both the value and the timing of the investment (**the application of real options to renewable energy investments in South Africa: the case of solar energy technology for small businesses and individual homeowners**). The study is specific to South Africa and only considers investments made by small businesses and individual homeowners in solar energy infrastructures.

Over the last ten years South African homeowners and businesses have had to endure both rising electricity prices and regular power outages. Not only are they interested in protecting themselves against rising energy costs, but they are also seeking a more reliable source. By investing in such an infrastructure, they are able to hedge energy prices, thus protecting themselves against unpredictable increases in electricity costs, and will be able to better forecast and manage their expenses. Furthermore, they will be contributing towards reducing the country's carbon footprint and, in terms of businesses, creating goodwill by improving their "green" credentials. The renewable energy source of solar has been selected for this study because of the international trend to adopt solar energy in preference to other renewable energy sources, competitive pricing and the potential to become even cheaper as technology improves, ease of installation, and the advantage of scalability. The latter allows homeowners to increase size as and when required and as and when their budgets permit. It is thus available to all and would become even more popular once users are able to sell any excess energy back to the electricity grid (Altman et al, 2011).

The hypothesis is thus: **real options are a useful decision tool when applied to solar energy investments being considered by small businesses and individual homeowners in South Africa**.

The study will observe electricity usage over a six-month period of a number of medium size homes that accommodate families of four/five with household incomes of around R100 000 per month and small businesses that typically generate monthly revenues of around R500 000 per month and then price those usages with the six largest metros and Eskom. Each set of figures, together with the cost of installing a solar infrastructure sufficient enough to generate the required energy, will then be applied to a real options model to determine whether such an installation is cost effective and when the timing of such an installation, within the next two years, is optimal[18]. From these results, the above hypothesis can then be tested.

3.2 Making sense of electricity tariffs

Both Eskom (Eskom, 2017) and municipal tariffs are structured and presented in a very unintelligible way. The consequences are that very few customers are able to understand them, let alone compare them in order to make rational conclusions and choices. In addition, there is a widespread perception that municipal electricity distributors buy electricity from Eskom and then resell it to customers within their area of supply at significantly higher prices than would be the case if Eskom had supplied directly. On closer examination, though, it is clear that this is not the case (Fin24, 2015).

Electricity customers have no choice as to who supplies them with electricity. All electricity distributors, i.e. Eskom and the various municipalities, are geographic monopolies. It is important, then, that pricing between distributors is equitable, rational and non-discriminatory. However, this is not the case. Municipalities have different population sizes and densities, and provide different services to different mixes of low, medium and high income and usage customers. In addition, municipalities have different mixes of domestic, commercial and industrial customers within their geographic areas of supply. There are also different levels of cross-subsidisation between the various customers. All of this results in a wide variance of electricity tariff rates and structures between municipal electricity distributors, and within Eskom distribution. Of the six largest metros (Johannesburg, Tshwane/Pretoria, Ekurhuleni/Germiston, eThekwini/Durban, Nelson Mandela Bay/Port Elizabeth, Cape Town) and Eskom, for limited-capacity supplies, eThekwini offers the lowest tariff and Tshwane the highest, for medium-consumption customers, i.e. in the range of 1000 – 2000 kWh per month, City Power (Johannesburg) provides the lowest pricing and Cape Town the highest, and for

[18] The real options model that will be used is one that has been set up to consider investments over a two-year period only.

high-consumption customers, i.e. in the range 2000 – 3000 kWh per month, again City Power provides the lowest pricing and Cape Town the highest. In these three ranges Eskom is somewhere in between (Fin24, 2015).

For both credit (conventional) and prepaid customers, Eskom and some municipal distributors have inclined block tariffs for electricity consumption where the electricity tariff rates increase depending on the level of usage. While Eskom has only two electricity blocks, other municipalities have more, e.g. City Power has five (City Power, 2017). In addition, both Eskom and some municipal distributors have extra charges, e.g. a credit customer of City Power with a 230 V single-phase option has a fixed monthly service charge, a fixed monthly capacity charge and a Demand Side Management (DSM) levy for any electricity consumed per month that is above the first 500 units. (Table 5 provides an example of such an account.)

Table 5: City Power residential single-phase tariff (conventional).

Assumed usage				1200 kWh
	Maximum size	Usage	Tariff (c/kWh)	
Block 1	500	500	110.65	553.25
Block 2	1,000	500	126.98	634.90
Block 3	2,000	200	136.35	272.70
Block 4	3,000		143.86	
Block 5	300,000		150.91	
Sub-total				1460.85
DSM levy (c/kWh)			2.00	14.00
Service charge				114.57
Capacity charge				337.52
Total charge				1926.94
Avg tariff (c/kWh)				160.58

Source: City Power, 2017.

For City Power's prepaid residential customers, rates are a little higher but they aren't required to pay the service charge and the capacity charge. Hence their average tariff is somewhat lower. (Table 6 provides an example of such an account.)

Table 6: City Power residential single-phase tariff (prepaid).

Assumed usage				1200 kWh
	Maximum size	Usage	Tariff (c/kWh)	
Block 1	500	500	116.16	580.80
Block 2	1,000	500	131.97	659.85
Block 3	2,000	200	141.70	283.40
Block 4	3,000		160.08	
Block 5	300,000		173.48	

Sub-total				1524.05
DSM levy (c/kWh)			2.00	14.00
Total charge				1538.05
Avg tariff (c/kWh)				128.17

Source: City Power, 2017.

City Power's tariffs also differ between residential, agricultural, business/commercial, and large consumers/industrial. Similarly, Eskom's tariffs differ between rural, urban and residential, local and non-local authorities, commercial and non-commercial (public facilities like churches, schools, halls, etc.), and international (Botswana, Mozambique, Zambia and Zimbabwe)[19]. Above all of that, Eskom's three-phase customers have an even more complex set of tariffs to navigate, what with seasonal and time-of-use tariffs having recently been introduced[20]! When one attempts to make any comparisons with renewable energy systems one must also take into consideration the deposits and connection fees that both Eskom and municipal distributors levy.

The current status of tariff structures provide opportunities for small investors and homeowners who are interested in seeking alternative means of providing their own electricity using renewable sources, and possibly even producing excess for resale.

3.3 Sample selection and data

In terms of individual homeowners, the sample was narrowed down to those residing in the middle-class/upper middle-class suburbs of South Africa's six largest metros. Typically, these homes would be between 250 and 400 square meters in size on stands of between 500 and 1500 square meters. The homes would comprise three or four bedrooms and two bathrooms. Each home would have at least two geysers and a fully equipped kitchen. Many of the homes would have a swimming pool. There would be four or five people residing on the property. A sample of three homes was taken from each of the six metros from various suburbs within those metros

[19] For the 2016/17 financial year Eskom's international rates were R0.663 per kWh (Eskom, 2017)! This low rate is attributed to Eskom reducing its regional prices from R0.762 per kWh in order to ensure a competitive and sustainable offering. Increased rainfall within the region resulted in improved availability of electricity from hydro generation.

[20] Eskom's high demand season is between June and August and its low demand season is between September and May. In terms of time-of-use Eskom has peak, standard and off-peak periods. This, then, means that there are six different rates!

that satisfied the above criteria[21]. The municipal or Eskom accounts for each of these homes for the six-month period May 2017 to October 2017 were analysed and the total electricity usage extracted. Since electricity usage of all these homes was within a narrow range it was decided to take an average and round the figure off to the closest 100 kWh. This, it was believed, would make the task of application to the real options model in the analysis a lot simpler. The average electricity usage rounded to the closest 100 kWh was calculated to be 1500 kWh per month. This figure was then used to ascertain the cost of electricity in each of the six metros and Eskom using both the conventional method of payment once an account has been received by the homeowner and the prepaid method if the homeowner has a prepaid meter installed (see Appendix 2). The cost of both conventional and prepaid electricity is the same in all six metros and Eskom except for Johannesburg and Germiston where prepaid electricity is slightly cheaper and, consequently, this study will only consider the conventional method of payment. Table 7 provides a summary.

Table 7: Summary of the cost of electricity in the six largest metros (homeowners).

Usage		**1500 kWh**
Metro	**Conventional**	**Prepaid**
	R	**R**
Johannesburg	2 342	1 963
Pretoria	2 545	2 545
Germiston	2 375	2 352
Durban	2 129	2 129
Port Elizabeth	2 455	2 455
Cape Town	2 866	2 866
Eskom	2 374	2 374

Source: Author.

[21] The reason for such a small sample from each metro is that, when obtaining the data, it was observed that the range of usage was small enough that any further data would not have had any significant effect on the average.

A similar exercise was performed for small businesses that generate monthly revenues of around R500 000 per month and that perform one of the following functions, i.e. services, manufacturing or agriculture. A sample of three businesses was taken from each of the six metros, one from each of the three abovementioned business types. The municipal or Eskom accounts for each of these businesses for the six-month period May 2017 to October 2017 were analysed and the total electricity usage extracted. Usage varied between around 22000 and 30000 kWh depending on the industry and the month/season. Again, for the same reason it was decided to take an average and round it to the nearest 1000 kWh. This yielded an average electricity usage of 26000 kWh per month with an average of 11000 kWh used during standard time, 4000 kWh during peak time and 11 000 kWh during off-peak time. To keep the calculations relatively simple the standard time will be used for the entire monthly usage of 26000 kWh. In the same way as for residential, this figure was then used to ascertain the cost of electricity in each of the six metros and Eskom using pricing from low season only again for simplicity (see Appendix 3)[22]. Table 8 provides a summary.

Table 8: Summary of the cost of electricity in the six largest metros (small businesses).

Usage	**26000 kWh, low season, standard time**
Metro	**Price (R)**
Johannesburg	34 882
Pretoria	31 145
Germiston	31 428
Durban	25 986
Port Elizabeth	25 986
Cape Town	27 577
Eskom	29 454

Source: Author.

Over the last five years or so all six of the metros and Eskom have considered small-scale on-grid solar PV embedded generation where homeowners and small businesses would be

[22] Low season runs for nine months from September until May while high runs for three months from June until August and so dominates at a ratio of 3:1.

permitted to install their own generating capacity in the form of solar PV systems. They would then make any excess capacity available to the electricity grid and either nett off against their consumption or receive a so-called feed-in tariff[23]. Netting off would effectively mean that the provider would buy any excess at the same tariff at which electricity is supplied at that time of day or time of year. A feed-in tariff would not be too dissimilar to the tariff paid to Eskom by the provider. In other words, the provider would be prepared to buy any excess at the same or similar tariff that it pays Eskom for its bulk electricity. The only condition with both of these options would be that the monthly account of the client could either be nett owing to the provider (purchases from the provider exceed generation by the client) or, at best, zero. At no time could the client become a nett generator of electricity for the provider. The client would still be required to pay all standard fees/charges, would need to install a bi-directional utility meter and possibly pay an additional meter reading fee. Table 9 provides a summary of the options currently offered by the six metros and Eskom.

Table 9: Summary of embedded generation options offered by the six largest metros.

Metro	**Embedded option (c/kWh)**
Johannesburg	Residential: 42.79
	Business: 36.14
Pretoria	Approved in principle but not yet finalised
Germiston	Under consideration
Durban	69.28
Port Elizabeth	Nett off
Cape Town	68.89
Eskom	Nett off

Source: Author.

[23] With netting off or "retail net metering" the meters run forward when solar PV clients are purchasing electricity from the grid, the meters stop when those clients produce electricity and consume it on their premises, and when the clients produce more electricity than is consumed on their premises the meter runs backwards. Thus, the clients pay the full tariff for all electricity taken off the grid, pay nothing for electricity when self-consuming electricity produced on their premises, and are paid the full tariff for all electricity exported onto the grid. At the end of the period the meters are read and the clients pay the net balance.

For those resident in metros that offer netting off, the situation is reasonably fair, except that the client cannot become a net generator and through this earn an income. In time, this might change though. For those resident in metros that offer feed-in tariffs this is somewhat limited (in terms of the relatively low tariff and being limited to purchases exceeding generation) but does allow some scope when choosing which solar system to install in terms of capacity and battery storage. For both the netting off and feed-in options, a solar PV system that provided sufficient electricity to satisfy one's average daily consumption would suffice where one could buy any extra capacity required and sell any excess generated, and potentially avoid having to purchase an expensive battery storage system.

3.4 Installing a solar PV system

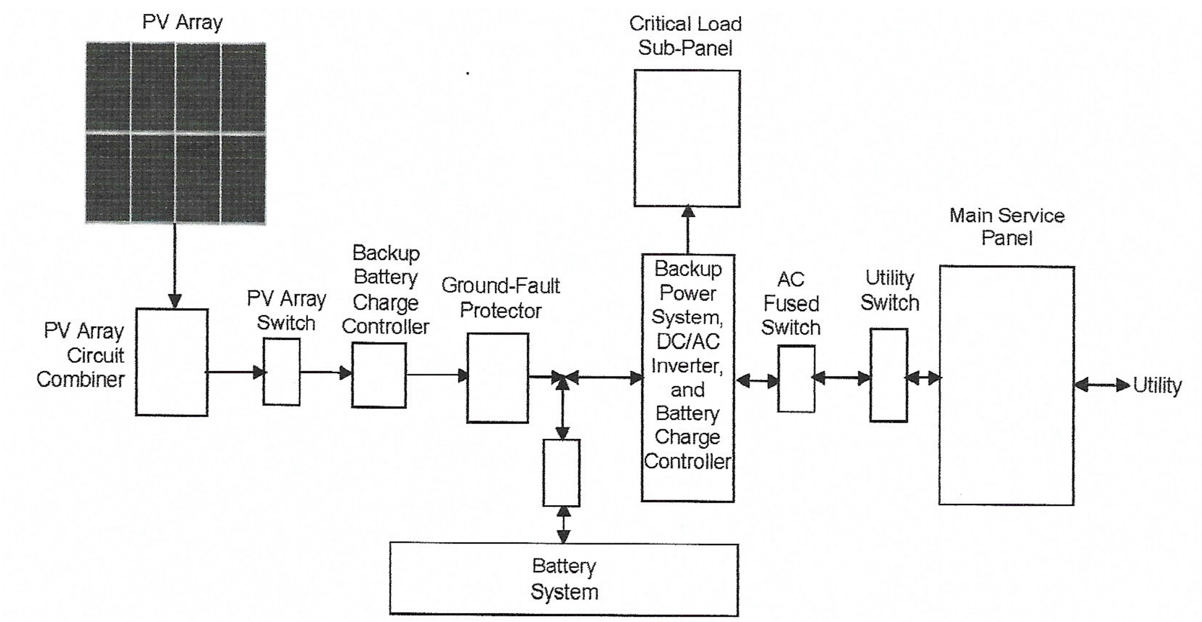
Solar PV systems convert sunlight directly into electricity. These systems allow homeowners and businesses to generate some or all of their daily electricity demand on their roofs and store any excess during the day in batteries for any future energy needs at night or at times when there is inclement weather. An inverter forms part of the system to convert DC current that is produced and stored by the system into AC current that is required by house/building appliances/machinery. The house/building can remain connected to the local provider at all times so that any electricity needed above what the solar system is able to provide, or any excess produced, is then either taken from the local provider or given to the local provider (see Figure 3). A very convenient addition to this system is an application ("app") that can be downloaded onto a smartphone, tablet or notebook to enable one to effectively monitor, control and manage the system from a remote site (California Energy Commission, 2001).

When installing a solar PV system, a number of factors need to be considered in order that the planning and installation are effectively executed. (One needs to remember that PV systems produce power in proportion to the intensity of sunlight striking the solar array surface. This can vary throughout the day and from day to day. Certain factors can affect the output of the system. One needs to understand these so that one has realistic expectations of the overall output and economic benefits under variable weather conditions over time.) Some of these factors that need consideration are:

- Select a system that satisfies one's needs in terms of budget, energy needs and available mounting areas and fits well with the local electricity provider

- Ensure that the roof area or installation site is capable of handling the desired system size otherwise make the necessary structural changes
- Locate the PV array to minimise shading and maximise exposure
- Ensure the location allows for easy maintenance (accumulation of dirt and dust)
- Ensure the system has a minimum of electrical losses
- Ensure the system is not affected too adversely by variable temperatures (California Energy Commission, 2001).

Figure 3: PV system components with battery backup.



Source: California Energy Commission, 2001.

For this study, a number of discussions were held with solar PV system suppliers at their premises and at the African Utility Week held in May 2017 at the Cape Town International Convention Centre (CTICC), where the aim of this study was explained and commitments obtained to supply proposals for the installation of solar PV systems for homeowners and businesses given the respective electricity needs of both (Paragraph 3.3). A general comment made in these discussions was the slow uptake of their solar PV systems as supplementary to the grid system or as independent systems and, consequently, that local prices were still a little inflated. Reasons cited were limited financing options, lack of attractive feed-in tariffs, little encouragement from the Government in terms of tax incentives because of Eskom's woes, and little encouragement from municipalities who benefit from the revenue received from electricity tariffs.

For each of the homeowner's and small business's monthly electricity needs (1500 kWh and 26000 kWh respectively) three proposals were obtained from reputable solar PV system suppliers who conduct business in all six metros. The prices, which included installation, were very similar and so for simplicity once again an average of the three was taken (Appendix 4). Table 10 provides a summary of the relevant material and installation prices.

Table 10: Summary of solar PV system prices.

	R (ex. VAT)
Homeowner (1500 kWh)	
Solar PV generation (PV modules + inverter)	120 000
Minimum system size – 5 kW	
Number of solar panels – 24	
Battery storage (Lithium)	110 000
Total	230 000
Business (26000 kWh)	
Solar PV generation (PV modules + inverter)	1 670 000
Minimum system size – 72 kW	
Number of solar panels – 320	
Battery storage (Lithium)	1 660 000
Total	3 330 000

Source: Author.

3.5 Research methodology

For this study, the real options model demonstrated in Appendix 1 will be used[24]. The model has been designed and set up using Microsoft Excel and is structured in such a way that makes

[24] The model was supplied by Peter Ritchken, after the author showed an interest in Ritchken's presentation and the concept of real options (ACQuFRR, 2016). Similar models

it reasonably easy to use. It has an area where the inputs are captured and then an area where the lattice is situated[25]. The lattice uses three different shades of colour which assist with understanding the outcome. Figure 4 gives a pictorial view of the input area. For a view of the lattice, one can refer to Appendix 1.

Figure 4: Inputs of real options model.

Underlying Volatility (number between 0 and 1)	
Riskless Rate (e.g. 0.05)	
Time to Final Decision (years)	
Number of Increments (per year)	
Discount Rate for Risky Project if all phases are successful (e.g. 0.12)	
Number of Phases	

Phase	1
Duration of Phase	
Cost of Phase	
Expected Benefit of Phase	
Technical Risk (prob. of success)	
Final Project	2
Duration of Phase	Ongoing
Cost of Phase	
Expected PV of Successful Project	
Technical Risk (prob. of success)	1

Source: ACQuFRR, 2016.

were developed by Medez et al (2009) and Lee & Shih (2010) in their respective real options valuations. Both these papers use similar inputs and construct similar lattices.

[25] Binomial lattices or decision trees are used in applications like whether, or not, to undertake a project, or which venture to choose. One must ultimately choose between two competing options which are depicted by decision nodes on a “tree”. The decision is based on the expected outcome of undertaking a particular course of action. Since the events will be determined in the future, their occurrence is uncertain. Decision tree analysis, then, involves forecasting future outcomes and assigning probabilities to those events. The binomial tree would factor in multiple paths that the project can take as time progresses. At every point in time the outcome will be determined by the path taken. A primary advantage of decision tree analysis is that it provides a comprehensive overview for the alternative scenarios of a decision. It is thus very useful in the application of valuing real options (Brandao et al, 2005).

In terms of the inputs, the first of the two input areas will remain unchanged for all of the calculations performed in this study. The relevant data will be captured once only since it is applicable for every one of the cases to be examined. For the second of the two input areas, all of the data will remain the same except for "Cost of Phase" and "Expected PV of Successful Project" in phase 2 which will differ from case to case. An explanation of each of the pieces of data required follows:

- "Underlying Volatility" refers to the volatility of prices related to solar equipment and installation, i.e. the total cost of installation. For this study, the price volatility of labour will be disregarded since wage inflation will probably be offset by a more competitive environment flowing from increased demand. Price volatility of solar equipment, however, will be dependent on foreign supplier prices and the Rand. For the former a value of 10,77% was calculated using price data over a six-year period[26] and for the latter a value of 11,85% will be used[27]. Combining the two as one would in a portfolio where the weights of each are assumed to be 50%, one obtains a combined volatility value of **8.00%**.
- "Riskless Rate" is the risk-free rate. Government bonds are generally deemed risk free because they are backed by the full faith and credit of the government or sovereign state. Most investors feel confident that the government will not default on its obligations to bond holders. In South Africa, the R186 South African Government Bond is the preferable government bond proxy due to its trading frequency. This indicates the bond's liquidity factor and so is widely used as the benchmark rate. For this study, a risk-free rate of **8,40%** will be used[28].
- "Time to Final Decision" is the time lapse between present day and the day that a decision needs to be made whether to invest in a solar PV system, or not. In option terminology, it is the time to expiry of the option. For this study, a time of **2** years will be used. There is no particular reason for choosing two years other than it would be convenient to know whether such an investment would be cost effective in the

[26] The US National Renewable Energy Laboratory (NREL) conducted a study of prices for residential, commercial and utility solar PV installations from 2010 to 2015. They concluded that price changes from year to year could mostly be explained by changes in the price of equipment and that labor cost changes from year to year were negligible.
[27] FxPro publish forex volatility data on a real-time basis. The volatility value of 11,85% was obtained on 25 January 2018.
[28] Standard Bank publish various market rates on a real-time basis. The R186 was offered at 8,40% on 25 January 2018.

next year or two. One could have used five years, for argument sake, but that does seem a little too far in the future for an investment of which one is eager to learn the outcome!

- "Number of Increments" is the number of periods within each year that the investment is being considered. In pictorial form, it is the number of nodes there are per year. For this study, a value of **3** will be used which would equate to a node representing a period of four months. Again, there is no particular reason for choosing three, other than it being convenient to know whether there have been any changes in the decision on a regular four-monthly basis. One could just as well have chosen four (a node would then represent three months) or two (a node would represent six months)!
- "Discount Rate for Risky Project" in this sense is the required rate of return. It is the minimum rate of return that investors would agree to accept for a risky investment. For this study, a rate of **15.00%** will be used. This is the rate used by the South African solar PV industry as an indication of the return one can expect from an investment in such a system.
- "Number of Phases" is the number of phases during the life of the option. In this case it is **2** since the first phase is the purchase of the option and the second the expiry/exercise of the option.
- "Duration of Phase" one is the length of time between the two phases, the purchase of the option and expiry/exercise of the option, or the duration of the option. In this case the period is **2** years.
- "Cost of Phase" one is the price of the option. For this study, an arbitrary value of **R100** will be used. An option is not purchased as such from the installer, but for an installer to keep his price unchanged for two years while a decision is being made might require some sort of financial commitment! Also, a value does need to be made available for completeness of the model.
- "Expected Benefit of Phase" one for this study is **0**. During the life of the option there is no expected benefit. A benefit will only accrue once the investment in a solar PV system is made. That will only occur if the so-called option is exercised and the installation done.
- "Technical Risk" of phase one is **1**. The model states that if there is no technical risk and the probability of success is 100% then to use a value of one. Phase one is

the duration of the option. No decisions have yet been made so there is not yet any technical risk.

- "Duration of Phase" two is set as ongoing. Once the system has been installed its production would be ongoing.
- "Cost of Phase" two is the cost of installing the solar PV system. In this study, this would depend on whether the client is a homeowner or a business, whether a battery system would be required, and whether there is netting off or a feed-in tariff. With the latter, there will be a monthly account from the provider for the difference between the provider's tariff and the feed-in tariff.
- "Expected PV of Successful Project" is the PV of savings expected over a 25-year period where the solar PV system is installed and electricity generated for the client from the system and not drawn from the grid. A period of 25 years is suggested by the industry as the expected life of the system. Again, a discount rate of 15% will be used and, for this study, electricity tariffs over the period will increase at a constant rate of 5% pa[29]. The assumption here is that any expected tariff increases will mostly be offset by increased efficiencies by Eskom and the six metros and that the regulator will base any annual increases on inflation as it did recently for Eskom's next financial year[30].
- "Technical Risk" of phase two is **1**. The model states that if there is no technical risk and the probability of success is 100% then to use a value of one. Phase two is when the option expires or is exercised and when the system could be installed. Solar PV systems are relatively simple to install especially for a business that is well versed in the task and comes highly recommended. For such an installation, the chances of the project not being successfully implemented, if instructed to proceed, is most probably zero!

As an example, then, for an Eskom homeowner where there is netting off of tariffs (the client would not be required to invest in a battery system), the two input areas of the real options

[29] On 18 January 2018 the South African Reserve Bank (SARB), at its Monetary Policy Committee (MPC) meeting, reduced its forecast for consumer price inflation (CPI) for 2018 and 2019 from 5,2% and 5,5% to 4,9% and 5,4% respectively.

[30] On 18 December 2017, The National Energy Regulator of South Africa (NERSA) granted Eskom a 5,23% tariff hike instead of the 19,9% increase requested by the utility. This pricing decision is in terms of an increase tariff for Eskom's clients, effective from April 2018. This does not include the metro increases to their clients. That is a process that is still pending.

model would look like those in Figure 5. Note that the inputs for the first input area will remain the same for all six metros and Eskom for both homeowners and businesses, and that the inputs for the second input area will also remain the same except for "Cost of Phase" and "Expected PV of Successful Project". The "Cost of Phase" will depend on whether the entity is a homeowner or business, whether a battery system is required and whether the provider offers netting off or a feed-in tariff. With netting off, for this study, no battery system will be required because the provider will effectively be acting as an energy storage system. With a feed-in tariff, for this study, again no battery system will be required but there will be an electricity account to settle with the provider on a monthly basis because of the difference between the provider's tariff and the feed-in tariff. The assumption is that the solar PV system installed will only produce enough electricity as is required by the homeowner or business. During times when the system is producing more than is required the excess will be sold back to the grid at the feed-in tariff. When the system is not producing enough any excess electricity that required is then bought from the provider at the provider's tariff. For this study, it will be assumed that 75% of what the system produces will be consumed by the homeowner/business and that there will be a trade with the remaining 25% with the homeowner/business paying the difference between the provider's tariff and the feed-in tariff. The other alternative in this case is to go off the grid completely and purchase a battery system. However, this study will not compare these two alternatives to see which is more cost effective and will leave that for a further study. For those two metros where there is neither netting off nor a feed-in tariff, i.e. Pretoria and Germiston, a battery system will need to be purchased, sufficient to store 25% of average daily energy needs, since they will be required, for this study, to go off the grid. Again, this study will not determine whether it is more cost effective to stay connected to the grid and abandon the option of purchasing a battery system, or whether it is more cost effective to have a combination of both. That will be left for a further study. The "Expected PV of Successful Project" will depend on whether the entity is a homeowner or a business and who the provider is.

Figure 5: Inputs of real options model for Eskom homeowner.

Underlying Volatility (number between 0 and 1)	0,080
Riskless Rate (e.g. 0.05)	0,084
Time to Final Decision (years)	2
Number of Increments (per year)	3
Discount Rate for Risky Project if all phases are successful (e.g. 0.12)	0,15
Number of Phases	2

Phase	1
Duration of Phase	2
Cost of Phase	100
Expected Benefit of Phase	0
Technical Risk (prob. of success)	1
Final Project	2
Duration of Phase	Ongoing
Cost of Phase	120 000
Expected PV of Successful Project	255 574
Technical Risk (prob. of success)	1

Source: ACQuFRR, 2016.

Table 11 provides a summary of the assumptions that will be made in this study for each of the six metros and Eskom.

Table 11: Summary of assumptions of client requirements per metro/Eskom.

Metro	Assumptions of client requirements
Johannesburg	Feed-in tariff, no battery system required, 75% of system production used and 25% traded.
Pretoria	Battery system required sufficient to store 25% of average daily needs.
Germiston	Battery system required sufficient to store 25% of average daily needs.
Durban	Feed-in tariff, no battery system required, 75% of system production used and 25% traded.
Port Elizabeth	Nett off, no battery system required.
Cape Town	Feed-in tariff, no battery system required, 75% of system production used and 25% traded.
Eskom	Nett off, no battery system required.

In final preparation for performing the various calculations using the real options model, it is necessary to establish the "Cost of Phase" two and the "Expected PV of Successful Project" for both homeowners and businesses within each of the six metros and Eskom. To obtain the latter a "Present Value of Growing Annuity Calculator" will be used[31] (Padmanathan et al, 2017). The inputs for the calculator chosen are as follows:

- Payment amount (i.e. the annual payment amount which is 12 x monthly electricity account)
- Payment growing rate per period (i.e. 5% pa in line with inflation expectations)
- Interest rate per period (i.e. 15% pa which is the discount rate suggested by the industry)
- Number of time periods (i.e. 25 years which is the suggested life span of the system) (Jung & Tyner, 2015).

Table 12 and 13 provide summaries of these.

Table 12: "Cost of Phase".

Metro	Homeowner (conventional)	Business
Johannesburg	165 753	2 355 901
Pretoria	230 000	3 330 000
Germiston	230 000	3 330 000
Durban	149 309	1 884 611
Port Elizabeth	120 000	1 670 000
Cape Town	169 306	1 930 096
Eskom	120 000	1 670 000

[31] There are a number of these calculators available on the internet. The one chosen for this study is the one provided by Thecalculator.co. A decision was made to use this particular type of calculator having studied the two papers of Padmanathan et al, 2017 and Jung & Tyner, 2015. In the former the concept of a "growing annuity" is discussed and in the latter each of the inputs is discussed and arguments presented in favour of what numerical values would be appropriate for the calculator.

Table 13: "Expected PV of Successful Project" for homeowner/business.

Metro	Homeowner (conventional)	Business
Johannesburg	252 129	3 755 244
Pretoria	273 983	3 352 935
Germiston	255 682	3 383 402
Durban	229 198	2 797 540
Port Elizabeth	264 294	2 797 540
Cape Town	308 541	2 968 820
Eskom	255 574	3 170 889

4. Results and analysis

As mentioned in chapter 3.5 Research Methodology, the real options model demonstrated in Appendix 1 will be used for this study. For each of the six metros and Eskom, and depending on whether it is a homeowner or a business, the relevant inputs will be made as per Tables 12 and 13. All the other inputs will remain the same for the entire study, as explained in this same chapter. The lattices for each will be observed to provide the adjusted NPV of the project and whether, or not, it would be appropriate to invest in the option, and for signals, if any, of whether, or not, it is appropriate to exercise the option to invest in a solar PV system within the two-year period chosen (here one is looking for nodes where the difference between the payoff and the option is not less than the required investment, i.e. dark blue boxes).

4.1 Results for homeowners for each of six metros and Eskom.

4.1.1 Johannesburg

The lattice for Johannesburg illustrates the following results:

- The expected saving after two years is R252 129, as shown in Table 13. According to the lattice the PV of these savings is R186 781.
- The call option is worth R46 578.
- The adjusted NPV of the investment = -R100 + R46 578 = R46 478. Therefore, investing in the project would be recommended.
- The number of nodes at the end of the two-year period where the difference between the payoff and the option is not less than the required investment, i.e. R165 753, and where the option will be exercised to invest in a solar PV system, is five out of a total of seven. In only two of the cases would the option to invest not be exercised.

4.1.2 Pretoria

The lattice for Pretoria illustrates the following results:

- The expected saving after two years is R273 983, as shown in Table 13. According to the lattice the PV of these savings is R202 971.
- The call option is worth R12 689.

- The adjusted NPV of the investment = -R100 + R12 689 = R12 589. Therefore, investing in the project would be recommended.
- The number of nodes at the end of the two-year period where the difference between the payoff and the option is not less than the required investment, i.e. R230 000, and where the option will be exercised to invest in a solar PV system, is two out of a total of seven. In five of the cases the option to invest would not be exercised.

4.1.3 Germiston

The lattice for Germiston illustrates the following results:

- The expected saving after two years is R255 682, as shown in Table 13. According to the lattice the PV of these savings is R189 413.
- The call option is worth R4 170.
- The adjusted NPV of the investment = -R100 + R4 170 = R4 070. Therefore, investing in the project would be recommended.
- The number of nodes at the end of the two-year period where the difference between the payoff and the option is not less than the required investment, i.e. R230 000, and where the option will be exercised to invest in a solar PV system, is one out of a total of seven. In six of the cases the option to invest would not be exercised.

4.1.4 Durban

The lattice for Durban illustrates the following results:

- The expected saving after two years is R229 198, as shown in Table 13. According to the lattice the PV of these savings is R169 794.
- The call option is worth R43 488.
- The adjusted NPV of the investment = -R100 + R43 488 = R43 388. Therefore, investing in the project would be recommended.
- The number of nodes at the end of the two-year period where the difference between the payoff and the option is not less than the required investment, i.e. R149 309, and where the option will be exercised to invest in a solar PV system, is five out of a total of seven. In only two of the cases would the option to invest not be exercised.

4.1.5 Port Elizabeth

The lattice for Port Elizabeth illustrates the following results:

- The expected saving after two years is R264 294, as shown in Table 13. According to the lattice the PV of these savings is R195 793.
- The call option is worth R94 251.
- The adjusted NPV of the investment = -R100 + R94 251 = R94 151. Therefore, investing in the project would be recommended.
- The number of nodes at the end of the two-year period where the difference between the payoff and the option is not less than the required investment, i.e. R120 000, and where the option will be exercised to invest in a solar PV system, is all seven of them. In none of the cases would the option to invest not be exercised.

4.1.6 Cape Town

The lattice for Cape Town illustrates the following results:

- The expected saving after two years is R308 541, as shown in Table 13. According to the lattice the PV of these savings is R228 572.
- The call option is worth R85 349.
- The adjusted NPV of the investment = -R100 + R85 349 = R85 249. Therefore, investing in the project would be recommended.
- The number of nodes at the end of the two-year period where the difference between the payoff and the option is not less than the required investment, i.e. R169 306, and where the option will be exercised to invest in a solar PV system, is all seven of them. In none of the cases would the option to invest not be exercised.

4.1.7 Eskom

The lattice for Eskom illustrates the following results:

- The expected saving after two years is R255 574, as shown in Table 13. According to the lattice the PV of these savings is R189 333.
- The call option is worth R87 791.
- The adjusted NPV of the investment = -R100 + R87 791 = R87 691. Therefore, investing in the project would be recommended.

- The number of nodes at the end of the two-year period where the difference between the payoff and the option is not less than the required investment, i.e. R120 000, and where the option will be exercised to invest in a solar PV system, is all seven of them. In none of the cases would the option to invest not be exercised.

4.2 Results for businesses for each of six metros and Eskom.

4.2.1 Johannesburg

The lattice for Johannesburg illustrates the following results:

- The expected saving after two years is R3 755 244, as shown in Table 13. According to the lattice the PV of these savings is R2 781 953.
- The call option is worth R790 360.
- The adjusted NPV of the investment = -R100 + R790 360 = R790 260. Therefore, investing in the project would be recommended.
- The number of nodes at the end of the two-year period where the difference between the payoff and the option is not less than the required investment, i.e. R2 355 901, and where the option will be exercised to invest in a solar PV system, is five out of a total of seven. In only two of the cases would the option to invest not be exercised.

4.2.2 Pretoria

The lattice for Pretoria illustrates the following results:

- The expected saving after two years is R3 352 935, as shown in Table 13. According to the lattice the PV of these savings is R2 483 915.
- The call option is worth R0.
- The adjusted NPV of the investment = -R100 + R0 = -R100. Therefore, investing in the project would not be recommended at any stage.

4.2.3 Germiston

The lattice for Germiston illustrates the following results:

- The expected saving after two years is R3 383 402, as shown in Table 13. According to the lattice the PV of these savings is R2 586 406.

- The call option is worth R0.
- The adjusted NPV of the investment = -R100 + R0 = -R100. Therefore, investing in the project would be not recommended at any stage.

4.2.4 Durban

The lattice for Durban illustrates the following results:

- The expected saving after two years is R2 797 540, as shown in Table 13. According to the lattice the PV of these savings is R2 072 469.
- The call option is worth R479 456.
- The adjusted NPV of the investment = -R100 + R479 456 = R479 356. Therefore, investing in the project would be recommended.
- The number of nodes at the end of the two-year period where the difference between the payoff and the option is not less than the required investment, i.e. R1 884 611, and where the option will be exercised to invest in a solar PV system, is five out of a total of seven. In only two of the cases would the option to invest not be exercised.

4.2.5 Port Elizabeth

The lattice for Port Elizabeth illustrates the following results:

- The expected saving after two years is R2 797 540, as shown in Table 13. According to the lattice the PV of these savings is R2 072 469.
- The call option is worth R660 663.
- The adjusted NPV of the investment = -R100 + R660 663 = R660 563. Therefore, investing in the project would be recommended.
- The number of nodes at the end of the two-year period where the difference between the payoff and the option is not less than the required investment, i.e. R1 670 000, and where the option will be exercised to invest in a solar PV system, is six out of a total of seven. In only one of the cases would the option to invest not be exercised.

4.2.6 Cape Town

The lattice for Cape Town illustrates the following results:

- The expected saving after two years is R2 968 820, as shown in Table 13. According to the lattice the PV of these savings is R2 199 356.
- The call option is worth R567 804.
- The adjusted NPV of the investment = -R100 + R567 804 = R567 704. Therefore, investing in the project would be recommended.
- The number of nodes at the end of the two-year period where the difference between the payoff and the option is not less than the required investment, i.e. R1 930 096, and where the option will be exercised to invest in a solar PV system, is five out of a total of seven. In only two of the cases would the option to invest not be exercised.

4.2.7 Eskom

The lattice for Eskom illustrates the following results:

- The expected saving after two years is R3 170 889, as shown in Table 13. According to the lattice the PV of these savings is R2 349 052.
- The call option is worth R937 211.
- The adjusted NPV of the investment = -R100 + R937 211 = R937 111. Therefore, investing in the project would be recommended.
- The number of nodes at the end of the two-year period where the difference between the payoff and the option is not less than the required investment, i.e. R1 670 000, and where the option will be exercised to invest in a solar PV system, is all seven of them. In none of the cases would the option to invest not be exercised.

4.3 Summary of results.

The real options model yielded some interesting results. Table 14 sets out a summary of the results obtained in the real options analysis on the six metros and Eskom. It illustrates the number of nodes, out of a total of seven, at the two-year point that indicate (with the colour blue) whether, or not, the option should be exercised.

It is clearly evident that the structure of the tariffs set out by the six largest metros and Eskom play a vital role as to whether, or not, homeowners and small businesses invest in a solar PV system. There are three distinct structures offered amongst them, although each metro and Eskom offer only one each thus giving them a monopoly in their specific geographical areas.

This is unfortunate for the homeowner/business because, if the structure in their area is not conducive to a solar PV investment, they do not have another alternative. The three distinct tariff structures are as follows:

- A tariff without any solar benefits (Pretoria and Germiston)
- A tariff coupled with a feed-in tariff (Johannesburg, Durban and Cape Town)
- A tariff coupled with netting off (Port Elizabeth and Eskom).

Table 14: Summary of results for homeowner/business.

Metro	Homeowner (conventional)	Business
Johannesburg	5 out of 7	5 out of 7
Pretoria	2 out of 7	0 out of 7
Germiston	1 out of 7	0 out of 7
Durban	5 out of 7	5 out of 7
Port Elizabeth	7 out of 7	6 out of 7
Cape Town	7 out of 7	5 out of 7
Eskom	7 out of 7	7 out of 7

Source: Author.

The results show that those providers using the first tariff structure do not make it attractive for homeowners/businesses to invest in a solar PV system. In fact, for businesses, the real options model provides a result that does not recommend investing at all and, for homeowners, not that much more comfort either. Using the second tariff structure the model provides much more confidence for the homeowners/businesses in terms of investing and, in fact, in one case, that of Cape Town homeowners, the model provides an emphatic “yes”. Using the third tariff structure the model provides an emphatic “yes” in all four cases except for businesses in Port Elizabeth, where confidence in terms of investing is high.

4.4 Analysis of results and confirmation of hypothesis.

The hypothesis set out in 3.1 Formulation of Hypothesis reads: **real options are a useful decision tool when applied to solar energy investments being considered by small businesses and individual homeowners in South Africa**. There is no doubt that real options are useful when applied to a scenario such as that tested above and that this hypothesis holds true. Not only do they guide the homeowner/business in terms of making effective decisions regarding investing in a solar PV system, but also assist with the timing of such investments. These types of investments are relatively costly and so, before committing, homeowners and businesses need to be confident of its success within the geographical area they are situated. If the confidence levels are not that high, and especially if the real options model advises against such investments, homeowners and businesses need to be wary. The two metros where the advice is given against such investments or where confidence is relatively low, are those where no solar energy benefits are offered (Pretoria and Germiston). Investments could be made, but then a costly battery system would need to be set up thus rendering the investment ineffective and costly to abandon. In this study, it should be remembered that a battery system providing back-up for 25% of the client's needs was used. Most experts in the field would advise on a facility with much more back-up, in some case as much as three days' worth! It does seem, then, that the addition of a battery system makes for a very costly installation and the probability of the entire system being cost effective less likely. At the other side of the spectrum, with netting off, it seems that the probability of the entire system being cost effective is high, in fact in some cases, a certainty. In the middle of the spectrum, with feed-in tariffs, the probability of success is reasonably good, with one case a certainty.

It has been shown in this study that real options provide the user with useful information. This information would guard against making an investment that would end up being ineffective and costlier than buying electricity from the relevant provider. The providers offer different tariff structures, some of which encourage investing in solar PV systems either as an ancillary to what the provider offers or to satisfy the client's total electricity needs. This study focused on the latter with two of the groups opting to maintain connection to the providers that offered either feed-in tariffs or netting off. This assisted them with avoiding investing in expensive battery systems. It is clear from his study that clients need the assistance and encouragement of the provider to make investing in a solar PV system cost effective. The clients need to be able to sell any excess generation back to the provider at a reasonable rate or, if possible, at the same rate that the client buys electricity from the provider. Then, when the client needs more electricity than it generates, in the evening for example, it could draw from the provider, thus effectively using the provider as a battery system.

5. Limitations, conclusion and suggestions for further research.

5.1 Limitations of the study.

When attempting to access the data for this study the first port of call was the websites of the respective metros and Eskom. The websites were generally found to be badly organised and confusing, to say the least. Some of them did not even have the latest available tariff structures advertised, i.e. for the financial year 2017/18. That means that they had not been updated in nearly a year! Also, attempting to contact the problematic metros and reach the right person was futile at times. In an attempt to resolve the issue much unnecessary searching and reading was done which eventually did produce the data used in the study in respect of the metros and Eskom. This could give rise to self-selection bias where proper tariffs were not extracted, thereby ensuring that the sample is not representative of the year or category intended. An attempt to be as accurate as possible at all times was still the objective, though.

As far as the data collected for costing the respective solar PV systems, this was collected directly from a number of suppliers and installers, and so the same issue was not experienced here.

This study was also limited in terms of homeowners and small businesses, only the six largest metros and Eskom, the large number of assumptions made and the model itself. This particular model was chosen for simplicity. A unique model could have been developed but that would have ended up being a study on its own! This study also only chose to look at real options in terms of making an investment and ignored the other options, i.e. option to defer, alter, abandon, switch or grow. Those, too, would require studies on their own! The reason for choosing this particular model was the comfort it presented having been developed, made public and used by an academic well versed in the subject.

5.2 Conclusion.

Speaking from an idealist's point of view, South Africa's energy future definitely lies in a decentralised electricity generation system, rather than relying on a single producer, Eskom. Communities should be the owners of their own energy generation. The abundance of solar energy in South Africa should make it possible for entire communities to become energy independent. The vision, then, would be a decentralised energy system focussing on renewables, such as solar panels on roof tops, that would empower households and small businesses where these individuals own these energy systems themselves. Not only would they then be in a position to satisfy their own energy needs, but would also be able to benefit by selling any excess to a service provider, like a local authority, through the electricity grid. This would go a long way to contributing towards conquering the emissions issue which is the responsibility of all countries. Also, both coal and nuclear stations rely heavily on fresh water for cooling purposes thus placing much stress on South Africa's already very depleted and damaged water resources. Renewable energy, with the added potential to reduce water demand and carbon emissions, must hence be at the core of South Africa's energy future. Renewables, especially solar PV and wind energy, present a win-win for both climate and water.

The aim of this study, then, was to determine whether or not the use of the real options approach is valuable in assisting both small businesses and individual homeowners in their quest to decide if and when an investment in a solar energy infrastructure would be cost effective. Not only is the cost of the investment an issue here, but equally so is the timing of such an investment. The study started with a background to the renewables industry and, in particular, in the South African context. This was an attempt to familiarise the reader with the dynamism of the industry and its potential. A review of the relevant literature was then presented as was a discussion on the data used and the methods employed to analyse this data. Conclusions were then drawn and the findings communicated providing a number of recommendations for each of the six metros and Eskom, and for both homeowners and small businesses. What transpired from the study was that the three different tariff structures offered by the different metros and Eskom (clients are restricted in terms of their choice of provider and thus the energy system is one of geographical monopoly) has a huge impact on whether, or not, an investment in a solar PV system is cost effective. The tariff where netting off is permitted offered the most promising results in terms of a successful investment, the feed-in tariff a somewhat mixed bag but tending towards being very positive, and the tariff structure offering neither (Pretoria and Germiston) being rather poor and in some cases recommending no investment at all. The metros and Eskom have historically been rather reluctant to consider encouraging renewable energy investments in their environments because they are so dependent on the revenues from electricity supply. Changes to this attitude are evident but a lot more needs to be done to have all providers move towards a netting off structure, which the study shows presents the most promising results, and where clients can avoid buying expensive battery systems and effectively use the provider as a battery system.

It has been shown in this study that the hypothesis presented in fact holds true and that real options do provide the user with useful information. This information would guard against making an investment that would end up being ineffective and costlier than buying electricity from the relevant provider. It is clear from his study that clients need the assistance and encouragement of the provider to make investing in a solar PV system cost effective. The clients need to be able to sell any excess generation back to the provider at a reasonable rate or, if possible, at the same rate that the client buys electricity from the provider. Then, when the client needs more electricity than it generates it could draw from the provider, thus, as already mentioned, effectively using the provider as a battery system.

5.3 Suggestions for further research.

There is no doubt that the South African energy sector has huge scope for further research and this is very wide and varied. One could start with the National Energy Regulation Act, 2004 and the Electricity Energy Regulation Act, 2006 which are very restrictive and which need a total overhaul in order to accommodate small electricity producers like homeowners and small businesses, not to mention the idea mentioned above of decentralization/deregulation[32]. One could then have a look at the physical infrastructure of South Africa's electricity system to determine how cost effective it presently is and advise in what way changes could be made to ultimately end up with more renewables and less coal and nuclear and to possibly present a holistic plan. This would go a long way in paving the way forward towards a healthier environment with less emissions and better conservation of South Africa's scarce water resources. Then one could assist the industry with rationalising and simplifying the tariff structure and structuring it such a way that is conducive to all participation at whatever level

[32] Stop press: The Minister of Public Enterprises gave Eskom the go ahead on 2 February 2018 to sign outstanding power purchase agreements with independent power producers. This is a big turnaround in Government and Eskom stance in terms of renewable energy and bodes well for the future of the industry.

without having to invest in an expensive battery system. As mentioned earlier in paragraph 3.5 Research Methodology, under the present regime, there is room for further study analysing both feed-in tariffs and netting off and whether, or not, it is more or less efficient employing a battery system, and to what extent.

In terms of real option analysis, since there is a relatively unfamiliar science within South Africa's energy sector, there is room for research in terms of building models that are appropriate to the local conditions. This would assist with answering questions regarding South Africa's issues within this sector, particularly regarding renewables. This study concentrated on solar alone and a narrow client base of homeowners and small businesses. This could be expanded to include other forms of renewable energy such as wind, which is very prevalent in certain parts of the country. It could also be expanded to include other categories of clients and providers. Then there are the different option types mentioned earlier that could be explored, e.g. the option to grow an existing wind farm in the Eastern Cape or the option to abandon power stations, which would be very useful in assisting Eskom with a retirement program for its coal fired power stations, if and when it decided to do so! Also, different option periods could be explored. This study was restricted to a two-year option with three intervals per year.

Finally, in terms of the hardware used to produce and store renewable energy, there would be lots of research opportunities around the equipment and its efficiency and effectiveness under the harsh South African conditions. A very important aspect of a renewable system, and which in this study proved to be crucial in the decision to invest or not, is storage. A number of storage facilities are being experimented with worldwide to determine their cost effectiveness and their efficiency levels. One could research this in a South African context to ascertain which system would be most suitable to the local conditions and which system would make most sense in terms of being financially viable.

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Appendices

Appendix 1: Example of real option analysis.

Example

Consider an investment that requires an initial investment of R100 today. At year 2, based on information obtained, management has an option to invest R1000 in a project. The expected revenues from this project are estimated to be R1200. There is much uncertainty about this number but the fixed costs of R1000 are certain.

Assume the riskless discount rate r is 2% continuously compounded, and that the appropriate discount rate r^* for the expected cash flows generated by the risky project is 8% continuously compounded. Further, assume the volatility of the project to be 25% per year, a relatively large figure given the riskiness of the project.

Calculate the NPV of this project using the traditional approach and then the real option approach.

Traditional approach:

NPV of Phase 1 = -R100
NPV of Phase 2 = -R1000e^{-2r} + R1200e^{-2r^*} = R61.78
NPV of Project = -R100 + R61.78 = -R38.22
Therefore, do not invest in the project.

Real option approach:

						2431.108
						1431.108
					2104.356	
					1111	
				1821.521		1821.521
				834.7658		821.5209
			1576.7		1576.7	
			596.5016		583.3448	
		1364.785		1364.785		1364.785
		406.859		378.0295		364.7847
	1181.352		1181.352		1181.352	
	266.8891		232.0839		187.996	
1022.572547		1022.573		1022.573		1022.573
169.5585478		137.4569		96.52328		22.57255
	885.1342		885.1342		885.1342	
	79.34653		49.39349		10.92134	
		766.1682		766.1682		766.1682
		25.20084		5.2841		0
			663.1917		663.1917	
			2.55662		0	
				574.0558		574.0558
				0		0
					496.9001	
					0	
						430.1145
						0

The first column is today. The last column is at the end of year two. Each column represents a period of four months.

The green boxes contain the value if the investment takes place.

The yellow boxes contain the value of the option conditional on success. At the nodes where the value is zero the project will no longer be considered. All others require management to wait further until such time that the difference between the option and the payoff is not less than the required investment of R1000.

The dark blue boxes are the ones where the option will be exercised to invest since the difference between the payoff and the option is not less than the required investment of R1000.

The first phase is an option that cost R100.

It gives the right after two years to invest R1000 and in return receive the PV of revenues from the project.

The expected revenues after two years are R1200. The PV of these revenues is R1022.57.

The call option is worth R169.56.

The question is whether one would pay R100 to receive something worth R169.56.

The adjusted NPV of Project = -R100 + R169.56 = R69.56

Therefore, do invest in the project!

Using the Black-Scholes model the price of the call option would be R172.17. As mentioned earlier, if the lattice were geared with smaller and smaller time increments, the option price will converge to this Black-Scholes value. In this lattice, a period of four months is used.

Source: ACQuFRR, 2016.

Appendix 2: Residential electricity tariffs for the six largest metros and Eskom.

2a: City Power residential single-phase tariff (conventional).

Assumed usage				1500 kWh
	Maximum size	Usage	Tariff (c/kWh)	
Block 1	500	500	110.65	553.25
Block 2	1,000	500	126.98	634.90
Block 3	2,000	500	136.35	681.75
Block 4	3,000		143.86	
Block 5	300,000		150.91	
Sub-total				1869.90
DSM levy (c/kWh)			2.00	20.00
Service charge				114.57
Capacity charge				337.52
Total charge				2341.99
Avg tariff (c/kWh)				156.13

Source: City Power, 2017.

City Power residential single-phase tariff (prepaid).

Assumed usage				1500 kWh
	Maximum size	Usage	Tariff (c/kWh)	
Block 1	500	500	116.16	580.80
Block 2	1,000	500	131.97	659.85
Block 3	2,000	500	141.70	708.50
Block 4	3,000		160.08	
Block 5	300,000		173.48	
Sub-total				1949.15
DSM levy (c/kWh)			2.00	14.00
Total charge				1963.15
Avg tariff (c/kWh)				130.88

Source: City Power, 2017.

2b: Tshwane residential single-phase tariff (conventional and prepaid).

Assumed usage				1500 kWh
	Size (kWh)	Usage	Tariff (c/kWh)	
Block 1	1 - 100	100	132.70	132.70
Block 2	101 - 400	400	155.30	621.20
Block 3	401 - 650	250	169.20	423.00
Block 4	+ 650	750	182.40	1368.00
Sub-total				2544.90
Environment levy (c/kWh) included			5.50	
Total charge				2544.90
Avg tariff (c/kWh)				169.66

Source: City of Tshwane, 2017.

2c: Ekurhuleni residential single-phase tariff (conventional).

Assumed usage			1500 kWh
	Usage	Tariff (c/kWh)	
Block 1	1500	156.11	2341.65
Sub-total			2341.65
Fixed charge			33.56
Total charge			2375.21
Avg tariff (c/kWh)			158.35

Source: City of Ekurhuleni, 2017.

Ekurhuleni residential single-phase tariff (prepaid).

Assumed usage			1500 kWh
	Usage	Tariff (c/kWh)	
Block 1	1500	156.11	2341.65
Sub-total			2341.65
Fixed charge			10.00
Total charge			2351.65
Avg tariff (c/kWh)			156.78

Source: City of Ekurhuleni, 2017.

2d: eThekwini residential single-phase tariff (conventional and prepaid).

Assumed usage			1500 kWh
	Usage	Tariff (c/kWh)	
Block 1	1500	141.90	2128.50
Sub-total			2128.50
Service charge included			
Total charge			2128.50
Avg tariff (c/kWh)			141.90

Source: eThekwini Municipality, 2017.

2e: Nelson Mandela Bay residential single-phase tariff (conventional and prepaid).

Assumed usage				1500 kWh
	Size (kWh)	Usage	Tariff (c/kWh)	
Block 1	1 - 350	350	130.30	456.05
Block 2	351 - 600	250	157.25	393.13
Block 3	601 - 900	300	173.97	521.91
Block 4	+ 900	600	180.68	1084.08
Total charge				2455.17
Avg tariff (c/kWh)				163.68

Source: Nelson Mandela Bay Municipality, 2017.

2f: Cape Town residential single-phase tariff (conventional and prepaid).

Assumed usage				1500 kWh
	Size (kWh)	Usage	Tariff (c/kWh)	
Block 1	1 - 600	600	169.12	1014.72
Block 2	+ 600	900	205.65	1850.85
Total charge				2865.57
Avg tariff (c/kWh)				191.04

Source: City of Cape Town, 2017.

2g: Eskom residential single-phase tariff (conventional and prepaid).

Assumed usage				1500 kWh
	Size (kWh)	Usage	Tariff (c/kWh)	
Block 1	1 - 600	600	111.69	670.14
Block 2	+ 600	900	179.61	1616.49
Sub-total				2286.69
Network capacity charge (R/day)			2.92	87.60
Total charge				2374.29
Avg tariff (c/kWh)				158.29

Source: Eskom, 2017.

Appendix 3: Business electricity tariffs for the six largest metros and Eskom.

3a: City Power business low voltage tariff.

Assumed usage			26000 kWh
	Usage	Tariff (c/kWh)	
Block 1	26000	94.76	24637.60
Sub-total			24637.60
Service charge			900.36
Capacity charge			804.96
Demand charge (R170.78/kVA)			8539.00
Total charge			34881.92
Avg tariff (c/kWh)			134.16

Source: City Power, 2017.

3b: Tshwane business low voltage tariff.

Assumed usage			26000 kWh
	Usage	Tariff (c/kWh)	
Block 1	26000	81.20	21112.00
Sub-total			21112.00
Service charge			2183.00
Demand charge (R157.00/kVA)			7850.00
Total charge			31145.00
Avg tariff (c/kWh)			119.79

Source: City of Tshwane, 2017.

3c: Ekurhuleni business low voltage tariff.

Assumed usage			26000 kWh
	Usage	Tariff (c/kWh)	
Block 1	26000	92.22	23977.20
Sub-total			23977.20
Service charge			2486.65
Demand charge (R62.05/kVA)			3102.50
Network charge (R37.23/kVA)			1861.50
Total charge			31427.85
Avg tariff (c/kWh)			120.88

Source: City of Ekurhuleni, 2017.

3d: eThekwini business low voltage tariff.

Assumed usage			26000 kWh
	Usage	Tariff (c/kWh)	
Block 1	26000	64.20	16692.00
Sub-total			16692.00
Service charge			3623.40
Demand charge (R85.79/kVA)			4288.00
Network charge (R27.66/kVA)			1383.00
Total charge			25986.40
Avg tariff (c/kWh)			99.95

Source: eThekwini Municipality, 2017.

3e: Nelson Mandela Bay business low voltage tariff.

Assumed usage			26000 kWh
	Usage	Tariff (c/kWh)	
Block 1	26000	64.20	16692.00
Sub-total			16692.00
Service charge			3623.40
Demand charge (R85.79/kVA)			4288.00
Network charge (R27.66/kVA)			1383.00
Total charge			25986.40
Avg tariff (c/kWh)			99.95

Source: Nelson Mandela Bay Municipality, 2017.

3f: Cape Town business low voltage tariff.

Assumed usage			26000 kWh
	Usage	Tariff (c/kWh)	
Block 1	26000	96.06	24975.60
Sub-total			24975.60
Service charge (R86.70/day)			2601.00
Demand charge			
Network charge			
Total charge			27576.60
Avg tariff (c/kWh)			106.06

Source: City of Cape Town, 2017.

3g: Eskom business low voltage tariff.

Assumed usage			26000 kWh
	Usage	Tariff (c/kWh)	
Block 1	26000	95.30	24778.00
Sub-total			24778.00
Service charge	26000	0.37	96.20
Capacity charge (R19.32/day)			579.60
Demand charge	26000	13.46	3499.60
Admin charge (R16.69/day)			500.70
Total charge			29454.10
Avg tariff (c/kWh)			113.29

Source: Eskom, 2017.

Appendix 4: Summary of proposals for supply/installation of solar PV systems

	Solar PV	System	Suppliers	
	A	**B**	**C**	**Average**
Homeowners (1500 kWh)				
Panels	50 376	47 976	51 600	50 000
Inverter	34 233	32 997	27 240	31 500
Consumables	15 356	14 199	11 099	13 500
Installation	24 250	22 500	28 000	25 000
Total	124 215	117 672	117 939	**120 000**
Battery Storage	107 499	111 599	110 499	110 000
Total	231 714	229 271	228 438	**230 000**
Businesses (26000 kWh)				
Panels	655 680	642 880	651 200	650 000
Inverter	456 325	440 850	452 950	450 000
Consumables	204 500	200 275	225 500	210 000
Installation	358 750	325 950	395 000	360 000
Total	1 675 255	1 609 955	1 724 650	**1 670 000**
Battery Storage	1 580 500	1 687 500	1 712 000	1 660 000
Total	3 255 755	3 297 455	3 436 650	**3 330 000**