A FINANCIAL MODEL TO EVALUATE SOLAR POWER IN FREE STATE DAIRY FARMS

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LIST OF ABBREVIATIONS AND ACRONYMS

AC	Alternative current
AGM	Absorbed glass mat
COP17	United Nations' 17^{th} Conference of the Parties
DC	Direct current
DOE	Department of Energy
Ed	Average daily electricity production from the given system
Em	Average monthly electricity production from the given system
GW	Gigawatt
Hd	Average daily sum of global irradiation per square metre
Hm	Average monthly sum of global irradiation per square metre
IPCC	Intergovernmental panel on climate change
IPPPP	DOE's Independent Power Producers Procurement Programme
IRR	Internal rate of return
kW	Kilowatt
kWh	Kilowatt-hours
m	metre
MPO	Milk Producers' Organisation
MPPT	Master power point tracking
NERSA	National Energy Regulator of South Africa
NPV	Net present value

PPI	Producer price index
PV	Photovoltaic
PV GIS	The European Commission's Photovoltaic Geographic Information System
SARS	South African Revenue Service
SPP	Straight payback period
TKAG	Treasure the Karoo Action Group
TOU	Time-of-use
Wh	Watt-hours

ABSTRACT

Amidst a global drive towards renewable energy South Africa still depends on coal-fired power stations to supply over 90% of its electricity supply. The country is struggling to keep up with electricity demand, and has experienced extreme electricity tariff increases and intermittent supply of electricity over the last eight years. Well-above-inflation electricity tariff increases are expected in the coming years. One of the energy-intensive industries that have been particularly hard hit by recent electricity tariff increases is the dairy industry. One of the problems that dairy farmers face is that escalating electricity prices have negative impact on profitability and are contributing to the rising number of milk producers leaving the industry. One of the renewable energy sources available to dairy farmers is solar photovoltaic (PV) energy. The primary objective of this study was to develop a financial model to evaluate the viability of own-generated solar power on Free State dairy farms.

Literature on different designs of solar PV systems and global applications thereof in the dairy industry was reviewed. Literature was also reviewed on financial tools that could be used to evaluate solar power, in particular, the simple payback period (SPP), internal rate of return (IRR) and net present value (NPV).

This study was a qualitative study that studied a small, medium and large dairy. The electricity consumption at each dairy was measured a half-hourly over a period of one year and interviews were conducted with each participant. The data collected was used in conjunction with information provided by the literature review. Software modelling was used to design a solar PV system that ideally suits the needs of each dairy. After this the SPP, IRR and NPV were calculated for the proposed solar system of each dairy and a cash-flow analysis was done for each dairy. All calculations were done on an after-tax basis. Since the productive life pan of a solar PV system is typically in excess of 25 years, an investment in such a system is typically an extremely-long-term investment, which requires a high capital outlay. It is difficult to predict the key variables that impact on the model over such a long period. Therefore scenario analyses were used in the model to predict the financial viability of a solar PV system for each dairy in a medium, worst- and best-case scenario.

Based on the results of the model it was concluded, firstly, that the Eskom tariff structure has a significant impact on the viability of solar PV systems for Free State dairy farms. Dairies that bought electricity at high tariffs during the times when most electricity was needed in the dairy resulted in significantly more positive financial indicators for a solar PV system. Secondly, it was concluded that in most scenarios an investment in a solar PV system would be financially viable (i.e. positive NPV, IRR greater than the prime interest rate and short payback periods relative to the system's productive life span), unless the key variables follow the trend of the worst-case scenario for solar power. Lastly, it was concluded that, based on the cash-flow analyses, the projected cash flows are largely positive for all three researched dairies in the medium and best-case scenarios and negative in the worst-case scenario.

The model developed in this study contributes to the knowledge base of the South African dairy industry and it can be used as a tool by the industry to evaluate solar power for dairy farms, and influence business decisions.

Key terms:

Financial, Model, Solar, Photovoltaic, Power, Dairy, Farms, Renewable, Energy, System

OPSOMMING

Ten midde van 'n wêreldwye neiging na hernubare energie is Suid-Afrika steeds afhanklik van steenkool kragsentrales vir die opwekking van meer as 90% van die land se energie. Die land sukkel om by te bly met die groeiende vraag na elektrisiteit, en het die laaste agt jaar buitensporige elektrisiteitstarief-verhogings en beurtkrag ondervind. Hoër as inflasie stygings in elektrisiteitstariewe word in die komende jare verwag. Een van die energie-intensiewe industrieë wat die negatiewe effek van stygende elektrisiteitstariewe tot 'n groot mate ondervind, is die suiwelindustrie. Een van die probleme wat melkboere ondervind, is dat stygende elektrisiteitstariewe 'n negatiewe impak op hul winsgewendheid het, en dit dra by tot die stygende aantal melkboere wat die industrie verlaat. Een van die hernubare energiebronne beskikbaar vir melkboere is solar fotovoltaïese energie (sonkrag). Die primere doel van hierdie studie was om 'n model te ontwikkel om die finansiele lewensvatbaarheid van sonkrag vir Vrystaatse melkplase te evalueer.

Literatuur oor ontwerpe van verskillende sonkragstelsels en die wêreldwye aanwending daarvan in die suiwelindustrie is bestudeer. Literatuur oor finansiële metodes om sonkragstelsels te evalueer, in besonder die eenvoudige terugbetalingstydperk, die interne opbrengskoers en die netto huidige waarde, is ook bestudeer.

Hierdie was 'n kwalitatiewe studie, wat 'n klein, medium en groot melkery gekies het vir die navorsing. Elektrisiteitsverbruik is halfuurliks vir 'n tydperk van een jaar by elke melkery gemeet, en onderhoude is met elke deelnemer gevoer. Die data wat versamel is, is saam met die inligting wat deur die literatuurstudie verkry is, gebruik en sagteware modellering is gebruik om die ideale sonkragstelsel vir elke melkery te ontwerp. Vervolgens is die terugbetaaltydperk, interne opbrengskoers en netto huidige waarde van die voorgestelde sonkragstelsel vir elke melkery bereken en 'n kontantvloei-analise uitgevoer. Alle berekenings is op 'n na-belasting basis gedoen. Aangesien die produktiewe leeftyd van 'n sonkragstelsel tipies meer as 25 jaar is, is 'n belegging in so stelsel normaalweg 'n langtermynbelegging wat 'n hoë kapitale uitset vereis. Dit is moeilik om die sleutelveranderlikes wat 'n impak het op hierdie model oor so 'n lang periode te voorspel.

Daarom is ‘n scenario-analise in die model gedoen om die finansiele lewensvatbaarheid van die sonkragstelsel te beoordeel in ‘n medium, beste en slegste scenario.

Gebaseer op die uitslae van die model is die eerste gevolgtrekking dat die Eskom-tariefstruktuur ‘n beduidende invloed op die lewensvatbaarheid van sonkrag op Vrystaatse melkerye het. Die model het beduidend meer positiewe finansiele uitslae voorspel vir ‘n sonkragstelsel vir die melkerye wat hoër Eskom tariewe betaal gedurende tye van die dag wanneer die meeste elektrisiteit gebruik word. Die tweede gevolgtrekking is dat ‘n sonkragstelsel in die meeste scenarios ‘n goeie belegging sal wees (positiewe netto huidige waarde, interne opbrengskoers hoër as die prima uitleenkoers en relatief kort terugbetaaltydperk in vergelyking met die produk se produktiewe leeftyd), behalwe as die sleutelveranderlikes die neiging van die slegste scenario vir ‘n sonkragstelsel volg. Die laaste gevolgtrekking is dat, gebaseer op die kontantvloei-analise, die geprojekteerde kontantvloei grootliks positief was in die medium en beste scenarios vir al drie melkerye wat by die navorsing betrokke was, en nagatief in die slegste scenario.

Die model wat in hierdie studie ontwikkel is dra by tot kennis van die Suid-Afrikaanse suiwelindustrie en dit kan as hulpmiddel deur die industrie gebruik word om sonkrag vir melkplase te evalueer en besigheidsbesluite te beinvloed.

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

You see, we should make use of the forces of nature and should obtain all our power in this way. Sunshine is a form of energy, wind and sea currents are manifestations of this energy. Do we make use of them? Oh no! We burn forests and coal, like tenants burning down our front door for heating. We live like wild settlers and not as though these resources belong to us. (Thomas A. Edison, 1916)

Today, nearly 100 years after Thomas Edison had this insight, the world still depends on fossil fuels (oil, coal and natural gas) for 78.2% of its total energy supply, followed by 19% from renewable sources, of which 9.3% is from traditional biomass (for example in open fires and stoves) and 9.7% is from modern renewables such as wind and solar power. Nuclear power accounts for 2.8% (Renewables Global Status Report, 2013, p. 19). The current global energy consumption breakdown is shown in Figure 1.1.

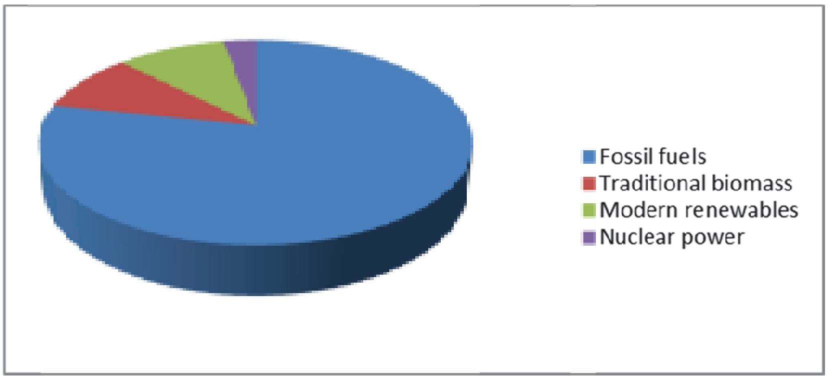

Figure 1.1: World energy consumption (Renewables Global Status Report, 2013)

There is a growing global consensus that consumption of finite resources, such as oil, natural gas and coal as primary energy sources, is not sustainable (Hall, Powers & Shoenberg, 2008; Hanlon & McCartney 2008; Lloyd & Subbarao 2008; Pushker & James, 2008). These researchers all argue that peak oil production will be reached in the near future and once this point has been reached there will be an irreversible decrease in oil production. Exactly when this peak will occur is difficult to determine and subject to speculation. As natural gas production is, to a large extent, closely linked to oil production, it is argued that the peak of gas production will occur shortly after the peak of oil production (Li, 2007, p. 453). There is general consensus that coal has a much longer-term outlook than oil and natural gas. According to Li (2007, p. 454) the world's supply of coal could last until the end of this century (on a lower estimate) or until the mid-22nd century (on a higher estimate), assuming that consumption grows at 2% per year.

Climate change and global warming are causing governments around the globe to enforce severe limitations on the consumption of fossil fuels long before supply runs out. The potentially catastrophic consequences of global warming have been debated for many years; these consequences include changes in weather patterns, rising sea levels, an increase in the occurrence and intensity of natural disasters and a decline of food production. Data shows that most of the main indicators of climate change follow a worse trend than the worst-case scenario published by the United Nations' Intergovernmental Panel on Climate Change (IPCC) in 2007 (Det Norske Veritas, n.d., p. 20). Governments across the globe are engaged in finding solutions for climate change, as was seen at the United Nations' 17th Conference of the Parties (COP17) in Durban, which took place in November 2011. According to the IPCC's most recent report, published in April 2014, a "massive shift" to renewable energy is required in order to meet the United Nations' target of limiting global warming to below the two degree level (McGrath, 2014). The report states that the use of renewable energy has increased dramatically over recent years and it is becoming economically competitive with fossil fuels. Not since the Marshall Plan, which was designed to uplift struggling economies in Europe after the Second World War, has there been such a well coordinated and worldwide effort to solve a global problem – in this case global warming (Femia & Caitlan, 2012; Thorning, 2006).

1.2 BACKGROUND

Eskom is a company wholly owned by the South African government and it is South Africa's primary electricity supplier. According to the Department of Energy (2012) almost 90% of the country's electricity is generated by means of coal-fired power stations. The nuclear power station at Koeberg, near Cape Town, generates 5% of South Africa's electricity, and a further 5% is generated by means of hydroelectric and pumped storage schemes (Department of Energy, 2012). In the light of global warming and climate change the debate about future sources of energy is intensifying, especially regarding "clean" technologies, such as nuclear energy and renewable energy. There is significant pressure on governments to move away from carbon-intensive energy generation, and this pressure is, for the first time, reflected in policy decisions being made in South Africa (Spencer, 2011, p. 42). The country has experienced recent increases in renewable energy generation, and in particular solar photovoltaic (PV) and wind generation. New coal-fired power stations, in particular Madupi and Kusile, are destined to come online within the next few years and coal will, in all likelihood, remain the main source of electricity in South Africa for many years to come.

Despite negative sentiments about nuclear energy, which were strengthened by the Fukushima nuclear disaster in March 2011, nuclear energy remains very much part of the planned energy mix for many countries, including South Africa. According to the Department of Energy's Integrated Resource Plan for Electricity (IRP) 2010–2030 (Department of Energy, 2011), new generation of 9,6 GW nuclear energy is planned until 2030, to supplement that generated by all existing and committed power plants. However, other countries have taken decisive steps away from nuclear generation. Leading this movement is Germany, which announced shortly after the Fukushima disaster that all nuclear plants in Germany would be shut down by 2022 (Evans, 2011). Nuclear-energy generation is mostly used in large-scale grid-feed applications, and is not applicable to smaller-scale business applications, which are the focus of this study.

Another option for energy generation for South Africa is by means of a controversial method called fracking. Fracking is a method of extracting gas from rock formations by blasting a mix of water, sand and chemicals into hard rock. Although it is difficult to make accurate predictions it is estimated that the Karoo has 390 billion cubic tons of underground gas reserves (SABC News, 2015). The government lifted a moratorium on shale-gas exploration on 7 September 2012, making it possible for energy giants such as Shell to proceed with the exploration of commercially feasible shale-gas deposits in the Karoo (Business Report, 2012b). The lifting of the moratorium resulted in an outcry from environmentalist groups, such as Greenpeace and Treasure the Karoo Action Group (TKAG), which argue that fracking is not a sustainable solution to the country's energy problems, and that it has potentially negative environmental implications, among which the contamination of water – a very scarce resource in the Karoo (Green Business Guide, 2012). However, Shell recently scaled down its efforts to pursue fracking in the Karoo, firstly because it has not yet been able to procure a licence from the South African government to extract shale gas, and secondly because of the recent drop in international oil prices (SABC News, 2015). The focus of this study is own generation of energy by dairy producers, thus fracking falls outside the scope of this study.

The South African government considers the expansion of renewable energy sources as a high priority. This is evident in the IRP (Department of Energy, 2011), which states that 17,8 GW of new renewable energy generation is planned until 2030, in addition to that generated by all existing and committed plants. The allocation for new renewable electricity generation is the highest of all the new generation categories. There are already changes in the way that energy is being produced, supplied, transformed and used in South Africa (Department of Energy, 2011). Figure 1.2 shows the new generation of energy planned by the Department of Energy until 2030.

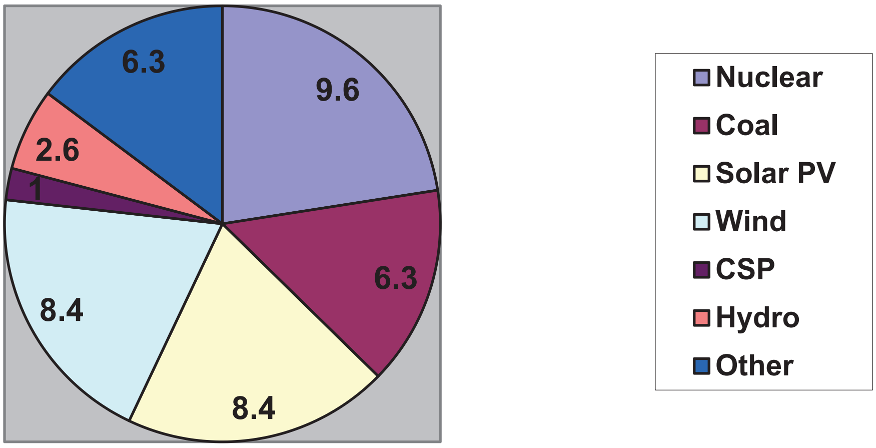

Figure 1.2: Total additional new capacity in GW until 2020 (Department of Energy Integrated Resource Plan for Electricity, 2011)

Eskom's support of energy-saving measures and own generation of energy is evident in various supportive programmes, for example the Standard Offer programme, Standard Product programme and Performance Contracting (Etzinger, 2011, p. 64).

In South Africa the public became acutely aware of the need for energy efficiency and the possibility of an energy crisis as a result of electricity cuts in 2008, and well-above-inflation increases in the average price of electricity between 2010 and 2015. The National Energy Regulator of South Africa (NERSA, 2010) announced price increases of 24.8% in 2010 and 25.8% in 2011. This was followed by an announcement by NERSA (2012) of a further 16,0% price increase in 2012. The accumulated rate of increase is a staggering 82,1% over three years. In October 2012 Eskom submitted an application to NERSA to increase electricity tariffs by 16% per year for the next five years (Eskom Holdings, 2012). This application was not granted; instead NERSA granted Eskom an annual increase of 8% for each of the next 5 years from 2013/2014 (Eskom Holdings, 2013). However, there are other mechanisms available to Eskom to effect increases in addition to the 8% granted by NERSA. For example, an additional 4.69% increase was recently granted as part of NERSA's revenue clearing account (RCA) mechanism, bringing the approved increase for 2015/2016 to 12.69% (Eskom Holdings, 2015a). Even with this increase it is evident that Eskom cannot make ends meet, as Fin24 (2015) reported that Eskom once again approached NERSA at the beginning of 2015 to apply for a further tariff increase from the approved 12.69% to 25.3%.

Globally one of the energy-intensive industries that is especially vulnerable to electricity tariff and production cost increases is the milk-producing industry. MacDonald, O'Donoghue, McBride, Nehring, Sandretto, and Mosheim (2007) identified a trend in the USA of bigger dairy farms contributing an increasing percentage of the country's total production, while smaller dairy farms contribute a declining percentage. MacDonald et al. (2007, p. 3) found that the main reason for this trend was increasing production costs. This trend is also evident in other countries as bigger dairy farms are better equipped to take advantage of economies of scale to lower production costs (MPO, 2012, p. 12; Newman & Savage, 2009, p. 184). In 2012 the Milk Producers' Organisation (MPO) reported that 81,3% of the country's milk was being produced by dairy operations with more than 200 cows in milk (MPO, 2012, p. 6). The report also states that, since 2009, dairy farms with fewer than 200 cows have produced a declining percentage of the country's milk, while dairy farms with more than 200 cows produced a growing percentage of the country's milk over the same period (MPO, 2012, p. 12). Fin24 (2011) reported that the producer price of milk was not keeping up with increasing production costs and that producer prices in November 2011 were, on average, 10% lower than in 2009. Coetzee (2013) reports that the producer price of milk had, to a large extent, remained stagnant between 2009 and 2013, while there had been a steady growth in input prices during the same period. This trend, namely, of milk prices not keeping up with input-cost increases, shows the predicament the South African dairy industry currently faces, and which could result in milk producers leaving the industry. Penderis

(2012) states that milk producers are already leaving the industry at an alarming rate, a phenomenon that could lead to milk shortages in South Africa.

Coetzee (2013) states that feed cost constitutes the largest part of a dairy farmer's total input cost, and that, in general, the farmer has very little control over input costs. According to Bezuidenhout (2012, p. 14) two additional factors contributing directly to increasing operating expenses and the deteriorating financial position of dairy farmers in South Africa are increasing electricity and fuel prices. It is evident that the dairy farmer has limited control over most input costs and the producer price of milk.

1.3 RESEARCH PROBLEM

1.3.1 Problem statement

Milk producers in South Africa are under pressure because of increasing production costs and stagnant or decreasing producer prices for milk (Fin24, 2011; Coetzee, 2013). South Africa has experienced extreme electricity price increases over recent years, and this is contributing to increasing operating expenses for energy-intensive operations, such as milk producers. The chief executive officer of the MPO, B. de Jongh stated (Personal communication, June 7, 2012) that dairy farms use electricity for most of their activities related to production, such as cooling of milk, operation of milk machines and irrigation of crops, and are vulnerable to any increases in the price of electricity. Above-inflation increases in electricity prices are likely in the next few years, as is the possibility of power cuts (Moneyweb, 2011). Consequently dairy farms, which are energy-intensive operations, face huge risks because of escalating electricity tariffs; this could impact negatively on the farms' profitability, and could even force farmers to leave the industry.

1.3.2 Problem questions

The research problem has generated the following research questions:

1. Is it financially viable for a dairy farm to invest in own generation of solar photovoltaic (PV) energy?
2. How aware and informed are dairy farmers about possible solar PV energy solutions?
3. What barriers are there for dairy farmers to implement solar PV energy systems as a means to manage their energy costs?

1.4 RESEARCH OBJECTIVES

The primary objective of the study is to develop a financial model to evaluate the viability of own generated solar PV energy in Free State dairy farms.

The secondary objectives are to:

- Analyse the daily, monthly and annual electricity usage patterns on small, medium and large dairy farms;
- Investigate the knowledge base and attitudes of dairy farmers regarding the implementation of own generated solar PV energy; and
- Determine the barriers of entry for using own generated solar PV energy on a dairy farm.

1.5 METHODOLOGY

The research methodology applied in this study involved a review of the literature on solar PV systems and its application in global dairy production. Literature relating to financial tools was reviewed to evaluate solar PV energy. The literature review provided the theoretical foundations for the research, and it was followed by an empirical study. Webster's Online Dictionary (2012) defines empirical research as any research that bases its findings on direct or indirect observation as its test of reality. Because of the exploratory nature of this research, the empirical research consisted of a qualitative investigation. Cooper and Schindler (2011, p. 183) state that qualitative methods are ideal for new-product development, especially concept testing, which is the nature of this study. The research was conducted in an ethical manner and caution was exercised to ensure that no one suffered adverse consequences as a result of the research.

The target population of the study is all members of the MPO in the Free Sate. Due to the interactive nature of the research as well as time and cost considerations participants were limited to the Free State province. Due to different production systems, financial structures and electricity-consumption patterns in small, medium and large dairies, one dairy in each of the following categories was selected:

1. Fewer than 250 cows in milk;
2. 250–750 cows in milk; and
3. More than 750 cows in milk.

Participants also had to satisfy the following criteria:

- Ability to measure the electricity consumption of the stable and the rest of the farm separately;
- Willingness to participate in the study and provide the required data;

- Availability for interviews; and
- Absence of physical constraints prohibiting a solar PV installation.

An electricity monitor was installed at all participating dairy farms to collect the following data continuously for a period of one year:

- Power consumption (kW); and
- Daily, weekly, monthly and annual energy consumption (kWh).

In addition to the electricity monitor, data regarding the participants' electricity consumption and operations was collected by means of in-depth interviews. This data includes:

- Financial performance of the dairy operation;
- The tax structure of the dairy operation;
- What portion of the capital outlay the participant would prefer to lend when making an investment in a solar PV system;
- Critical vs. non-critical electricity consumption; and
- Possibility of moving consumption towards peak PV yield (midday).

Based on data from the electricity monitors and the interviews the daily energy-consumption patterns were plotted, and a solar PV system that best fit the needs of each milk producer interviewed was designed. Figure 1.3 shows an example of a daily energy-consumption pattern and three options of solar PV systems of different sizes. System 1 is sized to never supply more energy than needed at any specific time of the day, thereby eliminating the need to store energy. System 2 is sized to produce a little more energy than needed at midday, giving the farmer the option of storing this energy in batteries as backup for critical applications during times of Eskom power cuts. System 3 is sized to provide enough energy for total daily consumption; in this case a large amount of energy needs to be stored for later consumption when the sun is not shining. System 3 is a typical case of energy being stored in the national grid, and of energy exported to the grid and imported again being measured by net-metering.

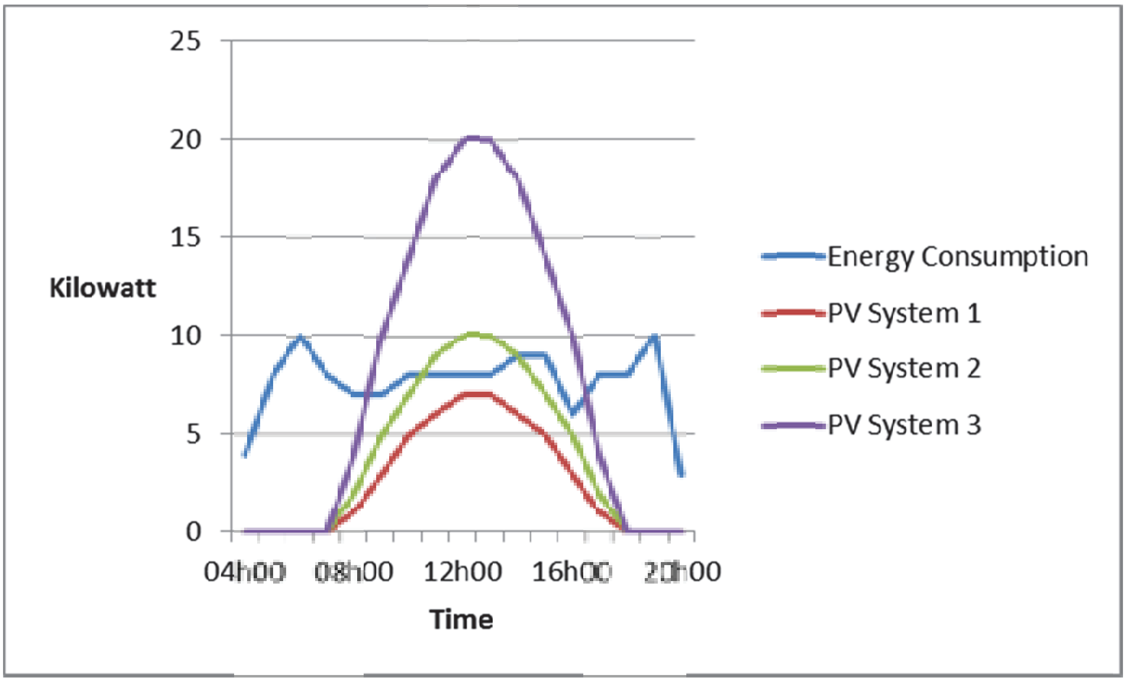

Figure 1.3: Example of energy consumption and solar PV yield curves

The following analysis techniques were used to evaluate the profitability of each solar PV system:

1. Simple Payback Period

The simple payback period (SPP) was calculated using the formula:

(Initial cost) / (Annual saving)

Where:

- The initial cost was based on the market related value of the system; and
- Different payback periods were calculated based on the assumptions of the scenario analyses.

2. Internal Rate of Return

The internal rate of return (IRR) was calculated using the formula:

$$0 = P_0 + P_1/(1+IRR) + P_2/(1+IRR)^2 + P_3/(1+IRR)^3 + \ldots + P_n/(1+IRR)^n$$

Where:

P_0 = the initial cash outlay; and

$P_{1\ldots n}$ = the annual savings.

The initial cash outlay was based on the market related installed cost of the solar system.

The annual savings were calculated on an after tax basis and based on the assumptions of the scenario analyses.

3. Net Present Value

The net present value (NPV) was calculated using the formula:

$$\mathrm{NPV}(i, N) = \sum_{t=0}^{N} \frac{R_t}{(1+i)^t}$$

Where:

i = the discount rate;

N = the total number of periods;

t = the time of the cash flow; and

R_t = the net cash flow.

The discount rate was calculated using the weighted cost of capital formula to accurately reflect the cost of debt and equity funds for the specific dairy farm. The cost of debt was based on the rate at which debt is available to the dairy from registered financial credit providers. The cost of equity funds was based on the rate of return being generated by equity funds in the dairy, as an indication of the opportunity cost of investment in the solar PV system.

The net cash flow was based on the annual yield (in kWh) of the solar system, and the current and assumed future values of Eskom tariffs, and was calculated on an after-tax basis.

The present value of the cash outlay required to purchase the solar PV system was based on the market related value of the system.

Since the South African Revenue Service (SARS) permits, in Article 12B of the Income Tax Act (Act 58 of 1962), that solar PV systems used in farming activities are written off over three years in a 50:30:20 ratio, this ratio was used in tax calculations and cash flow analyses.

1.6 DEMARCATION AND VALUE OF THE STUDY

With energy and climate change at the forefront of the global agenda and in the light of rising energy prices in South Africa there is a great need for research into alternative methods of generating energy. This study focuses on the financial feasibility of one of the renewable energy sources – solar PV energy – as an alternative to Eskom power on dairy farms. Some external factors may influence decisions relating to the viability of using solar PV energy at dairy farms at a specific time, but are not covered in this study:

- Regulation and policy blockages regarding net-metering

Although Eskom supports embedded generation and net-metering (Eskom Holdings, 2011, p. 10; Sustainable Energy Society of Southern Africa, 2012) and the practice is used widely in South Africa already, there is no policy yet that regulates net-metering for small-scale (less than 100 kW) alternative-energy systems. If and when it is necessary for a business to export excess energy into the grid, the electricity meter must be able to support this function, and the resellers of electricity at local level need to be involved in the implementation and monitoring of this. It is possible that applicants will experience red tape and be confronted by unwilling or uninformed officials at a local level, who could prolong the process.

- Selling of energy

This study assumes that solar PV energy generation is for own consumption; the purpose of exporting any energy to the national grid is merely for storage purposes, and the assumption is that this energy will be used by the dairy at a later stage. Any future possibility of being a net-exporter of energy (seller of energy), either to Eskom or to a third party, is excluded from the study.

- Fixed-tilt crystalline PV

This study focuses on conventional fixed-tilt crystalline PV applications. It does not investigate other forms of solar energy (for instance concentrated solar power) or other PV technologies (for instance thin-film), nor does it investigate moving devices (for instance solar trackers) for yield improvement.

- Government support and tax

This study excludes from its considerations any financial benefits from government or Eskom (e.g. rebates or grants) that might influence the financial viability of a solar PV system at a certain time while the benefit is applicable. The implementation of the new carbon tax has been delayed by treasury until 2016 (Mail & Guardian, 2014), thus the effects thereof are not included in the financial analysis of this study.

- Efficiency vs. generation

Although it is recommended that energy-efficiency measures, such as solar water heating and energy-efficient lighting, are implemented in a dairy operation, this study does not explore energy-efficiency measures, but focuses solely on the generation of electricity by means of solar PV systems.

1.7 LAYOUT OF THE STUDY

The layout of the study will be as follows:

In Chapter 1 the introduction and problem statement are presented. Furthermore, the objectives, methodology and demarcation of the study are explained.

In Chapter 2 a detailed perspective will be given on the general applications and configurations of solar PV systems, as well as its specific application in global dairy production, based on the literature review. The literature on three financial tools will also be reviewed to evaluate the investment of solar PV systems in dairy production: SPP, IRR and NPV.

In Chapter 3 the research methodology will be explained, including the data-collection process, assumptions made in the financial model and key variables used in the model. The processing and analysis of data will be described in detail.

In Chapter 4 the results of the research will be evaluated, including results from the installed energy meters and results from the site visits and interviews. Ultimately the results from the financial models developed for the researched dairies will be evaluated by applying the SPP, IRR and NPV tools in different scenarios.

In Chapter 5 the findings of the research will be summarised and conclusions drawn. Recommendations will be made regarding incorporation of solar PV energy in milk production in South Africa, based on the findings of the research.

CHAPTER 2

LITERATURE REVIEW

2.1 REVIEW OF RENEWABLE ENERGY TECHNOLOGIES AVAILABLE TO DAIRY FARMERS IN SOUTH AFRICA

2.1.1 Introduction

Renewable energy is defined by the Oxford Dictionary as “energy from a source that is not depleted when used” (Oxford Dictionary, 2014). Other definitions include references to the natural origin of renewable energy: “energy that is from an energy resource that is replaced rapidly by a natural process such as power generated from the sun or from the wind” (Science Daily, 2014). There are many energy sources that conform to this definition, for example hydro, tidal, geo thermal, biomass, solar and wind energy. However, not all of these energy sources are available, in a practicable sense, to Free State dairy farms for own generation of electricity. In this study two renewable energy sources are reviewed shortly, namely wind energy and biogas energy, while solar PV energy is discussed in greater detail. It is important to note that renewable energy sources are, in most cases, not mutually exclusive and can be used in conjunction with one another and to complement each other. For example, a source that could provide energy at night might be complementary to solar PV energy, which produces energy only while the sun is shining. As stated before, the focus of this study is largely on solar PV energy.

2.1.2 Wind energy

Globally wind energy is a major part of mainstream renewable energy and part of most countries' planning for new generation of renewable energy. The global wind-power capacity has seen rapid growth in recent years, rising from 17 GW in the year 2000 to 283 GW in 2012, with the leading countries being the USA (60 GW), Germany (31 GW) and China (13 GW) (Renewables 2013, p. 50). In South Africa the DOE is planning for 8.4 GW new wind generation capacity until 2030 (DOE, 2011, p. 7), this is equal to the planned solar PV new generation capacity. The first wind farms in South Africa have recently begun to feed electricity into the national grid (South African Wind Energy Association, 2014). Of the first eight wind farms planned by the DOE, seven are located in the Western and Eastern Cape because of its favourable wind conditions, and one at Victoria-West in the Northern Cape (Williams, 2012a). By 2012 not a single wind-energy project was planned for the Free State area by the DOE.

To date smaller-scale usage of wind energy for commercial purposes has not found widespread application in the Free State either. The generation of electricity by means of wind energy is most feasible in areas with consistently high and steady wind speeds (Rodrigues, et al., 2011, p. 308). The dairy farms researched in this study are all located within a 140 km radius of Bloemfontein, Free State Province. Based on daily measurements of wind speeds in Bloemfontein between March 2010 and February 2014, the annual average wind speed in Bloemfontein is less than 4 metres per second (Windfinder, 2014). Even in the windiest months of October to December, the average wind speed is a mere 5 metres per second. According to Kestrell, a South African manufacturer of wind turbines, their commercial- and household-scale turbines with a rated power over one kilowatt has a "cut in" wind speed of at least 4 metres per second and a rated wind speed of 12 metres per second (Kestrel, 2014). This means that these turbines will only start to produce electricity at 4 metres per second, and reach peak production at 12 metres per second. These figures are in line with the specifications of other international manufacturers of commercial scale wind turbines, for example Xzeres (Windenergy, 2014) and Gaia-wind (Gaia-wind, 2014).

According to Almero van Tonder, sales representative for Kestrel, the company has minimal sales in the central Free State region since it is not financially justifiable to invest in wind turbines in areas with such low and inconsistent wind speeds (Personal communication, January 22, 2013).

2.1.3 Bio-gas

There is a degree of synergy between dairy production and the production of electricity by means of bio-gas, since manure from dairy cows can be used in farm-based anaerobic digesters, which are used to generate electricity. However, recent international studies have found that this practice is not currently financially feasible for dairy farmers. Lazarus (2007) found that it was not financially feasible for Minnesota dairy farmers to invest in bio-gas plants unless there is a subsidy or other significant non-energy market benefit. Brown, Yiridoe and Gordon (2007) used NPV, IRR and SPP as criteria and found that bio-gas plants were not a feasible investment for Canadian dairy farmers. This view is confirmed by various other international studies, such as Gebrezgabher, Meuwissen and Lansink (2010) and Anderson, Hilborn and Weersink (2013).

The feasibility of any alternative energy source should be viewed in relation to the status quo – Eskom power in the case of South Africa. In light of rising Eskom electricity tariffs it is possible that it will become financially feasible for Free State dairy farmers to invest in biogas plants at some point in the future. However the relatively large capital outlay required to install a biogas plant is currently a major stumbling block. The Italian brand Rota Guido is currently one of a few systems available in South Africa. According to Claassen (2013, p. 90) the price of the smallest Rota Guido system is around R 16 million. Clearly this poses a challenge, especially for smaller dairy farms. In this regard it is much easier for Free State dairy farmers to generate renewable energy using a different technology that is modular – where it is possible to start with a small system and expand it over time – for instance, solar PV energy.

2.1.4 Solar energy

The focus of this study is on own generation of solar PV energy because of the following reasons:

- South Africa's climate is suitable for solar PV energy generation. Spencer (2011, p. 35) argues that solar is an ideal source of energy for South Africa because of the country's solar irradiation. This is confirmed by Williams (2012b), who reports that South Africa has some of the best solar radiation in the world, with certain locations being able to generate up to 50% more than in Spain and 20% more than in the USA.
- The cost of PV panels has, in the past, been a major barrier to entry to this technology in South Africa, but this has changed dramatically over recent years. According to Haw (2011, p. 44), the price of PV panels in South Africa has come down from around R 40/watt in 2008 to around R 12/watt in 2011. This trend has continued since 2011 – the price of PV panels is currently well below R 10/watt (Solarworld, 2015).
- Solar PV energy is one of the clean forms of energy generation that does not impact negatively on the environment.
- It is a proven technology with predictable generation profiles, and it has been used worldwide and refined for many years (Spencer, 2011, p. 35).
- Solar PV energy has short lead times as there is no shortage of supply. Erection of solar PV systems is relatively quick and easy (Spencer, 2011, p. 35).
- Solar PV systems have relatively low maintenance costs compared to other renewable energy systems, e.g. bio-gas and wind energy (Australian Business Council for Sustainable Energy, 2012, p. 11).
- Siraki and Pillay (2012, p. 1920) argue that, among the renewable energies, solar panels, in particular, have the potential for building integrated applications, and combine well with other sources of energy.
- Solar radiation has the same time variation as at least one contributor to electricity demand on a dairy farm, namely the cooling of milk. It means that most energy is

needed for cooling of milk at a time when the sun is shining. Applications like these have obvious advantages, as energy can be used directly as it is harvested from the sun, thus decreasing the need for storage of energy (Barnham, Mazzer & Clive, 2006, p. 161). This argument is confirmed by a recent report by the Emirates Solar Industry Association and PWC (2012, p. 3).

2.2 APPLICATIONS AND CONFIGURATIONS OF SOLAR PV SYSTEMS

2.2.1 Introduction

The photovoltaic effect is defined as the direct conversion of light into electricity (Wenham, et al, 2006, p.1). At 19 years old, the French scientist Edmund Bequerel was first to note the photovoltaic effect in 1839 while experimenting with metal electrodes and electrolyte in his father's laboratory. He observed that certain materials absorb photons of light and release electrons, resulting in an electric current that can be used as electricity (Honsberg & Bowden, 2013). In 1905 Albert Einstein published a paper that describes the theory behind the photovoltaic effect, which forms the foundation of quantum physics, and for which he later won the Nobel Prize in physics in 1922 (Panek, 2005, p. 1). The commercial solar age began in 1954, when Bell Laboratories built the first photovoltaic module in the USA. It was expensive and not expected to gain widespread usage, although the New York Times did forecast at the time that solar cells will eventually lead to "limitless energy from the sun" (Sunlight Electric, 2013). The first serious use of solar technology was made in the 1960s by the US space programme, when solar technology was used to provide power for spacecraft (NASA, 2013). Through the space programmes the technology gained credibility and proved its reliability, and production on a bigger scale started to drive costs down. During the US energy crisis of the 1970s PV energy was being used in commercial non-space applications for the first time (NASA, 2013). Today the PV industry is well established and growing, with total installed worldwide capacity reaching the 100 GW (100 000 MW) milestone in 2012 (Renewables Global Status Report, 2013, p. 40).

In order to evaluate the feasibility of solar power for Free State dairy farms, it is essential to review literature and have a thorough understanding of solar PV generation and how solar PV systems can be configured and applied to reach specific goals. It is also essential to review how solar power has previously been applied in dairy production worldwide, either with or without success. Lastly, a thorough understanding of the financial tools used to evaluate the viability of a solar PV system for a Free State dairy farm is necessary. In the case of this study, the focus is mainly on NPV.

2.2.2 Components of a solar PV system

The following are the main components, joined in different configurations of solar PV systems:

- PV array;
- Charge controller;
- Batteries;
- Battery inverter; and
- Grid inverter.

2.2.2.1 PV array

Solar cells are made of semiconductor materials, of which the crystalline silicon cell is the most common (Maxx Solar, 2015). Solar cells are mounted in a frame to form a solar module, commonly known as a PV panel. Modules are designed to supply electricity at a certain voltage and current. Modules are wired together to form a solar array. The solar array forms the basis of any PV system, as it is the point where electricity is generated in the form of direct current (DC). How this energy is then stored or used depends on the design of the PV system.

There are more than 100 solar module manufacturers worldwide, of which the top 15 manufacturers had 50% of global market share in 2012 (Renewable Global Status Report, 2013, p. 41). According to Solarworld (2015), the following are the main types of commercially available solar cells:

- Monocrystalline silicon cells are produced from high purity silicon. Cylindrical silicon ingots are cut into silicon wafers, giving monocrystalline cells their characteristic round-edged look. They are more efficient than polycrystalline cells and as a result the physical dimensions of the modules are smaller than that of polycrystalline modules. This is an advantage where the space of installation is of concern.
- Polycrystalline (also known as polysilicon or multi-crystalline cells) are produced by melting raw silicon and pouring it into square moulds, cooling it and wire cutting it into square wafers. Polycrystalline cells typically have a "shattered glass" look. They are cheaper to manufacture and typically less efficient than monocrystalline cells. The efficiency disadvantage has shrunk over recent years and has to be weighed against the economic advantage, when comparing monocrystalline to polycrystalline modules for a specific application.
- Thin film modules are manufactured by depositing several thin layers of photovoltaic material (for example amorphous silicon or cadmium-telluride) into a substrate. This process is cheaper and more conducive for mass production than the production of mono- and polycrystalline cells. Thin film modules are known to be more tolerant to shading, however they are less efficient and thus require bigger space for the same output, compared to mono- or polycrystalline cells. Thin film production declined in recent years; after a 15% decline in production in 2012 this technology had a global market share of 13% (Renewables Global Status Report, 2013, p.41).

The electricity output of a solar array is dependent on various factors, such as solar irradiation, shading, and cell temperatures. Solar arrays installed in the southern hemisphere should ideally face true north, with an elevation angle dependent on the specific application and the latitude of the installation site. A lower elevation angle will result in higher output during summer months, while a higher elevation angle will result in higher output during winter months (Solarworld, 2015). Fixed tilt solar arrays are normally installed at an elevation tilt of around 30˚. Various software programs are available to predict the output of a specified solar array in a specific geographical location under normal weather conditions.

2.2.2.2 Charge controller

A charge controller is used when the charging of batteries from the PV array forms part of the system design. The charge controller is linked between the PV array and the batteries. According to Microcare (2015) the main functions of the charge controller are:

- Efficient charging of the battery by adapting the voltage (V) to certain battery parameters;
- Preventing overcharging of the batteries by limiting the charging voltage; and
- Preventing deep discharging of batteries by disconnecting the load when the battery voltage reaches a pre-set minimum.

Other functions of charge controllers include overload and short circuit protection, integrated lightning protection, preventing reverse current (I) flowing into the PV array at night and the indication of battery voltage and charge current.

There are continuous innovations in charge controller technology. Modern intelligent charge controllers will adapt the charging voltage to different parameters, such as the type of battery, state of charge and battery temperature, in order to charge the battery bank more efficiently, resulting in longer battery life. Some charge controllers incorporate master power point tracking (MPPT) technology. This means that the maximum point of voltage and current is continually tracked by the charge controller, resulting in increases in charge current of up to

30% compared to the more conventional pulse-width modulation (PVM) charge controllers (Victron Off-grid, 2012, p. 50). Charge controllers incorporating MPPT technology are more expensive than the ones incorporating PVM technology; hence they were in the past mostly used in bigger applications. As the cost of MPPT technology is coming down, this technology is becoming common, even in smaller charge controllers.

2.2.2.3 Batteries

Batteries are used in off-grid applications to store energy for use at times when the sun is not shining, and in grid-connected applications as backup in case of power failures. A battery bank is normally an integral part of an off-grid solar PV system, since it is a requirement of most applications that energy is available at night or during cloudy weather.

It is essential to choose the appropriate type and size of battery bank to fulfil the requirements of a specific solar PV system. The following are characteristics of batteries that would be suitable for use in solar PV systems (Vader, 2012):

- Long service life under conditions of daily charging and discharging;
- Satisfactory recovery from a deep and prolonged discharge;
- Good charging efficiency; and
- Low self-discharge rate.

The battery bank is normally one of the most expensive components of an off-grid solar system, both in terms of initial capital outlay, and replacement of batteries. Batteries are also vulnerable: factors such as overcharge, deep discharge, very high or low temperatures and fast charge currents can diminish battery life (Microcare, 2015). Huge amounts of money are spent annually on research and development of technologies for storing energy more efficiently. However, most batteries still used in PV applications today are lead-acid batteries. Cells in a lead-acid battery have a positive and negative plate, covered in electrolyte. Except for lithium batteries, all the batteries discussed below are lead-acid. According to Maxx Solar (2015), batteries can be categorised as follows, according to their mechanical construction and purpose:

- Flat-plate automotive battery

This is the battery used in cars. It is designed with thin plates so that there is a large surface area exposed to the electrolyte, in order to provide high discharge currents for a short period of time when the engine is started. This type of battery is not designed for regular deep discharging and it is constantly on charge while the motor is running. These batteries are not recommended for solar applications.

- Flat-plate semi-traction battery

These batteries have thicker plates than automotive batteries and can handle a deep discharge better. However, they are not true deep cycle batteries. They are also called leisure batteries and are used in a variety of applications, including boats, camping, for standby and small scale solar applications.

- Flooded deep-cycle or traction battery

This can be either a thick-plate or tubular-plate battery. These batteries are common in power backup and solar PV systems. They are robust and accept a high number of charge-discharge cycles. They are normally cheaper than sealed batteries, but require some degree of maintenance, as distilled water needs to be added periodically.

- Sealed gel battery

The electrolyte in a gel battery is immobilised as gel, as opposed to liquid in flooded batteries. The sealed gel battery is maintenance free. Gel batteries are known for their long service life, and are normally more expensive than flooded batteries. Gel batteries are vulnerable to high temperatures; their service life diminishes quickly when they are regularly exposed to temperatures over 25˚C.

- Sealed AGM battery

AGM stands for “absorbed glass mat”. The electrolyte is absorbed into a thin fibre mat. An AGM battery is more suitable for delivery of high currents than a gel battery, but has a shorter service life than a gel battery. Although high temperatures diminishes the service life of any lead-acid battery, AGM batteries are known to perform relatively well in high temperatures compared to other lead-acid batteries. They are also maintenance free.

- Sealed lead-crystal batteries

The electrolyte in a lead-crystal battery is in the form of crystal. This provides excellent discharge capabilities as well as resistance to diminished service life as a result of high temperature. Lead-crystal batteries are normally more expensive than other lead-acid batteries.

- Lithium battery

Lithium battery technology is well established as these batteries are used in appliances such as cell phones and laptop computers. However, due to the cost of lithium batteries compared to lead-acid batteries, it has not found widespread use in solar applications to date. Lithium batteries have certain advantages over lead-acid batteries, such as a constant voltage, deeper discharge capacity and longer service life. The expansion of the solar industry is driving the cost of lithium batteries for solar applications down, and it is expected that this technology will gain market share in the coming years. Evidence of this has already been seen in May 2015 when Elon Musk of Tesla Motors announced that his company (which traditionally used lithium batteries in electric cars) would move into the home energy business (USA Today, 2015).

2.2.2.4 Battery inverter

A battery inverter changes DC produced by the PV panels and stored in the batteries, to alternative current (AC). It also changes the voltage (normally from a 12 V, 24 V, 36 V or 48 V battery bank) to the required voltage. In South Africa this means a battery inverter would typically supply 230 V AC. According to Microcare (2015), battery inverters can be categorised as either providing pure sine wave or not providing pure sine wave (modified sine wave or square wave) electricity. Inverters not providing pure sine wave are cheaper, but should only be used as specified for certain applications, such as lighting. Most appliances using electricity require pure sine wave, and supplying modified sine wave current to them will cause damage or diminish their life span.

Bigger battery inverters are often combined with electrical battery chargers and called inverter-chargers (Microcare, 2015). This means that apart from the DC connection to the battery bank, it can also have one or more AC inputs for connection to grid electricity or a backup generator, or both. This then gives the option to supply AC from the grid or generator through the inverter-charger to the required load, while at the same time charging the batteries. Inverter-chargers used in bigger integrated off-grid PV applications normally have multiple programmable options to be programmed in accordance with the requirements of the specific application.

2.2.2.5 Grid inverter

As the name implies, grid inverters are normally used in a grid-connected applications. They have much fewer options and functions than battery inverters, the main functions being to change the DC from the PV panels to AC, and to synchronise it with the grid electricity, if grid electricity is available. Quality grid inverters are built to specification to conform to the grid codes of different countries and utilities.

Sometimes grid inverters are also used in off-grid applications, particularly bigger applications, where energy is primarily used during the day when the sun is shining (Solarworld, 2015). These are called AC off-grid applications, as the DC from the PV panels is directly inverted to AC via the grid inverter, and then used immediately as it is produced. This is different from DC off-grid applications, where DC from the PV panels is first stored in batteries and later inverted to AC when required. AC systems are more efficient than DC systems as there are more system losses involved in storing energy in batteries than using it directly as it is produced (Solarworld, 2015).

2.2.3 Types of PV systems

PV systems can be grouped into standalone systems (also known as island systems), which are not connected to the public electricity grid, and grid-connected systems, which are either directly or indirectly connected to the public grid. Standalone systems can further be categorised as systems without energy storage facilities, systems with energy storage facilities, and hybrid systems.

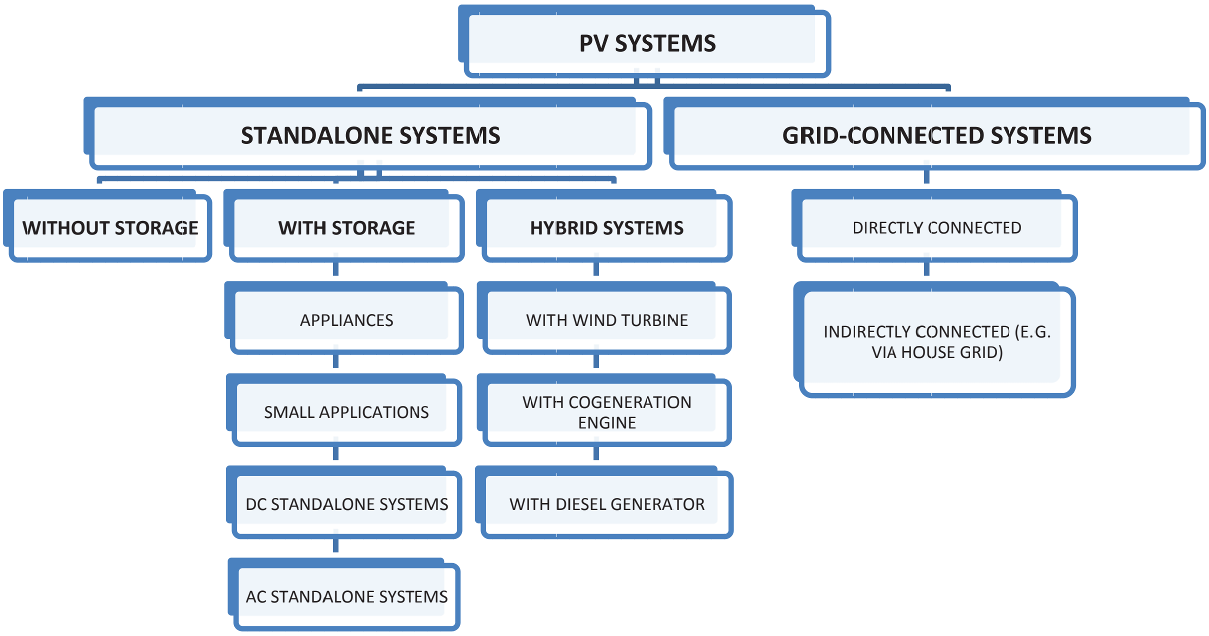

Figure 2.1 Types of PV Systems

Source: Planning and Installing Photovoltaic Systems (2010)

2.2.3.1 Standalone systems

Standalone systems are not connected to a national electricity grid. They are generally much smaller than grid-connected systems. The electricity that is generated is either used immediately as it is generated, or stored in batteries for later consumption. Standalone systems with battery storage can either provide DC directly from the battery bank to DC appliances, or can provide AC to AC appliances via a battery inverter. Since standalone systems are not connected to an electricity grid and PV systems are dependant on weather conditions, it often makes sense to combine standalone PV systems with other electricity generators, such as diesel generators, in so-called hybrid systems (Maxx Solar, 2015).

2.2.3.1.1 Standalone systems without storage

A system without energy storage capacity can only operate when the sun is shining. Since a PV system is normally required to operate for at least some hours after sunset, or in cloudy weather, the application of systems without storage is not widespread. One exception is PV systems used for water pumping, because water can be pumped (for example from a borehole) and stored (for example in a dam or tank) for consumption later. In water pumping applications it often makes more financial sense to pump water only when the sun shines, and storing the water, rather than storing the energy in batteries and pumping water when the sun is not shining (Microcare, 2015).

The DC can be supplied either directly from the PV array to the load, such as a DC water pump, or as shown in Figure 2.2, via a regulator that can perform certain functions, such as voltage regulation, dry run protection, switching off when the tank is full, etc.

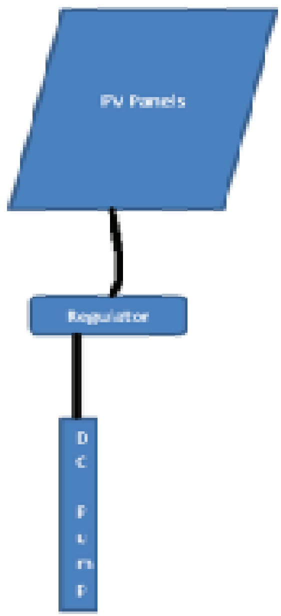

Figure 2.2 DC solar water pump

2.2.3.1.2 Standalone systems with storage

According to Microcare (2015), the main components of a standalone system with storage are:

- PV array;
- Charge controller;
- Batteries; and
- Inverter (in the case of AC loads).

A standalone system with storage implies that energy is stored in a battery bank. Storing energy in batteries is relatively expensive; this is one of the major limitations of standalone systems (Microcare, 2015). In systems providing DC only the energy from the PV array is stored in a battery bank via the charge controller, and DC is then supplied directly to DC appliances, such as 12 V lights (Figure 2.3). The advantage of this system is the absence of an inverter, both in terms of system efficiency, as the conversion of DC to AC implies certain energy losses, as well as in terms of financial viability, as an inverter is normally a costly component of the PV system. However the absence of an inverter limits the application of the system to DC loads only, whereas most bigger appliances use AC. For appliances using AC, it is necessary to include a battery inverter in the system in order to invert the DC in the battery bank to AC (Figure 2.4).

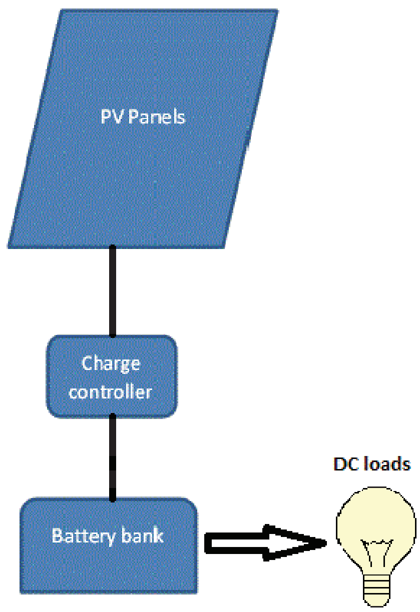

Figure 2.3 DC standalone system

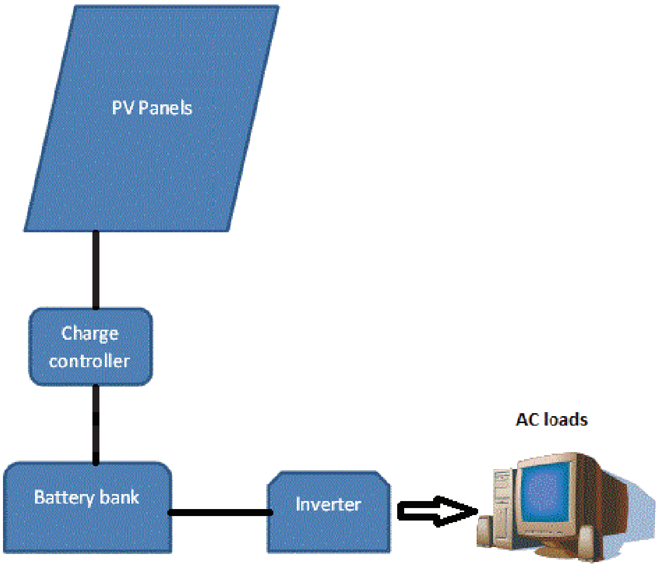

Figure 2.4 AC standalone system

As stated previously, a grid inverter can also be used in standalone systems. This is mostly done in applications where electricity is required primarily during daytime (Victron, 2012, p. 20). In this case DC from the PV array is inverted directly to AC and supplied to the load. Any excess energy not used by the load is then stored in the battery bank for later use (Figure 2.5).

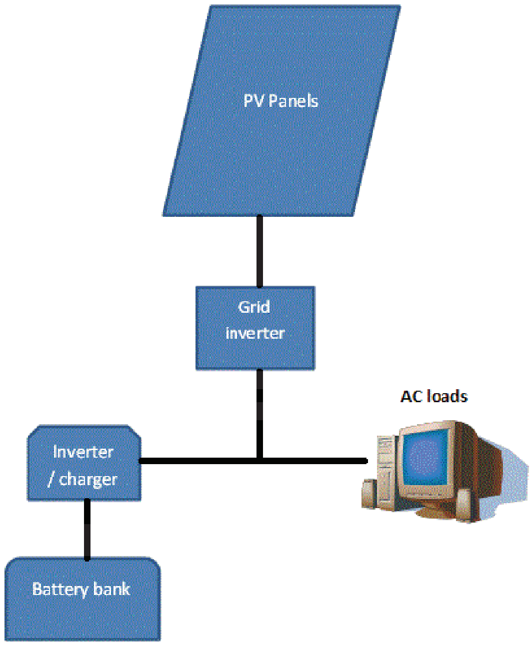

Figure 2.5 AC standalone system with grid-inverter

2.2.3.1.3 Hybrid systems

Solar PV systems can be combined with any other generator of electricity to form a hybrid system (Figure 2.6). PV systems are often combined with other renewable energy generators, such as wind generators or water turbines. However, hybrid systems relying on renewable energy sources only are often dependant on weather conditions and therefore a continuous supply of electricity is not guaranteed. For this reason PV systems are often combined with controllable generators, such as diesel generators, to ensure supply of electricity under any weather conditions.

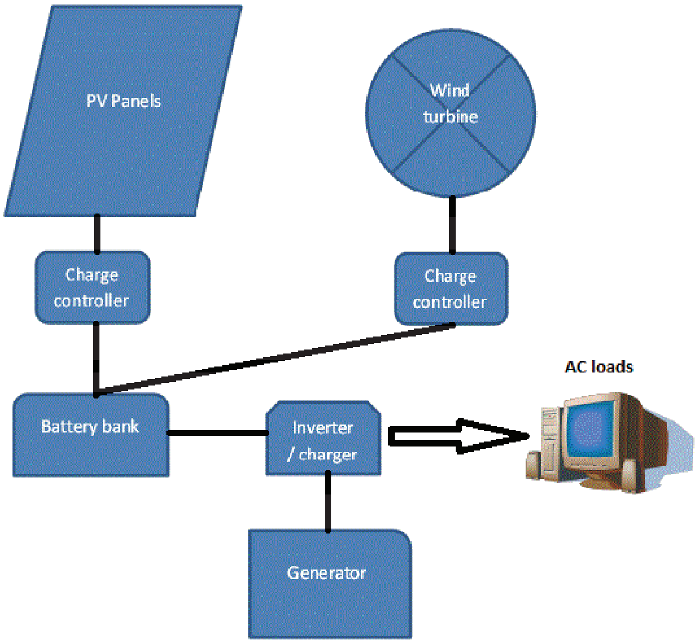

Figure 2.6 Hybrid system

2.2.3.2 Grid-connected systems

Grid-connected solar PV systems are connected to the national electricity grid. These systems are much simpler in design than off-grid systems as they normally have only two main components: the PV array and grid inverter (Microcare, 2015). They are typically larger than standalone systems. Grid-connected systems can be either directly connected to the grid, or indirectly, for example via a house grid or commercial grid.

2.2.3.2.1 PV systems connected directly to the grid

Large utility scale PV systems are normally connected directly to the grid (Figure 2.7). These systems form part of the energy supply of a country and feed electricity directly into the grid together with other generators, such as coal fired power stations and wind generators. There are numerous large scale PV projects currently under way in South Africa, as part of the DOE's Independent Power Producers Procurement Programme (IPPPP). These large scale systems fall outside the scope of this study.

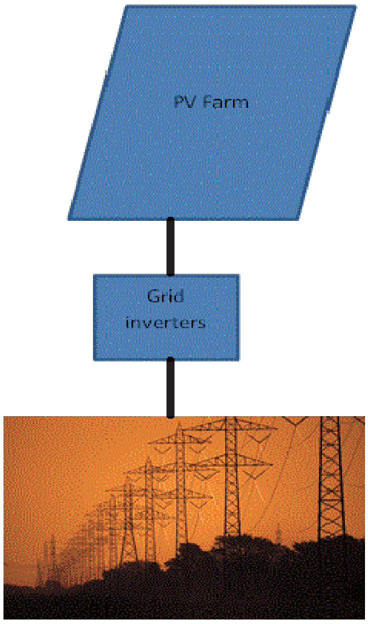

Figure 2.7 PV farm connected to the national grid

2.2.3.2.2 PV systems connected indirectly to the grid

Smaller grid-connected systems can be connected to the grid on the consumer's side of the electricity meter, for example in a household or commercial application. The energy (DC) from the PV array is supplied directly to the electricity grid (distribution board) of the building, via the grid inverter. The function of the grid inverter is to invert the DC from the PV array to AC, and to synchronise it with the grid electricity (Maxx Solar, 2015). This means that when electricity is consumed during the day it is, first, drawn from the PV array. Only when the electricity supply from the PV array is insufficient, will it be supplemented by grid electricity. When no electricity is supplied from the PV array, for example at night, the full load will be supplied by grid electricity. If at any time during the day the load drawn is less than what the PV array is supplying, the excess electricity will flow back into the national grid, through the electricity meter. In this case the electricity meter needs to be able to support this function, i.e. record the electricity flow in both directions. This is referred to as net-metering (Figure 2.8). In South-Arica it is necessary to have a grid connection agreement with Eskom or the local municipality (for areas inside the municipal electricity distribution area), whenever a solar PV system is connected to the grid. A correctly commissioned grid-connected system will not feed electricity from the PV system into the grid in case of a power failure, for instance, if the utility switches off the power for maintenance purposes.

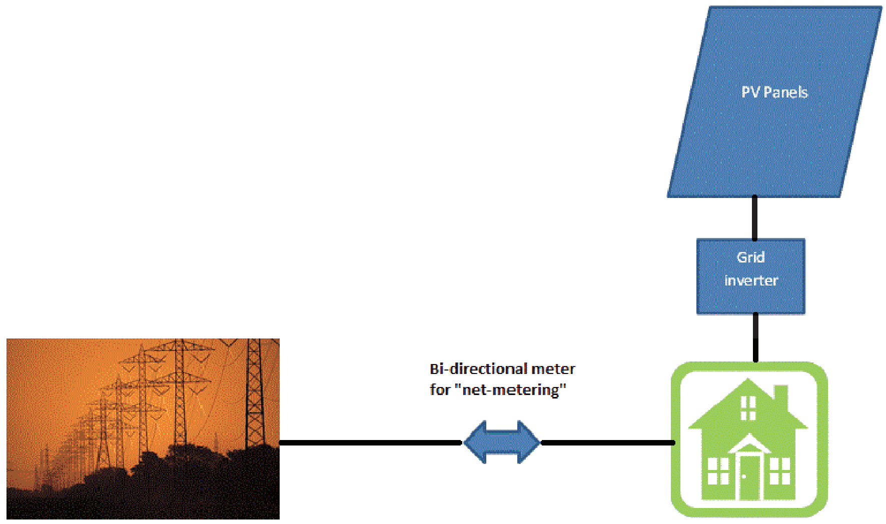

Figure 2.8 Household grid-connected system making use of net-metering

A household or commercial grid-connected system that is connected to the Eskom or municipal grid can be combined with a backup battery bank or diesel generator or both, to provide electricity in case of load shedding or grid power failure (Figure 2.9).

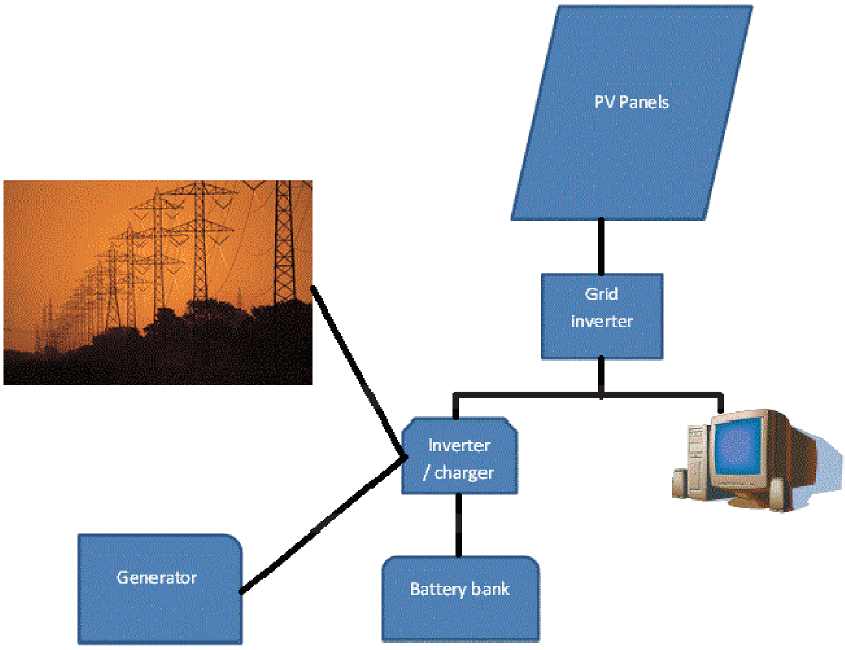

Figure 2.9 Household grid-connected system with battery and generator backup

2.3 GLOBAL APPLICATIONS OF PV ENERGY IN DAIRY PRODUCTION

The use of solar PV energy in agriculture is not a new concept. Solar PV technology has been used in various agricultural applications around the globe for many years, for example, the powering of fruit and vegetable cooling systems (Eltawil & Samuel, 2007) and drying of agricultural products (Hossain & Bala, 2007, Basunia & Abe, 2001). South African farmers are increasingly using solar PV energy for pumping water. According to Friend (Personal communication, December 8, 2012) the firm Telecom Techniques in Port Elizabeth is experiencing a growing trend of farmers converting water pumps to solar power. This trend is confirmed by Adams (Personal communication, December 11, 2012), who stated that the firm Nelson Adams in Cape Town sold a record amount of more than 1 000 solar powered water pumps to farmers in South Africa in 2012; this is more than the total amount sold from 2008 to 2011. Chel and Kaushik (2011) argue that renewable energy, including solar PV energy, holds great potential for agriculture; they predict that it will play an increasingly important role in sustainable agricultural development.

Although there is currently very little use of own generated solar PV energy on dairy farms in South Africa, various international studies suggest that it has the potential to be applied successfully in dairy production. A study done in Saudi Arabia by Rehman, Bader and Al-Moallem (2006) found that, based on the straight payback period, IRR and NPV of a 5 MW solar PV system, it was a sound investment. In this study the straight payback period was calculated at 9.6 years, the IRR 13.53% and the NPV USD 51.3 million. Although this PV system was bigger than what a dairy farm would use and was able to utilise economies of scale when making the capital investment, important conclusions can still be drawn from it because Saudi Arabia has similar irradiation to the Free State – around 2000 kWh/m^2/year. It is insightful that a favourable payback period, IRR and NPV was realised in this study by Rehman, Bader and Al-Moallem, even though, in 2006, the global price of PV panels was at a much higher level than current price levels. Consideration should also be given to the fact that, although the payback period was fairly long, it should be seen in light of the productive lifetime of PV panels, which is at least 25 years (Solarworld, 2012, p. 9). Various other studies confirm that, based on financial indicators such as SPP, IRR and NPV, solar PV energy is financially viable for dairy production:

- Murgia, Todde and Caria (2012) evaluated the operational performance of a grid-connected solar PV system on a dairy farm in Italy and found that the simple payback period of the investment was less than 10 years. Consideration should be given to the fact that data from 2009 and 2010 was used in this research; it can be expected that with the current, reduced price of PV panels the result would have been even more favourable.

- Desai et al. (2013) found that the use of solar PV energy on dairy farms in India was feasible, especially for reducing electricity use by refrigeration systems for cooling milk during the middle of the day when the sun is shining.
- After installing and monitoring a solar system on a dairy farm in California, Mason (2010, p 17) concluded that, based on the payback period and internal rate of return, it was a sound investment.
- Halberg (2008, p. 5) found that it was possible for Danish dairy and pig farmers to realise substantial electricity savings by using existing renewable energy technologies, including solar energy.
- Biggs (2012, p. 91) concluded that the most important factor for Canadian dairy farmers to switch to another energy source is the price of energy, and if new energy sources, such as solar PV, becomes available at competitive prices, farmers could easily switch to the new technology.

There have also been studies that concluded that solar PV energy is not a viable option for dairy farms:

- McCarthy et al. (2008) and Otiti and Soboyejo (2006) concluded that the cost of solar PV panels was too high to justify the capital outlay. However, as stated before, there has been a dramatic decrease in the price of solar PV panels since these studies were conducted. McCarthy et al. (2008) also found that it was more important for dairy farmers in Massachusetts, USA, to focus on energy efficiency measures to reduce energy consumption, than it was for them to generate solar PV energy. This was also the conclusion of Rodrigues et al. (2011, p. 315) for dairy farmers in Portugal.
- Otiti and Soboyejo (2006, p. 74) found that the inability of many sub-Saharan African applicants to obtain finance for solar PV systems for agro-processing activities presented a major stumbling block for them. This could be a challenge for South

African dairy farmers, although they seem in a better position to obtain financing from financial institutions than the population researched by Otiti and Soboyejo.

- The Welsh Dairy Development Centre (2012) found that the production yield of solar PV panels (with peak during mid-day) does not correlate well with the consumption pattern of a Welsh dairy farm (with early morning and later afternoon peaks). This resulted in a large portion of the energy being sold to the local electricity supplier during mid-day at low prices and then bought back during peak demand periods at much higher prices, rendering the project unviable. There is no feed-in tariff for small scale electricity generation by dairy farmers in South Africa yet. A similar situation of the aforementioned Welsh example of feeding electricity into the network at a lower rate and buying it back later at a higher rate, will have a negative effect on the financial viability of solar PV energy for dairy farms in the Free State. In this case options would need to be explored to feed less electricity into the network. These options could include storing energy in batteries, using solar PV energy to cover only the mid-day electricity base load of the dairy or moving consumption patterns of the dairy to fit the production yield of the solar PV system better.

2.4 FINANCIAL ANALYSIS OF SOLAR PV SYSTEMS

2.4.1 Introduction

There are many techniques available for determining the economic profitability of a capital investment. Various researchers agree about the dominance of SPP, IRR and NPV in capital investment analysis (Truong, Peat and Partington, 2013; Teach, 2003; Bara, Lungu & Oprea, 2009; Boehlje & Ehmke, 2005; Cooper, Cornick & Redmon, 2011). As stated before, the SPP, IRR and NPV will be calculated and used in this study to evaluate the financial feasibility of solar PV systems for Free State dairy farms. Table 2.1 provides a brief explanation of these three techniques.

Table 2.1: Definition and explanation of SPP, IRR and NPV

Technique	Definition	Explanation
Simple Payback Period (SPP)	A cost analysis to determine the number of years required to recover an initial investment through project returns (Capehart, Turner & Kennedy, 2012, p. 134)	A simple method of dividing annual savings or returns into the initial investment.
Internal Rate of Return (IRR)	A financial metric used to discount capital budgeting and to make the net present value of all future cash flows equal to zero (Wall Street Online Financial Dictionary, 2013)	The IRR of an investment is the discount rate at which the net present value of costs (negative cash flows) of the investment equals the net present value of the benefits (positive cash flows) of the investment.
Net Present Value (NPV)	The sum of the annual cash flows discounted for any delay in receiving them, minus the investment outlay (Boehlje & Ehmke, 2005, p. 2)	Also known as discounted cash flow, if the NPV is positive, the project is worth undertaking and vice versa.

2.4.2 Simple Payback Period

Ross, Westerfield & Jaffe (1999, p. 136) and Capehart et al. (2012, p. 134) state that, because of its simplicity, the Simple Payback Period (SPP) is still one of the most commonly used techniques to evaluate capital investments. However, there are some problems associated with this method:

- It does not consider the timing of cash flows within the payback period or the time value of money.
- Payments after the payback period are ignored. This is particularly significant in projects with a long life cycle, such as solar PV.
- There is no standard for payback period (as compared to NPV, for example, where the discount rate could easily be obtained from the capital market), and thus the choice is arbitrary to some extent.

Despite its shortcomings the SPP is still commonly used in the farming community as initial screen to determine the feasibility of a new project, and will thus be calculated and observed in this study. However, it will be used in combination with methods that consider the time value of money and that consider cash flows after the payback period, in this case IRR and NPV.

2.4.3 Internal Rate of Return

The IRR depends solely on the cash flow generated by a project (Ross, Westerfield & Jaffe, 1999, p. 136). This is why it is called the *internal* rate of return, as it is an intrinsic value not dependant on any external factors. By using this method the merits of the project is only decided on the basis of the discounted cash flows generated by the project. The general investment rule is: Accept the project if the IRR is greater than the discount rate and reject the project if the IRR is less than the discount rate.

IRR and NPV are related to each other as they both take the time value of money into account. As stated in Table 1.1, the IRR is the rate that causes the NPV of a project to be zero. This means that the IRR and NPV rule will always coincide exactly with each other: if a project is accepted because of the IRR rule (the IRR is greater than the discount rate), it will also be a positive NPV project. Alternately, if a project is rejected because the IRR is less than the discount rate, it will also be a negative NPV project (Ross et al., 1999, p. 142).

2.4.4 Net Present Value

NPV can be defined as the sum of the annual cash flows discounted for any delay in receiving them, minus the investment outlay (Boehlje & Ehmke, 2005, p. 2). This means that if the NPV of a project is positive it indicates that the project is financially viable, as proceeding with the project is essentially the same as receiving a cash amount today which is equal to the NPV value. According to Ross et al. (1999, p. 135) the key to NPV as a superior capital budgeting tool is its three attributes:

- NPV uses cash flows, which are more useful in capital budgeting, while earnings are more applicable for accounting purposes.
- NPV uses all the cash flows of the project, as opposed to some other techniques, which ignore cash flows beyond a certain point, for example, the Payback Period technique.
- NPV discounts the cash flows properly, while other approaches ignore the time value of money.

The ability to estimate benefits is a key factor determining the usefulness or accuracy of the NPV technique (Gordon & Loeb, 2006, p. 124). In an environment with little or no risk it is easy to determine the discount rate of borrowed capital, because it would be close or equal to the lending rate of major banks. This seems particularly applicable to solar PV energy generation, as it is an established technology of which the key benefits (being the generation of electricity) can be predicted fairly accurately over the long term for a specific geographical area (Spencer, 2011, p. 35).

In recent years various researchers have asked whether NPV alone is sufficient to evaluate the economic profitability of a capital investment, or whether it should be combined with real options analysis. Truong et al. (2007, p. 1) and Teach (2003, p. 1) argue that, although real options techniques have gained a toehold in capital budgeting, it is not yet part of the mainstream. Others (Denison, 2009; Teach, 2003) argue that NPV alone is too rigid to evaluate the contingent nature of strategic decisions, and that NPV analysis needs to be done in conjunction with real options analysis. This argument seems plausible for investment decisions where active management is crucial, for example, flexible assembly, contract manufacturing or procurement contracts. Real options analysis is also a useful tool for helping managers reduce escalation of commitment, in other words, helping them to know when to abandon a project and to avoid "throwing good money after bad" (Denison, 2009, p. 133). However, the nature of a solar PV system investment for a dairy farmer is not one of active management; once the initial investment decision has been made, there are few further management inputs required, and the yield of a solar PV system is fairly predictable. Having evaluated the literature on NPV and the nature of solar PV systems, real options analysis is not included in this study.

2.4.5 A financial model to evaluate solar power

This study endeavours to put forward a financial model that will accurately evaluate the viability of solar power for Free State dairy farms, compared to the status quo, which is Eskom power. Although the annual yield of a solar PV system is fairly predictable over its lifespan, there are risks associated with such a system; these risks need to be properly accounted for in the model to ensure the model's accuracy and usefulness. Risks associated with a solar PV system include:

- Quality issues: If the system does not perform as expected over the 25 year period it will lead to increased maintenance costs, possible premature replacement of components and possible increased insurance cost;
- The technology might become obsolete. Since a solar PV system is such a long term investment it is possible that, over time, another, more efficient technology might cause solar PV to become outdated. Although such a development will not stop the solar PV system from producing electricity as planned, it might limit the farmer's opportunity to take advantage of the new technology; and
- Certain variables, such as interest rates and escalation of Eskom tariffs, are unpredictable. As pointed out by Gordon and Loeb (2006, p. 124), it means that, although NPV is a superior capital budgeting technique, for the reasons discussed earlier, and although an NPV analysis could theoretically be done correctly, it is still possible that some of these unpredictable variables can cause the projected cash flows of a solar PV system to go unmet in practice.

These risks are difficult to quantify and will be addressed in the model by means of scenario analyses, and by incorporating the following variables:

Scenario 1 = medium scenario

Scenario 2 = worst-case scenario for solar PV

Variables: high interest rate, high inflation rate, low Eskom annual tariff increases and low monetary values of own-generated electricity compared to Eskom rates.

Scenario 3= best-case scenario for solar PV

Variables: low interest rate, low inflation rate, high Eskom annual tariff increases and high monetary values of own-generated electricity compared to Eskom rates.

The following variables will be kept constant for all scenarios over the project lifetime:

- SARS tax rates and applicable income tax regulations; and
- Eskom rate structures.

2.5 SUMMARY

The review of the literature relating to the different components and applications of solar PV systems, as well as the financial tools to evaluate solar power in Free State dairy farms as described in this chapter form the basis of the research. This foundation will be used in Chapter 3 to present a comprehensive description of the qualitative methodology used in the research to provide answers to the stated research questions and to reach the objectives stated in Chapter 1.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 INTRODUCTION

The main objective of this chapter is to demonstrate the methodology used to build a financial model to evaluate solar power in Free State dairy farms, including an explanation of the variables included and the assumptions made in the model.

The first part of the model involved designing a solar system that could supply the electricity needs of each dairy involved in the research. Numerous solar-design-software models have been developed. Over the years these models have been refined to give fairly accurate designs for solar systems to meet certain requirements. This research used the design tool developed by the European Commission's joint research centre. The software model is called Photovoltaic Geographic Information System (PV GIS). The data collected by means of the energy meters and interviews are used in conjunction with PV GIS to design and size an ideal solar PV system for providing in the energy needs of each dairy, or as close as possible to the total energy needs of each individual dairy, while also incorporating net-metering as explained in Paragraph 2.2.3.2.2.

The second part of the model involved determining the annual electricity savings that would be generated by the solar system. Each dairy's specific Eskom electricity charges (Rand per kWh) were used as a basis for the value of each kWh generated by the solar system, and then adjusted in three scenario analyses to account for different scenarios based on the variables used and assumptions made in the model.

The third part of the model involved calculating the SPP, IRR and NPV of the solar system, as well as evaluating the cash-flow implications for each dairy. Based on the outcome of these calculations a proper evaluation could be made on the financial viability of an investment in solar power for each dairy.

3.2 DATA-COLLECTION PROCESS

All members of the target population belong to the MPO in the Free State. Because of the qualitative nature of this study, only three dairies were selected for inclusion in the research, based on the criteria explained in Chapter 1:

1. Dairy A has approximately 150 cows in milk and is situated in the Bloemfontein area;
2. Dairy B has approximately 400 cows in milk and is situated in the Clocolan area; and
3. Dairy C has approximately 900 cows in milk and is situated in the Bloemfontein area.

Data were collected, first, by installing energy meters on the electrical distribution boards at each dairy. Over a period on one year, from 1 September 2013 until 31 August 2014, these energy meters recorded the electricity use in the dairy half-hourly, thus providing an accurate account of the energy consumption (kWh) as well as peak power (kW) of the dairy on a daily, weekly, monthly and annual basis. The exact activities that consume energy from the distribution board of each dairy will differ from one dairy to another. For example, at one dairy the mixing of feed and at another dairy, the security lighting for the farm buildings might be included in the dairy's electricity consumption. The same applies regarding certain activities that might be related to the dairy, but fed with electricity from another electrical distribution board than the one with the meter. The focus of the research was not to define and limit the electricity consumption to specific dairy activities, but rather to build a model to evaluate solar power as a replacement for Eskom power at that specific distribution point in the dairy.

Secondly, data was collected by means of interviews with the owners, accountants, insurers and tax consultants of each dairy. By conducting in-depth interviews with these parties accurate data were collected on the following:

- How aware and informed the participants are about solar PV energy and what their attitudes are towards the possibility of implementing this technology in their dairies;
- What barriers the participants perceive to implementing solar PV systems at their dairies as a means of managing their electricity costs;
- The preferred location of a possible solar PV system, either on available north-facing roof space and/or an open space close to the dairy;
- The preference for using own capital vs. borrowed capital to invest in a solar PV system;
- The Eskom rate structure of each dairy;
- The ability and willingness to change operations in the dairy in order to move electricity consumption away from the traditional early morning and late afternoon peaks, towards midday consumption;
- The tax structure of the dairy and tax implications of investing in a solar PV system; and
- The insurance portfolio of the dairy and the cost of additional insurance to cover the solar PV system.

3.3 ASSUMPTIONS

The model is based on the following assumptions:

- Eskom electricity tariffs will never decline, but will increase annually over the time frame of the model.

- Eskom does not currently allow renewable-energy systems to be connected on the low-voltage side of its network (Eskom, 2015b). It is assumed that Eskom will allow this in the near future. This assumption is based on the outcome of recent talks between Eskom, AgriSA, the banking sector and the Department of Trade and Industry (Du Preez, 2015, p. 32).
- Eskom will require its clients to be net importers of electricity on a monthly basis. In other words, clients will get a credit for exporting energy into the grid but it will not be possible for clients to carry this credit over from one calendar month to the next. This assumption is in line with the practice of net-metering as it is currently applied in certain local municipalities, for example, Nelson Mandela Bay (Energy Cybernetics, 2015). If Eskom allows net-metering on an annual basis it would be beneficial to end customers, as consumers would be able to use excess energy that was generated during summer months in winter, thus enabling them to build bigger solar PV systems. There is no clear indication from Eskom yet whether this would be the case, as a result monthly net-metering is assumed.
- It would be possible for the client to feed electricity into the Eskom grid, both in terms of physical restraints (for example the size of the Eskom transformer) and of the capacity and willingness of Eskom to receive electricity at that point if excess electricity from the dairy is fed into the grid at midday.
- Eskom will assign different values to electricity sold to its customers and to own-generated electricity "banked" by customers on the Eskom grid, to account for factors such as administration and maintenance cost to the grid.
- The tax structure and income-tax rates of the dairies participating in the research will remain constant over the time frame of the model.
- Since PV modules have such a long life span (most PV module manufacturers offer performance warranties of at least 25 years) it is difficult to predict all financial costs and benefits. It is assumed that the PV modules will not have to be replaced over the course of 25 years. It is also fairly certain that these modules will not stop producing immediately after 25 years. In fact, according to the warranty terms of most manufacturers they should still be producing at 80% of their original capacity after

this period. However, in the light of a high probability of huge technological advancement over such a long period, it is not certain whether these modules will be of any value after 25 years. For the purpose of this study it is assumed that the modules will have no value after 25 years.

- It is difficult to predict the productive life span of solar inverters. Most manufacturers give a standard warranty of 5–7 years. In some cases this warranty can be extended for up to 20 years, at a cost, which gives an indication of the expected life span of the product. For the purpose of this research it is assumed that the price of the inverters will increase annually by the assumed inflation rate, that the inverters will have to be replaced fully after 12 years, and that inverters will have no value after 25 years. It is further assumed that, over and above maintenance costs to the complete solar system, there will be no maintenance cost for the inverters specifically over its life span.
- The software of the European Commission's joint research centre is used in the research, specifically the PV GIS tool. This solar design tool is commonly used in designing and sizing solar systems across the world. However, the purpose of the study is not to design the most efficient solar system possible, but to do financial analyses on realistic system designs. Although there are different approaches to system design it is assumed that the results of the software used provide realistic system designs on which financial analyses can be based.
- It is not financially viable for the dairies involved in the research to store all its energy in batteries and disconnect from the grid (Microcare, 2015; Solarworld, 2015; Maxx Solar, 2015). This might be an option in future as battery technology evolves. It is assumed that the solar PV system will only have an effect on the variable portion (Rand/kWh) of the electricity bill. As the dairies involved in the research would not disconnect from the Eskom grid, Eskom's normal fixed charges still apply. It is further assumed that the solar PV system would not have an effect on the monthly maximum demand charge. This assumption is made, firstly, because the yield of a solar PV system falls mostly outside the peak consumption times of the dairies involved. Secondly, cloud cover, either during the morning or afternoon peak consumption time, is quite possible for at least one day per month, and whatever small

effect the solar PV system would have had on peak demand would then be nullified and the normal peak demand charge would apply for that month.

- All tax incentives (e.g. the allowance for energy efficiency savings under Article 12L of the Income Tax Act) that could not be verified as applicable to solar PV systems were excluded from the financial model. Similarly, support programmes (e.g. support programmes by the Department of Trade and Industry for Black Economic Empowerment projects in the solar industry) were excluded from the financial model.

3.4 KEY VARIABLES

The following were identified as the key variables of the model:

- Prime interest rate;
- Inflation rate;
- Escalation of Eskom tariffs; and
- The monetary value of own-generated electricity.

3.4.1 Prime interest rate

According to the Farlex Online Financial Dictionary (2015) the prime interest rate is defined as the rate at which commercial banks lend to their best (prime) customers. In this research the prime interest rate is taken as a base rate at which dairy farmers would be able to obtain capital with the purpose of investing in solar PV systems. Assuming all other factors remain constant, a higher interest rate would result in higher cost of borrowed capital and risk, resulting in less favourable financial indicators for an investment in solar PV. Figure 3.1 shows South Africa's prime interest rate for the last 10 years (SA Reserve Bank, 2015).

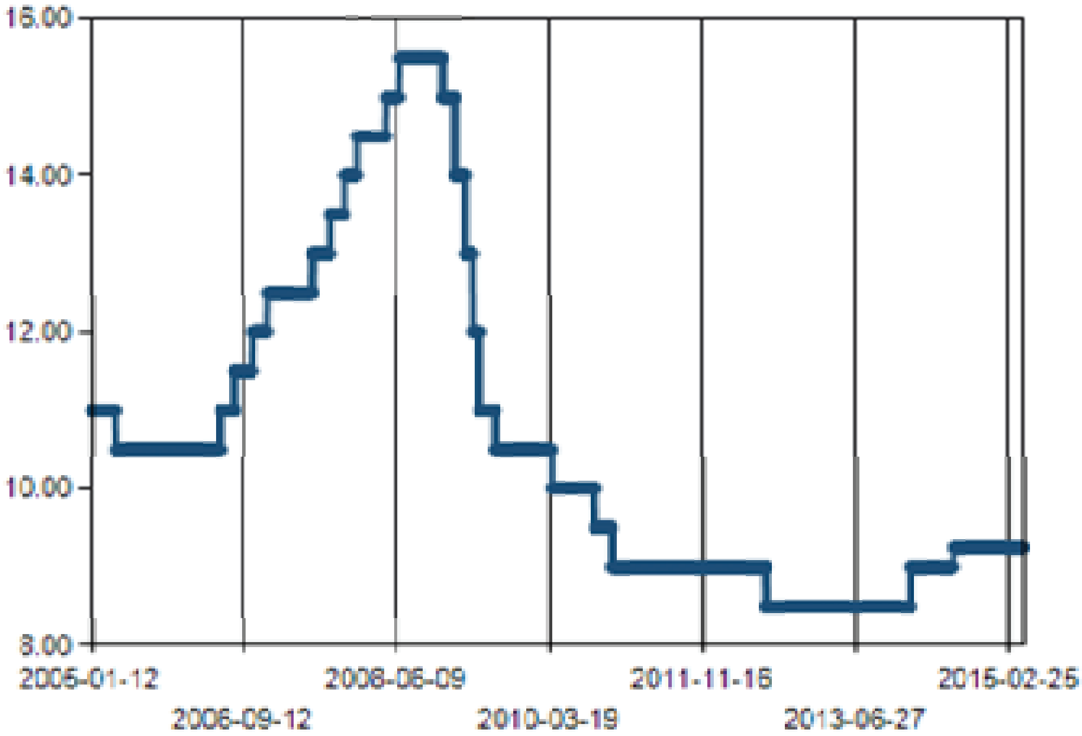

Figure 3.1: Prime interest rate 2005-2015

As can be seen from Figure 3.1, the prime interest rate declined steadily from its 10-year highest rate of 15.5% in June 2008, to the lowest rate of 8.5% in July 2012. After that, two rate increases brought it to its current level of 9.25%. In the light of this trend a slightly negative approach is taken in this research with regard to the interest rates in the financial model, pegging it at the following values:

- Medium scenario: prime rate 9.25%;
- Worst-case scenario for solar PV: prime rate plus 3.5% = 12.75%; and
- Best-case scenario for solar PV: prime rate minus 1% = 8.25%.

3.4.2 Inflation

Assuming all other factors remain constant, a higher inflation rate would result in higher maintenance and insurance costs, resulting in less favourable financial indicators for an investment in solar PV. In the research the Production Price Index (PPI) is used as a measure of inflation. The PPI is defined by the Business Directory (2015) as a relative measure of average change in price of a basket of representative goods and services sold by manufacturers and producers in the wholesale market. According to Statistics South Africa (2015), producer prices have been fairly volatile over the last 10 years, with the PPI inflation rate ranging between 19.1% in August 2008 and minus 4.1% in June 2009. PPI rates increased by an average of 6.29% between January 2013 and February 2015. In the research this value is taken as a medium value of inflation, and adjusted upwards and downwards as follows in the scenario analysis:

- Medium scenario: 6.29%;
- Worst-case scenario for solar PV: 12%; and
- Best-case scenario for solar PV: 4%.

3.4.3 Eskom tariff increase

Because current Eskom electricity tariffs are taken as a basis of the value of electricity generated by the solar PV system, smaller Eskom tariff increases will result in lower values for energy generated by the solar PV system, resulting in less favourable financial indicators for the solar PV system. Table 3.1 shows the historical average price increases from 1988 to 2013 (Eskom Holdings, 2015).

Table 3.1: Eskom's historical average approved tariff increase

Year	Average approved tariff increase %
1988	10
1989	10
1990	14
1991	8
1992	9
1993	8
1994	7
1995	4
1996	4
1997	5
1998	5
1999	4.5
2000	5.5
2001	5.2
2002	6.2
2003	8.43
2004	2.5
2005	4.1
2006	5.1
2007	5.9
2008	27.5
2009	31.3
2010	24.8
2011	25.8
2012	16
2013	8

As can be seen in Table 3.1 Eskom's tariff has increased at well above inflation rates since 2008. In 2014 the tariff was increased by 8%. As was discussed in Chapter 1, Eskom's latest application to NERSA involves increasing the latest approved tariff of 12.69% for 2015/16 to a staggering 25.3% (Fin24, 2015). It is evident that Eskom is currently struggling to make ends meet. In the light of this reality the Eskom tariff increases are pegged in the model at the following values:

- Medium scenario: the latest approved rate of 12.69% for the next financial year, plus the same rate of 12.69% for the following five years, plus an annual rate increase equal to the inflation rate over the remainder of the time frame of the model.
- Worst-case scenario for solar PV: the latest approved rate of 12.69% for the next financial year, plus an annual increase equal to the assumed PPI of 6.29% plus 3% for the following five years, plus an annual increase equal to the assumed PPI over the remainder of the time frame of the model.
- Best-case scenario for solar PV: the latest approved rate of 12.69% for the next financial year, plus 17.69% (12.69% + 5%) for the following five years, and an annual rate increase equal to the assumed PPI rate plus 2% over the remainder of the time frame of the model.

3.4.4 Monetary value of own-generated electricity

The monetary value of each own-generated kWh is clearly quite important in determining the financial viability of a solar PV system. Higher monetary values of own-generated electricity will result in better financial indicators for a solar PV system. However, there are important unknowns which make it difficult to quantify this variable. A distinction should be made between own-generated electricity that is used immediately when it is produced and own-generated electricity that is not used as it is produced, but stored on the Eskom grid for later consumption:

- For each kWh that is used directly as it is produced, the value would be equal to the value of a kWh bought from Eskom at that same time, less any fixed cost (monthly charge) that Eskom might charge for storing electricity on its grid.

- The value of each kWh stored on the Eskom grid would be the "feed-in tariff" (Rand per kWh) that Eskom compensates the client for, less any fixed cost (monthly charge) that Eskom might charge for storing electricity on its grid.

At the time when this research was conducted Eskom had not given any indication of what their feed-in tariff might be, and whether they will have both a fixed charge (amount per month) and variable charge (amount per kWh) for allowing clients to store energy on their grid. In the absence of any certainty regarding what type of charges will apply, and their values, it makes no sense to quantify the charges by means of scenario analysis or even to calculate the electricity portion that each dairy will consume directly or store for later consumption. Thus, in this study the value of an own-generated kWh is simply accounted for by means of a percentage of the value of a kWh bought from Eskom at the same time. These percentages are pegged at the following values:

- Medium scenario: 80%;
- Worst-case scenario for solar PV: 70%; and
- Best-case scenario for solar PV: 90%.

3.5 DATA PROCESSING AND ANALYSIS

3.5.1 Designing of solar PV system

The first part of designing a financial model to evaluate the viability of solar power in Free State dairy farms involves designing a solar system that could provide in the energy needs of each dairy. Since the energy consumption of each dairy was recorded this data forms the basis for designing the solar system.

PV GIS is used to design and size the ideal solar PV system that can provide in the energy needs of each dairy, taking the following variables into account:

- Radiation and other weather patterns at the specific geographical location;
- The total energy needs (kWh) of each dairy;

- The type of installation (i.e. roof mounted or free standing);
- The type of PV technology used, in this case crystalline silicon modules; and
- The inclination and orientation of the PV modules at each dairy.

3.5.2 Determining the capital outlay and savings

The capital outlay of the solar PV system designed for each dairy is based on the current value of installed solar PV systems, including supply of all equipment and materials plus complete installation and commissioning of the designed system on each dairy.

PV GIS software provided the monthly and annual predicted kWh yield of each designed solar PV system. The next step in the model was to assign financial values to the kWh yield of each system designed. This was done by taking as a base the Eskom tariffs for each dairy. In other words, the saving of each kWh produced by the solar PV system is, as a best-case scenario, assumed to be equal to the value of a kWh bought from Eskom at the same time, because each kWh produced by the solar PV system does not need to be bought from Eskom. This, then, provides a best-case scenario for the financial value of the yield of the solar PV system for each dairy. However, this scenario is not realistic as it assumes that Eskom assigns the same value to a kWh that a client stores on its grid and to a kWh bought from Eskom, without charging the client a fee for administration and maintenance for using Eskom's grid for the purpose of storing energy. As explained in Paragraph 3.4.4, Eskom had, at the time of conducting this research, not given any indication of what this fee might be or whether it would comprise a variable portion (amount per kWh) or fixed portion (amount per month) or both. Thus, a percentage value was assigned to the financial value of the yield of the system to account for three different scenarios.

After the financial yields for the solar PV system had been determined for each dairy, these yields needed to be adjusted to take into account all operational expenses of the solar PV system. One of the great benefits of a solar PV system is its low operational cost (Australian Business Council for Sustainable Energy, 2012, p. 11). Market-related values were taken as a base for full maintenance contracts as well as the added cost of insurance as a result of installing the solar PV system of each dairy. All savings and expenses of each solar PV system were accounted for in the model on an after-tax basis.

3.5.3 Calculation of financial indicators

The SPP, IRR and NPV were calculated for each dairy using the data as described in Paragraph 3.5.2 on an after-tax basis over a 25-year period. The correctness of the model was confirmed by Mr. Neels Grobbelaar, a chartered accountant (personal communication, T Roos & Co. Professional Accountants, April 15, 2015). The period of 25 years was chosen because most PV module manufacturers give a 25-year performance warranty. Because it is difficult to predict all financial costs and benefits accurately over such a long period, certain assumptions needed to be made, as described in Paragraph 3.3.

Based on the outcomes of the SPP, IRR and NPV calculations the financial viability of the solar PV system for each dairy was determined.

The main focus of this study in determining the financial viability of a solar PV system for Free State dairy farms was on SPP, IRR and NPV. However, capital repayment and interest payments are not intrinsic to these financial tools. Therefore, the cash-flow implications of an investment in a solar PV system were also calculated in the model. Gloy and LaDue (2003) researched capital-investment decisions made by a group of dairy farmers in New York and found that, in addition to NPV, IRR and SPP, the ability to make loan payments is an important determining factor in investment decisions. It can be assumed that this factor will also play an important role in capital investment decisions by South African dairy farmers. The net-cash-flow implications were determined by first calculating the annual loan repayments (cash outflows) and comparing that with the cash savings generated by the solar PV system. All cash-flow calculations were done on an after-tax basis.

3.6 CONCLUSION

The qualitative nature of this study called for qualitative methods of data collection, processing and analysis in order to build a meaningful financial model to evaluate the viability of solar power in Free State dairy farms. Energy use as measured by the energy meters installed provided the data. However, it was necessary to collect additional data about factors that influence the financial viability of solar power; this was done during site visits and in-depth interviews. The financial model is built on comprehensive and accurate data and recognised financial methods are used to evaluate the investment in a solar PV system. Thus the model can be applied as a useful tool in scenario analysis of solar power for Free State dairy farms.

CHAPTER 4

RESEARCH RESULTS

4.1 INTRODUCTION

In this chapter the data gathered from the installed energy meters, site visits, interviews and software modelling (for system design as well as calculation of financial indicators) are described separately for each researched dairy. This is followed by an evaluation of the financial models for each dairy.

4.2 RESEARCH RESULTS: DAIRY A

4.2.1 Results from energy meter

Dairy A stopped operations on 14 August 2014. According to the owner of Dairy A the operation was no longer profitable. This confirms the findings of the literature review, namely, that smaller dairies are contributing a declining percentage of the total South African milk production, because they are not able to harness the economies of scale of larger dairies. Even though 1 September 2013 was selected as the start date for the data collection process because this was the first complete month that energy meters for all three dairies were installed, electrical consumption data collected during August 2013 is available for Dairy A. In order to obtain a realistic electrical consumption figure for the month of August for Dairy A, the data of 15–31 August 2013 was added to the data of 1–14 August 2014.

The total energy consumption as measured by the electricity meter at Dairy A is summarised in Table 4.1.

Table 4.1: Total electricity consumption of Dairy A

Dairy A **Month**	**Total monthly consumption (kWh)**
September 2013	2 249
October 2013	2 297
November 2013	2 200
December 2013	2 125
January 2014	1 643
February 2014	1 423
March 2014	1 644
April 2014	1 550
May 2014	1 632
June 2014	1 560
July 2014	1 477
1-14 August 2014	554
15-31 August 2013	1 207

Calculated figure August	1 761
Annual total	21 561
Monthly average	1 797
Daily average	59
Spring monthly average (Sept-Nov)	2 249
Summer monthly average (Dec-Feb)	1 730
Autumn monthly average (March-May)	1 609
Winter monthly average (Jun-Aug)	1 599

The average power (kW) consumption of Dairy A, as measured on a half-hourly basis by the energy meter from 15 August 2013 to 14 August 2014 is summarised in Figure 4.1.

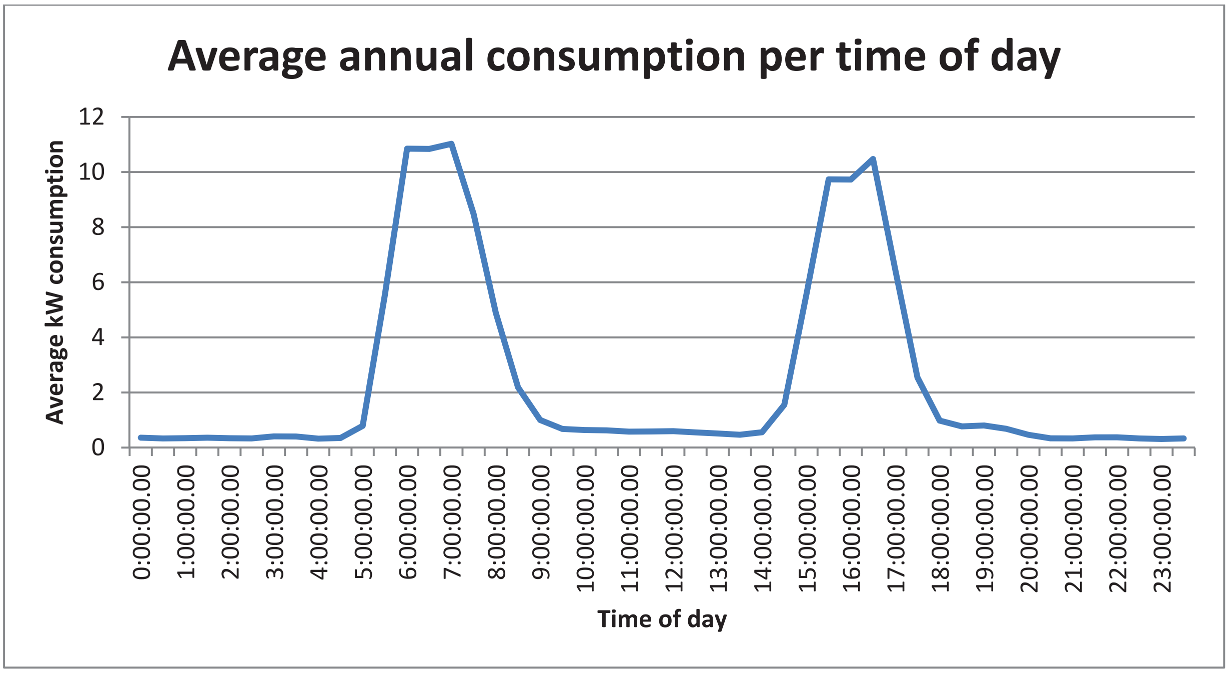

Figure 4.1: Average power (kW) consumption of Dairy A per time of day for period 15 August 2013–14 August 2014

An initial observation of the total monthly and annual consumption (Table 4.1), as well as the average per time of day consumption pattern for Dairy A (Figure 4.1), shows the following:

- Electricity consumption was the highest during the months September to December 2013. The highest consumption was in October 2013 and the lowest consumption occurred in February 2014.
- The typical dairy early morning and later afternoon peaks are obvious. These correspond with the milking times at Dairy A. These peak consumption times fall outside the peak solar production time, which is around midday.
- Morning peak consumption is approximately 11 kW at around 07:00, and afternoon peak consumption is approximately 10.5 kW at around 16:30.

- Consumption is very low (below 1 kW) daily from 20:00 to 04:00.

4.2.2 Results from interviews

The following information was obtained during site visits and interviews:

- The owner of Dairy A possessed some knowledge about solar PV energy but he was not knowledgeable enough to make an informed decision about the financial viability of a solar PV system for the dairy operation.
- He considered the capital outlay to be the main barrier preventing the technology to be more widely used in the dairy industry.
- A total of 126 m^2 of suitable, unobstructed north-facing corrugated-iron roof space is available for the installation of solar modules. This space is sufficient for a roof-mounted PV system of roughly 12.6 kW. There is also enough open space for a free-standing solar PV system in close proximity to the dairy. However, the owner of Dairy A decided to opt for a roof-mounted system, if it was possible, in order to save on the cost of constructing mounting structures, and to have the open areas around the dairy available for other activities. The direction (azimuth) of suitable roof space is 159˚ and lends itself to installation of PV panels at an inclination of 30˚.
- The dairy is operated in a trust.
- The preference would be to make use of 100% loan capital for installation of the solar PV system, and not to make use of any equity funds.
- The Eskom rate structure applicable to the dairy is Landrate. This rate structure is explained in Table 4.4.
- Since all energy-consuming activities are critical for operations at Dairy A, the participant was not interested in storing energy in batteries to provide backup for low-energy consumption activities, e.g., lighting or electronics, in the case of grid failure. The dairy has a backup generator to provide backup power in case of power outages.

- The participant expressed a desire for a solar system that is big enough to provide in the total energy requirement or as close as possible to the total energy requirement of Dairy A in order to effect maximum electricity savings.
- It was not possible, and the participant at Dairy A was not willing to change operations at the dairy in order to create a shift of energy consumption from the current early morning and late afternoon peak periods towards midday, when solar radiation is at its highest.

4.2.3 Design of solar PV system

A simple grid-connected solar PV system with incorporation of net-metering was chosen as the optimal design, based on the following requirements of Dairy A:

- The main requirement of Dairy A was that the solar PV system achieved maximum electricity savings. A grid-connected system is the most efficient and has the least amount of loss, because DC from the panels is converted to AC and fed directly on the dairy's electricity network without being stored in batteries.
- The electricity consumption of Dairy A was too high to consider going completely off-grid and storing the total energy requirement in batteries.
- Dairy A has a backup generator, thus batteries are not needed to provide backup for certain functions.
- Since most of the electricity of Dairy A was used outside peak sun hours, as can be seen from Figure 4.1, energy must be stored and be available when solar power is not sufficient. In a grid-connected system energy can be stored on the grid by means of net-metering.

4.2.4 Results from PV GIS model

The size of the ideal PV system was determined using the PV GIS model. The following parameters were incorporated for Dairy A:

- Location: 28°55'23" South, 26°7'13" East
- Elevation: 1 298 m
- Fixed system inclination: 30˚
- Orientation: 159˚
- Solar radiation database: PVGIS-CMSAF
- Nominal power of the PV system: 10.0 kW (crystalline silicon)
- Estimated losses due to temperature and low irradiance: 17.2% (using local ambient temperature)
- Estimated loss due to angular reflectance effects: 2.5%
- Other losses (cables, inverter etc.): 6.0%
- Combined PV system losses: 24.1%

The results of the PV GIS model for a 10 kW grid-connected and rooftop-mounted solar system for Dairy A is summarised in Table 4.2.

Table 4.2: PV GIS results for 10 kW grid-connected solar PV system for Dairy A

Fixed system: inclination=30°, orientation=159°				
Month	E_d	E_m	H_d	H_m
January	48.10	1 490	6.58	204
February	48.90	1 370	6.68	187
March	52.10	1 620	7.06	219
April	47.00	1 410	6.16	185
May	45.60	1 410	5.80	180
June	45.10	1 350	5.61	168
July	47.80	1 480	5.98	185
August	50.40	1 560	6.52	202
September	53.10	1 590	7.04	211
October	52.20	1 620	7.08	219
November	51.10	1 530	6.95	209
December	48.80	1 510	6.69	207

Yearly average	**49.2**	**1 500**	**6.51**	**198**
Total for year	**18 000**		**2 380**	

E_d: Average daily electricity production from the given system (kWh)

E_m: Average monthly electricity production from the given system (kWh)

H_d: Average daily sum of global irradiation per square metre received by the modules of the given system (kWh/m^2)

H_m: Average monthly sum of global irradiation per square metre received by the modules of the given system (kWh/m^2)

Source: PVGIS © European Communities, 2001-2012

4.2.5 Evaluation of results

Table 4.3 provides a comparison of the energy requirement of Dairy A, as measured by the energy meter, and the projected energy yield of the proposed 10 kW grid-connected solar PV system.

Table 4.3: Comparison of the energy requirement of Dairy A to the yield of the proposed 10 kW grid-connected solar PV system

Dairy A Month	Total monthly consumption (kWh)	Total monthly yield (kWh)	% Yield to consumption	Yield in fin model
September 2013	2 249	1 590	71%	1 590
October 2013	2 297	1 620	71%	1 620
November 2013	2 200	1 530	70%	1 530
December 2013	2 125	1 510	71%	1 510
January 2014	1 643	1 490	91%	1 490
February 2014	1 423	1 370	96%	1 370
March 2014	1 644	1 620	99%	1 620
April 2014	1 550	1 410	91%	1 410
May 2014	1 632	1 410	86%	1 410
June 2014	1 560	1 350	87%	1 350
July 2014	1 477	1 480	100%	1 477
August 2014	1 761	1 560	89%	1 560
Annual total	**21 561**	**17 940**	**83%**	**17 937**

It is projected that the proposed 10 kW solar PV system will produce 83% of the total annual electricity demand of Dairy A. In most months a shortfall is expected, especially in the months of September to December, when a shortfall of up to 30% is expected. This does not pose a threat to the energy requirement of Dairy A as the shortfall would be seamlessly supplemented by Eskom power in the grid-connected solar PV system. A slight overproduction is projected for July. Depending on certain variables, such as weather conditions and changes in electricity consumption, it is possible that, in some years, there could be an overproduction of electricity in February and March. In the light of the assumption made in Paragraph 3.3, namely, that Eskom would require its clients to be net importers of electricity on a monthly basis, it will not be possible to carry this overproduction over to the next month, resulting in this energy being forfeited by Dairy A. Thus the 10 kW system would be used for financial analysis and the system size would not be increased further. Furthermore, because of this assumption the yield would be limited to the monthly energy requirement for purposes of the financial model, as indicated in the last column of Table 4.3.

4.2.6 Financial model

The inputs of the financial model of Dairy A are summarised in Table 4.4.

Table 4.4: System and financial inputs for Dairy A

SYSTEM INFORMATION	
Installed Capacity (kWp)	10
Annual degradation of PV panels	0.70%
FINANCIAL INFORMATION	
Capital outlay	R 200 000
Loan percentage	100%
Loan amount	R 200 000
Current cost of solar inverters	R 40 000
Client Eskom rate structure: Landrate 1	
Energy charge (R/kWh)	R 0.75
Reliability service charge (R/kWh)	R 0.0029
Network demand charge (R/kWh)	R 0.188
Total charge (R/kWh)	R 0.9436
Eskom approved increase from April 2015	12.69%
Total charge (R kWh) year 1	R 1.06

Loan period (years)	15
Annual loan repayment medium scenario	R 24 701
Annual loan repayment PV worst case	R 29 972
Annual loan repayment PV best case	R 23 283

SARS Tax rate	40.00%
SARS Mortification Year 1	50.00%
SARS Mortification Year 2	30.00%
SARS Mortification Year 3	20.00%

Weighted average cost of capital (WACC)

Percentage loan capital	100.00%
Percentage equity	0.00%
Loan capital rate	9.25%
Equity rate	8.00%
WACC rate	9.25%

Expenses

Annual insurance rate all risk including theft	8.00%
First loss % of total system	5.00%

Annual amount all risk including theft	R 800
Annual insurance rate fire and acts of God	0.75%
Annual amount fire and acts of God	R 1 500
Total insurance cost year 1	R 2 300
Maintenance rate per 100 kW	R 6 000
Total maintenance cost year 1	R 600

The results of the financial model of Dairy A are summarised in Table 4.5. The detailed financial model of Dairy A is shown in Appendices A1 – A4.

Table 4.5: Financial results for Dairy A

10 kW Grid-connected Solar PV System for Dairy A

	Scenario 1	Scenario 2	Scenario 3
KEY VARIABLES	**Medium case**	**PV Worst case**	**PV Best case**
Annual prime interest rate	9.25%	12.75%	8.25%
Annual production price index (PPI)	6.29%	12.00%	4.00%
Annual Eskom tariff increase year 1	12.69%	12.69%	12.69%
Annual Eskom tariff increase years 2-6	12.69%	9.29%	17.69%
Annual Eskom tariff increase year 7-25	6.29%	6.29%	8.29%
Value of own-generated electricity as % of Eskom tariff	80%	70%	90%
FINANCIAL INDICATORS			
PV Net present value (NPV)	R 21 908	R -68 557	R 160 966
PV Internal rate of return (IRR)	11.10%	1%	17.47%
PV Simple payback period (SPP)	9-10 years	22-23 years	7-8 years

4.3 RESEARCH RESULTS: DAIRY B

4.3.1 Results from energy meter

The total energy consumption as measured by the electricity meter at Dairy B is summarised in Table 4.6.

Table 4.6: Total electricity consumption of Dairy B

Dairy B **Month**	**Total monthly consumption (kWh)**
September 2013	12 522
October 2013	13 422
November 2013	13 670
December 2013	13 716
January 2014	13 659
February 2014	11 341
March 2014	12 155
April 2014	11 965
May 2014	12 802
June 2014	13 304

July 2014	13 600
August 2014	14 402
Annual total	156 558
Monthly average	13 047
Daily average	429
Spring monthly average (Sept-Nov)	13 205
Summer monthly average (Dec-Feb)	12 905
Autumn monthly average (March-May)	12 307
Winter monthly average (Jun-Aug)	13 769

The average power (kW) consumption of Dairy B, as measured on a half-hourly basis by the energy meter from 1 September 2013 to 31 August 2014 is summarised in Figure 4.2.

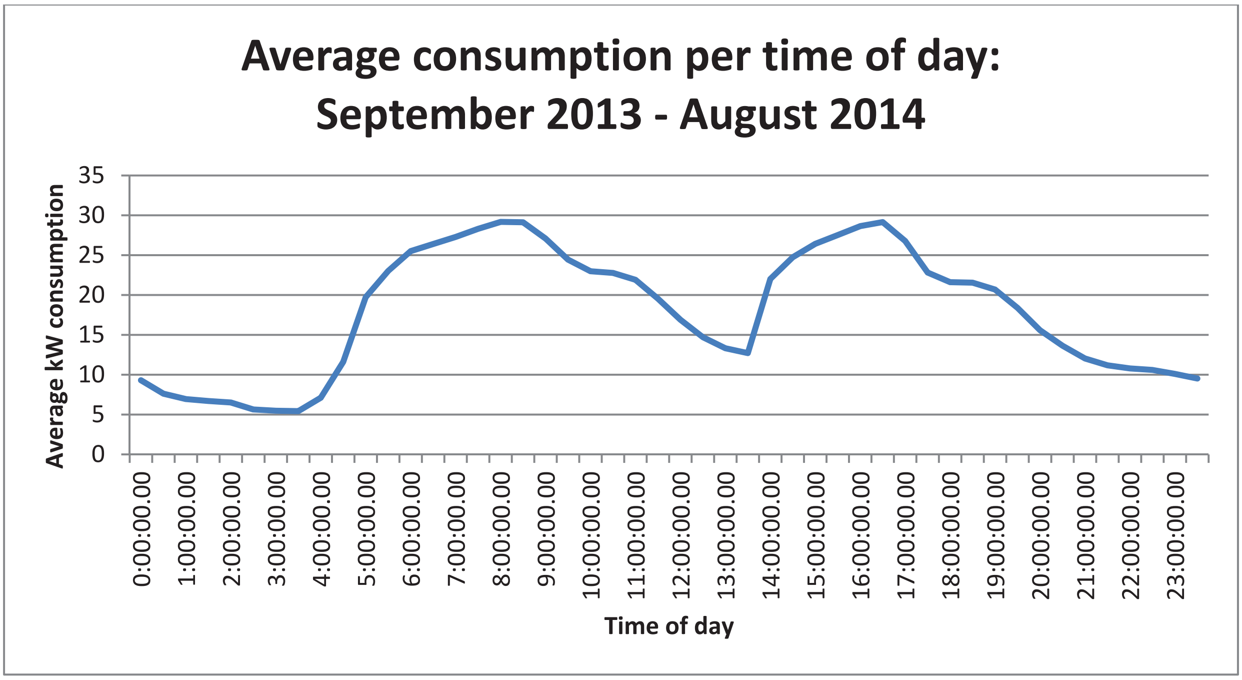

Figure 4.2: Average power (kW) consumption for Dairy B per time of day for period 1 September 2013 to 31 August 2014

An initial observation of the total monthly and annual consumption (Table 4.6) as well as the average per time of day consumption pattern for Dairy B (Figure 4.2) shows the following:

- Consumption was fairly constant over the 12 months, with most electricity being used in August and the lowest consumption occurring in February.
- The typical dairy early morning and later afternoon peaks are observed. These correspond with the milking times at Dairy B. These peak-consumption times fall outside the peak solar production time, which is around midday.
- Morning peak consumption of approximately 29 kW is around 08:00 and afternoon peak consumption of approximately 29 kW is around 16:30.
- Consumption is much lower from 22:00 to 04:00 daily and varies between 5 and 10 kW during this time.

4.3.2 Results from interviews

The following information was obtained during site visits and interviews with the owner of Dairy B and his auditor and insurance broker:

- The owner of Dairy B was fairly knowledgeable about solar PV energy but did not know enough about the financial implications of an investment in solar PV to be able to make an informed decision.
- He considered the lack of knowledge and certainty about solar PV technology as the main barrier preventing the technology to be more widely used in the dairy industry.
- A total of 458 m^2 of suitable, unobstructed north-northwest facing (152˚) corrugated-iron roof space is available for the installation of solar modules. This space is sufficient for a roof-mounted PV system of roughly 46 kW. The inclination of the corrugated iron roofs is 20˚. There is also enough open space for a freestanding solar PV system in close proximity to the dairy. If sufficient roof space is available the owner of Dairy B would prefer to install a roof-mounted solar PV system.
- The dairy is operated in a trust.
- The preference is to make use of 100% loan capital for installation of the solar PV system, and not to use any equity funds.
- The Eskom rate structure applicable to the dairy is Landrate. This rate structure is explained in Table 4.9.
- Since all energy-consuming activities are critical for operation of Dairy B, the participant was not interested in storing energy in batteries to provide backup for low-energy consumption activities, e.g., lighting or electronics, in the case of grid failure. The dairy has a backup generator to provide backup power in case of power outages.
- The participant expressed a desire for a solar system that is big enough to provide in the total energy requirement, or as close as possible to the total energy requirement, of Dairy B in order to effect maximum electricity savings.

- It is not possible, and the participants at Dairy B were not willing to change operations at the dairy in order to create a shift of energy consumption from the current early morning and late afternoon peak periods towards mid-day, when solar radiation is at its highest.

4.3.3 Design of solar PV system

A simple grid-connected solar PV system with incorporation of net-metering was chosen as the optimal design, based on the following requirements of Dairy B:

- The main requirement for Dairy B is for the solar PV system to effect maximum electricity savings. A grid-connected system is the most efficient and has the least amount of loss, as DC from the panels is converted to AC and fed directly on the dairy's electricity network, without being stored in batteries.
- The electricity consumption of Dairy B is too high to consider going completely off-grid and storing the total energy requirement in batteries.
- Dairy B has a backup generator, thus batteries are not needed to provide backup for certain functions.
- Since most of the electricity of Dairy B is used outside peak sun hours, as can be seen from Figure 4.2, energy must be stored for use when solar power is not sufficient. In a grid-connected system energy can be stored on the grid by means of net-metering.

4.3.4 Results from PV GIS model

The following parameters were incorporated for Dairy B:

- Location: 28°57'34" South, 27°29'57" East
- Elevation: 1638 m
- Optimal system inclination: 31˚
- Optimal orientation: 180˚ (true north)
- Solar radiation database: PVGIS-CMSAF
- Nominal power of the PV system: 75.0 kW (crystalline silicon)
- Estimated losses due to temperature and low irradiance: 11.4% (using local ambient temperature)
- Estimated loss due to angular reflectance effects: 2.5%
- Other losses (cables, inverter etc.): 6.0%
- Combined PV system losses: 18.8%

Only 458 m^2 of suitable north-facing roof space is available and this space is spread out over three buildings at Dairy B. According to the PV GIS model the solar PV system is sized at 75 kW; this would require roof space of approximately 750 m^2. Thus, a free standing system is proposed for Dairy B, built at optimal azimuth and inclination. The results of the PV GIS model this system is summarised in Table 4.7.

Table 4.7: PV GIS results for 75kW grid-connected solar PV system for Dairy B

Fixed system: inclination=31°, orientation=180°				
Month	E_d	E_m	H_d	H_m
January	371.00	11 500	6.31	196
February	388.00	10 900	6.60	185
March	411.00	12 800	6.92	215
April	375.00	11 300	6.16	185
May	376.00	11 700	5.99	186
June	373.00	11 200	5.81	174
July	401.00	12 400	6.28	195
August	420.00	13 000	6.74	209
September	430.00	12 900	7.11	213
October	402.00	12 500	6.78	210
November	393.00	11 800	6.65	200
December	371.00	11 500	6.32	196

Yearly average	**393**	**11 900**	**6.47**	**197**
Total for year	**143 000**		**2 360**	

E_d: Average daily electricity production from the given system (kWh)

E_m: Average monthly electricity production from the given system (kWh)

H_d: Average daily sum of global irradiation per square metre received by the modules of the given system (kWh/m^2)

H_m: Average sum of global irradiation per square metre received by the modules of the given system (kWh/m^2)

Source: PVGIS © European Communities, 2001-2012

4.3.5 Evaluation of results

The energy requirement of Dairy B as measured by the energy meter was compared to the projected energy yield of the proposed 75 kW grid-connected solar PV system in Table 4.8.

Table 4.8: Comparison of the energy requirement of Dairy B to the yield of the proposed 75 kW grid-connected solar PV system

Dairy B Month	Total monthly consumption (kWh)	Total monthly yield (kWh)	% Yield to consumption	Yield in fin model
September 2013	12 522	12 900	103%	12 522
October 2013	13 422	12 500	93%	12 500
November 2013	13 670	11 800	86%	11 800
December 2013	13 716	11 500	84%	11 500
January 2014	13 659	11 500	84%	11 500
February 2014	11 341	10 900	96%	10 900
March 2014	12 155	12 800	105%	12 155
April 2014	11 965	11 300	94%	11 300
May 2014	12 802	11 700	91%	11 700
June 2014	13 304	11 200	84%	11 200
July 2014	13 600	12 400	91%	12 400
August 2014	14 402	13 000	90%	13 000
Annual total	**156 558**	**143 500**	**92%**	**142 477**

It is projected that the proposed 75 kW solar PV system will produce 92% of the total annual electricity demand of Dairy B. This is a higher percentage than the proposed systems for Dairies A and C; this is because the energy consumption of Dairy B is more stable from month to month than that of Dairies A and C, which makes it possible to design a system that provides a higher percentage of the total energy needs without having excessive overproduction in certain months. In most months a shortfall of between 4% and 16% is expected for Dairy B. These shortfalls would be supplemented seamlessly by Eskom power in the grid-connected solar PV system. A slight overproduction is projected for the months of March and September. Depending on certain variables, such as weather conditions and changes in electricity consumption, it is also possible that, in some years, there could be an overproduction in February and April. In the light of the assumption made in Paragraph 3.3, namely, that Eskom would require its clients to be net importers of electricity on a monthly basis, it will not be possible to carry this overproduction over to the next month, resulting in this energy being forfeited by Dairy B. Thus, the 75 kW system would be used for financial analysis and the system size would not be increased further. Also, because of this assumption the yield would be limited to the monthly energy requirement for purposes of the financial model, as indicated in the last column of Table 4.8.

4.3.6 Financial model

The inputs of the financial model of Dairy B is summarised are Table 4.9.

Table 4.9: System and financial inputs for Dairy B

SYSTEM INFORMATION	
Installed Capacity (kWp)	75
Annual degradation of PV panels	0.70%
FINANCIAL INFORMATION	
Capital outlay	R 1 500 000
Loan percentage	100%
Loan amount	R 1 500 000
Current cost of solar inverters	R 190 000
Client Eskom rate structure: Landrate 1	
Energy charge (R/kWh)	R 0.75
Reliability service charge (R/kWh)	R 0.0029
Network demand charge (R/kWh)	R 0.188
Total charge (R/kWh)	R 0.9436
Eskom approved increase from April 2015	12.69%
Total charge (R/kWh) year 1	R 1.06

Loan period (years)	15
Annual loan repayment medium scenario	R 185 255
Annual loan repayment PV worst case	R 224 791
Annual loan repayment PV best case	R 174 625

SARS Tax rate	40.00%
SARS Mortification Year 1	50.00%
SARS Mortification Year 2	30.00%
SARS Mortification Year 3	20.00%

<u>Weighted average cost of capital (WACC)</u>

Percentage loan capital	100.00%
Percentage equity	0.00%
Loan capital rate	9.25%
Equity rate	8.00%
WACC rate	9.25%

<u>Expenses</u>

Annual insurance rate all risk including theft	8.00%
First loss % of total system	5.00%

Annual amount all risk including theft	R 6 000
Annual insurance rate fire and acts of God	0.75%
Annual amount fire and acts of God	R 11 250
Total insurance cost year 1	R 17 250
Maintenance rate per 100 kW	R 6 000
Total maintenance cost year 1	R 4 500

The results of the financial model of Dairy B are summarised in Table 4.10. The detailed financial model of Dairy B is shown in Appendices B1 – B4.

Table 4.10: Financial results for Dairy B

75 kW Grid-connected Solar PV System for Dairy B			
	Scenario 1	**Scenario 2**	**Scenario 3**
KEY VARIABLES	**Medium case**	**PV Worst case**	**PV Best case**
Annual prime interest rate	9.25%	12.75%	8.25%
Annual production price index (PPI)	6.29%	12.00%	4.00%
Annual Eskom tariff increase year 1	12.69%	12.69%	12.69%
Annual Eskom tariff increase year 2-6	12.69%	9.29%	17.69%
Annual Eskom tariff increase year 7-25	6.29%	6.29%	8.29%
Value of own-generated electricity as % of Eskom tariff	80%	70%	90%
FINANCIAL INDICATORS			
PV Net present value (NPV)	R 299 871.41	-R 407 780.37	R 1 403 523.13
PV Internal rate of return (IRR)	12.51%	5%	18.70%
PV Simple payback period (SPP)	9-10 years	17-18 years	7-8 years

4.4 RESEARCH RESULTS: DAIRY C

4.4.1 Results from energy meter

The energy meter at Dairy C experienced mechanical failure as a result of Eskom's load shedding. As a result, most of the half-hourly data from 2014 was lost. However it was possible to retrieve the total monthly consumption data for the full year from September 2013 to August 2014, as is summarised in Table 4.11.

Table 4.11: Total electricity consumption of Dairy C

Dairy C **Month**	**Total monthly consumption (kWh)**
September 2013	17 566
October 2013	20 731
November 2013	22 443
December 2013	24 773
January 2014	25 173
February 2014	25 363
March 2014	20 095
April 2014	21 322

May 2014	20 179
June 2014	20 579
July 2014	18 772
August 2014	20 271
Annual total	**257 267**
Monthly average	**21 439**
Daily average	**705**
Spring monthly average (Sept-Nov)	**20 247**
Summer monthly average (Dec-Feb)	**25 103**
Autumn monthly average (March-May)	**20 532**
Winter monthly average (Jun-Aug)	**19 874**

The average power (kW) consumption of Dairy C, as measured on a half-hourly basis by the energy meter from 19 July 2013 to 10 January 2014, is summarised in Figure 4.3.

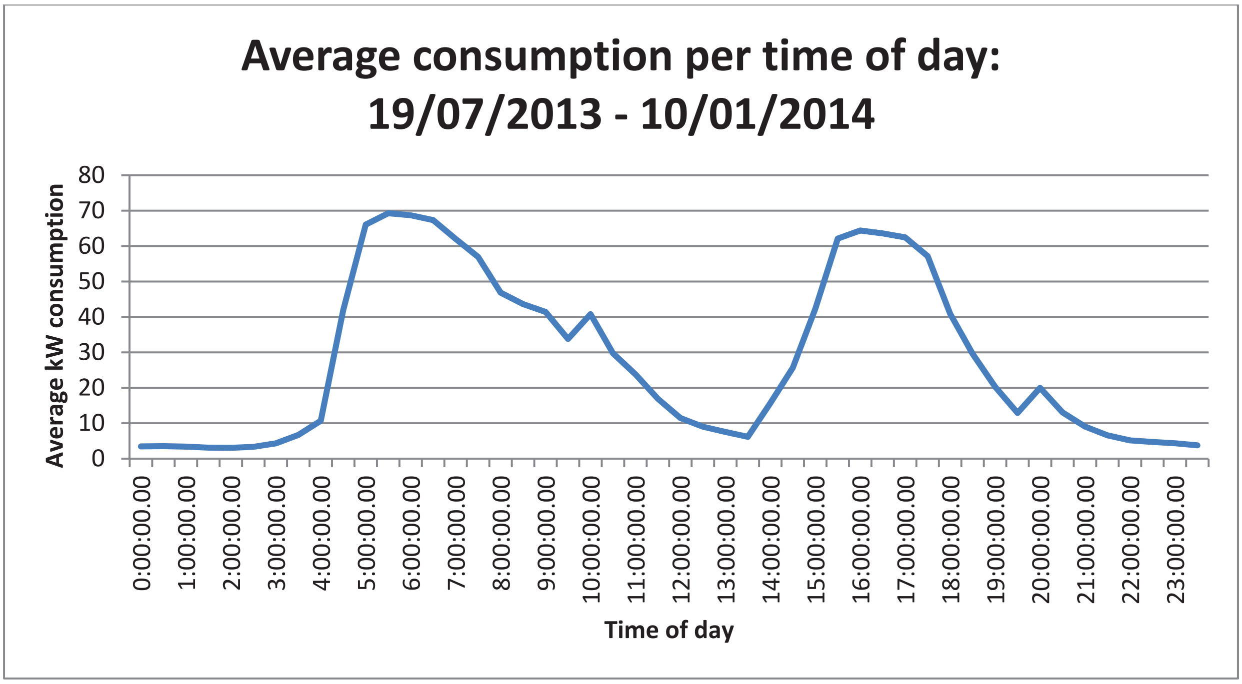

Figure 4.3: Average power (kW) consumption for Dairy C per time of day for period 19 September 2013 to 10 January 2014

An initial observation of the total monthly and annual consumption (Table 4.11) as well as the average per time of day consumption pattern for Dairy C (Figure 4.3) shows the following:

- Electricity consumption is fairly constant from March to November, with higher consumption during the summer months, from December to February.
- The typical dairy early morning and later afternoon peaks are observed. These correspond with the milking times at Dairy C. These peak consumption times fall outside the peak solar production time, which is around midday.
- Morning peak consumption of approximately 70 kW is around 05:30 and afternoon peak consumption of approximately 65 kW is around 16:30.
- The average consumption is lower (1–5 kW) during the night from 23:00–03:00 than during the day.

4.4.2 Results from interviews

The following information was obtained during site visits and interviews with the owner of Dairy C and his auditor and insurance broker:

- The owner of Dairy C had in the past done some research on renewable energy sources that could be used in the dairy, including solar PV and bio-gas. However he is not convinced that either is currently a financially viable option for his dairy. He has a negative outlook regarding Eskom's ability to provide stable and affordable electricity in future, and hence is very interested in the outcome of the research.
- He saw no real barriers to incorporating solar PV technology in his dairy once it has been proven as a financially viable option.
- A total of 510 m^2 of suitable, unobstructed north-northwest facing (154˚) corrugated-iron roof space is available for the installation of solar modules. This space is sufficient for a roof-mounted PV system of roughly 51 kW. The inclination of the corrugated iron roofs is 17˚. There is also enough open space for a free-standing solar PV system in close proximity to the dairy.
- The dairy is operated in a trust.
- The preference would be to make use of 100% loan capital for installation of the solar PV system, and not make use of any equity funds.
- The Eskom rate structure applicable to the dairy is Ruraflex. This is a time-of-use (TOU) rate structure whereby electricity is charged according to the time of day as well as the season in which it is used, as demonstrated in Appendices C5 – C16.
- Since all energy-consuming activities are critical for operation in Dairy C, the participant was not interested in storing energy in batteries to provide backup for certain low-energy consumption activities, e.g., lighting or electronics, in the case of grid failure. The dairy has a backup generator to provide backup power in case of power outages.

- The participant expressed a desire for a solar system that is big enough to provide for the total energy requirement, or as close as possible to the total energy requirement, of Dairy C in order to effect maximum savings.
- It is not possible and the participants at Dairy C were not willing to change operations at the dairy in order to create a shift of energy consumption from the current early morning and late afternoon peak periods towards mid-day, when solar radiation is at its highest.

4.4.3 Design of solar PV system

A simple grid-connected solar PV system with incorporation of net-metering is chosen as the optimal design, based on the following requirements of Dairy C:

- The main requirement for Dairy C is for the solar PV system to affect maximum electricity savings. A grid-connected system is most efficient and has the least amount of loss, as DC from the panels is converted to AC and fed directly on the dairy's electricity network without being stored in batteries.
- The electricity consumption of Dairy C is too high to consider going completely off-grid and storing the total energy requirement in batteries.
- Dairy C has a backup generator, thus batteries are not needed to provide backup for certain functions.
- Since a large portion of the electricity of Dairy C is used outside peak sun hours, as can be seen from Figure 4.3, energy must be stored for use when solar power is not sufficient. In a grid-connected system energy can be stored on the grid by means of net-metering.

4.4.4 Results from PV GIS model

Only 510 m^2 of suitable north-facing roof space is available and this space is spread out over three buildings at Dairy C. According to the PV GIS model the solar PV system is sized at 120 kW; this would require roof space of approximately 1 200 m^2. Thus, a free-standing system is proposed for Dairy C, built at optimal azimuth and inclination. The results of the PV GIS model of this system is summarised in Table 4.12.

Table 4.12: PV GIS results for 120 kW grid-connected solar PV system for Dairy C

Fixed system: inclination=31°, orientation=180°				
Month	E_d	E_m	H_d	H_m
January	596.00	18 500	6.36	197
February	609.00	17 100	6.50	182
March	658.00	20 400	6.94	215
April	595.00	17 900	6.10	183
May	592.00	18 400	5.91	183
June	588.00	17 600	5.73	172
July	625.00	19 400	6.13	190
August	661.00	20 500	6.67	207

September	684.00	20 500	7.07	212
October	660.00	20 400	6.96	216
November	640.00	19 200	6.79	204
December	604.00	18 700	6.46	200
Yearly average	**626**	**19 000**	**6.47**	**197**
Total for year	**229 000**		**2 360**	

E_d: Average daily electricity production from the given system (kWh)

E_m: Average monthly electricity production from the given system (kWh)

H_d: Average daily sum of global irradiation per square metre received by the modules of the given system (kWh/m^2)

H_m: Average sum of global irradiation per square metre received by the modules of the given system (kWh/m^2)

Source: PVGIS © European Communities, 2001-2012

4.4.5 Evaluation of results

The energy requirement of Dairy C as measured by the energy meter is compared to the projected energy yield of the proposed 120 kW grid-connected solar PV system described in Table 4.13.

Table 4.13: Comparison of the energy requirement of Dairy C to the yield of the proposed 120 kW grid-connected solar PV system

Dairy C **Month**	**Total monthly consumption (kWh)**	**Total monthly yield (kWh)**	**% Yield to consumption**	**Yield in fin model**
September 2013	17 566	20 500	117%	17 566
October 2013	20 731	20 400	98%	20 400
November 2013	22 443	19 200	86%	19 200
December 2013	24 773	18 700	75%	18 700
January 2014	25 173	18 500	73%	18 500
February 2014	25 363	17 100	67%	17 100
March 2014	20 095	20 400	102%	20 095
April 2014	21 322	17 900	84%	17 900
May 2014	20 179	18 400	91%	18 400
June 2014	20 579	17 600	86%	17 600
July 2014	18 772	19 400	103%	18 772
August 2014	20 271	20 500	101%	20 271
Annual total	**257 267**	**228 600**	**89%**	**224 504**

It is projected that the proposed 120 kW freestanding solar PV system will produce 89% of the total annual electricity demand of Dairy C. In most months a shortfall of between 2% and 33% is expected for Dairy C. These shortfalls would be supplemented seamlessly with Eskom power in the grid-connected solar PV system. A slight overproduction is projected for the months of March, July and August. A fairly big overproduction of 17% is projected for September. This is because September is typically one of the highest-yield months in terms of PV production for this area, and it corresponds with the lowest measured consumption of the year for Dairy C. Depending on certain variables, such as weather conditions and changes in electricity consumption, it is possible that, in some years, there could be an overproduction in October. In the light of the assumption made in Paragraph 3.3, namely, that Eskom would require its clients to be net importers of electricity on a monthly basis, it will not be possible to carry this overproduction over to the next month, resulting in this energy being forfeited by Dairy C. Thus, the 120 kW system would be used for financial analysis and the system size would not be increased further. Also, because of this assumption the yield would be limited to the monthly energy requirement for purposes of the financial model, as indicated in the last column of Table 4.13.

4.4.6 Financial model

The inputs of the financial model of Dairy C are summarised in Table 4.14.

Table 4.14: System and financial inputs for Dairy C

SYSTEM INFORMATION	
Installed Capacity (kWp)	120
Annual degradation of PV panels	0.70%
FINANCIAL INFORMATION	
Capital outlay	R 2 400 000
Loan percentage	100%
Loan amount	R 2 400 000
Current cost of solar inverters	R 275 000
Client Eskom rate structure:	
Ruraflex (> 300 km and < 600 km; < 500 V)	Refer to TOU tariffs
Reliability service charge (R/kWh)	R 0.0029
Network demand charge (R/kWh)	R 0.188
Total charge (R/kWh)	Refer to TOU tariffs
Eskom approved increase from Apr 2015	12.69%

Total charge (R/kWh) year 1	Refer to TOU tariffs
Loan period (years)	15
Annual loan repayment medium scenario	R 296 407
Annual loan repayment PV worst case	R 359 665
Annual loan repayment PV best case	R 279 400
SARS Tax rate	40.00%
SARS Mortification Year 1	50.00%
SARS Mortification Year 2	30.00%
SARS Mortification Year 3	20.00%

Weighted average cost of capital (WACC)

Percentage loan capital	100.00%
Percentage equity	0.00%
Loan capital rate	9.25%
Equity rate	8.00%
WACC rate	9.25%

Expenses

Annual insurance rate all risk including theft	8.00%
First loss % of total system	5.00%
Annual amount all risk including theft	R 9 600
Annual insurance rate fire and acts of God	0.75%
Annual amount fire and acts of God	R 18 000
Total insurance cost year 1	R 27 600
Maintenance rate per 100 kW	R 6 000
Total maintenance cost year 1	R 7 200

The results of the financial model of Dairy C are summarised in Table 4.15. The detailed financial model of Dairy C is shown in Appendices C1 – C16. The Ruraflex TOU tariff structure is shown in Appendices C5 – C16.

Table 4.15: Financial results for Dairy C

120kW Grid-connected Solar PV System for Dairy C			
	Scenario 1	**Scenario 2**	**Scenario 3**
KEY VARIABLES	**Medium case**	**PV Worst case**	**PV Best case**
Annual prime interest rate	9.25%	12.75%	8.25%
Annual production price index (PPI)	6.29%	12.00%	4.00%
Annual Eskom tariff increase year 1	12.69%	12.69%	12.69%
Annual Eskom tariff increase year 2-6	12.69%	9.29%	17.69%
Annual Eskom tariff increase year 7-25	6.29%	6.29%	8.29%
Value of own-generated electricity as % of Eskom tariff	80%	70%	90%
FINANCIAL INDICATORS			
PV Net present value (NPV)	R 56 260.54	-R 876 329.05	R 1 498 770.94
PV Internal rate of return (IRR)	9.66%	0%	15.64%
PV Simple payback period (SPP)	11-12 years	25-26 years	8-9 years

4.5 EVALUATION OF FINANCIAL MODELS OF DAIRIES A, B AND C

4.5.1 Evaluation of SPP, IRR and NPV

The results of the SPP, IRR and NPV calculations for Dairies A, B and C are summarised in Table 4.16.

Table 4.16: Summary of SPP, IRR and NPV calculations for Dairies A, B and C

	Scenario 1 Medium case	Scenario 2 PV Worst case	Scenario 3 PV Best case
Dairy A			
PV Net present value (NPV)	R 21 907.77	-R 68 557.45	R 160 966.15
PV Internal rate of return (IRR)	11.10%	1%	17.47%
PV Simple payback period (SPP)	9-10 years	22-23 years	7-8 years
Dairy B			
PV Net present value (NPV)	R 299 871.41	-R 407 780.37	R 1 403 523.13
PV Internal rate of return (IRR)	12.51%	5%	18.70%
PV Simple payback period (SPP)	9-10 years	17-18 years	7-8 years

Dairy C

PV Net present value (NPV)	R 56 260.54	-R 876 329.05	R 1 498 770.94
PV Internal rate of return (IRR)	9.66%	0%	15.64%
PV Simple payback period (SPP)	11-12 years	25-26 years	8-9 years

As can be seen in Table 4.16, there are considerable differences between the financial indicators for the three researched dairies, as well as between the scenario analyses for the dairies.

Firstly, when the financial indicators of the three dairies are compared it can be seen that Dairies A and B give more positive results for an investment in a solar PV system than Dairy C. This can be ascribed to the lower Eskom rate structure of Dairy C, making an investment in solar PV power less viable than in Dairies A and B. Dairies A and B pay a fixed Landrate tariff of R 1.06 per kWh in the 2015/2016 financial year. As can be seen in Appendices C5–C16, Dairy C pays a variable rate according to its time of use, which varies between 56 cents per kWh in off-peak times during the low season (September–May) and R 2.79 per kWh in peak times in the high season (June–August). However, the projected yield of the solar PV system for Dairy C is relatively low during these peak times, only between 22 and 23% during the weekday peak times and none at all over weekends. As a result the average Eskom tariff paid by Dairy C (which forms the basis of the value of the electricity produced by the solar PV system) is much lower for Dairy C, resulting in a lower NPV and IRR and longer payback periods.

An additional minor contributor for the poorer results of Dairy C is the fact that there was a poor fit during September between the yield of the proposed solar PV system and the consumption of Dairy C. September is typically a high-yield month for solar energy, because of high radiation combined with lower temperatures, whereas it was the month with the lowest electricity consumption by Dairy C. This resulted in a projected overproduction of 2 934 kWh for September, and because of the assumption that net-metering can only be done on a monthly basis, this amount is discarded by the model.

When observing the three different scenarios for the three dairies it is quite evident that, with the assumptions made and the levels of the key variables set as they are, there are fairly large differences in the results of the model. For all three researched dairies the medium and best-case scenarios resulted in a positive NPV as well as an IRR that is more than the prime interest rate, indicating that the investment in a solar PV system would be a good investment in these circumstances. The SPP ranges between 9 and 12 years for the three dairies. This can be interpreted as quite long. However, it should be remembered that the product has a very long life span, at least 25 years, and when the SPP is compared to the product productive life span it is relatively short.

The worst-case scenario for all three researched dairies resulted in a negative NPV, very low IRR and long payback periods. It can be argued that the worst-case scenario variables are not quite realistic as it is unlikely that Eskom would improve its service delivery to the point that electricity tariffs would rise moderately amidst high interest rates and high inflation rates, as is projected in this scenario. However, it is still useful to observe the results of the model for this scenario. On the other hand, it can be argued that the solar PV best-case scenario (relatively low interest rates and inflation rates combined with a high escalation in Eskom tariffs) is quite possible, as this was the case in the recent past.

4.5.2 Evaluation of the cash-flow analysis

Since the value of Eskom electricity is taken as a basis in the model for determining the value of own-generated electricity by means of a solar PV system, the value of own-generated electricity increases over time as Eskom tariffs increase. On the other hand, the loan repayment amount is calculated in the model as a fixed amount to be paid monthly over a period of 15 years. This means that cash flow would be under pressure initially and steadily improve as the value of the own-generated electricity increases. However, the fact that SARS permits the capital outlay to be written off over three years in a 50:30:20 ratio for income tax purposes, has a major positive impact on the cash flow of a solar PV investment over the first three years, as can be seen in Appendices A2–A4, B2–B4 and C2–C4. Table 4.17 summarises the cash-flow analysis for the three researched dairies.

Table 4.17: Summary of cash-flow analysis

	Scenario 1 **Medium case**	**Scenario 2** **PV Worst case**	**Scenario 3** **PV Best case**
Dairy A net cash flow	Positive years 1-3 Negative years 4-12 Positive years 13-25	Positive years 1-3 Negative years 4-12 and 15 Positive years 13, 14, 16-25	Positive years 1-3 Negative years 4-5 Positive years 6-25
Dairy A cumulative net cash flow	Positive years 1-25	Positive years 1-6 Negative years 7-21 Positive years 22-25	Positive years 1-25

Dairy B net cash flow	Positive years 1-3 Negative years 4-12 Positive years 13-25	Positive years 1-3 Negative years 4-12 and 14-15 Positive years 13 and 16-25	Positive years 1-3 Negative year 4 Positive years 5-25
Dairy B cumulative net cash flow	Positive years 1-25	Positive years 1-6 Negative years 7-21 Positive years 22-25	Positive years 1-25
Dairy C net cash flow	Positive years 1-3 Negative years 4-12 and 14-15 Positive years 13 and 16-25	Positive years 1-3 Negative years 4-15 Positive years 16-25	Positive years 1-3 Negative years 4-7 Positive years 8-25
Dairy C cumulative net cash flow	Positive years 1-9	Positive years 1-5	Positive years 1-25

	Negative years 10-15	Negative years 6-25
	Positive years 16-25	

The following observations can be made from Table 4.17:

- The net cash flow is positive over the first three years for all three dairies in all scenarios. This is a result of the permitted income-tax deduction described above.
- After the first three years the net cash flow turns negative for all three dairies in all scenarios. This is a result of the growing savings not yet keeping up with the loan payments during this time. This period varies between 1 and 15 years, with relatively short periods of negative cash flow in the best-case scenarios and 15 years of negative cash flows is the worst-case scenarios.
- The net cash flow turns positive for all dairies in all scenarios after year 15. This is a result of the loan being paid off in 15 years.
- The cumulative net cash flows are fairly positive for all three dairies. This is, to a large extent, the result of the positive impact of the income-tax deductions in years 1 to 3, which boost the cash flow over this period and have a positive effect on the cumulative net cash flow over the remainder of the guaranteed 25-year productive life span of the solar panels. Only in one instance is the cumulative net cash flow negative after 25 years: the worst case scenario for Dairy C.
- It is insightful that the cumulative net cash flow remains positive for the entire period of years 1 to 25 for the medium and best-case scenarios of Dairies A and B. This means that, for a dairy with a similar Eskom tariff structure as Dairies A and B, and if the key variables in fact remain within the range of the medium and best-case scenarios, a solar PV system would never impact negatively on such a dairy's cash flow over the system's life span of 25 years.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 INTRODUCTION

Everyone in South Africa, including the government, institutions and individuals, has a moral responsibility to preserve the environment. This responsibility includes changing the way that things have been done in the past with regard to energy management, and moving towards cleaner, more environmentally friendly methods of energy consumption and generation. In the global arena the pressure on governments is mounting to accelerate the move towards cleaner energy. It is likely that this pressure will, in the future, be filtered downwards towards institutions and individuals in the form of various sanctions and support measures. In South Africa various tax incentives and support schemes (e.g. Eskom rebate programmes on solar water heating and LED lighting) have already been instituted. On the other hand, the introduction of carbon tax could force businesses to reconsider their energy management programmes more urgently. As part of these energy management programmes businesses need to consider the application of alternative energy sources and investigate its financial viability. Questions regarding payback periods, rates of return, net present values and cash-flow implications need to be answered.

One of the energy-intensive industries that should give high priority to energy management is the dairy industry. Energy management on a dairy farm should include energy-efficiency measures, for example solar water heating, energy-efficient lighting and power-factor correction. This study has shown that, in addition to energy-efficiency measures, the generation of electricity by means of a solar PV system at the point of consumption warrants careful consideration by dairy farmers. A financial model was developed to evaluate the feasibility of own-generated solar PV energy in dairy farms. The model has shown that, dependent on certain variables, the investment in solar PV technology can be a financially viable option for dairy farmers in South Africa. It is a useful tool to assist dairy farmers in decision making regarding an investment in solar power for a dairy farm.

5.2 LITERATURE REVIEW

There have been significant developments in renewable-energy-generation methods. The effect of these developments is visible in the rapid expansion of renewable-energy generation by means of renewable sources, including wind, solar and biogas. In this study the literature relating to several of these sources was reviewed, and although the emphasis of the study was not to make a financial comparison between these sources, it was concluded that solar PV technology is ideally suited for small-scale generation of renewable energy in dairies in an area with high solar radiation, such as the Free State province of South Africa. Several global applications of solar PV technology on dairy farms were also reviewed and reasons for their success or failure were investigated.

Furthermore, the various components of solar PV systems were investigated, as were the different ways these components could be combined in different types of solar systems, with the purpose of determining which system would be best suited and financially viable for the needs of Free State dairy farmers.

Lastly, the literature on the financial tools SPP, IRR and NPV were reviewed and it was concluded that these tools would be used, in combination with a cash-flow analysis, to develop a financial model to evaluate the feasibility of a solar PV system to largely replace Eskom power on Free State dairy farms.

5.3 METHODOLOGY

This is a qualitative study, whereby information from the literature review, measured data from electricity meters, software models and interviews with participants, were used to build a financial model with the purpose of answering the research questions and fulfilling the primary and secondary research objectives. The following steps were taken to ensure that all relevant information that could have a material effect on the model was taken into consideration:

1. To start with, it was necessary to measure the electricity usage of each dairy accurately. For this purpose the peak power and consumption patterns were measured by means of energy meters over a period of one year.
2. A solar PV system that could provide in the dairy's electricity needs needed to be designed. The review of the literature on solar PV systems provided a basis in this regard. The specific needs and requirements of each dairy were taken into account in designing the solar PV systems. There were some minor differences in certain requirements of the three researched dairies. However, the following main themes were the same for all three dairies:
   - They require a solar system that could provide in all or close to all of their energy needs;
   - They prefer to use 100% loan capital for financing the system;
   - All three researched dairies have backup diesel generators and are less concerned with backup power than with the maximum Eskom electricity saving that the system can generate; and
   - It is not possible, or the participants are not willing to investigate the possibility of changing operations in the dairy in order to shift electricity consumption patterns towards peak solar radiation times (midday).

3. Because of the amount of electricity used in the three dairies as well as the requirements above, a grid-connected solar system without any battery backup was chosen as the basic design for all three dairies.
4. Subsequently the size of the solar PV system for each dairy needed to be determined, taking into account the assumptions regarding net-metering made in Paragraph 3.3 above. In determining the size of the solar PV system a range of local parameters needed to be taken into account to accurately predict the yield of the system, including weather patterns, solar radiation and specific on-site installation variables. For this purpose the widely used PV sizing tool of the European Commission (PV GIS) was used to provide a monthly yield prediction for each solar PV system that was designed.
5. Once each solar PV system had been designed and the yield (monthly kWh) predicted, the financial model was built. The basic logic of the model is that there is a capital outlay for the solar PV system, plus some operational expenses, which generates a saving in Eskom electricity over a period of 25 years. Certain variables are difficult to predict over such a long period of time, hence a scenario analysis was done (with a medium, best- and worst-case scenario for the solar PV investment); the key variables are the prime interest rate, the inflation rate, escalation of Eskom tariffs and the assumed value of own-generated electricity. Based on the extrapolation of the model over 25 years, the SPP, IRR and NPV were calculated, and the cash-flow implications of the investment in the solar PV system were determined.

An investment in a solar PV system is a long-term investment. Many of the variables that would influence the results of the model are not yet known or could change considerably over time, hence the need to make assumptions and to conduct scenario analyses. However, business decisions often need to be taken in times of uncertainty and with the best possible information at hand. This model took all relevant variables as identified by the literature review and interviews into account and provides Free State dairy farmers with a tool that can be used to evaluate the financial viability of solar power. Furthermore, the model was designed to evolve over time: as certain variables become known (e.g. Eskom feed-in tariffs) or as new variables appear (e.g. tax incentives) – they can be incorporated in the model to provide an updated financial evaluation of the viability of solar power. Although the research was done on Free State dairy farms, the model that was designed can be applied to dairy farms elsewhere in South Africa, as all geographical and site-specific variables can be taken into account.

5.4 CONCLUSIONS

The following secondary objectives of this study as stated in Paragraph 1.4 was reached:

- To analyse the daily, monthly and annual electricity usage patterns on small, medium and large dairy farms in the Free State. This objective was primarily achieved by analysing the data provided by the installed energy meters, and to a lesser extent by analysing the data gathered in the interviews. The following are the main conclusions drawn from the analyses:
    1. The daily peak consumption corresponds with the morning and afternoon milking times.
    2. Most of the daily electricity consumption (kWh/day) falls outside the peak production time – midday – of a solar PV system.
    3. The monthly electricity consumption (kWh/month) was fairly constant and no corresponding pattern could be detected among the three researched dairies.
    4. The participants of all three dairies were either not willing or not able to change operations in the dairies in order to effect major changes in the electricity consumption patterns.
- To investigate the knowledge base and attitudes of dairy farmers regarding the implementation of own-generated solar PV energy. This was achieved by conducting in-depth interviews. The main conclusions drawn in this regard was that there was some degree of knowledge of solar power among all participants, but not enough for them to make informed investment decisions. All participants were very interested in

the outcome of the research and how it could assist them in evaluating solar power for their operations.

- To determine the barriers of entry for using own-generated solar PV energy on a dairy farm. This objective was also reached by conducting in-depth interviews. For Dairy A the required capital outlay posed the biggest barrier to investing in a solar PV system. The participants of Dairies B and C were mainly concerned with their lack of knowledge on the financial viability of investing in a solar PV system.

The primary objective of this study was to develop a financial model to evaluate the viability of own-generated solar PV energy in Free State dairy farms. The model that was developed is built on comprehensive and accurate data, and recognised financial methods are used in the model to evaluate an investment in solar power for dairy farms. The model was reviewed by a chartered accountant to confirm the correctness of all calculations, including the tax implications. Applying the model to the three researched dairies provided the following insights:

- The results of the model provide a more positive outlook for a solar PV system for Dairies A and B than for Dairy C. The main difference between the model for Dairies A and B on the one hand and Dairy C on the other, is the Eskom tariff structure applicable to the dairies. Dairies A and B are on a fixed tariff structure (Landrate), whereas Dairy C is on a time-of-use structure (Ruraflex). As demonstrated in Appendices C5–C16, a solar PV system in the Free State generates a relatively small percentage of electricity during the peak-rate times. Keeping in mind that the value of the own-generated electricity is based on the value of buying electricity from Eskom at that time, it makes sense that the results for Dairy C is less positive. It can thus be concluded that a solar PV system is less viable for a dairy with a rate structure similar to that of Dairy C, where the majority of electricity is generated at times of relatively cheap Eskom power. This conclusion is significant, as it is possible that Eskom could in future require dairies that connect a solar PV system on the low-voltage side of

Eskom’s grid to move to a time-of-use tariff structure, as is the requirement for connection on the medium-voltage side (Du Preez, 2015). If this requirement materialises it means that dairies with a fixed rate structure, like Dairies A and B in the research, would need to run the model as if they are on the time-of-use structure to get the desired outcome.

- The results of the model for each dairy differ considerably across the three scenarios. The medium and best-case scenario results were positive for all three dairies, i.e. positive NPV, IRR greater than prime interest rate, and payback periods that are relatively short compared to the product’s productive life span. On the other hand, the results were negative for the worst-case scenarios of all three dairies. Based on this observation it can be concluded that an investment is a solar PV system is viable for all three dairies, unless Eskom prices increase moderately and Eskom charges a high amount for net-metering amidst high inflation and interest rates, as stated by the variables in the worst-case scenario. It should be kept in mind that an investment in a solar PV system is a very-long-term investment, thus making it difficult to predict the variables in the model accurately. The variables in the model would always be set to some degree, according to the subjective opinion of the business owner who needs to make the decision. This is exactly the purpose of the model: to provide a dairy farmer with a tool that can evaluate the viability of using solar power for his/her dairy based on certain variables that he/she needs to take a stance on.
- The cash flow analysis provides important insights into the viability of a solar PV system for Free State dairy farmers. The fact that dairy farmers are allowed by SARS to depreciate the system over three years in a 50:30:20 ratio has a major positive effect on the cash flow in the first three years, as well as the cumulative cash flow for the full 25 year period. It is insightful that the cumulative cash flows for Dairies A and B remained positive for the full 25-year period in the medium and best-case scenarios, and was only negative between years 10 to 15 in the medium scenario for Dairy C. According to A. du Toit, Nedbank Free State area manager, positive cash-flow projections for renewable energy systems would be viewed favourably by

financial institutions and could lead to preferential lending rates to fund these investments (Personal communication, November 12, 2013).

The model developed in this study contributes to the knowledge base of the South African dairy industry, as it can be used as a tool by the industry to evaluate solar power for dairy farms and influence business decisions.

5.5 RECOMMENDATIONS

5.5.1 Recommendations to farmers

It is recommended that dairy farmers place a high priority on energy management, including energy-efficiency measures and own generation of electricity. It is evident that the dairy farmer has limited control over most input costs and the producer price of milk. However, this study confirms research in other countries that has shown that it is possible for dairy farmers to control one input cost – electricity prices – by means of own generation of renewable energy. The model that was developed in this research gives dairy farmers a useful tool to evaluate one of the renewable energy sources available to them – solar power. As technology develops (e.g. technological advancements in energy storage) and as policy changes take place, the model can be adopted to new assumptions to guide investment decisions.

5.5.2 Recommendations to Eskom

South Africa needs a more intelligent electricity grid. The only way in which the Eskom network can currently ascertain what the immediate electricity demand is, is by means of information that is collected from meters at the end users' side of the grid (Green Business

Guide, 2014). When the demand rises more coal needs to be supplied to and combusted by the coal-fired power stations. On the other hand, when demand decreases coal must be left to burn out, resulting in wastage. So, there is an obvious lag in response time resulting in inefficiencies and wasted energy. A smarter grid should be able to utilise real-time information on demand-and-supply patterns, thus resulting in more efficient use of a variety of generation sources, including fluctuating renewable sources, such as solar and wind energy, as well as flexible sources, such as gas, to help supply short-term spikes in demand.

It is further recommended that Eskom makes net-metering possible for all its customers as soon as possible, including smaller commercial applications that want to connect on the low-voltage side of Eskom's network. Eskom has a responsibility towards the environment and to solving the current electricity-shortage crisis in South Africa. This study has shown that it could be a good investment for dairy farmers to be part of this solution by own generation of solar power. However, one of the key variables influencing the financial viability of such an investment is the fees that Eskom would charge for net-metering and the rates at which Eskom would credit end customers for exporting own-generated electricity onto the Eskom grid. It would be a pity if Eskom set the charges for storing energy on its grid so high that it renders the own generation of solar PV energy unviable, as was the case in the study of the Welsh Dairy Development Centre (2012). It is recommended that Eskom institutes processes as soon as possible and set these fee structures at levels that encourage the generation of solar power by commercial applications such as dairy farms.

5.5.3 Recommendations for further studies

In order to help the cause of dairy farmers to manage their electricity cost it is recommended that further research be undertaken in the following areas:

- Investigating how electricity is used by different appliances in dairies and how it can be managed in order to increase the electricity efficiency and reduce the overall electricity consumption of dairies;
- Research on possible means of better aligning the energy-consuming activities in dairies with peak solar radiation times, thus reducing the cost of storage of own-generated renewable energy;
- Investigating how off-grid systems and mini grids can be used to electrify rural Africa, where the grid will not reach in foreseeable future, in light of decentralisation of electricity supply by means of renewable energy.
- Financial analysis of using the Eskom grid to store own-generated renewable energy by means of net-metering on the low-voltage side of the Eskom grid, in order for Eskom to recover its costs of maintaining the grid while still encouraging the expansion of own-generation of renewable energy.

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Appendix A1: Dairy A financial model summary

10kW Grid-connected Solar PV System for Dairy A			
	Scenario 1	**Scenario 2**	**Scenario 3**
KEY VARIABLES	**Medium case**	**PV Worst case**	**PV Best case**
Annual prime interest rate	9.25%	12.75%	8.25%
Annual production price index (PPI)	6.29%	12.00%	4.00%
Annual Eskom tariff increase year 1	12.69%	12.69%	12.69%
Annual Eskom tariff increase year 2 - 6	12.69%	9.29%	17.69%
Annual Eskom tariff increase year 7 - 25	6.29%	6.29%	8.29%
Value of own generated electricity as % of Eskom tariff	80%	70%	90%
FINANCIAL INDICATORS			
PV Net present value (NPV)	R 21 908	R -68 557	R 160 966
PV Internal rate of return (IRR)	11.10%	1%	17.47%
PV Simple payback period (SPP)	9 - 10 years	22 - 23 years	7 - 8 years

Appendix A2: Dairy A medium scenario calculations

		Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	March
Solar PV yield (kWh)		**1410**	**1410**	**1350**	**1477**	**1550**	**1590**	**1560**	**1477**	**1510**	**1490**	**1370**	**1620**
Eskom charge year 1 (R / kWh)		1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06
Total savings year 1 (R)		1 499	1 499	1 436	1 571	1 648	1 691	1 659	1 571	1 606	1 584	1 457	1 723
Value of own generated elec (%)	80%	1 199	1 199	1 148	1 256	1 319	1 353	1 327	1 256	1 285	1 268	1 165	1 378

	PV CALCULATIONS										
Year	Capital Outlay	Savings	Cost: Maint	Cost: Insurance	Total Cost	Net Savings	Tax: Sav & Exp	Tax: Mortificati	Net Tax Implication	Net after tax saving	NPV calc
1	200000	15 154	600	2 300	2 900	12 254	4 902	40 000	35 098	47 352	-152 648
2		16 957	638	2 445	3 082	13 875	5 550	24 000	18 450	32 325	32 325
3		18 976	678	2 598	3 276	15 699	6 280	16 000	9 720	25 420	25 420
4		21 234	720	2 762	3 482	17 751	7 101	0	-7 101	10 651	10 651
5		23 761	766	2 936	3 701	20 060	8 024	0	-8 024	12 036	12 036
6		26 589	814	3 120	3 934	22 655	9 062	0	-9 062	13 593	13 593
7		28 063	865	3 317	4 182	23 882	9 553	0	-9 553	14 329	14 329
8		29 620	920	3 525	4 445	25 175	10 070	0	-10 070	15 105	15 105
9		31 262	977	3 747	4 724	26 538	10 615	0	-10 615	15 923	15 923
10		32 996	1 039	3 983	5 021	27 975	11 190	0	-11 190	16 785	16 785
11		34 826	1 104	4 233	5 337	29 489	11 796	0	-11 796	17 693	17 693
12		36 758	1 174	4 499	5 673	31 085	12 434	0	-12 434	18 651	18 651
13	83 170	38 796	1 248	4 782	6 030	32 766	13 107	16 634	3 528	36 294	-46 877
14		40 948	1 326	5 083	6 409	34 539	13 815	9 980	-3 835	30 704	30 704
15		43 219	1 409	5 403	6 812	36 407	14 563	6 654	-7 909	28 498	28 498
16		45 616	1 498	5 743	7 241	38 375	15 350	0	-15 350	23 025	23 025
17		48 146	1 592	6 104	7 696	40 449	16 180	0	-16 180	24 270	24 270
18		50 816	1 692	6 488	8 180	42 635	17 054	0	-17 054	25 581	25 581
19		53 634	1 799	6 896	8 695	44 939	17 976	0	-17 976	26 963	26 963
20		56 608	1 912	7 330	9 242	47 367	18 947	0	-18 947	28 420	28 420
21		59 748	2 032	7 791	9 823	49 925	19 970	0	-19 970	29 955	29 955
22		63 062	2 160	8 281	10 441	52 621	21 048	0	-21 048	31 572	31 572
23		66 559	2 296	8 802	11 098	55 461	22 184	0	-22 184	33 277	33 277
24		70 250	2 440	9 355	11 796	58 455	23 382	0	-23 382	35 073	35 073
25		74 146	2 594	9 944	12 538	61 609	24 643	0	-24 643	36 965	36 965

			CASH FLOW			
Year	Annual loan repayment	Interest portion	Tax benefit	Loan Cash flow	Net cash flow	Cum net cash flow
1	24 701	18 230	7 292	17 408	29 944	29 944
2	24 701	17 606	7 042	17 658	14 667	44 611
3	24 701	16 921	6 768	17 932	7 487	52 098
4	24 701	16 170	6 468	18 233	-7 582	44 516
5	24 701	15 347	6 139	18 562	-6 526	37 990
6	24 701	14 444	5 777	18 923	-5 330	32 660
7	24 701	13 454	5 381	19 319	-4 990	27 669
8	24 701	12 368	4 947	19 753	-4 648	23 021
9	24 701	11 178	4 471	20 230	-4 307	18 714
10	24 701	9 872	3 949	20 752	-3 967	14 748
11	24 701	8 441	3 376	21 324	-3 631	11 117
12	24 701	6 872	2 749	21 952	-3 301	7 816
13	24 701	5 151	2 060	22 640	13 654	21 469
14	24 701	3 264	1 305	23 395	7 309	28 778
15	24 701	1 194	478	24 223	4 275	33 052
16	0	0	0	0	23 025	56 077
17	0	0	0	0	24 270	80 347
18	0	0	0	0	25 581	105 928
19	0	0	0	0	26 963	132 892
20	0	0	0	0	28 420	161 312
21	0	0	0	0	29 955	191 267
22	0	0	0	0	31 572	222 839
23	0	0	0	0	33 277	256 116
24	0	0	0	0	35 073	291 188
25	0	0	0	0	36 965	328 154

Appendix A3: Dairy A worst-case calculations

		Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	March
Solar PV yield (kWh)		1416	1410	1380	1377	1350	1590	1564	1477	1510	1490	1530	1620
Eskom charge year 1 (R/kWh)		1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.36	1.06	1.06	1.06	1.06
Total savings year 1 (R)		1 498	1 499	1 438	1 571	[illegible]	1 681	1 658	1 571	1 308	[illegible]	1 657	[illegible]
Value of own generated elec (%)	70%	1 096	1 260	1 085	1 389	[illegible]	1 184	1 161	1 099	1 124	[illegible]	1 330	[illegible]

	PV CALCULATIONS												CASH FLOW			
Year	Capital Outlay	Savings	Cost: Maint	Cost: Insurance	Total Cost	Net Savings	Tax: Sav & Exp	Tax: Mortificati	Net Tax Implication	Net after tax saving	NPV calc	Annual loan repayment	Interest portion	Tax benefit	Loan Cash flow	Net cash flow	Cum net cash flow
1	200000	13 260	600	2 300	2 900	10 360	4 144	40 000	35 856	46 216	-153 784	29 972	25 229	10 092	19 880	26 335	26 335
2		14 390	672	2 576	3 248	11 142	4 457	24 000	19 543	30 685	30 685	29 972	24 588	9 835	20 137	10 548	36 884
3		15 617	753	2 885	3 638	11 979	4 792	16 000	11 208	23 187	23 187	29 972	23 860	9 544	20 428	2 759	39 643
4		16 948	843	3 231	4 074	12 874	5 150	0	-5 150	7 724	7 724	29 972	23 033	9 213	20 759	-13 034	26 609
5		18 393	944	3 619	4 563	13 830	5 532	0	-5 532	8 298	8 298	29 972	22 095	8 838	21 134	-12 836	13 772
6		19 961	1 057	4 053	5 111	14 850	5 940	0	-5 940	8 910	8 910	29 972	21 030	8 412	21 560	-12 650	1 122
7		21 068	1 184	4 540	5 724	15 344	6 138	0	-6 138	9 206	9 206	29 972	19 821	7 928	22 044	-12 837	-11 715
8		22 236	1 326	5 085	6 411	15 825	6 330	0	-6 330	9 495	9 495	29 972	18 448	7 379	22 593	-13 098	-24 813
9		23 470	1 486	5 695	7 180	16 289	6 516	0	-6 516	9 774	9 774	29 972	16 890	6 756	23 216	-13 443	-38 255
10		24 771	1 664	6 378	8 042	16 729	6 692	0	-6 692	10 038	10 038	29 972	15 121	6 048	23 924	-13 886	-52 141
11		26 145	1 864	7 143	9 007	17 138	6 855	0	-6 855	10 283	10 283	29 972	13 112	5 245	24 727	-14 444	-66 586
12		27 595	2 087	8 001	10 088	17 507	7 003	0	-7 003	10 504	10 504	29 972	10 833	4 333	25 639	-15 135	-81 720
13	155 839	29 125	2 338	8 961	11 298	17 827	7 131	31 168	24 037	41 864	-113 975	29 972	8 245	3 298	26 674	15 190	-66 530
14		30 741	2 618	10 036	12 654	18 087	7 235	18 701	11 466	29 553	29 553	29 972	5 307	2 123	27 849	1 703	-64 827
15		32 446	2 932	11 240	14 173	18 273	7 309	12 467	5 158	23 431	23 431	29 972	1 971	789	29 184	-5 753	-70 580
16		34 245	3 284	12 589	15 873	18 372	7 349	0	-7 349	11 023	11 023	0	0	0	0	11 023	-59 557
17		36 144	3 678	14 100	17 778	18 366	7 346	0	-7 346	11 020	11 020	0	0	0	0	11 020	-48 537
18		38 149	4 120	15 792	19 912	18 237	7 295	0	-7 295	10 942	10 942	0	0	0	0	10 942	-37 595
19		40 265	4 614	17 687	22 301	17 964	7 185	0	-7 185	10 778	10 778	0	0	0	0	10 778	-26 816
20		42 498	5 168	19 809	24 977	17 521	7 008	0	-7 008	10 512	10 512	0	0	0	0	10 512	-16 304
21		44 854	5 788	22 186	27 974	16 880	6 752	0	-6 752	10 128	10 128	0	0	0	0	10 128	-6 176
22		47 342	6 482	24 849	31 331	16 011	6 404	0	-6 404	9 607	9 607	0	0	0	0	9 607	3 431
23		49 968	7 260	27 831	35 091	14 877	5 951	0	-5 951	8 926	8 926	0	0	0	0	8 926	12 357
24		52 739	8 131	31 170	39 302	13 437	5 375	0	-5 375	8 062	8 062	0	0	0	0	8 062	20 419
25		55 664	9 107	34 911	44 018	11 646	4 658	0	-4 658	6 987	6 987	0	0	0	0	6 987	27 406

Appendix A4: Dairy A best-case calculations

		Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	March
Solar PV yield (kWh)		1418	1480	1380	1477	1350	1590	1566	1407	1510	1480	1130	1620
Eskom charge year 1 (R / kWh)		1.08	1.36	1.36	1.08	1.08	1.08	1.08	1.36	1.08	1.08	1.08	1.08
Total savings year 1 (R)		1 498	1 436	1 432	1 571	1 548	1 691	1 659	1 571	1 506	1 584	1 457	1 729
Value of own generated elec (%)	90%	1 348	1 385	1 230	1 414	1 393	1 522	1 493	1 414	1 445	1 425	1 311	1 556

	PV CALCULATIONS													CASH FLOW			
Year	Capital Outlay	Savings	Cost: Maint	Cost: Insurance	Total Cost	Net Savings	Tax: Sav & Exp	Tax: Mortificati	Net Tax Implication	Net after tax saving	NPV calc		Annual loan repayment	Interest portion	Tax benefit	Loan Cash flow	Net cash flow	Cum net cash flow
1	200000	17 048	600	2 300	2 900	14 148	5 659	40 000	34 341	48 489	-151 511		23 283	25 229	10 092	13 192	35 297	35 297
2		19 924	624	2 392	3 016	16 908	6 763	24 000	17 237	34 145	34 145		23 283	24 588	9 835	13 448	20 696	55 993
3		23 284	649	2 488	3 137	20 147	8 059	16 000	7 941	28 088	28 088		23 283	23 860	9 544	13 739	14 349	70 342
4		27 211	675	2 587	3 262	23 949	9 580	0	-9 580	14 369	14 369		23 283	23 033	9 213	14 070	299	70 642
5		31 800	702	2 691	3 393	28 408	11 363	0	-11 363	17 045	17 045		23 283	22 095	8 838	14 445	2 599	73 241
6		37 164	730	2 798	3 528	33 636	13 454	0	-13 454	20 181	20 181		23 283	21 030	8 412	14 871	5 310	78 551
7		39 963	759	2 910	3 669	36 294	14 517	0	-14 517	21 776	21 776		23 283	19 821	7 928	15 355	6 421	84 972
8		42 973	790	3 027	3 816	39 157	15 663	0	-15 663	23 494	23 494		23 283	18 448	7 379	15 904	7 590	92 562
9		46 210	821	3 148	3 969	42 241	16 896	0	-16 896	25 345	25 345		23 283	16 890	6 756	16 527	8 817	101 379
10		49 690	854	3 274	4 128	45 563	18 225	0	-18 225	27 338	27 338		23 283	15 121	6 048	17 235	10 103	111 482
11		53 433	888	3 405	4 293	49 140	19 656	0	-19 656	29 484	29 484		23 283	13 112	5 245	18 038	11 446	122 927
12		57 458	924	3 541	4 464	52 993	21 197	0	-21 197	31 796	31 796		23 283	10 833	4 333	18 950	12 846	135 773
13	64 041	61 785	961	3 682	4 643	57 142	22 857	12 808	-10 049	47 094	-16 948		23 283	8 245	3 298	19 986	27 108	162 881
14		66 439	999	3 830	4 829	61 610	24 644	7 685	-16 959	44 651	44 651		23 283	5 307	2 123	21 161	23 490	186 371
15		71 443	1 039	3 983	5 022	66 421	26 568	5 123	-21 445	44 976	44 976		23 283	1 971	789	22 495	22 481	208 852
16		76 824	1 081	4 142	5 223	71 601	28 641	0	-28 641	42 961	42 961		0	0	0	0	42 961	251 813
17		82 610	1 124	4 308	5 432	77 179	30 872	0	-30 872	46 307	46 307		0	0	0	0	46 307	298 120
18		88 833	1 169	4 480	5 649	83 184	33 273	0	-33 273	49 910	49 910		0	0	0	0	49 910	348 031
19		95 523	1 215	4 659	5 875	89 649	35 859	0	-35 859	53 789	53 789		0	0	0	0	53 789	401 820
20		102 718	1 264	4 846	6 110	96 608	38 643	0	-38 643	57 965	57 965		0	0	0	0	57 965	459 785
21		110 455	1 315	5 040	6 354	104 101	41 640	0	-41 640	62 460	62 460		0	0	0	0	62 460	522 245
22		118 774	1 367	5 241	6 608	112 166	44 866	0	-44 866	67 300	67 300		0	0	0	0	67 300	589 545
23		127 720	1 422	5 451	6 873	120 848	48 339	0	-48 339	72 509	72 509		0	0	0	0	72 509	662 054
24		137 340	1 479	5 669	7 148	130 193	52 077	0	-52 077	78 116	78 116		0	0	0	0	78 116	740 169
25		147 685	1 538	5 896	7 434	140 251	56 100	0	-56 100	84 151	84 151		0	0	0	0	84 151	824 320

Appendix B1: Dairy B financial model summary

75kW Grid-connected Solar PV System for Dairy B			
	Scenario 1	Scenario 2	Scenario 3
KEY VARIABLES	Medium case	PV Worst case	PV Best case
Annual prime interest rate	9.25%	12.75%	8.25%
Annual production price index (PPI)	6.29%	12.00%	4.00%
Annual Eskom tariff increase year 1	12.69%	12.69%	12.69%
Annual Eskom tariff increase year 2 - 6	12.69%	9.29%	17.69%
Annual Eskom tariff increase year 7 - 25	6.29%	6.29%	8.29%
Value of own generated electricity as % of Eskom tariff	80%	70%	90%
FINANCIAL INDICATORS			
PV Net present value (NPV)	R 299 871	R -407 780	R 1 403 523
PV Internal rate of return (IRR)	12.51%	5%	18.70%
PV Simple payback period (SPP)	9 - 10 years	17 - 18 years	7 - 8 years

Appendix B2: Dairy B medium-scenario calculations

		Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	March
Solar PV yield (kWh)		11900	11700	11200	12400	13000	12512	12900	11400	11500	11400	10900	12155
Eskom charge year 1 (R/kWh)		1.08	1.08	1.08	1.06	1.06	1.06	1.08	1.08	1.08	1.08	1.08	1.08
Total savings year 1 (R)		12 318	12 448	11 909	13 186	13 823	13 315	13 392	12 547	12 238	12 128	11 590	12 925
Value of own generated elec (%)	80%	9 313	9 853	9 523	10 548	11 058	10 652	10 633	10 038	9 783	9 785	9 272	10 340

	PV CALCULATIONS										
Year	Capital Outlay	Savings	Cost: Maint	Cost: Insurance	Total Cost	Net Savings	Tax: Sav & Exp	Tax: Mortificati	Net Tax Implication	Net after tax saving	NPV calc
1	1 500 000	121 202	4 500	17 250	21 750	99 452	39 781	300 000	260 219	359 671	-1 140 329
2		135 626	4 783	18 335	23 118	112 508	45 003	180 000	134 997	247 505	247 505
3		151 767	5 084	19 488	24 572	127 195	50 878	120 000	69 122	196 317	196 317
4		169 829	5 404	20 714	26 118	143 711	57 484	0	-57 484	86 227	86 227
5		190 041	5 744	22 017	27 761	162 280	64 912	0	-64 912	97 368	97 368
6		212 658	6 105	23 402	29 507	183 151	73 260	0	-73 260	109 891	109 891
7		224 452	6 489	24 874	31 363	193 089	77 236	0	-77 236	115 853	115 853
8		236 900	6 897	26 438	33 335	203 564	81 426	0	-81 426	122 139	122 139
9		250 038	7 331	28 101	35 432	214 606	85 842	0	-85 842	128 764	128 764
10		263 905	7 792	29 869	37 661	226 244	90 498	0	-90 498	135 747	135 747
11		278 541	8 282	31 748	40 030	238 511	95 405	0	-95 405	143 107	143 107
12		293 989	8 803	33 745	42 548	251 441	100 577	0	-100 577	150 865	150 865
13	395 059	310 294	9 357	35 867	45 224	265 070	106 028	79 012	-27 016	238 054	-157 006
14		327 502	9 945	38 123	48 068	279 434	111 774	47 407	-64 366	215 067	215 067
15		345 666	10 571	40 521	51 092	294 574	117 829	31 605	-86 225	208 349	208 349
16		364 836	11 236	43 070	54 306	310 530	124 212	0	-124 212	186 318	186 318
17		385 070	11 942	45 779	57 722	327 348	130 939	0	-130 939	196 409	196 409
18		406 426	12 694	48 659	61 352	345 073	138 029	0	-138 029	207 044	207 044
19		428 966	13 492	51 719	65 211	363 755	145 502	0	-145 502	218 253	218 253
20		452 756	14 341	54 972	69 313	383 443	153 377	0	-153 377	230 066	230 066
21		477 866	15 243	58 430	73 673	404 193	161 677	0	-161 677	242 516	242 516
22		504 368	16 201	62 105	78 307	426 061	170 425	0	-170 425	255 637	255 637
23		532 340	17 220	66 012	83 232	449 108	179 643	0	-179 643	269 465	269 465
24		561 864	18 304	70 164	88 468	473 396	189 358	0	-189 358	284 038	284 038
25		593 025	19 455	74 577	94 032	498 992	199 597	0	-199 597	299 395	299 395

			CASH FLOW			
Year	Annual loan repayment	Interest portion	Tax benefit	Loan Cash flow	Net cash flow	Cum net cash flow
1	185 255	136 727	54 691	130 564	229 107	229 107
2	185 255	132 043	52 817	132 437	115 067	344 174
3	185 255	126 907	50 763	134 492	61 825	405 999
4	185 255	121 275	48 510	136 745	-50 518	355 481
5	185 255	115 099	46 040	139 215	-41 847	313 634
6	185 255	108 327	43 331	141 924	-32 033	281 601
7	185 255	100 902	40 361	144 894	-29 040	252 561
8	185 255	92 760	37 104	148 151	-26 012	226 549
9	185 255	83 832	33 533	151 722	-22 958	203 590
10	185 255	74 042	29 617	155 638	-19 891	183 699
11	185 255	63 307	25 323	159 932	-16 825	166 874
12	185 255	51 536	20 615	164 640	-13 775	153 099
13	185 255	38 629	15 452	169 803	68 251	221 350
14	185 255	24 477	9 791	175 464	39 604	260 953
15	185 255	8 958	3 583	181 672	26 677	287 631
16	0	0	0	0	186 318	473 949
17	0	0	0	0	196 409	670 358
18	0	0	0	0	207 044	877 402
19	0	0	0	0	218 253	1 095 655
20	0	0	0	0	230 066	1 325 721
21	0	0	0	0	242 516	1 568 236
22	0	0	0	0	255 637	1 823 873
23	0	0	0	0	269 465	2 093 338
24	0	0	0	0	284 038	2 377 376
25	0	0	0	0	299 395	2 676 771

Appendix B3: Dairy B worst-case calculations

		Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	March
Solar PV yield (kWh)		11300	11700	11200	12400	13800	11522	12500	11800	11500	11540	10900	12185
Eskom charge year 1 (R/kWh)		1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06
Total savings year 1 (R)		12 018	12 441	11 906	13 185	13 823	12 315	13 292	12 547	12 229	12 228	11 590	12 925
Value of own generated elec (%)	70%	8 411	8 709	8 337	9 230	9 675	8 621	9 304	8 783	8 560	8 560	8 113	9 047

	PV CALCULATIONS											CASH FLOW					
Year	Capital Outlay	Savings	Cost: Maint	Cost: Insurance	Total Cost	Net Savings	Tax: Sav & Exp	Tax: Mortificati	Net Tax Implication	Net after tax saving	NPV calc	Annual loan repayment	Interest portion	Tax benefit	Loan Cash flow	Net cash flow	Cum net cash flow
1	1 500 000	106 051	4 500	17 250	21 750	84 301	33 721	300 000	266 279	350 581	-1 149 419	224 791	189 219	75 688	149 103	201 478	201 478
2		115 092	5 040	19 320	24 360	90 732	36 293	180 000	143 707	234 439	234 439	224 791	184 409	73 764	151 027	83 412	284 890
3		124 904	5 645	21 638	27 283	97 621	39 048	120 000	80 952	178 572	178 572	224 791	178 948	71 579	153 211	25 361	310 251
4		135 552	6 322	24 235	30 557	104 995	41 998	0	-41 998	62 997	62 997	224 791	172 749	69 100	155 691	-92 694	217 557
5		147 107	7 081	27 143	34 224	112 883	45 153	0	-45 153	67 730	67 730	224 791	165 712	66 285	158 506	-90 776	126 781
6		159 648	7 931	30 400	38 331	121 317	48 527	0	-48 527	72 790	72 790	224 791	157 724	63 090	161 701	-88 911	37 871
7		168 502	8 882	34 048	42 931	125 572	50 229	0	-50 229	75 343	75 343	224 791	148 655	59 462	165 329	-89 986	-52 115
8		177 848	9 948	38 134	48 082	129 765	51 906	0	-51 906	77 859	77 859	224 791	138 360	55 344	169 447	-91 588	-143 702
9		187 711	11 142	42 710	53 852	133 859	53 543	0	-53 543	80 315	80 315	224 791	126 673	50 669	174 122	-93 806	-237 509
10		198 121	12 479	47 836	60 314	137 807	55 123	0	-55 123	82 684	82 684	224 791	113 405	45 362	179 429	-96 745	-334 253
11		209 109	13 976	53 576	67 552	141 557	56 623	0	-56 623	84 934	84 934	224 791	98 343	39 337	185 453	-100 519	-434 773
12		220 706	15 653	60 005	75 658	145 048	58 019	0	-58 019	87 029	87 029	224 791	81 245	32 498	192 293	-105 264	-540 037
13	740 235	232 946	17 532	67 206	84 737	148 209	59 284	148 047	88 764	236 972	-503 263	224 791	61 834	24 734	200 057	36 916	-503 121
14		245 866	19 636	75 270	94 906	150 960	60 384	88 828	28 444	179 404	179 404	224 791	39 799	15 920	208 871	-29 467	-532 588
15		259 501	21 992	84 303	106 295	153 207	61 283	59 219	-2 064	151 143	151 143	224 791	14 785	5 914	218 877	-67 734	-600 322
16		273 893	24 631	94 419	119 050	154 843	61 937	0	-61 937	92 906	92 906	0	0	0	0	92 906	-507 416
17		289 083	27 587	105 749	133 336	155 747	62 299	0	-62 299	93 448	93 448	0	0	0	0	93 448	-413 968
18		305 116	30 897	118 439	149 336	155 779	62 312	0	-62 312	93 468	93 468	0	0	0	0	93 468	-320 500
19		322 037	34 605	132 652	167 257	154 780	61 912	0	-61 912	92 868	92 868	0	0	0	0	92 868	-227 632
20		339 897	38 757	148 570	187 328	152 570	61 028	0	-61 028	91 542	91 542	0	0	0	0	91 542	-136 090
21		358 748	43 408	166 399	209 807	148 941	59 576	0	-59 576	89 365	89 365	0	0	0	0	89 365	-46 726
22		378 644	48 617	186 366	234 984	143 660	57 464	0	-57 464	86 196	86 196	0	0	0	0	86 196	39 470
23		399 643	54 451	208 730	263 182	136 462	54 585	0	-54 585	81 877	81 877	0	0	0	0	81 877	121 347
24		421 807	60 986	233 778	294 764	127 044	50 818	0	-50 818	76 226	76 226	0	0	0	0	76 226	197 574
25		445 201	68 304	261 831	330 135	115 066	46 026	0	-46 026	69 039	69 039	0	0	0	0	69 039	266 613

Appendix B4: Dairy B best-case calculations

		Apr	Mar	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	March
Solar PV yield (kWh)		11300	11700	11200	12400	13000	12521	12500	11800	11500	11500	10900	12155
Eskom charge year 1 (R / kWh)		1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06
Total savings year 1 (R)		12 015	12 441	11 906	13 185	13 823	13 316	13 290	12 547	12 228	12 228	11 590	12 925
Value of own generated elec (%)	90%	10 814	11 197	10 718	11 867	12 441	11 984	11 963	11 293	11 006	11 006	10 431	11 632

	PV CALCULATIONS										
Year	Capital Outlay	Savings	Cost: Maint	Cost: Insurance	Total Cost	Net Savings	Tax: Sav & Exp	Tax: Mortificati	Net Tax Implication	Net after tax saving	NPV calc
1	1500000	136 352	4 500	17 250	21 750	114 602	45 841	300 000	254 159	368 761	-1 131 239
2		159 349	4 680	17 940	22 620	136 729	54 692	180 000	125 308	262 037	262 037
3		186 225	4 867	18 658	23 525	162 700	65 080	120 000	54 920	217 620	217 620
4		217 634	5 062	19 404	24 466	193 168	77 267	0	-77 267	115 901	115 901
5		254 341	5 264	20 180	25 444	228 896	91 559	0	-91 559	137 338	137 338
6		297 238	5 475	20 987	26 462	270 776	108 310	0	-108 310	162 466	162 466
7		319 626	5 694	21 827	27 521	292 105	116 842	0	-116 842	175 263	175 263
8		343 700	5 922	22 700	28 622	315 079	126 031	0	-126 031	189 047	189 047
9		369 588	6 159	23 608	29 766	339 821	135 929	0	-135 929	203 893	203 893
10		397 425	6 405	24 552	30 957	366 468	146 587	0	-146 587	219 881	219 881
11		427 359	6 661	25 534	32 195	395 163	158 065	0	-158 065	237 098	237 098
12		459 547	6 928	26 556	33 483	426 064	170 426	0	-170 426	255 639	255 639
13	304 196	494 160	7 205	27 618	34 822	459 338	183 735	60 839	-122 896	336 442	32 246
14		531 380	7 493	28 723	36 215	495 165	198 066	36 504	-161 562	333 603	333 603
15		571 404	7 793	29 871	37 664	533 740	213 496	24 336	-189 160	344 580	344 580
16		614 442	8 104	31 066	39 171	575 271	230 108	0	-230 108	345 163	345 163
17		660 721	8 428	32 309	40 737	619 984	247 994	0	-247 994	371 990	371 990
18		710 487	8 766	33 601	42 367	668 120	267 248	0	-267 248	400 872	400 872
19		764 000	9 116	34 945	44 062	719 939	287 975	0	-287 975	431 963	431 963
20		821 544	9 481	36 343	45 824	775 720	310 288	0	-310 288	465 432	465 432
21		883 423	9 860	37 797	47 657	835 766	334 306	0	-334 306	501 460	501 460
22		949 962	10 254	39 309	49 563	900 399	360 160	0	-360 160	540 239	540 239
23		1 021 513	10 665	40 881	51 546	969 967	387 987	0	-387 987	581 980	581 980
24		1 098 453	11 091	42 516	53 608	1 044 845	417 938	0	-417 938	626 907	626 907
25		1 181 188	11 535	44 217	55 752	1 125 436	450 175	0	-450 175	675 262	675 262

			CASH FLOW			
Year	Annual loan repayment	Interest portion	Tax benefit	Loan Cash flow	Net cash flow	Cum net cash flow
1	174 625	121 782	48 713	125 913	242 848	242 848
2	174 625	117 253	46 901	127 724	134 313	377 162
3	174 625	112 337	44 935	129 691	87 930	465 091
4	174 625	106 999	42 800	131 826	-15 925	449 167
5	174 625	101 204	40 482	134 144	3 194	452 361
6	174 625	94 913	37 965	136 660	25 805	478 166
7	174 625	88 082	35 233	139 393	35 871	514 037
8	174 625	80 666	32 266	142 359	46 688	560 725
9	174 625	72 614	29 046	145 580	58 313	619 038
10	174 625	63 873	25 549	149 076	70 804	689 843
11	174 625	54 382	21 753	152 873	84 226	774 068
12	174 625	44 078	17 631	156 994	98 644	872 713
13	174 625	32 891	13 157	161 469	174 973	1 047 686
14	174 625	20 746	8 298	166 327	167 276	1 214 961
15	174 625	7 560	3 024	171 602	172 978	1 387 939
16	0	0	0	0	345 163	1 733 102
17	0	0	0	0	371 990	2 105 092
18	0	0	0	0	400 872	2 505 964
19	0	0	0	0	431 963	2 937 927
20	0	0	0	0	465 432	3 403 360
21	0	0	0	0	501 460	3 904 819
22	0	0	0	0	540 239	4 445 059
23	0	0	0	0	581 980	5 027 039
24	0	0	0	0	626 907	5 653 946
25	0	0	0	0	675 262	6 329 208

Appendix C1: Dairy C financial model summary

120kW Grid-connected Solar PV System for Dairy C			
	Scenario 1	**Scenario 2**	**Scenario 3**
KEY VARIABLES	**Medium case**	**PV Worst case**	**PV Best case**
Annual prime interest rate	9.25%	12.75%	8.25%
Annual production price index (PPI)	6.29%	12.00%	4.00%
Annual Eskom tariff increase year 1	12.69%	12.69%	12.69%
Annual Eskom tariff increase year 2 - 6	12.69%	9.29%	17.69%
Annual Eskom tariff increase year 7 - 25	6.29%	6.29%	8.29%
Value of own generated electricity as % of Eskom tariff	80%	70%	90%
FINANCIAL INDICATORS			
PV Net present value (NPV)	R 56 261	R -876 329	R 1 498 771
PV Internal rate of return (IRR)	9.66%	0%	15.64%
PV Simple payback period (SPP)	11 - 12 years	25 - 26 years	8 - 9 years

Appendix C2: Dairy C medium scenario calculations

		Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	March
Solar PV yield (kWh)		17900	16460	17690	18772	[illegible]	17566	20400	19200	18760	18500	17100	[illegible]
Total savings year 1 (R)		13 812	14 193	20 814	22 365	14 233	13 595	15 751	14 421	14 435	14 281	13 202	15 516
Value of own generated elec (%)	80%	11 050	11 364	16 651	17 892	11 388	10 844	12 601	11 856	11 548	11 427	10 561	12 415

Year	PV CALCULATIONS Capital Outlay	Savings	Cost: Maint	Cost: Insurance	Total Cost	Net Savings	Tax: Sav & Exp	Tax: Mortificati	Net Tax Implication	Net after tax saving	NPV calc
1	2 400 000	157 586	7 200	27 600	34 800	122 786	49 114	480 000	430 886	553 671	-1 846 329
2		176 340	7 653	29 336	36 989	139 351	55 741	288 000	232 259	371 611	371 611
3		197 327	8 134	31 181	39 316	158 011	63 205	192 000	128 795	286 807	286 807
4		220 811	8 646	33 143	41 788	179 023	71 609	0	-71 609	107 414	107 414
5		247 090	9 190	35 227	44 417	202 673	81 069	0	-81 069	121 604	121 604
6		276 497	9 768	37 443	47 211	229 286	91 714	0	-91 714	137 572	137 572
7		291 831	10 382	39 798	50 180	241 651	96 660	0	-96 660	144 991	144 991
8		308 016	11 035	42 302	53 337	254 679	101 872	0	-101 872	152 808	152 808
9		325 099	11 729	44 962	56 692	268 407	107 363	0	-107 363	161 044	161 044
10		343 129	12 467	47 790	60 257	282 871	113 148	0	-113 148	169 723	169 723
11		362 158	13 251	50 796	64 048	298 111	119 244	0	-119 244	178 866	178 866
12		382 244	14 085	53 992	68 076	314 167	125 667	0	-125 667	188 500	188 500
13	571 797	403 443	14 971	57 388	72 358	331 084	132 434	114 359	-18 074	313 010	-258 787
14		425 817	15 912	60 997	76 910	348 908	139 563	68 616	-70 948	277 960	277 960
15		449 433	16 913	64 834	81 747	367 686	147 074	45 744	-101 331	266 355	266 355
16		474 359	17 977	68 912	86 889	387 469	154 988	0	-154 988	232 482	232 482
17		500 666	19 108	73 247	92 354	408 312	163 325	0	-163 325	244 987	244 987
18		528 433	20 310	77 854	98 164	430 270	172 108	0	-172 108	258 162	258 162
19		557 740	21 587	82 751	104 338	453 402	181 361	0	-181 361	272 041	272 041
20		588 672	22 945	87 956	110 901	477 771	191 108	0	-191 108	286 663	286 663
21		621 320	24 388	93 488	117 877	503 443	201 377	0	-201 377	302 066	302 066
22		655 778	25 922	99 369	125 291	530 487	212 195	0	-212 195	318 292	318 292
23		692 147	27 553	105 619	133 172	558 975	223 590	0	-223 590	335 385	335 385
24		730 533	29 286	112 262	141 548	588 985	235 594	0	-235 594	353 391	353 391
25		771 048	31 128	119 324	150 452	620 597	248 239	0	-248 239	372 358	372 358

Year	Annual loan repayment	Interest portion	CASH FLOW Tax benefit	Loan Cash flow	Net cash flow	Cum net cash flow
1	296 407	218 763	87 505	208 902	344 769	344 769
2	296 407	211 268	84 507	211 900	159 711	504 480
3	296 407	203 050	81 220	215 187	71 620	576 100
4	296 407	194 039	77 616	218 792	-111 378	464 722
5	296 407	184 158	73 663	222 744	-101 140	363 582
6	296 407	173 323	69 329	227 078	-89 506	274 076
7	296 407	161 443	64 577	231 830	-86 840	187 236
8	296 407	148 416	59 366	237 041	-84 233	103 003
9	296 407	134 131	53 652	242 755	-81 711	21 292
10	296 407	118 467	47 387	249 020	-79 298	-58 006
11	296 407	101 292	40 517	255 891	-77 024	-135 030
12	296 407	82 458	32 983	263 424	-74 924	-209 954
13	296 407	61 807	24 723	271 685	41 325	-168 629
14	296 407	39 162	15 665	280 742	-2 782	-171 411
15	296 407	14 332	5 733	290 674	-24 319	-195 730
16	0	0	0	0	232 482	36 752
17	0	0	0	0	244 987	281 739
18	0	0	0	0	258 162	539 901
19	0	0	0	0	272 041	811 942
20	0	0	0	0	286 663	1 098 605
21	0	0	0	0	302 066	1 400 670
22	0	0	0	0	318 292	1 718 962
23	0	0	0	0	335 385	2 054 348
24	0	0	0	0	353 391	2 407 739
25	0	0	0	0	372 358	2 780 097

Appendix C3: Dairy C worst-case calculations

		Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	March
Solar PV yield (kWh)		17980	18400	17600	18712	20571	17566	20440	19300	18790	18500	17100	20095
Total savings year 1 (R)		13 812	14 193	20 814	22 365	24 323	12 554	15 711	14 823	14 435	14 281	13 202	15 519
Value of own generated elec (%)	70%	9 668	9 935	14 576	15 655	16 983	8 489	11 006	10 376	10 105	9 998	9 241	10 863

	PV CALCULATIONS										
Year	Capital Outlay	Savings	Cost: Maint	Cost: Insurance	Total Cost	Net Savings	Tax: Sav & Exp	Tax: Mortificati	Net Tax Implication	Net after tax saving	NPV calc
1	2 400 000	137 888	7 200	27 600	34 800	103 088	41 235	480 000	438 765	541 853	-1 858 147
2		149 642	8 064	30 912	38 976	110 666	44 267	288 000	243 733	354 400	354 400
3		162 399	9 032	34 621	43 653	118 746	47 499	192 000	144 501	263 248	263 248
4		176 244	10 115	38 776	48 891	127 352	50 941	0	-50 941	76 411	76 411
5		191 269	11 329	43 429	54 758	136 510	54 604	0	-54 604	81 906	81 906
6		207 574	12 689	48 641	61 329	146 245	58 498	0	-58 498	87 747	87 747
7		219 086	14 212	54 478	68 689	150 397	60 159	0	-60 159	90 238	90 238
8		231 237	15 917	61 015	76 932	154 305	61 722	0	-61 722	92 583	92 583
9		244 061	17 827	68 337	86 164	157 898	63 159	0	-63 159	94 739	94 739
10		257 597	19 966	76 537	96 503	161 093	64 437	0	-64 437	96 656	96 656
11		271 883	22 362	85 721	108 084	163 799	65 520	0	-65 520	98 280	98 280
12		286 961	25 046	96 008	121 054	165 908	66 363	0	-66 363	99 545	99 545
13	1 071 393	302 876	28 051	107 529	135 580	167 296	66 918	214 279	147 360	314 656	-756 737
14		319 674	31 417	120 432	151 850	167 824	67 130	128 567	61 438	229 262	229 262
15		337 403	35 187	134 884	170 072	167 331	66 932	85 711	18 779	186 110	186 110
16		356 115	39 410	151 070	190 480	165 635	66 254	0	-66 254	99 381	99 381
17		375 865	44 139	169 199	213 338	162 527	65 011	0	-65 011	97 516	97 516
18		396 710	49 435	189 503	238 938	157 772	63 109	0	-63 109	94 663	94 663
19		418 712	55 368	212 243	267 611	151 101	60 440	0	-60 440	90 660	90 660
20		441 933	62 012	237 712	299 724	142 209	56 884	0	-56 884	85 325	85 325
21		466 443	69 453	266 238	335 691	130 752	52 301	0	-52 301	78 451	78 451
22		492 311	77 788	298 186	375 974	116 338	46 535	0	-46 535	69 803	69 803
23		519 615	87 122	333 969	421 091	98 524	39 410	0	-39 410	59 114	59 114
24		548 433	97 577	374 045	471 622	76 811	30 724	0	-30 724	46 087	46 087
25		578 849	109 286	418 930	528 216	50 632	20 253	0	-20 253	30 379	30 379

			CASH FLOW			
Year	Annual loan repayment	Interest portion	Tax benefit	Loan Cash flow	Net cash flow	Cum net cash flow
1	359 665	302 750	121 100	238 565	303 288	303 288
2	359 665	295 054	118 022	241 643	112 756	416 044
3	359 665	286 317	114 527	245 138	18 110	434 154
4	359 665	276 399	110 560	249 105	-172 694	261 460
5	359 665	265 140	106 056	253 609	-171 703	89 757
6	359 665	252 358	100 943	258 722	-170 975	-81 218
7	359 665	237 848	95 139	264 526	-174 288	-255 506
8	359 665	221 376	88 550	271 115	-178 532	-434 038
9	359 665	202 676	81 070	278 595	-183 856	-617 894
10	359 665	181 448	72 579	287 086	-190 430	-808 324
11	359 665	157 349	62 940	296 725	-198 446	-1 006 770
12	359 665	129 992	51 997	307 668	-208 124	-1 214 893
13	359 665	98 935	39 574	320 091	-5 435	-1 220 328
14	359 665	63 679	25 472	334 194	-104 932	-1 325 260
15	359 665	23 655	9 462	350 203	-164 093	-1 489 353
16	0	0	0	0	99 381	-1 389 972
17	0	0	0	0	97 516	-1 292 456
18	0	0	0	0	94 663	-1 197 793
19	0	0	0	0	90 660	-1 107 132
20	0	0	0	0	85 325	-1 021 807
21	0	0	0	0	78 451	-943 356
22	0	0	0	0	69 803	-873 553
23	0	0	0	0	59 114	-814 439
24	0	0	0	0	46 087	-768 352
25	0	0	0	0	30 379	-737 973

Appendix C4: Dairy C best-case calculations

		Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	March
Solar PV yield (kWh)		17508	18400	17680	18772	20271	17556	20900	19000	16760	18500	17100	20096
Total savings year 1 (R)		13 812	14 193	20 814	22 365	24 230	13 565	15 751	14 821	14 435	14 280	13 352	15 518
Value of own generated elec (%)	90%	12 431	12 773	18 733	20 128	21 808	12 208	14 176	13 339	12 992	12 855	11 482	13 967

	PV CALCULATIONS												CASH FLOW			
Year	Capital Outlay	Savings	Cost: Maint	Cost: Insurance	Total Cost	Net Savings	Tax: Sav & Exp	Tax: Mortificati	Net Tax Implication	Net after tax saving	NPV calc	Annual loan repayment	Interest portion	Tax benefit	Loan Cash flow	Net cash flow	Cum net cash flow
1	2 400 000	177 284	7 200	27 600	34 800	142 484	56 994	480 000	423 006	565 490	-1 834 510	279 400	194 850	77 940	201 460	364 030	364 030
2		207 185	7 488	28 704	36 192	170 993	68 397	288 000	219 603	390 596	390 596	279 400	187 605	75 042	204 358	186 237	550 268
3		242 129	7 788	29 852	37 640	204 490	81 796	192 000	110 204	314 694	314 694	279 400	179 739	71 896	207 505	107 189	657 456
4		282 967	8 099	31 046	39 145	243 822	97 529	0	-97 529	146 293	146 293	279 400	171 199	68 480	210 921	-64 628	592 829
5		330 693	8 423	32 288	40 711	289 982	115 993	0	-115 993	173 989	173 989	279 400	161 927	64 771	214 630	-40 641	552 188
6		386 468	8 760	33 580	42 340	344 129	137 651	0	-137 651	206 477	206 477	279 400	151 860	60 744	218 656	-12 179	540 009
7		415 577	9 110	34 923	44 033	371 544	148 617	0	-148 617	222 926	222 926	279 400	140 931	56 372	223 028	-102	539 907
8		446 878	9 475	36 320	45 794	401 083	160 433	0	-160 433	240 650	240 650	279 400	129 065	51 626	227 774	12 876	552 783
9		480 537	9 854	37 773	47 626	432 910	173 164	0	-173 164	259 746	259 746	279 400	116 183	46 473	232 927	26 819	579 602
10		516 730	10 248	39 283	49 531	467 199	186 880	0	-186 880	280 320	280 320	279 400	102 196	40 879	238 522	41 798	621 399
11		555 650	10 658	40 855	51 513	504 138	201 655	0	-201 655	302 483	302 483	279 400	87 011	34 805	244 596	57 887	679 286
12		597 502	11 084	42 489	53 573	543 929	217 572	0	-217 572	326 357	326 357	279 400	70 525	28 210	251 190	75 167	754 453
13	440 284	642 506	11 527	44 188	55 716	586 790	234 716	88 057	-146 659	440 131	-153	279 400	52 626	21 050	258 350	181 780	936 233
14		690 899	11 989	45 956	57 945	632 954	253 182	52 834	-200 348	432 607	432 607	279 400	33 193	13 277	266 123	166 483	1 102 717
15		742 937	12 468	47 794	60 262	682 675	273 070	35 223	-237 847	444 828	444 828	279 400	12 095	4 838	274 562	170 265	1 272 982
16		798 895	12 967	49 706	62 673	736 222	294 489	0	-294 489	441 733	441 733	0	0	0	0	441 733	1 714 715
17		859 067	13 485	51 694	65 180	793 888	317 555	0	-317 555	476 333	476 333	0	0	0	0	476 333	2 191 048
18		923 772	14 025	53 762	67 787	855 985	342 394	0	-342 394	513 591	513 591	0	0	0	0	513 591	2 704 639
19		993 350	14 586	55 913	70 498	922 852	369 141	0	-369 141	553 711	553 711	0	0	0	0	553 711	3 258 350
20		1 068 169	15 169	58 149	73 318	994 851	397 940	0	-397 940	596 911	596 911	0	0	0	0	596 911	3 855 261
21		1 148 623	15 776	60 475	76 251	1 072 372	428 949	0	-428 949	643 423	643 423	0	0	0	0	643 423	4 498 684
22		1 235 137	16 407	62 894	79 301	1 155 836	462 335	0	-462 335	693 502	693 502	0	0	0	0	693 502	5 192 186
23		1 328 168	17 063	65 410	82 473	1 245 694	498 278	0	-498 278	747 417	747 417	0	0	0	0	747 417	5 939 603
24		1 428 205	17 746	68 026	85 772	1 342 433	536 973	0	-536 973	805 460	805 460	0	0	0	0	805 460	6 745 062
25		1 535 777	18 456	70 747	89 203	1 446 574	578 629	0	-578 629	867 944	867 944	0	0	0	0	867 944	7 613 006

Appendix C5: Dairy C January time-of-use tariff calculations

Time	Ave Irradiance (W / m²)	Ave energy (Wh / m²)	Cum energy (Wh / m²)
05:37	36	9	9
05:52	50	13	22
06:07	56	14	36
06:22	95	24	60
06:37	138	35	94
06:52	185	46	140
07:07	234	59	199
07:22	284	71	270
07:37	335	84	353
07:52	385	96	450
08:07	433	108	558
08:22	481	120	678
08:37	528	132	810
08:52	570	143	952
09:07	611	153	1 105
09:22	649	162	1 267
09:37	684	171	1 438
09:52	716	179	1 617
10:07	745	186	1 803
10:22	771	193	1 996
10:37	793	198	2 194
10:52	812	203	2 397
11:07	827	207	2 604
11:22	838	210	2 814
11:37	846	212	3 025
11:52	850	213	3 238
12:07	851	213	3 450
12:22	847	212	3 662
12:37	841	210	3 872
12:52	830	208	4 080
13:07	816	204	4 284
13:22	798	200	4 483
13:37	777	194	4 678
13:52	752	188	4 866
14:07	723	181	5 046
14:22	692	173	5 219
14:37	657	164	5 384
14:52	620	155	5 538
15:07	579	145	5 683
15:22	536	134	5 817
15:37	491	123	5 940
15:52	444	111	6 051
16:07	395	99	6 150
16:22	345	86	6 236
16:37	295	74	6 310
16:52	245	61	6 371
17:07	195	49	6 420
17:22	148	37	6 457
17:37	103	26	6 483
17:52	64	16	6 499
18:07	50	13	6 511
18:22	36	9	6 520
18:37	22	6	6 526
		6 526	

Days in Jan				
Moday - Friday	22.14			
Saturday	4.43			
Sunday	4.43			
Total	31			
Total Yield Jan (PV GIS)	18 500			
Yield Mon - Frid	13 214			
Yield Sat	2 643			
Yield Sun	2 643			
Total yield (kWh)	**18 500**			
Eskom Tariff	Tariff (R/kWh)	Netw Demand Charge (R/kWh)	Reliability Charge (R/kWh)	Tot Eskom Charge (R/kWh)
Peak	0.8480	0.188	0.0029	**1.040**
Standard	0.5845	0.188	0.0029	**0.775**
Offpeak	0.3708	0.188	0.0029	**0.562**
Yield	Solar	Solar	Solar	
Monday to Friday	Yield (%)	Yield (kWh)	Yield (R)	
Peak 07h00 - 10h00	22.63%	2991	3 110.98	
Peak 18h00 - 20h00	0.41%	55	58.87	
Standard 06h00 - 07h00	1.82%	240	186.07	
Standard 10h00 - 18h00	74.81%	9885	7 665.17	
Standard 20h00 - 22h00	0.00%	0	0.38	
Offpeak 22h00 - 06h00	0.33%	44	24.46	
Total	100.00%	13214	11 043.57	
Saturday				
Standard 07h00 - 12h00	47.47%	1255	972.77	
Standard 18h00 - 20h00	0.41%	11	8.48	
Offpeak 12h00 - 18h00	49.97%	1321	741.90	
Offpeak 20h00 - 07h00	2.15%	57	31.85	
Total	100.00%	2643	1 755.00	
Sunday				
Offpeak all day	100%	2643	1 484.66	
TOTAL		18500	14283	

Appendix C6: Dairy C February time-of-use tariff calculations

Time	Ave Irradiance (W / m²)	Ave energy (Wh / m²)	Cum energy (Wh / m²)
05:52	33	8	8
06:07	46	12	20
06:22	84	21	41
06:37	129	32	73
06:52	178	45	118
07:07	230	58	175
07:22	283	71	246
07:37	337	84	330
07:52	391	98	428
08:07	443	111	539
08:22	494	124	662
08:37	543	136	798
08:52	589	147	945
09:07	633	158	1 103
09:22	674	169	1 272
09:37	711	178	1 450
09:52	746	187	1 636
10:07	777	194	1 830
10:22	804	201	2 031
10:37	828	207	2 238
10:52	848	212	2 450
11:07	864	216	2 666
11:22	876	219	2 885
11:37	886	221	3 106
11:52	889	222	3 328
12:07	889	222	3 551
12:22	886	222	3 773
12:37	879	220	3 992
12:52	867	217	4 209
13:07	852	213	4 422
13:22	833	208	4 630
13:37	810	203	4 833
13:52	784	196	5 029
14:07	753	188	5 217
14:22	720	180	5 397
14:37	683	171	5 568
14:52	642	161	5 729
15:07	599	150	5 879
15:22	553	138	6 016
15:37	504	126	6 142
15:52	454	114	6 256
16:07	402	101	6 356
16:22	348	87	6 443
16:37	294	74	6 517
16:52	240	60	6 577
17:07	188	47	6 624
17:22	138	35	6 658
17:37	92	23	6 681
17:52	52	13	6 694
18:07	33	8	6 702
18:22	18	5	6 707
		5 707	

Days in Feb				
Moday - Friday	20.00			
Saturday	4.00			
Sunday	4.00			
Total	28.00			
Total Yield Feb (PV SIS)	17 100			
Yield Mon - Fri	12 214			
Yield Sat	2 443			
Yield Sun	2 443			
Total yield (kWh)	**17 100**			
Eskom Tariff	Tariff (R/kWh)	Netw Demand Charge (R/kWh)	Reliability Charge (R/kWh)	Tot Eskom Charge (R/kWh)
Peak	0.8492	0.183	0.0029	**1.046**
Standard	0.5645	0.183	0.0029	**0.775**
Offpeak	0.3709	0.183	0.0029	**0.562**
Yield	Solar	Solar	Solar	
Monday to Friday	Yield (%)	Yield (kWh)	Yield (R)	
Peak 07h00 - 10h00	22.64%	2765	2 876.36	
Peak 18h00 - 20h00	0.19%	23	24.15	
Standard 06h00 - 07h00	1.63%	199	154.28	
Standard 10h00 - 18h00	75.42%	9212	7 142.97	
Standard 20h00 - 22h00	0.00%	0	0.00	
Offpeak 22h00 - 06h00	0.12%	15	8.44	
Total	100.00%	**12214**	**10 206.19**	
Saturday				
Standard 07h00 - 12h00	47.90%	1170	906.95	
Standard 18h00 - 20h00	0.19%	5	3.60	
Offpeak 12h00 - 18h00	50.18%	1226	688.61	
Offpeak 20h00 - 07h00	1.75%	43	24.04	
Total	100.00%	**2443**	**1 623.20**	
Sunday				
Offpeak all day	100%	**2443**	**[illegible]**	
TOTAL		**17100**	**13202**	

Appendix C7: Dairy C March time-of-use tariff calculations

Time	Ave irradiance (W/m^2)	Ave energy (Wh/m^2)	Cum energy (Wh/m^2)
06:22	74	19	19
06:37	123	31	49
06:52	178	45	94
07:07	238	59	153
07:22	295	74	227
07:37	354	89	316
07:52	412	103	418
08:07	469	117	535
08:22	524	131	666
08:37	577	144	811
08:52	627	157	967
09:07	673	168	1 136
09:22	718	179	1 315
09:37	758	189	1 504
09:52	792	198	1 702
10:07	825	206	1 908
10:22	853	213	2 121
10:37	878	220	2 341
10:52	899	225	2 565
11:07	915	229	2 794
11:22	928	232	3 026
11:37	937	234	3 260
11:52	941	235	3 495
12:07	942	236	3 731
12:22	938	235	3 966
12:37	930	233	4 198
12:52	919	230	4 428
13:07	903	226	4 654
13:22	883	221	4 874
13:37	859	215	5 089
13:52	832	208	5 297
14:07	800	200	5 497
14:22	765	191	5 688
14:37	728	182	5 870
14:52	683	171	6 041
15:07	637	159	6 200
15:22	588	147	6 347
15:37	536	134	6 481
15:52	481	120	6 601
16:07	424	106	6 707
16:22	365	91	6 798
16:37	305	76	6 874
16:52	248	62	6 936
17:07	187	47	6 983
17:22	131	33	7 015
17:37	80	20	7 035
17:52	38	9	7 044
		7 044	

Days in March				
Moday - Friday	22.14			
Saturday	4.43			
Sunday	4.43			
Total	31.00			
Total Yield March (PV GIS	20 096			
Yield Mon - Fri	14 354			
Yield Sat	2 871			
Yield Sun	2 871			
Total yield (kWh)	**20 096**			
Eskom Tariff	Tariff (R/kWh)	Netw Demand Charge (R/kWh)	Reliability Charge (R/kWh)	Tot Eskom Charge (R/kWh)
Peak	0.8492	0.138	0.0029	**1.440**
Standard	0.5846	0.138	0.0029	**0.776**
Offpeak	0.3706	0.138	0.0029	**0.362**
Yield	Solar	Solar	Solar	
Monday to Friday	Yield (%)	Yield (kWh)	Yield (R)	
Peak 07h00 - 10h00	22.82%	2276	3 407.47	
Peak 18h00 - 20h00	0.00%	0	0.00	
Standard 06h00 - 07h00	1.33%	191	148.13	
Standard 10h00 - 18h00	75.85%	10887	8 441.68	
Standard 20h00 - 22h00	0.00%	0	0.00	
Offpeak 22h00 - 06h00	0.00%	0	0.00	
Total	100.00%	14354	11 997.28	
Saturday				
Standard 07h00 - 12h00	48.29%	1386	1 074.97	
Standard 18h00 - 20h00	0.00%	0	0.00	
Offpeak 12h00 - 18h00	50.38%	1446	612.43	
Offpeak 20h00 - 07h00	1.33%	38	21.46	
Total	100.00%	2871	1 708.86	
Sunday				
Offpeak all day	100%	2871	1 612.96	
TOTAL		20096	15319	

Appendix C8: Dairy C April time-of-use tariff calculations

Time	Ave Irradiance (W/m^2)	Ave energy (Wh/m^2)	Cum energy (Wh/m^2)
06:37	59	15	15
06:52	115	29	43
07:07	172	43	86
07:22	230	58	144
07:37	290	73	217
07:52	349	87	304
08:07	407	102	406
08:22	469	116	522
08:37	517	129	651
08:52	569	142	793
09:07	617	154	947
09:22	662	166	1 113
09:37	708	176	1 289
09:52	742	186	1 474
10:07	773	194	1 668
10:22	808	202	1 870
10:37	832	208	2 078
10:52	854	214	2 291
11:07	872	218	2 509
11:22	885	221	2 731
11:37	898	224	2 954
11:52	899	225	3 179
12:07	900	225	3 404
12:22	895	224	3 628
12:37	888	222	3 850
12:52	875	219	4 069
13:07	859	215	4 283
13:22	837	209	4 492
13:37	812	203	4 696
13:52	782	196	4 891
14:07	749	187	5 078
14:22	712	178	5 256
14:37	671	168	5 424
14:52	629	157	5 580
15:07	579	145	5 725
15:22	529	132	5 857
15:37	474	119	5 976
15:52	419	105	6 080
16:07	360	90	6 170
16:22	300	75	6 245
16:37	243	60	6 305
16:52	180	45	6 350
17:07	122	31	6 381
17:22	62	16	6 396
17:37	12	3	6 396
		6 396	

Days in April	
Monday - Friday	21.43
Saturday	4.29
Sunday	4.29
Total	30.00
Total Yield Apr (PV 3-5)	17 900
Yield Mon - Frid	12 786
Yield Sat	2 557
Yield Sun	2 557
Total yield (kWh)	**17 900**

Eskom Tariff	Tariff (R/kWh)	Netw Demand Charge (R/kWh)	Reliability Charge (R/kWh)	Tot Eskom Charge (R/kWh)
Peak	0.8432	0.188	0.0029	**1.04**
Standard	0.5845	0.188	0.0029	**0.77**
Off-peak	0.3739	0.188	0.0029	**0.56**

Yield	Solar Yield (%)	Solar Yield (kWh)	Solar Yield (R)
Monday to Friday			
Peak 07h00 - 10h00	22.36%	2859	2 974.00
Peak 18h00 - 20h00	0.00%	0	0.00
Standard 06h00 - 07h00	0.68%	86	67.01
Standard 10h00 - 18h00	76.96%	9840	7 630.20
Standard 20h00 - 22h00	0.00%	0	0.00
Off-peak 22h00 - 06h00	0.00%	0	0.00
Total	100.00%	12786	10 671.21
Saturday			
Standard 07h00 - 12h00	49.00%	1253	971.60
Standard 18h00 - 20h00	0.00%	0	0.00
Off-peak 12h00 - 18h00	50.32%	1287	722.61
Off-peak 20h00 - 07h00	0.68%	17	9.71
Total	100.00%	2557	1 704.22
Sunday			
Off-peak all day	100%	2557	1 436.91
TOTAL		17900	13812

Appendix C9: Dairy C May time-of-use tariff calculations

Time	Ave irradiance (W / m²)	Ave energy (Wh / m²)	Cum energy (Wh / m²)
07:07	124	31	31
07:22	196	49	80
07:37	260	65	145
07:52	322	81	226
08:07	383	96	321
08:22	442	111	432
08:37	498	125	556
08:52	551	138	694
09:07	601	150	844
09:22	648	162	1 006
09:37	691	173	1 179
09:52	730	183	1 362
10:07	766	192	1 553
10:22	797	199	1 752
10:37	824	206	1 958
10:52	847	212	2 170
11:07	865	216	2 386
11:22	879	220	2 606
11:37	888	222	2 828
11:52	893	223	3 051
12:07	894	224	3 275
12:22	890	223	3 497
12:37	881	220	3 718
12:52	868	217	3 935
13:07	851	213	4 147
13:22	829	207	4 355
13:37	803	201	4 555
13:52	772	193	4 748
14:07	738	185	4 933
14:22	699	175	5 108
14:37	657	164	5 272
14:52	611	153	5 425
15:07	561	140	5 565
15:22	508	127	5 692
15:37	452	113	5 805
15:52	393	98	5 903
16:07	332	83	5 986
16:22	269	67	6 053
16:37	204	51	6 104
16:52	130	33	6 137
17:07	69	17	6 154
		6 154	

Days in May				
Monday - Friday	22.14			
Saturday	4.43			
Sunday	4.43			
Total	31.00			
Total Yield May (PV GIS)	18 400			
Yield Mon - Fri	13 143			
Yield Sat	2 629			
Yield Sun	2 629			
Total yield (kWh)	**18 400**			
Eskom Tariff	Tariff	Netw Demand	Reliability	Tot Eskom
	(R/kWh)	Charge (R/kWh)	Charge (R/kWh)	Charge (R/kWh)
Peak	0.6492	0.188	0.0029	**1.044**
Standard	0.5846	0.188	0.0029	**0.775**
Off-peak	0.2709	0.188	0.0029	**0.562**
Yield	Solar	Solar	Solar	
Monday to Friday	Yield (%)	Yield (kWh)	Yield (R)	
Peak 07h00 - 10h00	22.12%	2908	3 034.39	
Peak 18h00 - 20h00	0.00%	0	0.00	
Standard 06h00 - 07h00	0.00%	0	0.00	
Standard 10h00 - 18h00	77.88%	10235	7 936.57	
Standard 20h00 - 22h00	0.00%	0	0.00	
Off-peak 22h00 - 06h00	0.00%	0	0.00	
Total	100.00%	13143	**10 960.97**	
Saturday				
Standard 07h00 - 12h00	49.58%	1303	1 010.60	
Standard 18h00 - 20h00	0.00%	0	0.00	
Off-peak 12h00 - 18h00	50.42%	1325	744.50	
Off-peak 20h00 - 07h00	0.00%	0	0.00	
Total	100.00%	2629	1 755.09	
Sunday				
Off-peak all day	100%	2629	1 436.63	
TOTAL		18400	15150	

Appendix C10: Dairy C June time-of-use tariff calculations

Time	Ave irradiance (W/m²)	Ave energy (Wh/m²)	Cum energy (Wh/m²)
07:22	168	42	42
07:37	243	61	103
07:52	307	77	180
08:07	369	92	272
08:22	428	107	379
08:37	485	121	500
08:52	538	135	635
09:07	588	147	782
09:22	634	159	940
09:37	677	169	1 109
09:52	715	179	1 288
10:07	751	188	1 476
10:22	782	196	1 672
10:37	809	202	1 874
10:52	832	208	2 082
11:07	850	213	2 294
11:22	864	216	2 510
11:37	873	218	2 728
11:52	878	220	2 948
12:07	879	220	3 168
12:22	875	219	3 387
12:37	868	217	3 603
12:52	853	213	3 816
13:07	838	209	4 026
13:22	814	204	4 229
13:37	788	197	4 426
13:52	758	190	4 616
14:07	724	181	4 796
14:22	685	171	4 968
14:37	643	161	5 128
14:52	597	149	5 278
15:07	547	137	5 414
15:22	494	124	5 538
15:37	438	110	5 647
15:52	379	95	5 742
16:07	318	79	5 821
16:22	251	63	5 884
16:37	175	44	5 928
16:52	104	26	5 954
		5 954	

Days in June				
Monday - Friday	21.43			
Saturday	4.29			
Sunday	4.29			
Total	30.00			
Total Yield Jun (PV GIS)	17 600			
Yield Mon - Fri	12 571			
Yield Sat	2 514			
Yield Sun	2 514			
Total yield (kWh)	**17 600**			
Eskom Tariff	Tariff (R/kWh)	Netw Demand Charge (R/kWh)	Reliability Charge (R/kWh)	Tot Eskom Charge (R/kWh)
Peak	2.6005	0.188	0.0028	**2.794**
Standard	0.7887	0.188	0.0028	**0.980**
Offpeak	0.4283	0.188	0.0028	**0.619**
Yield	Solar	Solar	Solar	
Monday to Friday	Yield (%)	Yield (kWh)	Yield (R)	
Peak 07h00 - 10h00	21.64%	2720	7 601.47	
Peak 18h00 - 20h00	0.00%	0	0.00	
Standard 06h00 - 07h00	0.00%	0	0.00	
Standard 10h00 - 18h00	78.36%	9851	9 654.36	
Standard 20h00 - 22h00	0.00%	0	0.00	
Offpeak 22h00 – 06h00	0.00%	0	0.00	
Total	100.00%	12571	17 255.83	
Saturday				
Standard 07h00 - 12h00	49.52%	1245	1 219.62	
Standard 18h00 - 20h00	0.00%	0	0.00	
Offpeak 12h00 – 18h00	50.48%	1269	785.96	
Offpeak 20h00 – 07h00	0.00%	0	0.00	
Total	100.00%	2514	2 005.58	
Sunday				
Offpeak all day	100%	2514	1 556.93	
TOTAL		17600	20814	

Appendix C11: Dairy C July time-of-use tariff calculations

	Ave irradiance	Ave energy	Cum energy					
Time	(W/m²)	(Wh/m²)	(Wh/m²)					
07:07	127	32	32	Days in July				
07:22	207	52	84	Monday - Friday	22.14			
07:37	274	69	152	Saturday	4.43			
07:52	339	85	237	Sunday	4.43			
08:07	401	100	337	Total	31.00			
08:22	461	115	452					
08:37	519	130	582	Total Yield Jul (PV 6IB)	18 772			
08:52	573	143	725	Yield Mon - Fri	13 409			
09:07	623	158	881	Yield Sat	2 682			
09:22	671	168	1 049	Yield Sun	2 682			
09:37	714	179	1 227	Total yield (kWh)	18 772			
09:52	754	189	1 416					
10:07	789	197	1 613	Eskom Tariff	Tariff	Network Demand	Reliability	Tot Energy
10:22	821	205	1 818		(R/kWh)	Charge (R/kWh)	Charge (R/kWh)	Charge (R/kWh)
10:37	848	212	2 030	Peak	2.6035	0.188	0.0029	2.794
10:52	871	218	2 248	Standard	0.7687	0.188	0.0029	0.960
11:07	889	222	2 470	Off-peak	0.4280	0.188	0.0029	0.619
11:22	903	226	2 696					
11:37	913	228	2 924	Yield	Solar	Solar	Solar	
11:52	918	230	3 154	Monday to Friday	Yield (%)	Yield (kWh)	Yield (R)	
12:07	919	230	3 384	Peak 07h00 - 10h00	22.31%	2991	8 358.01	
12:22	915	229	3 612	Peak 18h00 - 20h00	0.00%	0	0.00	
12:37	906	227	3 839	Standard 06h00 - 07h00	0.00%	0	0.00	
12:52	893	223	4 062	Standard 10h00 - 18h00	77.69%	10418	10 005.22	
13:07	875	219	4 281	Standard 20h00 - 22h00	0.00%	0	0.00	
13:22	853	213	4 494	Off-peak 22h00 - 06h00	0.00%	0	0.00	
13:37	827	207	4 701	Total	100.00%	13409	18 363.23	
13:52	799	199	4 900					
14:07	762	191	5 090	Saturday				
14:22	723	181	5 271	Standard 07h00 - 12h00	49.69%	1333	1 305.40	
14:37	680	170	5 441	Standard 18h00 - 20h00	0.00%	0	0.00	
14:52	633	158	5 599	Off-peak 12h00 - 18h00	50.31%	1349	835.44	
15:07	583	146	5 745	Off-peak 20h00 - 07h00	0.00%	0	0.00	
15:22	529	132	5 877	Total	100.00%	2682	2 140.84	
15:37	472	118	5 995					
15:52	412	103	6 098	Sunday				
16:07	349	87	6 185	Off-peak all day	100%	2682	1 660.61	
16:22	283	71	6 256					
16:37	215	54	6 310	TOTAL		18772	22165	
16:52	133	33	6 343					
17:07	14	4	6 347					
		6 347						

Appendix C12: Dairy C August time-of-use tariff calculations

Time	Ave irradiance (W/m²)	Ave energy (Wh/m²)	Cum energy (Wh/m²)
06:52	119	30	30
07:07	190	48	78
07:22	257	64	142
07:37	322	81	223
07:52	386	96	319
08:07	448	112	431
08:22	506	126	557
08:37	561	140	697
08:52	615	154	851
09:07	666	166	1 017
09:22	711	178	1 195
09:37	754	188	1 383
09:52	794	199	1 582
10:07	829	207	1 789
10:22	860	215	2 004
10:37	887	222	2 226
10:52	910	228	2 453
11:07	928	232	2 685
11:22	942	236	2 921
11:37	952	238	3 159
11:52	957	239	3 398
12:07	957	239	3 637
12:22	953	238	3 876
12:37	945	236	4 112
12:52	932	233	4 345
13:07	914	229	4 573
13:22	890	223	4 797
13:37	867	217	5 013
13:52	836	209	5 222
14:07	802	201	5 423
14:22	764	191	5 614
14:37	721	180	5 794
14:52	675	169	5 963
15:07	626	157	6 119
15:22	573	143	6 263
15:37	517	129	6 392
15:52	458	115	6 506
16:07	397	99	6 606
16:22	333	83	6 689
16:37	268	67	6 756
16:52	203	51	6 807
17:07	127	32	6 838
17:22	68	17	6 855
		6 855	

Days in August				
Moday - Friday	22.14			
Saturday	4.43			
Sunday	4.43			
Total	31.00			
Total Yield Aug (PV GIS)	20 271			
Yield Mon - Frid	14 479			
Yield Sat	2 896			
Yield Sun	2 896			
Total yield (kWh)	**20 271**			
Eskom Tariff	Tariff (R/kWh)	Netw Demand Charge (R/kWh)	Reliability Charge (R/kWh)	Tot Eskom Charge (R/kWh)
Peak	2.6035	0.138	0.0029	2.794
Standard	0.7987	0.138	0.0029	0.900
Offpeak	0.4263	0.138	0.0029	0.519
Yield	Solar	Solar	Solar	
Monday to Friday	Yield (%)	Yield (kWh)	Yield (R)	
Peak 07h00 - 10h00	22.64%	3278	9 160.73	
Peak 18h00 - 20h00	0.00%	0	0.00	
Standard 06h30 - 07h00	0.43%	63	61.58	
Standard 10h30 - 18h00	76.92%	11138	10 911.13	
Standard 20h30 - 22h00	0.00%	0	0.00	
Offpeak 22h00 - 06h00	0.00%	0	0.00	
Total	100.00%	14479	20 133.47	
Saturday				
Standard 07h30 - 12h00	49.14%	1423	1 393.95	
Standard 18h30 - 20h00	0.00%	0	0.00	
Offpeak 12h00 - 18h00	50.43%	1460	904.29	
Offpeak 20h00 - 07h00	0.43%	13	7.79	
Total	100.00%	2896	2 306.02	
Sunday				
Offpeak all day	100%	2896	1 793.22	
TOTAL		20271	24233	

Appendix C13: Dairy C September time-of-use tariff calculations

Time	Ave Irradiance (W / m²)	Ave energy (Ah / m²)	Cum energy (Ah / m²)
06:22	45	11	11
06:37	98	25	36
06:52	155	39	75
07:07	216	54	129
07:22	280	70	199
07:37	345	86	285
07:52	409	102	387
08:07	472	118	505
08:22	533	133	638
08:37	592	148	786
08:52	648	162	948
09:07	701	175	1 124
09:22	750	188	1 311
09:37	796	199	1 510
09:52	837	209	1 719
10:07	875	219	1 938
10:22	908	227	2 165
10:37	937	234	2 399
10:52	961	240	2 640
11:07	981	245	2 885
11:22	996	249	3 134
11:37	1010	253	3 386
11:52	1010	253	3 639
12:07	1010	253	3 891
12:22	1010	253	4 144
12:37	999	250	4 394
12:52	985	246	4 640
13:07	968	242	4 881
13:22	943	236	5 117
13:37	915	229	5 346
13:52	883	221	5 567
14:07	846	212	5 778
14:22	805	201	5 979
14:37	760	190	6 169
14:52	712	178	6 347
15:07	659	165	6 512
15:22	604	151	6 663
15:37	545	136	6 799
15:52	484	121	6 920
16:07	421	105	7 026
16:22	357	89	7 115
16:37	292	73	7 188
16:52	227	57	7 245
17:07	165	41	7 286
17:22	108	27	7 312
17:37	50	13	7 325
17:52	13	3	7 328
		7 328	

Days in September				
Monday - Friday	21.43			
Saturday	4.29			
Sunday	4.29			
Total	30.00			
Total Yield Sep (PV GIS)	17 565			
Yield Mon - Fri	12 547			
Yield Sat	2 509			
Yield Sun	2 509			
Total yield (kWh)	17 565			
Eskom Tariff	Tariff (R/kWh)	Netw Demand Charge (R/kWh)	Reliability Charge (R/kWh)	Tot Eskom Charge (R/kWh)
Peak	0.8492	0.1188	0.0029	**1.340**
Standard	0.5845	0.1188	0.0029	**0.775**
Off-peak	0.3709	0.1188	0.0029	**0.562**
Yield	Solar	Solar	Solar	
Monday to Friday	Yield (%)	Yield (kWh)	Yield (R)	
Peak 07h00 - 10h00	22.44%	2816	2 926.19	
Peak 18h00 - 20h00	0.00%	0	0.00	
Standard 06h00 - 07h00	1.02%	128	98.51	
Standard 10h00 - 18h00	76.54%	9603	7 446.71	
Standard 20h00 - 22h00	0.00%	0	0.00	
Off-peak 22h00 - 06h00	0.00%	0	0.00	
Total	100.00%	12547	10 471.41	
Saturday				
Standard 07h00 - 12h00	48.64%	1221	946.45	
Standard 18h00 - 20h00	0.00%	0	0.00	
Off-peak 12h00 - 18h00	50.34%	1263	709.71	
Off-peak 20h00 - 07h00	1.02%	26	14.33	
Total	100.00%	2509	1 670.49	
Sunday				
Off-peak all day	100%	2509	1 409.30	
TOTAL		17565	13555	

Appendix C14: Dairy C October time-of-use tariff calculations

Time	Ave irradiance (W / m²)	Ave energy (Wh / m²)	Cum energy (Wh / m²)
06:07	42	11	11
06:22	82	21	31
06:37	131	33	64
06:52	185	46	110
07:07	242	61	171
07:22	300	75	246
07:37	359	90	335
07:52	418	105	440
08:07	475	119	558
08:22	530	133	691
08:37	584	146	837
08:52	634	159	996
09:07	682	171	1 166
09:22	727	182	1 348
09:37	768	192	1 540
09:52	805	201	1 741
10:07	839	210	1 951
10:22	869	217	2 168
10:37	894	224	2 392
10:52	916	229	2 621
11:07	934	234	2 854
11:22	947	237	3 091
11:37	956	239	3 330
11:52	961	240	3 570
12:07	961	240	3 810
12:22	958	240	4 050
12:37	950	238	4 287
12:52	937	234	4 522
13:07	921	230	4 752
13:22	900	225	4 977
13:37	875	219	5 196
13:52	846	212	5 407
14:07	813	203	5 610
14:22	777	194	5 805
14:37	736	184	5 988
14:52	692	173	6 162
15:07	645	161	6 323
15:22	595	149	6 472
15:37	542	136	6 608
15:52	487	122	6 730
16:07	429	107	6 836
16:22	371	93	6 929
16:37	312	78	7 007
16:52	253	63	7 070
17:07	195	49	7 119
17:22	140	35	7 154
17:37	90	23	7 176
17:52	48	12	7 188
18:07	28	7	7 195
		7 195	

Days in October				
Moday - Friday	22.14			
Saturday	4.43			
Sunday	4.43			
Total	31.00			
Total Yield Oct (PV GIS)	20 400			
Yield Mon - Frid	14 571			
Yield Sat	2 914			
Yield Sun	2 914			
Total yield (kWh)	20 400			
Eskom Tariff	Tariff (R/kWh)	Netw Demand Charge (R/kWh)	Reliability Charge (R/kWh)	Tot Eskom Charge (R/kWh)
Peak	1.3492	0.188	0.0029	1.340
Standard	0.5645	0.188	0.0029	0.775
Offpeak	0.3709	0.188	0.0029	0.562
Yield	Solar Yield (%)	Solar Yield (kWh)	Solar Yield (R)	
Monday to Friday				
Peak 07h00 - 10h00	22.67%	3303	3 435.61	
Peak 18h00 - 20h00	0.09%	13	13.69	
Standard 06h00 - 07h00	1.53%	223	172.76	
Standard 10h00 - 18h00	75.71%	11032	8 554.65	
Standard 20h00 - 22h00	0.00%	0	0.00	
Offpeak 22h00 - 06h00	0.00%	0	0.00	
Total	100.00%	14571	12 176.90	
Saturday				
Standard 07h00 - 12h00	48.09%	1401	1 086.75	
Standard 18h00 - 20h00	0.09%	3	2.04	
Offpeak 12h00 - 18h00	50.29%	1466	823.32	
Offpeak 20h00 - 07h00	1.53%	45	25.03	
Total	100.00%	2914	1 937.14	
Sunday				
Offpeak all day	100%	2914	1 637.14	
TOTAL		20400	15751	

Appendix C15: Dairy C November time-of-use tariff calculations

Time	Ave irradiance (W / m²)	Ave energy (Wh / m²)	Cum energy (Wh / m²)
05:37	30	8	8
05:52	43	11	18
06:07	50	13	31
06:22	91	23	54
06:37	138	35	88
06:52	189	47	135
07:07	242	61	196
07:22	297	74	270
07:37	352	88	358
07:52	407	102	460
08:07	461	115	575
08:22	513	128	703
08:37	563	141	844
08:52	611	153	997
09:07	658	164	1 161
09:22	699	175	1 336
09:37	738	185	1 520
09:52	774	194	1 714
10:07	806	202	1 915
10:22	834	209	2 124
10:37	859	215	2 338
10:52	880	220	2 558
11:07	897	224	2 783
11:22	909	227	3 010
11:37	918	230	3 239
11:52	923	231	3 470
12:07	923	231	3 701
12:22	920	230	3 931
12:37	912	228	4 159
12:52	900	225	4 384
13:07	884	221	4 605
13:22	864	216	4 821
13:37	841	210	5 031
13:52	813	203	5 234
14:07	782	196	5 430
14:22	747	187	5 617
14:37	709	177	5 794
14:52	668	167	5 960
15:07	622	156	6 116
15:22	576	144	6 260
15:37	524	131	6 390
15:52	472	118	6 508
16:07	419	105	6 613
16:22	364	91	6 704
16:37	309	77	6 781
16:52	253	63	6 844
17:07	200	50	6 894
17:22	148	37	6 931
17:37	100	25	6 956
17:52	59	15	6 971
18:07	43	11	6 982
18:22	30	8	6 989
18:37	19	4	6 993
		6 993	

Days in November				
Monday - Friday	21.43			
Saturday	4.29			
Sunday	4.29			
Total	30.00			
Total Yield Nov (PV GIS)	19 200			
Yield Mon - Frid	13 714			
Yield Sat	2 743			
Yield Sun	2 743			
Total yield (kWh)	**19 200**			
Eskom Tariff	Tariff (R/kWh)	Netw Demand Charge (R/kWh)	Reliability Charge (R/kWh)	Tot Eskom Charge (R/kWh)
Peak	0.8492	0.188	0.0029	1.040
Standard	0.5445	0.188	0.0029	0.735
Off-peak	0.3709	0.188	0.0029	0.562
Yield	Solar Yield (%)	Solar Yield (kWh)	Solar Yield (R)	
Monday to Friday				
Peak 07h00 - 10h00	22.57%	3095	3 216.39	
Peak 18h00 - 20h00	0.32%	44	45.39	
Standard 06h00 - 07h00	1.67%	229	171.92	
Standard 10h00 - 18h00	75.18%	10310	7 594.19	
Standard 20h00 - 22h00	0.00%	0	0.00	
Off-peak 22h00 - 06h00	0.26%	36	20.11	
Total	100.00%	13714	11 453.60	
Saturday				
Standard 07h00 - 12h00	47.69%	1308	1 014.24	
Standard 18h00 - 20h00	0.32%	9	6.17	
Off-peak 12h00 - 18h00	50.06%	1373	771.36	
Off-peak 20h00 - 07h00	1.93%	53	29.80	
Total	100.00%	2743	1 822.16	
Sunday				
Off-peak all day	100%	2743	1 540.84	
TOTAL		19200	14821	

Appendix C16: Dairy C December time-of-use tariff calculations

Time	Ave irradiance (W / m²)	Ave energy (Wh / m²)	Cum energy (Wh / m²)
05:22	27	7	7
05:37	40	10	17
05:52	52	13	30
06:07	56	14	44
06:22	95	24	68
06:37	140	35	103
06:52	188	47	150
07:07	237	59	209
07:22	288	72	281
07:37	339	85	366
07:52	390	98	463
08:07	439	110	573
08:22	487	122	695
08:37	533	133	828
08:52	577	144	972
09:07	619	155	1 127
09:22	657	164	1 291
09:37	693	173	1 464
09:52	726	182	1 646
10:07	755	189	1 835
10:22	781	195	2 030
10:37	804	201	2 231
10:52	823	206	2 437
11:07	838	210	2 646
11:22	850	213	2 859
11:37	858	215	3 073
11:52	862	216	3 289
12:07	863	216	3 504
12:22	859	215	3 719
12:37	852	213	3 932
12:52	842	211	4 143
13:07	827	207	4 349
13:22	808	202	4 552
13:37	787	197	4 748
13:52	762	191	4 939
14:07	733	183	5 122
14:22	701	175	5 297
14:37	668	167	5 464
14:52	628	157	5 621
15:07	587	147	5 768
15:22	543	136	5 903
15:37	498	125	6 028
15:52	450	113	6 140
16:07	401	100	6 241
16:22	350	88	6 328
16:37	299	75	6 403
16:52	248	62	6 465
17:07	198	50	6 514
17:22	150	38	6 552
17:37	104	26	6 578
17:52	64	16	6 594
18:07	52	13	6 607
18:22	40	10	6 617
18:37	27	7	6 624
18:52	14	4	6 627
		6 627	

Days in December				
Moday - Friday	22.14			
Saturday	4.43			
Sunday	4.43			
Total	31.00			
Total Yield Dec (PV GIS)	18 700			
Yield Mon - Frid	13 357			
Yield Sat	2 671			
Yield Sun	2 671			
Total yield (kWh)	**18 700**			
Eskom Tariff	Tariff (R/kWh)	New Demand Charge (R/kWh)	Reliability Charge (R/kWh)	Tot Eskom Charge (R/kWh)
Peak	1.3192	0.0188	0.0029	**1.340**
Standard	0.7545	0.0188	0.0029	**0.775**
Offpeak	0.5209	0.0188	0.0029	**0.542**
Yield Monday to Friday	Solar Yield (%)	Solar Yield (kWh)	Solar Yield (R)	
Peak 07h00 - 10h00	22.58%	3016	3 136.62	
Peak 18h00 - 20h00	3.56%	67	89.71	
Standard 06h30 - 07h00	1.81%	241	187.16	
Standard 10h00 - 18h00	74.66%	9973	7 733.30	
Standard 20h00 - 22h00	0.00%	0	0.00	
Offpeak 22h00 - 06h00	0.46%	60	33.68	
Total	100.00%	**13357**	**11 196.67**	
Saturday				
Standard 07h00 - 12h00	47.37%	1265	981.20	
Standard 18h00 - 20h00	0.50%	13	10.39	
Offpeak 12h00 - 18h00	49.88%	1332	748.49	
Offpeak 20h00 - 07h00	2.26%	60	33.65	
Total	100.00%	**2671**	**1 773.53**	
Sunday				
Offpeak all day	100%	**2671**	**1 500.71**	
TOTAL		**18700**	**14455**	