Innovative green finance for renewable energy interventions in gap housing for South Africa - A case study of rooftop PV for Windmill Park residential complex, Johannesburg.

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A research report submitted to the Faculty of Engineering and the Built Environment at the University of the Witwatersrand, in partial fulfilment of the requirements for the degree of Master of Architecture (Sustainable Energy Efficient Cities)

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DECLARATION

I declare that this research report is my own unaided work. It is being submitted for the degree of Masters of Architecture in Sustainable Energy Efficient Cities to the University of Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other university.

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21 December 2018

Abstract

In light of the current rapid growth of the gap housing market segment, the electricity crisis facing South Africa and adverse impacts of coal-based electricity generation on climate change, this study helps to qualify the viability of integrating rooftop solar pv in gap housing towards improving gap housing affordability and mitigating power challenges currently facing the country.

Using a case study approach, the study addressed four key research questions which are: affordability of housing in the gap housing market in South Africa, estimating the generation potential from the available rooftop space in the case study area, establishing a business model for integrating rooftop solar pv in the gap housing market, and the extent to which rooftop solar pv can augment housing affordability in the gap market segment. Various software and web-based applications were utilized to establish the solar pv generation potential of the study area.

From the available rooftop space of 36 593.65m^2 in Windmill Park Estate, a production potential of 7 848 124.71 kW/h per annum was estimated. This is sufficient to make the estate a net-zero grid electricity consumer. Based on these findings, two scenarios were analysed using the net present value (NPV) to determine the profitability and the business model for integrating rooftop solar pv in the case study. Exporting only 50% of the generated electricity proved the most viable scenario with thirteen to fourteen year payback period. Affordability to purchase housing in the estate increased by R 399,633.30 in the twentieth year and rent affordability increased by R 706.25 per month in the first year.

This understanding of the extent to which rooftop solar pv can augment housing affordability is important to encourage, guide and inform policy makers and other stakeholders in the formulation and deployment of various gap housing finance schemes that support such interventions.

Keywords: Rooftop solar pv, gap housing market, housing affordability, business model.

Dedication

Thank you Lord for your presence in my life, for without you, this work would not have been possible. I would like to dedicate this work to my mom and dad, Mr and Mrs Kaluba. There is no doubt in my mind that without your love and encouragement, I could not have completed this process.

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CPPA	Central Power Purchasing Agent
CSR	Corporate Social Responsibility
DNI	Direct Normal Irradiation
FIT	Feed-in Tariff
FLISP	Finance Linked Individual Subsidy Programme
GHG	Greenhouse Gas
GHI	Global Horizontal Irradiance
GIS	Geographical Information Systems
GW	Gigawatt
GWh	Gigawatt-hour
IDC	Industrial Development Corporation
IRP	Integrated Resource Plan
kW	Kilowatt
kWh	Kilowatt-hour
LiDAR	Light detection and ranging
MW	Megawatt
MWh	Megawatt hour
MYPD3	Multi-Year Price Determination 3
NERSA	National Energy Regulator of South Africa
NETFIT	Net Feed-in Tariff
NGO	Non-government Organisation
NPV	Net Present Value
NREL	National Renewable Energy Laboratory
NTNU	Norwegian University of Science and Technology
OECD	Organization for Economic Co-operation and Development
PV	Photovoltaic
RE	Renewable Energy
REFIT	Renewable Energy Feed-in Tariff
REFSO	Renewable Energy Finance and Subsidy Office

REGC	Renewable Energy Grid Code
SABS	South Africa bureau of standrds
SARS	South African Revenue Service
SSEG	Small-scale Embedded Generation
SSPVEG	Small-Scale Photovoltaic Embedded Generation
UKZN	University of KwaZulu-Natal

Chapter 1: Introduction and background to the study

1.1 Introduction

In 1994, the South African government took up a constitutional mandate to give access to adequate housing and electricity among other essential social services. Since the dawn of democracy, the government's commitment to providing sustainable human settlements for the poor has been remarkable by most measures (Department of Human Settlements, 2014). From 1994 to 2013 the number of people living in formal housing increased by 50% while the number of households with access to grid electricity also increased from one-third to two-thirds. (Tibane and Vermeulen, 2014; Bekker *et al*, 2008). This significant turnaround can be attributed to policy and institutional changes brought about by the government which was elected in 1994. However, the policies and instrument shifts implemented by the government have not gone without faults. For example, the various housing policies employed to address housing backlogs for the poor have inadvertently entrenched a gap in the housing market (Tibane and Vermeulen, 2014) now characterised by the private sector operations for the middle class and state facilitated provision for the poor. Moreover, failure to implement some of the policies stipulated in the Energy White Paper 1998 have contributed to the electricity crisis currently facing South Africa especially since 2008, including escalating electricity tariffs, low generation capacities and high carbon dioxide emissions due to high dependency on coal for power generation (Urbach, 2012).

Electricity costs can have a significant burden on housing affordability because it adds more pressure to the overall financial burden of households. The gap housing market, which has emerged due to housing affordability challenges, is especially susceptible to these financial difficulties (Mbongwe, 2013). Incorporating rooftop solar pv for electricity generation in housing offers the potential to make housing more affordable since it can reduce electricity cost burdens and provide other economic benefits for households (Clean Energy Group, 2006). Studies conducted on the advantages of incorporating rooftop solar pv in residential buildings have shown positive results (Clean Energy Group, 2006; Reinecke *et al*., 2013; Ziuku and Meyer, 2013). Moreover, in light of the housing affordability challenges and electricity shortages currently facing South Africa, it is imperative that a variety of innovative measures are considered in the delivery of both housing and electricity towards improved quality of life for beneficiary households. This study explores rooftop pv as one of these innovations in both its technological and affordability dimensions.

1.2 Background and context

The affordable housing programme has undergone considerable change since the approval of the Comprehensive Plan for Development of Sustainable Human Settlements in 2004 (Department of Human Settlements, 2004). Since the implementation of Comprehensive Housing Plan (CHP), the government and the private sector delivered 5 677 614 formal houses from 1994 to 2014 (Department of Human Settlements, 2014). Consequently, the proportion of people living in formal housing increased from 64% in 1996 to 77.7% in 2011 (*ibid*). The figures indicate a significant progress in housing delivery. Nonetheless, Charlton and Kihato (2006) have argued that housing policy shifts implemented since 1994 are not explicitly entrenched in a rigorous interrogation of the needs of the people. While a certain level of success has been recorded in housing delivery, the proliferation of informal settlements and protests over housing in South Africa indicate inadequacies of the housing policies (*ibid*). The past five years have seen housing delivery slump by 25% setting the housing backlog to around 2.3-million (Kings, 2014). Mounting evidence of housing delivery inadequacies indicates that current housing policies are not working satisfactorily and are not likely to work in the future given the low levels of GDP growth rates and the high levels of unemployment (Financial and Fiscal Commission, 2012).

The primary focus of the subsidized housing programs initiated in 2000/02 was to address housing backlog for households earning incomes of less than R3 500 (South Africa Human Rights Commission, 2003). The program assumed that households earning incomes of over R3 500 can access formal housing finance from financial institutions (through the market), but this did not materialize (Rust, 2010). For this reason, the shortage of housing supply and finance for households earning between R3 501 and R10 000 has created a housing affordability challenge in the housing market, which is termed now the 'gap market' (Financial and Fiscal Commission 2012).

1.2.1 South Africa's gap housing market

The gap housing market is better understood by describing households that fall in this housing group. Rust (2012:4) defines the gap housing group by categorizing households based on income levels; availability of housing and finance affordability. Households earning incomes between R3 500 and R9 000 constitute the gap market while households earning between R9 001 - R15 000 constitute the gap/affordable market. These two categories represent the income bands most susceptible to deficiencies in housing supply and housing finance challenges (*ibid*). The distinction between the two gap market categories lies in the loan affordability because households earning between R3 500 - R9 000 can only afford loans from R 116 702 to R 233 404, while households earning between R9 001 - R15 000 can afford loans from R 233 404 to R 483 481 (*ibid*). Households within these income groups can only afford these loan amount because financial institutions only offer home loans that are based on repayments not exceeding 30% of the applicant's gross income (Centre for Affordable Housing Finance in Africa, 2016).

The shortage of new houses in the gap market segment is approximately 650 000 (Rust, 2006). However, the number is increasing by 132 000 housing units every year (*ibid*). The South African government is aware of this problem and has committed to address the situation by putting in place initiatives that could improve the situation. The Finance-Linked Individual Subsidy Program (FLISP) was specifically introduced to help people earning between R 3 500 and R 15 000 to access housing through affordable housing finance (Rust, 2006; 2009). However, FLISP has already encountered several challenges in meeting its purpose. The challenges include; getting banks to participate in the program; bureaucratic delays within provincial governments in implementing the program and problems of indebtedness prevalent amongst targeted households thus making it difficult for them to access the bonds (National Housing Finance Corporation, 2013).

1.2.2 Housing affordability challenges

On its own, increased housing supply in the gap market cannot alleviate overall housing affordability challenges at purchase or operation stages. Ensuring affordable electricity and other utility bills is a critical strategy to address housing affordability because households also have to afford operating costs for the houses they acquire or rent (Clean Energy Group, 2006:1). Escalating electricity tariffs has become the norm in South Africa such that affordability of electricity and its regular availability is no longer a problem unique to low-income households. In March 2015, Eskom confirmed electricity tariff increase based on the Multi-year Price Determination (MYPD3) for 2013/14 to 2017/18 in an attempt to recoup R7.8 billion of under-recovered costs from the previous year's operation (Le Cordeur, 2014). MYPD3 marks the third electricity tariff increase since 2009, and in contrast to MYPD1 and MYPD2 that had three year durations, MYPD3 will run five years consecutively (Inglesi and Pouris, 2010; Eskom, 2012). According to National Energy Regulator of South Africa (NERSA) (2013), MYPD3 entails 16% tariff increments per year for the next five years, which will result to a price of 128c/kWh by 2017/18 from 61c/KWh in 2013.

Apart from escalating electricity tariffs, South Africa equally needs to manage the challenges of power generation capacity. Since 2007, Eskom, the state-owned power company has been unable to generate adequate electricity to meet increasing demands, which resulted into widespread load shedding between 2008 and 2015 (Inglesi and Pouris, 2010; Institute of Risk Management South Africa, 2015). Eskom attributes its incapacity to generate adequate electricity to lack of government funding for the expansion and maintenance of its power plants (*ibid*). Currently, South Africa's total power capacity is 43.5 GW, of which 40.7 is generated from twenty-seven thermal power stations and the additional 2.8 GW is from imports and Independent Power Producers (IPPs). (Edkins, Maquard and Winkler, 2010). As a result, the country ranks among the top coal consuming economies with China, USA, Japan, and India as the leading global coal users accounting for 82% of the global coal usage (Hall, 2012). The dependency on coal for electricity generation in South Africa can be attributed to the abundant coal resources available in the country estimated at 30 156 million tonnes (BP, 2015:30). The International Energy Agency (2015a) reminds us that, regardless of the economic benefits of coal for countries with reserves, the adverse environmental impact of coal use, and especially carbon emissions, ought not to be ignored.

Despite the challenges to meet electricity demand, the number of households unable to afford electricity services in South Africa also keeps increasing due to high unemployment rates, weakening wage levels, and escalating electricity tariffs. As such, alternative electricity generation methods that can mitigate electricity supply shortfall and capable of alleviating energy poverty ought to be put in place (Clean Energy Group, 2006). In any case, the South African government has shown policy commitment to transform to a green economy by embracing a more diversified energy mix away from coal dependency (Wentworth, 2014). Solar energy is among the renewable energy sources considered for integration into the country's energy mix (Department of Energy, 2015).

1.2.3 Renewable energy

Renewable technologies in South Africa started gaining more traction from 2010 after the promulgation of the REFIT programme that attracted various stakeholders and stimulated the renewable energy (RE) market (Gets and Mhlanga, 2013; Department of Energy, 2015). After the technology proved to be a success towards electricity shortage mitigation during the 2008 electricity crisis, the Integrated Resource Plan 2020-2030 (IRP) set a new target of 17.8 GW RE electricity generation, equivalent to 42% of the 52GW of the estimated electricity demand by 2030 (Department of Energy, 2015). RE technologies, being considered to achieve the 17.8 GW target include biomass, wind power, solar and small-scale hydro (*ibid*). Currently, however, wind power is the most dominant of renewable energy sources in South Africa but solar pv is also gaining popularity and rapidly catching up largely because the technology has undergone significant price reductions (Cooke, Dawe and Steele, 2016).

Reduced cost of solar pv systems coupled with the abundant solar resources enjoyed in the country present a great opportunity for the country to transform its energy sector. South Africa's solar resource is very attractive with estimated solar radiation capacities of between 4.5 and 6.5kWh/m^2/day (Ziuku and Meyer, 2013). Barriers such as inhibitive regulations, policy incentives, as well as financing constraint optimized exploitation of the solar resource (Department of Energy, 2011). Gets and Mhlanga (2013:22) argue that the high levels of subsidization of coal power in comparison to renewable energy costs creates an uneven policy and financial playing field for renewables. Consequently, solar electricity generation has historically been out-competed by conventional coal-based electricity generation (Wiginton, Nguyen and Pearce, 2010).

In 2009, South Africa pledged to reduce Carbon emissions by 34% by 2020 and 42% by 2025 with the help of the international community (Department of Energy, 2015). In this respect, the government implemented climate change mitigation policies aimed towards reducing CO_2 emissions. Nonetheless, the countries CO_2 emissions are still on a steep rise. Teske, Adam and Smith, (2010) attribute this to the disjointed nature in which RE policies are being implemented at national, provincial and local levels. The Department of Energy which carries the mandate of introducing and implementing various renewable energy policies depends upon the support of other government institutions to successfully execute its function (Covery and Averesch, 2012). The institutional arrangements formed through the DoE are aimed at creating a broad cross-government co-ordinated approach in addressing climate change mitigation policies (Winkler, 2009). By and large, however, there is little indication that this objective has been achieved (*ibid*). The various programs and initiatives outlined in the climate change policies remain unimplemented due to lack of institutional coordination (Covery and Averesch, 2012).

The electricity supply challenges experienced in 2008 presented an opportunity for the South African government to demonstrate the efforts of implementing climate change mitigation programs. This opportunity, however, was lost when Eskom authorised the construction of two very large coal-fired power stations (Medupi and Kusile) which will have a combined generation capacity of 9,560 MW with approximately 60 million tons co_2 emission potential (Blignaut, 2012). The estimated Co_2 emission potential of the two power stations is equivalent to 26% of Eskom 2010/2011 emission load of 230.3million tons (*ibid*).

The renewable energy policies set in the National Energy Efficiency Strategy (NEES) have not been adequately implemented towards contributing to overall climate change mitigation (Covery and Averesch, 2013) . The White Paper on Renewable Energy 2003 envisioned 10,000 GWh RE electricity generation by 2013 when the government started setting RE targets in 2003 (Department of Minerals and Energy,1998). It has become evident however that not much was done towards achieving this objective because by 2013 this target had not been met (Eberhard *et al*. 2014). Moreover, there was a lot of confusion about whether this figure represented a cumulative generation or an annual target and whether the figure represented renewable energy services other than electricity (*ibid*). As grid electricity becomes more constrained and the climate change impacts get more imminent, it is important that the country invests more in renewable energy and lessen fossil fuel infrastructure developments.

1.3 Problem statement

Recent development in climate change and climate variability have heightened the need to address power generation methods currently employed in South Africa. As of 2010, the country was the 12th largest emitter of CO_2 (and other GHG-emissions) in the world with the energy sector accounting for 78.7% of the total emissions, mainly because of the country's heavy reliance on coal for electricity generation (Department of Environmental Affairs, 2014:37). The built environment presents plenty of opportunities to implement energy efficiency measures and renewable energy technologies such as solar pv, but this has remained underutilized (Ziuku and Meyer, 2013). Studies conducted by Reinecke *et al.* (2013) and Ziuku and Meyer (2013) to determine the financial viability of rooftop pv on residential housing using available roof area concluded that solar pv is economically feasible and that this technology ought to be considered for integration in the development of housing. However, a systematic appraisal, especially concerning the technology's potential to improve housing affordability has not been conducted so far. Within the limited context of a case study, this study addresses this gap through an appraisal within the gap market housing opportunity.

1.4 Rationale of the study

The study aims to appraise the viability of rooftop solar pv when integrated into gap housing delivery to mitigate the energy challenges currently facing the country. A strategy that incorporates solar pv in housing supply can reduce household electricity bills, mitigate energy poverty, improve the health of the occupants by reducing the use of indoor-polluting energy sources and reduce carbon emission from electricity generation based on coal (Kaluarachchi, 2009:21). The increasing gap housing market presents an excellent opportunity to increase solar pv uptake in South Africa. The report informs policymakers and other stakeholders on the ongoing gains in rooftop solar pv technology in order to guide the formulation and deployment of various housing finance schemes, which would cover the cost of such interventions in gap housing developments.

1.5 Research questions

The process of the study was guided by a key research question and five sub-questions as follows:

1.5.1 Main research question

To what extent could grid interactive embedded generation with rooftop pv enhance affordability in the gap housing market while also addressing climate change mitigation and electricity generation capacity goals of South Africa?

1.5.2 Research sub-questions

- What is the extent of the affordability gap in the gap housing market?

- What is the generation capacity from the available roof area in Windmill Park Estate relative to household electricity demand versus surplus for export to the grid?
- What export levels would be adequate to generate significant income to cover upfront capital costs of solar pv installation and augmenting affordability of gap housing in Windmill Park Estate?
- What business and financing model would be suitable for solar pv integration on existing houses in the gap housing market?
- To what extent would such an intervention alleviate South Africa's electricity-generation capacity constraints and support climate change mitigation goals?

1.5.3 Working hypothesis

The study was guided by a working hypothesis stating that grid interactive embedded generation with rooftop pv can significantly augment affordability of housing in the gap housing market while also addressing climate change and improving electricity generation capacity goals for South Africa. The study seeks to demonstrate that affordability of gap housing in Windmill Park Estate can be improved by deploying rooftop solar pv on the available roof area using an appropriate business and financing model as an example.

1.6 Research approach

The research question was addressed using a case study approach from which primary data was obtained. On-site visual survey was performed to assess the study area first-hand while online secondary databases were utilised to reinforce data obtained from the site. Secondary data collected includes the number of houses in the complex, building roof shapes and the roof inclination angles. The site was also examined for any obstructions occurring on the rooftop surfaces because only by understanding the conditions of the rooftop surfaces was it possible to determine the rooftop area available for solar pv deployment. Secondary data was also utilised to inform the study of household electricity consumption patterns.

Secondary data used in this research report was obtained from the university library and internet searches including experts' reports, conference proceedings, web-based information systems, journal articles, specialist surveys, and case study reports.

1.7 Limitations and delimitations of the study

This report assesses the extent to which rooftop solar pv can improve housing affordability in the gap housing market and the extent to which the intervention can contribute towards climate change mitigation through alternative electricity generation methods. It was considered necessary to set this study within a case study context from which data could be gathered and analyzed. However, the key findings presented in this study are founded on a methodology that utilized certain assumptions that can have significant implications when adapting the results to other contexts. Generalizability of these results is subject to certain limitations. Limitations encountered when conducting this study are highlighted below.

The study is constrained by a lack of information on the household electricity consumption patterns in Windmill Park Estate. To address the related sub-question "What is the generation capacity from the available roof area in Windmill Park Estate relative to household electricity demand with surplus for export to the grid?", it was important first to understand the monthly power (kWh/month) consumption patterns in the estate for four months (March, June, September and December). This lack of data caused a major obstacle in finding a meaningful relationship between energy demand and energy produced from rooftop solar pv in Windmill Park Estate. In this regard, data on households' electricity usage are based on Eskom's general estimations for low and middle-income household electricity use patterns. The effects of using these data are that it is not the actual representation of electricity consumed in the estate, which would then have implications for the results presented in Tables 5.3. However, efforts were made to ensure that this data is as reliable as possible by cross-referencing to other studies that have been done on affordable housing electricity consumption patterns (see Section 5.2 for details).

Using the data item as an average also helps in balancing across over versus under-consuming households.

The second limitation relates to the accuracy of the rooftop sizes and roof tilt angles presented in Chapter 4. The overall sizes of the rooftop areas and roof tilt angles presented in this study cannot be verified as completely accurate due to lack of access to the as-built drawings of the buildings in the estate. Drawings could not be obtained from Ekurhuleni Metropolitan Municipality due to inefficiency in archiving on the part of the municipality. The researcher was deferred several times before being told the drawings could not be accessed. It was also difficult to access the drawings from the developers of the project (FNB Commercial Property Finance (CPF) and Kiron Projects). Due to the size of these organizations, it was difficult to get access to individuals who were directly involved in the project, who could access the drawings or identify the architects responsible for the designs. The researcher was constantly being referred to individuals who did not have information about the construction documents of the project. In this regard, the study relied on onsite measurements and online tools for the measurements as detailed in Section 4.4.

The third limitation to this study involves incomes that can be accrued from exporting electricity to the grid. Due to unavailability of reliable data in the sector, operational and maintenance costs for the rooftop solar pv installation proposed for Windmill Park Estate has not been factored into the study. To the researchers knowledge, there are no prior research studies on the costs of operating and maintaining grid connected rooftop solar pv over the lifespan of the system in South Africa. Therefore, it was not possible to obtain reliable secondary data to form the basis for determining the cost of operating and maintaining residential rooftop solar pv in Windmill Park Estate for the entire lifespan of the system (25 years). Secondary data from international case studies could not be utilized because of the significant economic financial disparities between such countries and South Africa. Using such data would render the resulting findings in this study unreliable. Primary data could not be collected for analysis because determining the costs of operating and maintaining grid connected rooftop solar pv over the desired period, to obtain the necessary data for the analysis, was beyond the scope of this study due to time constraints. As such, results in Table 5.3 represent gross incomes and not net revenues from solar pv electricity sales. Therefore, data for the payback time for solar pv installation are likely to be on the optimistic side. However, the study assumes that operational and maintenance costs would remain low throughout the technical life of the pv systems.

The fourth limitation of this research relates to the generation potential of rooftop solar pv presented in this study and the data utilised to calculate the estimates. The use of either satellite-based data or solar radiation maps constructed using ground measurements would result in estimates that are not accurate because these data sources, in themselves, are subject to uncertainties (see section 2.3.1 and 2.3.2 for details). To keep the margin of error to the minimum, both satellite-based data and solar radiation maps were used so that the data sets complement each other because the sources of error from each data set are different.

The fifth limitation is that rooftop solar pv generation potential is highly influenced by contextual factors such as topography and weather conditions (National Renewable Energy Laboratory, 1992). For this reason, it is important to note that rooftop solar pv generation potential estimates in this study cannot be directly transferred for use in other studies without customization to contextual conditions in this regard.

The findings presented in this study are based on a methodology that used some assumptions about small scale embedded generation (SSEG) policy mechanisms. In this study, it is assumed that Ekurhuleni Metropolitan Municipality would compensate for power exported onto the grid from rooftop solar pv electricity generation using the NETFIT proposed by Bischof-Niemz (2015). Currently, however, Ekurhuleni metropolitan municipality does not compensate for electricity exported to the grid nor does it permit net-metering (South Africa Photovoltaic Industry Association, 2015). However, the municipality does allow connection to the grid and is currently working on policies, regulations and tariff models for small-scale embedded generators (*ibid*).

1.8 Definition of key concepts

Key concepts used in the study are defined as follows:

Business model in this study describes the rationale of how a third-party driven rooftop solar pv project captures social value and return on investments in Windmill Park Estate using innovative green finance (Frantzis *et al*., 2008:4-2). The essence of the business model in this study was to define the manner in which a third party could utilise innovative green finance to support the installation of rooftop solar pv as a social investment and how the social investment would be converted into revenue and profit stream.

Gap housing market refers to the segment in the property market that has emerged due to the divide between people who earn too little to purchase private housing through the normal market but too much to qualify for subsidized housing (Fiscal and Financial Commission, 2012). In South Africa, the gap housing segment includes people earning between R 3 500 and 15 000 and is typically made up of public sector workers and laborers (Centre for Affordable Housing Finance in Africa, 2015a).

Housing affordability: Maclennan and Williams, (1990:9-10) described housing affordability as being concerned with the acquisition of a given standard of accommodation, at a price or rent that does not impose an unreasonable financial burden on the household, in the eyes of a third party, more especially the government. Three variables encompassed in housing affordability include; household income levels, the price of the house available for sale and the terms of the mortgage finance (Centre for Affordable Housing Finance in Africa, 2016). Historically, the accepted measure of affordability in the US, Canada and Britain has been housing costs that do not exceed 30% of a household's gross income. The Centre for Affordable Housing Finance in Africa (2015b) also believes that households should not spend more than 25 – 30% of their gross income on housing. Besides, financial institutions including First National Bank, Nedbank and ABSA only offer home loans that are based on repayments not exceeding 30% of the applicant's gross income (Fin24, 2011). Families paying more than 30% of their household incomes to finance housing are considered cost burdened, and may have difficulties meeting other basic needs such as food, clothing, transportation, and medical care.

Housing finance refers to the money required to build or purchase housing in the form of mortgage or rent repayments (King, 2009). This kind of funding is what allows for the production and consumption of accommodation. People in the gap housing segment have access to two types of housing finance which are conventional mortgages and Finance-Linked Individual Subsidy Programme (FLISP). Despite having access to the two kinds of housing finance, households within this segment still find it difficult access adequate housing because the funds are inadequate for purchasing newly built houses available on the market (Centre for Affordable Housing Finance in Africa, 2015a).

Innovative green finance refers to the funding mechanism proposed for financing the rooftop solar pv investment in Windmill Park Estate. Schaefer (2011:4) defines green finance as "a strategic method to integrate the financial sector in the transformation process towards low-carbon and resource efficient economies, and in the context of adaptation to climate change". Emerging economies now having to pursue economic growth in our time where development mainly escalates environmental degradation with impacts such as climate change, face a dire need for resource-efficient investments (*ibid*). Such investments, however, like the one proposed in this study, are frequently inhibited by a lack of reliable funding streams. Innovative green finance was identified as a strategic approach to overcome the financial challenge that would inhibit investing on rooftop solar pv in Windmill Park Estate.

Microgrid refers to an approach to electricity distribution in Windmill Park Estate that will interact with the utility grid to facilitate rooftop solar pv electricity management (Slann, 2013). The microgrid will connect all the rooftop solar pv systems to computer systems that will monitor, control, and balance power demand and supply within the estate and to the utility grid (Colavito, 2014).

Net present value (NPV) refers to the evaluation method used in this study to determine the overall value of investing in rooftop solar pv in Windmill Park Estate based on a series of cost and revenue flows over a period of 25 years (Ong and Thum, 2013). NPV facilitates assessments of profitability of an investment by representing the value of such future costs and revenues in monetary value at present (South African rand) of all future cash flows of the project relative to the social discount rate (*ibid*).

Net-energy metering refers to a measuring mechanism where a customer of grid electricity, who is also self-generating on-site using technologies such as solar pv that is grid interactive, is compensated for electricity exported to the grid (Eskom, 2015a). Electricity exports to the grid occur when the solar pv system generates more electricity than the capacity needed for home use at a particular time. This is especially the case during daylight hours. At night and in times when the solar pv generation potential is at its minimum, customers depend on grid power to meet their energy demands.

Payback period refers to the period of time taken to recoup the initial capital cost expended on installing rooftop solar pv in Windmill Park Estate (Van der Wath, 2014). For example, the payback period for an investment of R10,000 on a project generating a profit of R1000 every year for 10 years is 10 years because, in the 10th year, profits accumulate to R10,000, which is equal to the investment amount. The warranty for most solar pv systems is 25 years, as such, calculations for the payback period in this study were calculated with this time frame in mind (Jordan and Kurtz, 2012). Calculating solar pv payback time in this study was based on the rooftop solar pv generation potential, the electricity consumption patterns in the study area, the cost of grid electricity, the proposed feed in tariff (FIT), and the incomes derived from exporting varying levels of electricity to the grid.

Prosumer refers to energy consumers who also produce their own power from different types of on-site generators such as wind turbines, diesel generators and solar photovoltaic (PV) systems (Rickerson *et al*., 2014). This study focuses primarily on households in Windmill Park Estate and the power generated from the proposed rooftop solar pv system.

Roof azimuth orientation refers to the displacement angle (y) between the reference direction north (N) on a horizontal plane and the reference line on the same plane, as the reference direction, drawn normal from the roof surface (Roof surface reference line) in question to a point perpendicular to the position of the sun in the sky (Bari, 2001) as illustrated in Figure 1.1.

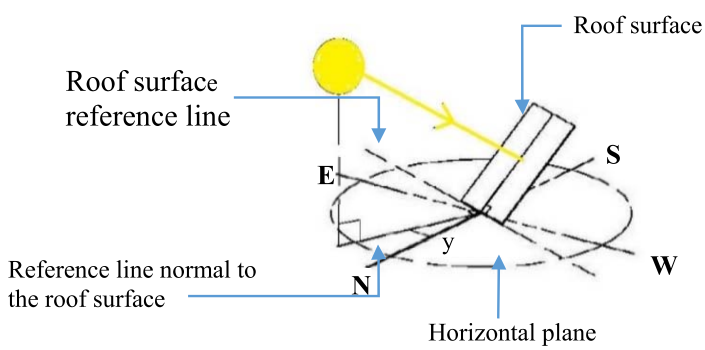

Figure 1.1. Roof azimuth orientation (Source: Adapted from Bari, 2001: 1207)

Roof tilt angle refers to the roof slope angle (x) of the roof surface on which the rooftop solar pv panels are mounted as illustrated in Figure 1.2. In this study the rooftop solar panels are assumed to have a fixed tilt angle and hence the roof tilt angle of the roof surface is equal to the tilt angle of the solar panels.

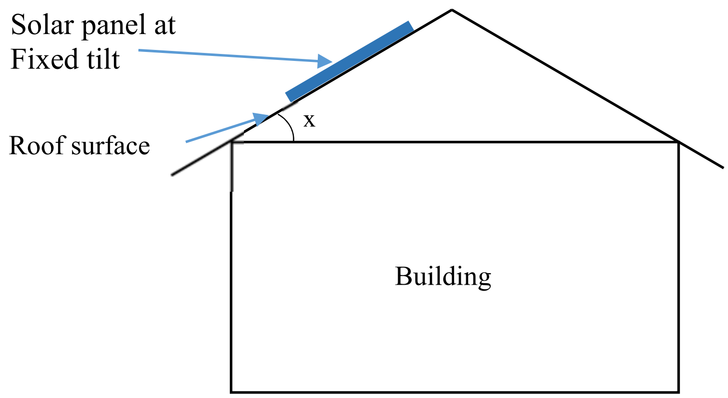

Figure 1.2 Roof tilt angle

Rooftop solar PV potential refers to the amount of electricity that can be generated by a photovoltaic system mounted on the rooftop. A number of factors including solar radiation, available rooftop area, and the generation capacity of the solar pv system influences the generation potential of solar pv (Jakubiec and Reinhart, 2012). Understanding the production potential for solar pv is essential for utility planning, deploying financing schemes, accommodating grid capacity and formulating future adaptive energy policies (Wiginton, Nguyen, and Pearce, 2010).

The *social discount rate* is used in NPV calculations to factor in the social costs and benefits distributed over time on a given social investment. (Harrison, 2010). When used to calculate the NPV, a positive NPV indicates that the social benefits of an investment outweigh the foregone benefits of the resources the investment displaces from alternative uses (*ibid*). The social discount rate used to establish the net present value (NPV) of investing in rooftop solar pv in Windmill Park Estate is 3% (International Energy Agency, 2015b). This measure assisted the study to adjust the value of future cash flows from the PV system to present day values.

1.9 Outline of the research report

The overall structure of the study takes the form of six chapters, including this introductory chapter. The remainder of the study is organized as follows:

Chapter two lays out the theoretical dimensions of the research by discussing the methods in which rooftop solar pv has been integrated into gap housing using an appropriate business model. This chapter is divided into three major sections; the first section appraises studies on the concept of the "gap housing market" in South Africa and the housing delivery challenges that have given rise to this market segment. The second section appraises studies on the generation potential of rooftop solar pv and the factors that influence the capacity that can be generated. This section draws on both local and international studies. The third section appraises studies on business models used to incorporate solar pv in affordable housing to guarantee financial viability of the integration. The section also discusses the enabling mechanisms available in South Africa in support of rooftop solar pv business models including green finance for RE technologies.

The discussion about the methods employed to answer the research questions are explained in Chapter three. The chapter describes the process underpinning the study and the rationale behind the methods. The chapter starts by describing the data used in the study and how data were collected and analysed. Ethical considerations which guided the research are also explained in this chapter.

Chapter four is dived into three major sections that address two research questions including the extent of the affordability gap in the gap housing market and the rooftop solar pv generation capacity from the available roof area in Windmill Park Estate. The first section presents an assessment of the extent to which households in the gap market segment can afford 'gap housing' available on the market with specific reference to houses in Windmill Park Estate. The section starts by highlighting challenges in the gap housing market in general and goes on to show preliminary findings regarding housing affordability in Windmill Park Estate. The findings are based on the current conditions for accessing housing finance and the housing subsidies available for households in the gap market segment in general. The second section establishes solar pv potential in Windmill Park Estate. The section starts with a discussion on the process used to determine the available rooftop area for solar pv deployment. The procedure used to establish incoming solar radiation on the estate is also presented in this section. Preliminary results on solar pv potential of the estate, from the available rooftop area based on latest data on the technical performance of pv modules are also presented in this section. The section then goes on to discuss the significance of rooftop solar pv electricity generation to Africa's GHG emission reduction and climate change mitigation. The section concludes with a discussion about household electricity consumption patterns in Windmill Park estate to establish quantities of electricity generated from solar pv sufficient for self-consumption and export to the grid.

Chapter five analyses the preliminary findings presented in Chapter 4 to derive key findings for this study The chapter starts by appraising the business model option and the best possible scenario with which to employ the proposed business model towards incorporating solar pv in Windmill Park Estate. By drawing upon the entire report, tying up the various theoretical and empirical strands, the study then consolidates the key finding through an evaluation of the preliminary results presented in chapter 4. The resulting findings presented in this chapter are used to evaluate the significance of incorporating rooftop solar pv in affordable housing in relation to the key issues highlighted under research questions and the working hypothesis. Finally, chapter 6 summarizes the results of this work and draws conclusions.

Chapter 2: Literature appraisal

2.1 Introduction

The literature appraisal covers the related body of work on the gap housing market and rooftop solar pv. The appraisal was undertaken to gain insight into the current state of affairs on the two issues noted above in order to facilitate optimised contextualisation of the study. Sources of information included books, research reports, academic journals, newspaper articles, internet sites, government and non-governmental organizations (NGO) publications. The review generated the critical issues and concepts related to the social, technical and economic aspects of the study.

2.2 South Africa's gap housing market

The report by the Financial and Fiscal Commission (2012) explains how the gap market has developed over time and appraised the main problems faced by this segment of the housing market. The report raised concerns about the Finance-Linked Individual Subsidy Program (FLISP) for households earning between R 3 500 and R 15 000 and the shortage of appropriately priced housing for purchase in the property market. The report indicated that FLISP is insufficient to enable households acquire adequate housing. Furthermore, the subsidy is only available for newly built houses and not for existing homes. According to the Centre for Affordable Housing Finance in Africa (2015a), the cheapest newly constructed house in the market in South Africa is R 370 000, which is only affordable to the top FLISP target market. The report argues that existing houses may be cheaper to buy than newly built houses for this housing market segment (*ibid*).

Among other studies on the gap housing market by the same author, Rust (2012) highlighted four key challenges in this market. These include credit indebtedness of the households in this segment; challenges of access to mortgage finance; limited housing supply; and concerns over FLISP relating to lengthy application process for beneficiaries and the insufficiency of the provincial budgets to sustain the programme. She pointed out that these difficulties are further exacerbated by household's inability to meet housing needs adequately due to low-income levels and the diminishing ability to afford housing due to prioritization of other consumer goods such as food, clothing and cars. However, the most recent report by the Centre for Affordable Housing Finance in Africa (2015a) argues that low income is not the only problem preventing households from accessing housing finance in this market. The report indicates that nearly 50% of credit active consumers currently on their mortgage are not paying on time with some falling far behind to the degree of facing legal procedures, judgments or administration orders. The report further points out that only 3 out of 10 mortgage finance applicants are approved, and the rest are turned down because of weak credit records.

Deficiency in housing supply is another constraint identified in the gap housing market (Financial and Fiscal Commission, 2012). Earlier on, Khaki (2009) had hinted on this challenge through a study which set out to evaluate the challenges of affordable housing delivery from the property developers' perspective. Results from the survey showed that developers are not attracted to affordable housing developments because of the limit profit margins associated with the production of such housing. The study also revealed that developers face challenges in accessing funds for affordable housing development. Other factors such as planning restrictions; land costs for affordable housing development and costs of bulk infrastructure services were stated as hindrances to timely and successful developments (Financial and Fiscal Commission, 2012; Khaki, 2009). The report by the Centre for Affordable Housing Finance in Africa (2015a) puts this into perspective by demonstrating the impacts of delayed implementation of housing developments against funding opportunities for housing developers. The report illustrates the impact of delivery delays on housing development costs showing cash flow distributions over time and the characteristics that attract funders to fund a housing project. From the supply perspective, the report suggests that regulatory procedures within municipalities that deal with the scale, pace and cost of housing delivery should be addressed to improve affordable housing supply.

Findings in the three reports are significant when looking at the affordability of housing in the gap market from the housing developers' perspective and the related problems. While Khaki (2009) only focused on the views of housing developers in the Western Cape, the reports published by the Financial and Fiscal Commission (2012) and Centre for Affordable Housing Finance in Africa (2015a) present the general perception of developers towards the development of affordable housing in South Africa. Regarding the supply of affordable housing, innovative measures that address both housing affordability and mitigate climate change need critical consideration.

The most significant finding in Khaki (2009) in relation to this study is that some affordable housing developers are willing to integrate environmentally conscious technologies including rooftop solar pv in their housing developments as a sustainable measure to combat climate change. When asked whether they would consider incorporating environmental technologies into their housing developments, 30% responded that they are already using the technologies, 50% are still researching, 10% are not sure, and 10% were completely against the idea. The study also reported that the idea of integrating rooftop solar pv as an alternative source for electricity generation has received support from the Minister for Human Settlements and some financial institutions. The idea was also supported because of the long-term economic benefits that come with the technology (Khaki, 2009:74). However, the report raised concerns regarding the upfront capital costs associated with renewable energy technologies and the lack of awareness about these technologies among households in the affordable housing market.

Collectively, these reports provide evidence that there is need to improve housing affordability in the gap housing market both from the financial side and supply side. These findings are relevant to this study because integration of solar pv in affordable housing can only be successful if housing developers, the government, and financial institutions are willing to support the intervention as indicated in Khaki (2009).

2.3 Rooftop solar PV potential

Understanding the amount of solar radiation available at a given location at any given time is important for solar pv deployment. A wide range of studies have been published on the methods of quantifying solar radiation for this purpose. This information is desirable in solar energy to ascertain the potential and efficiency of solar pv electricity generation from a given location (Fu and Rich, 1999). However, due to the inherent importance of solar radiation data for solar pv system sizing, it is imperative that the accuracy and quality of available terrestrial solar radiation data and derived solar maps are understood. Given the centrality of this issue to solar pv potential, this section will explore studies on reliability of solar radiation data and the various methods used to record these data.

2.3.1 Measuring and modelling solar radiation

Data from several sources suggest that the amount of solar radiation reaching the surface of the earth is affected by multiple factors such as the earth's geometric rotation; the earth's revolution around the sun; topography and atmospheric conditions (National Renewable Energy Laboratory (NREL), 1992; Myers, 2003; Lysko, 2006; Suri and Cebecauer, 2013). NREL (1992) identified cloud cover as one of the predominant factors that influence redistribution of solar radiation in the atmosphere and further established a relationship between geographical features such as mountains, water bodies, and cloud formation. These features redistribute solar radiation as diffuse and direct beam radiation to make up the components measured in solar radiometry.

Lysko (2006) investigated how solar irradiance is measured and factors that affect the accuracy of the measurements. The study presents details on equipment used, their key characteristics and how factors such as calibration, standardization, and maintenance influence the accuracy of the solar radiation data. A comprehensive literature survey on the methods employed for measuring solar radiation led to a finding on the importance of improved instruments and enhanced data collection systems for more accurate capture of the angular distribution of diffuse irradiance. To validate her conclusions, the study examined solar radiation measuring and dataacquiring systems at the University of KwaZulu-Natal (UKZN) and the Norwegian University of Science and Technology (NTNU) for global and diffused radiation. The findings indicate that solar radiation data provided at UKZN is unreliable in comparison to data from NTNU due to lack of system maintenance at the former site.

A conference paper presented by Myers (2003) also reported errors in solar radiation data. The study attributed these errors to solar instrumentation calibrations, measurements, and solar radiometer response characterization as the main components of vulnerability in measured solar radiation data. The study indicated that solar radiation measurements and models can have measurement uncertainties of about 25 to 100 W/m^2 in hemispherical recorded data, and +/-25 W/m^2 in direct beam measured data.

Suri and Cebecauer (2013) compared the accuracy of solar radiation data prepared from both on-site ground-measuring campaigns and satellite-based solar radiation data. The study also indicated that the main instruments used in solar industry are subject to error with a confidence level of 95% for satellite instruments and 80% to 99% for ground measuring instruments. This uncertainty is minimal and can therefore be assumed to be equivalent to the user's uncertainty levels in any research project (*ibid*).

The accuracy of the resulting findings of rooftop solar pv generation potential in this study is dependent on the quality of the solar radiation data as discussed in the following section. In this regard, it was important that related studies be appraised in order to inform this study on the reliability of measuring instruments that are used to collect solar radiation data. From the three studies that have been appraised, it was established that uncertainties in the measuring instruments used to prepare solar radiation data are unavoidable. As such the related uncertainties on the generation potential of solar pv relative to the data utilised have been highlighted as one of the limitations of the study as discussed in Section 1.7.

2.3.2 Solar radiation modelling with geographical information systems (GIS)

The previous sections discussed the various methods used to capture solar radiation data. This part will now look at the availability of solar radiation data. Fluri (2009) present an overview of the solar radiation data available in South Africa. The central focus of the study was to appraise the availability of solar radiation data for solar energy technologies and how these data have been derived. The study discussed tools and solar radiation components used to produce solar resource maps for the country. The study indicates that solar resource maps available in South Africa are constructed using solar radiation measurements taken from the ground, or from satellite-derived data. Data obtained from ground sensors provides high-frequency solar radiation which can be very accurate for a particular site if the equipment used is accurate and well maintained (Suri and Cebecauer, 2013). Satellite-based data, on the other hand, provides low-frequency data representing long histories over larger territories (*ibid*). It is not possible to obtain instantaneous values with the same degree of accuracy when using satellite-based measurements, as is when using ground measuring sensors. However, aggregated values provided from satellite data are very reliable (*ibid*).

Based on the distinction stated above, Fluri (2009) also argue that the most accurate data sets for the production of solar resource maps are the ones based on ground measurements. This method, however, is expensive and the equipment used to capture ground measurements requires high maintenance. Moreover, the process of obtaining data is time-consuming, and there are few weather stations in South Africa which can provide such data for solar resource mapping. Satellite data sets, on the other hand, are relatively cheap; quick to access and provides data for up to 20-year period. The major drawback of this data source is that the maps are of very low resolution and hence not sharply defined for easy interpretation. In order to address concerns such as the ones expressed in Fluri (2009), the Centre for Renewable and Sustainable Energy Studies (2014) released two updated solar maps for South Africa. One shows Direct Normal Irradiation (DNI) and the other one shows Global Horizontal Irradiation (GHI). The updated maps show 10% higher values in DNI and the updated yearly GHI is higher by 3%. These maps have been updated based on a large number of high-quality ground measured data sets from fourteen radiometric stations around the country.

In light of the concerns raised in the previous section (Myers, 2003; Lysko, 2006; Marcel and Cebecauer, 2013), availability of this accuracy-enhanced database for solar radiation maps improved the validity of the modelling for solar pv potential for Windmill Park Estate as presented in subsequent chapters of this study.

2.3.3 Calculating available rooftop area for rooftop solar pv

The previous section established the availability of data for solar resource in South Africa. This section appraises literature on how to calculate the available rooftop area from which the solar resource can be measured.

Understanding the characteristics and quality of rooftop area available for solar pv installation is vital for the evaluation of solar pv potential (Melius Margolis and Ong, 2013). Different methods and techniques have been developed for this purpose. The methods range from basic multipliers of total building space to methods that involve sophisticated modelling based on 3-dimensional models using GIS systems.

Melius, Margolis and Ong (2013) reviewed the literature on three major rooftop-area estimation methods used when determining solar pv potential. These methods include constant-value methods, manual selection methods and GIS-based methods. Thirty-five studies and six patented methods were reviewed with the central focus of establishing how previous studies attempted to estimate roof area for solar pv potential. The review gives a detailed description of how these methods are used and the circumstances under which they are deemed applicable including estimating solar pv potential in a region or simply identifying rooftop suitability for solar pv deployment. The study argues that constant-value methods are the most commonly used in estimating rooftop area. One of the approaches under constant-value methods is by establishing the most common rooftop shape in the region and determining a multiplier that can be applied to all the roofs in that region to calculate the total rooftop area. A variation of this method is using population density of a region as a measure of the total rooftop area of that region. These methods are popular because they are easy to use, less time consuming, and are not resource intensive. The main disadvantage of these methods is that the outcomes are hard to validate because of the uncertainties over numerous assumptions taken.

Under the manual-selection method, suitable roof surfaces are derived manually based on aerial photography maps from web-based platforms such as google and Bing maps. The process is time-consuming, and it is hard to replicate results across multiple regions. For accurate, quicker and more generalizable data of available roof area estimates, GIS-based methods are used. Such methods rely on validated software to compute rooftop areas of high suitability by applying ideal values for rooftop characteristics. The biggest disadvantage of these methods is that they are time-consuming, require extensive use of computers, and can be expensive.

After identifying that methods in the literature incorporate a variety of assumptions, Melius, Margolis, and Ong (2013) set out to determine a core set of guidelines for estimating available roof area. This approach (known as the "NREL method") is argued to reflect the best of industry practices in this field. The distinguishing feature of the NREL approach is that it uses broad specifications to define roofing details rather than assumptions. These include slope; orientation; shade and size. It also employs light detection and ranging (LiDAR) data with building footprint maps to create a digital surface model while ArcGIS tools model rooftop features such as shading, slope angle and aspect. Data sets presented in this method include unshaded roof space area, roof panels with 60 degrees slopes or less, orientations ranging anywhere from east to west, and the average number of hours of sunlight per day averaged annually for March 21, June 21, September 21, and December 21(Critical dates in the solar cycle across the year)..

Melius Margolis and Ong (2013) was upraised to guide this study on the appropriate method to employ when determining the available rooftop area in Windmill Park Estate given the characteristic area and the limited time available for carrying out this study. Selection of the method used to determine the available rooftop area in this study was based on the details available to ensure that assumptions are based on the specific knowledge of the buildings and surrounds of the study area.

2.3.4 Calculating solar pv potential from available rooftop area

Reinecke *et al.* (2013) employed the solar GIS information methodology to identify the rooftop pv potential on existing high cost, medium-cost and low-cost houses in Riversdale South Africa. The study employed geographical information software (GIS) to determine the available rooftop space and a software program, PVplanner 11, was used to improve the accuracy of the results.

The first stage was to determine the available roof space for solar pv installation in Riversdale. Visual inspection was conducted for prequalification of roof suitability. Assumptions for qualifications included structural soundness, security and size of roofing space. Roofs with azimuth orientations greater than 70^o or less than 290^o were discarded because solar pv panel efficiency would reduce by 15% if such roofs are utilised (Reinecke *et al*., 2013). North facing roof surfaces with large shaded portions were also discarded because shading reduces the generation potential of the PV panel placed on such surfaces. Once the suitable roofs were identified, the average roof azimuth and tilt angles for houses in Riversdale were estimated using Google Earth Pro while the global horizontal irradiance (GHI) and the latitude tilt irradiance incident on the roof surfaces with 30^o pitch was estimated using satellite-derived data from HelioClim v2.

After establishing the solar distribution across Riversdale, the solar pv potential was derived based on a reference (TEI130/140-36P) polycrystalline PV panel specifications. The installed capacity was estimated using equation 1 below:

Installed capacity (kW_{peak}) = C_{tilt} (A_{roof} x 0.133)……………..……..……..Equation 1
(Reinecke *et al*., 2013:51)

Where kW_{peak} = installed capacity in kilowatt hours (peak), A_{roof} is the available roof area, C_{tilt} is the cosine correlation to the roof area to carter for the roof tilt, and 0.133 kWp is an estimation factor for installed capacity for every meter square of available roof. The study does not provide an explanation on how the installed capacity factor of 0.133 kWp was derived.

Reinecke *et al.* (2013) highlighted that using this method for calculating solar pv potential for a range of rooftop orientation and tilt angles is quite complex and subject to some errors that could result into inaccurate results for rooftop solar pv generation potential. Anticipated inaccuracies in this regard include those for the roof tilt angles and azimuth orientations. In order to minimise these errors, a decision matrix for GIS modelling based on azimuth angles, tilt angles and irradiance was devised to establish correction factors based on the deviations of the roofs from an optimally orientated roof with a 32° tilt and 0° azimuth angle using PVPlanner11. The software program was used on 24 specific reference studies having different tilt and azimuth orientations for a 1kWp system to determine the deviations regarding electricity production for all the roofs that were not optimally oriented. After establishing the variation factors for the roofs, the following two equation were used to determine the generation potential in Riversdale:

Generation capacity per m^2 roof space ($kWh/m^2/year$) = C_{irr} x 1516 x (1 – C_{matrix})……………………………………………………………..Equation 2

Generation capacity per kW_{peak} (kWh/ kW_{peak} /year) = [C_{irr} x 1516 x (1 – C_{matrix})] x C_{tilt} (A_{roof} x 0.133)…………………………………………………….Equation 3

Where (KWh/ KW_{peak} /year),C_{irr} is the correction factor for irradiance and C_{matrix} is correction factor for decision matrix.

The Reinecke *et al.* (2013) study highlighted some of the important aspects to consider when calculating the generation potential for rooftop solar pv that has been used in this research. However, to eliminate the use of a decision matrix and correction factors for the roof tilt angles, azimuth orientations and ultimately, the generation potential, a more specific approach was used in this study as detailed in Section 4.4.

2.4 Rooftop solar PV business models

Upfront costs associated with solar pv technologies inhibit the adoption of the technologies at the desired scale. South Africa is particularly susceptible to this problem because inflation and the inadequacy of appropriate financial products constitute additional impediments for a more extensive diffusion of the technology (Meier, 2014). However, the last five years have seen rooftop solar pv electricity generation technology become cost-competitive with grid electricity in South Africa (*ibid*). Bischof-Niemz (2015) attributes this to the constant electricity tariff increases and the decline in the prices of solar pv systems globally. This has created significant interest among stakeholders such as residential consumers and private investors with a view to invest in solar pv electricity generation. A turnkey installation for an average residential PV system with a few kWp (kilowatt peak) generation capacity presently costs less than R 100 000, which is affordable for most residential customers with access to appropriate financial products (*ibid*). However, this is not the case for households in the gap market segment, who can barely even afford to access financing towards their basic housing needs.

Innovative business models can play a significant role in spreading rooftop solar pv technology especially in cases where people do not have access to sufficient funding for such investments (Buchner, Heller and Wilkinson, 2012). The following section appraises literature on the possible business models for rooftop solar pv. Business models will be discussed together with the enabling mechanisms that promote the adoption of solar pv on a larger scale.

2.4.1 Enabling mechanisms for rooftop solar pv business models

The enabling mechanisms discussed in this section focus on grid-tied rooftop solar pv embedded generation and do not address the details of policy and regulatory frameworks. According to the renewable energy grid code (REGC),the underlying principle for rooftop solar pv embedded generation is that the system must be connected to the municipality or utility distribution network (NERSA, 2015). Four Grid connection options discussed in the section are (i) self-consumption connection, (ii) net metering option, (iii) feed-in tariffs option and (iv) the proposed net feed-in tariff by Bischof-Niemz (2015).

Self-consumption connection:

In the self-consumption mechanism, rooftop solar pv is installed for the sole purpose of consumption at the premises where the system is installed (Tuson and MacDonald, 2014). The system consists of one utility meter, and the system sizing is based on the electricity consumption patterns of the prosumer (*ibid*). In instances where the prosumer load is exceeded, there is no financial compensation for electricity supplied to the grid (*ibid*). As per municipality requirements, notification should be given for connection of this type of system to ensure that the installation is inspected and certified for compliance with the South Africa Bureau of Standards (SABS) 0142 (*ibid*). Figure 2.1 illustrates the configuration for self-consumption.

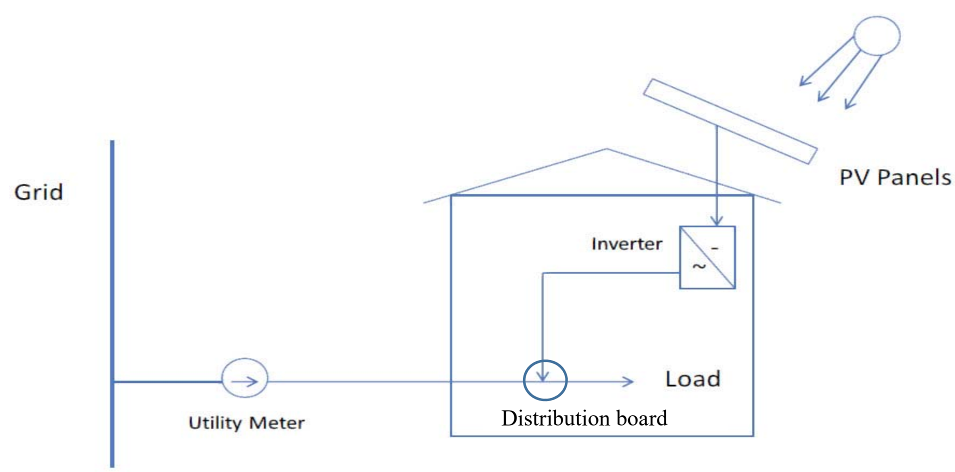

Figure 2.1. Self-consumption (Source: Adopted from Tuson and MacDonald, 2014:44)

Net-metering:

In contrast to the self-consumption system, net metering is intended for self-consumption as well as export of surplus to the grid (Tuson and MacDonald, 2014). In this case, the prosumer receives compensation for electricity supplied to the grid (*ibid*). The distinctive feature in the design of this system is the bi-directional utility metre which records electricity imported and exported by the prosumer (*ibid*). The bi-directional meter can record electricity exported and imported on separate registers enabling the prosumer to restrict export to surplus electricity generated on site (*ibid*). The connection is illustrated in Figure 2.2 below

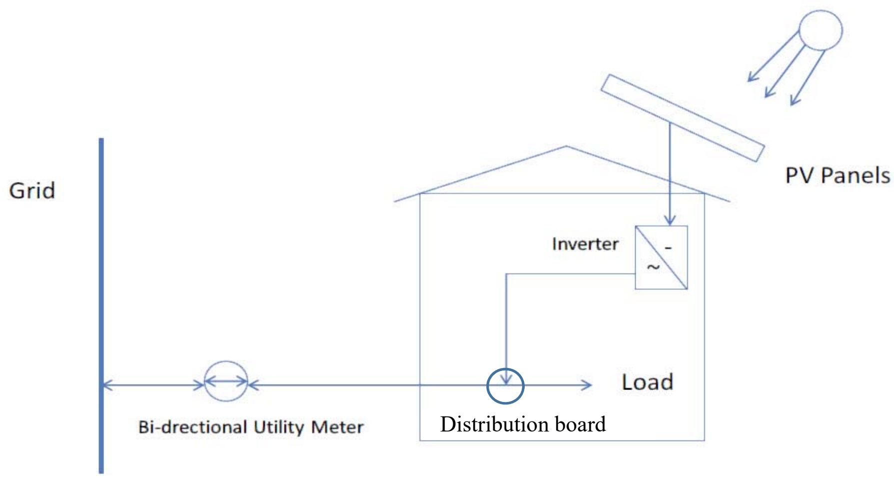

Figure 2.2. Net metering (Source: Adopted from Tuson and MacDonald, 2014:46)

Feed-in tariffs:

Feed-in tariffs (FIT) are designed to encourage the adoption and deployment of renewable energy technologies because they facilitate/guide electricity distributors on the purchase of electricity generated from qualifying generators at pre-determined tariffs (Tuson and MacDonald, 2014). Unlike the Net-metering system where the meter reverses to measure electricity exported to the grid when there is excess, the FIT connection system is characterised by two meters (M1 and M2) that record electricity generated and consumed by the prosumer separately to facilitate independent pricing. Another distinguishing feature of FITs from the other mechanisms is the amount of tariff paid to the prosumer or the FIT level for electricity exported to the grid (Reinecke *et al*., 2013). FIT levels can be determined using different approaches depending on how effective the policy is intended to be towards improving solar pv uptake (*ibid*). Figure 2.3 below shows the meter arrangement for the FIT mechanism.

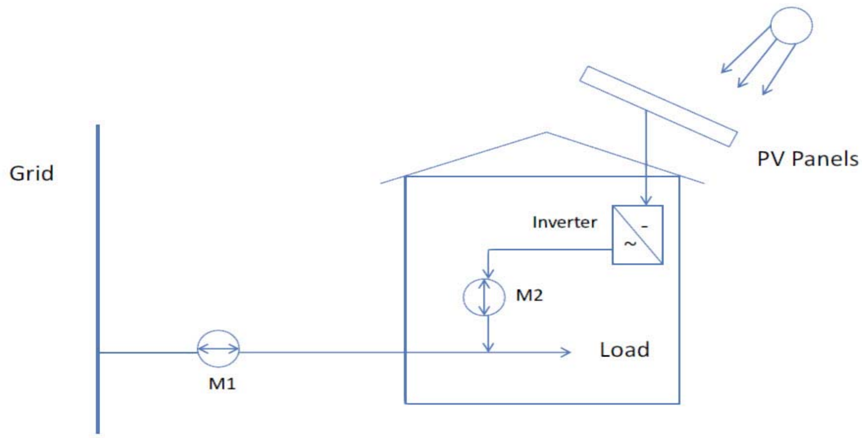

Figure 2.3. FIT metering (Source: Adopted form Tuson and MacDonald, 2014:46)

Net Feed-in tariff:

Bischof-Niemz (2015) has proposed a conceptual regulatory framework suitable to promote rooftop solar pv in South Africa based on Net Feed-in Tariff (NETFIT) concept. NETFIT entails an improvement on net metering concept with a few adjustments. Unlike the other mechanisms discussed above, NETFIT is capable of establishing a business case for rooftop solar investors without compromising electricity distributors like municipalities and utility companies (*ibid*). The concept proposes an establishment of an entirely regulated Central Power-Purchasing Agency (CPPA) that will buy electricity from Small-Scale Photovoltaic Embedded Generators (SSPVEG) and distribute to the grid (*ibid*). Such an agency would be responsible for buying surplus power from generators for a guaranteed tariff and reimburse municipalities and utility companies for lost gross margins on self-consumed electricity (*ibid*) by potential customers. CPPA would require a subsidy to run the scheme. The two proposed sources of financing include selling power purchased from Small-Scale Photovoltaic Embedded Generators to utility distributors and supplementary funding from taxes (*ibid*). Figure 2.4 below illustrates the roles and responsibilities of the stakeholders within a NETFIT enabling mechanism. The advantage of this arrangement is that a solar pv proprietor is de-risked from inconsistencies in cash flow from revenue streams because of the stable guaranteed tariff from CPPA .The risk of income inconsistencies is carried by the CPPA and ultimately the taxpayers.

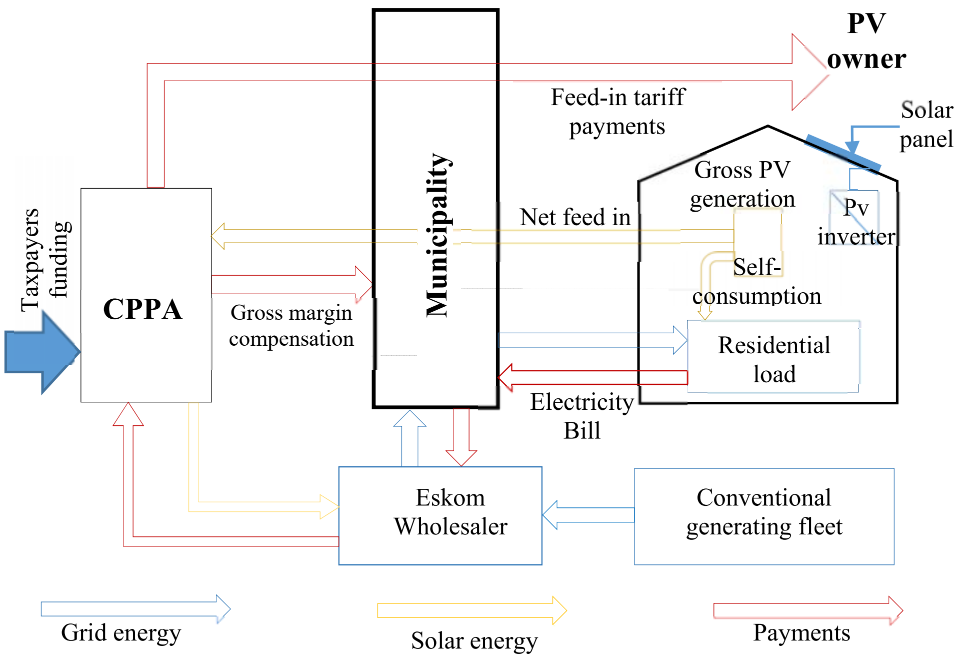

Figure 2.4. Proposed NETFIT (Source: Adopted from Bischof-Niemz, 2015:24)

Table 2.1 below highlights some of the advantages and disadvantages of the enabling mechanisms for rooftop solar PV business models discussed above.

Table 2.1: Advantages and disadvantages of enabling mechanisms

	Advantages	Disadvantages
Self-consumption	• Simplified connection rules make it easier to connect solar pv to the grid. • The connection approval process is short since there is no application required for the connection.	• There is no compensation for electricity exported to the grid. • There is a risk of loss of revenues to municipalities for every kWh of electricity not purchased.

Net metering	• There is an expectation of monitory payment for electricity exported to the grid. • The bidirectional meter records the amount of electricity exported to the grid which makes it easier for the prosumer to claim compensation for electricity exported.	• There is a limit to the amount of electricity that can be exported to the grid. • There is no obligation placed on utility companies to purchase electricity from prosumers. • There is a risk of loss of revenues to municipalities for every kWh of electricity not purchased. • An application to connect the system to the grid is required, which can result in lengthy approval periods.
Feed in tariff	• Prosumers are encouraged to export electricity to the grid since utility companies are obligated to buy at a predetermined price.	• There is a limit to the amount of electricity that can be exported to the grid. • The system requires an additional meter and extra wiring. • There is a risk of loss of revenues to municipalities for every kWh of electricity not purchased. • An application to connect the system to the grid is required, which can result in lengthy approval periods.
Net feed In tariff	• The NFIT system will be centrally and municipality registered, which can make it easier to plan system requirements with regards to congestion and maintenance. • Energy costs for the prosumer are reduced by approximately R 1.2 for every kWh of electricity generated and consumed. • Electricity exported to the grid is purchased	• The system proposes an electricity tariff increase of R0.002kWh across-the-board. • This approach requires establishing another government-run organization. • Society is required to compensate municipalities for lost revenues.

	at a predetermined price. • This approach attempts to reduce the loss of revenue by ensuring that the CPPA compensates the municipality for its fixed costs even in cases where electricity is not imported from the grid by prosumers.	

2.4.2 Business models

Even though there seems to be general perception that investing in solar pv is a capital-intensive endeavour with deferred returns on investment, a vast and growing body of literature indicates otherwise. In fact, there is now ample evidence suggesting that the solar pv sector has grown and continues to rise very rapidly in South Africa and around the globe due to falling solar pv panel prices (Bischof-Niemz, 2015). As in most other countries, South Africa has seen the prices of photovoltaic (PV) systems drastically reduced while electricity tariffs keep increasing (*ibid*). This reduction in prices has made pv embedded generation increasingly attractive for electricity consumers to supplement the main power supply (*ibid*). Given this, NERSA (2015) is considering a model to stimulate the uptake of solar pv through feed-in tariffs for the benefit of both users and the municipality. In addition, feed-in tariffs can potentially open up many business opportunities in small-scale solar pv electricity sub-sector.

Whereas the bulk of research on rooftop solar pv business models are focussed on OECD countries (Meier, 2014; Krämer and Herrndorf, 2012), Meier (2014) notes that findings and recommendations from such studies are relevant to and can be applied in other countries. However, adjustments have to be made for these models to suit the socio-economic policies and political contexts of the country for which they are to be adapted.

Reichel (2015) produced an industry-based publication which explored two business models to consider when investing in rooftop solar pv for small-scale distributed generation within the US-market. Business models discussed include leasing or purchasing of the rooftop solar pv systems. Purchasing rooftop solar pv system for own proprietorship entails accessing funding for the upfront capital cost of the investment while leasing a system installed on one's property or renting a house that has a rooftop solar pv system requires minimal or zero upfront costs. The leasing arrangement works on a third-party ownership principle whereby the company or individual owns the solar pv system and the lessee pays monthly instalments for the system. Two possible payment options were identified when leasing a solar pv system. The first option involves payment of a small initial down payment for the system permitting the lessee to pay lower monthly instalments while the second option involves prepaid leases that compress the annual payments into one discounted upfront cost.

Lease agreements can be structured either as solar lease contract or as a power purchase agreement. Under the solar lease agreement, lease contracts are signed for the right to use power produced by the system for specified monthly payments. Monthly payments are predetermined in this arrangement regardless of how much electricity is generated by the system or the amount of power used. The power purchase agreement works in a different way in that power produced by the system is bought at a set price per kWh, such that the lessee only pays for electricity generated by the system and used by the lessee. Both types of agreements can include an escalation schedule in the contract outlining escalations in rental or cost per kWh over time. The lease term is usually 20 years and during this period, the individual or company that owns the solar pv system (the lessor) would be entitled to all the financial incentives available for the installation. The lessee benefits indirectly by having to pay lower monthly utility bills than they would normally pay for electricity supplied by utility from the grid. Another advantage to the lessee is that the cost of maintenance or damage-risks to the system are mitigated as they become the responsibility of the system owner. One major disadvantage identified in the leasing arrangement is that there are no returns on investment for costs incurred by the lessee in the use of the system. For the owner, upfront costs of investing in rooftop solar pv systems can be leveraged from available incentives and programs, which can be exploited to increase investment returns or reduce the capital commitment. These include payments or credits according to electricity production; property tax exemptions and income tax credits; net metering policies; on softer terms loans; and rebate programs from government agencies or utility companies.

Most of the incentives for solar pv programs as discussed by Reichel (2015) apply to the US where solar pv market is driven by a more comprehensive range of renewable energy policies and regulations. In South Africa however, policy mechanisms in support of the rooftop solar pv technologies have not yet evolved to an adequate level, and most of the renewable energy programs that can be used to promote rooftop solar pv technologies are still in their pilot phase (Reinecke *et al*., 2013). Although some municipalities around the country have taken up the initiative to offer FITs to encourage rooftop solar pv, viable financing models have not emerged as yet. Examples of available financial incentive include Eskom's pilot small-scale renewable energy program; SARS's Accelerated Depreciation Programme; IDC's Green Efficiency Programme; and carbon mitigation and trading schemes (*ibid*).

2.4.2.1 Solar PV business model case study

Dean *et al.* (2011) presented an ideal solar pv business model in a case study report on the formulation of a new residential financing model for integrating photovoltaic systems into affordable housing developments (Figure 2.5). The business model was developed and initiated by a non-profit community development corporation to incorporate rooftop solar pv in affordable housing in Denver in the US. The organization managed to finance the project by combining private equity funding with government incentives (Federal tax credits and utility rebates) and public sector financing to install rooftop solar pv systems on twelve independent rooftops to supply renewable energy to thirty households living in affordable housing (*ibid*). The program is considered the most successful housing production model in the US because it integrates solar pv systems in affordable housing in a way that would potentially encourage the adoption of solar pv system in the sub-sector of the housing market across the country (*ibid*).

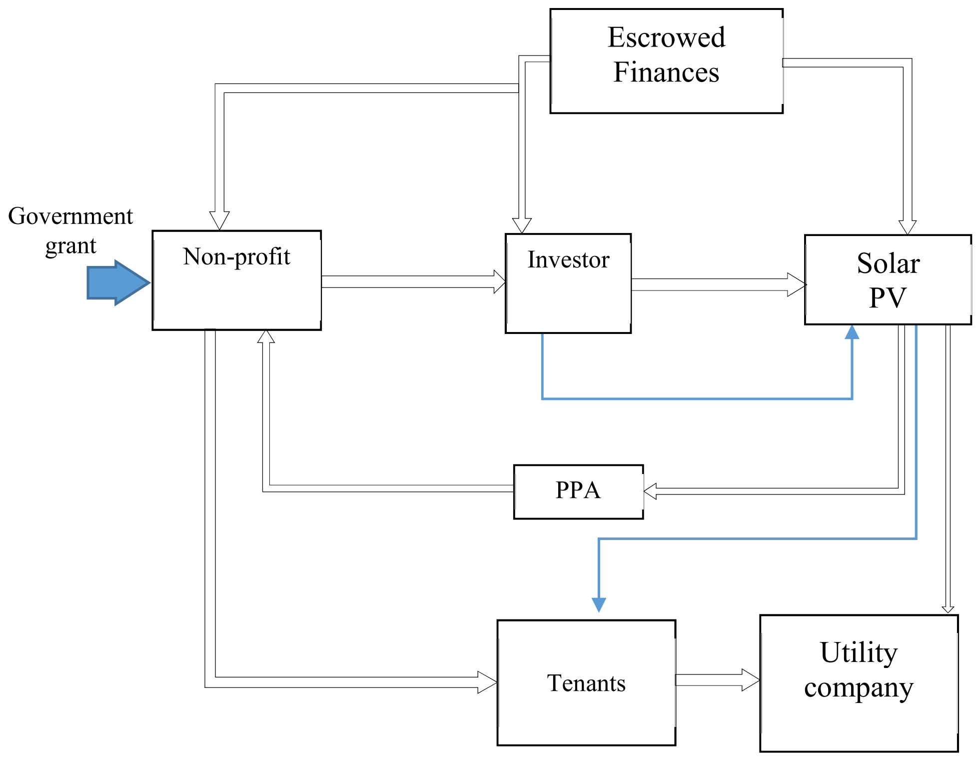

Figure 2.5. Financial flow diagram for solar PV business model (Source: Adopted from Dean *et al*. 2011:4-5)

One of the objectives of the project was to develop an innovative financing model for integration of solar pv in affordable housing that could be replicated by other affordable housing developers. The innovative financing model for solar pv installations involved the non-profit tax-exempt community development corporation using an investment company to fund the installation. Funding for the system was set up on a third-party ownership basis whereby the non-profit organization was not permitted to benefit from the states available renewable energy incentives. A limited liability company registered by equity investors owns the solar pv system. The company will own the system for 20 years, and all tax incentives captured on the project are accrued to the enterprise. The financial arrangement is in such a way that the company will own the installation for 20 years and will be selling solar electricity to non-profit organization through a Power

Purchase Agreement (PPA) based on the annual average electricity generation projections of the solar pv system. The contractual arrangement provides an option for the non-profit to purchase the pv system from the investor at a fair market price at the beginning of the seventh year. It is projected that the investor will have made significant returns on their investment through incentives at the beginning of the seventh year.

2.4.3 Innovative green finance for renewable energy

As stated earlier in the appraisal, financing the upfront capital cost of solar pv is one of the most critical issues to consider when planning investing in this technology. The central question then is how the investor would successfully mobilize finances to invest in solar pv. In order to meet Africa's increasing energy demand and mitigate electricity insecurity facing the continent, it is necessary to set the continent on a more sustainable energy path by putting in place innovative environment-related financing instruments. Although private sector funding would play a critical role in financing clean energy projects, related uncertainties and low returns on investment imply that part of the expenditure would have to be covered from public sources for some time to come (Schaefer, 2011).

South Africa is committed to attracting both domestic and foreign investors to invest in utility-scale renewable energy projects. Local finances primarily comprise two key groups including commercial banks and development finance institutions (Wentworth, 2014). The two principal development finance institutions actively engaged in the funding of large-scale renewable energy projects include the Development Bank of South Africa (DBSA) and Industrial Development Corporation (IDC) (*ibid*). In contrast, no systematic funding channels exist for small-scale rooftop solar pv installations.

Commercial banks involved in green financing for medium and small-scale solar pv projects through corporate and individual installations include Rand Merchant Bank (RMB), Investec, Nedbank, Standard Bank, and ABSA (Wentworth, 2014).

Financing mechanisms used by these institutions include subordinate debt financing, equity financing and senior debt financing (*ibid*)

Wentworth, (2014) provided important insights about the status quo of South Africa's green finance market. The evidence presented in this section provided the study with potential sources of innovative green finance, which were necessary when appraising funding sources for the rooftop solar pv system investment in Windmill Park Estate.

2.4.4 Rooftop solar pv investment payback period and net present value

One of the key factors dominating the overall decision of investing in rooftop solar has to do with the payback period which is essentially the period it takes the system to recover the capital cost of investment from the revenues generated by the solar pv system (Van der Wath, 2014; Ong and Thum, 2013). Calculating payback periods for long-term investments, however, may not be effective when evaluating rooftop solar pv profitability. Ong and Thum (2013) argues that renewable energy projects usually yield benefits over long periods and as such, the net present value (NPV) should be used to assess the profitability of such investments. Drawing insights from both a local and international study, this section appraises literature on evaluating the viability of rooftop solar pv using the payback period approach and the NPV method (Van der Wath, 2014; Ong and Thum, 2013).

A study by Van der Wath (2014) investigated the payback period for a rooftop solar pv system installed at Eric Miles Cheshire home for the disabled in Cape Town. The objective of the study was to collect empirical evidence to determine how long it would take the system to recover the initial capital costs of the investment and other incomes that would be generated thereafter. Prior to commencing with the investigation, Van der Wath (2014) highlighted key factors that were considered in the evaluation including the initial capital costs of the solar pv system and the cost of grid electricity. The system installed comprised a 45-50 kWp solar pv system comprising inverters, cabling, mounting structures and remote monitoring equipment all worth €90 000 (R1 037 714.00 for that time period) which was offered as a grant for the purpose of the study.

After installation, the system was monitored for 5 months from 13th August to 13th December 2013. The objective was to record monthly system outputs from January to December to establish annual outputs of the system. However, this did not suffice because the system was not commissioned as scheduled. In this regard, annual systems outputs were determined by extrapolating yields for the seven months that were not monitored. The yields were throttled by 7.44% to derive annual system outputs based on the performance output yields for the months recorded.

Having established the annual output for the first year of the installation, Van der Wath (2014) estimated the annual outputs for the system over a 25-year period, which is the estimated technical lifespan of the system. Annual outputs were reduced by 0.7% consecutively for 25 years in accordance with the solar panel degradation rate. Subsequently, the tariff structure was derived to calculate incomes that would be generated from the solar system from electricity bill savings. This was done using weekend and weekday tariffs based on the consumption patterns at Eric Miles Cheshire home for the disabled. The study indicated that all electricity generated from the system was consumed during the day hence the tariff used to calculate savings was based on the peak electricity tariff, which was estimated at R 0.9807/kwh. This electricity tariff was then assumed to escalate at 8% for next four years according to Eskom multiyear price determination 3 (MYPD3), and 7% for the remainder of the installation. MYPD is a methodology used by Eskom to establish electricity price adjustment over a period based on the corporation's operation and revenue requirements (Eskom, 2012). This methodology is employed to facilitate a regular and foreseeable electricity price path for both businesses and households facilitate financial planning (*ibid*).

To calculate the payback period, annual service costs of R 10 377 were included as part of the expenditure on the system. Expenses such as loan repayments, interests and insurances were not included in the cash flows of the systems. These factors were excluded because the project was funded by a grant and the cost of insurance were offset by Eric Miles Cheshire home insurance. After all the data were analysed, the study found that the solar pv would pay back the initial investment in year 10, with a net cumulative income of R 5 531 279.00 over the next 15 years.

As mentioned at the beginning of this section, using payback period for establishing profitability of a solar pv system has certain drawbacks. The major drawback of using payback period in Van der Wath's (2014) study was that the method did not take into account the time value of money at each period returns were made in relations to value of money at the time of investment. To account for other factors such as inflation and depreciation that affect the time value of money, NPV is the most appropriate approach to use when determining desirability of investing in renewable energy (Ong and Thum, 2013).

NPV analyses the profitability of an investment because it compares the value of money today and the value of money tomorrow by a discount rate over the lifespan of the project. The two basic steps followed in calculating NPV include establishing the present value of each of the cash flows and discounting them to the present value in relation to the initial investment. Discounting is the process of adjusting future cash flows to relevant present day values (Boyte-White, 2015). Equation 4 below is used to calculate NPV.

NPV = ∑ {Net Period Cash Flow/(1+R)^T} – Initial investment………Equation 4

Where R is the discount rate and T is the number time period (*ibid*). The formula presented above can either generate a negative or positive NPV depending on the discount rate used (*ibid*). A higher NPV shows that the investment is more lucrative while a negative NPV is an indication that costs outstrips the present value of the returns based on the discount rate utilized (Mendell, 2013). Higher discount rates often lead to negative NPVs (*ibid*).

Ong and Thum (2013) investigated the profitability of solar pv systems for seven projects in Malaysia using a discount rate of 9%. Interestingly, findings from the study showed negative NPV values for all the seven projects. The conclusion was that the negative NPV values resulted from the cost of solar pv modules, which contribute between 50% to 60% to the total project cost. It is possible,however, that this conclusion is flawed because the study did not take into account the effects of the discount rate on the resulting NPV values.

The study carried out by the International Energy Agency (2015b) to compare the unit cost of generating electricity across multiple technologies gives a better insight into how discount rates affect NPV results. The analysis used three discount rates including the social discount rate of 3%, 7% and 10%, which were based on assumed global markets and renewable energy policies (*ibid*). The results revealed that the unit cost of generating electricity, based on the NPV was lowest for 3% discount rate and highest for 10% discount rate. For projects involving environmental applications, low discount rates are usually recommended (Harrison, 2010).

Together these studies provided important insights about calculating the payback period for solar pv investments and the importance of using NPV as a measure of establishing the desirability of an investment that were utilised in this study.

Chapter 3: Research Method

3.1 Introduction

The study aims to appraise the viability of rooftop solar pv in the gap housing market as an opportunity towards improving housing affordability. Chapter 2 discussed the relevant concepts of the research and evaluated existing literature. This chapter presents the methods used in collecting and analysing data. The chapter begins by examining the research methods used in the study and gives a description of the case study area. Thereafter, the chapter provides an overview on the data utilized in the study with details on how the data were collected, recorded and transcribed. The final section of the chapter looks at the ethical considerations followed in the study.

3.2 Research methodology (Theory of research)

A qualitative research method and case study was considered the best approach to this investigation. This is because these methods provided the framework within which the research question could be explored and analysed in specific contextual conditions using a variety of data sources. This approach has been widely applied in the social sciences and has been found to be particularly useful in practical-oriented fields (Starman, 2013). According to Starman (2013), social sciences can only offer concrete cases and context-dependent knowledge since researchers have not been successful at producing general, context-independent theories. The study fits perfectly into these methods because case studies are also known to examine how casual mechanisms operate in detail by inductively observing the interaction of variables within a single case and thus identify available conditions that activate the causal mechanism and also show unexpected aspects of the causal mechanism (George and Bennett, 2005).

The case study allowed for added depth and realism to the research in appraising if integrated rooftop solar pv in gap housing can augment affordability. According to Baxter and Jack (2008:544), case studies allow for exploration of an issue through a variety of lenses, which considers various features of the phenomenon to be appraised. Deriving solar pv potential is one of the main components of the study, and pertinent to this calculation is the available rooftop area that can be dedicated to solar pv panel installation and the amount of solar irradiance reaching this surface (Jakubiec and Reinhart, 2012). Performing such calculations without an empirical context would constitute a highly abstract process, which would render the results close to meaningless. Contextual analysis of solar pv potential for this study guaranteed that the study remained within a reasonable and empirically valid scope.

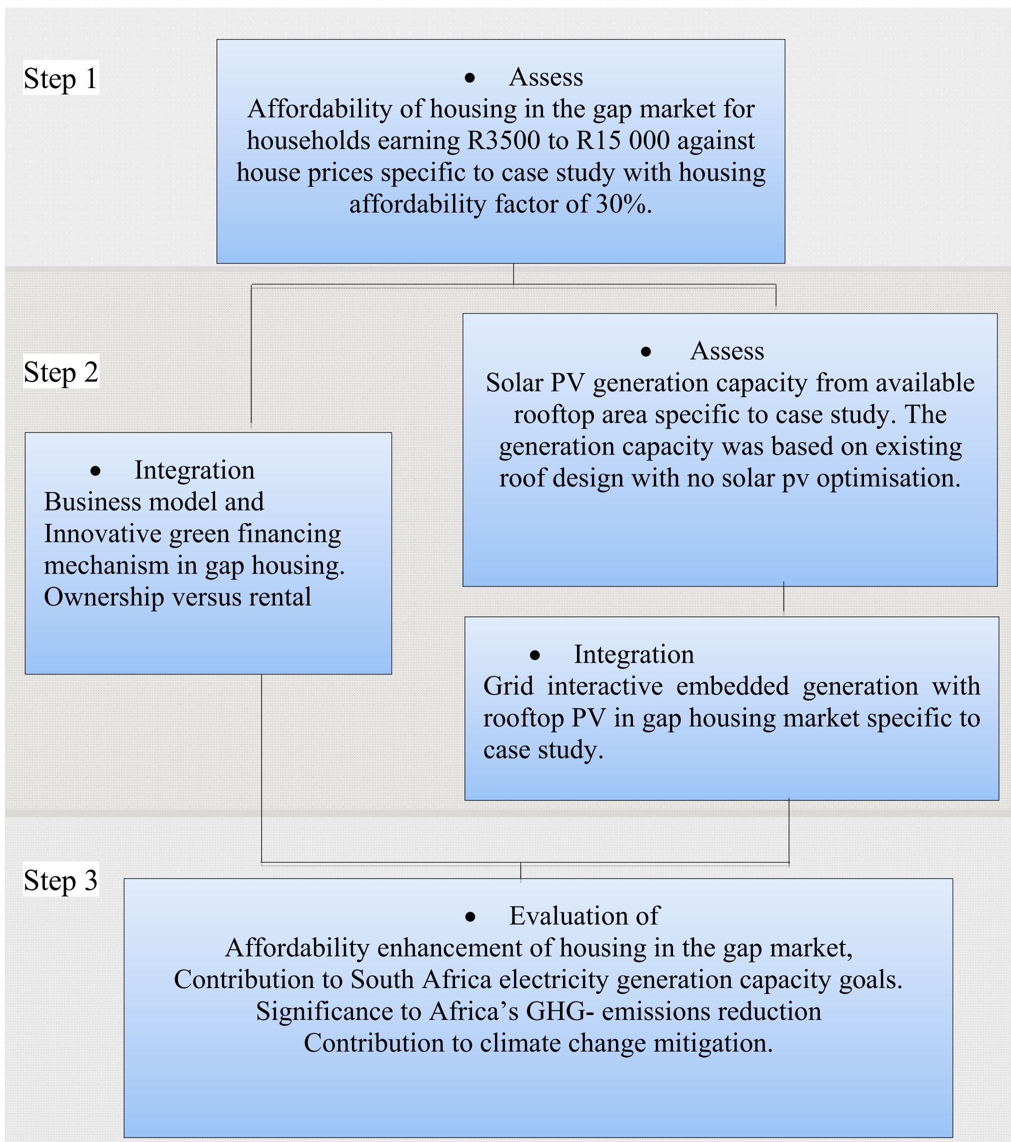

Figure 3.1.research design and overall approach

The research question posed in the study does not only seek to mitigate housing affordability problems inherent in the in gap housing segment in South Africa but also endeavours to address the country's electricity generation capacity goals as well as global climate change mitigation goals. To achieve the research objective, a three-step procedure to answer the research questions was followed as outlined in Figure 3.1.

With particular reference to the case study, the first step was to establish the extent of housing affordability in the housing market gap in South Africa. This analysis was conducted by exploring housing affordability through finance mechanisms accessible to households earning between R 3 500 and R 15 000 (Gap market segment). To identify the extent that households can afford housing in the case study, the method used by the Center for Affordable Housing Finance in Africa (2015a) was employed. In this approach, families are assessed for loan affordability and FLIST eligibility based on their monthly gross incomes with the underlying principle that they do not spend over 30% of their incomes to finance housing mortgages or rents (*ibid*). After establishing accessible housing finance, the results are compared with the prices of houses in the complex to determine the income band that is more likely to purchase housing in the estate. The analysis presented in this chapter was based on present day costs of houses in the estate and did not consider variations of housing prices overtime.

Households that currently own or rent accommodation in the estate were not included in the housing affordability assessment because the study targeted aspiring first time home owners and tenants. The theoretical basis of the assessment is the 30% housing affordability measure to access housing finance as defined in Section 1.8. As such, the study assumed that current landlords and tenants already have access to such finances. Details of the procedure followed in step one are presented in Section 4.3.

After this had been done, the next step was to determine the solar pv potential of Windmill Park Estate in step 2. Detailed procedures and calculations involved in these estimations are outlined in Section 4.4. The first procedure was to estimate the available rooftop area for solar pv installation followed by estimates of solar irradiance available in the estate. Procedures followed to select the appropriate business model for this study are also presented in the step. Procedures that were followed include establishing the surplus electricity that could be exported to the utility grid based on annual electricity consumption patterns in the estate, identifying enabling mechanisms for rooftop solar pv embedded generation, applying the mechanisms for the analysis of two scenarios, and identification of the best possible scenario to render the business model financially viable.

Interpretations of the findings in step two are then presented in the third and final step. In this step, solar pv is evaluated for its contribution towards South Africa's electricity generation capacity goals, and the significance to Africa's greenhouse gas emissions reduction, and the input of the intervention towards climate change mitigation.

3.3 Research data and data collection tools

Various data sources of both secondary and primary data were utilized for the research.

Table 3.1. Research data and data sources

Data required for step one		
Data collected	Source	Data type
Cost of houses in Windmill Park Estate	Lightstone property toolkit/NatRent managing agent	Secondary
Housing affordability reports/Home loan affordability	Desktop search (CAHF and DHS) ABSA Affordability home loan calculator (literature reports)	Secondary
Data required for step two		
Available roof area	Google Earth and Bing maps	Primary/Secondary

	Revit architecture software (Aerial imagery)	
Roof azimuth orientations	Google Earth and Bing maps Revit architecture software (Aerial imagery)	Primary/Secondary
Roof pitch angles	Visual observation Blocklayer.com online tool (Estimation)	Primary
Incident, annual average solar irradiation	Helioclim-3 Version 5	Primary/Secondary
Solar panel types and outputs capacities	SA solar PV suppliers (Desktop search)	Secondary
Rooftop solar PV generation potential	Solarius PV version 7	Primary/secondary
Annual electricity consumption patterns	Eskom (Literature reports)	Secondary
Capital costs for rooftop solar PV installation	Sustainable Energy Africa (Literature reports)	
Data required for step three		
South Africa's electricity generation capacity goals	Desktop search (Eskom, Department of Energy) (Literature reports)	Secondary
GHG emission reports	Desktop search (DEA , IPCC, Eskom, DoE, and Urban Earth) (Literature reports)	Secondary
Climate change mitigation	Desktop search (Environmental protection agency, OECD, IPCC) (Literature reports)	Secondary

Data required for step one of the research included pricing of houses and electricity use patterns in Windmill Park Estate. Lightstone Property toolkit was utilised to obtain the cost of houses in the estate. This online toolkit provides tailored information about residential properties in South Africa by making use of the deeds registry database. The toolkit can provide information about any registered property report including legal descriptions, ownership history, size, location and 20 most recent sales. ERF numbers are required to feed into the system in order to obtain this information. For this purpose, a random sample of 20 erf numbers representing housing units in the estate were used. The erf numbers were obtained from the online Ekurhuleni Municipality interactive map. In addition to the information provided by Lightstone Property toolkit, a telephone interview was conducted with the managing agent of the complex to confirm current costs and rental for the different housing types.

The following data collections tools were used to collect data for step two. Google Earth and Bing maps were utilised to obtain aerial imagery of the study area, and the imaging was then used as a reference for digitizing rooftop outlines and for determining azimuth orientations of the roofs. Bing maps were the first preference for obtaining aerial imagery for this purpose because it provided high-resolution orthographic aerial and satellite imagery with less cloud cover over the study area. However, the map is not up to date with the current developments on Windmill Park Estate and thus displayed the north-western portion (freestanding houses) of the site as bare land. Google Earth aerial imagery was used for the better representation of the north-eastern part of the study area. In contrast to Bing maps, cloud cover compromised the quality of the images from Google Earth. However, the detail displayed in the maps was sufficient for digitizing the roof layouts. The method of using two aerial imagery platforms proved necessary for this study because roofs on the south-western portion of the site are more intricate and thus required a high-resolution image for the detail to be captured. Details of how these procedures were carried out are outlined in Section 4.4

In addition to Google Earth and Bing maps, direct visual observation of the site was conducted to verify roof inclination angles and to identify possible shading on the roof surface from chimneys, trees and other objects. A video recording was also created to prevent revisiting the field several times for data verification. Still photos were taken and field notes were made to supplement these data. Incoming solar radiation in the estate was estimated using Helioclim-3 version 5, an online image database providing solar radiation estimates at ground level. To ensure validity and reliability of the secondary data obtained from Heliclim-3, the updated solar maps for South Africa were used as updated secondary data references points.

Part of stage two data included gathering information about annual electricity consumption patterns in the form of monthly electricity bills in Windmill Park Estate. The research sought to draw these data from three data sources including NatRent Property Management Company (the estate managing agent), Ekurhuleni Metropolitan Municipality and residents in the estate from a random sample of 20 houses. However, this was not sufficient because NatRent does not give access to information they consider confidential without consent from their clients.

Ekurhuleni Metropolitan Municipality could not provide the data for households using prepaid meters because data is not captured in the required format (kWh/month for individual households). The Municipality indicated that preparing the data in this format was going to be time-consuming. Data obtained from households that were randomly selected in the sample proved to be unreliable. Most residents approached had no idea how much kWh/month they consume and instead gave approximate monetary figures spent on electricity. Residents also indicated that they only purchase electricity depending on what they can afford at a particular moment. Residents that use mobile banking applications to purchase prepaid electricity provided some information. However, even these data proved to be unreliable because of inconsistencies in the purchases. Residents stated that some purchases were made using cash and the records were missing. Some households claimed that household members responsible for the purchase of electricity were not available during the times the researcher visited the study area. A scheduled visit could not be organized because the researcher was only allowed two visits into the estate by the managing agent NatRent. Unavailability of these data prompted the researcher to resort to secondary data sources as a substitute for the primary data. It is very likely that the secondary data utilised is similar to the expected primary data because these data are also based on case study surveys of household's electricity consumption patterns (Adam, 2010:22; Smart living handbook, 2011:68; Reinecke *et al.,* 2013:90; Department of Energy, 2013).

Data utilised for stage three included all the resulting findings from Chapters 4 and 5 as well as secondary data. After concluding data analysis in Section 5.3, the results were used to interpret how the integration of rooftop solar pv in Windmill Park Estate could contribute towards South Africa electricity generation capacity goals, climate change mitigation goals and GHG emission reduction. In order to establish realistic interpretations, secondary data were utilised to guide the study on how South Africa could improve electricity generation capacities and how this could address climate change mitigation for the country. Secondary data were also utilised to interpret how the findings could address Africa's greenhouse gas emissions reduction. Secondary data utilised for this stage were drawn from reports by Environmental Protection Agency, OECD, IPCC, Urban Earth, Eskom, the Department of Energy and the Department of Environmental Affairs using desktop searches.

3.4 Data analysis and interpretation

As stated earlier, a case study approach was adopted to answer the research questions. In order to improve on validity of the research, methods were triangulated to enable the study to identify inconsistencies in the results generated by different data collection methods (Johansson, 2003). Varied evidence was collected for analysis to allow data to complement or contradict each other (*ibid*). Three sets of analyses were carried out in this study including two preliminary analyses and one final analysis. The resulting findings were then interpreted in relation to the overall research question as captured in the final chapter of this study.

The first preliminary analysis involved the assessment of housing affordability in the gap market segment with particular reference to Windmill Park Estate. The focus of this analysis was to ascertain the extent to which households in the gap market segment can afford to either purchase or rent a house in the estate based on varying income levels, access to mortgage finance, the accessible FLISP amount and the current cost of housing in the estate. A housing affordability measure of 30% was used as the basis of housing affordability. This measure was used because most studies consistently motivate that households should not spend more than 30% of their gross incomes to finance housing (Centre for Affordable Housing Finance in Africa, 2015a). Based on the five functions stated above, the extent of housing affordability was determined using two sets of analyses including one for affordability to purchase (new ownership) and the second one for affordability to rent housing (aspiring rental). The scale of affordability to purchase was determined by identifying the income groups that can adequately finance and purchase a house in the estate against those that cannot. The rent affordability scale was measured through the identification of income groups that can adequately afford to rent accommodation in the estate and those that cannot.

The second preliminary analysis involved estimating the rooftop solar pv generation capacity in Windmill Park Estate. Generation capacity was defined as the amount of power that could be generated by rooftop solar pv in Windmill Park Estate using the available roof area. It should be pointed out here that the methodology used to determine the generation potential in the estate was based on the entire available rooftop area and not rooftop areas as per household. Ground floor housing units in double-storey structures do not have rooftop area for mounting solar pv panels. Therefore, it was necessary to treat the available rooftop area as communal area of the estate so that all housing units could be included in the analyses. Another reason for this approach was to overcome the complexities of installing rooftop solar panels on apartment rooftops for individual household use but rather facilitate for effective allocation and management of power for shared use.

Determining the generation capacity involved three stages which are: determining the usable rooftop area for solar pv placement in the entire complex, determining the amount of solar radiation available in the area and finally estimating the generation capacity from the available rooftop area. The available rooftop area was calculated using detail-specific data collected from Windmill Park Estate using data collection tools presented in the previous section. The second procedure involved the use of online tools and secondary data to determine the average monthly kW/m^2 of solar radiation available in the estate for 12 months (1st January to 31st December). Finally, after these data were available, solarius-PV version 7 software was used to determine the generation potential for rooftop solar pv for the case study.

The final analysis utilised the resulting findings in Chapter 4 to establish how rooftop solar pv could be integrated into Windmill Park Estate to augment housing affordability using an appropriate business model. This involved five stages which are: establishing the quantities of surplus electricity generated from the rooftop solar pv system that could be exported to the grid, establishing the cost of installing the rooftop solar pv system in the estate, identifying the appropriate framework for the business model, identifying an appropriate scenario to use in the business model and finalising analyses of the extent to which housing affordability could be improved using the business model.

Data on surplus electricity for export to the grid were derived utilising secondary data sources from solarius-PV version 7 and literature/technical reports. . Secondary data from research/technical reports were used to estimate the annual electricity consumption patterns in the estate. Capital costs of installing rooftop solar pv in Windmill Park Estate were derived using secondary. In this procedure, data from Solarius-PV software and the cost of installation of solar pv (R per/kWp) were used in an equation to derive the installation costs (see Section 5.2 for details).

The next procedure was to identify an appropriate enabling mechanism and business model for rooftop solar. Once the framework was established, key roles of the parties in the framework were also established including identification of the potential sources of innovative green finance for funding the project. Two scenarios were analysed in this framework to establish an appropriate business model to use in the study. The appropriate scenarios were selected based on

desirability using the net present value as a measure. NPV in this case was calculated by using a social discount rate deemed to be more appropriate for the project.
Once the business model was established, the final analysis was carried out to derive the key findings of the study. The analysis involved determining the extent to which savings made from using electricity generated from the solar pv system could improve the affordability of housing in Windmill Park Estate.

Results in this study were reviewed and interpreted within the context of previously published work to obtain general feel of how integrating rooftop solar pv in affordable housing in South Africa can contribute towards improving South Africa's electricity generation capacity goals, Africa’s GHG- emissions reduction, and climate change mitigation. Interpretations of how rooftop solar pv can improve South Africa's electricity generation capacity goals were carried out through a review of the current government's plans and commitments towards improving electricity generation capacities and the electricity generation methods. These plans and commitments were then explained in terms of how rooftop solar pv electricity generation potential can contribute towards the proposed electricity generation goals. Conceptions about rooftop solar pv contributions towards electricity generation capacity goals in South Africa laid the basis for interpreting how rooftop solar pv can contribute towards reducing Africa's GHG emissions. South Africa supplies two-thirds of Africa's electricity and is the continent's largest contributor of GHG emissions. Based on this fact, the argument is presented that reducing GHG emissions in South Africa through alternative electricity generation methods such as rooftop solar pv can significantly contribute towards reduction of Africa’s GHG emissions in general. Collectively, these interpretations are discussed on a global scale about how rooftop solar pv can contribute towards climate change mitigation.

3.5 Ethical considerations

To ensure ethical considerations of the study, the proposed research was guided by the ethical standards of The University of the Witwatersrand. The researcher obtained formal permission from NatRent Property Management Company (the managing agent for Windmill Park Estate) during a telephone interview to get access to the premises to conduct the research. The researcher also requested for information about electricity usage patterns in the form of monthly electricity bills for households in the complex from the managing agent 'NatRent', Ekurhuleni Metropolitan Municipality and from residents in the estate present during the investigation through an interview. In this regard, participation information sheets with sufficient details about the purpose of the research were issued to the participants interviewed. All participants were informed of their rights to withdraw from the research at any time, and that they would not receive compensation for participation (Mouton and Babbie, 2001:523). The study ensured that no physical, psychological or social harm was caused to participants and everyone present in the study area during the investigation (Kimmel, 2007).

The contextual identity of the case study area was necessary to maintain valuable information about solar pv generation potential and location. In this regard however, no confidentiality concerns were raised by the managing agent about using the actual name of the estate in this study.

Chapter 4: Housing affordability and rooftop solar pv generation potential in Windmill Park Estate

4.1 Introduction

The following chapter presents analyses carried out to derive preliminary findings of this study. The chapter is divided into three main sections. An elaborate description of the study area is presented in the opening section of the chapter followed by analyses of housing affordability levels in the gap market segment with specific reference to the case study. The last section outlines methods followed to determine rooftop solar pv generation potential using the available rooftop area in the case study area.

4.2 Description of the case study

Windmill Park Estate in Boksburg was selected as a case study for this research. Boksburg is one of the urban nodes of the East Rand region of the Gauteng province and falls under the Ekurhuleni Metropolitan Municipality. Annual average temperatures range from 16.6°C in June to 26.2°C in January. The climate is warm, and the city is often described as having a temperate environment.

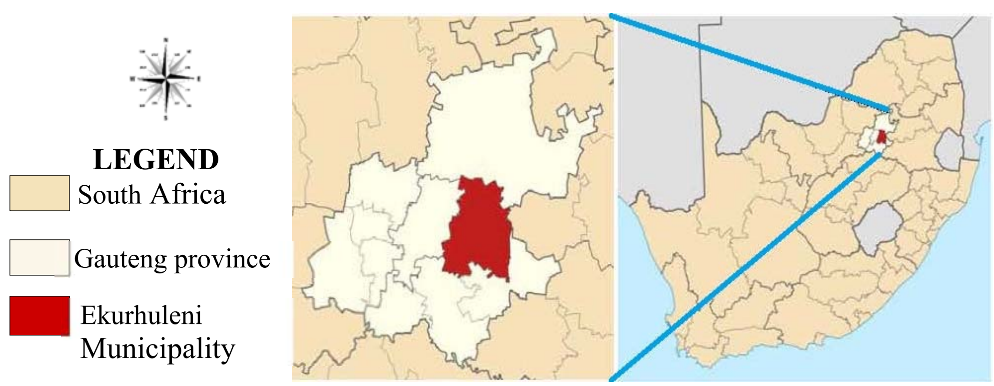

Figure 4.1. Location of Windmill Park Estate (Source: Adopted from Wikipedia, 2015)

According to Köppen-Geiger climate classification system, Boksburg experiences dry winters mostly characterised by subtropical high pressure, and rainy summer season caused by tropical air masses.

The case study area is situated on the western periphery of Boksburg, on a relatively flat site measuring approximately 541 207 m^2. The development comprises of 830 two-and three-bedroomed apartments, townhouses and free standing houses. The estate is divided into two sections by a wire fence which stretches across the site. Freestanding houses are situated on the north-western part (Figure 4.2c) while apartments and townhouses are located on the south-western portion (Figure 4.2d). In light of the housing challenges facing South Africa, the development was aimed at meeting housing needs for households within the gap market segment.

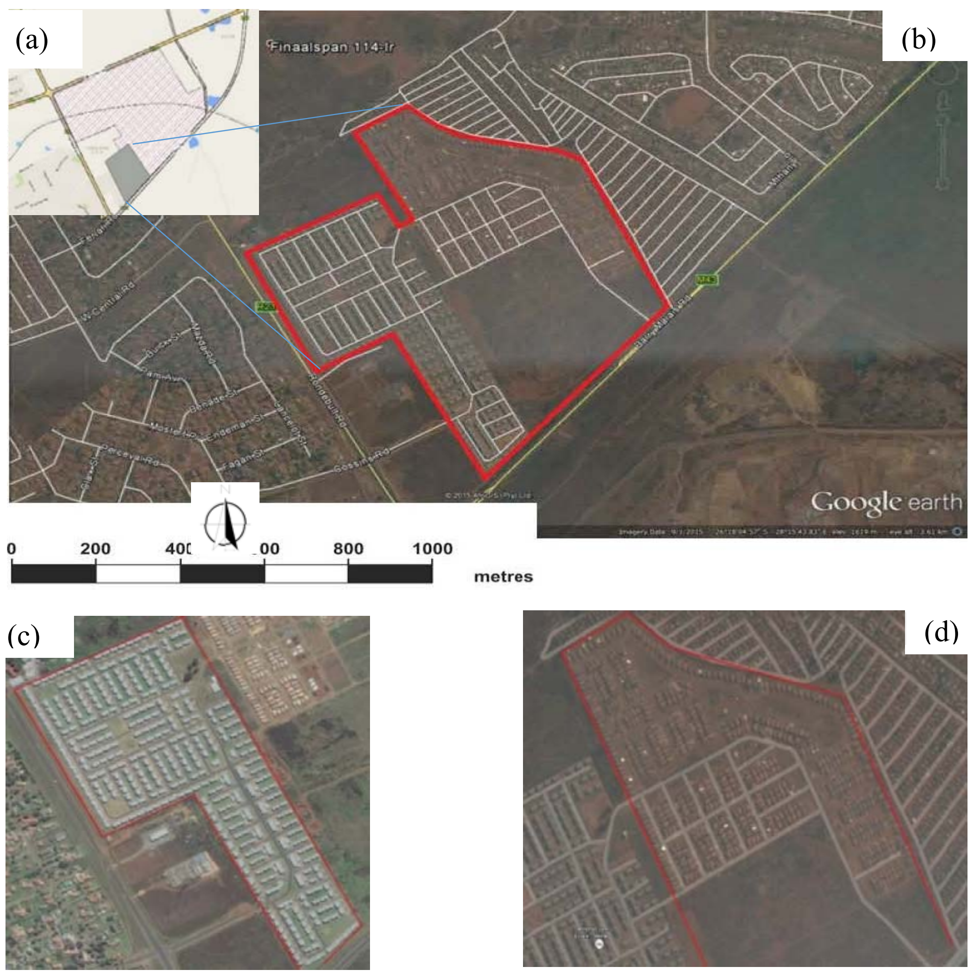

Figure 4.2 Aerial imagery of Windmill Park Estate (Source: Adopted from Google Earth, 2015; Bing maps, 2015)

Windmill Park Estate was selected as the case study because it contains aspects specific to housing supply in the gap market segment that is pertinent to the study. These aspects include housing types and quality for the intended target market as well as the tenure options available. Another aspect that influenced the selection of this particular case study is proximity. Due to time and financial constraints, it was deemed suitable for the researcher to find a case study that is easily accessible. This is the largest affordable housing development project targeting the gap market segment close to the researchers' locality.

4.3 Analysis of housing affordability for Windmill Park Estate

The primary objective of this section is to assess the financial capacity of households in the gap market segment to finance housing for purchase and rent in Windmill Park Estate using the current available subsidies and access to mortgage bonds given their income levels. The assessment is based on aspiring first time owners intending to purchase or rent a house in Windmill Park Estate. The analysis utilized nationally representative secondary data about income levels for households in the gap market segment and the cost of gap houses with specific reference to the current price of houses in Windmill Park Estate.

Demand for affordable housing is primarily influenced and impacted by household incomes and households' existing credit commitments (Center for Affordable Housing Finance in Africa, 2015a). In South Africa, the current prime interest rate for mortgage loans is 10.50% (Steyn, 2016). Mortgage loans are accessible depending on the borrower's credit score. Based on this, a loan may be offered at interest rate of prime plus or prime minus a percentage (Center for Affordable Housing Finance in Africa, 2015a). Prime plus interest on the affordable market is usually charged at 2% although this may vary among individual customers (*ibid*). In South Africa, borrowers with a good credit score can obtain mortgages for over 20 years with monthly installments calculated at 30% of the households or individual income. This section analyses the housing affordability in Windmill Park Estate based on accessible housing finance from FLISP, mortgages for gap market households and gap household incomes. Data were analyzed using ABSA online home loan calculators.

4.3.1 First-time ownership

Windmill Park Estate is a residential estate developed to address housing needs for households in the gap market segment. Modern two and three bedroom house prices in the estate range from R 285 000 to R 340 000 for sale (NatRent, 2016). Qualifying FLISP beneficiaries intending to acquire a house in Windmill Park Estate can use the subsidy to either decrease the initial mortgage loan amount or supplement the shortfall between the qualifying loan and the total house price. However, monthly income determines the FLISP amount that the applicant (beneficiary) can access. FLISP amounts can range from R10 000 to R87 000. Appendix A shows the low and high FLISP bands that are currently offered by the National Housing Finance Corporation (2016).

After establishing the qualifying FLISP amounts, it was also necessary to establish affordable loan amounts for households in the gap market segment. This process involved using the ABSA online affordable home loan calculators to calculate affordable loan amounts. Data inputted in the online tool included; gross monthly incomes (Rands); interest rate (%); and the home loan term (Years). Once these data are provided, the online tool automatically calculates the affordable home loan amount. Loan affordability amounts were calculated using 12.50% as the interest rate (which is 2% above the current prime interest rate of 10.50%) based on 20-years mortgages with monthly installments calculated at 30% of the household's or individual's income (Center for Affordable Housing Finance in Africa, 2015a) . Table 4.1 below shows housing affordability amounts supplemented by the FLISP subsidy for qualifying households in the gap market segment as computed in Microsoft Excel. The table sets out housing affordability at R 500 income increments for households earning between R 3 500 and R 15 000.

Table 4.1 Housing affordability with FLIST supplementation

Household Monthly Income	30 % Instalments of household Income	Accessible Loan amount at 12.5% annual interest Rate	FLISP qualification	Housing affordability
R 15 000.00	R 4 500.00	R 396 077.76	R 10 050.00	R 406 127.76
R 14 500.00	R 4 350.00	R 382 875.16	R 13 425.00	R 396 300.16
R 14 000.00	R 4 200.00	R 369 672.57	R 16 800.00	R 386 472.57
R 13 500.00	R 4 050.00	R 356 469.90	R 19 500.00	R 375 969.90
R 13 000.00	R 3 900.00	R 343 267.39	R 23 550.00	R 366 817.39
R 12 500.00	R 3 750.00	R 330 064.80	R 26 925.00	R 356 989.80
R 12 000.00	R 3 600.00	R 316 862.21	R 30 300.00	R 347 162.21
R 11 500.00	R 3 450.00	R 303 659.61	R 33 675.00	R 337 334.61
R 11 000.00	R 3 300.00	R 290 457.02	R 37 050.00	R 327 507.02
R 10 500.00	R 3 150.00	R 277 254.43	R 40 425.00	R 317 679.43
R 10 000.00	R 3 000.00	R 264 051.84	R 43 800.00	R 307 851.84
R 9 500.00	R 2 850.00	R 250 849.25	R 47 175.00	R 298 024.25
R 9 000.00	R 2 700.00	R 237 646.65	R 50 550.00	R 288 196.65
R 8 500.00	R 2 550.00	R 224 444.06	R 53 925.00	R 278 369.06
R 8 000.00	R 2 400.00	R 211 241.47	R 57 300.00	R 268 541.47
R 7 500.00	R 2 250.00	R 198 038.88	R 60 675.00	R 258 713.88
R 7 000.00	R 2 100.00	R 184 836.29	R 64 050.00	R 248 886.29
R 6 500.00	R 1 950.00	R 171 633.69	R 66 750.00	R 238 383.69
R 6 000.00	R 1 800.00	R 158 431.1	R 70 800.00	R 229 231.10
R 5 500.00	R 1 650.00	R 145 228.51	R 74 175.00	R 219 403.51
R 5 000.00	R 1 500.00	R 132 025.92	R 77 550.00	R 209 575.92
R 4 500.00	R 1 350.00	R 118 823.33	R 80 925.00	R 199 748.33
R 4 000.00	R 1 200.00	R 105 620.74	R 84 300.00	R 189 920.74
R 3 500.00	R 1 050.00	R 92 418.14	R 87 000.00	R 179 418.14

According to National Housing Finance Corporation (2016), FLISP can be used in two ways. The first one is reducing the initial mortgage loan payment to make monthly payment affordable and the second is using FLISP to supplement the shortfall between the qualifying mortgage and the total price of the desired house.

Tables 4.2 and 4.3 demonstrate how FLISP can be accessed for purchasing the lowest and highest priced houses in the Windmill Park Estate for qualifying households. The analysis is based on a 20-year mortgage loan using 12.5% interest rate, which is 2% above the current prime interest rate or 10.50% (ABSA, 2016; Center for Affordable Housing Finance in Africa, 2015a).

Table 4.2 below shows how FLISP can be used to reduce the initial mortgage loan amount by making monthly loan repayment instalments affordable. The lowest and highest selling prices for houses in Windmill Park Estate is R 285 000.00 and R 340 000.00 respectively. The approved loan amount for the cheaper house is R 285 000.00 with expected loan repayment instalment of R3 238.00 per month. With the application of FLISP as a subsidy, monthly loan instalments are reduced to R 2 817.00, which is R 421.00 less every month. For the most expensive house in the estate, monthly loan instalments are reduced by R 247.00.

Table 4.2. Using FLISP to reduce monthly loan repayments

Property Price/approved loan amount	**Monthly home loan repayments without FLISP**	**FLISP Subsidy applied to loan amount**	**Eventual home loan amount**	**FLISP decreases monthly home loan repayments**	**Total saving on monthly loan repayment**
R285 000.00	R3 238.00	R37 050.00	R247 950.00	R 2 817.00	R421.00
R 340 000.00	R3 862.00	R23 550.00	R316 450.00	R3 595.00	R247.00

Table 4.3 shows how FLISP can be used to augment the shortfall between the qualifying loan amount and total cost of the house. Qualifying beneficiaries aspiring to buy a house worth R 285 000.00, with the approved loan amount of R 247 950.00 can use a FLISP subsidy of R 37 050.00 to supplement the approved loan amount. On the other hand, beneficiaries aspiring to buy the house worth R 340 000 can utilise a FLISP subsidy of R 23 550.00 to supplement the approved loan amount.

Table 4.3. Using FLISP to augment available amount to buy a house

Property Price	Approved loan amount	FLISP Subsidy amount	Eventual home loan amount	FLISP used as a home loan top up
R 285 000	R 247 950.00	R 37 050.00	R 247 950.00	R 285 000
R 340 000	R 316 450.0	R 23 550.00	R 316 450.00	R 340 000

4.3.2 Rental housing affordability

The rent for two and three bedroomed apartments in Windmill Park Estate range from R 3 000 to R 3 500 (NatRent, 2016). No subsidy exists for rental affordability in the gap market and as such, the analysis of rental affordability is based on household incomes for households in the gap market segment. Table 4.4 shows the extent of rental affordability for households in the gap market segment. This analysis was carried out in Microsoft excel using 30% as the housing affordability rate according to the definition adopted by the Center for Affordable Housing Finance in Africa (2015a). The table sets out rental affordability at R 500 income increments for households earning between R 3 500 and R 15 000 and the implications on household's monthly salaries.

Table 4.4. Rental housing affordability

Household Monthly Income	Affordable rentals (30% of income)	Low range rent in Windmill Park Estate	Balance on monthly income	upper range rent in Windmill Park Estate	Balance on monthly income
R 15 000.00	R 4 500.00	R 3 000.00	R 12 000.00	R 3 500.00	R 11 500.00
R 14 500.00	R 4 350.00	R 3 000.00	R 11 500.00	R 3 500.00	R 11 000.00
R 14 000.00	R 4 200.00	R 3 000.00	R 11 000.00	R 3 500.00	R 10 500.00
R 13 500.00	R 4 050.00	R 3 000.00	R 10 500.00	R 3 500.00	R 10 000.00
R 13 000.00	R 3 900.00	R 3 000.00	R 10 000.00	R 3 500.00	R 9 500.00
R 12 500.00	R 3 750.00	R 3 000.00	R 9 500.00	R 3 500.00	R 9 000.00
R 12 000.00	R 3 600.00	R 3 000.00	R 9 000.00	R 3 500.00	R 8 500.00
R 11 500.00	R 3 450.00	R 3 000.00	R 8 500.00	R 3 500.00	R 8 000.00
R 11 000.00	R 3 300.00	R 3 000.00	R 8 000.00	R 3 500.00	R 7 500.00

R 10 500.00	R 3 150.00	R 3 000.00	R 7 500.00	R 3 500.00	R 7 000.00
R 10 000.00	R 3 000.00	R 3 000.00	R 7 000.00	R 3 500.00	R 6 500.00
R 9 500.00	R 2 850.00	R 3 000.00	R 6 500.00	R 3 500.00	R 6 000.00
R 9 000.00	R 2 700.00	R 3 000.00	R 6 000.00	R 3 500.00	R 5 500.00
R 8 500.00	R 2 550.00	R 3 000.00	R 5 500.00	R 3 500.00	R 5 000.00
R 8 000.00	R 2 400.00	R 3 000.00	R 5 000.00	R 3 500.00	R 4 500.00
R 7 500.00	R 2 250.00	R 3 000.00	R 4 500.00	R 3 500.00	R 4 000.00
R 7 000.00	R 2 100.00	R 3 000.00	R 4 000.00	R 3 500.00	R 3 500.00
R 6 500.00	R 1 950.00	R 3 000.00	R 3 500.00	R 3 500.00	R 3 000.00
R 6 000.00	R 1 800.00	R 3 000.00	R 3 000.00	R 3 500.00	R 2 500.00
R 5 500.00	R 1 650.00	R 3 000.00	R 2 500.00	R 3 500.00	R 2 000.00
R 5 000.00	R 1 500.00	R 3 000.00	R 2 000.00	R 3 500.00	R 1 500.00
R 4 500.00	R 1 125.00	R 3 000.00	R 1 500.00	R 3 500.00	R 1 000.00
R 4 000.00	R 1 000.00	R 3 000.00	R 1 000.00	R 3 500.00	R 500.00
R 3 500.00	R 875.00	R 3 000.00	R 500.00	R 3 500.00	R 0.00

4.3.3 Preliminary findings on housing affordability

Despite being developed to address housing needs for households in the gap housing segment, it is apparent from Table 4.1 that not all households in the gap market segment can afford to purchase a house in Windmill Park Estate. The table demonstrates that only households earning between R 9 000 to R 15 000 can afford to buy a house in the estate. Households earning between R 9 000 to R 11 500 can afford to buy the cheapest house on the estate while households earning between R 12 000 to R 15 000 can afford to purchase the most expensive houses in the estate.

From the results presented in Table 4.4, it is apparent again that not all households within the gap market segment can access housing for rent in Windmill Park Estate. The table shows that households earning between R 3 500 to R 9 500 cannot afford to rent the cheapest house available for rent in Windmill Park Estate (R 3 000/month). Affordability, in this regard, starts for households earning between R 10 000 to R 15 000. However, households earning between R 10 000 to R 11 500 cannot afford to rent the most expensive house available for rent in the estate (R 3 500).

It has been established that households earning between R 3 500 to R 8 500 cannot afford to access housing in Windmill Park Estate either for renting or first time ownership. This is in spite of these households being within the FLISP target market. While the subsidy is intended to assist households access adequate housing, the data demonstrate that the cost of available houses in the estate hinders some families in this housing segment from accessing the available housing at the set ownership or rental costs.

4.4 Estimating solar pv potential in Windmill Park Estate

This section presents the process followed to estimate rooftop solar pv generation potential in Windmill Park Estate based on the available rooftop area. The quantity of solar radiation reaching the surface and the area of the unobstructed roof space available for solar pv panel placement are the two crucial components for calculating the generation potential of rooftop solar pv (Jakubiec and Reinhart, 2012). A discussion of the methods employed in calculating available roof area and incoming solar radiation is presented in this section followed by detailed procedures applied to estimate the generation potential for rooftop solar pv. The solar pv potential in Windmill Park Estate was estimated according to the procedure discussed in Chapter 3.

4.4.1 Calculating available rooftop area in Windmill Park Estate

Tools utilised to determine the available roof area include Bing Maps, Google Earth and Revit Architecture. These tools were used to assist in estimating the available roof area and related azimuth orientation. Bing Maps and Google Earth images utilised in this study are shown in Figure 4.2. The varying roof inclination angles and related azimuth orientations in Windmill Park Estate rendered the site appropriate for an in-depth analysis of solar pv potential.

Before commencing with the estimation of the rooftop area, the reliability of the information presented on the maps in Figure 4.2 was crosschecked with the data collected from the direct visual observation through a site visit. The visual inspection was done to identify any objects that could cause shading on the roofs such as trees and chimneys. Site photos shown in Figures 4.3 were taken from points indicated on the site layout in Figure 4.4. The photos give a general impression of roof characteristics and other features in Windmill Park Estate.

Figure 4.3. Rooftop surfaces and other characteristics at Windmill Park Estate

Figure 4.4. Windmill Park Estate site layout guide to photo-views

Once the site was inspected, a number of tasks were outlined to estimate available rooftop area for solar pv placement. The first step was digitising the rooftop surfaces in the study area for easy identification and marking of roof inclination angles and azimuth orientations. The method of digitizing roofs using maps as background reference was used because the researcher did not have access to site plans used for construction of the houses in the study area as earlier discussed in Section 1.7. Google and Bing Map images in Figure 4.2 were exported and scaled in Revit Architecture application where rooftop outlines where digitised as shown in Appendix C and D.

The second task was to identify roofs with acceptable azimuth orientations. For the southern hemisphere, it is recommended that North facing roof surfaces be used for solar pv placement to increase the efficiency of the solar panels. In this regard, roofs having azimuth orientations greater than 70º and less than 290º were not included in the study because the generation potential of solar pv on such roofs can be reduced by as much as 15% or more (Reinecke *et al.*, 2013:46). Azimuth angles for roofs in Windmill Park Estate were resolved in Revit architecture using the google north arrow as the true north. Roofs having optimum azimuth orientations are highlighted in Appendix C. Parking bay roofs were also not included in this study due to uncertainties on their structural capacity to support the extra weight of solar pv panels. Some parking roofs were already showing signs of collapsing. Figure 4.5 below shows an example of the collapsing parking pay roof in the estate.

Figure 4.5. Collapsing parking bay roof structure

Roof tilt angles for double storey buildings (in brickwork) were calculated using the measurements of the "run" and the "rise" of the various roof types on the site. The "run" was calculated using a measuring tape while the distance of the "rise" was estimated by counting the number of brick courses and multiplying this number with the standard brick and mortar module vertical measurement. The measurements were then inputted in the online roof pitch calculator tool as presented in Blocklayer.com (2016), to calculate the roof tilt angle. A similar procedure was followed for plastered and painted single storey buildings. However, all measurements for these buildings were taken using a measuring tape. Figure 4.6 below gives an example of the measurements for the ‘Run’ and ‘Rise’ that were measured to calculate the roof tilt (y) angles as defined in Section 1.8.

Figure 4.6. Roof run and rise for roof tilt angles

Roof surfaces having similar azimuth and tilt angles were grouped and coded according to the codes presented in Table 4.5. Preparation of data in this way ensured that the solar irradiance incident on roof surface areas is estimated as per azimuth orientation and roof tilt angles as presented in Appendix C and D. The advantage of using this approach was that it simplified the process of designing the solar pv system in Solarius-PV software since all the available rooftop areas were specifically analysed of their generation potential based on the specific details about the azimuth and roof tilt angles (see Section 4.4.3 for details). For this reason, correction factors used by Reinecke's *et al*. (2013) for optimum orientation were obviated.

Table 4.5. Roof and azimuth orientation coded groups

Code	Azimuth orientation (in degrees)	Roof tilt angle (In Degrees)
Ar_1	45°	13°
Ar_2	53°	13°
Ar_3	63°	13°
Ar_4	63°	14°
Ar_5	63°	16°
Ar_6	63°	23°
Ar_7	300°	23°
Ar_8	304°	23°
Ar_9	332°	16°
Ar_{10}	332°	14°
Ar_{11}	332°	23°

4.4.2 Estimating solar irradiance in Windmill Park Estate

Solar irradiance incident on the available roof surface in Windmill Park Estate was estimated using Helioclim-3 version 5. This is a web-based application that uses satellite solar radiation data to provide solar irradiance incident on the surface of a plane. Solar radiation data for the case study was processed by inputting fixed tilt angles and azimuth orientations with 0.250 albedo (established according to the ground surface albedo values presented by the Germany Energy Society (2008:13). This value describes approximately 95% of the ground surface characteristics in the Windmill Park Estate.

The graph in Figure 4.7 shows solar irradiance incident on each of the surfaces identified in Table 4.5. The data shows Global Horizontal Irradiation (GHI) from 2004/2005. Old data was used because Helioclim-3 offers two options when seeking to retrieve this information. A fee is charged for accessing latest solar irradiance information while old data can be used without any fees. Due to budget constraints, the free option was chosen. The web service provider for Helioclim-3 version 5, 'SoDa', has not explained the accuracy trade-off between using data from the free version and the paying version on Helioclim-3. In this regard, secondary data sources were utilised to verify the data presented in the graph as explained below.

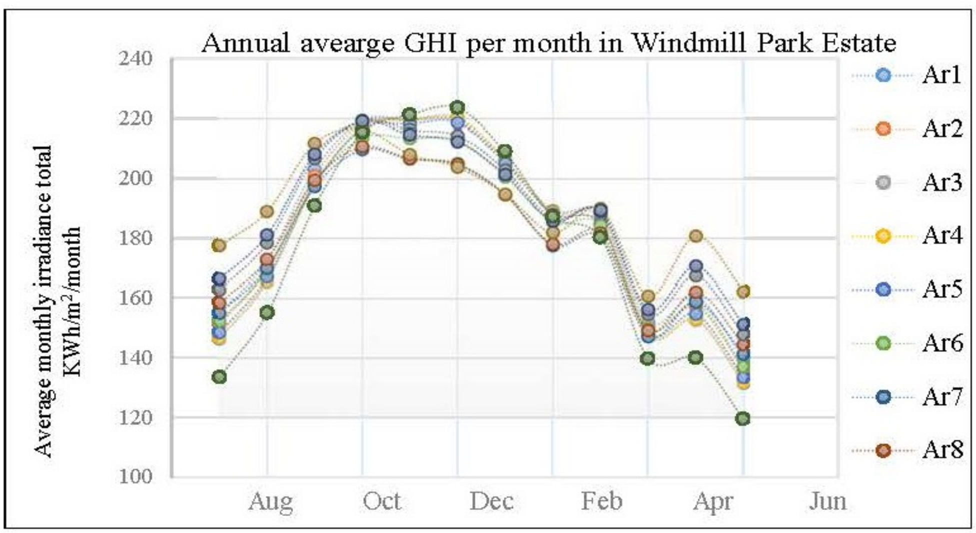

Figure 4.7. Solar irradiance incident on the rooftop surfaces

In order to ensure the reliability of the data, the new high-resolution accuracy-enhanced solar resource maps for South Africa were utilised to confirm data presented in the graphs. The maps were used to crosscheck whether the solar irradiance provided by Helioclim-3 is within the range shown in the new updated solar resources maps for South Africa. The maps have been updated using high-quality solar resource data obtained from fourteen high standard radiometric stations including six new stations set up in areas where high accuracy ground measurements were not previously available in South Africa (Centre for Renewable and Sustainable Energy Studies, 2014). The maps have been constructed by updating existing SolarGIS satellite-derived solar resource data with ground-measured data (*ibid*). The solar resource map shows long-term Global Horizontal Irradiation (GHI) averages with a spatial resolution of 1-km for 1994- 2013 (*ibid*). The accuracy-enhanced solar resource maps have been used in this study because they show data that are more accurate with reduced uncertainties. According to the Centre for Renewable and Sustainable Energy Studies (2014), the long-term estimates for GHI has been cut in the ranges of ±3% to ±4% on the new solar resource maps compared to the previous maps.

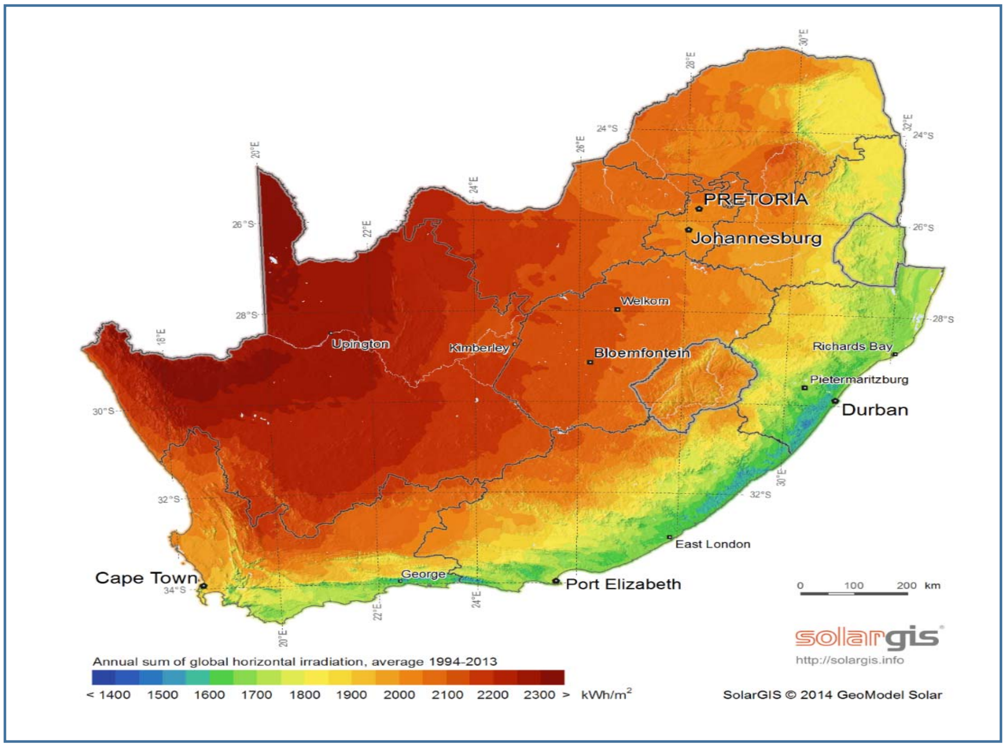

Figure 4.8. Updated Global Horizontal Solar Irradiation (GHI) map of South Africa (Source, Centre for Renewable and Sustainable Energy Studies, 2014)

Figure 4.9. Global horizontal solar irradiation distribution across Windmill Park Estate

According to Figure 4.8, GHI distribution across Windmill Park Estate is between 1950 kWh/m^2/year and 2150 kWh/m^2/year, which is in line with the readings obtained from Helioclim-3. The highest annual solar irradiance reading obtained in Helioclim-3 was 2 135.14 kWh/m^2/year and the lowest was 1998.45 kWh/m^2/year as shown in Figure 4.9. The data were subsequently applied in Solarius-PV software as will be discussed in the subsequent Section.

4.4.3 Solar pv generation potential in Windmill Park Estate

To date, various methods have been developed to assess generation potential for rooftop solar pv. The most recent studies have used solar pv design software to determine solar pv potential, see for example (Sharma, Verma and Singh, 2014). In this study, Solarius-PV software was used to establish the pv potential in Windmill Park Estate. Solarius-PV is a grid-tied solar pv design and analysis calculator that utilizes graphical inputs from computer-aided design (CAD) data and shading analysis from site photos for professional solar pv potential results (ACCA software, 2013).

The procedure employed in this study estimated the generation potential using specific parameters of the azimuth and tilt angles for the roofs as shown in Table

4.5. Using these parameters ensured that errors and hence the need for correction factors were minimised compared to the procedure presented in Reinecke's *et al*., (2013). Solarius-PV input parameters for this estimation included location coordinates of the study area and the altitude of the site. This data enabled the software to establish the geographical location of the site. Other data inputted into Solarius-PV include average daily solar irradiance incident on the rooftop surfaces in kWh/m^2 as obtained from Helioclim-3, roof pitches and azimuth orientations, connection type (whether single phase or three phase), available roof area, solar pv module type and inverter size.

Estimating solar pv potential in Solarius-PV requires systematic input data unique to the site of the proposed installation. The first step is the input process of the geographical location using site coordinates and the solar irradiation incident on the planes. Data utilised for this includes site coordinates obtained from Google Earth and solar irradiance data from Helioclim V3 presented in Figure 4.7. Step two involved the design of the system which requires data for the connection type, solar pv panel type, inverter type and roof azimuth and tilt angles. For the purpose of this study, a Tenesol - TE200-54P Si multi-crystalline reference solar panel with a SUNWAYS - PT 30k inverter on single-phase connection was used. The system sizing was done with the assistance of Solalius-PV based on the expected power output in accordance with the solar radiation data supplied in the software. Component types were selected based on availability on the South African market. The third step was the actual design of the solar pv array which requires the definition of the available surfaces for solar pv placement.

The software allows importation of CAD drawings for easy identification of surfaces. CAD drawings presented in Appendix C and D were used to automate the identification of roof surfaces. Further survey information such as the direction of the slope and the height of the roof surfaces is inputted into the software. Whereas solarius-PV can account for shading that may be caused by obstacles in proximity to the roofs, no obstacles were identified for the study area as can be seen in the aerial imagery and site photos in Figures 4.3 and 4.4. Once this data were provided, the software automatically determined the available roof surfaces, taking into account the roof tilt angle, and produces a solar pv panel layout on the available roof surface. After establishing the layout of the solar panels, the software then generates the results for solar pv potential as shown in Table 4.6 below.

Table 4.6. Solar PV generation potential in Windmill Park Estate

Code	Available roof area (m^2)	Total module surface area m^2	Solar PV module number	Total Annual energy kWh	Total Power kW
Ar_1	270.00	252.34	168	55 860.88	33.60
Ar_2	140.00	126.00	84	27 726.52	16.80
Ar_3	581.00	563.00	372	122 494.57	75.00
Ar_4	5 153.07	4 956.60	3300	1 078 256.51	660.00
Ar_5	3 328.96	3 143.69	2093	683 903.12	418.60
Ar_6	7 731.63	7 412.37	4935	1 605 861.07	987.00
Ar_7	67.35	60.08	40	13 016.78	8.00
Ar_8	303.09	270.36	180	59 256.28	36.00
Ar_9	3 375.77	3 214.28	2140	724 206.07	428.00
Ar_{10}	7 044.24	6 951.26	4628	1 560 340.47	925.60
Ar_{11}	8 598.54	8 453.26	5628	1 917 202.44	1 125.60
Totals	1361.44	1271.78	23568	7 848 124.71	4714.20

The section discussed the process used to estimate rooftop solar pv electricity generation potential for the case study. Discussion about how web-mapping services such as Google Maps and Bing Maps were utilized with a computer aided design software Revit architecture to estimate the available rooftop area for solar pv deployment was presented.

4.4.4 The significance of rooftop solar pv to Africa's GHG emissions reduction and climate change mitigation

Having estimated the solar pv potential in Windmill Park Estate, this section moves on to discuss the significance of solar pv electricity generation to the reduction of greenhouse gas emissions and climate change mitigation.

Like many developing nations, South Africa is experiencing increased demand for electricity to sustain economic growth. Greenhouse gas (GHG) emissions resulting from the methods currently employed to provide energy services have contributed significantly to the increase in atmospheric GHG concentrations (IPCC (Intergovernmental Panel on Climate Change), 2011).

Records from the official GHG emission compilation in 2000 indicated that South Africa's emissions were at 435 million tonnes of carbon dioxide (Urban Earth, 2012). The latest unverified compilation from the Air Quality Management Unit from the Department of Environmental Affairs in 2009 showed a 76 million tonnes increase in the CO_2 emissions. The chart in Figure 4.10 below shows GHG emissions from four different sectors of the economy including energy, forestry and other land uses (AFOLU), industrial process and product use (IPPU) and waste.

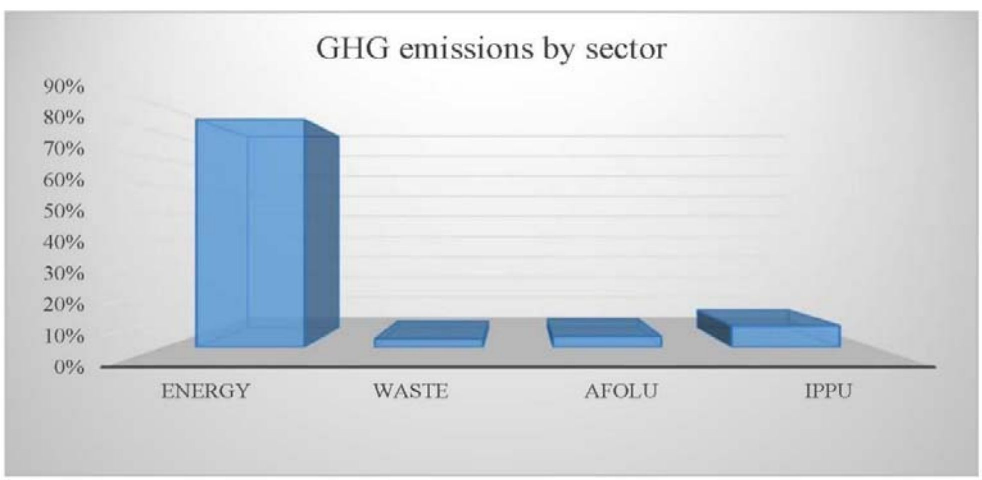

Figure 4.10. South Africa's GHG emissions by sector as per estimates for 2010 (Source: Adopted from Department of Environmental Affairs, 2014: 37)

From this chart, it is evident that the energy sector is by far the largest contributor of CO_2 in South Africa. The report further noted that the source of emissions from this sector came from the combustion of fossil fuels and coal in particular for the production of electricity as well as petroleum refineries. Between 2000 and 2010, the energy sector alone contributed 75.1% and 78.7% of South Africa's total GHG emissions respectively (DEA, 2014:37). This emission rate made the country's power generation processes the highest direct contributor to GHG emissions in Africa (*ibid*).

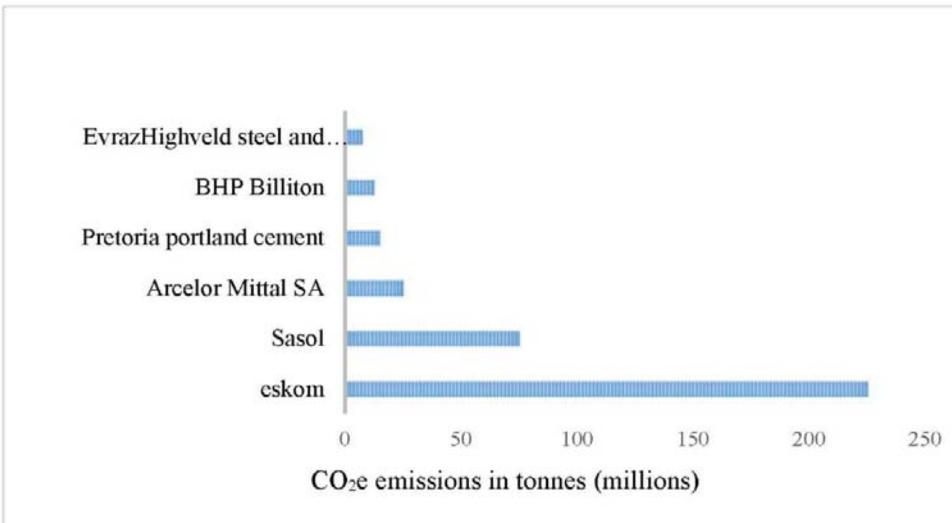

Figure 4.11. South Africa's top direct emitters of GHGs (Source, Urban Earth, 2012)

Studies conducted by International Energy Agency (IEA) in 2009 show that South Africa is the world's 12th largest CO_2 emitter, and Africa's largest emitter (Urban Earth, 2012). What is evident is that about 40% of Africa's total GHG emissions are generated by South Africa Studies conducted by the IEA were based on GHG emissions from energy consumption only, and did not include emissions from other sectors of the economy (*ibid*). Figure 4.11 shows South Africa's top direct GHG emitters in the energy and industrial sectors and Figure 4.12 shows Africa's GHG top emitters.

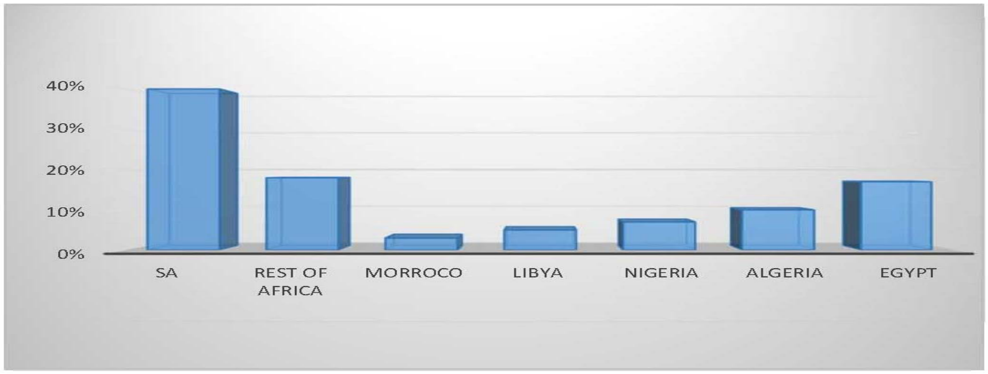

Figure 4.12 South Africa's contribution to Africa's GHG emissions (source: Adopted from Urban Earth, 2012:8)

It is apparent from the charts above is that South Africa's electricity production methods are a major contributor to GHGs in Africa. Cutting emissions from electricity production can thus make a significant contribution to GHG emissions reduction in both South Africa and the continent at large.

The build-up of greenhouse gases in the atmosphere has significant impacts on global climate. Initially GHGs always played a very important role in keeping the earth's temperature in balance (Environmental Protection Agency, 2015), however, increased quantities of these gases have led to adverse consequences like global warming which is resulting to global climate change. Increased production of these gases through human activity, including burning fossil fuels to generate electricity, has increased the concentration of GHGs in the atmospheres (*ibid*). Two-thirds of the global GHG emissions are reported to be coming from developing countries including South Africa (Organisation for Economic Co-operation and Development (OECD), 2008). The OECD (2008) projections indicate that GHG quantities in the atmosphere will continue increasing indefinitely into to the future if nothing is done to abate the problem. Apart from providing financial benefits and energy security, as demonstrated in this study, Rooftop solar pv can make a significant contribution to abating climate change if deployed properly into the residential sector, not only in South Africa but the continent as a whole.

4.5 Households electricity consumption patterns in Windmill Park estate

This purpose of this section was to establish the household's electricity consumption patterns in Windmill Park Estate. The data was necessary for assessing quantities of electricity generated from solar pv sufficient for self-consumption and export to the grid. Due to the reasons outlined in Section 3.3 however, it was not possible to obtain primary data for electricity consumption patterns for the estate. Secondary data was utilised to this effect.

Various reports have been published about household energy consumption patterns in South Africa (Aitken, 2007; Winkler, 2006; Senatla, 2011; Statistics South Africa, 2015; Department of Energy, 2013, Sustainable Energy Africa, 2014a). Most of these reports, however, focus on general household energy consumption patterns and only indicate the percentage of electricity usage relative to other energy sources. Some studies, on the other hand, give some indication of average monthly electricity consumption patterns for low to mid-income household's, stating the consumption patterns to range between 250 kWh -1000 kWh (Adam, 2010:22; Smart living handbook, 2011:68 ; Reinecke *et al*., 2013:90; Department of Energy, 2013).

The figures presented above indicate that electricity consumption patterns vary considerably from household to household. In this regard, it was important in this study to establish an averaged consumption value. By calculating the 'average' for electricity consumption patterns presented above, this study was able to establish that on average low to mid-income households consume 625 kWh/month. This value was crosschecked with Eskom's (2014) publication that estimated electricity usage patterns based on electrical appliances used in low to mid-income households. These appliances include a television set; an electric stove; a refrigerator with a freezer; a pressing iron; a microwave oven; lighting fixtures; electric heater; geyser; and an electric kettle. The publication estimated electricity consumptions based on the power ratings of these appliances and the presumed daily hourly usage of such appliances. Based on this methodology, the publication estimated that an average household uses between 500 kWh to 750 kWh of electricity in a month, which also averages to 625 kWh/month.

This section has established that individual households in Windmill Park Estate consume 625 kWh of electricity per month on average. This figure is based on secondary data which was crosschecked with Eskom estimates to ensure validity before the estimate could be used in the analyses in Chapter 5.

Chapter 5: Business and financing model for integrating rooftop soar pv in Windmill Park Estate

5.1 Introduction

This chapter presents the application of the key findings in Chapter 4 to establish the business and financing model for integrating rooftop solar pv in Windmill Park Estate. The chapter draws from the findings that emerged from Sections 4.4 and 4.5 to determine the cost of installing rooftop solar pv and the potential for surplus electricity for export to the grid from Windmill Park Estate. The section then shows how the business model was conceptualised and developed to integrate rooftop solar pv in affordable housing using innovative green finance. Finally, the chapter presents the key findings after applying the viable investment scenario in the business model. Data capture and analysis for the modelling were performed using Microsoft Excel 2013.

5.2 Business model and the net present value

The aim of this section is to answer the sub-question "What is the generation capacity of the available roof area in Windmill Park Estate relative to household electricity demand and surplus for electricity export to the grid?" This question was answered by utilising data obtained from Solarius-pv as presented in Table 4.6 and data for average household electricity consumption in Windmill Park Estate as presented in Section 4.5. Annual electricity export to the grid in Windmill Park Estate was calculated using Equation 5 as follows.

$E=A-B$……………………………………………………….………..........Equation 5

Where E is electricity annually exported to the grid, A is the annual generation potential of the available rooftop space in Windmill Park Estate given in Table 4.6, and B is the estimated annual average electricity consumption in the estate. It should be noted that variables presented in this equation have been aggregated to be in line with the generation potential of rooftop solar pv which has also been annualised.

This was done to facilitate the calculations for net present values (NPV) for rooftop solar pv investment for the entire lifespan of the system (25 years).

The relationship given in Equation 5 presented a good model to determine the annual electricity available for export to the grid from Windmill Park Estate. Based on the finding presented in Section 4.5, the annual electricity consumption in Windmill Park Estate was calculated using Equation 6 below.

$B = c_{(average)} * n_{(estate)} * 12$……………………..………………......…..……..Equation 6

Where $C_{(average)}$ is the average electricity demand per month for individual houses, $n_{(estate)}$ is the total number of housing units on the estate and 12 is the number of months in a year. Using Equation 6 above, the average electricity consumption in the estate was estimated to be 6 225 000 kWh/year.

The next step aimed at establishing export levels adequate to generate significant income to cover upfront capital costs of solar pv installation and augmenting affordability of gap housing in Windmill Park Estate. To accomplish this, installation costs of the solar pv system was established based on the costs of the system sizing. As discussed in Section 3.4 and in Section 4.4, the approach used to determine the generation potential was based on combining available rooftop area in the estate without specifically allocating available rooftop spaces to individual households for solar pv placement and generation potential. Using this methodology, however, requires management of power generated from rooftop solar pv in respect to electricity distribution within the estate as well as surplus exports to the grid. In this regard, the study assumed that the rooftop solar pv system is connected to the utility grid via a microgrid system for energy management. Due to time constraints however, this study does not cover the technical and financial feasibility of introducing microgrid connection for electricity management within the estate.

To complete the investigation, reference data for the cost of installing grid-tied rooftop solar pv in South Africa was used to establish the installation costs of the system. Installation costs were calculated using Equation 7 below.

$I(cost) = P_{kW} * y$……………………………...Equation 7

Where $I_{(cost)}$ is the gross installation cost of solar pv, $P_{(kW)}$ aggregate power capacity of the solar panels in kW and y is the cost of installation per kW. Sustainable Energy Africa (2014b:1) reported that the cost of installation for rooftop solar pv in residential buildings is R 27 000 for every 2 kW peak installation. Using Equation 7 and the power rating for the proposed system in Windmill Park Estate system presented in Table 4.6, the cost of installation for solar pv was estimated at R 63 633 600.00 excluding vat (Value added tax).

5.2.1 Business model and innovative green finance for solar pv in Windmill Park Estate

Having completed the calculations for the installation cost of solar pv, a business model and the financing option for the system was conceptualised and appraised. It was important to establish an appropriate business model based on: the available enabling mechanisms, as discussed in the literature appraisal; the roles of the parties within the model; and the sources of funding for the investment.

Firstly, it is necessary to establish exactly how the business model would operate. The NEFIT mechanism (Bischof-Niemz, 2015) discussed in the literature appraisal was considered the most appropriate framework from which to conceptualise a business model for this study. The argument, however, is that the proposed NETFIT concept is merely an enabling mechanism and does not represent a business model as defined by Frantzis *et al*. (2008:4-2). The selection procedure for the business model followed the criteria that the model address three critical aspects which are; financing of the system; ownership of the PV system; and the financial relationship between the investor and the rooftop owners. The business model under Dean *et al*. (2011) was selected because it presented a logical business relationship that could be incorporated into Bischof-Niemz (2015) mechanism. This model presented a clear financial flow among the stakeholders and gave a clear indication of how rooftop owners could benefit from a third-party owned solar pv business model.

The NETFIT concept developed by Bischof-Niemz (2015) addresses various aspects of rooftop solar pv embedded generation concerning establishment of a business model. These aspects include: power flows, which means that import and export of electricity generated from rooftop solar pv is allowed with a use of a bi-directional meter; the option of varying tariffs for imported and exported electricity, whereby, the tariff for export is lower than the tariff for import; and rooftop solar pv investment security, which means that the tariffs received for electricity exported to the grid are guaranteed over the lifetime of the solar pv system (*ibid*). The other important aspect of the proposed NETFIT concept that was important in the establishment of the business model for this study was that funding options within the mechanism are not limited to the municipalities' financial system but open to nationwide funding schemes including green finance.

After establishing how the business model was to be developed, it was necessary to identify the stakeholders and their roles within the business model. The business model for this study was based on a third-party ownership and the key players were identified as follows; households in Windmill Park Estate were categorised as prosumers; the investor, was responsible for raising the funds to purchase the system as an investment; the central power purchasing agency (CPPA), was responsible for purchasing power generated from Windmill Park Estate and selling it to and Ekurhuleni Metropolitan Municipality. One major limitation in this approach is that the CPPA does not yet exist in the South African electricity market/sector.

As stated earlier, the key responsibility identified for the investor was to raise funding for the purchase of the solar pv system. Leveraging private financing for distributed RE projects such as the one proposed in this study is challenging because there are limited options available for investors to source funding (Engerati, 2016).

However, in light of the challenges facing South Africa towards implementing sustainable development projects, there is a growing interest within the private sector to participate in corporate social responsibility (CSR) programmes through partnerships with the public sector and non-profit organisations towards contributing in renewable energy investments (*ibid*).

One of the goals of this study was to identify institutions within the private sector and non-profit organisations involved in funding social investment programs involving renewable energy such as rooftop solar pv. Broadly speaking, innovative green finance was identified as the main financing stream that would facilitate green finance opportunities for integrating rooftop solar pv in Windmill Park Estate. As discussed in the literature appraisal, the primary focus of the innovative green finance mechanisms is to facilitate financial investments that can contribute towards green economic growth (Lindenburg, 2014; The World Economic Forum, 2013).

Potential sources of innovative green finance identified for this study included the South African government, international organisations and some local financial institutions. The South Africa government has shown commitment towards encouraging green growth through its re-evaluation of investment priorities by supporting investors looking to invest in renewable energy. Examples of this commitment include the establishment of government offices that provide financial assistance such as the Renewable Energy Finance and Subsidy Office (REFSO), established under the Department of Energy (Wentworth, 2014). The main responsibilities of this office include providing renewable energy subsidies and advising investors on other sources of finance for renewable energy investments (*ibid*). The government has also collaborated with the Industrial Development Corporation (IDC) and the German Development Bank, KfW, under the framework 'South African–German Financial Cooperation', to establish a ZAR 500 million fund towards investment in renewable energy projects (*ibid*). This fund is accessible to investors in the private sector planning to implement projects that can reduce the strain on grid electricity through embedded generation based on renewable energy.

Financial institutions identified as possible sources of finance within the green market include the Development Bank of South Africa (DBSA), The FirstRand Group, and ABSA (Nhamo, 2014). After appraising existing funding sources, the concept for the business model was developed as shown in Figure 5.1.

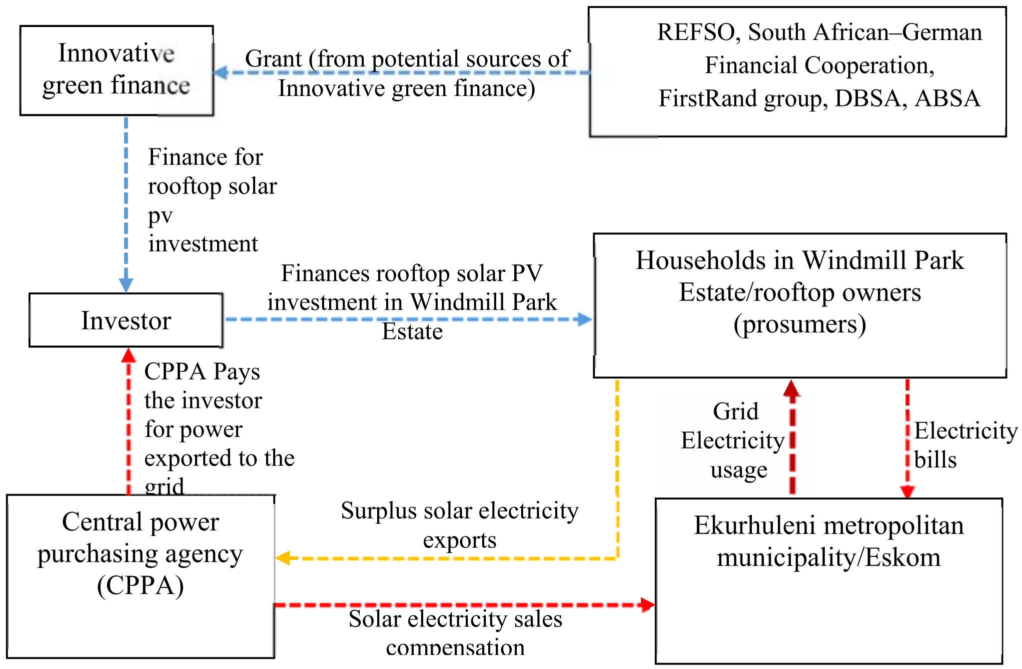

Figure 5.1. Concept for solar pv business model

5.2.2 Net present value and payback period

Once the concept was established, the process of appraising viability of the investment was carried out. This process was done by analysing two scenarios based on the net present value (NPV) as a criterion of appraising viability. NPV provides a measure of profitability and attractiveness of the investment in Windmill Park Estate based on discounted cash flows over the system's lifespan of 25 years. The NPV approach also enabled the study to establish the payback period based the present value of money rather than nominal future cash flows.

As mentioned in Section 5.2.1, it is assumed that the investment is a social investment, and as such, the NPV was calculated from a social investment standpoint. Three standard elements were considered to calculate the NPV for this study. These are: the net period cash flows (costs and revenues); the discount rate; and the duration of the rooftop solar pv system. Based on these factors, the NPVs for the two scenarios were calculated using Equation 8 below (Boyte-White, 2015).

NPV = ∑ {Net Period Cash Flow/(1+R)^T} - Initial Investment………Equation 8

Where T is the time period and R is the social discount rate.

Net period cash flows for the project were calculated according to the procedure used by Van der Wath (2014:68) (See section 2.4.4 for details). The procedure was adopted because it captures net cash flows of the system based on electricity tariff escalations over time and it accounts for the degradation of electricity generation/exports by the PV system over time. In order to employ Van der Wath's (2014:68) procedure, however, the proposed NETFIT of 0.70 R/kWh proposed by Bischof-Niemz (2015) was used to substitute Van der Waths' (2014) tariff. Bischof-Niemz's (2015) tariff was used because Ekurhuleni Municipality has not yet implemented feed-in tariff for rooftop solar pv embedded generation, and moreover, the tariff proposed under Bischof-Niemz's (2015) was assumed to be adequate minimum for feed-in tariff for embedded solar pv generators.

In the analysis, the NETFIT was assumed to escalate at 9.4% for the first and second year of the installation (2016/17) in accordance to Eskom's Multi-Year Price Determination 3 (MYPD3) (Pretorius and Le Cordeur, 2016). For the remaining years of the installation, an escalation of 8% per annum is assumed, based on the electricity tariff increase forecasts by Loubser (2016).

Projected cash flows into and out of the solar pv investment in Windmill Park Estate based on the anticipated lifespan of the pv system (25 years) are shown in Table 5.1. The degradation rate of the system is also included in the calculation to account for reduced output performance of the solar panels over time. The rate used in this study is 0.7%, which is in accordance with the manufacturer's specifications of the reference panel used in this study.

Net period cash flows for the NPV were captured in per annum periods for a period of 25 years. Cash flows were captured on an annual basis in accordance with the data for electricity generation potential as explained in Section 5.2. The social discount rate, R, used is based on the social discount rate of 3% adopted from the methodology used by the International Energy Agency (2015b) when establishing the cost of generating RE electricity in South Africa (see section 2.4.4 for details).

A social discount rate was employed so that the investment in Windmill Park Estate could be evaluated from a social stand point rather than a private investment perspective so that policy impacts on the investment that occur in different years over the installation of the system are accounted for. The initial investment used is the capital cost of the installation of the rooftop solar pv system in Windmill Park Estate as established under Section 5.2.

Based on the assumptions and data discussed above, Tables 5.1 and 5.2 display the results obtained from using two theoretical scenarios as explained here below. However, these scenarios were examined in order to appraise the most appropriate approach to use as a business model based on attractiveness of the investment based on NPV approach. The two scenarios were set up in an attempt to answer two sub-questions:

- What is the generation capacity from the available roof area in Windmill Park Estate relative to household electricity demand with surplus for export to the grid?
- What export levels would be adequate to generate significant income to cover upfront capital costs of solar pv installation and augmenting affordability of gap housing in Windmill Park Estate?

5.2.3 Scenario 1: Transform Windmill Park Estate into a Net-Zero-Energy prosumer

As discussed earlier in Sections 4.4.3 and 5.2, the available rooftop space in Windmill Park estate is sufficient to transform the complex into a Net-Zero-Energy prosumer. In this scenario, it was assumed that Windmill Park Estate consumes energy produced from rooftop solar pv according to the maximum annual demand of 6 225 000 kWh as estimated in Section 5.2. When this approach was assessed for desirability using Equation 8, the derived NPV was -R 31 383 051.97. This implies that the present value of the revenues that can be generated using this approach are exceeded by the present value of the Investment by R 31 383 051.97 from a social investment standpoint.

The implications of the resulting NPV in scenario 1 on the payback period are revealed in Table 5.1. It is apparent from the table that capital costs of R 63 633 600.00 would not be recovered within the 25-year lifespan of the pv system. At the end of the 25th year, the investor will have a R 31 383 051.97 deficit towards paying the upfront cost of the solar pv system. On the other hand, occupants will profit from reduced electricity bills for the entire lifespan of the system operation. The negative NPV in this case does not indicate a bad investment but rather indicates that resources can be reviewed and economised so that the model can be enhanced (Mendell, 2013). In this regard, the approach in Scenario 1 addressed sub-question 1 presented above but does not address research sub-question 2.

Table 5.1. Scenario 1: Transform Windmill Park Estate into a Net-Zero-Energy consumer

Yr.	Annual kWh generation at 0.7% degradation	Annual kWh export after 6,225,000 kWh consumption	Escalated tariff NetFit (Rands)	Discounted Annual income from solar power (Rands)	Discounted Accumulated gross Income (Rands)
1	7,848,124.71	1,623,124.71	0.8	1,260,679.39	1,260,679.39
2	7,793,187.84	1,568,187.82	0.88	1,300,787.35	2,561,466.74
3	7,738,635.52	1,513,635.52	0.95	1,315,931.38	3,877,398.12
4	7,684,465.07	1,459,465.07	1.02	1,322,650.13	5,200,048.25
5	7,630,673.82	1,405,673.82	1.1	1,333,801.24	6,533,849.49
6	7,577,259.10	1,352,259.10	1.19	1,347,669.89	7,881,519.38
7	7,524,218.29	1,299,218.29	1.29	1,362,734.53	9,244,253.92

8	7,471,548.76	1,246,548.76	1.39	1,367,811.57	10,612,065.49
9	7,419,247.92	1,194,247.92	1.5	1,372,937.38	11,985,002.87
10	7,367,313.18	1,142,313.18	1.62	1,376,981.03	13,361,983.90
11	7,315,742.00	1,090,741.99	1.75	1,378,956.63	14,740,940.54
12	7,264,531.80	1,039,531.80	1.89	1,378,011.64	16,118,952.18
13	7,213,680.07	988,680.07	2.04	1,373,415.76	17,492,367.94
14	7,163,184.31	938184.31	2.2	1,364,550.78	18,856,918.72
15	7,113,042.02	888,042.02	2.38	1,356,600.91	20,213,519.64
16	7,063,250.73	838,250.73	2.57	1,342,491.26	21,556,010.90
17	7,013,807.97	788,807.97	2.78	1,326,732.20	22,882,743.09
18	6,964,711.32	739,711.32	3	1,303,507.32	24,186,250.41
19	6,915,958.34	690,958.34	3.24	1,276,702.19	25,462,952.60
20	6,867,546.63	642,546.63	3.5	1,245,168.72	26,708,121.32
21	6,819,473.80	594,473.80	3.78	1,207,932.88	27,916,054.20
22	6,771,737.488	546,737.49	4.08	1,164,179.83	29,080,234.03
23	6,724,335.325	499,335.33	4.41	1,115,770.08	30,196,004.11
24	6,677,264.978	452,264.98	4.76	1,059,025.74	31,255,029.86
25	6,630,524.123	405,524.12	5.14	995,518.18	32,250,548.03

5.2.4 Scenario 2: Windmill Park Estate consumes 3 112 500 kWh of generated electricity

As a follow up to the approach for Scenario 1, Scenario 2 was conceptualised to optimize the electricity that could be used for self-consumption in the estate and the surplus that could be exported to the grid. In this scenario, 3 112 500 kWh of the total electricity generated from solar pv is consumed while 3 112 500 kWh of what ought to be consumed is also exported to the grid annually. This ultimately reduces the consumption of electricity produced from rooftop solar pv in the estate to 50%. Residents purchase the other 50% from Ekurhuleni Metropolitan Municipality at the standard tariff to satisfy their energy demands. But it could also be that with complementary energy efficiency interventions by the estate stakeholders, general consumption can be reduced by close to 50% thus mitigating the need for import from the grid.

When this approach was assessed for desirability, a positive NPV of R 83 197 806.84 was generated. This implies that the present value of future returns is R 83 197 806.84, which is higher than the present value of the investment from a social investment standpoint. The overall financial modelling effect of this approach on the payback period is presented in Table 5.2. The table reveals that upfront capital costs are recovered between the 13th to 14th years, after which the accumulated revenues on the investment till the 25th year amounts to R 83197806.84. Based on these results, Scenario 2 proved to be the most appropriate approach to use in the proposed business model. The scenario was selected because it addressed both sub-questions 1 and 2.

Having established the desirable scenario, the following section discusses how the business model was employed to answer the sub-questions of this study.

Table 5.2. Scenario 2: Windmill Park Estate consumes 3 112 500 kWh of generated electricity

Yr.	Annual kWh generation at 0.7% degradation	Annual kWh export 3,112,500 consumption	Escalated tariff NetFit (Rands)	Annual income from solar power (Rands)	accumulated amount
1	7,848,124.71	4,735,624.71	0.8	3,678,155.12	3,678,155.12
2	7,793,187.84	4,680,687.84	0.88	3,882,557.55	7,560,712.66
3	7,738,635.52	4,626,135.52	0.95	4,021,890.87	11,582,603.54
4	7,684,465.07	4,571,965.07	1.02	4,143,374.38	15,725,977.92
5	7,630,673.82	4,518,173.82	1.1	4,287,158.07	20,013,135.99
6	7,577,259.10	4,464,759.10	1.19	4,449,606.89	24,462,742.88
7	7,524,218.29	4,411,718.29	1.29	4,627,398.59	29,090,141.47
8	7,471,548.76	4,359,048.76	1.39	4,783,091.95	33,873,233.42
9	7,419,247.92	4,306,747.92	1.5	4,951,145.50	38,824,378.92
10	7,367,313.18	4,254,813.18	1.62	5,128,888.57	43,953,267.49
11	7,315,741.99	4,203,241.99	1.75	5,313,895.03	49,267,162.52
12	7,264,531.80	4,152,031.80	1.89	5,503,966.46	54,771,128.98

13	7,213,680.07	4,101,180.07	2.04	5,697,116.30	60,468,245.27
14	7,163,184.31	4,050,684.31	2.2	5,891,554.96	66,359,800.23
15	7,113,042.02	4,000,542.02	2.38	6,111,353.75	72,471,153.99
16	7,063,250.73	3,950,750.73	2.57	6,327,281.50	78,798,435.49
17	7,013,807.97	3,901,307.97	2.78	6,561,788.25	85,360,223.74
18	6,964,711.32	3,852,211.32	3	6,788,304.46	92,148,528.20
19	6,915,958.34	3,803,458.34	3.24	7,027,751.63	99,176,279.83
20	6,867,546.63	3,755,046.63	3.5	7,276,773.96	106,453,053.79
21	6,819,473.80	3,706,973.80	3.78	7,532,334.50	113,985,388.29
22	6,771,737.49	3,659,237.49	4.08	7,791,692.70	121,777,081.00
23	6,724,335.33	3,611,835.33	4.41	8,070,684.36	129,847,765.35
24	6,677,264.98	3,564,764.98	4.76	8,347,270.01	138,195,035.37
25	6,630,524.12	3,518,024.12	5.14	8,636,371.48	146,831,406.84

5.3 Derivation of the Key finding

This chapter has focused on establishing the income generation potential given the generation and export capacity for rooftop solar pv in Windmill Park Estate. Once this data were derived, it was necessary to establish the manner in which the finances would flow towards enhancing housing affordability based on Scenario 2. This was done by using the concept presented in Figure 5.1 to develop the business model and define how it will deliver towards augmenting housing affordability. Figure 5.2 below demonstrate the operation of the proposed business model for this study. As can be seen from the figure, households depend on electricity bill savings that result from using electricity generated from rooftop solar pv to finance their housing costs. This revenue stream is facilitated and maintained by the CPPA which purchases electricity exported to the grid from the estate to finance the solar pv investment. The agency also compensates the municipality to reduce the loss of revenue due to the intervention in Windmill Park Estate (see table 2.1 for details). It would, however, be important to note that households in the estate still depend on the grid electricity for 50% of their energy demand.

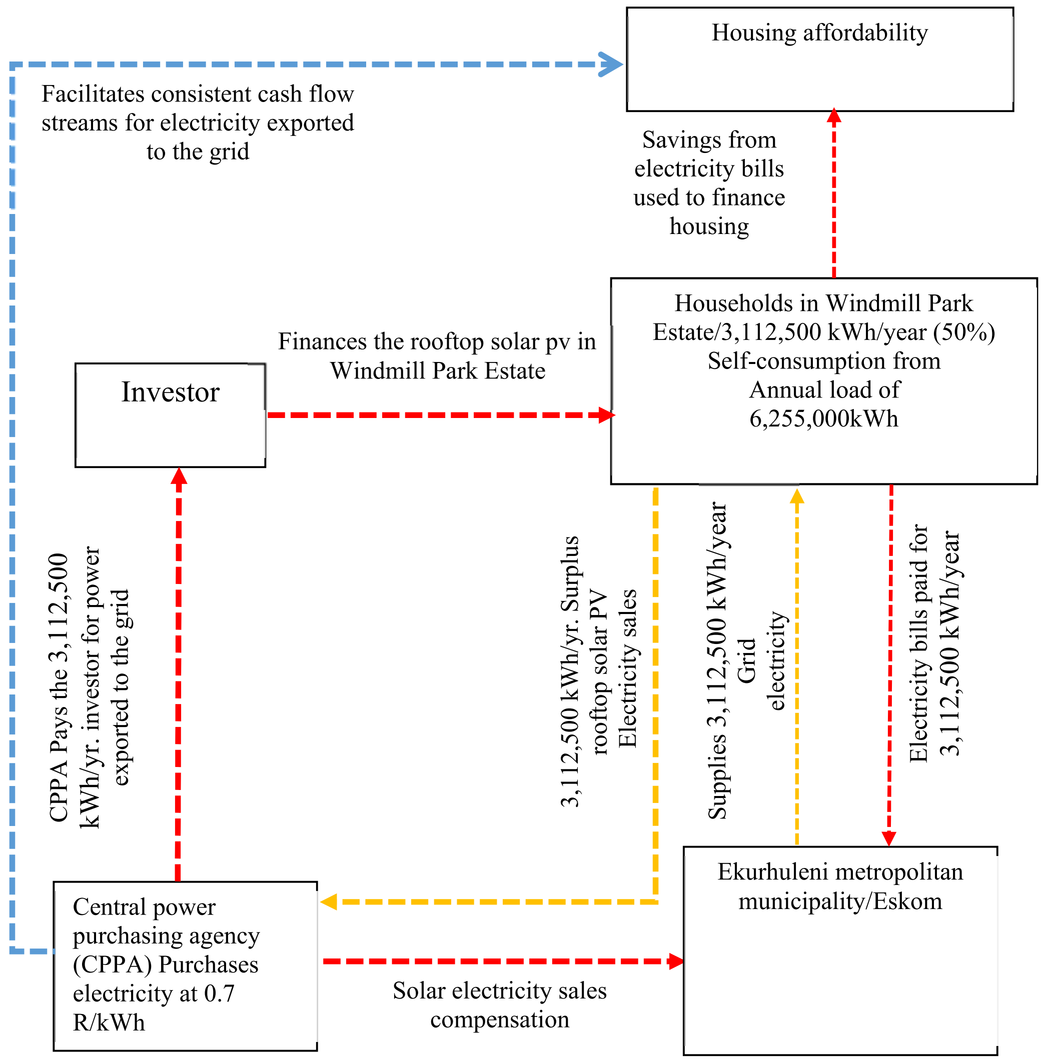

Figure 5.2. Business model

Table 5.3 below shows incomes that can be accrued from using electricity generated from installation of rooftop solar pv. What is interesting about the results presented in this table is that solar pv can shift households from a high electricity tariff block to a low electricity tariff block based on Ekurhuleni Municipality electricity tariff structure (Ekurhuleni Metropolitan Municipality, 2015). Overall, these results indicate that savings from electricity bills increase successively for each year over the lifespan of the installation in accordance with the escalating electricity tariffs. The table also shows that households are able to contribute as much as R 399 633.30 towards mortgage repayments from accrued savings in the 20th year of the rooftop solar pv installation in Windmill Park Estate.

Table 5.3. Accruing savings based on the business model

yr.	Monthly bills before solar PV with 625 kWh/Household consumption Tariff charge R/kWh 1.60 (> 600 < = 700) A.2 Block		Monthly bills after solar PV with 312.5 kWh/Household consumption Tariff charge R/kWh 0.94 (< 600) A.1 Block		Savings from electricity bills From using 50% PV power and 50% grid power (Rands)	
	Escalated tariff (Rands)	Electricity bill (Rands)	Escalated tariff	Electricity bill (Rands)	Monthly (Rands)	Annual accumulated (Rands)
1	1.60	1000	0.94	293.75	706.25	8475.00
2	1.75	1094	1.03	321.36	772.64	17746.65
3	1.91	1196.84	1.11	347.07	849.77	27943.87
4	2.07	1292.58	1.20	374.84	917.74	38956.79
5	2.23	1395.99	1.30	404.82	991.17	50850.77
6	2.41	1507.67	1.40	437.21	1070.46	63696.29
7	2.61	1628.28	1.51	472.19	1156.09	77569.41
8	2.81	1758.54	1.63	509.96	1248.58	92552.35
9	3.04	1899.23	1.76	550.76	1348.47	108734.00
10	3.28	2051.17	1.90	594.82	1456.35	126210.21
11	3.54	2215.26	2.06	642.41	1572.85	145084.46
12	3.83	2392.48	2.22	693.80	1698.68	165468.65
13	4.13	2583.88	2.40	749.30	1834.58	187483.60
14	4.46	2790.59	2.59	809.25	1981.34	211259.73
15	4.82	3013.84	2.80	873.99	2139.85	236937.99
16	5.21	3254.94	3.02	943.90	2311.04	264670.43
17	5.62	3515.34	3.26	1,019.42	2495.92	294621.51
18	6.07	3796.57	3.52	1,100.97	2695.60	326968.72
19	6.56	4100.29	3.80	1,189.05	2911.24	361903.63
20	7.09	4428.31	4.11	1,284.17	3144.14	399633.30
21	7.65	4782.58	4.44	1,386.90	3395.68	440381.41
22	8.26	5165.19	4.79	1,497.86	3667.33	484389.41
23	8.93	5578.4	5.18	1,617.69	3960.71	531917.98
24	9.64	6024.67	5.59	1,747.10	4277.57	583248.82
25	10.41	6506.65	6.04	1,886.87	4619.78	638686.20

Through the analyses of the key findings from Chapter 4, the business model for integrating rooftop solar pv in Windmill Park Estate has been established in this chapter. Scenario 2 was identified as the most viable option for the business model based on NPV calculations and the payback period. A noteworthy finding in this analysis relates to the profitability of the investment. The results have shown that rooftop solar pv investment would be a profitable investment from a social standpoint.

Results in Table 5.2 show that the pv system would pay off the upfront costs of investments of R 63 633 600.00 between the 13th and 14 the year after which a total cumulative net income of R 83 197 806.84 could be generated at the end of the 25th year based on discounted returns. The findings presented under Scenario 2 as the proposed business model also give insights about savings from electricity bills from using 50% solar pv generated electricity and 50% grid electricity. These data will be utilised in the following chapter to assess the extent to which the savings can augment housing affordability in the case study area.

Chapter 6: Consolidation of findings and overall conclusions

6.1 Introduction

The concluding chapter of this study addresses the primary research question which was stated as follows: To what extent could grid interactive embedded generation with rooftop pv enhance affordability in the gap housing market while also addressing climate change mitigation and electricity generation capacity goals of South Africa?

The chapter starts with an assessment of the key findings presented in Chapters 4 and 5 in order to substantiate on the working hypothesis of this study. By drawing upon the entire report, tying up the various theoretical and empirical strands, the study then consolidates the key finding. Conclusions and recommendations are then presented, and research gaps are highlighted for future research towards integrating rooftop solar pv in affordable housing to augment housing affordability.

6.2 Extent to which grid interactive embedded generation with rooftop pv can augment housing affordability in Windmill Park Estate

After the data in Table 5.3 were derived, the study established the extent to which the savings can augment housing affordability in Windmill Park Estate by drawing from preliminary results presented in Tables 4.1 and 4.4 in Chapter 4. Two sets of assessments were conducted including assessment for purchase affordability and rental affordability for houses in Windmill Park Estate. To establish the extent to which affordability for aspiring first time owners could be augmented, accumulated incomes from the savings from electricity bills in the 20th year were added to the FLISP and home loan qualification amounts for the various household income levels in the gap market segment. Table 6.1 compares the affordability levels when savings from electricity bills are factored to loan repayments.

Table 6.1. Housing affordability (First time ownership)

Household Monthly Income	Accessible Loan amount at 12.5% annual interest Rate	FLISP qualification	Initial Housing affordability level	Augmented Housing affordability Levels
R 15 000.00	R 396 077.76	R 10 050.00	R 406 127.76	R 805 761.06
R 14 500.00	R 382 875.16	R 13 425.00	R 396 300.16	R 795 933.46
R 14 000.00	R 369 672.57	R 16 800.00	R 386 472.57	R 786 105.87
R 13 500.00	R 356 469.90	R 19 500.00	R 375 969.90	R 775 603.20
R 13 000.00	R 343 267.39	R 23 550.00	R 366 817.39	R 766 450.69
R 12 500.00	R 330 064.80	R 26 925.00	R 356 989.80	R 756 623.10
R 12 000.00	R 316 862.21	R 30 300.00	R 347 162.21	R 746 795.51
R 11 500.00	R 303 659.61	R 33 675.00	R 337 334.61	R 736 967.91
R 11 000.00	R 290 457.02	R 37 050.00	R 327 507.02	R 727 140.32
R 10 500.00	R 277 254.43	R 40 425.00	R 317 679.43	R 717 312.73
R 10 000.00	R 264 051.84	R 43 800.00	R 307 851.84	R 707 485.14
R 9 500.00	R 250 849.25	R 47 175.00	R 298 024.25	R 697 657.55
R 9 000.00	R 237 646.65	R 50 550.00	R 288 196.65	R 687 829.95
R 8 500.00	R 224 444.06	R 53 925.00	R 278 369.06	R 678 002.36
R 8 000.00	R 211 241.47	R 57 300.00	R 268 541.47	R 668 174.77
R 7 500.00	R 198 038.88	R 60 675.00	R 258 713.88	R 658 347.18
R 7 000.00	R 184 836.29	R 64 050.00	R 248 886.29	R 648 519.59
R 6 500.00	R 171 633.69	R 66 750.00	R 238 383.69	R 638 016.99
R 6 000.00	R 158 431.1	R 70 800.00	R 229 231.10	R 628 864.40
R 5 500.00	R 145 228.51	R 74 175.00	R 219 403.51	R 619 036.81
R 5 000.00	R 132 025.92	R 77 550.00	R 209 575.92	R 609 209.22
R 4 500.00	R 118 823.33	R 80 925.00	R 199 748.33	R 599 381.63
R 4 000.00	R 105 620.74	R 84 300.00	R 189 920.74	R 589 554.04
R 3 500.00	R 92 418.14	R 87 000.00	R 179 418.14	R 579 051.44

The second assessment involved the extent to which savings can augment rent affordability with specific reference to rental rates in Windmill Park Estate. The assessment was done using savings from the first year of installation. These savings were added to the initial rental affordability amount to establish levels to which the rental affordability rate can be augmented in the first year of the installation. As stated earlier, income from electricity-bill savings increases every year, implying that rental affordability increases every consecutive year of the installation. The study did not estimate affordability increments for every year of the installation because other data such as forecasts of rental prices in the estate were necessary to carry out the investigation to that level of detail. Table 6.2 shows the results for rental housing affordability supplemented by savings from electricity bills.

Table 6.2. Rental housing affordability

Household Monthly Income	Affordable rentals (30% of income)	Low range rent in Windmill Park Estate	upper range rent in Windmill Park Estate (Rands)	Affordability in the 1st year with R 706.25 supplement
R 15 000.00	R 4 500.00	R 3 000.00	R 3 500.00	R 5 206.25
R 14 500.00	R 4 350.00	R 3 000.00	R 3 500.00	R 5 056.25
R 14 000.00	R 4 200.00	R 3 000.00	R 3 500.00	R 4 906.25
R 13 500.00	R 4 050.00	R 3 000.00	R 3 500.00	R 4 756.25
R 13 000.00	R 3 900.00	R 3 000.00	R 3 500.00	R 4 606.25
R 12 500.00	R 3 750.00	R 3 000.00	R 3 500.00	R 4 456.25
R 12 000.00	R 3 600.00	R 3 000.00	R 3 500.00	R 4 306.25
R 11 500.00	R 3 450.00	R 3 000.00	R 3 500.00	R 4 156.25
R 11 000.00	R 3 300.00	R 3 000.00	R 3 500.00	R 4 006.25
R 10 500.00	R 3 150.00	R 3 000.00	R 3 500.00	R 3 856.25
R 10 000.00	R 3 000.00	R 3 000.00	R 3 500.00	R 3 706.25
R 9 500.00	R 2 850.00	R 3 000.00	R 3 500.00	R 3 556.25
R 9 000.00	R 2 700.00	R 3 000.00	R 3 500.00	R 3 406.25
R 8 500.00	R 2 550.00	R 3 000.00	R 3 500.00	R 3 256.25
R 8 000.00	R 2 400.00	R 3 000.00	R 3 500.00	R 3 106.25
R 7 500.00	R 2 250.00	R 3 000.00	R 3 500.00	R 2 956.25
R 7 000.00	R 2 100.00	R 3 000.00	R 3 500.00	R 2 806.25

R 6 500.00	R 1 950.00	R 3 000.00	R 3 500.00	R 2 656.25
R 6 000.00	R 1 800.00	R 3 000.00	R 3 500.00	R 2 506.25
R 5 500.00	R 1 650.00	R 3 000.00	R 3 500.00	R 2 356.25
R 5 000.00	R 1 500.00	R 3 000.00	R 3 500.00	R 2 206.25
R 4 500.00	R 1 125.00	R 3 000.00	R 3 500.00	R 1 831.25
R 4 000.00	R 1 000.00	R 3 000.00	R 3 500.00	R 1 706.25
R 3 500.00	R 875.00	R 3 000.00	R 3 500.00	R 1 581.25

This section set out to establish the extent to which integrating rooftop solar pv in Windmill Park Estate can augment housing affordability. One of the more noteworthy findings to emerge from this study is that savings from electricity bills accumulate to as much as R 399 633.30 in the 20th year of installation of the system. This amount in itself is sufficient to enable households within the gap market segment to access housing in Windmill Park Estate without mortgage finance or FLISP. House prices in the estate range from R 285 000 and R 340 000. From the data presented in Table 6.1, after mortgage and FLISP supplements the lowest housing affordability range for households after integrating solar pv could move up to R 579 051.44 for households earning R 3 500, and the highest housing affordability range could move up to R 805 761.06 in the 20th year.

The second major finding was that rental affordability has also increased. Table 6.2 shows rental housing affordability before and after integrating rooftop solar pv in Windmill Park Estate. Initial rental affordability was set at 30% of the household income. From the table, we can see that after integrating solar pv, the income bracket for households able to afford rental housing in the estate increased. The entry level rental housing affordability income bracket has reduced from R 10 000 to R 8 000. However, it is important here to note that electricity-bill savings included in this analysis only represent first-year bill savings. From the data presented in Table 5.3, electricity-bill savings increase on an annual basis from R 706.25/month in the 1st year to R 4 619.78/month in the 25th year of the installation. The affordability levels in the years following the 1st year of installation, however, are subject to rental prices in those particular time periods because rent prices are subject to change (either to increase or reduce) depending on prevailing economic conditions in each period.

The combination of findings provides support for the working hypothesis for this study that grid interactive embedded generation with rooftop pv can augment affordability of housing in the gap housing market.

6.3 Interpretation of findings

In this study, the generation potential for solar pv from the available rooftop area in Windmill Park Estate was established. This was done with the specific aim of determining the extent to which grid interactive embedded generation with rooftop pv could enhance housing affordability in the gap market segment while also addressing climate change and electricity generation capacity goals of South Africa. The study has focused on establishing the generation potential from the estate to determine how much income can be generated from exporting generated electricity to augment housing affordability in the complex. By drawing from the findings presented in Section 6.2, this section explains the importance of integrating rooftop solar pv in affordable housing to provide additional insights into the following:

- South Africa's electricity generation capacity goals
- Significance to Africa's GHG- emissions reduction

6.3.1 South Africa electricity generation capacity goals.

South Africa has set arduous electricity generation capacity goals to meet projected demand for electricity. Eskom's electricity demand projections show that the country will need to increase electricity supply by 77 960 MW by 2025 because of the expected economic growth (Inglesi and Pouris, 2010). The current electricity crisis, however, shows that Eskom lacks the capacity to deliver desired levels of electricity. Through the Integrated Resource Plan for Electricity 2010-2030, the Department of Energy (2011) has laid down a proposed electricity generation through new-build fleet for South Africa to sustain electricity needs of the growing economy.

Rooftop solar pv has been recognized as one of the energy sources that can make a significant contribution to the transformation of the electricity generation sector. The Integrated Resource Plan for Electricity 2010-2030 indicates that solar pv solutions can contribute about 8 400 MW to the expected electricity demand. The key significant finding emerging from this study is that rooftop solar pv has the potential to reduce demand for Eskom electricity and increase supply to supplement the grid. Although the current study is based on a small case study area, the finding that 7.8 MWh of clean energy can be generated from 1 361.44m^2 of rooftop area is very encouraging. The correlation between available roof area and the quantity of electricity that can be generated from solar pv implies that results from this study could be transferable to other residential rooftop spaces in the country. Nonetheless, caution must be exercised when extrapolating this data because of the localised nature of solar pv electricity generation and other factors that influence capabilities to export to the grid. An important fact to keep in mind, though, is that South Africa, in general, has abundant solar resource which significantly enhances the generation potential of rooftops as demonstrated through this study..

Given that a significant portion of South Africa's built up area is comprised of residential buildings of different types, rooftop solar pv for residential buildings can significantly enhance South Africa's electricity generation capacity goals as guided by the findings of this study. Overall findings of the report support the IRP goal of solar pv's contribution to the country's generation potential. However, even greater consideration should be given to deployment of solar pv in residential buildings given the two-fold benefits of electricity generation coupled with improved housing affordability as demonstrated by the findings presented in this study.

6.3.2 Significance to Africa's GHG emissions reduction

The assessment on the Integration of solar pv on residential houses in Windmill Park Estate has demonstrated that the technology-system has the potential to make households zero net consumers of grid electricity. South Africa's residential sector consumes about 17% of Eskom's electricity thus indicating that integrating solar pv in residential buildings can reduce this percentage significantly (Department of

Environmental Affairs, 2014). In 2014/15, Eskom (2015b) distributed 11 586 GWh of electricity to 5 338 723 of its residential customers at a CO_2 emission rate of 1.01 tons for every MWh of electricity generated. This translates to 11 701 860 tons of CO_2 emissions in that period alone. As per the case study findings discussed in Section 5.2.3, a 50% up take scenario of rooftop solar pv can reduce this emission by 5 850 930 tons/year (5 850.93 Gg CO_2 eq) in the residential sector in South Africa. This can be a significant contribution towards CO_2 emission reduction for the country considering that this sector contributed 170 964 Gg CO_2 eq in the period 2000-2010 (Department of Environmental Affairs, 2014:73).

6.4 Conclusions and recommendations

This study sought to answer the research question: To what extent could grid interactive embedded generation with rooftop pv enhance affordability in the gap housing market while also addressing climate change and electricity generation capacity goals of South Africa? The study has provided an overview of the generation potential in the case study and proposed a business model to apply for deploying rooftop solar pv in the gap housing market. The study has also endeavoured to determine the income generation potential from solar pv and established the extent to which such an intervention could enhance housing affordability in the gap housing market. The significance of the findings towards reducing South Africa's GHG emissions and the contribution to climate change mitigation have been highlighted.

Based on the available rooftop area in the case study presented in Table 4.6, the study has demonstrated solar pv generation potential of 7 848 000.71 kWh annually. From this, the study calculated the amount that could be exported to the grid by using an estimate of annual electricity consumption in the complex. The annual electricity consumption in the complex was estimated at 7 500 kWh/per annum per household which added up 6 225 000 kWh for the estate. The analysis in Section 5.2.3 demonstrated that the generation potential of the available rooftop space was adequate to meet the household electricity demands in the estate. This, however, did not prove to make a viable business sense as the analysis also demonstrated that the payback for the system would not be met within the entire lifespan of the system. This necessitated further analysis to establish a viable option to export electricity to the grid that would make financial sense for the required investment. In addition, the option also had to augment housing affordability for households in Windmill Park Estate. The option that proved most viable is presented in Table 5.2. In this option, electricity consumption for households in the estate was reduced by 50% in order to allow for the other 50% to be exported to the grid.

The results from exporting 50% solar pv generated electricity to the grid confirm that grid interactive embedded generation with rooftop pv can significantly augment affordability of housing in the gap housing market. The most expensive house in the case study area is R 340 000 whereas the total savings from electricity bills that can contribute to housing finance is R 399 633.30 in the 20th year. From this finding, we can deduce that integrating rooftop solar pv in Windmill Park estate would enable households to finance 100% of the purchase price. Furthermore, the entry-level rental housing affordability income bracket improved from R10 000 to R8 000 in the first year of the installation.

It is evident from this study that grid interactive embedded generation with rooftop pv can significantly augment affordability of housing in the gap housing market. What is now needed is a cross-national study on how the business model developed in this study can be adapted for other housing typologies to encourage the adoption of rooftop solar pv for clean energy generation. It is stated in Chapter 4 that Windmill Park Estate in an estate developed to meet housing needs for the growing gap housing market in South Africa. But nonetheless, most of the existing houses and new housing developments in South Africa exhibit similar characteristics in that they have rooftop areas that could be utilised for rooftop solar pv installations.

Further work also needs to be done to establish how the proposed business model can be utilised by housing developers in affordable housing delivery. As highlighted in Chapter 2, housing developers are not attracted to affordable housing developments because of the limited profit margins associated with the production of such housing. The attractive financial gains presented in the findings in Chapter 5 and 6 with regards to investing on rooftop solar pv should be a motivating factor to attract more housing developers to invest in affordable housing supply.

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Appendices

Appendix A: FLISP subsidy tables

No	Lower FLIP	Higher FLISP	Amount	No	Lower FLIP	Higher FLISP	Amount
1	R3 501	R3 600	R87 000	24	R5 801	R5 900	R71 475
2	R3 601	R3 700	R86 325	25	R5 901	R6 000	R70 800
3	R3 701	R3 800	R85 650	31	R6 501	R6 600	R66 750
4	R3 801	R3 900	R84 975	32	R 6 601	R 6 700	R 66 075
5	R3 901	R4 000	R84 300	33	R6 701	R6 800	R65 400
6	R4 001	R4 100	R83 625	34	R6 801	R6 900	R64 725
7	R4 101	R4 200	R82 950	35	R6 901	R7 000	R64 050
8	R4 201	R4 300	R82 275	36	R7 001	R7 100	R63 375
9	R4 301	R4 400	R81 600	37	R7 101	R7 200	R62 700
10	R4 401	R4 500	R80 925	38	R7 201	R7 300	R62 025
11	R4 501	R4 600	R80 250	39	R7 301	R7 400	R61 350
12	R4 601	R4 700	R79 575	40	R7 401	R7 500	R60 675
13	R4 701	R4 800	R78 900	41	R7 501	R7 600	R60 000
14	R4 801	R4 900	R78 225	42	R7 601	R7 700	R59 325
15	R4 901	R5 000	R77 550	43	R7 701	R7 800	R58 650
16	R5 001	R5 100	R76 875	44	R7 801	R7 900	R57 975
17	R5 101	R5 200	R76 200	45	R7 901	R8 000	R57 300
18	R5 201	R5 300	R75 525	46	R8 001	R8 100	R56 625
19	R5 301	R5 400	R74 850	47	R8 101	R8 200	R55 950
20	R5 401	R5 500	R74 175	48	R8 201	R8 300	R55 275
21	R5 501	R5 600	R73 500	49	R8 301	R8 400	R54 600
22	R5 601	R5 700	R72 825	50	R8 401	R8 500	R53 925
23	R5 701	R5 800	R72 150	51	R8 501	R8 600	R53 250

No	Lower FLIP	Higher FLISP	Amount	No	Lower FLIP	Higher FLISP	Amount
52	R8 601	R8 700	R52 575	85	R 11 901	R 12 000	R 30 300
53	R8 701	R8 800	R51 900	86	R 12 001	R 12 100	R 29 625
54	R8 801	R8 900	R51 225	87	R 12 101	R 12 200	R 28 950
55	R9 001	R9 000	R50 550	88	R 12 201	R 12 300	R 28 275
56	R9 001	R9 100	R49 875	89	R 12 301	R 12 400	R 27 600
57	R9 101	R9 200	R49 200	90	R 12 401	R 12 500	R 26 925
60	R 9 401	R 9 500	R 47 175	91	R 12 501	R 12 600	R 26 250
61	R 9 501	R 9 600	R 46 500	92	R 12 601	R 12 700	R 25 575
62	R 9 601	R 9 700	R 45 825	91	R 12 501	R 12 600	R 26 250
63	R 9 701	R 9 800	R 45 150	92	R 12 601	R 12 700	R 25 575
64	R 9 801	R 9 900	R 44 475	93	R 12 701	R 12 800	R 24 900
65	R 9 901	R 10 000	R 43 800	94	R 12 801	R 12 900	R 24 225
66	R 10 001	R 10 100	R 43 125	95	R 12 901	R 13 000	R 23 550
67	R 10 101	R 10 200	R 42 450	94	R 12 801	R 12 900	R 24 225
68	R 10 201	R 10 300	R 41 775	95	R 12 901	R 13 000	R 23 550
69	R 10 301	R 10 400	R 41 100	101	R 13 501	R 13 600	R 19 500
70	R 10 401	R 10 500	R 40 425	102	R 13 601	R 13 700	R 18 825
71	R 10 501	R 10 600	R 39 750	103	R 13 701	R 13 800	R 18 150
72	R 10 601	R 10 700	R 39 075	104	R 13 801	R 13 900	R 17 475
73	R 10 701	R 10 800	R 38 400	105	R 13 901	R 14 000	R 16 800
74	R 10 801	R 10 900	R 37 725	106	R 14 001	R 14 100	R 16 125
75	R 10 901	R 11 000	R 37 050	107	R 14 101	R 14 200	R 15 450
76	R 11 001	R 11 100	R 36 375	108	R 14 201	R 14 300	R 14 775
77	R 11 101	R 11 200	R 35 700	109	R 14 301	R 14 400	R 14 100
78	R 11 201	R 11 300	R 35 025	110	R 14 401	R 14 500	R 13 425
79	R 11 301	R 11 400	R 34 350	111	R 14 501	R 14 600	R 12 750
80	R 11 401	R 11 500	R 33 675	112	R 14 601	R 14 700	R 12 075
81	R 11 501	R 11 600	R 33 000	113	R 14 701	R 14 800	R 11 400
82	R 11 601	R 11 700	R 32 325	114	R 14 801	R 14 900	R 10 725
83	R 11 701	R 11 800	R 31 650	115	R 14 901	R 15 000	R 10 050
84	R 11 801	R 11 900	R 30 975				

Appendix B: Structured interview guide

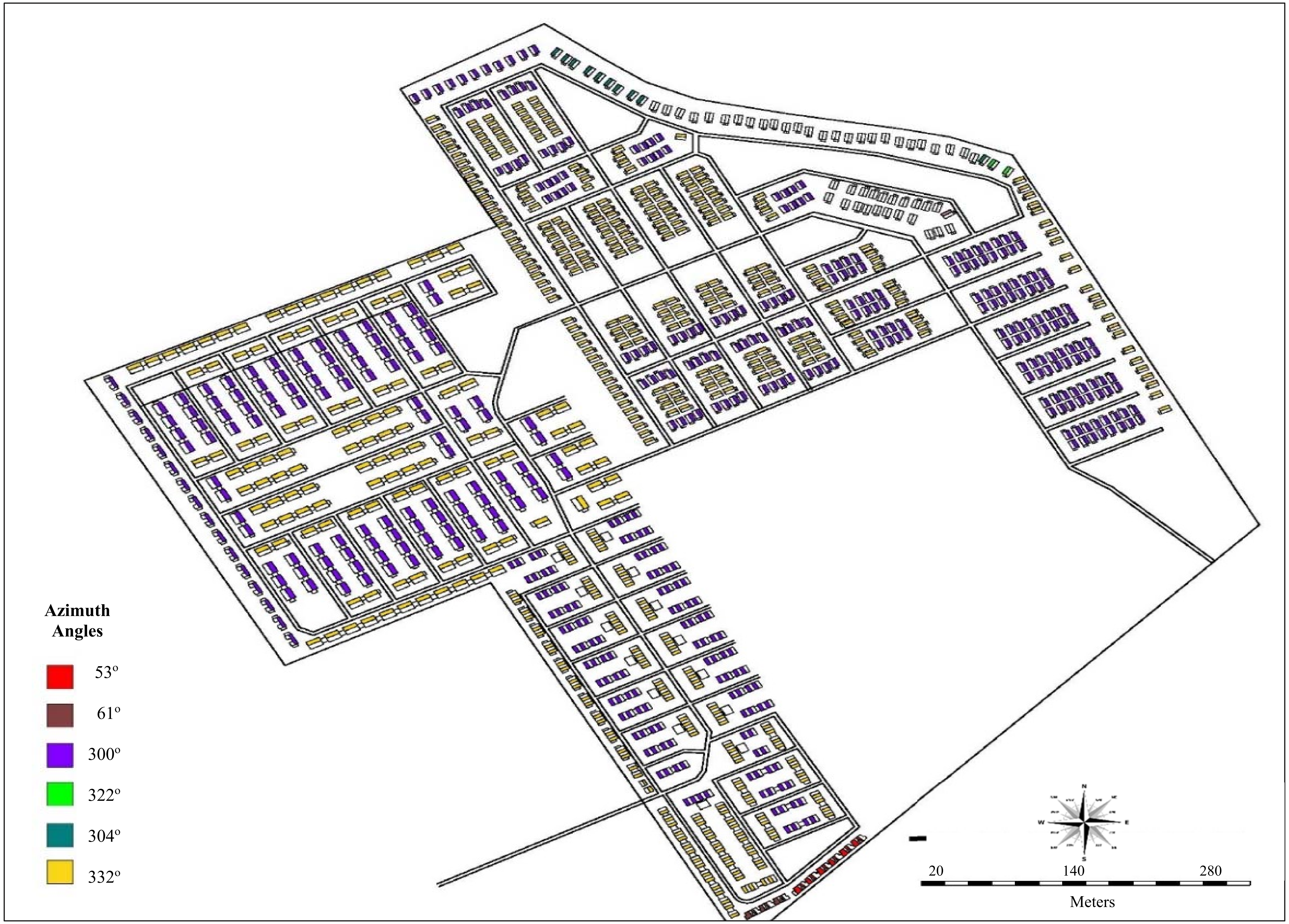
NatRent (interview questions)

How many house-types are in Windmill Park Estate?

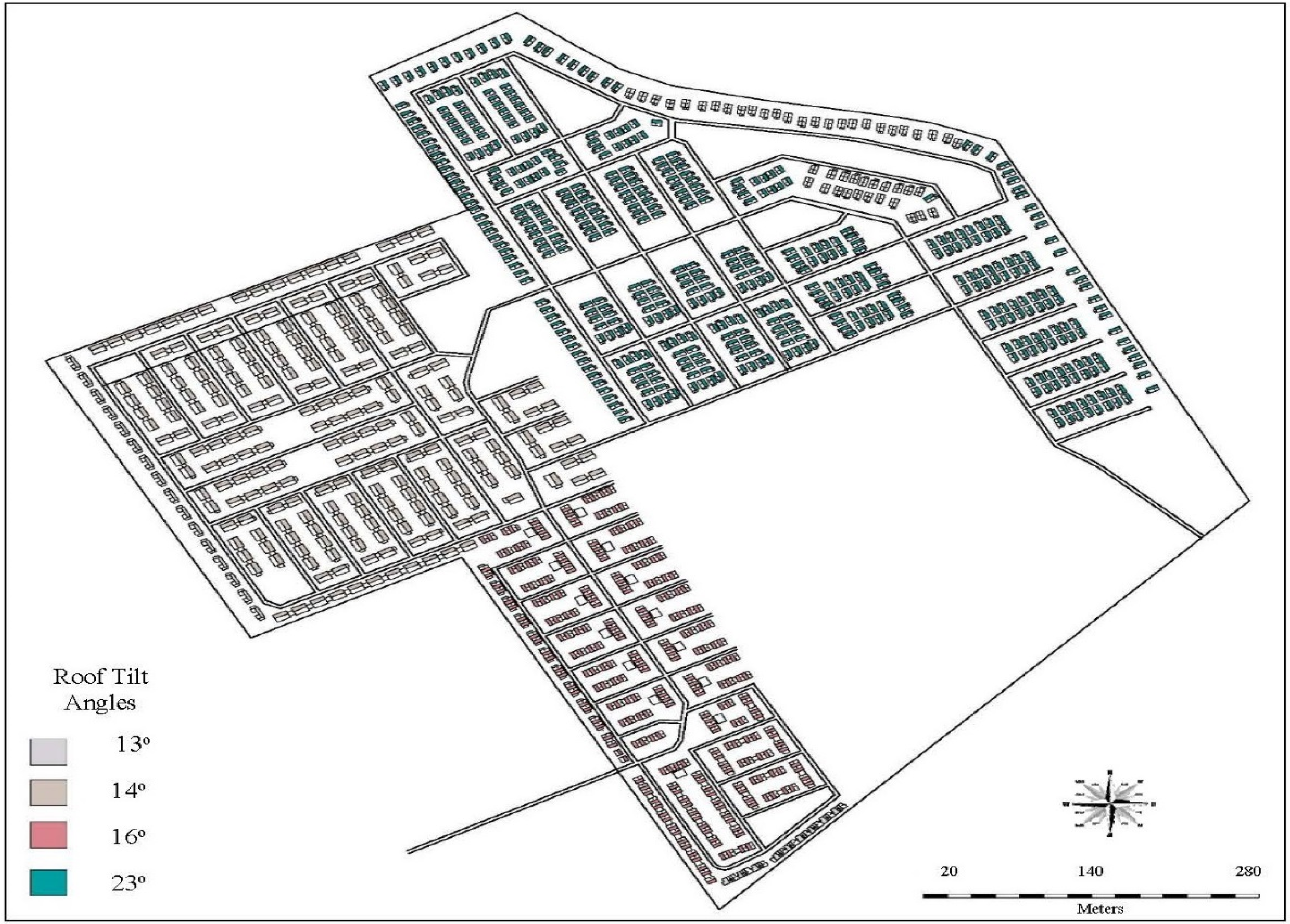
What is the cost for the individual house types?

How are the electricity demand patterns in Windmill park estate in winter and summer?

Appendix C: Digitised rooftop surfaces grouped according to azimuth orientation angles



Appendix D: Digitised rooftop surfaces grouped according to azimuth orientation angles



Appendix E: Ethics clearance

SCHOOL OF ARCHITECTURE AND PLANNING
HUMAN RESERCH ETHICS COMMITTEE

ACKNOWLEDGEMENT OF RETROSPECTIVE APPLICATION FOR ETHICS CLEARANCE
PROTOCOL NUMBER: SOAP48/24/06/2016

PROJECT TITLE:	Innovative green finance for renewable energy interventions in gap housing for South Africa - A case study of rooftop PV for Windmill Park residential complex, Johannesburg
INVESTIGATOR/S:	Besa Kaluba
SCHOOL:	Architecture and Planning
DEGREE PROGRAMME:	MArch in Sustainable and Energy Efficient Cities
DATE CONSIDERED:	20th June 2016
DECISION OF THE COMMITTEE:	Retrospective Acknowledgement
EXPIRY DATE:	20th June 2017

CHAIRPERSON
(Professor Daniel Irurah)

DATE:

cc: Supervisor/s: Prof. Daniel Irurah

DECLARATION OF INVESTIGATORS

I/We acknowledge that appropriate permission should have been sought, this acknowledgement does not entitle the applicant to conduct further research under this protocol number.

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