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The Levelized Cost of Electricity for a Small Scale Solar PV System in South Africa

Colin Ross, James Anthony, MCom CA (SA), and Michael Harber CA (SA)

University of Cape Town

Abstract:

Purpose: *The purpose of this paper is to provide a tentative model to assist a business in South Africa in determining the present cost of producing electricity using a solar photovoltaic (PV) system. This cost can then be compared to the cost of purchasing electricity as most businesses do, i.e. off the power grid from ESKOM. This model is intended to assist the business in perfoming a cost comparison and deciding how it will meet its electricity demands. What is the levelized cost of electricity for a solar PV system in South Africa?Are solar PV systems economically feasible for businesses in South Africa?*

Methodology and Approach: *The two most prominent methodologies used to determine the cost of producing electricity using a solar PV system are using a levelized cost of electricity (LCOE) calculation and using a computer application.This paper adopts the LCOE methodology as this approach allows for more transparent calculations as the formulas used are presented and analysed. The underlying assumptions are also presented when using the LCOE methodology, which allows for the assumptions to be critically analysed.*

Findings: *The present cost of producing electricity from a solar PV system is determined by calculating the levelized cost of electricity (LCOE). The results of a scenario analysis performed on the levelized cost of electricity calculation used in this paper resulted in a reasonable range for the cost of producing electricity using a solar PV system to be between R0.914678 and R2.07 per kilowatt hour (kWh). This result implies that there is currently potential for a solar PV system to be economically feasible for a South African business.*

The economic feasibility of a solar PV system is determined by the specific circumstances a business faces. These circumstances are represented by the variables in the LCOE formula. The results of the sensitivity analysis performed on the LCOE calculation indicates that the cost of producing electricity using a solar PV system is most sensitive to changes in the discount rate, the level of insolation at the location the panels will be placed, the initial cost of the system and the efficiency of the panel. As a result of this the economic feasibility of a solar PV system for an individual business will be determined by the values assigned to these variables by that business given its unique circumstances.

1. INTRODUCTION

South Africa is currently facing an electricity crises with load shedding occurring in 2008 and 2015. Load shedding in this context is defined as the act of reducing the electricity demand on the grid by stopping the electricity supply to certain consumers. Load shedding is occurring in South Africa due to the fact that ESKOM is unable to supply enough electricity tothe grid to meet South Africa's electricity demands.

ESKOM is a South African state owned enterprise that generates approximately 95% of the electricity used in South Africa (ESKOM, 2015). Due to the fact that ESKOM produces the vast majority of South Africa's electricity most businesses in South Africa are forced to obtain their electricity from ESKOM. Poor service delivery, as evidenced by load shedding, and the escalating cost of purchasing electricity from ESKOM makes obtaining electricity from alternative sources a potentially attractive option. The fact that the South African government expects load shedding to continue until 2018 makes alternative sources of electricity even more attractive (Reuters, 2015).

One of the potential alternative sources of electricity is solar photovoltaic (PV) systems. The South African Government has already recognized solar PV systems potential as evidenced by its approval of the installation of solar PV systems with the capacity to produce 1484 megawatts of electricity through the Renewable Energy Independent Power Producer Procurement Program (REIPPPP) (Eberhard, Kolker and Leigland, 2014).

This paper will evaluate whether solar PV systems could also be used by South African businesses to subsidise its use of ESKOM as its sole supplier of electricity. This is achieved by focusing on determining the levelized cost of electricity for a solar PV system. Determining the levelized cost of electricity would enable a business to determine the economic feasibility of using the PV system.

Economic feasibility is determined by comparing the present cost of obtaining electricity from ESKOM over the life of the PV system, to the present cost of obtaining electricity from the PV system. If the net present cost of the solar PV system is less than the net present cost of purchasing electricity from ESKOM over the life of the PV system, the solar PV system is considered to be economically feasible.

Although this paper focuses on the economic feasibility of a PV system it also briefly considers whether a PV system is technically feasible as a source of electricity for a business on a stand-alone basis or as part of a hybrid system.

2. RESEARCH QUESTIONS

The purpose of this paper is to provide a tentative model to assist a business in South Africa in determining the present cost of producing electricity using a solar photovoltaic (PV) system. This cost can then be compared to the cost of purchasing electricity as most businesses do, i.e. off the power grid from ESKOM. This model is intended to assist the business in perfoming a cost comparison and deciding how it will meet its electricity demands.

What is the levelized cost of electricity for a solar PV system in South Africa?

Are solar PV systems economically feasible for businesses in South Africa?

3. LITERATURE REVIEW

This literature review consists of 6 sections that will evaluate the existing body of knowledge surrounding the research questions.

3.1. Generating Electricity Using Solar Energy

There are two broad categories of solar electricity generation, concentrated solar power (CSP) and photovoltaic cells (PV cells). This paper is analysing electricity production for individual businesses in South Africa hence CSP is inappropriate and only PV systems are considered. CSP requires a large amount of flat space to function (Fluri, 2009). Specifically the gradient of the land has to be below 7% for slopes facing South East to South West or below 2% for all other orientations (Fluri, 2009). Further onlyland with an area of at least 2km^{2}is suitablefor CSP systems (Fluri,2009).Most businesses will not have land that meets the requirements for CSP systems and a further problem is that small scale CSP systems are not available in South Africa.

PV systems can be separated into 2 main categories: silicon and polymer. Polymer is less efficient than silicon based cells and polymer also experiences significant degradation (Jorgensen, Norrman and Krebs, 2008 and Mateker, Sachs-Quintana, Burkhard, Cheachareon and McGehee,2015).Polymer PV systems experience two periods of degradation: an initial burn period in which efficiency drops rapidly and then a slower linear degradation (Mateker et al, 2015).The initial burn period is significant and results in the system losing approximately 40% of its starting efficiency in the first 3500 hours of exposure to sunlight after which the linear degradation begins (Mateker et al 2015). Although silicon PV systems do experience a burn period it is both shorter and significantly slower than polymer PV systems (Quintana and King, 2002).

There are numerous reasons for polymer solar cells instability including oxygen from the atmosphere oxidizing the organic layer which causes degradation (Jorgensen et al, 2008). Silicon basedPV systems do not have the same level of deficiencies. As a result of polymer PV systems instability and inefficiency this paper analyses the use of silicon based photovoltaic systems.

3.2. The Development of PV Cells

Across the world PV systems are seen to have potential and as a result there is a large amount of research and development involving this type of system. This has resulted in the cost of PV systems continuously decreasing over time.

In the recent past the cost of solar PV systems has been decreasing in the United States. Davidson, James, Margolis, Fu and Feldman (2014, 10) found that the reduction in the price of solar systems for residential units in the United States (US)between quarter 4 of 2010 to quarter 4 of 2013 was 46%.

Prices have decreased to such an extent in the US that purchasing solar PV systems has become economically rational for individual households. Davidson et al (2014, 13) estimated that in California the fair market value of asolar PV system was $4.59/W in quarter 4 of 2013 and that the cash purchase price was at most $3.98. Hence households were deriving $0.61 per watt installed and used.

The point in time at which the cost of producing electricity using solar PV systems equals the electricity price from the grid is called grid parity. Due to the fact that the cost of producing electricity using solar PV systems is decreasing at a significant rate in real terms makes grid parity a realistic scenario in many countries. Bhandari and Stadler (2009, 1642) estimated that grid parity for the German end user market would be reached between 2013 and 2014 due to grid electricity costs increasing over time whereas PV systems prices decreasing over time.

The cost of producing electricity using solar PV systems is decreasing in South Africa too.Eberhard, Kolker and Leigland (2014, 17) showed that the average bids for the production of electricity using solar PV systems for the Renewable Energy Independent Power Producer Procurement Program (REIPPPP) decreased 68% in real terms from 276c to 88c per kWh from 4 November 2011 to 19 August 2013.

The REIPPPP is a South African governmental project in which the private sector is invited to bid on producing renewable energy from different sources including solar PV. These bids include a return estimated at 17% for projects accepted in 2011 and 13% for projects accepted in 2013 (Eberhard et al, 2014). As a result of this it is clear the actual cost of producing electricity using the solar PV systemwas below the average nominal bid of 99c per kWh as of 19 August 2013.

Reducing the nominal bid price of 99c by 13% provides an estimate for the cost of producing electricity on a large scale using solar PV systems of 87.61c. This cost can be used as a reasonability check for the present cost of the smaller scale PV system that will be used by South African businesses. The cost per kWh of the smaller PV system should be higher than 87.61c asthe smaller systems lack economies of scale.

Further declines in the price of solar PV energy are also predicted. Feldman, Barbose, Margolis, James, Weaver, Darghouth, Fu, Davidson, Booth and Wiser (2014, 14) predict a decrease in price of between 3% and 12% in 2014. Haysom, Jafarieh, Anis, Hinzerand Wright (2014) predict a learning rate of between 12% and 14% for PV systems.

There are numerous factorsthataffect the predicted rate of decrease in the cost of producing electricity using solar PV systems including improved technology, improved production techniques, the average size of PV systems and the cost of silicon (Haysom et al, 2014). System size affects the cost of the electricity produced as the larger the size of the system the lower the fixed cost per watt produced by the system, resulting in a lower total cost per watt.

Silicon costs have the potential to have a large effect on the cost of solar PV panels as it did during the silicon shortage between 2003 and 2006 (Haysom et al, 2014). However a similar shortage is unlikely to occur again due significant increases in manufacturing supply and increased competition (Haysom et al, 2014).

The continuous decrease in the price of PV systems is an important factor in this paper for two reasons. Firstly it creates a timing factor for a business considering whether to purchase a PV system. Any present positive impact the system may have over its life if purchased immediately may be less than the present value of purchasing a system in any subsequent year. Secondly it is an indication that over time solar PV systems will become more economically feasible as electricity prices are on an upward trend whereas solar PV systems prices are on a downward trend.

3.3. Technical and Economic Feasibility of Photovoltaic Systems for use by Businesses

There is not a consensus in current literature as to the technical feasibility of solar PV systems for commercial use. The reason for this lack of consensus can partially be attributed to the different physical locations of the solar projects being examined.

For example southern latitudes within Europe provide an environment where PV systems are technically feasible on a stand-alone basis throughout the year, whereas northern latitudes within Europe would not be technically feasible in the winter months (Kylili and Fokaides, 2014).

The reason for the difference between Southern and Northern latitudes is that during winter the northern locations receive significantly less global irradiance resulting in a lower production of electricity (Kylili and Foakaides, 2014). The level of irradiance has been shown to have a large effect on the amount of electricity a solar PV system generates (Hirata and Tani, 1998).

In a case study done in Norway, a country in the northern latitudes of Europe, a solar PV system was found not to be technically feasible as a stand-alone system. This was due to the fact that although it could meet a business' electricity needs during most of the year, it could not do so in the winter months (Harald Hammer, 2014).

Locations in the Southern latitudes of Europe, where solar PV systems are technically feasible, receive annual global irradiance of between 1406 and 1734kWh/m^2 (Kylili and Fokaides, 2014). This is equivalent to daily global irradiance of between 3.85 and 4.75kWh/m^2. As shown in figure 1 daily solar irradiance is significantly higher in South Africa than in these Southern locations of Europe and hence South Africa appears to be better suited to the production of solar electricity. The average daily solar irradiance in South Africa is between 4.5 and 6.5kWh/m^2 (South African Government, 2014).

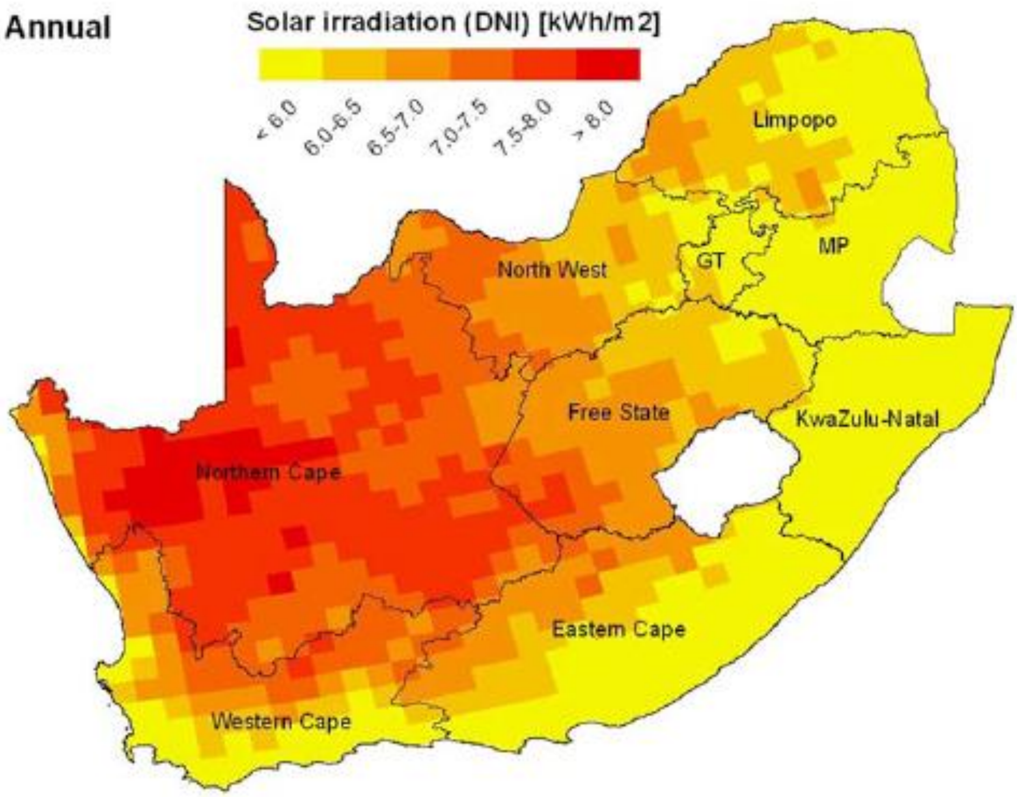

Figure1. *Fluri (2012) – Solar Irradiation in South Africa*

As with technical feasibility current literature also lacks consensus on whether solar PV systems are economically feasible. The differing conclusions surrounding economic feasibility can be partially attributed to both the physical location of the PV system being examined as well as the period in time at which the paper was written. The time at which the paper was written has an effect on the conclusion as the cost of solar PV systems decreases significantly every year.

There are numerous studies that indicate that renewable energy sources (RES) are viable alternative sources of electricity for businesses or remote populations. Dalton, Lockington and Baldock (2008, 955) showed that a renewable energy system, consisting of a solar PV systems and a wind energy conversion system, used by a hotel is technically feasible and economically viable as an addition to a grid-connected supply in Australia. This is as a result of a grid/RES system being more economical than the grid only system over the 20 year life span of the RES system. However the stand alone RES system was shown not to be economically feasible (Dalton et al, 2008).

In Europe Kylili and Foakaides (2014, 12) found that the internal rate of return for small scale solar PV systems was positive for a total cost per watt of up to €4 for European solar PV systems. However Kylili and Foakaides (2014) did not calculate the cost per watt of producing electricity using a solar PV system.Harald Hammer (2014, 3) found that a solar PV system installed by a business would not be economically feasible in Norway, despite the fact that it would have a positive discounted cash flows over its lifetime.

However research has shown that solar PV systems situated in South Africa have potential. Dekker, Nthontho and Chowdhury (2012) aimed to establish whether a hybrid diesel generator-solar photovoltaic system was more economically viable in South Africa than a stand-alone diesel generator system. The paper found that in every climate in South Africa the hybrid system was more economical than the straight diesel generator system (Dekker et al 2012, 110).

From the above discussion it appears that South Africa experiences conditions that are ideal for the production of electricity using solar PV systems given South Africa’s high level of irradiation. In order to determine the potential of electricity generated by solar PV systems in South Africa the cost of producing the electricity must be calculated.Numerous methodologies could be used to quantify the cost of producing solar electricity.

4. Methodology and Approach

The two most prominent methodologies used to determine the cost of producing electricity using a solar PV system are using a levelized cost of electricity (LCOE) calculation and using a computer application.

One such computer application is HOMER which is an energy system optimization tool which can be used to calculate the electricity production of a system as well as the net present cost of the system (National Renewable Energy Laboratory,2011).HOMER requires numerous inputs in order to calculate the net present cost of a solar PV system including the level of irradiation at the location, the cost of the different components of the system and 24 hour load data. Load data is defined as the electricity demanded at a point in time.

The LCOE is a method used to fairly compare energy costs produced by different means (Darling, You, Veselka and Velosa, 2011). The LCOE is the quotient of the present value of the total life time costs of the solar PV system and the life time standard rated electricity output of the solar PV system.

This paper adopts the LCOE methodology as this approach allows for more transparent calculations as the formulas used are presented and analysed. The underlying assumptions are also presented when using the LCOE methodology, which allows for the assumptions to be critically analysed.

4.1. Levelized Cost of Electricity

There are numerous different formulas for determining the LCOE. Two such formulas are (Darling, You, Veselka and Velosa, 2011):

$$nominal\ LCOE = \frac{\sum_{n=1}^{N} \frac{R_n}{(1+DR_{nominal})^n}}{\sum_{n=1}^{N} \frac{Q_n}{(1+DR_{nominal})^n}}$$

Where

Q_n =>electricity generated in year n

R_n =>revenue from electricity sales in year n

$DR_{nominal}$ => nominal discount rate

$$LCOE = \frac{Project\ cost + \sum_{n=1}^{N} \frac{AO}{(1+DR)^n} - \frac{RV}{(1+DR)^n}}{\sum_{n=1}^{N} \frac{Initial\ \ kWh \times (1-SDR)^n}{(1+DR)^n}}$$

Where

AO => annual operation costs

DR => discount rate

RV => residual value

SDR => system degradation rate

N => number of years the system is in operation

Branker, Pathak and Pearce (2011) reviewed the methodology for properly calculating the LCOE for solar PV systems. As a result of the review a formula was developed. This formula will be used to determine the LCOE of solar PV systems in South Africa. The formula as per Branker, Pathak and Pearce (2011, 4472) is:

$$LCOE = \frac{\sum_{t=0}^{T} \frac{(I_t + O_t + M_t + F_t)}{(1+r)^t}}{\sum_{t=0}^{T} S_t \frac{(1-d)^t}{(1+r)^t}}$$

Where:

T =>Life of the project [years]

t => Year t

I_t =>Initial investment =>cost of the system including construction, installation, etc. [$]

M_t => Maintenance costs for t [$]

O_t => Operation costs for t [$]

F_t => Interest expenditures for t [$]

r => Discount rate for t [%]

S_t => Yearly rated energy output for t [kWh/year]

d => Degradation rate [%]

LCOE calculations result in a single number that represents the cost per kWh. However this single number is the result of numerous assumptions which if changed will have a material effect on this cost per kWh (Darling et al, 2011). Due to these assumptions effect on the cost per kWh it is common practice to include a sensitivity analysis when calculating the LCOE so as to provide the cost per kWh under different circumstances thereby implicitly providing a reasonable range.

4.2. Variables in the LCOE Formula

In order to effectively use this formula the different variables must be assigned values that are as accurate as is possible.

The life of a solar PV system is determined by considering the degradation rate and the point at which the system is considered to fail. Typically a system is considered to fail at the point at which the systems initial efficiency has declined by 20% (Jordan and Kurtz, 2012). Efficiency in this context refers to power conversion efficiency of the solar cell which is defined as the percentage of the solar energy to which the cell is exposed that is converted into electrical energy (U.S Department of Energy, 2013). The degradation rate is the rate at which the power conversion efficiency decreases.

Jordan and Kurtz (2012, 1) obtained 2000 degradation rates from literature from the period 1962 to 2012 and then determined the mean and median degradation rates based on this sample. Jordan and Kurtz (2012, 1) found that the mean degradation rate was 0.7% and the median degradation rate was 0.5%. This correlates to lifetimes of 28 and 40 years. Most manufacturers guarantee degradation rates that result in system life times of between 20 and 25 years (Branker, Pathak and Pearce, 2011). As a result of this, this paper uses a life time of 28 years as this life time is both supported by current papers on this topic and is similar to the length of time guaranteed by suppliers.

A 28 year life time implies a degradation rate of 0.7%, hence this is the rate that will be used. It is the mean rate found by Jordan and Kurtz (2012) and as with the life time of the project it is similar to the rate guaranteed by the supplier.

The maintenance and operation costs are typically determined as a percentage of the initial investment. The European Commission (2005, 25) determined that the rate applied to the initial investment would be between 0.5% and 1% as of 2030. Both Bhandari and Stadler (2009, 1638) and Kohle, Kohle and Joshi (2002, 162) used a rate of 1% of the initial investment for operation and maintenance costs when determining the cost of a stand-alone PV system. Darling et al (2011) analysed the assumptions underlying the calculation of LCOE. The paper used an initial cost per watt of $2.7 resulting in a cost per kilo watt of $2700, operation and maintenance costs were considered to vary between $8/kW/year and $20/kW/year, with the most likely cost being $10/kW/year (Darling et al 2011). These estimates correlate to rate of 0.29% and 0.74% of the initial investment with the most likely rate being 0.37%. These results are once again in line with the other two findings.

The next variable to be considered is the yearly rated energy output. This can be determined by using either of the following formulas:

Daily power output = Efficiency x Array area (m^2) x Insolation ($kWh/m^2/day$)

Daily power output = System size (Watts) x Peak Sunshine Hours

Peak sunshine hours = Insolation = Irradiation

In order to calculate the yearly rated energy output the efficiency of the panel must be determined. The highest independently confirmed efficiency for crystalline silicon solar cells is 25.6% ± 0.5% (Green, Emery, Hishikawa, Warta and Dunlop, 2015). It is important to note that each type of silicon photovoltaic solar panel will have a different efficiency. For example the multicrystalline silicon Omni 60/245-265/3BB has an efficiency of 16.21% and the efficiency of Solar Frontier's thin film solar panels goes up to 13.8% (Sinetech, 2015).

Along with cell efficiency the insolation that the cell is exposed to must also be known to determine the yearly rated energy output. There are 6 climate zones in South Africa, each of which has different levels of insolation (Dekker et al, 2012). The 6 zones are as follows:

Zone Description	Major Centre
Cold Interior	Johannesburg, Bloemfontein
Temperate	Pretoria, Polokwane
Hot interior	Makhado, Nelspruit
Temperate Coastal	Cape Town, Port Elizabeth
Sub-tropical Coastal	East London, Durban
Arid Interior	Upington, Kimberly

Dekker et al (2012) – Climate Zones

The levels of insolation shown in table 1 below are obtained from Retscreen International's climate database for one of the major centres in each of the different zones. Retscreen obtains this data from various ground monitoring stations and from NASA's global satellite database. The irradiation at each of these major centres will be used as proxies for the zone in which they are situated.

Table1. *Insolation in major centres within each climate zone*

Town	Cape Town	East London	Pretoria	Nelspruit	Bloemfontein	Upington
Average $kWh/m^2/day$	5.19	4.41	5.48	4.99	5.85	6.17

The final variable needed to determine the yearly rated energy output is the system size in either watts or meters squared. For both of the above formulas the system size is dependent on the electricity needs of the underlying business. As a result the system size is a function of the electricity needs of the business, the level of irradiation and the efficiency of the solar cell.

An alternative simpler and less robust formula suggested by Branker, Pathak and Pearce (2011, 4472) to determine the yearly rated energy output is:

365 days x number of hours the system operates x system size

South Africa on average experiences more than 2500 hours of sunlight per year (South African Government, 2014). However different locations obtain different amounts of sunlight, which will affect the amount of electricity the solar PV system produces. It is important to note that this formula only provides a rough estimate as to what the actual yearly rated energy output is.

All of the methods determining the yearly rated energy output are simplistic. A more accurate method would be to perform a solar resource and temperature assessment and a sun path analysis (Hammer, 2014). This involves collecting information about the daily irradiation at the position where the panels will be placed, the gradient at which the panels will be placed and the effect of shading. Other factors such as resistance and the average temperature at which the cells operate also affect the yearly rated energy output, but are not accounted for in these formulas.

The next variable considered is the discount rate. The discount rate used in the LCOE calculation must be determined by the individual businesses. When determining the discount rate the businesses should consider the required rate of return for this specific project, the purchase of the solar PV system. Using a different required rate of return for each separate project is appropriate as different projects have different levels of risk (Correia, Flynn, Uliana and Wormald, 2011:7-20).

The weighted average cost of capital (WACC) is generally accepted to be the appropriate discount rate as it represents the cost of the next Rand of funding. The formula for the weighted average cost of capital is as follows (Correia et al, 2011:7-4):

$$WACC = K_d(1-t)\left(\frac{D}{V}\right) + K_e(\frac{E}{V})$$

Where

K_d = cost of debt

K_e = cost of ordinary equity

t = marginal tax rate

D = market value of debt

E = market value of equity

V = market value of the firm

The weighting of the different sources of finance, $\frac{D}{V}$ and $\frac{E}{V}$, should be determined by considering the business' target capital structure. If the business has no target capital structure, the market value of the sources of finance should be used and if the market values cannot be determined book values should be used (Correia et al, 2011:7-3).

The cost of debt is determined by multiplying the interest rate charged on the debt by one minus the tax rate (Correia et al, 2011:7-3). This is due to the fact that the interest expense provides a tax shield. In this paper the prime interest rate will be used as a proxy for the interest rate that a business will be charged. The current prime interest rate is 9.5% (South African Reserve Bank, 2015). Hence the cost of debt is considered to be 6.84% (9.5x[1-0.28]).

The cost of equity can be determined using various models such as the capital asset pricing model (CAPM), the dividend discount model or the Fama and French 3 factor model (Correia et al, 2011:7-13). The most commonly used model in South Africa is the capital asset pricing model (Correia and Cramer, 2008). The formula used to calculate the cost of equity using the CAPM is (Correia et al, 2011:7-15):

$$k_r = R_f + \beta(R_m - R_f)$$

Where

k_r = the return required by equity holders

R_f = the risk-free rate

β = the beta of the share

R_m = the return on the market portfolio

In order to determine the project specific WACC the business should consider the project's specific risk characteristics. The solar PV system's returns are independent of the movements on the JSE which is commonly used as the proxy for the market portfolio. This is due to the fact that the majority of the project costs are incurred immediately and these costs are not linked to the market portfolio. Further the output of the project is electricity that is produced based on factors that are independent of the market. As a result the beta of a solar PV system project is 0 resulting in the cost of equity equalling the risk free rate.

A liquid government bond with a similar term to the underlying investment is commonly used as the proxy for the risk free rate (PWC, 2012). Currently the risk free rate for long term investments in South Africa is considered to be the yield to maturity on the R186 government bond (PWC, 2012). The current yield to maturity on the R186 government bond is 8.21% (South African Reserve Bank, 2015).

As a result of this analysis the appropriate discount rate for a solar PV system project will be between the risk free rate and cost of debt. From an investor perspective the solar PV system project is considered to be low risk for the following reasons: approximately 90% of its costs are paid up-front, hence there is low risk that the project costs will differ significantly from that which is budgeted, the market for the projects output is exclusively the company itself so there is no risk that there will not be demand for the output and the efficiency of the system is guaranteed resulting in the systems output being relatively certain.

Another potential investor perspective could be that the project's purpose is to provide electricity and hence the project falls within the general utility industry. As a result of this the investor or business may demand a return that is equivalent to the return expected from a company in the utility sector.

There are no publicly traded general utility companies that trade on the Johannesburg Securities Exchange (JSE), hence there is no industry beta for South African utility companies. In America the general utility beta is 0.59 (Damodaran, 2015). It is reasonable to assume that utility companies would have betas below 1 as the demand for utilities is inelastic and is unlikely to be affected by factors that affect other industries listed on stock exchanges.

If the business requires the solar PV project to provide a return equivalent to that of a utility company a different cost of equity would be calculated. The risk free rate discussed previously is still appropriate, hence the risk free rate would be 8.21%. The project beta would be 0.59 as this is the beta for general utility companies in the United States and is in line with expectations given the nature of the utility industry, as previously discussed. The market risk premium is the premium that the market earns on the risk free rate. In South Africa the premium used in practice varies between 3% and 7% and is based on historical returns (Correia and Cramer, 2008). In practice during 2012 in South Africa the mean premium was 5.35% and the median premium was 5%, hence a premium of 5.2% is reasonable (Correia and Cramer, 2008). Calculating the CAPM based on these assumptions results in a cost of equity of 11.278%.

Other studies calculating the cost of electricity generated using PV panels used various discount rates without any explanation as to the reason for the use of the specified rates. Rehman, Bader and Al-Moallem (2006, 1852) used a rate of 5% for a system in Saudi Arabia and Kohle, Kohle and Joshi (2002, 162) used a discount rate of 10% for a system in India. Due to the fact that the appropriate discount rate is specific to the circumstances a business faces, the rates used in studies outside of South Africa and that are not from the current year cannot be considered to be reasonable for the purpose of this paper.

The remaining variables used in the formula, system size, finance costs and the initial investment are determined without specific reference to literature.

5. THEORY

This section will address the variables used in the LCOE formula that were not addressed in the literature review as well as the present value of purchasing electricity from ESKOM.

5.1. Variables in the LCOE Formula

The system size will need to be determined by the individual businesses. There are numerous factors that should be considered when deciding on the size of the system. Firstly the business will need to decide if it will have a stand-alone PV system or use the PV system to subsidise its electricity use.

Using the PV system to subsidies its electricity use provides the business with greater certainty that its electricity needs will be supplied. This is because the business will obtain its electricity from two separate sources. However given the load-shedding experienced by South Africa it may be beneficial to have a system that could supply the needs of the business independently of the grid, even if a grid-connected system is used. This paper does not consider the use of a stand-alone PV system.

In order to determine the size of the system the business should perform an assessment of its electricity needs. This assessment will determine the peak electricity needs of the business during the day as well as the amount of electricity the business uses over an entire day and an entire year. A distribution of the businesses daily requirements is then created. The size of the PV system is then determined based upon this assessment. This assessment can be performed by the business from which the panels will be purchased and installed.

A simplistic method that can be used to determine the business' electrical demand at the initial stage of the project when determining whether to purchase a solar PV system, is to use the prior year's annual electricity consumption as a proxy for the businesses actual requirements. This assessment will not account for peak daily electricity usage and different levels of electricity used in different periods of the year.

The initial cost of purchasing the PV system is based upon the size of the system. The PV system that will be purchased consists of 3 components the solar PV panels, labour and the balance of the system. The balance of system includes all components of the PV system other than the PV panels. Banker et al (2011, 4475) found that the balance of the system and labour costs represent 50% of the system cost. Sinetech (2015), a South African company that supplies the components of solar PV systems, provides the following formula to determine the estimated cost of a solar PV system:

kWh/day required ÷ 6 x 1000 x 28

The final variable is finance charges. Finance charges represent the expense the business incurs as a result of financing the initial investment. The WACC takes these expenses into account and as a result if the WACC is used as the discount rate finance charges can be ignored in the numerator. However if the discount rate does not take finance charges into account, these charges should be added to the numerator.

5.2. Present Value of Purchasing Electricity from ESKOM

In order to determine the economic feasibility of a solar PV system the cost of purchasing electricity from ESKOM over the life of the system is compared to the cost of producing electricity using a solar PV system. Hence the present value of purchasing electricity from ESKOM must be determined.

Due to the fact that the discount rate used is unlikely to equal the escalation in the cost of purchasing electricity from ESKOM, the present cost of purchasing electricity from ESKOM is not an accurate reflection of the cost of purchasing electricity from ESKOM over the life of the PV system. An accurate present cost can be determined by calculating the weighted average present cost of electricity over the life of the PV system using the following formula:

$$\sum_{i=0}^{27}\left(\frac{current\ cost\ per\ kWh(1+g)^i}{(1+r)^i} \times \frac{1}{28}\right)$$

Where:

g =>annual increase in cost of purchasing electricity from ESKOM

r => discount rate

This formula escalates the current cost of obtaining one kWh from ESKOM by the annual increase in the cost of electricity and then discounts it at the discount rate resulting in the present cost of purchasing electricity in period i. This cost is then multiplied by $\frac{1}{28}$ to weight it appropriately. This process is repeated 28 times, which is the life of the PV system.

The sum of these weighted costs is then calculated which results in the present cost per kWh of purchasing electricity from ESKOM over the life of the PV system.

In order for this formula to be used the current cost per kWh, discount rate and the annual increase in the cost of purchasing electricity from ESKOM must be determined.

In order to determine the cost per kilowatt hour, the business first needs to determine into which category of purchaser it falls in terms of the tariff structure (City of Cape Town, 2015). The business will be a commercial consumer and the cost per kWh will be determined by the electrical capacity the business requires, measured in terms of kilovolt-amperes, and the electricity demanded annually, measured in kWh. An example of the tables used to determine into which category the business falls is provided in table 2 (page 17).

The appropriate discount rate has already been discussed. It has been suggested that the business use its weighted average cost of capital. In order to determine the future increases in the cost of purchasing electricity from ESKOM the process by which those increases are determined must be understood. The process by which the electricity price is set in South Africa is as follows:

- ESKOM or the relevant municipality applies for increases in electricity tariffs to the National Energy Regulator of South Africa (NERSA) (South African Government Department of Minerals and Energy, 2008).
- NERSA considers the application by evaluating the terms of section 16 of the Electricity Regulation Act of 2006. This Act requires NERSA to consider factors such as thecosts expected to be incurred and ESKOM's financing requirements (South African Government Department of Minerals and Energy, 2008).
- Based on this evaluation NERSA decides on the annual rate at which the electricity tariff will increase for the period under question.

In 2013 NERSA approved an annual tariff increase of 8% for the 2013 to 2018 period (NERSA, 2013). For the same period Eskom requested an increase of 16% (NERSA, 2013). However the actual average increases in the cost of electricity for the period 2013 to 2015 was 33% (derived from data supplied by ESKOM). ESKOM has requested an increase in the cost of electricity of 25.3% for 2016 although this request was rejected by NERSA (South African Government News Agency, 2015). Neither the long term approved tariff increases nor ESKOM's long term requests for tariff increases are an accurate estimate of the actual increases realised.

The compound annual growth rate in the price of electricity from 1996 to 2014 is 9% (derived from data supplied by ESKOM). Given the large variability in past increases in the cost of electricity, the inaccuracy of NERSA's and ESKOM's estimates, the transitional state that the South African electricity industry is in and the lack of academic literature on the topic there is no reasonable growth rate that can be used. As a result it is suggested that the current cost of electricity be used as a proxy as for the present cost of purchasing electricity from ESKOM over the life of the PV system.

6. METHOD

The method is broken up into 10 steps:

Step 1 - Determine the Yearly Electricity Requirements

This is achieved by the business either performing an assessment of its annual electricity demand or hiring another business in the industry to do so. As discussed previously the business could also use its prior year's electricity consumption as a proxy.

Step 2 – Determine the Discount Rate

The business calculates its discount rate. A reasonable option for the discount rate is the project specific weighted average cost of capital.

Step 3 – Calculate the Yearly Rated Energy Output per Panel

The business first decides on which panel it will purchase if it were to invest in the solar PV system.

Next it considers the 2 options for calculating the yearly rated energy output of the chosen panel. Calculating both would result in a control to ensure accuracy as the amounts should be equal to one another.

Option 1 – using the panels efficiency and size as well as the insolation for the physical location of the panel

S_t per panel per year = Efficiency x Array area (m^2) x Insolation ($kWh/m^2/day$) x 365

> The efficiency and array area will be supplied by the manufacturer of the panel. For the purposes of this paper the product specifications information was provided by a supplier in order to ensure that realistic and accurate numbers have been used in this paper.
>
> Insolation can be obtained from RETscreen or by determining in which climate zone the business is located and then using the applicable insolation supplied in table 1.

Option 2 – using the systems size in watts as well as the insolation for the physical location of the panel

S_t per panel per year = System size (Watts) x Peak Sunshine Hours x 365 ÷ 1000

> System size in watts will be supplied by the manufacturer of the panel.
>
> Peak sunshine hours = insolation (obtained from RETscreen or table 1 as above)

Step 4 – Calculate the Number of Panels that Need to be Purchased

Panels needed = kWh needed per year ÷ kWh produced per panel per year

Step 5 – Calculate the Initial Cost of Purchasing and Installing the System

Option 1 – Sinetech method

I_t = Annual kWh required ÷ 365 ÷ 6 x 1000 x 28

Option 2 – Branker et al (2012)

I_t = number of solar panels needed x price per solar panel x 2

Step 6 – Calculate the Operation and Maintenance Costs

Operation and maintenance costs are equal to 1% of the initial cost as discussed in the literature review.

Step 7 – Determine the Life of the Project and the Degradation Rate

T = 28 years as discussed in the literature review.

d = 0.7% as discussed in the literature review.

Step 8 – Substitute the Variables into the LCOE Formula

In order to calculate the LCOE generated from a solar PV system this paper uses a formula derived by Branker et al (2012):

$$LCOE = \frac{\sum_{t=0}^{T} \frac{(I_t+O_t+M_t+F_t)}{(1+r)^t}}{\sum_{t=0}^{T} S_t \frac{(1-d)^t}{(1+r)^t}}$$

Step 9 – Determine the Cost of Purchasing Electricity from ESKOM

In order to calculate the present cost per kWh of electricity purchased from ESKOM this paper uses the current cost per kWh as a proxy. This information can be obtained from numerous sources including the ESKOM and City (example City of Cape Town) websites a sample for the City of Cape Town is provided below:

Table2. *City of Cape Town 2015*

COMMERCIAL CUSTOMERS					
SMALL POWER USERS (For supply up to a maximum of 500 kVA)					
SMALL POWER USERS 1 (High consumption - >1000 kWh / MONTH)					
Service charge		R/day		30.00	34.20
Energy charge		c/kWh		126.87	144.63
SMALL POWER USERS 2 (Low consumption - <1000 kWh / month)					
Energy charge		c/kWh		207.97	237.09
OFF PEAK *This tariff is reserved for existing customers only as of 1 July 2012*					
Minimum charge		R/day		100.31	114.34
Energy charge		c/kWh		100.00	114.00

Step 10 – Compare the Cost per Kilowatt Hour of ESKOM and the Solar PV System

The option with the lower cost per kilowatt hour should be chosen.

7. Calculation

Step 1 - Determine the Yearly Electricity Requirements

Assume that there is a business in Cape Town that requires a solar PV system to produce28000 kWh in its first year of operation. This results in the business falling into the high consumption bracket which has a lower cost per kWh than the low consumption bracket as per table 2. Due to the cost per kWh being lower for the high consumption bracket, if the solar PV system is feasible in this scenario it would also be feasible in the low consumption bracket.

Step 2 – Determine the Weighted Average Cost of Capital

$$WACC = K_d(1-t)\left(\frac{D}{V}\right) + K_e(\frac{E}{V})$$

Most business' will have a mix of debt and equity financing and hence the appropriate WACC will fall between the after tax cost of debt 6.84% and the cost of equity either 11.278% or 8.21% depending on the business' assumptions. If the business uses a cost of equity of 11.278% and has a debt to equity ratio of $\frac{2}{3}$ the resulting WACC would be 9.5%. This rate, 9.5%, is the rate assumed for this calculation.

Step 3 – Calculate the Yearly Rated Energy Output per Panel

Assume the business has chosen to purchase JKM260P-60 panels to meet its electricity requirements, if it were to choose to use a solar PV system. The specifications and cost of a JKM260P-60 solar panel were obtained from Sinetech (2015).

Option 1 – using the panels efficiency and size as well as the insolation for the physical location of the panel

S_t per panel per year = Efficiency x Array area (m^2) x Insolation (kWh/m^2/day) x 365

$\therefore S_t = 0.1589 \times 1.65 \times 0.992 \times 5.19 \times 365$

$\therefore S_t = 492.7$kWh

Option 2 – using the systems size in watts as well as the insolation for the physical location of the panel

S_t per panel per year = System size (Watts) x Peak Sunshine Hours x 365 ÷ 1000

$\therefore S_t = 260 \times 5.19 \times 365 \div 1000$

$\therefore S_t = 492.53$kWh

Step 4 – Calculate the Number of Panels that Need to be Purchased

Panels needed = kWh needed per year ÷ kWh produced per panel per year

∴ Panels needed = 28 000÷ 492.5

∴ Panels needed = 56.85≈ 57

Step 5 – Calculate the Initial Cost of Purchasing and Installing the System

Option 1 –Sinetech method

$I_t = 28\,000 \div 365 \div 6 \times 1000 \times 28$

$\therefore I_t = 357\,990.86$

Option 2 – Branker et al (2011)

$I_t = 57 \times 3001 \times 2$

$\therefore I_t = 342\,114$

Average $I_t = (357\,991 + 342\,114) \div 2$

∴ Average $I_t = 350\,052$

Step 6 – Calculate the Operation and Maintenance Costs

Operation and maintenance costs = 0.01 x 350 052

∴ Operation and maintenance costs = 3 500.52

Step 7 – Determine the Life of the Project and the Degradation Rate

T = 28 years as discussed in the literature review.

d = 0.7% as discussed in the literature review.

Step 8– Substitute the Variables into the LCOE Formula

Using an excel spreadsheet results in the following calculation and output

Variables	
Annual Electricity Required	28000
Annual Electricity Generated per panel	492.69679
Insolation	5.19
Panels needed	57
Initial costs	350 052
Operation and maintenance costs	3500.5243
Discount rate	0.095
Degradation rate	0.007
Standard rated energy output	28083.717

Year	$\sum_{t=0}^{T} \frac{(I_t + O_t + M_t + F_t)}{(1+r)^t}$	$\sum_{t=0}^{T} S_t \frac{(1-d)^t}{(1+r)^t}$
0	350052.4338	
1	3345.230455	26743.74091
2	3055.004981	24252.54313
3	2789.958887	21993.40212
4	2547.907659	19944.70165
5	2326.85631	18086.83903
6	2124.982932	16402.03759
7	1940.623682	14874.17655
8	1772.25907	13488.63682
9	1618.501434	12232.16106
10	1478.083501	11092.72688
11	1349.847946	10059.43177
12	1232.737851	9122.388813
13	1125.787991	8272.632047
14	1028.116887	7502.030705
15	938.9195316	6803.211407
16	857.4607595	6169.487605
17	783.0691867	5594.795609
18	715.1316774	5073.636566
19	653.0882898	4601.023844
20	596.4276619	4172.435322
21	544.6827963	3783.770114
22	497.4272112	3431.309336
23	454.2714258	3111.680521
24	414.8597496	2821.825349
25	378.8673512	2558.970385
26	345.997581	2320.600541
27	315.979526	2104.435011
28	288.5657772	1908.405449
	385573.0819	268523.0361

Cost per kWh	1.435903

Step 9 – Determine the Cost of Purchasing Electricity from ESKOM

This is achieved by using the tables supplied by the City of Cape Town (refer to table 2).

Cost per kWh = 144.63 + $\frac{3420 \times 365}{28083.9}$ = 189.07

Step 10 – Compare the Cost per Kilowatt Hour of ESKOM and the Solar PV System

ESKOM's present cost per kWh = 189.07c

PV system's present cost per kWh = 143.59c

The PV system is cheaper and is hence economically feasible. Given these circumstances the business should invest in the solar PV system.

8. Results

As mentioned the LCOE calculation results in a single number that is dependent and highly sensitive to the assumptions used in the calculation. This section of the paper will perform a scenario analysis in order to determine the sensitivity of the LCOE calculation to changes in the underlying variables and in order to determine in which circumstances obtaining electricity from a solar PV system is cheaper than obtaining electricity from ESKOM and vice versa.

Specifically results have been obtained by applying reasonable assumptions to the LCOE calculation that would result in the highest and lowest costs per kWh. This has been done in order to determine the reasonable range for the cost per kWh of producing electricity using a solar PV system. Each variable is also varied individually in order to determine the sensitivity of the LCOE calculation to changes in each of these variables.

Three different discount rates are used. The after tax cost of debt of 6.84%.The cost of equity assuming the business requires the project to make a return that is equivalent to that of utility company, 11.278%. A rate of 9.5% which represents the WACC if the business has a debt equity ratio of $\frac{2}{3}$, a cost of equity of 11.278% and a cost of debt of 6.84%.These rates were used as they represent the range in which the discount rate should fall in terms of the analysis done in this paper.

The location of the panels is set to be in East London and Upington as these locations have the lowest and highest levels of insolation respectively. The initial cost is varied by 12% as this is the rate at which the cost of solar PV systems are expected to decrease year on year (Haysom et al, 2014). The life of the project is varied between 28 and 40 years as these are the life times that correspond to degradation rates of 0.5% and 0.7%, the median and mean ranges calculated by Jordan and Kurtz (2012, 1).Operation and maintenance costs are set at 0.5% and 1% as this represents the range determined by the European Commission (2005, 25).

For the purpose of this analysis the cost of electricity is assumed to be 154.5c ((152+157) ÷2) as this is the average rate for pre-paid commercial electricity users as per NERSA's approved municipal tariff benchmark for the 2014/2015 financial year (NERSA, 2015). The actual rate will depend on the business' municipality, specific electricity needs and the category into which the business chooses to be placed.

It is not appropriate to use the average bid price for solar PV systems from the REIPPPP as the cost of acquiring electricity from ESKOM for a number of reasons. This number only represents the price at which the independent producer will sell electricity to ESKOM and hence excludes transport costs, ESKOM's mark up and numerous other costs. Further ESKOM's current generation capacity is 42 gigawatts, hence the total approved capacity for solar PV systems only makes up 3.5% of the current generation capacity of ESKOM (ESKOM, 2015). Due to the fact that a very small percentage of the total generation capacity of ESKOM will consist of solar generation in the near future it would be in appropriate to base the cost of purchasing electricity from ESKOM on bid prices for solar PV electricity generation.

Table3. *Scenario analysis for the LCOE of a small scale solar PV system*

Conditions	Solar PV cost per kWh	ESKOM cost per kWh
EL 28KkWh EUL 28 OM 1% DR 9.5%	1.560903	1.545
EL 28KkWh EUL 40 OM 1% DR 9.5%	1.469176	1.545
EL 28KkWh EUL 28 OM 0.5% DR 9.5%	1.489004	1.545
EL 28KkWh EUL 28 OM 1% DR 6.84%	1.283636	1.545
EL 28KkWh EUL 28 OM 1% DR 9.5% I_t 12% discount	1.373594	1.545
EL 28KkWh EUL 28 OM 0.5% DR 9.5% Efficiency increased 10%	1.484737	1.545
EL 56KkWh EUL 28 OM 1% DR 9.5%	1.560903	1.545
EL 28KkWh EUL 28 OM 1% DR 11.278% I_t 12% increase Efficiency -10%	2.072389	1.545
UP 28KkWh EUL 28 OM 1% DR 9.5%	1.323637	1.545
UP 28KkWh EUL 40 OM 1% DR 9.5%	1.245853	1.545
UP 28KkWh EUL 28 OM 0.5% DR 9.5%	1.293152	1.545
UP 28KkWh EUL 28 OM 1% DR 6.84%	1.088516	1.545
UP 28KkWh EUL 28 OM 1% DR 9.5% I_t 12% discount	1.1648	1.545
UP 28KkWh EUL 28 OM 1% DR 9.5% Efficiency increased 10%	1.263919	1.545
UP 56KkWh EUL 28 OM 1% DR 9.5%	1.323637	1.545
UP 28KkWh EUL 28 OM1% DR 6.84% I_t 12% discount Efficiency +10%	0.914678	1.545

Where:

EL => East London

KkWh => 1000 kilowatt hours

EUL => Estimated useful life

OM => Operation and maintenance costs

DR => Discount rate

I_t => Initial costs

UP =>Upington

9. Discussion of Results

This section will discuss the results obtained, the effect of simplifying assumptions and the reasonable range for the cost of producing electricity using a solar PV system.

9.1. Sensitivity Analysis

The cost of producing electricity using a solar photovoltaic system varies considerably depending on the variables inputted into the LCOE formula.

Increasing the insolation from 4.41kWh/m^2/day to 6.17kWh/m^2/day (39.9% increase) resulted in the cost per kWh decreasing from R1.560903 to R1.323637 (15.2% decrease). This indicates that the cost per kWh of producing electricity using a PV system is sensitive to changes in the level of insolation, hence it is important that the business obtains a precise measurement of insolation at the position it intends to install the PV system.

The insolation level at which grid parity is reached using the standard assumptions (annual demand of 28 000kWh, project life 28 years, operation and maintenance costs 1% and a discount rate of 9.5%) is 4.454kWh/m^2/day. Inspecting table 1 it is clear that only East London, representing the sub-tropical coastal regions of South Africa, has a lower insolation level than this.

Increasing the estimated useful life (which is equivalent to decreasing the degradation rate) by43% (12 years) resulted in the cost per kWh decreasing 5.87%. Although there is a negative relationship between the life of the project and cost per kWh, the cost per kWh is not sensitive to changes in the life of the project. This is as a result of the length of the project causing the discount factor to be very high near the end of the life of the project (if the discount rate is 9.5% after 28 years the discount factor is 0.0679). This in turn causes any further lengthening of the life of the project to have little effect on the final net present cost per kWh, as the increase in the sum of the costs and the increase in the sum of the standard rated energy output as a result of the lengthened project life is discounted by a large discount factor.

As with the estimated useful life the cost per kWh is not sensitive to changes in operation and maintenance costs. If operation and maintenance costs decrease 50% the cost per kWh decreases by approximately 4.6%. This is due to the fact that operation and maintenance costs make up approximately 9% of the present value of the total life time costs of the systems and are subject to a large discounting factor, hence large changes in the rate applied to initial system costs has a small effect on the cost per kWh.

The cost per kWh is highly sensitive to changes in the discount rate. If the discount rate decreases 28% the cost per kWh decreases 17.76%. This is an indication that each individual business may have very different results depending on the discount rate that it considers to be appropriate. Hence it is important that each individual business performs an analysis before investing in solar panels.

The following table indicates the level of insolation that results in grid parity for different discount rates, assuming the other standard assumptions apply:

Table4. *Level of insolation required for grid parity for different discount rates*

Discount rate	Applicable where	Level of insolation required for grid parity
Prime interest rate after tax = 6.84%	Business is funded wholly by debt financing and the cost of debt is equal to the prime interest rate.	3.181kWh/m^2/day
Risk free rate = 8.21%	Project returns are considered to be independent of JSE returns and the business is funded wholly by equity financing.	3.775kWh/m^2/day
9.5%	Discount rate = WACC. Cost of equity = 11.278%, cost of debt = 6.84%, equity weighting of 60% and debt weighting of 40%.	4.455kWh/m^2/day
11.278%	The business requires the project to provide a return that is equivalent to that of a utility company and the business is wholly financed by equity.	5.685kWh/m^2/day

Comparing the required level of insolation per the above table (table 4) to the level of insolation in each climate zone (table 1) provides insight as to which climate zones in South Africa have potential for the installation of small scale solar PV panels. If the after tax prime interest rate or the risk free rate is used as the discount rate all climate zones would be economically feasible as they all have levels of insolation above the level required to achieve grid parity. If a rate of 9.5% is used as the discount rate only the sub-tropical coastal regions would not be considered viable per the above table. Finally if 11.278% is used as the discount rate only the cold interior and arid interior would be economically feasible, if the assumptions presumed in the table are used.

The reason that the cost per kilowatt hour is sensitive to changes in the discount rate is due to the fact that a large proportion of the systems life time costs are incurred at initiation of the project (91% for Cape Town under the standard conditions) and as a result are wholly unaffected by the discount rate. Whereas the yearly rated energy output is heavily affected by the discount rate as every year the output is subject to a discounting factor.

The cost per kWh is also sensitive to changes in efficiency of the panel. Assuming that a panel could be purchased that is same in every way to the JKM260P-60 except it had an efficiency that was 10% better than the JKM260P-60 the cost per kWh would decrease by approximately 4.87%. The reason for this sensitivity is the fact that the efficiency of the panel has a large effect on the amount of electricity the panel produces, which in turn has a significant effect on the cost per kWh.

The cost per kWh is even more sensitive to changes in the cost of the panel. For example if the business could acquire a panel that was the same in every way to the JKM260P-60 except that it was 12% cheaper the cost per kWh would decrease by about 12%. This is due to the fact that the initial cost of the system would be 12% cheaper and given that these costs represent approximately 91% of the present value of the total life time costs of the system this discount would have a significant effect. Operation and maintenance costs are also reduced by a lower initial cost which further amplifies the benefit of the discount.

It is important to note that as previously discussed the learning curve for solar PV systems is expected to be between 12% and 14% (Haysom et al, 2014). Hence if a PV system is purchased in 2016 the business can expect the initial costs to be between 12% and 14% cheaper than they are in 2015, resulting in a reduction in the cost per kWh of between 12% and 14%.

In terms of the model used in this paper increasing the annual electricity demand has no effect on the cost per kWh of the PV system. This is as a result of a simplifying assumption that allows the model to be used generally. This assumption relates to the formulas used to determine the initial cost of the system.

9.2. Unrealistic Assumptions

The Branker et al (2011, 4472) formula assumes that there are no economies of scale, which in reality there are. For example a portion of the balance of the system are fixed or stepped fixed costs with respect to the amount of electricity that needs to be produced, as a result the more electricity that needs to be produced the lower the cost per kWh will be. Hence this formula is slightly unrealistic. The formula used by Sinetech assumes a constant cost per kWh, which is unrealistic for the same reasons discussed for the formula suggested by Branker et al (2011).

There are other simplifying assumptions that affect the results. As mentioned using a single level of insolation for a climate zone is not completely accurate as within each zone there will be different levels of insolation at different locations. Numerous factors could cause this including shade or higher humidity (Dekker et al, 2012). This would affect the amount of electricity the panels produce.

This paper also assumes that the systems are completely efficient which is not realistic. Numerous factors affect the efficiency of the system including the temperature at which the system operates and the amount of dust that is present at the panel's location.

9.3. Reasonable Range

Given the sensitivity of the cost per kWh to the assumptions used it is recommended that businesses perform a scenario analysis to determine a reasonable range and base their decisions on that range.

The reasonable range is determined by selecting and adjusting variables, which have a major impact on the cost per kWh and are subject to change, in such a manner as to minimise or maximise the cost per kWh. In terms of the research performed in this paper, in general, given the conditions applicable in South Africa the reasonable range for the cost of producing electricity using a solar PV system is between R0.914678 and R2.07 per kWh (as per table 3).

The LCOE is sensitive to changes in the following variables: the initial cost of the system, the efficiency of the panel, the discount rate and the level of insolation. Hence these are the variables that should be adjusted when a business is performing its sensitivity analysis.

10. Scope for Further Research

Wherever there are unrealistic assumptions there is scope for further research. For example research could be performed in order to further split the different climate zones based on the levels of dust present and then determine the effect of dust on the level of electricity produced.

There is also scope to further research the specific business decision. For example research could be performed to determine the ideal time to invest in a solar PV system. This is an important decision as once a system is purchased there is no option to exit the project, however every year the cost of the system is decreasing and its efficiency is improving. However at the same time as the systems cost is decreasing the cost of purchasing electricity from ESKOM is increasing. As a result there is a trade-off between buying the system immediately and acquiring electricity at cheaper rate from this point in time and buying the system later at a cheaper cost but paying more to purchase electricity for the present period.

There is also scope to research the economic rationality of investing in a stand-alone system. This system will cost more than the grid connected system, but will also provide a more secure source of electricity and will completely eliminate the opportunity cost of having to close down the business due to load-shedding.

The benefits associated with using a solar PV system can also be researched further. For example research can be done to determine the opportunity cost savings of not having to close down the business as a result of load shedding if a stand-alone system is used.

Solar PV systems could also receive certain tax breaks. For example S12B - deductions in respect of certain machinery, plant, implements, utensils and articles used in farming or production of renewable energy, S12K – exemption of certified emission reductions and S37B – deductions in respect of environmental expenditure of the Income Tax Act would reduce the costs of the solar PV system.

There are also non-financial benefits that could be researched. For example the reduction in pollution as a result of using renewable energy, the meeting of renewable energy targets, the reduction on the reliance of coal and the opportunity for employment as a result of a strong renewable energy sector.

Further research can also be performed on the cost of purchasing electricity from ESKOM. For example there does not appear to be any research on the long term price path of the cost of purchasing electricity from ESKOM. Research can also be done to determine in which category a business should decide to be placed in order to be most economical in purchasing electricity from ESKOM, given the different tariff structures in the different municipalities.

11. Conclusion

The results of this paper suggest that only sub-tropical coastal regions of South Africa do not have sufficient insolation to make it economically rational for a business to install a solar PV system provided the standard assumptions are valid. This conclusion was reached by comparing the cost of electricity purchased from ESKOM to the cost of producing electricity using a solar PV system in the 6 different climate zones in South Africa.

Hence this paper tentatively suggests that businesses outside of sub-tropical coastal regions in South Africa that have the required area to install solar panels should perform an analysis to determine whether a solar PV system should be installed given the business' specific circumstances.

There are numerous factors that have a significant effect on the cost of producing electricity using a solar PV system. These include the initial cost of the system, the efficiency of the solar panel, the level of insolation at the specific location the solar panel will be installed and the discount rate used by the business. These four factors will have the largest impact on whether it would be economically rational for a business to invest in a solar PV system.

If a business were to find that currently it was not economically rational to invest in a solar PV system, it should still consider whether it may be rational in the future. This is due to the fact that the cost of solar PV systems is decreasing over time whereas the cost of purchasing electricity from ESKOM is increasing over time.

There are also numerous benefits that have not been accounted for in the method used in this paper. These include potential tax breaks, opportunity cost savings and benefits to the environment.

This paper aimed to provide a tentative general model that would assist a business in determining the present cost of producing electricity using a solar PV system and the cost of purchasing electricity from ESKOM. The general nature of the model required certain simplifying assumptions to be made and as a result the output of this model is an estimation and should not be seen as the absolutely correct cost. It is recommended that instead of using a single cost per kWh to make a decision, businesses should make use of scenario analysis to determine a reasonable range and base its decision on that. In general the reasonable range for the cost of producing electricity using a solar PV system in South Africa is estimated to be between R0.914678 and R2.07 per kWh in terms of the research performed in this paper.

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AUTHORS' BIOGRAPHY

Colin Ross, is an associate lecturer at the University of Cape Town, in the College of Accounting. His research interests are in the area of accounting, corporate and investment finance and management accounting.

James Anthony, is a senior lecturer at the University of Cape Town, in the College of Accounting and he teaches postgraduate classes in management accounting and finance. His research interests are in the fields of management accounting.

Michael Harber, is a lecturer at the University of Cape Town, in the College of Accounting and he teaches postgraduate classes in corporate governance and auditing. His research interests are in the fields of accounting, corporate governance and auditing.