An investigation into the financial impact of residential Rooftop PV on Stellenbosch Municipality

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Declaration

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Abstract

Worldwide, electricity utilities are recognising and responding to the threat that a large uptake of rooftop photovoltaic (PV) solar installations might have on their traditional business model, based on volumetric sales. Likewise, in South Africa there is a concern that the trend of households investing in rooftop PV might have significant impact on the business model of electricity delivery services by Eskom and local governments. Since South African municipalities are responsible for managing electricity distribution, they face similar challenges to traditional energy utilities across the world. Historically, South African municipalities served as local distributors of electricity and many municipalities relied on the revenue generated from electricity sales to cross-subsidise other services that were underfunded. If the number of rooftop PV installations continues to rise in South Africa, this might have a negative impact on the financial balance of South African municipalities. This research investigates the financial impact that increasing installations of grid-connected rooftop PV at a household level might have on local governments, using Stellenbosch Municipality as a case study. An extreme-case scenario approach is used to measure the financial impact. Assumed in this scenario is that the absolute maximum of installed embedded generated electricity, as set by NRS standard, will be channeled back to the grid by households. The NRS standard provides a guide as to how much maximum installed embedded generated electricity can be fed to the grid before an in-depth grid study needs to be conducted. The research looks specifically at the residential areas in Stellenbosch with high electricity use, determined by an examination of the electricity use in the different suburbs. Moreover, criteria are set to determine which households from these high electricity use suburbs may be regarded as potential investors in solar rooftop PV. If these criteria are applied, it means 541 households could (each) potentially connect a 3

kWp rooftop PV system. This leads to an annual reduction of approximately ZAR 1.3 million in the municipality's expenditure for the electricity supply from Eskom. It also leads to a loss in income of ZAR 3.7 million by the municipality as a result of electricity sales reduction, resulting in a net loss of ZAR 2.4 million. The net loss would be equivalent to a 0.6% financial reduction on the total electricity revenue of ZAR 413.7 million for the municipal financial year 2013/2014. If the maximum grid capacity approach were practised, this would mean 2 255 households would be able to connect a 3 kWp solar system to the grid. This would result in a loss in income of ZAR 15.3 million and a saving of ZAR 5.5 million. The net loss would be ZAR 9.8 million, which would be equivalent to a 2.4% reduction on the total electricity revenue of ZAR 413.7 million for the municipal financial year 2013/2014.

Opsomming

Elektrisiteitsverskaffers oor die wêreld heen gee erkenning aan en reageer op die moontlike bedreiging wat grootskaalse gebruik van dak-fotovoltaïese (FV) soninstallasies vir hul tradisionele sakemodelle op volumetriese skaal kan inhou. In Suid-Afrika is daar ook kommer dat die neiging van huishoudings om dak-FV stelsels te installeer aanmerklike gevolge vir die sakemodelle van elektrisiteitsdiensverskaffers soos Eskom en plaaslike regerings kan hê. Aangesien Suid-Afrikaanse munisipaliteite verantwoordelik is vir die bestuur van elektrisiteitsverspreiding, kom hulle voor soortgelyke uitdagings as tradisionele energieverskaffers oor die wêreld heen te staan. Suid-Afrikaanse munisipaliteite dien vir geruime tyd reeds as plaaslike verspreiders van elektrisiteit en talle munisipaliteite is afhanklik van die inkomste wat uit elektrisiteitsverkope gegenereer word om ander dienste wat onderbefonds is, te kruissubsidieer. Indien dak-FV installasies voortgaan om in Suid-Afrika toe te neem, kan dit ŉ negatiewe impak op die finansiële balans van Suid-Afrikaanse munisipaliteite hê. In hierdie studie is ondersoek ingestel na die finansiële impak wat toenemende installasies van netwerkgekoppelde dak-FV installasies op huishoudelike vlak op plaaslike regerings kan hê, met Stellenbosch Munisipaliteit as gevallestudie.

ŉ Uiterstegeval-scenario-benadering is gebruik om die finansiële impak te bereken. In hierdie scenario is aanvaar dat die absolute maksimum geïnstalleerde ingebedde gegenereerde elektrisiteit, soos volgens NRS-standaard bepaal, deur huishoudings terug na die netwerk gelei sal word. Die NRS-standaard verskaf ŉ gids rakende die hoeveelheid maksimum geïnstalleerde ingebedde gegenereerde elektrisiteit wat in die netwerk gevoer kan word voordat ŉ diepte-netwerkstudie uitgevoer moet word. Daar is spesifiek gekyk na woongebiede in Stellenbosch met hoë

elektrisiteitsverbruik, wat bepaal is deur ŉ ondersoek na die elektrisiteitsverbruik in die onderskeie voorstede.

Kriteria is gestel om te bepaal watter huishoudings in hierdie voorstede met hoë elektrisiteitsverbruik as potensiële beleggers in dak-FV stelsels beskou kan word. Indien hierdie kriteria toegepas word, beteken dit dat 541 huishoudings (elk) moontlik ŉ 3 kWp-dak-FV stelsel kan koppel. Dit sal lei tot ŉ jaarlikse verlaging van ongeveer ZAR1.3 miljoen in die Munisipaliteit se uitgawes vir elektrisiteitsverskaffing deur Eskom. Dit lei ook tot ŉ verlore inkomste van ZAR3.7 miljoen deur die Munisipaliteit as gevolg van verlaging van elektrisiteitsverkope, wat tot ŉ netto verlies van ZAR2.4 miljoen sal lei. Die netto verlies sal gelykstaande wees aan ŉ 0.6%- finansiële verlaging van die totale elektrisiteitsinkomste van ZAR413.7 miljoen vir die munisipale finansiële jaar 2013/2014. As die maksimum-netwerkkapasiteitsbenadering toegepas sou word, sal dit beteken dat 2 255 huishoudings ŉ 3 kWp-sonstelsel aan die netwerk sal kan koppel. Dit sal lei tot ŉ verlore inkomste van ZAR15.3 miljoen en ŉ besparing van ZAR5.5 miljoen. Die netto verlies sal ZAR9.8 miljoen wees, wat gelykstaande is aan ŉ 2.4%-verlaging van die totale elektrisiteitsinkomste van ZAR413.7 miljoen vir die munisipale finansiële jaar 2013/2014.

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List of Acronyms and Abbreviations

BIT	Block Incline Tariff
CS	Community Solar
DG	Distributed Generation
DoE	Department of Energy
CFO	Chief Financial Officer
EDI	Electricity Distribution Industry
EE	Energy Efficiency
EEG	Embedded Energy Generator
EG	Embedded Generation
EIUG	Energy Intensive User's Group
ESKOM	Electricity Supply Company
ESLC	Electricity Suppliers Liaison Committee
EWWS	Electricity Water & Waste Services
FiT	Feed-in Tariff
GDP	Gross Domestic Product
GW	Gigawatt
GWh	Gigawatt hour
HV	High Voltage
IIC	Innovation Infrastructure Committee
IPP	Independent Power Producer
IRP	Integrated Resource Plan
kW	Kilowatt
kWh	Kilowatt hour
kWp	Kilowatt power
LRAM	Lost Revenue Adjustment Mechanisms
LSM	Living Standards Measure

LV	Low Voltage
MEC	Mineral Energy Complex
MIG	Manufacturers Interest Group
MV	Medium Voltage
MVA	Mega Voltage Ampere
MW	Megawatt
NERSA	National Energy Regulator of South Africa
NMD	Notified Maximum Demand
PV	Photovoltaic
RE	Renewable Energy
REFIT	Renewable Energy Feed-In Tariff
REIPPPP	Renewable Energy Power Producer Procurement Programme
RES-E	Renewable Energy Systems for Electricity
SAPVIA	South African Photovoltaic Industry Association
SWH	Solar Water Heater
TOU	Time-of-Use
TWh	Terrawatt hour
VFTPC	Victoria Falls and Transvaal Power Company
VOST	Value of Solar Tariffs
Wp	Watt power

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Chapter 1 – Introduction

1.1 Change of traditional electricity market

Global megatrends such as rapid urbanisation, resource scarcity, technical breakthroughs, climate change, and demographic and social change are at the root of an energy transformation (PWC, 2014). In the light of abstract socio-technical transitions, this study endeavours to understand the more practical implications of such transitions in the South African context. Worldwide, the uptake of consumer-based power generation technologies has increased and in some places even boomed, causing a disruption in a once robust regime of centralised vertically integrated electricity utilities. One of the most rapidly growing technologies is rooftop photovoltaic (PV). Electricity utilities across the world are feeling the threat of the rapid expansion of rooftop PV on their revenue. Utilities managed to not only recover costs through a volumetric sales system but also to generate a surplus or profit on top of it. Since households are able to produce their own decentralised electricity through rooftop PV, and thereby reduce their consumption from the grid, sales of utilities are threatened. Rooftop PV therefore serves as a disruptive technology to the traditional order that has worked well for decades.

In principle, South African municipalities are responsible for the network and electricity delivery, mostly within their jurisdictional border. They face similar challenges to traditional energy utilities across the world. This study seeks to find an answer on what the financial impact would be on South African municipalities and in particular, Stellenbosch Municipality. This introductory chapter will initially provide a background to contextualise the topic. After providing the background, the research will be further refined with the research question and objectives of the study set out that are leading throughout this research.

1.2 Background

In South Africa, at least 86% of the total electricity produced is coal based (Pegels, 2010:494). South Africa is the largest producer of greenhouse gas emissions on the continent, and in contrast to other developing countries with relatively low GDP and high rates of poverty; the emissions per capita are high. These are comparable to many EU countries like Germany and the United Kingdom, and almost five times higher than similar developing countries such as Brazil and India (Baker, Newell, & Phillips, 2014). According to Winkler & Marquand (2009) the largest share of emissions in South Africa comes from the energy sector. The electricity sector is responsible for 47% of the emissions and the coal-to-liquids process produces another 10%. The extreme energy and electricity intensity partly reflects the abundance of coal but more importantly, the historical under-pricing of coal and electricity by authorities. Eskom, the national electricity provider, proposed a price agreement with the government in 1991 to reduce the real price of electricity to benefit electricity intensive industries and put them in a competitive position on the international market (Kohler, 2014). Apart from carbon emissions, the generation of electricity from coal is very water intensive (de Groot, van der Veen, & Sebitosi, 2013). This is particularly not desirable in an already water constrained country like South Africa. Coal may be seen as reliable and affordable at present, but in future the cost of the damage that coal power causes, will far outweigh the initial savings.

Moreover, the current South African national electricity reserve margin is under huge constraint and blackouts as experienced in 2008 are currently occurring regularly across the country. South Africa’s electricity network, owned and controlled by Eskom, has a total generation capacity of 42 000 MW. Almost a quarter of this generation capacity is not functioning, mainly due to maintenance issues. In addition, mass electrification, strong economic growth in a number of sectors and inadequate maximum load planning resulted in unmet electricity demand (Krupa & Burch, 2011). According to Roula Inglesi-Lotz & Blignaut

(2014), the electricity supply shortages are partially a result of the political, social and economic changes the country has undergone in the past two decades. Two new coal-fired electricity power plants, Kusile and Medupi are still not functioning to complement the already constrained grid. As a result of Eskom's backlog in maintenance and a constrained reserve margin, the electricity prices are increasing dramatically every year. The National Energy Regulator of South Africa (NERSA) opted, at the end of February 2013, for an increase of 8% for each year (SAPA, 2013). NERSA called on municipalities to submit applications to increase the electricity tariffs, and approved a municipal electricity tariff guideline increase of 7% for the year 2013/2014. The increase in tariffs for Eskom's centralised supply of electricity and a decrease in costs to produce energy from renewable sources results in a competitive advantage for renewable energy technologies. For a long time renewable energy could not compete with the cheap coal in the country, but current trends indicate the price for coal-based electricity is increasing while the costs of producing energy from renewable resources is decreasing (Walwyn & Brent, 2015).

The recent load-shedding events and the black out in 2008 show that the dependency on Eskom has an effect on both businesses and citizens within municipalities. According to Mcdonald (2009) a survey undertaken by the Western Cape Investment and Trade Promotion Agency, electricity reliability is the second largest constraint to business growth. Electricity failures are viewed as paralysing the economy. According to energy expert Chris Yelland, Eskom's load-shedding events since December 2014 have caused a serious negative impact on the South African economy (Writer, 2015). In an article written by Van der Nest (2015), Chris Yelland points out that stage 1 of controlled blackouts resulting in 10 hours of load shedding per day for 20 days in a month, costs the economy R20 billion. Using the same time parameters, stage 2 is estimated to result in losses of R40 billion per month, and stage 3 in losses totalling R80 billion per month. These costs affecting the productive economy are based on R100 per kWh of unserved energy. When considering South Africa's GDP of approximately R4 trillion in 2014, this means, by estimation, that 1% to 2% of GDP could be wiped out per month with controlled blackouts (Van der Nest, 2015). Locally within municipalities the damage is also being felt. The chairperson of the South African Photovoltaic Industry Association, David Chown, says that economic activity is being lost because of the power cuts, which damage small businesses in particular. Combined with the effect on jobs this is already eroding municipal revenues (Donnelly, 2015). This results in the question of whether alternative energy is a liability or an asset on the balance sheet. On the one side solar PV system investments by citizens might negatively affect the finance of a municipality in terms of loss in sales. On the other hand, it might have a positive effect in terms of partly relieving the electricity constraint on the economy and development of the town. This issue will be explored in depth in the research findings and analysis chapter of this study.

The above scenarios create a platform conducive to the growth of alternative power generation. The most recent adjusted IRP in 2013 has a dedicated a chapter on embedded energy, in contrast to the IRP of 2011 in which embedded generation was not mentioned at all. The South African government states in the new IRP that given the progress and reduction of cost of photovoltaic generation, it is expected that electricity consumers will start installing small-scale distributed generation to meet electricity requirements. This trend will also be stimulated by the rising electricity costs of Eskom's electricity. According to Janisch, Euston-Brown, & Borchers (2012) electricity departments used to show resistance to initiatives such as solar water heaters and energy efficiency programmes that were linked to reduced sales of electricity and the threat of revenue loss. The recent IRP shows an acceptance that changes are inevitable and that a managed response is desirable. The IRP (DoE, 2013) acknowledges that this trend may proceed with or without the support and approval of national and local governments but that it would be prudent to be proactive in incentivising the appropriate implementation in order to derive social benefits from this development, rather than watching from the side lines and a potentially sub-optimal result because authorities only considered the risk rather than the opportunities (DoE, 2013). The question that unfolds from here is ‘what is the cost for municipalities of hanging on in the *business as usual* mode’ or ‘what is the cost of doing business differently’? So what would the cost be of unregulated rooftop PV, and what would the cost be of regulated and monitored rooftop PV?

1.3 Refining the topic

I intend to focus my research on the impact of rooftop solar PV investments by residential electricity consumers on South African municipalities. In this research Stellenbosch Municipality is used as a case study.

In the light of sustainability, it is important for the municipalities to transition away from selling coal-based conventional energy from Eskom, to the acceptance and stimulation of renewable energy technologies. Since municipalities are functioning as electricity distributors and are the closest authority to citizens, they form a key role in transitioning towards decentralised renewable energy and energy efficiency. However, this transition is not without consequences and will impact the municipality, especially in financial terms. One of the first and most important concerns for politicians is the risk of revenue loss as a result of Renewable Energy Technology (RET) interventions within municipal electricity distribution borders. The surplus on the revenue is used to supplement the municipal coffers and to cross-finance other services that are underfunded. According to Swilling (2013) without cross-subsidisation in the City of Cape Town, it would not have been possible to provide services for all in a city divided by class. According to a report written by the Western Cape Government (2013) the most pressing challenge for governments is to provide adequate services and also to improve living conditions for the urban poor, and to do this financial resources are needed. It is therefore not surprising that municipalities take a protective stance when there is a threat to revenue income from which services are financed. The protection of revenue is perceived as one of the main reasons not to embrace alternative forms of energy used by citizens. As such, there is a locked-in disincentive to encourage citizens to save electricity and a good incentive to limit investment in residential embedded generation (Western Cape Government, 2013).

Although there are more electricity consumer categories that could have been investigated, this study will look specifically at the residential sector and what the impact will be on the budget of local municipalities if households are going to invest in solar rooftop PV on a large scale. The decision was made to use the residential sector to be the focal point of this study for a number of reasons. Firstly, with nearly 60% of total consumption, this is the largest electricity income source for Stellenbosch Municipality according to their budget plan. Moreover, it is the residential sector that causes most of the fluctuations in electricity usage, with increased electricity usage during peak hours (Ijumba, Sebitosi, & Pillay, 2008). The final factor is the historical division between rich and poor residential areas, which is still very apparent in Stellenbosch. Stellenbosch is one of the most unequal municipalities in South Africa. It is believed that the rich residents, through high electricity consumption levels and the inclining block tariff (IBT) system, and therefore, higher contributions to the surplus on electricity revenue are in essence cross-financing the poor. If the rich were to invest in embedded generation, the cream would be taken off the surplus, which could have been used to subsidise services for the poor.

1.4 Research question, aim and objectives

The assumption is made that middle- to high-use households in Stellenbosch Municipality will invest in rooftop solar PV systems and that the maximum grid capacity to receive embedded generation will be fully utilised. This study will be based on actual data from a sample PV system in Stellenbosch giving the solar output of the system on particular days over the municipal financial year 2013/2014. For a given design, the performance of a PV system is influenced by climatic and operational factors. Therefore, the outcome of the study might differ in proportion as variables change. This thesis aims to find out what exactly the impact is of rooftop PV installations on the electricity revenue of Stellenbosch Municipality.

The following main question is formulated:

What will be the impact on Stellenbosch Municipality's electricity revenue if households in identified high electricity use suburbs install the maximum capacity for embedded generation according to NRS standard to feedback electricity produced by rooftop PV to the grid?

In order to find an answer to this question the following objectives are formulated:

<u>Theoretical framework</u>

- Building a theoretical framework that analyses the threat to traditional business models of utilities across the world and to expose and compare different perspectives on the matter
- To narrow down on the South African realm of decentralised electricity and provide an in-depth analysis of the financial challenges of service delivery for South African municipalities

<u>Case study</u>

- To analyse and contextualise financial dependency on electricity revenue and electricity service provision, in the socio-economically diverse town of Stellenbosch Municipality
- To model the impact of solar rooftop PV systems by households on electricity consumption profile and electricity revenue of Stellenbosch Municipality in order to inform meaningful planning practice

1.5 Personal motivation for the study

My interest in municipal dilemmas and challenges grew when I was doing an internship at Stellenbosch Municipality from August 2012 until March 2013. Although I did not work on the electricity section of the Engineering Department specifically, this internship still provided me with insights and practical knowledge about how a local government works, the experience of working within the political environment of a municipality and the challenges municipalities and officials face. Furthermore, the internship provided me with contacts within the municipality, which I have used to complete my research.

Whilst I was working at the municipality, I often encountered red tape and had to find creative ways in order to reach my goals. One of the crucial keys to get sustainable projects going, apart from human and knowledge capital, is financial capital. Given the backlog in infrastructure, financial capital is vital to get the town up to speed with the growing (student) population and business activities in town. As the revenue from electricity is quite high compared to other income sources, it is not surprising the municipality wants to protect this.

Another challenge is that municipalities cannot be seen as just governmental entities that provide services. A municipality consists of people who form a very important part in how the municipality operates and what the perception is of the current status and the way forward. This means that when there is a high turnover of officials within a municipality, this changes the dynamic within the municipality and the perception of the challenges and how to deal with them. However, the transition of society towards adopting investment in renewable energy technologies has a social context that should not be ignored. This social context will determine how the municipality will handle the transition and if they are willing to adapt. In my opinion, the most important factor for success is not financial but the forward thinking capacity of municipal officials and a willingness to change. This research will, however, only look specifically at the revenue impact but it should be kept in mind that it is up to people how to deal with impacts such as perceived revenue loss. Does the municipality remain in a business-as-usual scenario and be resistant to change? Or will key players within the municipality bravely face the challenge and look for alternatives to keep up with an inevitable transition and steer it to a sustainable model, both financially as well as environmentally. A negative impact can be a seed for positive change. It is in people's hands if they are going to let the seed sprout towards a better purpose.

1.6 Definitions of key concepts

DER:	Distributed Energy Resources: typically refer to energy efficiency, demand response, and distributed generation. DER is now expanding to include customer-level energy storage (Faruqui & Grueneich, 2014).
RES-E:	Renewable Energy Systems for Electricity
Prosumer:	Consumer of grid provided electricity and producer of home generated electricity and fed back to the grid.
Net metering:	"Net metering is an electricity policy, which allows utility customers to offset some or all of their electricity use with self-produced electricity from RES-E systems" (Poullikkas, 2013).
Feed-in-Tariff (FiT):	A set price for electricity fed back into the electricity grid (Mountain & Szuster, 2014)
Inclining block tariffs (IBT):	The tariff is divided into four consumption blocks and each subsequent block has a higher price per kWh of energy. The amount payable is the sum of consumption per block multiplied by the energy rate/price per unit associated with each block. The selection of the blocks, the limits and the prices per unit have been set by NERSA and is required to be implemented by Eskom as is (Eskom, 2010).

Distributed Generation (DG)	Also referred to as embedded generation (EG). Energy generation in small-scale systems, close to the point of consumption. The main technologies used for this application are solar photovoltaic (PV), micro-wind turbines, and micro-combined heat and power systems (Richter, 2013a). In this thesis only rooftop solar photovoltaic systems will be referred to, unless stated otherwise.
Value of Solar Tariffs:	(VOST) A rate design policy in the U.S. that gives customers with solar installations credit for the electricity generated by a photovoltaic system (PV) system (NREL, 2015).

1.7 Chapter outline

The first chapter provides a background and context to the research topic that serves as a foundation from which a research question and objectives are formulated. Furthermore, a personal motivation to conduct this research is given as well as definitions for key concepts to clarify frequently used concepts throughout this thesis.

The second chapter consists of a literature review, which provides a contextual and theoretical framework to the research topic. It will first focus on the threat to the traditional business model as a result of residential rooftop PV of utilities across the world and their ways of dealing with this challenge. The second part of the literature review contextualises electricity provision and service delivery challenges within South Africa and specifically the consequent municipal revenue threat from residential rooftop PV.

The third chapter outlines the methodology and design of this research. In this chapter, it is explained which tools and methods have been used to arrive at the research findings and results. It also discusses the potential risks and challenges one can come across whilst conducting the research.

The fourth chapter contains the research findings and analysis, which is structured into four sections. The four sections are following each other in a logical sequence to come to the final answer of the research question in this thesis. The first set of research findings is about electricity provision in Stellenbosch and provides a financial context to electricity service delivery. The second set of findings provides the results on how much grid capacity there is to receive embedded generation, in the residential high electricity use suburbs. The third set of findings gives the results on the question of how much impact there is on the electricity load profile of Stellenbosch Main substation and Cloetesville substation. The last set of findings gives the financial impact as a result of residential rooftop PV in Stellenbosch and thereby providing an answer on the main research question of this study.

The fifth chapter provides a conclusion to this study, a reflection on the research process and recommendations for further research.

Chapter 2 – Literature Review

2.1 Introduction

The literature review expands on the crisis of traditional utilities in a changing energy sector. In this way, the literature review will help to identify the manner in which the current knowledge on the topic has developed and the perspectives of authors in the field (DePoy & Gitlin, 2015). The review will explore the responses to the changing energy market and the challenges faced in different countries. Thereafter, it narrows down to South African municipalities specifically. A context is provided to the central topic of a potential revenue threat as a result of rooftop PV, with relation to a municipality's financial and service delivery challenges. In essence, as South African municipalities are responsible for the network and electricity delivery (within their jurisdictional border) (Sebitosi, 2010a), they face challenges similar to more traditional energy utilities across the world. This is especially relevant, since municipalities are allowed to generate a surplus on the revenue (Swilling & de Wit, 2010). The main difference between a municipality and a private utility is that the extra money generated in a municipality is a surplus used to supplement other critical services that demand extra finance, and private utilities generate a profit for shareholders.

The literature also provides insights into what has been researched already on the topic, and where there are still gaps. The knowledge gained from this literature research will then be used as a context from which to analyse the results of this study.

2.1.1 Changing the traditional electricity utility market

Worldwide, renewable energy has become increasingly affordable and accessible for a wide range of consumers due to technical advances, falling prices, and innovations in finance options driven by policy support. Renewable energy is considered essential in meeting the current and future energy demands, and reducing the impact on the environment. In addition, in developing countries and markets, manufacturers and investors in renewable energy (RE) have increased in number (REN21, 2014). As stated in a report on energy transformation, global megatrends like rapid urbanisation, resource scarcity, technical breakthroughs, climate change, and demographic and social change are the root cause for challenges and new opportunities in the energy sector (PWC, 2014). These megatrends are affecting all markets and are having a particular impact on energy. Changes in consumer behaviour, new forms of competition, renewable and distributed energy, and the regulatory changes that these megatrends bring about create new opportunities and challenges, and can rapidly eclipse a current company or country's strategy (PWC, 2014). According to Nillesen, Pollitt, & Witteler (2014), almost 40% of senior managers, from a survey conducted amongst 53 power utilities in 35 countries, predict a transformation of the existing power utility business model, in which the future model might even be unrecognisable between now and 2030. Less than 10% of the managers expect the business model to remain the same (Nillesen et al., 2014). Undoubtedly, the energy sector, which has been an uncomplicated business for decades, working well with centralised utilities for energy provision, is entering uncharted territory where the outcome is not entirely predictable. In fact, the future is essentially unpredictable, depending on what assumptions are made and to which country or part of the world one refers. What applies in Germany may not necessarily apply in America or any other country (Anon., 2015b). However, according to Sioshansi (2014) although German and other European utilities' financial distress appears to be more pressing than the financial impacts on utilities in other parts of the world, the fundamentals of the disruption in the traditional business model are strikingly similar. Utilities in a number of economies across the world are discovering that their traditional business model is eroding rapidly, if not collapsing. As stated in the REN21 report (REN21, 2015), due to concerns about a shrinking customer base and revenue loss, utilities in many countries continued to push back against the expansion of rooftop solar PV. In many U.S. jurisdictions and in Europe, the debate continues about retail tariff design and net metering laws within the context of increasing

Distributed Generation (DG). In Australia, major utilities acted to slow or halt the development of solar PV installations as they were concerned about their future business model (Parkinson, 2014). In Japan, utilities restricted PV access to the grid (REN21, 2015). The signs of change are initially noticeable in countries with a mature economy, with low or non-existent energy demand growth, high and rising electricity tariffs, ambitious renewable targets, and supportive policies that encourage decentralised generation (Sioshansi, 2014). However, over time, similar conditions as those in mature economies are expected to apply to an increasing number of countries (Sioshansi, 2014).

2.1.2 Death Spiral – the threat to the traditional utility business model

As noted in the introduction, utilities across the world are taking a resistant stance against the massive uptake of rooftop PV by the residential sector. Rooftop PV signals a disruption to their business model, leading it into a death spiral. This section elaborates on the death spiral concept, what it entails and how it comes about. Different perspectives from authors on the death spiral theory are given, as well as their views on if, how, and to what extent it might impact the traditional utilities' business model.

"A utility death spiral refers to the reinforcing feedback loop of higher prices for electricity paired with customers who are switching to lower-cost alternatives" (Hedman, 2014). This principle is illustrated in Figure 1 as depicted below. A detailed explanation, as well as a discussion on the relevance and urgency of the death spiral theory will be provided in this section.

Figure 1 The Utility Death Spiral (Hedman, 2014)

Context to developments resulting in the death spiral

According to Nillesen, Pollitt, & Witteler (2014), the electricity sector worldwide is shifting from a mainly centralised large-scale production, to the introduction of small-scale decentralised electricity production, which has consequences for the traditional utility business model. The traditional business formula of utilities, i.e. revenue collection based on volumetric (consumption-based) sales, has increasingly been under pressure since the introduction of energy efficiency and distributed generation. The sales structure is often called ‘volumetric’ since it is based on the amount of electricity consumed by the customer. In South Africa, this is also a prevalent business model used by Eskom as well as local municipalities that buy electricity from Eskom and resell it to customers. Stellenbosch

Municipality also has a sales system based on increasing volume to recover its costs for electricity provision.

The urgency to revise the old business model was not pressing, until the rapid increase in distributed generation and the rise of prosumers (consumers of grid electricity who produce DG as well). Over the past few years, the number of residential households installing rooftop PV has increased worldwide. Despite a substantial decline in new solar PV installations in in European countries, challenges to reach targets in China and a slow emergence of new PV markets in the world, 2014 marked another record year with an added capacity of 40 GW making a global total of 177 GW. Over three years, until the end of 2014, more than 60% of all operated PV capacity worldwide was added (REN21, 2015). One reason for this increase is that the price of electricity supplied by rooftop PV has fallen below the retail price of grid electricity in some areas (Cai, Adlakha, Low, De Martini, & Mani Chandy, 2013). In addition, in many parts of the world, the price for electricity from the power grid is expected to rise over the next decade due to upgrades and infrastructure capital replacements. In the U.S., the high sunken costs, another barrier for adoption of rooftop PV, has been partially overcome by expansion in third party PV leasing offerings (Cai et al., 2013). These mainly economic incentives offer households a reason to reduce their electricity purchases from the grid by investing in energy efficiency and/or a rooftop PV installation that supplies them with electricity. This leads to a decrease in electricity sales for utilities. The problem is that the costs incurred by utilities do not decrease in proportion to the decrease in electricity consumed. This is because the fixed costs utility companies pay for transmission and distribution infrastructure are so high that they need to be recovered over a long period (Cai et al., 2013). In addition, it is the capacity that creates the cost for utilities, not the kWh provided. Figure 2 shows a utility's costs in schematic proportion to cost recovery through volumetric sales and fixed charges. As can be seen, the fixed costs are not recovered through just fixed charges, but mainly through volumetric sales (NREL, 2009). Figure 2 is a schematic explanation from the National Renewable Energy Laboratory in the U.S. to show the disparity between cost recovery and volumetric pricing. As it is based on a virtual utility in the U.S., the proportions may, therefore, vary per utility operating in different countries and in different circumstances. However, the essence of the message Figure 2 provides remains the same.

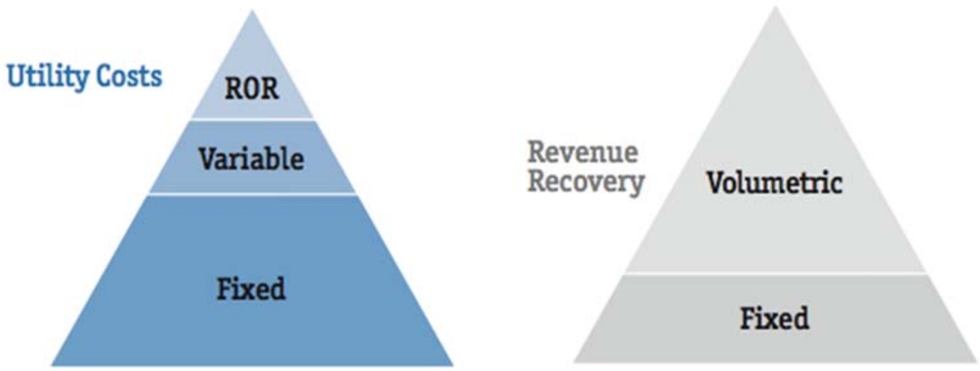

Figure 2 Utility's allowed costs and revenue recovery (NREL, 2009)

As a result of decreases in electricity demand, overall electricity rates must increase so that utilities can continue to recover the fixed costs. As the grid electricity tariffs increase further, this leads to more incentives for people to invest in rooftop PV. Therefore, rooftop PV adoption in combination with increasing electricity rates leads to a positive feedback loop, a process in which a disturbance to the system includes a constant re-enforcing in the magnitude of the occurrence (Cai et al., 2013). From a utility's perspective, this may lead to a death spiral, representing an unstable dynamic process that threatens the prospects for the financial viability of utilities (Costello & Hemphill, 2014). To make the problem for utilities worse, the most expensive hours to generate and transmit electricity are contemporaneous with electricity peak demand hours (Duthu & Bradley, 2015). PV generated electricity occurs during the day, when higher electricity consumption is encouraged through a lower price. At peak hours, electricity consumption is discouraged by charging higher prices. The electricity consumption during the day is then reduced by PV generation and not during peak hours when it could be beneficial to reduce electricity consumption. Charging tariffs according to the time, day and season during which electricity is consumed is called a Time-of-Use (TOU) system. In the case of Stellenbosch, Eskom charges the municipality according to a TOU system. In South Africa it would be an advantage to reduce the peak demand as Eskom cannot currently meet this demand.

However, there are also researchers who challenge the advocates of the death spiral theory and find it an exaggeration of reality, and that predictions of the demise of the utility industry should be taken with a pinch of salt (Raskin, 2014). Advocates of the death spiral theory state that the death spiral "envisions a utopian (for consumers) and dystopian (for utilities) in which electricity from the utility grid is widely displaced by distributed energy sources that supply electricity at prices below utility service from the electricity grid" (Raskin, 2014). The growth in distributed generation represents a trend that is expected to enable households and businesses to substantially reduce their electricity purchases in large portions. The traditional utility companies will be confronted by a synergetic wave of consumer sentiment, new technologies and public policy collectively acting against the utility companies' business model. Advocates claim that the traditional utility industry faces a mortal threat in the near future as a result of distributed generation and other emerging technologies that allow people to bypass the electricity grid (Graffy & Kihm, 2014). According to Graffy & Kihm, (2014) utilities would be wise to not rely on the current cost recovery model, as they will be unable to recover investments due to emerging competition. Raskin (2014) finds this theory an overestimation as it disregards the critical role subsidies play in supporting distributed generation. Furthermore, according to Raskin (2014) sellers of distributed generation acknowledge that their business model will fail without substantial subsidies from the government, which is tilting the playing field heavily in their favour. However, Felder & Athawale (2014) counter this statement by arguing that all generation sources in the electric power industry have received and continue to receive subsidies, and particularly fossil fuels. Moreover, the environmental cost of fossil fuel based energy is still not internalised in market prices, resulting in a cost advantage over non-emitting sources such as wind and solar (Felder & Athawale, 2014). Furthermore, a key finding of studies based on a series of interviews with German utility managers conducted by Richter (2013b) is that utilities don't perceive distributed PV as a threat to their current business model. The results of these studies contradict the conclusions of articles from advocates of the death spiral theory (Richter, 2013a). This, however, raises the question of whether researchers are overestimating the influence of distributed generation or whether utilities are underestimating the threat of distributed generation on their business model (Richter, 2013b).

Also Costello (2015) is less convinced as to whether rooftop PV would have as much of a disruptive effect as many researchers claim. Costello (2015) states "One uncertainty is whether rooftop solar PV will have a disruptive effect or, instead, have a ''boutique'' or ''niche'' effect on retail electric markets". The optimistic expectations for rooftop PV may well fall short of the prospects currently envisioned by solar advocates and others. One reason for this is that the utility's electricity distribution system has a restricted capability to manage large amounts of variable energy coming from distributed generation. This could limit the growth of distributed generation (Costello, 2015). Raskin (2014) argues that "even when energy from distributed sources achieves cost parity with central station energy, it will have to be combined with cost-effective and reliable storage before it can be compared with utility service". Up until today, storage technology that can perform this function in a cheap, environmentally friendly, and reliable way is still in its infancy (Raskin, 2014). Even Tesla's Powerwall, which was introduced at the beginning of 2015 and enjoyed much media attention, did not crack the grid storage problem, nor is it a cheap and environmentally friendly investment (Blumsack, 2015). As final argument Raskin (2014) notes that no reason exists for technological and economical advances to happen only in the sphere of distributed generation. According to Raskin (2014) there is a high probability that technological advances make electricity from the utility grid more desirable. Although this might be true for some utilities in the world, Raskin fails to take into consideration the political environment and other factors that make the electricity from the conventional grid less reliable in present and future times, as currently experienced in South Africa, for example.

In contrast to Raskin (2014) who emphasises the threat to utilities' business model because of subsidies and hidden subsidies under net metering, Felder & Athawale (2014) argue that the so-called death spiral is not a result of disruptive competition from resources such as subsidies, net-metering, tax credits and policies to promote renewable energy but that the problem lies in the inherent design of rate structures based on volumetric sales. "Since much of the transmission and distribution of fixed costs is recovered via volumetric charges, cost recovery is threatened if there is a major decrease in volume of sales (and over-recovery of costs may occur if volumes increase). In an environment of nearly flat load growth combined with a substantial set of well-intentioned subsidies (including net metering, tax credits, and renewable portfolio standards to promote cleaner energy sources such as solar and other distributed generation that are on the customer side of the meter), the current volumetric-based rate design will not sustain cost recovery for transmission and distribution owners" (Felder & Athawale, 2014). In South Africa, however, it is questionable as to whether there will be a nearly flat load growth, as electricity demand is linked to electrification of houses, development, and the growth of economy.

Felder & Athawale (2014) argue that replacement of utility provided electricity by DG would not be an issue if the grid did not provide value. However, the grid continues to provide value to both DG and non-DG owners, as it is not cost-effective today or in the near future to completely bypass it (Felder & Athawale, 2014). DG requires the ability to store electricity and balance each customer's supply and demand individually, which is more expensive than using the grid (Felder & Athawale, 2014). Until this balance changes the majority of rooftop PV owners rely on the grid for necessary and valuable services at a lower cost than off the grid. And this service should be reflected in tariffs equally amongst all consumers.

Raskin (2014), Costello (2015), (Richter, 2013b) and Felder & Athawale (2014) have pointed out a number of valid points that need to be taken seriously in the debate regarding the threat of DG on the traditional utility business model, and whether it would lead to a death spiral. Even though the death spiral theory in itself might be extreme in reflecting the current utility's business model challenge, it is, however, evident that several factors have created a perfect storm for the traditional utilities, requiring re-examination of traditional business models, decision making on decentralised investments, and revenue generating activities (Nillesen et al., 2014). The traditional business model is not equipped for the challenges massive PV installations bring, nor is it equipped for any other factors that would reduce sales as the business model is structured in such a way that it relies on the volume of sales to recover both variable and fixed costs. A re-examination of the inherent structure of the traditional business model is therefore needed.

The next section will examine the highly debated net-metering programme that many countries had in place to stimulate the uptake of rooftop PV and its consequence for the utility's revenue. Furthermore, it reviews alternative billing schemes that aim to be fairer and less harmful to utilities.

2.1.3 Re-examination of electricity service rate structures and net metering

Though it seems unlikely that distributed generation is going to take over the entire electricity provision industry, the billing structure of electricity will need to be re-examined in order to reclaim fixed costs and to value the provision of grid services that cannot be replaced by the distributed generation that DG owners make use of. Firstly, the shortcomings of a net-metering system that pays DG customers for their excess electricity will be reviewed. Secondly, a closer look will be taken at the design of rate structures. Thereafter, examples will be given from utility business model case studies from several countries in the world.

Poullikkas (2013) defines that “Net metering is an electricity policy, which allows utility customers to offset some or all of their electricity use with self-produced electricity from RES-E[1] systems”. Net metering works by using a meter that is able to record electricity current flows in both directions. Alternatively, the two channels can be metered separately and the DG generated electricity can be subtracted from the grid electricity use. However, the last option requires more proactive policies and utility consumer cooperation. A variant on the net metering is Time-Of-Use (TOU) which requires a smart meter that is programmed to measure the electricity use at any given time of day. Thus, under a net-metering programme, a utility is required to purchase its customer’s excess PV generation at the same retail electricity price they charge for providing electricity. Cai et al., (2013) argue that this results in two major problems: firstly, distribution of costs from relatively wealthier DG owners to non-DG customers. Secondly, when paying the full electricity tariff for DG energy, utilities are not able to recover fixed costs and are not valued for providing the grid as a constant back up system for DG owners. Since a portion of the normal electricity tariff is used to recover fixed infrastructural costs, residential customers owning rooftop PV will contribute less to these costs than customers without PV (Cai et al., 2013). In addition, Kirsch & Morey (2015) argue that net-metering policies will not be sustainable in the long term as they allow for excessive payments to DG owners, financed through implicit taxes on electricity consumers who have not installed rooftop PV. Moreover, in California, America, it is evident that consumers who install DG tend to be from a higher-income group (Kirsch & Morey, 2015). The rich invest in PV, paying less for electricity whilst redistributing costs for poor consumers for whom electricity prices rise to recover revenue to pay off fixed costs. Therefore, the burden of paying net-metering costs falls disproportionately on consumers from lower-income groups. As a consequence, if the case of California were applied to more parts of the world, net-metering policies returning the full rate for DG electricity would have a regressive tendency of being generally available to and used by the more affluent, and placing an additional cost burden on those customers who are less affluent (Kirsch & Morey,

[1] Renewable Energy Systems for Electricity

2015). In South Africa, however, there is an inclining block tariff in place with higher prices for high consumers (usually the more wealthy consumers) and lower prices for poorer households, who by consuming less fall into a lower block tariff and receive the first 50 kWh for free. In Stellenbosch for example, in the first block (0-51 kWh) consumers will pay 70.69 cents per kWh. In the last block, block 4 (>601 kWh), consumers will pay 139.10 cents per kWh. The intention was to partly cross-subsidise electricity for the poor by the rich. Net metering would, in this case, not drastically turn the cross-subsidisation around but perhaps result in less cross-subsidisation by the wealthier consumers.

Poullikkas (2013), however, counters the arguments of Kirsch & Morey (2015) and states that they point out misconceptions about net metering, specifically that it would reduce a utility's revenue. A similar argument is made against energy efficiency, leading to reduced electricity purchases from consumers. He does say, however, that this statement of revenue impact would be true if everyone were to install a PV system. He also notes that a utility's revenue would be impacted far more by energy efficiency than by PV systems. He finds that if PV and energy efficiency were to actually impact a utility's revenue, then tariff schemes should be restructured to guarantee the services a grid provides. Poullikkas (2013) also challenges the perception that net metering is a mechanism that transfers subsidies from non-DG owners to DG owners. He compares a PV system to connecting a new home to the grid that requires more grid capacity, which is also paid for by revenue generated through other consumers. Both new connections and PV systems represent expanding business opportunities and according to Poullikkas, utilities have found a way to deal with economic growth by using the same rate structures for more than a century. He also notes that net metering offers multiple benefits to the utility, the consumer and community. A well-designed net-metering policy provides the utility a low cost and administratively easy way to deal with residential PV systems. Poullikkas (2013) argues that PV generation correlates strongly with utility peak loads and the generation of PV systems is easy to predict. In this way, utilities obtain the benefit of additional capacity, which is paid for by the PV customers.

The next sections will look at perspectives and case studies from several countries as a response to the perceived utility business model threat by distributed generation and their retail tariff structures.

2.1.4 Australia

Australia occupies the seventh rank globally for adding new solar generated capacity by 0,9 GW in 2014 (REN21, 2015). Over a period of five years, from 2009 to 2014, the capacity of PV in Australia expanded from 50 MW_p to 4 GW_p, an 80-fold increase (MacGill & Bruce, 2015). This trend was driven by several factors, such as rising electricity prices, falling prices for PV, a strong Australian dollar and support from federal and state government (MacGill & Bruce, 2015). At the end of 2012, approximately 12% of Australian residential houses had solar PV installations on their rooftops (Mountain & Szuster, 2014). South Australia has the highest residential PV installation rate with 25% (MacGill & Bruce, 2015). More significant, is the installation of 900 000 residential rooftop PV systems between 2010 and 2012, making Australia's market penetration the highest in the world. In 2013, Australia counted more than 1.1 million rooftop PV installations, which started from 8 000 installations in 2007 (Mountain & Szuster, 2014).

Since this massive expansion leads inevitably to a decrease in electricity demand, it is not surprising that major utilities in the country were concerned about the threat of distributed solar PV and acted to slow or halt the expansion of solar PV (REN21, 2015). Policy makers in Australia agreed that PV became "too successful", and state government support for the technology was removed a few years ago (MacGill & Bruce, 2015). Despite the removal of state support, growing public acceptance, ongoing subsidies under the Federal Renewable Energy Target, and deployment-driven cost reductions have resulted in an added PV capacity of between 800 and 900 MW (MacGill & Bruce, 2015). The debate should critically review the costs and benefits of PV, where the key problems lie for utilities in terms of threat to their revenue, and how a different business model can perhaps change the course before radical decisions are made by governments.

One of the reasons for the massive uptake of residential solar PV, along with rising electricity prices and declining PV system costs, was the availability of capital and production subsidies between 2010 and 2012. Capital subsidies were paid through a mandatory renewable energy certificate scheme. The clean energy regulator has allowed electricity retailers to surrender a certain number of certificates each year. The retailers recover the costs of these certificates from electricity sales to all energy users. The production subsidies consist of the Feed-in-Tariff (FiT), a set price for electricity fed back to the grid, and an extra payment offered by energy retailers to PV households for electricity exported to the electricity grid. The retailers in turn recover the costs of the legislated FiT by charging this to the regulated utilities. The utilities in turn recover this from the jurisdictional government, who then recover the costs through a levy imposed on all electricity consumers (Mountain & Szuster, 2014). The argument is that these subsidies place a disproportionate burden on non-rooftop PV households. It would, however, be too easy to draw this conclusion without taking other factors into consideration.

Rooftop PV also can have a positive impact on prices. 900 000 PV rooftops supply 3.4 TWh per annum. 90% of this is produced between 10 a.m. and 4 p.m., a time during which the supply-cost curve is most likely relatively high (Mountain & Szuster, 2014). In South Australia, for example, the PV share would be 15%. The network costs in Australia are extraordinarily high and therefore a reduced peak capacity demand could be beneficial. The cost per MW of added capacity on the distribution network is $3 million[2], and on the transmission network, $1.3 million per MW. Based on the assumption that 900 000 PV

[2] Assumed is that the currency is U.S. $ dollar and not Australian (AUD$) dollar as in the article the amounts are related to international standards. Furthermore, other amounts that concerned Australian dollar were specifically noted as AUD$.

installations would avoid an augmentation of the transmission and distribution network, the avoided expenditure can be estimated to be between $72 million and $168 million annually. 1.8 TWh of the 3.4 TWh PV production is transferred to the grid and consumed by other electricity consumers. Since it reduces the grid electricity consumption supplied by the utility, it results in a loss of income of $252 million. This loss is thus more than the avoided grid expansion that would be needed to increase the capacity to carry an increased electricity demand. Moreover, the maximum peak demand is still after sunset, which does require a certain amount of maximum grid capacity (Mountain & Szuster, 2014). MacGill & Bruce (2015) add that PV systems were reducing peak demand in some areas, which might reduce longer-term costs. However, network savings from peak load reduction are generally less than the value of the network tariff. A more thorough assessment could find, however, that in some parts of Australia the benefit may exceed the costs.

The previous analysis might suggest that households with PV are able to impose a higher cost on households without a rooftop PV installation (Mountain & Szuster, 2014). A crude way to fix the problem would be to increase the fixed charges for PV households. However, PV is just a part of a broader suite of challenges. In Australia, air conditioning has, for example, a high impact on peak demand (MacGill & Bruce, 2015). The peak demand hours are the most costly for the utility, and the most desirable to reduce to also avoid network augmentation. The extra load caused by air conditioners during peak hours leads to increased tariffs as well. As a result of households installing large air conditioning installations, the grid needed to be expanded. Households with rooftop PV that are told to pay higher prices because of the increased tariffs, even though in total these households use less electricity, will become frustrated with the national utility. One of the reasons tariffs increased in Australia was because of grid expansion due to households installing large air conditioning installations. As these tariff increases were put on all electricity consumers and not just the households who installed the air conditioners, the households with air conditioners were not confronted with the full cost of consequential grid expansion of which they benefitted greatly (Mountain & Szuster, 2014).

According to Mountain & Szuster (2014), more should have been done by government, academics and regulators to understand the impact of distributed generation on the public interest and utilities alike. Moreover, according to MacGill & Bruce (2015) there is no ‘one size fits all’ solution. Distributed energy challenges will differ greatly between electricity industries, as the factors influencing the problem are many and varied per region in which a utility supplies electricity.

2.1.5 United States

The United States experienced an addition of 6.2 GW_p solar PV installations in 2014, making a total of 18.3 GW_p (REN21, 2015). This 30% increase was driven by a continuing decrease in the installation costs of PV systems, stable policy options and innovative financing (REN21, 2015). In 2014, the residential rooftop PV demand grew by 1.2 GW, which reflects a demand growth of more than 50% for the third year in a row. Several large corporates launched a programme in which they bought PV in bulk to reduce installation costs for their employees. The individual states also had a few of these initiatives (REN21, 2015).

Historically, in most U.S. states DG was a marginal issue for which proactive regulatory action seemed unnecessary (Costello, 2015). However, because of the booming increase in DG investments over the last few years, bold regulatory action aligned with the public interest is needed. PV generation has the potential to transform the U.S. electricity industry as continuation of the rapid growth of the industry is expected through this decade (Costello, 2015). According to Satchwell, Mills, & Barbose (2015), U.S. utilities’ financial interests are poorly aligned with on-site solar PV installations under traditional regulation. Especially under net-metering arrangements, customer sited PV can result in revenue erosion and lost earnings opportunities for utilities as well as increased retail rates for regular electricity consumers. Both Costello (2015) and Satchwell, Mills, & Barbose (2015a) advocate incremental changes to utility regulatory and business models to mitigate the impacts. However, the efficacy of these changes will depend on the design and particular utility circumstances.

Satchwell et al. (2015b) look specifically at revenue decoupling and lost revenue adjustment mechanisms (LRAMs) as tools to moderate revenue impacts. They state that the effectiveness of these instruments is highly dependent on the utility's design and characteristics. The results of their research are based on the characteristics of two prototypical energy utilities in the U.S.; a vertical integrated utility in the south-west of the country, and a wires-only utility and default service supplier in the north-east. Both of these utilities have a revenue collection scheme that consists of a fixed customer charge ($/customer), volumetric demand charge ($/kW) and volumetric energy charges ($/kWh). Costello (2015) takes a more detailed look at the shortcomings of current tariff structures and the implications for the utilities' business model. In addition, he looks at the deficient compensation of DG owners for the value they add. He also suggests alternative rate-making approaches and explains through an example the difference between tariff structures based on net metering and Value of Solar Tariffs (VOST). The VOST tariff is "A rate design policy that gives customers with solar installations credit for the electricity generated by a photovoltaic system (PV) system" (NREL, 2015). The concept was introduced as an alternative to net metering. It tracks how much energy is sold in two directions, from customer to utility and from utility to customer and at what rate the electricity is priced. In this manner the DG customer will pay normal electricity prices for electricity consumed from the grid but will receive a fair rate for the DG electricity the customer sells back to the utility (NREL, 2015).

Satchwell et al. (2015b) argue that the greatest example for the current utility challenge is earlier ratepayer-funded energy-efficiency (EE) programmes for which a variety of regulatory tools have been developed to align energy efficiency targets with utility financial interests. Like distributed solar PV, EE programmes also decrease sales of utilities as their traditional model runs on volumetric sales. Studies in EE identified rate-making and regulatory options for mitigating the negative rate impact from distributed solar PV. According to Faruqui & Grueneich, (2014) the impact of energy efficiency possibly has as great or even greater impact on utility sales than distributed generation. Fifty experts in North America were asked to project the impact of energy efficiency on reduction of energy sales by the year 2020. Some projected small impacts and others big. However, even the small impacts were seen as significant. The impact was predicted to be between 5% and 15% (Faruqui & Grueneich, 2014). New buildings are far more energy efficient than existing, older buildings, which means that as time goes on households will consume fewer kWh to live a comfortable life. In fact, in California all new buildings will need to meet zero net energy (ZNE) standards, i.e. producing as much as they consume, starting in 2020 (Anon., 2015a). What needs to be considered, however, is that new buildings consume electricity at a location where no electricity was consumed before, assuming that an existing building was not demolished and replaced. There are, however, more reasons in the U.S. for electricity sales to slow down. Since the economy is still sluggish and less work opportunities are available, young adults have moved back in with their families causing a significant delay in the establishment of new, independent families. At the same time, the younger generation prefers to live in city centres where less electricity is consumed due to the smaller houses and apartments available, compared to larger houses in the countryside which naturally require more energy consumption (Faruqui & Grueneich, 2014).

This shows us that distributed generation should be put into a larger context with many more parameters influencing the business model of utilities.

2.1.6 Options to deal with revenue loss

The previous sections have pointed out a context to utility's revenue threat as a result of a booming residential rooftop PV uptake in Australia and the U.S. and ways in which this threat is being responded to. This section will look at the options for dealing with revenue loss by re-examining the dominant business model of utilities across the world.

The electric power sector is undergoing a fundamental transition towards a more decentralised, sustainable-based production of energy from renewable energy sources. As a consequence, utilities as major players will need to find new ways of creating, delivering, and capturing value from renewable energy technologies (Richter, 2013a). In order to remain competitive in the electricity sector, utilities will need to develop new business models (Richter, 2012). Ideally, a utility's business model should be designed in such a way that it would mitigate adverse impacts from distributed PV on their revenue whilst enabling a sustainable energy transition by facilitating energy efficiency and the growth of distributed PV (Satchwell et al., 2015b).

Change of electricity rate design – decoupling

The interruptive working of rooftop PV, led to re-examining the traditional utility business model based on volumetric sales. Many authors are convinced that the root cause of revenue loss is not a result of rooftop PV as a disruptive innovation, but rather the inherently unsustainable electricity rate design. Since most of the fixed costs related to distribution and transmission are recovered through volumetric charges, cost recovery or revenue is threatened when a major decrease in the volume of sales occurs (Felder & Athawale, 2014). Kirsch & Morey (2015) emphasise that getting the retail tariffs right is essential in assuring efficient and reliable electricity service in a world with distributed generation.

Instead of calling a halt to the installations of rooftop PV, as is occurring in some parts of the world, authors suggest decoupling as a solution to this problem (Xue, Sullivan, Peltola, Peters, & Leiber, 2014; Hirst, Blank, & Moskovitz, 1994; Lesh, 2009; Eto, Stoft, & Belden, 1997). Decoupling refers to breaking the link between a utility's recovery of fixed costs and kWh sales (Xue et al., 2014). Lesh (2009:66) defines decoupling as "A regulatory term indicating that, through any one of several means, a given energy utility does not derive the portion of its revenues necessary to provide it an opportunity to recover its fixed costs of service on the basis of its sales of natural gas or electricity". The aim of decoupling is to maintain the financial health of utilities whilst unlocking the significant potential for energy efficiency savings that reduce customer bills and carbon emissions simultaneously (Lesh, 2009). In the U.S. in the nineties, decoupling was emerging as an important regulatory strategy to insulate utility revenues from sales fluctuations (Eto et al., 1997). Hirst et al. (1994) suggest a two-way mechanism for decoupling. Firstly, the link between utility revenue and number of sales in kWh must be broken. Secondly, the revenues need to be recoupled to another source of income, such as the growth in the number of consumers or determinants of changes in fixed costs. However, the two-way mechanism Hirst et al. (1994) is suggesting is in conflict with the aim of energy efficiency and distributed generation. By recoupling the revenue to an increased number of consumers, at least the same amount of electricity is being produced. This shows that a decoupling mechanism in this way would not eliminate the incentive to expand. It would, in fact, reinforce it (Kihm, 2009). Kihm (2009) argues that the effectiveness of decoupling depends on particular factors. As these factors differ per utility, decoupling should be seen as a tactical tool to be used for *some* utilities but not as an overall strategic instrument that can be used effectively on *all* utilities.

Lesh (2009) points out two ways of decoupling. Firstly, periodic rate adjustment "… to ensure that a utility records as revenue for fixed cost recovery no more and no less than the amount of revenue authorized for that cost coverage". This means that customers, depending on whether the revenues the utility received were less than or greater than those authorised by the regulator, receive refunds or pay surcharges to the utility. This option would become very difficult for South African municipalities, as this is only possible with credit meters. The second option is a ’straight fixed-variable’ rate design. In this structure, the fixed costs of service are recovered through charging a monthly fixed rate and the variable energy provision charge only covers the variable cost of electricity. However, while the second option does truly decouple the link between sales and fixed cost recovery, it also significantly diminishes the incentive for consumers to conserve electricity or to invest in energy efficiency (Sebitosi, 2010a; Lesh, 2009). In addition, Abrardi & Cambini (2015:123) state that “… an obvious flaw of decoupling policies is that, while they do not discourage utilities to adopt energy conservation programmes, they neither provide incentives to their efficient realisation”. One more critical point to note is that higher fixed tariffs in relation to variable tariffs mean a higher burden on poorer electricity consumers when the fixed tariffs would not be adjusted according to the household income. For low-income households, raising fixed tariffs could mean they cannot afford electricity anymore, and need to disconnect to avoid high fixed tariffs before even using electricity. Or if households were not yet connected to the grid, it might hamper people from connecting to the grid at all.

Another point to note is that it is not clear if decoupling measurements is enough to mitigate revenue impact. As Faruqui & Grueneich (2014) state “… while decoupling has been used to offset erosion of utility revenues for energy efficiency to date, it is unclear if it can be sufficiently effective in a world of widespread distributed energy resources (DER)” (Faruqui & Grueneich, 2014:306). In addition to decoupling measurements, Costello (2015) points out that the ideal retail tariff would include a demand charge that reflects when electricity is demanded and accounts for a customer’s contribution to peak hours. This means using a TOU rate design by utilities and electricity distributing municipalities.

Sustainable and fair rate design for distributed generation owners

Apart from re-examining the tariff structure of utility supplied electricity, the rate structure for distributed generated electricity supplied back to the grid by rooftop PV owners should be questioned as well. Including net metering in a legal framework in South Africa as suggested by Sebitosi (2010a) would surely increase incentives for adopting grid connected rooftop PV by households. However, as elaborated on in an earlier section, it is not a fair and sustainable model, as it does not reflect the value utilities provide and from which DG owners are benefiting without paying for their costs. At this point in time, customers with rooftop PV still need the grid more than the grid needs them (Smith & MacGill, 2014). DG owners should be compensated for the benefits they provide such as transmission loss reduction, distribution avoided capacity and voltage support, and they should pay for the grid services they rely on (Costello, 2015). However, business models will have to be designed in such a way that they not only reflect the many values of distributed PV but also the costs that the technology incurs (Smith & MacGill, 2014).

Two alternative rate-making approaches as pointed out by Costello (2015) are currently under review in the United States. The main aim of these three approaches is to ensure DG owners pay their fair share of grid costs or receive fair compensation for the electricity sold to the local utility.

The first approach is to redesign retail tariffs in such a way that they reflect the causal link between cost and tariff, for example, tariffs that include demand charges to reflect system-wide capacity costs. This could be realised by the use of smart meters that are able to calculate demand charges based on the maximum amount of electricity utilised over a short period of time (Costello, 2015).

The second approach is designed to compensate DG owners for their on-site solar electricity generation, and separately for their gross consumption under the utility's retail tariff. A leading example is the Value of Solar Tariffs (VOST). The utility providing electricity, bills customers for using electricity from the grid under the applicable tariff and separately credits DG owners for all solar generated energy under the approved VOST. In contrast to net metering under the VOST, the electricity generation and consumption are treated as two independent activities. VOST in this sense provides a fair compensation to DG customers and rewards the solar generated energy for its economic and other benefits, whilst avoiding over payment by non-DG customers. In theory, using the VOST system would end the subsidy and cost shifting, which happens currently under net metering. The price paid for solar electricity by the utility reflects the actual avoided cost. For example: a customer owning a solar installation buys all of the electricity consumed through the normal retail tariff system that is in place and sells all the DG electricity at a tariff that reflects the avoided cost of the utility. These avoided costs are mostly related to generation (e.g. fuel and capacity costs) and to a lesser extent, distribution and transmission (Costello, 2015).

Using an example, Costello (2015) illustrates the difference between VOST and net metering assuming an electricity consumption of 1 000 kWh a month and a production of 600 kWh a month. In this example, the tariff for retail electricity is 10 cents per kWh. Assumed is a utility's avoided cost of 7 cents per kWh, the fixed cost is then 3 cents per kWh. When using the regular net-metering system, the consumer's net bill would be USD 40 [(1 000 kWh – 600 kWh) x 10 cents]. When using VOST, which is based on the avoided cost of the utility, the customer pays USD 100 for grid electricity and receives a compensation of USD 42 for the DG electricity produced. The net bill is then USD 58. Under the VOST system, the utility recovers the same amount for fixed costs from the DG customer as before; the utility loses USD 42 of revenue but at the same time the costs also decrease by USD 42 (600 kWh x 7 cents). Under VOST, based on the utility's avoided cost, the customer pays USD 100 for the electricity consumed but receives a credit of USD 42 for the electricity he produces. His net bill is then USD 58. The problem, as utilities view it, is that prior to installing the PV solar system, the customer contributed USD 30 [(10 cents – 7 cents) x 1 000 kWh] toward the utility's fixed costs. In contrast, with VOST, under net metering the utility receives USD 18 less from the DG owner, which is needed to recover fixed costs (Costello, 2015).

What should be questioned is how to measure the benefits that DG offers to the grid, to other consumers and to society as a whole. Only paying the avoided costs to the DG owner is a start, but this does not reflect the extra benefits solar PV systems provide. It also does not reflect the full benefits the grid provides to the DG owner (Duthu & Bradley, 2015). It is questionable if some of these benefits can be expressed in economic value. To be certain, it will be difficult and time consuming to determine the tariffs under this system. In addition, the risks of high uptake of DG systems are not included in the calculation, i.e. issues such as harmonic distortion, voltage flicker and capacity limits. Together with reducing or avoiding the potential costs of DG, and in order to realise potential benefits for both sides, increased cooperation and coordination between the utility and DG consumer might be needed (Duthu & Bradley, 2015).

Ownership of renewable energy assets

According to Richter (2013b), German utilities have failed to benefit from the transformation of the energy industry towards renewable energy technologies. It is estimated that utilities lost approximately 97% of the distributed generation market to investors and households from outside the electric power industry. Richter (2013a:1228) points out "… organizational scholars argue that companies survive by changing and reconfiguring their assets and knowledge according to changes in their external environment". In order to benefit from the energy transition, utilities should adjust their current business model by finding new ways of value creation and value capture by building up assets and knowledge in the field of renewable generation (Richter, 2012). Richter (2012) suggests two approaches, which follow a different logic of value creation that should be looked at. The one is a utility-side business model, and the other is a customer-side business model. The first business model is very similar to traditional centralised power plants. Bulk generation of renewable energy is fed to the conventional grid and delivered to the consumer. The customer-side renewable energy business model comprises small-scale energy generation close to the end-users, in other words, distributed generation.

Blansfield & Jones (2014) add that direct utility involvement in distributed generation makes good business sense. Funkhouser, Blackburn, Magee, & Rai (2015) offer community solar as a solution to mitigate the concerns of revenue loss by utilities. Community solar (CS), administered by the utility or a third party entity in which multiple customers can participate, appears to be an alternative deployment model for PV whilst integrating distributed generated solar PV. Blansfield & Jones (2014) provide an example of a community solar project in California. In California, a utility launched a community solar project where the utility is the owner. Community members can become leaseholders that own Renewable Energy Credits or Certificates (REC). In addition to this project, the utility also launched a 'SunRate' programme. In this programme, consumers can choose to have 50%, 75% or 100% of their electricity usage covered by solar energy. This makes it possible for the utility to ensure sufficient revenue collection and provides an opportunity for people to invest in green energy (Blansfield & Jones, 2014).

As proposed to Drakenstein municipality in South Africa (Kritzinger, Meyer, Van Niekerk, & Scholtz, 2015), Stellenbosch Municipality could invest in municipally generated and owned electricity through investments in rooftop solar PV. This would not only mitigate potential revenue loss but also suit Stellenbosch Municipality's sustainability and innovation agenda.

2.1.7 Concluding remarks

This first section of the literature review has provided a context to the research topic in a broader, global perspective. It was set out to explain why and how the traditional centralised utility electricity provision is moving towards a more decentralised and renewable production of electricity. The distributed generation boom caused revenue losses for utilities in many parts of the world. The death spiral theory might be too extreme in modelling the financial challenge of utilities. However, even though the death spiral theory might not be a perfect reflection of reality, it is evident that utilities need to change their business model and rate-making in order to survive. The next sections of the literature review will look specifically at the South African context.

2.2 Introduction – The South African case

This section of the literature review narrows down to the South African context regarding renewable energy challenges. It provides a background on the history of electricity in South Africa and renewable energy developments. As this research is focussed on the residential sector, a section is dedicated to the significance of the residential sector in South Africa. Thereafter, electricity distribution and the financial challenges faced by South African municipalities are discussed as well as municipal financial management, and service delivery. The impact of technical and non-technical losses on revenue is discussed in the last paragraph as these factors shed more light on the losses to a utility or municipality's revenue than either distributed generation or energy efficiency.

2.2.1 From decentralised electricity generation to Eskom's monopoly – and back again?

To contextualise this study in time, it is relevant to reflect on the history of South Africa's electrification. Questions being answered in this section are: how did history bring us to the electricity status as currently experienced in the country, and what have the roles of local government been throughout South Africa's electricity history?

The first electricity publicly supplied in South Africa dates to 1882 when streetlights were switched on in the Kimberly diamond mining area (Gentle, 2009). As with later years, electrification of South Africa followed the demands of the mining industry (Gentle, 2009). The country's Energy Intensive User's Group (EIUG) includes some of the world's largest mining and resource extraction industries like BHB Billiton, Anglo American, Xtrata, and the coal-to-liquids pioneer Sasol. The EIUG has enormous bargaining power, giving them the position to lobby collectively for low tariffs and favourable policy making. The members of the EIUG consume around 44% of South Africa's electricity and therewith also represent the largest emitters of greenhouse gasses (Baker et al., 2014).

According to Bekker, Eberhard, Gaunt, & Marquard (2008) the electrification of South Africa went through several institutional and policy phases. The period from the late 1980s to 1994 saw the process move from an initial scattered structure, to the strong appearance of an electrification programme in the policy agenda. Before 1990, less than a third of South Africa's population had access to electricity (Bekker et al., 2008). However, South Africa did have a very energy intensive economy at that time and Eskom had a reserve margin of 55% in 1990 as a result of overbuilding in 1980 (Bekker et al., 2008). Furthermore, the 1987 Eskom Act scrapped section 6(4) of the Electricity Act from 1922, the year that Eskom came into being. The 1922 Act specified that electricity should be supplied in the public interest and that the operations should be carried out for ”neither a profit nor a loss”. Eskom should operate independently from the state, meaning Eskom had to finance its operational costs and capital expansion out of revenue generated by electricity sales. This also indicates that Eskom's business model was based on volumetric sales. The 1987 Act changed the wording of the 1922 Electricity Act: ”To provide the system by which the electricity needs of the consumer may be satisfied in the most cost-effective manner, subject to resource constraints and the national interest” (Gentle, 2009). This is also known as the neo-liberal restructuring of Eskom prior to, and after the end of, the apartheid era.

From 1994 to 1999, the apartheid frameworks were dismantled and reformed. In 1996, just two years after apartheid ended, the electrification of households percentage had risen to 58%, with only one in four non-urban black South Africans having electricity, in contrast to 97% of non-urban white South Africans (Bekker et al., 2008). When the apartheid regime made place for a democratically elected government in 1994, it had left an enormous legacy with a stark contrast between rich and poor. Moreover, the country was left with a racially based division of infrastructure provision (Winkler & Marquand, 2009). The struggle to implement an inclusive non-racial urbanism after the democratisation of South Africa in 1994 has marked the divisive impacts of the neo-liberal alternatives and the limits of inclusive urbanism (Swilling, 2013). To date, one-third of the South African population is still living without electricity, mostly in the rural areas. This is because millions of people from low-income groups do not have enough regular income to purchase electricity even if they are connected to the grid and this despite the fact they account for no more than 5% of South Africa's national electricity consumption (Baker et al., 2014).

Gentle (2009) reviews the history of the socio-economic character of Eskom and uses it as an index for the changing character of the state, which simultaneously underpinned the changing character of social forces. 1948 marks the rise of systematic racial engineering and it was also during this year that Eskom transitioned from a state regulator of private- and municipal-electricity generation and distribution to that of a state monopoly, controlling electricity generation, transmission and provision. At the time the Power Act was reviewed, South Africa had more than 58 electricity providers including 40 municipalities and 18 private companies. The municipal power stations and other independent power stations used high-grade coal that was transported via rail, using steam-driven trains, to the location where coal was used to produce steam to drive the power station turbines (Gentle, 2009). According to Eberhard (2004), potential economies of scale in power plants, the requirements for large amounts of capital, and the fact that electricity was seen as an essential element of the government's industrialisation strategy were the main drivers for shifting from competition and private ownership to increasing public ownership of the electricity industry. The availability of cheap and abundant electricity was a key item on the industrialisation agenda. This surplus and cheap electricity was available due to the over-investment in electricity generation capacity in the '80s. It was possible at this time for Eskom to provide electricity at one of the lowest prices in the world. The municipalities were generating electricity at a higher cost than Eskom could, because Eskom expanded through a search for increasing economies of scale. More power stations became centrally controlled, including the Victoria Falls and Transvaal Power Company, VFTPC, in 1948 and from 1979 the transmission lines became interconnected and nationally controlled (Eberhard, 2004). Moreover, it was cheaper to produce electricity at a centralised location as it was more costly to transport coal to municipal electricity generation plants (Gentle, 2009). Because of uncertainties in the oil market in 1970, the economy increasingly shifted to electricity. As the economy in South Africa grew at an unprecedented rate and electricity demand soared, the result was a very low reserve margin of only 11% in 1975. Because planners and engineers from Eskom expected power shortages they advised at the time that more power stations be built. This led to an overbuilding. As a result, by the end of 1983 Eskom had a generation capacity of 22 260 MW which was double the capacity being operated (Eberhard, 2004). Another factor that affected the price was the usage of low-grade coal from South Africa's largest domestic reserve (Eberhard, 2004).

Swilling (2013) points out that the apartheid government had mounted a very aggressive privatisation strategy, which included the neo-liberalisation of Eskom. Eskom transformed from a traditional public utility into a market-oriented for-profit utility. This framework included an aggressive strategy to take over the entire value chain, which included the removal of electricity provision by local governments.

To conclude, it is only a few decades ago that South Africa operated a decentralised electricity system in which local governments managed the generation and provision of electricity. Currently, the municipalities are dependent on Eskom's electricity supply before it can be distributed to citizens.

2.2.2 PV market in South Africa

This section elaborates on the development of the PV market in South Africa and the transition the electricity sector undergoes, in order to provide a context around what may be expected to happen and the factors influencing the uptake of solar PV installations by the residential sector.

Until recently, the circumstances for investment in renewable energy in South Africa were not ideal due to several factors influencing the market. Pegels (2010), in her paper, examined these barriers for renewable energy adoption in South Africa. One of them was that the price of South Africa's conventional coal-based electricity was one of the lowest in the world, and more importantly, far lower than the price per kWh for renewable generated electricity. The comparative cost of renewable energy technologies against conventional electricity was a great stumbling block. The risk factor of investing in renewables was another factor, as it was a quite a young market with very few peers for new investors to take learning points from (Pegels, 2010). Even though the market is developing quickly today, it is still in an emergent stage, which restrains some households from installing the solar PV system and makes them wait for more experience and knowledge to develop within the industry (Ahlfeldt, 2013). Furthermore, in the political spheres, hiccups were experienced. The government had made plans to introduce the policy instrument Renewable Energy Feed-In Tariff (REFIT) in 2009 to stimulate the renewable energy market (Baker et al., 2014). This policy failed, despite great interest from Renewable Energy Independent Power Producers. Uncertainties in government policies and regulations were among the reasons for failure of this government incentive (Swilling & Annecke, 2012). After four years of struggling, the REFIT policy was replaced by the highly successful Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) (Baker et al., 2014). The aim of the REI4P is to install 17.8 GW of electricity generated from renewable sources over the period 2012–2030. According to Odendaal (2015) since the announcement of the first preferred REIPPPP bidders in 2011, 92 renewable energy projects, with a nominal capacity of 6 243 MW has been procured. With a fifth window due in 2016, South Africa's energy minister announced the procurement of an additional 6 300 MW in energy capacity from Independent Power Producers in future bidding windows (Odendaal, 2015).

Although this programme seemed an expensive option at first, only designed as a response to reduce South Africa's carbon emissions, this view has changed (Walwyn & Brent, 2015). The escalating costs of coal-based electricity generation, the rapidly falling costs of solar PV and wind energy, and the increasing competition in the bidding processes have altered the prospect. Round three finished off the bidding process with a 23% discount for renewable energy costs compared to the cost of new coal-based electricity generation. It also experienced a 28% discount compared to global renewable energy prices (Walwyn & Brent, 2015). Walwyn & Brent (2015) used learning curves based on historical trajectories as a method to predict the cost of PV modules in future. The assumption has been made that prices will fall over time for new technologies as a result of the following factors: increased competition, innovation, 'learning by doing' and 'economies of scale'. According to this methodology, and if the learning rates for PV modules are maintained, it is predicted that the cost will drop below the cost of coal-based energy from 2015 onwards.

The market in photovoltaic panels has experienced a tremendous growth after implementation of the REIPPPP programme and South Africa holds further huge potential for investments in the photovoltaic market. Moreover, a survey of the developments in the South African PV market shows that 90% of the industry stakeholders experienced constant or increased revenue over the past 12 months (PV Insider, 2014b). This indicates that a stable income is being derived from the industry and that the market provides ample opportunities and potential growth (PV Insider, 2014b). According to Odendaal (2015) the renewable energy projects from the REIPPPP contributed to R168 billion in economic infrastructure spent in South Africa, which boosted the stalled economy as a whole.

However, the success of the REIPPPP does not mean immediate success for the development of the residential rooftop PV market. The residential rooftop PV market still experiences many challenges and the potential still needs to be unlocked further. The policy around the REIPPPP is quite established but the policies around grid-connected embedded generation are still evolving and municipalities seem uncertain as to what role to play in the transition. According to PV Insider (2014b) there is a lot of progress within the commercial and industrial sector but there is no framework for residential usage of solar power. This has to do with the size voltage of the connections, since there are clear rules for medium-voltage MV connections but not for low-voltage (LV) connections. The conditions and capabilities of the national grid to receive embedded generation from rooftop PV are also questionable. However, Frank Spencer (2015), Chair of Embedded Generation Sub-Committee at the South African Photovoltaic Industry Association (SAPVIA)[3], is optimistic about the uptake of rooftop PV by the residential sector. He states that the trend in residential PV uptake is uncertain but that it has been growing exponentially. Since there is an unclear regulatory environment, most people are building solar systems quietly without informing anyone what they are doing. He says that the cost of PV has halved since 2008 in South Africa. He estimates the cost of small residential PV systems to be R20 – R25/W_p (with no battery system). Large simple commercial rooftop PV installations are estimated at R14/W_p at the low end but can be as high as R18/W_p in certain installations. At SAPVIA, the current building rate is estimated at 1 to 2 MW per month of which an estimated 100 to 200 kW_p is installed for the residential sector (Spencer, 2015).

2.2.3 Significance of the residential sector in South Africa

This section elaborates on the significance of the residential sector in South Africa. Although the residential sector makes up only 15% to 18% of the national electricity consumption in South Africa, the electricity demand by households has increased in absolute terms by 50%

[3] Referenced in his own capacity

since the 1980s and continues to be the third-largest market for electricity consumption after mining and manufacturing (Mcdonald, 2009). It demands approximately 40 000 GWh per annum (Ijumba et al., 2008). Figure 3 shows the annual as well as monthly average electricity usage by households in 2012 (Dekenah, 2014). Moreover, the residential sector accounts for 95% of all the electricity connections and 75% of the national variable load (Mcdonald, 2009). The problem this creates for municipalities is that because of the high number of individual connections dispersed over a wide area, higher distribution costs are incurred to households in comparison to, for example, commercial or industrial users (National Treasury, 2011). Another crucial factor is that the residential sector contributes around 35% of the demand during peak hours (Ijumba et al., 2008). This is the period Eskom is often nearing the maximum generating capacity or reaches the point where it cannot supply the demand, often resulting in load-shedding to prevent blackouts (Ijumba et al., 2008).

LSM	DT PET 2012 Estimate	
	Year 1 (kwh/mth)	Year 15 (kWh/mth)
1	100	140
2	121	169
3	138	192
4	176	246
5	234	322
6	382	498
7	517	640
8	623	727
9	1036	1480
10	1785	2550
Annual Kwh Est.	42, 171, 635, 049	55.850, 339, 224

Figure 3 Average monthly consumption in kWh by South African LSM households 2012 (Dekenah, 2014)

It is, however, the urban middle and upper class that is responsible for most of the residential consumption (Dekenah, 2014). One factor is the affordability; another factor is the widespread use of increasingly electricity intensive appliances in this income group. Another factor is that, despite the drastic electricity price increase, electricity in South Africa is still one of the cheapest in the world (Mcdonald, 2009). The high electricity consumption by the middle- to high-income group residents in South Africa results in high carbon footprints with the average suburban household consuming approximately 9 600 kWh per year (Mcdonald, 2009). It is, however, questionable as to what is meant by a suburban household by McDonald. When looking at statistics from Dekenah (2014) the households from LSM[4] 9 and 10 in South African consume on average 1 036 kWh and 1 785 kWh per month for 2012, resulting in an average annual consumption of 12 432 kWh and 21 420 kWh in 2012. However, it is the groups LSM 6 to 10 combined that contribute significantly to the national electricity load profile. When combining these groups it results in an average of 869 kWh totalling an average annual consumption of 10 423 kWh. When averaging all the LSM households together (from LSM1 to LSM 10) this results in a monthly average usage of 511 kWh and an annual average usage of 6 134 kWh. To put this into a global perspective, households in the U.S. consumed on average 909 kWh per month (ranging from a monthly average of 531 kWh for Maine and 1 245 kWh for Louisiana) or 10 908 kWh average on an annual basis (U.S. Energy Information Administration, 2013).

NERSA, the National Energy Regulator of South Africa introduced the Inclining Block Tariff (IBT) in 2010. In this system, consumers are divided into four blocks based on how much electricity they use. The electricity consumers pay more per kWh once they reach the next block. Tariffs in the higher-use blocks include a surplus, which is used to cross-subsidise tariffs in the low-use blocks. The intention of the IBT was to lower the burden of tariff increases on the poor and to promote energy efficiency (National Treasury, 2011). In general, the high-income groups use more electricity and are consuming in the block with the highest electricity tariffs. The high-income and high-electricity using households are

[4] The LSM is a South African measurement system that divides the population into 10 consumer segments with 10 being the highest segment (wealthiest group) and 1 being the lowest segment (poorest group)

considered to be able to invest in rooftop PV. If a high proportion of the fixed costs like maintenance and transmission etc. is recovered through volumetric sales, the revenue impact will be exacerbated (Funkhouser et al., 2015) when most of the surplus is generated from the households that would be considered viable to invest in rooftop PV. In South Africa, where these consumers not only just consume more electricity but also pay more as they fall into higher tariff charges due to this high consumption, this effect should be taken into account as it can affect the revenue even more negatively. If municipalities in South Africa were to react in a 'business as usual' way, the response to rooftop PV would be to just raise the tariff within the volumetric sales system. This could disproportionally place an extra burden to pay for fixed costs onto households with lower budgets. Another option would be to restrict the installations of rooftop PV, as in countries such as Australia and Japan. However, as in these countries it is seen to be a 'business as usual' response and not a sustainable long-term strategy. What should be done is to review the entire business model on which municipalities and utilities run with regard to electricity.

2.2.4 Electricity distribution and financial challenges by municipalities

Eskom supplies approximately 60% of the electricity directly to the consumers, and local authorities that buy bulk supplies from Eskom distribute the remainder. Some of these local authorities generate small amounts of electricity for sale in their own area of jurisdiction (Eberhard, 2004). At this point in time, 8 metropolitans, 44 districts and 226 local municipalities buy electricity in bulk from Eskom and put a mark-up on the tariff to finance electricity service delivery (e.g. electricity department, distribution, capacity, maintenance, losses etc.) (Bischof-Niemz, 2013). Eskom cross-subsidises the lower tariffs for rural and low-income domestic consumers from industrial tariffs and the surpluses earned on sales to local authorities. In turn, large municipalities make an additional surplus from reselling Eskom's electricity. A surplus differs from profit as surplus will be distributed elsewhere to supplement income where it is needed and a profit is used as earnings for shareholders.

This surplus enables the municipalities to subsidise property rates and to finance other municipal services (Eberhard, 2004). However, most of the smaller municipalities face debt because of non-payment by a substantial proportion of the low-income consumers, and the lack of technical and managerial capacity within the municipality with resulting inefficient operations (Eberhard, 2004). According to National Treasury (2013), as Table 1 indicates, it is mostly A-level authorities (metropolitans) that are generating a surplus on electricity. Most of the B-level (local authorities) and C-level (district municipalities) are running at losses. However, the revenue on electricity of metropolitans has also started to diminish in recent years (National Treasury, 2013).

Electricity net surplus by category of municipality

R million	2006/07	2007/08	2008/09	2009/10	2010/11	2011/12	2012/13
					Medium-term estimates		
Category A (Metros)	2 888	3 211	3 350	2 454	2 945	2 166	1 151
Category B (Locals)	1 487	1 473	1 251	795	608	-331	-1 282
Secondary cities	815	618	577	341	339	-87	-785
Large towns	310	406	374	151	214	-92	-285
Small towns	304	372	253	252	37	-80	-205
Mostly rural	58	77	46	50	17	-72	-7
Category C (Districts)	-21	-28	-48	-25	4	-4	-7
TOTAL	**5 840**	**6 129**	**5 803**	**4 018**	**4 165**	**1 500**	**-1 421**

Table 1 Electricity net surpluses by category of municipality (National Treasury, 2013)

Eberhard (2004) points out that in the 1990s, the financial problems of electricity distributors, and the low levels of access to electricity were an overriding concern. Many small, poorly managed municipal distributors were not financially viable and were not in a position to provide sufficient services to either existing customers or new, unconnected households. These social, political and economic challenges are a legacy of the apartheid era, which continues to impact the present politics of energy transitions (Baker et al., 2014). Apart from struggling with technical capacity, the electricity departments in these municipalities lack the income generated by large industrial consumers and face a huge backlog in connecting low-income consumers. Some of these have already merged with larger municipalities but most of these municipalities lack viability. According to Savage (2007), transfers of the smaller municipalities towards metropolitans have not resolved the funding problems. Many of these municipalities have also curtailed spending on the essential maintenance needed to secure electricity supply within the municipality (Eberhard, 2004). What also needs attention is that municipalities can cut off electricity, which is a great lever to enforce payment (Mcdonald, 2009). This cannot be done for services such as water (National Treasury, 2011).

Although there are many similarities between local authorities in South Africa, it should be recognised that every municipality has its own unique challenges within a different context and therefore there is no such thing as a ‘one size fits all’ solution (Swilling & de Wit, 2010).

2.2.5 Municipal financial management and service delivery

Municipalities in South Africa have very specific service delivery responsibilities. One of the points of section 152 of the Constitution of South Africa (1996) is that local governments have to ensure provision of services to communities in a sustainable manner. Section 153 of the Constitution adds that a municipality must structure and manage its administration and budgeting and planning processes to give priority to the basic needs of the community, and to promote social and economic development of the community (1996). According to National Treasury (2013), at the heart of a municipality is the need to manage its finances to deliver these services. However, for many municipalities, the majority of the income comes from revenue on services like electricity. Many municipalities’ financial survival is dependent on electricity revenue, due to the history of municipalities operating as electricity distributors (Janisch et al., 2012). According to Odendaal (2013) some local governments derived up to 70% of their income from turnover on electricity. This percentage is highly questionable though, as most of the financially healthy municipalities receive up to 30% of their revenue on electricity, without taking grants from national government into consideration (Statistics South Africa, 2013). This information leads to a municipal conundrum: stimulating energy efficiency and renewable energy technologies could lead to a loss of revenue and thereby reduce the municipal budget to cross-finance services that run at a loss. This could put the overall sustainability aims, in environmental as well as social terms, of a town in jeopardy.

This section highlights the municipal financial management structure and service delivery. At the core of a municipality lies the need to manage finances well in order to provide adequate service delivery to the citizens. The regulation of municipal finance ”Aims to make municipalities more accountable, financially sustainable and capable of delivering essential services to their community” (Savage, 2007). The reason why this section is dedicated to municipal financial management is because municipalities' finances are a crucial factor in assuring adequate service delivery, and these are affected by the distribution and sales of electricity. According to Swilling & de Wit (2010) the core challenge of municipal officials since 1994 has been to find fiscally viable ways to expand the EWWS services into poor areas and simultaneously to operate and maintain these services for municipalities as a whole. Moreover, the realisation grew that the development strategies also had to address the question of sustainable resource use. The sustainable resource use in this context means to ensure that natural resource consumption will not deplete or destroy the Earth's life supporting eco-systems, currently and in future. The capacity required for municipalities to deal with these major challenges is undermined by serious limits to the available financial resources. The complexity of these challenges includes the transformation of political governance, responding towards more equitable service delivery among diverse class groups, the call for a sustainable approach, and the unstable supply of resources such as water and electricity (Swilling & de Wit, 2010). In the end, the financial management structure should be sustainable in order for the municipality to function sustainably. The wide range of complexities and challenges highlight both opportunities and constraints and require creative and unknown approaches to deal with them.

There are three main sources for generating income for municipalities. The first one comes from property rates and taxes, based on the value of properties owned by both citizens and businesses. The second is to generate revenue by charging tariffs for providing services such as electricity, water and sewage, sanitation and refuse removal, and the use of municipal facilities. The third is via subsidies and grants from provincial and national government. Many municipalities that are not able to generate a lot of revenue on charges of service provision rely mostly on funding transfers from national government and other government agencies. Municipalities receive unconditional grants and conditional grants in the form of the Municipal Infrastructure Grant (MIG) (Local Government Action, n.d.). A small part of a municipal income comes from, for example, interest received, renting of equipment and facilities, and fines (Statistics South Africa, 2013). According to Local Government Action (n.d.) it seems that municipalities do not spend all of the money that is allocated to them through the MIG fund. Mismanagement and lack of capacity are reasons this money is not spent in its entirety. There were 272 municipalities that did not spend a quarter of the allocated money during the municipal financial year of 2010/11 and some of the grant had to be returned to National Treasury (Local Government Action, n.d.). When looking at the revenue impact as a result of rooftop PV, this should also be put into the bigger context of income generation by municipalities. When municipalities lose so much money that could have been spent on infrastructure due to mismanagement, it makes less sense to see rooftop PV as a threat to the overall income and financial stability of a municipality.

Each financial year, the municipality reviews its IDP and budget to be spent on service delivery. In developing the IDP and to allocate budget, the municipality needs to consult the community as dictated in chapter 4 of the Municipal Systems Act (Local Government Action, n.d.). With regards to determining the tariffs on electricity, municipalities are bound to legislation in the Municipal Finance Management Act and Municipal Systems Act. Before preparing budgets and tariff adjustments, municipalities must apply for tariff increases to the National Energy Regulator of South Africa (NERSA) (Nersa, 2013).

Savage (2007) points out that financial management of local governments has long been regarded as a labyrinth of highly specialised regulations and rules. It was carefully watched by municipal accountants with the intent to obscure financial performance from public scrutiny. Policy makers were prevented from analysing the structure, performance and possibilities of local governance finance by the absence of data on municipal financial management and performance (Savage, 2007). However, this view nowadays is changing as financial management within municipalities, rather than seeing it as purely a matter of implementation, is increasingly seen as a matter of strategic management (Savage, 2007). In order to optimise service delivery and deliver on developmental mandates, effective management of revenues, expenditure and debt is critical for municipalities. Since the year 2000, the significant increase in the availability and quality of financial data on municipalities reflects the importance of the role of municipal financial management. However, according to Savage (2007) longitudinal information remains unreliable, due to extensive reforms to reporting standards and formats, and incompleteness of earlier data sets. Moreover, the financial performance and management varies across the country according to size and context. Arguably, municipal finance and management is a multi-faceted issue; it is both a source for service delivery and governance processes, as well as a measurement system of the effectiveness of the municipal transformation programme.

2.2.6 Technical and non-technical losses

What also needs to be considered is how technical and non-technical losses impact the electricity consumption profile and consequently the revenue of municipalities. “Simply, losses could be defined as the difference between the metered units of electricity entering the distribution network and those leaving the network paid for through electricity accounts, whether estimated or metered, in a well-defined period of time” (Navani, Sharma, & Sapra, 2012:757). “Technical losses are regarded as the electrical system losses which are caused by network impedance, current flows and auxiliary supplies. The sources of technical losses may be directly driven by network investment or by network operation. Non-technical losses arise from several areas including theft, un-billed accounts, and estimated customer accounts, errors due to the approximation of consumption by un-metered supplies and metering errors” (Navani, Sharma, & Sapra, 2012:757). Both these losses will reduce the revenue from electricity for municipalities or for Eskom, depending on where the electricity is being lost on the line. The non-technical losses are, for example, electricity theft, fraud and corruption, metering failure, or misreading of meters (Yelland, 2008). Technical loss refers to, for example, electricity that is bought from Eskom but gets lost in the transmission lines or gets lost whilst being converted. The longer the distance from generation source to end-use, the more electricity will be lost. Moreover, it is evident that with increased consumer load power transmission losses will increase (Sebitosi, 2010b). According to de Groot, van der Veen, & Sebitosi (2013) in the case of the Western Cape, electricity has to be transmitted over a distance of between 800 and 1 370 km. This is because of South Africa’s highly centralised electricity network due to the abundance of coal reserves in the north-east of the country. As a consequence, a large number of coal-fired power plants are located in this region and a large amount of electricity has to be transmitted from here to the rest of the country. Apart from distribution electricity losses, as the Western Cape is the furthest region from the coal-fired power plants in the north-east, the transmission costs are higher for this region compared to the rest of the country (Eskom, 2014). As distributed generated rooftop PV is decentralised and close to the end-user, fewer losses are experienced with this technology (Sebitosi, 2010b).

Electricity theft in South Africa and non-payment of electricity accounts for approximately 3 600MW or the equivalent of the output of one coal fired power plant. This is 10% of the total national electricity demand of 36 000MW in 2008 (Yelland, 2008). However, even though theft might look like it is a small amount of the total energy consumption it can have a huge impact. Percentages in electricity theft should be seen in the light of eating up the surplus. This percentage is much higher when seen as a decrease of surplus than if seen as a percentage of the total electricity consumption. Bekker et al. (2008) point out in their article that by the mid-'90s, it had become apparent that electricity was by no means going to be self-funding, as was hoped for in earlier decades. This reality was exacerbated by the emergence of 'non-technical losses'; electricity theft through illegal connections, and/or bypassing the electricity meter.

Electricity theft can be found at farms, industries, companies or households. However, the municipality usually finds out once the industry or company is leaving and another entity or person is going to occupy the building. Electricity theft can be recognised when the safe lock on the meter is broken (Stellenbosch Municipality, 2014).

This section has defined technical and non-technical losses and pointed out their impact on revenue from electricity. It also shows that the threat of residential rooftop PV should be seen in a wider context. There are more factors such as technical and non-technical losses and, as mentioned earlier, energy efficiency that can have a significant impact on electricity revenue reductions. Distributed generation in the form of rooftop PV can also have significant advantages, as less technical losses are experienced since electricity is generated close to the end-users.

2.2.7 Concluding remarks

The last sections of the literature review have specifically looked at the South African context regarding electricity provision and renewable energy. First, the South African history of electricity service provision was discussed. This paragraph showed that in the past many South African municipalities used to generate and provide electricity before it became centralised. Currently, municipalities rely on Eskom for electricity provision before they can distribute it to the consumers. However, since the introduction of distributed generation a decentralisation shift is happening again. Despite the success of REIPPPP, the residential rooftop PV market still experiences many challenges. An important aspect of the research will be to find out if the peak demand can be reduced by residential PV. On average, municipalities generate 30% revenue on electricity provision, which is critical to the financial credibility of municipalities and, therefore, is to be protected. However, there are also municipalities that have losses on electricity. Although there will be plenty of similarities between municipalities, every municipality deals with their own unique challenges and therefore, there is no such thing as a ‘one size fits all’ solution.

Chapter 3 – Research design, methodology and methods

The aim of this study is to inform municipal decision makers and planners through applied research with an analytical angle. This will enable policy makers to deepen their knowledge on specific practical questions regarding embedded generation and to create or adjust policies accordingly. “Input into policy dialogue is often a research-based process and in fact much of what planners do involves data gathering, processing and interpretation (Odendaal, Duminy, & Watson, 2010:3)”. Much of what is written up by planners, reflected upon and taught is often intuitively based on case work (Odendaal et al., 2010:3). In essence, a case study refers to a process in which a specific case is studied and analysed in depth using research methods most appropriate to the enquiry (AAPS, 2012).

This study specifically uses Stellenbosch Municipality as a case study and therefore the single case study approach will be used as an overarching method. In order to illustrate a holistic understanding of the situation a mixed-method approach is used, combining quantitative and qualitative methods. The dominant method used to analyse data in this research will, however, be quantitative as most data is collected and analysed in numeric form (Muller, 2008). After analysis and interpretation of the data, a simulation approach is used in building models for understanding possible future scenarios based on a critical analysis of data from previous years. Due to the fact that average cases don’t often reveal as much information as extreme cases (AAPS, 2012) I have chosen to plot an extreme case scenario. According to Zucker, (2009) to incorporate rigour into the study design, an important technique is the use of a negative case to serve as a study ‘control’. The use of the extreme case in this regard is helpful for comparative purposes. This extreme case approach is used to model future scenarios of the share of embedded generation onto the municipal electricity grid as compared to conventional municipal distributed electricity. It provides a clear and solid point of departure from which policy makers can base their decisions.

An extreme case scenario allows policy and decision makers to regulate and draw up appropriate policies according to the criteria they favour to guide a positive sustainable transition. However, there is no perfectly balanced sustainable transition and trade-offs will be inevitable. The art is to steer the transition in the most favourable direction, which requires the fewest negative trade-offs.

In this chapter, I endeavour to provide the reader with a practical framework with details of the steps that are followed to come to the final results. It will start with a brief on the research problem and the objectives that form the base of the research. The other paragraphs will elaborate on the methods being used to find answers on the research question and objectives.

3.1 Conceptualising research design

Research process

Figure 4 below represents the research process that consists of a series of closely related activities. These activities are not conducted in pure sequence but they are iterative and overlap each other continuously, hence they will not always follow each other as depicted below. At each step in the research process, constant anticipation is needed to determine the requirements of the next step (Kothari, 2004).

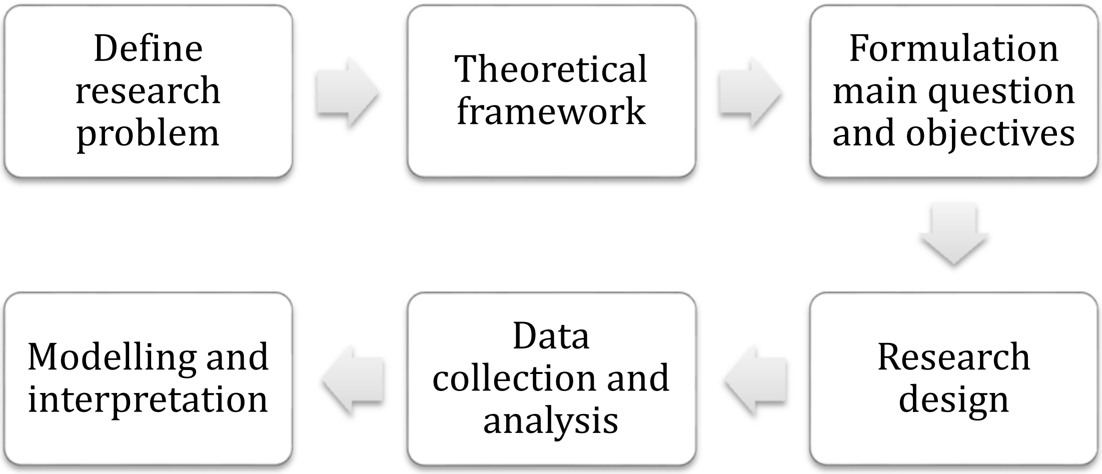

Figure 4 Flow chart of the research process

Research problem and objectives

I intend to provide a contribution to the existing knowledge through an objective and systematic method of collecting and analysing data, and reaching certain conclusions about the relevant problem (Kothari, 2004). The problem identified is that there is a perceived revenue loss for local municipalities if electricity consumers within the municipal borders start producing and consuming their own electricity instead of buying it from the municipality. Therefore, the increasing uptake of renewable energy in the form of rooftop PV by the residential sector is seen as a positive development in the light of sustainability but might have a negative impact on local governments in terms of their legislated revenue sources. Given this context, the following main question is formulated:

What will be the impact on Stellenbosch Municipality's electricity revenue if households in identified high electricity use suburbs install the maximum capacity for embedded generation according to NRS standard to feedback electricity produced by rooftop PV to the grid?

In order to find an answer to this question, the following objectives are formulated:

Theoretical framework

- Building a theoretical framework that analyses the threat to traditional business models of utilities across the world and to expose and compare different perspectives on the matter
- Honing in on the South African issue of decentralised electricity provision and providing an in-depth analysis of the financial challenges of service delivery for South African municipalities

Case study

- To analyse and contextualise financial dependency on electricity revenue and electricity service provision in the socio-economically diverse town of Stellenbosch
- To model the impact of solar rooftop PV systems by households on electricity consumption profiles and the electricity revenue of Stellenbosch Municipality in order to define meaningful planning practice

The literature review will provide an analytical framework around the first objectives through critical analysis. The final objectives will be explored in the case study and modelling scenarios that result from the quantitative data.

3.2 Literature review

A traditional literature review will be conducted with a conceptual review lens. “A conceptual review aims to synthesise areas of conceptual knowledge that contribute to a better understanding of the issue” (Jesson, Matheson, & Lacey, 2011:15). Contributions of knowledge in the field will be woven together in a theoretical framework in a logical, systemic way to holistically review the context and scope of the problem. This will help with reviewing and revising the research question and objectives if needed.

Case studies that have been conducted for other municipalities, regarding a similar topic will be critically reviewed to see what has been done and what still could be done in the field. An example will be the study of the impact of rooftop PV in Hessequa, South Africa. I will also examine whether these studies could give a satisfactory answer to my research question or if there are possible new ways of looking at the problem. In the literature review, a historical context will be given to show where the current status of the political structure of electricity distribution comes from and how it has been shaped since its existence in South Africa. This is important to understand the current economic and political environment around electricity. The literature review in this sense helps to identify ways in which the current knowledge on the topic has developed (DePoy & Gitlin, 2015). Thereafter, current trends and ways of thinking within the field of my research topic are explored.

3.3 Selection of research methods and tools

At the start of the research different methods that were intended to be used in this study were explored. According to Zucker (2009) when reviewing the research question, students should ask how they can get the information they are looking for and list possible methods in their minds. The diagram below shows the steps that will be taken in the data gathering and analysis processes. All the fieldwork done culminates in the analysis and interpretation of a set of data (Kothari, 2004) and in this particular study, mainly quantitative data will be presented. A Secondary Data Analysis approach will be used to analyse existing quantitative data from Stellenbosch Municipality. Due to the fact that the study looks at secondary data and not first-hand collected data, it is difficult to trace collection errors. However, as opposed to what Mouton (2001) argues, to a certain extent it is still possible to critically evaluate the validity of the data from the municipality. Efforts are made by using formulas to examine the validity.

During the analysis process, the data from the different sources is broken up into manageable trends and relationships. This allows a critical analysis of the relationships between the constructs and variables and to establish themes in the data (Mouton, 2001). Figure 5 shows the data sources and tools for analysis scheme. Firstly, the residential areas to be researched have been identified and mapped. Secondly, an electricity grid map from the municipality concerning high and medium-voltage cables and transformers is used to calculate the maximum capacity the grid can receive in terms of embedded generation in the researched residential areas according to the NRS 097-2-series policy. Thirdly, recorded data from a photovoltaic system is used to track the hourly solar PV generation profile from July 2013 until July 2014. This period is chosen as it is in line with the most recent and completed municipal financial year. Using the financial year prevents dealing with different tariffs. Every year, Eskom and local government prices change depending on NERSA's approval. Lastly, a program to track the municipal electricity output from the substations will be used to plot a profile of the electricity output for Stellenbosch Municipality. The program is from Zimele Technology. It provides hourly data for the substations – Stellenbosch Main station (in Onder Papegaaiberg) and Cloetesville. For calculation purposes, a check needs to be done to ascertain which area is connected to which substation.

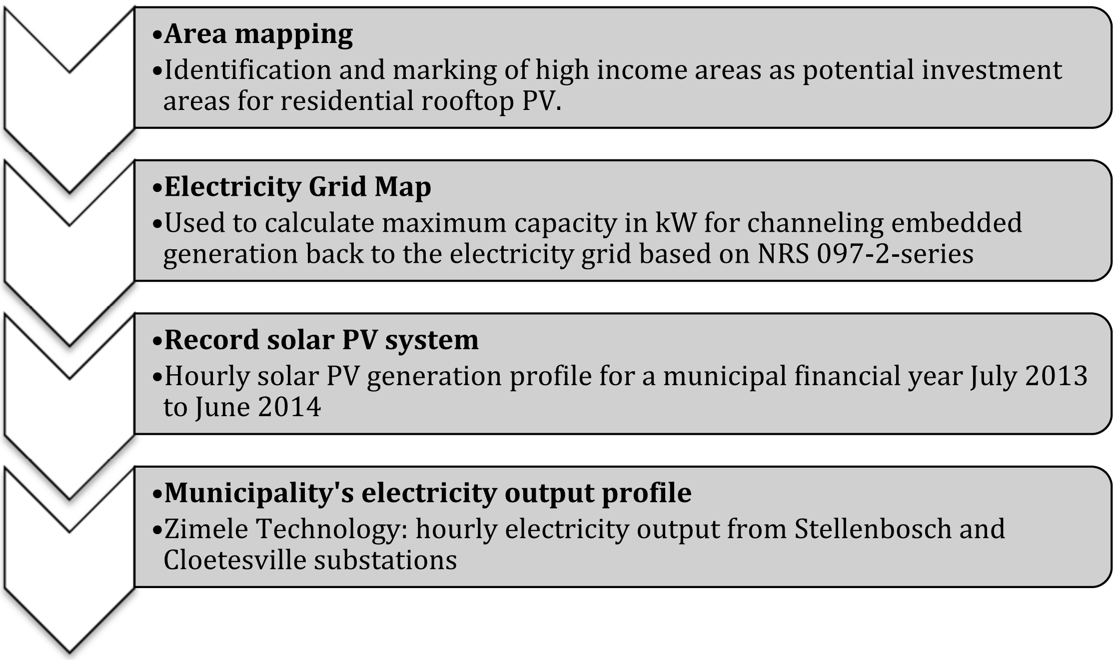

Figure 5 Data sources and tools for analysis

Area Mapping

According to AAPS (2012), a case study involves the analysis of a unit, defining the minimum level of the research. AAPS (2012) determines that the three basic units of analysis are the individual, the household and the community. This study specifically looks at the middle- to high-income community in Stellenbosch. The assumption is made that middle- to high-income households in Stellenbosch Municipality will invest in rooftop solar PV systems, as this is the group that is financially able to invest in this technology. Figure 6 below shows the areas that will be researched. These areas are Uniepark, Paradyskloof & Die Boord, Dalsig, Onder Papegaaiberg and Welgevonden. The areas are connected to different electricity substations namely Jan Marais, Cloetesvile, Golf Club, Markotter and Main Substation. For these areas, an extreme case scenario will be plotted. The extreme case scenario is based on occupying the maximum kilowatt on the grid as allowed according to the NRS 079-2- series.

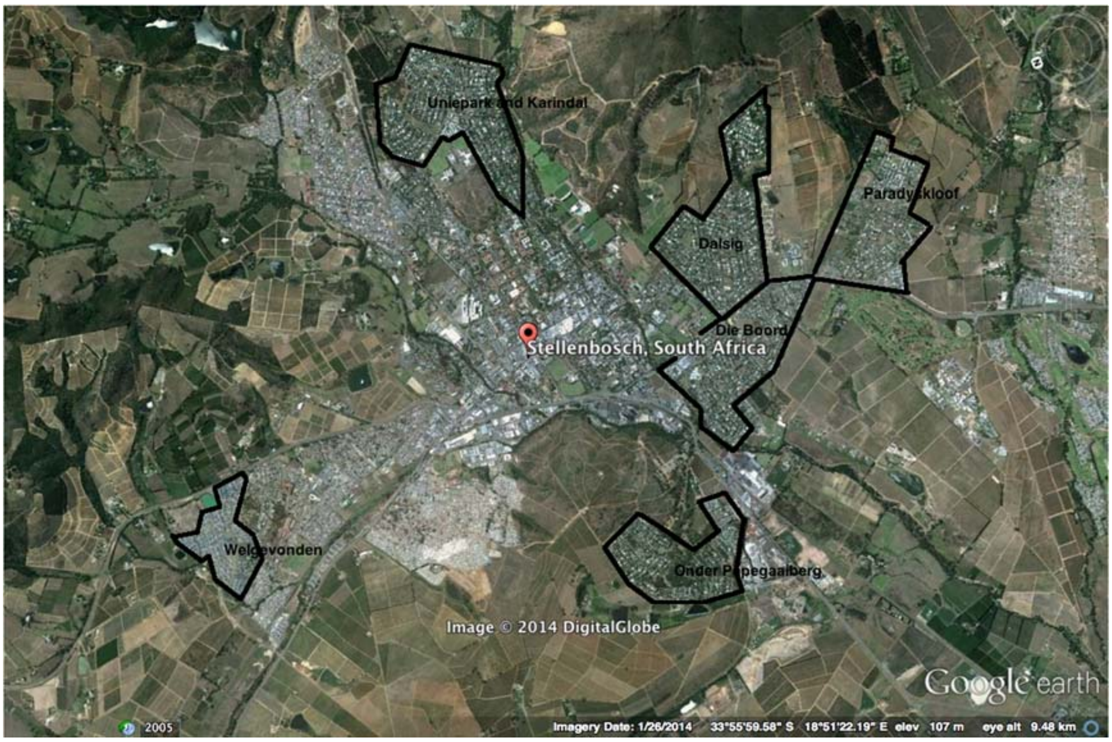

Figure 6 Typology: identified high-income areas in Stellenbosch marked for research

Electricity Grid Map

After the research areas have been identified, the first step should be to calculate the maximum capacity the current electricity grid in Stellenbosch can receive. This will function as a foundation for further research steps. The calculations will only be done for the medium-voltage electricity grid cables and transformers that are connected to households in the identified areas. The policy NRS 097-2-series is going to function as a basis for the calculations. This means that this policy will be used as a safe guideline since there is no specific electricity grid study available to indicate what the share of embedded generation can be onto the electricity grid, and as part of the electricity that flows through tranformers. The map in Figure 7 illustrates the different electricity substations in Stellenbosch and their interconnectedness. Stellenbosch receives 66 kV high voltage electricity from Eskom and transforms it into medium voltage to be distributed on the Stellenbosch electricity grid before it will be transformed into low voltage that is suitable for household use. Not being considered in the calculations are: commercial, industrial, university property and student residences outside the university property, municipal buildings, and government facilities such as the library and the hospital. The study solely reviews the impact from the residential sector.

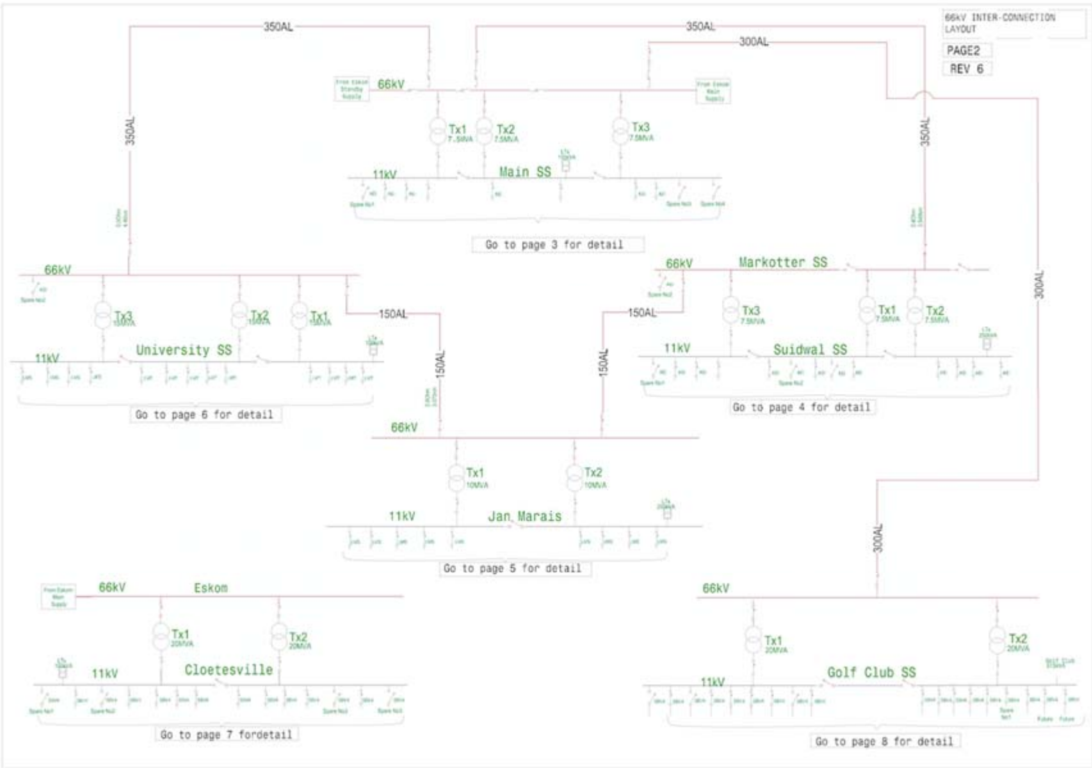

Figure 7 Stellenbosch’ 66kV electricity substations and interconnections

Municipality’s electricity output profile

Figure 8 illustrates an example of the electricity load profile from the 66 kV Stellenbosch substation on a day in July. The amount of electricity output is given per half hour and shows when the peak, off-peak and standard hours occur. The data from this graph will be converted into average hourly data as the electricity generation from the sample solar PV system is also projected per hour of the day.

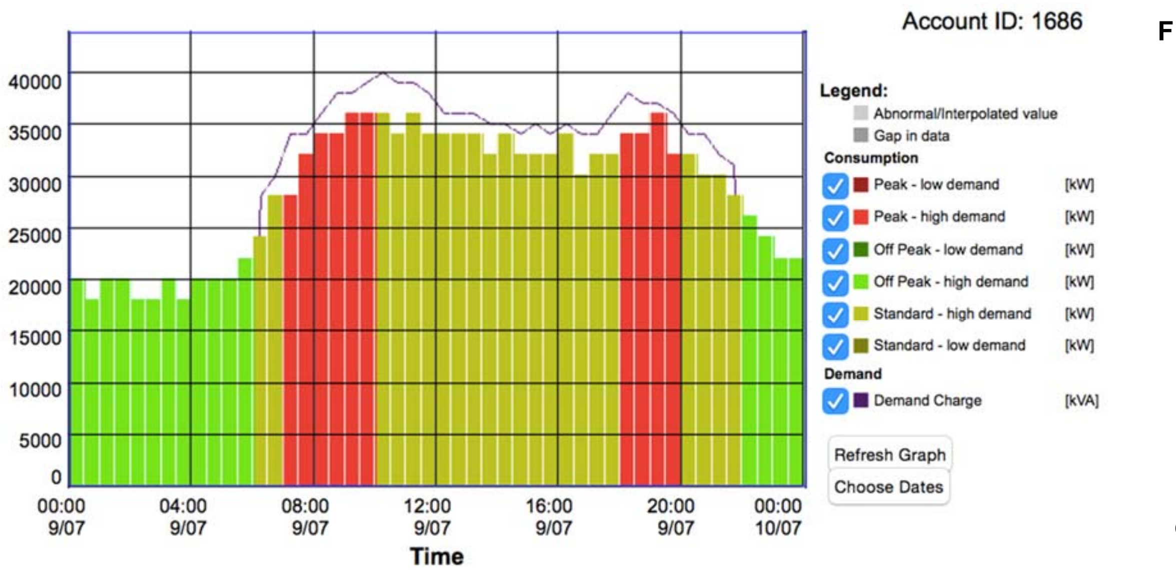

Figure 8 Electricity Use Zimele Technologies: Stellenbosch 66kV substation

Sample solar photovoltaic system

The data of a photovoltaic system, with an output size of 1.68 kW will be used as a tool to measure what the solar penetration was from July 2013 – June 2014. Data will be pooled for every hour of every day in this period. For every month one typical day will be selected as the day to use the data from to provide as realistic an outcome as possible. Selecting a typical day means selecting a day according to what is considered a normal day for the particular season the month falls in. For example, December is a hot summer month with longer daylight hours. A specific, sunny day will be selected and used for further calculations.

Modelling

After these steps have been taken, all the gathered data needs to be analysed and linked to each other. Excel will be used as a tool to make connections between the data points, to build formulas and to model future scenarios out of the data and formulas.

The models will represent a simulation of modelling part starts by simulating future extreme case scenarios. According to Kothari (2004:5) a “Simulation approach involves the construction of an artificial environment within which relevant information and data can be generated. This permits an observation of the dynamic behavior of a system (or its sub-system) under controlled conditions”. In the context of business or social sciences the application of the term ‘simulation’ refers to “The operation of a numeric model that represents the structure of a dynamic process. Given the values of the initial condition, parameters and exogenous variables, a simulation is run to represent the behavior of the process over time”.

The extreme case scenario will be plotted for different seasons in a year for Stellenbosch. The Zimele Technology system provided by Stellenbosch Municipality will be used to provide the electricity output for the selected day and will form the basis of the model. A calculation will be made as to what proportion of this electricity output, for a particular substation on a particular day, will be reduced by rooftop solar electricity.

Interpretation

The modelled scenarios will be interpreted in the larger context of conducted and available research in the field. Mouton (2001:109) states "Interpretation means relating someone's results and findings to existing theoretical frameworks or models, and showing whether these are supported or falsified by the new interpretation". The results of my research will be looked at from a single case study point of view. However, Mukhija (2010) presents an unconventional approach of a primary case informed by multiple secondary cases. It is argued in Mukhija 2010's article that under certain conditions focusing on one case, following some additional secondary cases might be a better way of conducting an in-depth single case study. Therefore, the results of the study will not only be looked at from an isolated single case point of view but will also be analysed considering previous conducted studies on a similar topic for other municipalities. To conclude, comparisons will be made within the single case study of the impact in different seasons under different climate conditions and comparisons will be made with previous studies.

3.4 Single case study method

As it involves a detailed study of developmental factors (i.e. changes over time), the case study method is well suited to analyse complex planning challenges. It emphasises the importance of local and regional contexts (AAPS, 2012). A single case research approach will, therefore, be used to gain an in-depth understanding and multi-faceted exploration of the phenomenon. This approach is a popular one, if not pervasive in planning, policy and business research (Mukhija, 2010). In this case study, the social and economic phenomenon is that of an expected increase in investment by residences in embedded generation, which might have implications for municipal revenue on services. Although the study might be seen as merely an economic study, the economy forms part of the wider complex social context. The economic impact of the phenomenon could lead to social consequences or social transformation. Moreover, the socio-economic context of Stellenbosch, still mainly formed by a legacy of apartheid shows stark contrast with areas that are considered high-income and able to invest in embedded generation, and poor areas that are not even connected to the conventional electricity grid. Regulations and policies of the past still determine where people are living today in Stellenbosch and which communities are financially able to invest in solar PV systems.

Previous studies have shown generalised outcomes of the impact of the phenomenon that I am researching. Yin (2013:13) argues, however, that scientific facts are rarely based on single experiments. Usually they are based on a multiple set of experiments that have replicated the same phenomenon under different circumstances. This study does not aim for a generalisation of results as the results are different, depending on the context in which conditions such as seasonality, political-technical systems and load shedding events affect the use of electricity. This study, however, looks at the financial year 2013—2014 in which load-shedding events were still limited, compared to the municipal financial year of 2014—2015. Days on which load-shedding events occurred have been avoided in this study.

3.5 Data gathering and networking

Field exploration will be necessary in the data gathering process. This includes going to events like the Renewable Energy Festival in Cape Town and Energy Efficiency Forum meetings. Semi-structured interviews and emailing specific questions to key persons will be used as tools to gain information. More specifically focussed on Stellenbosch, it will be useful, if not critical, to go to IIC meetings to keep up to date with developments of the different infrastructure working groups, and in particular the energy working group. The research that will be conducted will be used as input for policy drafts regarding electricity challenges in Stellenbosch Municipality. More specifically, it will be of value in the regulation of allowing embedded generation to be connected to the municipal electricity grid.

As I have worked at Stellenbosch Municipality before, it gives me the opportunity to use the network I have already built within the municipality. As stated in the AAPS (2012:12) report, “Producing a good case requires intimate inside knowledge of key events and actors. It requires breaking through the surface of ‘how things appear’ to reach the messy, ambiguous world of ‘how things are’”. The ability to network and use both formal and informal connections in order to get the data needed to fulfil the research study will, therefore, be key. Experience tells me that people are more helpful in face-to-face and informal meetings than via very structured and planned interviews or email. It is more important to build trust in the research for the professionals I interact with, and at all times to respect their comfort zones. As my research will be used in policy making, I am also planning to keep professionals from Stellenbosch Municipality and Stellenbosch University updated on my research by giving presentations should there be an appropriate opportunity to do so. In my view, it is crucial to be open to the knowledge of others in order to widen my perspective on sustainability challenges in Stellenbosch. It is also crucial to maintain relationships in case more or alternative data is required to fulfil the research successfully. There are many examples of researchers who have failed to conduct case study research due to political and inter-personal obstacles (AAPS, 2012). It is, therefore, crucial to consider all potential barriers to access data and to create alternative plans if the required data is inaccessible or unavailable.

3.6 Concluding remarks

This methodology chapter has shown how the research is planned and which methods will be used in order to achieve the necessary information to find an answer to the research question. Furthermore, data sources are pointed out and a detailed description is given for how the data will be analysed and linked before modelling. Crucial steps in the process, as well as boundaries and limitations have been pointed out.

Chapter 4 – Case study Stellenbosch: Research findings and analysis

4.1 Introduction

This chapter presents the findings of the research, leading towards formulating an answer to the main question of this study:

What will be the impact on Stellenbosch Municipality's electricity revenue if households in identified high electricity use suburbs install the maximum capacity for embedded generation according to NRS standard to feedback electricity produced by rooftop PV to the grid?

This chapter is divided into four sections with research findings. The sections are structured so that they follow each other in a logical sequence. The findings are analysed in each section and sub-conclusions are drawn. The first set of research findings will shine a spotlight on the current developments concerning electricity provision, with special emphasis on the financial dependency of Stellenbosch Municipality on electricity revenue. It is important to know what part of electricity revenue the municipality intends to protect. The findings of the first section also show why this research focuses particularly on residential areas in Stellenbosch. The second set of findings present the grid capacity in the residential, high electricity use suburbs of Stellenbosch to receive embedded generation from rooftop PV. This will lead to a discussion on how these findings will determine how many households can potentially afford a 3 kWp rooftop PV system. The grid capacity will be the basis for the third set of findings, i.e. the electricity in kWh that could potentially be taken off from the electricity load profile in Stellenbosch for the Cloetesville and Stellenbosch main electricity substations in an extreme case scenario. In the fourth and final set of findings, this will be translated into financial terms, which will provide the answer to the main question: will the financial impact be as a result of embedded generation in an extreme case scenario?

4.2 Research findings 1: Electricity service provision in Stellenbosch and financial dependency

This first section of the case study chapter presents the initial findings of the research. It provides an analysis of Stellenbosch's current developments regarding municipal electricity service provision, partly constructed by qualitative research through interviews with officials of Stellenbosch Municipality, and partly by quantitative data, derived from municipal documents and databases. The findings and analyses provided in this section contextualise the research question and objectives, and will serve as the backbone of the next sections that form part of the case study.

The analyses will unravel the state of financial dependency of Stellenbosch Municipality on electricity revenue. Furthermore, it will explain why the residential sector is being used as a typology in this study, what the electricity consumption trends are in Stellenbosch, and the difference in electricity usage in different suburbs. It also justifies the income and electricity-use group for which it would make the most sense to invest in rooftop PV. Lastly, this chapter will point out the different pricing and payment structures of electricity.

<u>Electricity provision and Notified Maximum Demand</u>

The Stellenbosch municipality purchases electricity in bulk from the state electricity utility, Eskom. Electricity is received via high-voltage 66kV electricity lines to its main substations in Cloetesville, Stellenbosch, and Franschhoek. From there, the municipality is responsible for the distribution of the electricity within its licensed area of supply, as regulated by NERSA, the National Energy Regulator of South Africa (Energy Working Group, 2015). Approximately 88% of the electricity requirement is distributed by the Stellenbosch Municipality, which is purchased from Eskom on a Time-of-Use basis. Eskom directly supplies around 10% to the end-users (Stellenbosch Municipality, 2014). A small percentage (2%) of the electricity within Stellenbosch's jurisdictional borders is distributed and billed by Drakenstein Municipality. The reason that Pniel and Johannesdal are billed by Drakenstein Municipality is that this area is connected to a substation in Drakenstein. This substation is closer to these suburbs and it works better in terms of cost efficiency and maintenance. For these reasons, a decision was made to put the electricity provision and billing under the responsibility of the municipality in which the substation was located (Stellenbosch Municipality, 2014).

Stellenbosch Municipality distributes the electricity received from Eskom through the substations to the consumers. The electricity is distributed via medium-voltage (11kV) cables to transformers in the different suburbs where it is converted into low-voltage electricity suitable for supply to end-users. Municipalities who receive electricity from Eskom are allocated a Notified Maximum Demand (NMD) per main substation that indicates the maximum electricity demand for that particular substation. If the electricity demand of the municipality exceeds the NMD, the municipality risks being fined by Eskom. The total NMD that has been allocated to the municipality by Eskom is 80 MW. 55 MW is allocated to Stellenbosch Main substation, which is located in Onder Papegaaiberg. Recently, Eskom allowed the municipality an increase of the NMD from 8 MVA to 9 MVA for the Franschhoek substation and from 15 MVA to 16 MVA for the Cloetesville substation. Previously, loans were taken from Eskom to finance the increased NMD MVA. Nowadays, however, the amount is paid as a one-off settlement (Stellenbosch Municipality, 2014).

Conclusion

The municipality has an allocated NMD in MVA per substation that receives high-voltage electricity from Eskom. It is costly to increase the NMD. Therefore, even though the municipality receives revenue for selling electricity, and one would expect revenue increases by selling more electricity this needs to be weighed against the bill from Eskom for increasing the NMD.

Analysis of financial dependency on electricity revenue

The most commonly used argument by municipalities is the fear of potential revenue loss as a result of embedded generation. For many years, Stellenbosch Municipality has been able to make a surplus on electricity revenue by distributing and selling electricity to citizens. In general, municipalities generate surpluses on the sales of electricity, which in many cases is used to cross-finance other services that are underfunded (Swilling & de Wit, 2010).

In order to answer the research question, it is important to provide an in-depth analysis of the financial and electricity service context of Stellenbosch Municipality, with particular regard to the electricity related expenditure and revenue. Figure 9 shows the total revenue by source in the year 2011 to 2012 in Stellenbosch. The reason that this year is chosen is because it provides actual data. The most recent years are still projected in forecast, rather than actual data, which does not provide solid facts. The figure indicates that 31% of the total revenue came from the service charges on electricity and formed the biggest source of income for the municipality, followed by other service charges (22%) and property rates (18%). Since the share of electricity revenue is the largest, it is not surprising that the municipality endeavours to protect this revenue and uses it as an argument to question the allowance of implementation of grid-connected embedded generation by current consumers. However, the argument is incomplete when expenditure on electricity services is not considered. The 31% reflects the revenue but not the actual surplus that is used to supplement the municipal coffers. The next paragraph will point out the difference between revenue on electricity and the expenditure.

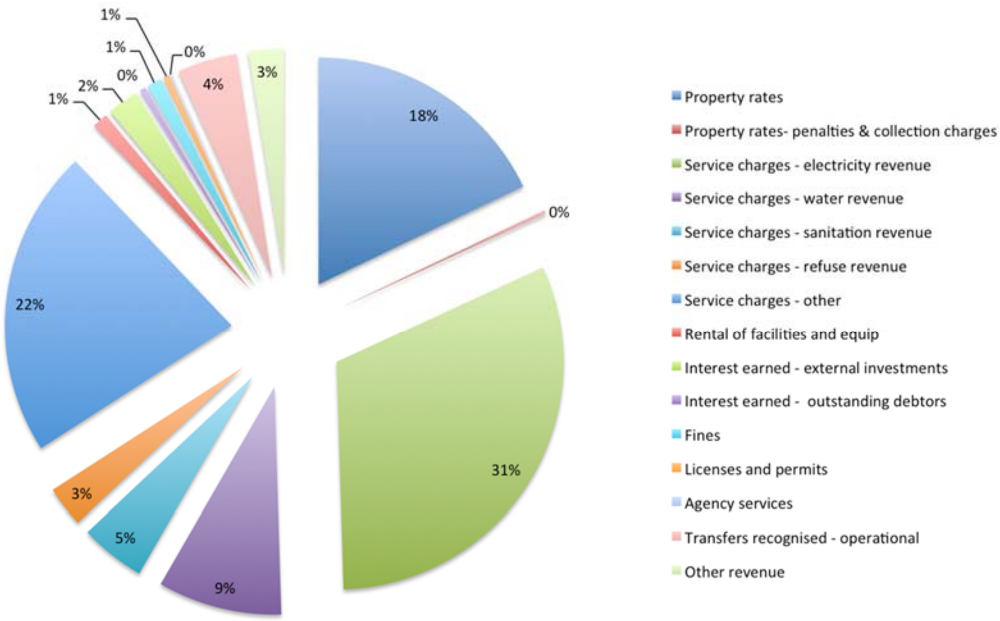

Figure 9 Revenue Stellenbosch Municipality by Source 2011/2012

An analysis of the electricity revenue and expenditure between 2009 and 2012 is provided in Figure 10. In the 2009/2010 financial year, the expenditure almost equalled the revenue. The surplus generated in this year was approximately 1.8% or R4 633 000 in absolute terms. In 2010/2011, the surplus increased significantly compared to the previous year. The surplus was 14.8% and R45 307 000 in absolute terms. This means that in one year the surplus increased almost 10 times. In 2011/2012, the surplus decreased to 6% of the total revenue. In absolute terms, the surplus was R32 609 000. The 2012/2013 municipal financial year generated R26 425 000 – a 7% surplus. The 2013/2014 municipal financial year is the one that is used as the research year for this study. In this year, the revenue on electricity was R413 698 000 and the expenditure R381 089 000. This provided the municipality with a surplus of R32 600 000, which is approximately 8% of the total revenue. According to National Treasury (2013) in general, the surplus on electricity at municipalities is decreasing. However, when looking at Figure 10 this cannot be said for Stellenbosch Municipality, as their surplus fluctuates with an upward trend.

According to Andrew Janisch (2014), municipalities tend to push to keep a 10% surplus. However, according to the data provided in Figure 10, the surplus fluctuates for Stellenbosch Municipality. It is difficult to know from this data if the municipality is striving to protect a certain percentage in surplus on the revenue. More quantitative and qualitative data would be needed to predict a long-term trend and to unpack the revenue and expenditure costs. In some years there may be more maintenance or upgrading scheduled than in others. What also needs to be mentioned is that Distributed Generation (DG) will not only impact the revenue but could also impact the costs for the municipality. However, the magnitude of the impact on the two sides of the balance sheet might differ. For example, if households put up rooftop PV, it will diminish the revenue, as households will buy less electricity from the municipality. It will, however, also diminish the expenditure for the municipality, as the municipality purchases less electricity from Eskom. Moreover, certain solid costs like maintenance will remain, or become higher because of extra maintenance to prevent a destabilised grid due to more grid-connected embedded generation. These factors combined might affect the future surplus on electricity.

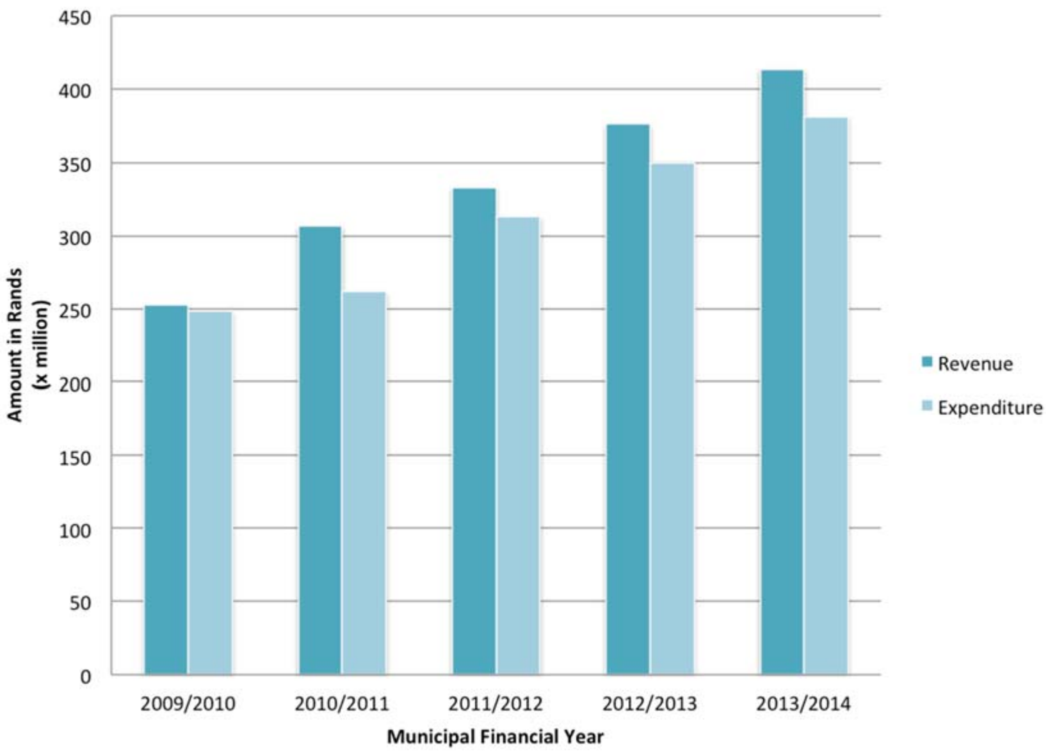

Figure 10 Division between electricity revenue and expenditure

Concluding remarks

The revenue on electricity services for Stellenbosch Municipality is approximately 30%, as a share of the total revenue on service provision and other income. The threat of revenue loss as a result of grid connected embedded generation is often used as an argument by municipalities to question DG allowance. It is, however, the surplus (revenue minus the expenditure) that is used to supplement the municipal coffers. It will therefore be important to look at the potential effect of DG on both the revenue and expenditure and more importantly, on the surplus.

The significance of the residential sector

This thesis focuses solely on the residential sector of Stellenbosch. There are three main reasons for this. First, the residential sector contributes the largest proportion to the revenue on electricity. Figure 11 indicates the revenue percentage per category consumer during 2012/2013 in Stellenbosch. From the pie chart, one can see that the category 'domestic consumer' is by far the biggest revenue provider, with almost 60 percent of the total. Secondly, the residential sector consumes the major amount during peak hours, which are very costly hours for the municipality compared to standard or off-peak hours.

The domestic category is divided into prepaid and credit meters. The prepaid meters account for 24% and the credit meters for 35%. The municipality aims to have all the electricity meters prepaid in the next three to five years to prevent non-payment and meter failures (Stellenbosch Municipality, 2014).

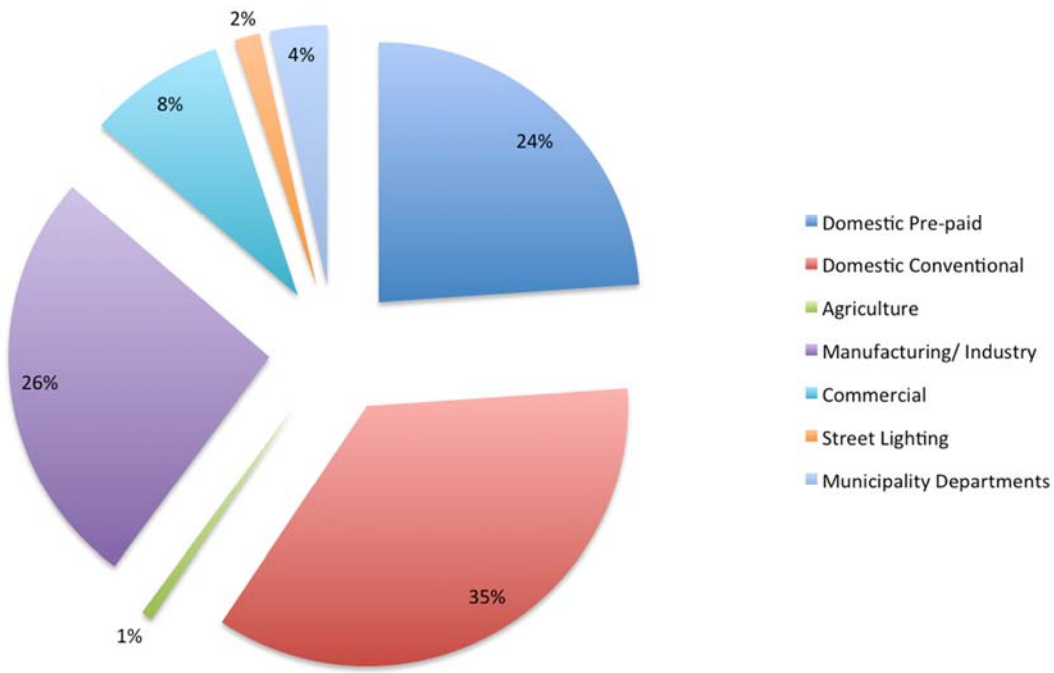

Figure 11 Revenue per category consumer in Stellenbosch in 2012/2013

Concluding remarks

Two main reasons in this section that have been given as justification for the choice to focus on the residential sector as research group are:

1) Almost 60% of revenue on electricity comes from the residential sector

2) The residential sector contributes the most to peak hour consumption when electricity is relatively more expensive for the municipality

Consumption trends

Figure 12 shows the trend of the total electricity consumption of all sectors combined in Stellenbosch in kilowatt-hours in the period from 2003 to 2013. Over the first five years the consumption of electricity increased gradually from 325 000 000 kWh to 360 000 000 kWh until 2008. In 2008, the amount of electricity consumed decreased to approximately 345 000 000 kWh. This sudden drop in consumption could be explained by the blackouts that occurred in 2008. In addition, 2008 was the first year in which the basic service fee was implemented. As a result of the basic service fee, consumers received fewer units per paid amount. For example: if someone bought electricity units for R100, a service fee of R28.50 was deducted, leaving the consumer with only R61.50 value in units. A consequence of the implementation of the basic service fee may have been that people tried to consume less electricity or could simply afford less electricity (Stellenbosch Municipality, 2014).

Moreover, in 2009 the block incline tariff was introduced, drastically changing the tariff structure. It was an incentive to remove load-shedding and to put more pressure on the high consumers to reduce their consumption. At that time, the municipality advertised for people to consume less electricity. The target was a 10% decrease in electricity consumption. If this was achieved, then the municipality would not have to implement load-shedding to bring the consumption down in a forced way (Stellenbosch Municipality, 2014).

The electricity consumption rose exponentially in the year 2012/ 2013. The main reason for this is the increase in new developments within Stellenbosch Municipality. Most of the new development is to be found in the residential area. A lot of new student residences have been built in an attempt to meet the increasing student housing demand. In addition, the commercial sector has also increased; an example of this is the expansion of Eikestad Mall (Stellenbosch Municipality, 2014).

A note to Figure 12 needs to be made: the reason for the sudden drop in electricity usage in 2011/2012 is not clear and could not be explained by the municipality.

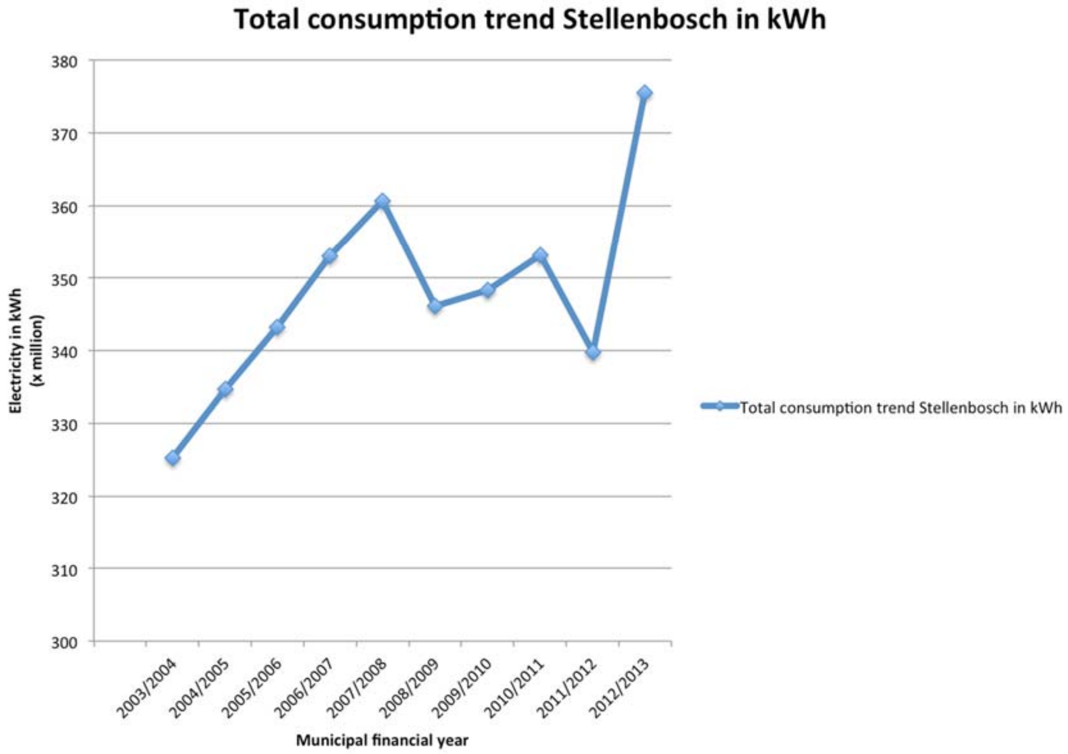

Figure 12 Total consumption trend Stellenbosch in kWh from 2003 to 2013

Figure 13 projects the consumption trend for the period 2009-2014 for consumers using a prepaid meter. This graph has been drawn from secondary data provided by Stellenbosch Municipality. The data shows the monthly electricity purchases by consumers over a period of five years. The reason it starts with the month of July is because the municipal financial year starts in this month. The graph shows clear spikes during the winter months and decreases in electricity consumption during summer months. The electricity consumption trend shows a slight linear increase over these five years, indicating that the overall electricity consumption by consumers with a prepaid meter is increasing. The trend shows a consistent flow, which is explained by the way data is collected. Consumers pay for electricity upfront, before it is being used, usually at the beginning of the month. All the electricity purchased in one month, will be registered as electricity used in that month. Even if electricity will be used in the next month, this averages out. Apart from this, because of the tariff block incline system, it makes more sense for consumers to manage electricity purchases carefully.

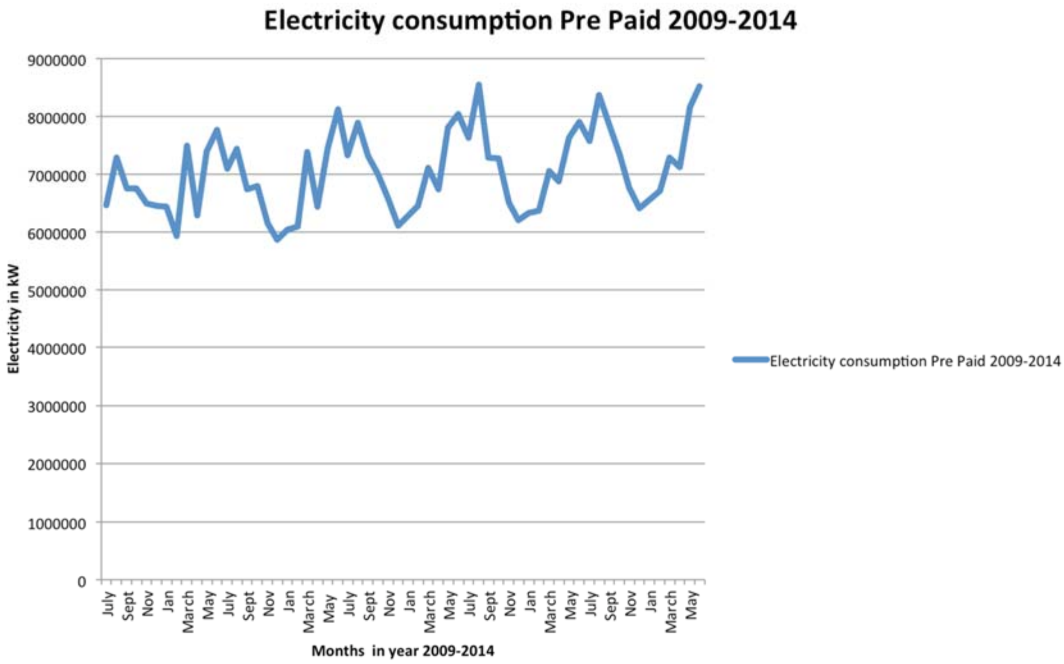

Figure 13 Electricity consumption for pre paid meters 2009-2014

Figure 14 shows the consumption trend for consumers in Stellenbosch with a credit meter for the period 2009-2014. This graph is also based on data showing the monthly usage for consumers with a credit meter and was also provided by the municipality. Unlike Figure 13, Figure 14 is not very clear and is inconsistent. The inconsistency of the trend in the graph can be explained by the method of reading of credit meters. The reading of credit meters happens manually, which incurs reading and reporting mistakes whilst collecting data. The reading may also be done inconsistently, as there are low values in certain months and sudden extreme increases in values in other months. The third reason can be data records based on estimations rather than actual data.

The graph does however show a steep increase in electricity usage in relative and absolute terms by credit meters.

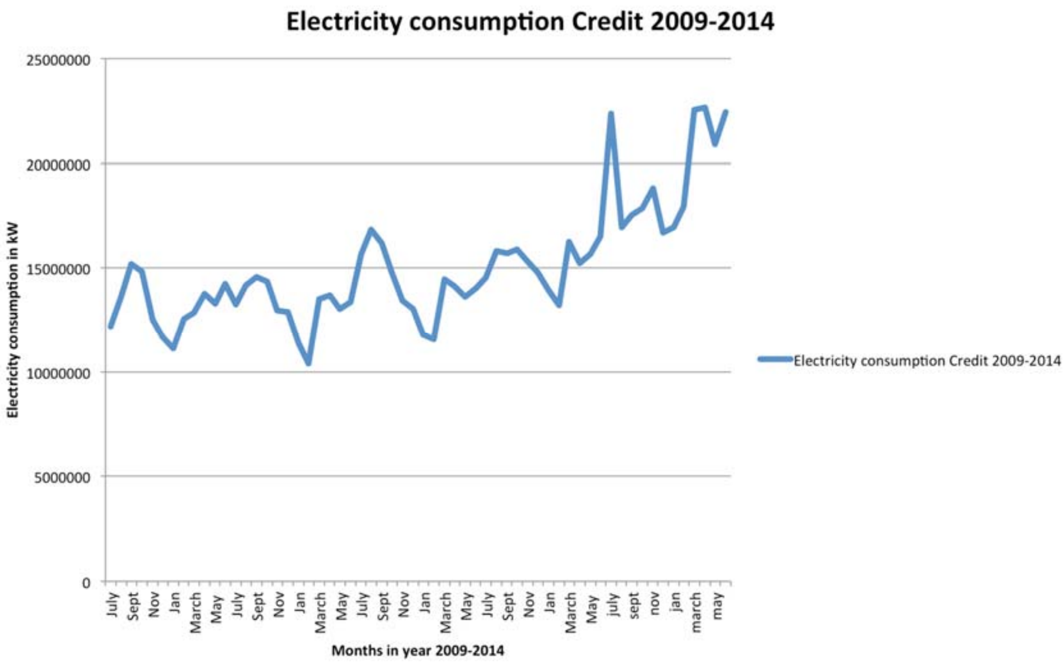

Figure 14 Electricity consumption for credit meters 2009-2014

Concluding remarks

This section has shown that the prepaid data recorded by the municipality is more accurate than the recorded credit data. For further calculations, this should be kept in mind. Since the data of Figure 13 (recorded prepaid meter data) and Figure 14 (recorded credit data) does not add up to Figure 12 (total electricity consumption), some data may be missing or recorded incorrectly.

Furthermore, despite electricity price increases, the electricity demand and consumption still shows an increasing trend. This also challenges the price elasticity of electricity, specifically for Stellenbosch Municipality.

Moreover, the municipality aims to move away from credit meters, yet the credit meter electricity consumption data shows a sharper increase in the last few years than the prepaid electricity consumption data.

Consumption behaviour

Electricity consumption per suburb

This paragraph specifically analyses the consumption behaviour for the residential sector in Stellenbosch. Table 2 shows the average consumption for households per suburb for prepaid and credit meters for the municipal financial year 2013-2014. The results are based on data provided by Stellenbosch Municipality on electricity usage per consumer in Stellenbosch. Zero values have been omitted from the original data when calculating averages, which means that the results are slightly higher than if zero values were considered. This was done to ensure a more realistic result. In the high-use suburbs, the zero purchase of electricity in a month will not be because of a tight budget. The zero values may indicate a change of meter, an overseas trip, and the sale of residential property; and in the case of the credit meters, an inconsistent meter reading. However, for a low-use suburb like Kayamandi, zero values may mean that even though a household is grid-connected, it does not have the budget to pay for electricity that month. However, for users who consume below a certain amount, and have an income below a certain amount, a free basic electricity of 60 kWh is provided.

Data from the municipality has been used to arrive at the results. The data showed the electricity consumption for every month over the past five years for both recorded prepaid and credit meters in Stellenbosch. Some further filtering was needed to get to the meters suitable for sampling. Firstly, the data for the municipal financial year from July 2013 to June 2014 was filtered out. Secondly, all commercial, industrial, agricultural, utilities, university, and government buildings were removed from the data sheets. Empty rows were also removed. Thirdly, all the meters in the different identified suburbs were put into separate files to keep a clear overview.

	Average Consumption kWh in a month		Max Consumption kWh in a month	
	Credit Meter	Pre Paid	Credit	Pre Paid
Uniepark & Karindal	1107	1071	9750	9080
Dalsig & Brandwacht	1048	963	7725	10895
Die Boord & Paradyskloof	881	854	10924	15774
Onder Papegaaiberg	726	597	5032	5645
Welgevonden		518		3117
Idas Valley	653	483	4518	3790
Cloetesville	571	424	6678	2648
Kayamandi	422	156	1198	2679

Table 2 Average and maximum consumption in different suburbs

A division is made between high consumption areas and low consumption areas in the table. The high consumption suburbs are used in this study as potential solar rooftop PV investing suburbs, which are the five top areas. The on-average highest consumers are found in the suburbs Uniepark and Karindal, with 1107 kWh on average for credit meters, and 1 071 kWh for prepaid meter users. The suburbs Dalsig and Brandwacht closely follow Uniepark with 1 048 kWh for credit meters and 963 kWh on average for prepaid meters. In contrast, the two lowest electricity-consuming suburbs are Kayamandi, with 422 kWh[5] for credit meters and 156 kWh for prepaid meters, and Cloetesville with 571 kWh for credit meters, and 424 kWh on average for prepaid meters. These consumption figures are more than half of the top range electricity consuming areas.

Onder Papegaaiberg and Welgevonden consume considerably less than the top three in the high electricity consuming suburbs. Even though Welgevonden is considered a middle- to upper-class property estate, it consumes a similar average to Idas Valley, which is considered a mixed-income area. Welgevonden was only developed a few years ago, so it only has prepaid meters. The municipality strives to change the credit meters to prepaid meters and therefore new developments will have a prepaid meter installed automatically.

[5] Note: Kayamandi credit data is based on 13 credit meters which influences the viability of the data

Table 2 also shows us households with a prepaid meter use less electricity on average than households with a credit meter. This may be psychological, in that when consumers pay upfront and it is clear to see that the meter is running down when electricity is being used, the household will be more careful with their electricity consumption. If people know what they have paid for a certain number of units, and know that they need to get more electricity once they run out, they are more likely to be aware of saving electricity than when they receive a bill after the fact. This is in contrast to credit meters, where people pay an amount that is calculated based on previous use. This does not stimulate energy efficiency or energy reduction.

The shift from credit meters to prepaid meters can therefore have positive effects on the consumption behaviour in terms of energy efficiency. In short, prepaid meters have the potential to increase energy efficiency and reduce electricity use at the consumer level. However, prepaid meters, especially the ones that are currently being installed, are having a negative impact on the trend of rooftop PV installations. This is because prepaid meters always runs forward, clocking up electricity use, instead of backwards if electricity is fed into the grid, as prepaid meters are not sensitive to what direction the currents are coming from (Brent, 2015).

Furthermore, the maximum kWh the top consuming household uses per suburb is given. This tells us that there are exceptionally high electricity consumers. The highest maximum is 15 774 kWh in a particular month for a household in Die Boord with a prepaid meter. However, in the month after this exceptional amount was recorded, no electricity was bought, which means that this amount could be averaged out over two months. Moreover, the annual consumption for this household was 56 812 kWh, which is still less than the top annual consumption of 76 505 kWh by another household. The annual total top consumption is left out of the table to keep it neat and clear. The annual consumption data is, however, still based on the same electricity consumption data provided by Stellenbosch Municipality.

However, averages, maximums and medians don't provide as much information per suburb, as determining how many households consume electricity above a certain number of kWh. Table 3 and Table 4 depicted below show how many households consume in the categories above 600, 1 000, 2 000, 3 000, 4 000, 5 000, and 10 000 kWh per month for prepaid and credit meters. >600 is determined as the first category, as from this amount of consumption, electricity is most expensive. The number of meters per suburb used as the research group is given in the column next to the suburbs. Flats, empty cells or non-residential consumers have been filtered out. For the prepaid meters, half to two-thirds of the households fall into >600 electricity consumption or above. In contrast, in the low-consuming areas such as Kayamandi, only 19 out of 1 287 households with a prepaid meter consume more than 600 kWh per month. For Cloetesville, this figure is around a quarter as 197 out of 728 consume more than 600 kWh per month. Idas Valley however, is very similar compared to Onder Papegaaiberg but in percentage terms, there are less households consuming in the >1 000 category in this area.

The number of households in the high-use categories is significantly higher for credit meters than for prepaid meters, across all suburbs. The credit meter table makes it clearer that more households in the high-consuming suburbs also fall into higher-consuming categories. If a household has a credit meter, this is also more beneficial in terms of installing rooftop PV as the meter can run backwards.

However, what should be noted is that despite Idas Valley, Cloetesville and Kayamandi having less households consuming in high categories, it does not mean there are no households able to invest in embedded generation. In this study only the top five suburbs are used as a research group, however, it is possible to use this data for a further study in which the other suburbs are included.

Pre Paid		Electricity Consumption						
Suburbs	Amount of meters	>600	>1000	>2000	>3000	>4000	>5000	>10000
Uniepark & Karindal	**160**	106	73	34	18	8	6	0
Dalsig & Brandwacht	**163**	95	71	28	9	7	3	1
Die Boord & Paradyskloof	**569**	340	209	67	25	10	8	1
Onder Papegaaiberg	**159**	75	33	3	1	1	1	0
Welgevonden	**546**	258	63	3	1	0	0	0
Idas Valley	**346**	118	34	3	1	0	0	0
Cloetesville	**728**	197	37	1	0	0	0	0
Kayamandi	**1287**	19	12	1	0	0	0	0

Table 3 Number of households per suburb with pre paid meter consumption per category

Credit		Electricity Consumption						
Suburbs	Amount of meters	>600	>1000	>2000	>3000	>4000	>5000	>10000
Uniepark & Karindal	**507**	425	309	121	56	24	12	0
Dalsig & Brandwacht	**462**	388	270	98	25	7	3	1
Die Boord & Paradyskloof	**1066**	837	557	129	36	15	4	1
Onder Papegaaiberg	**368**	257	132	18	4	2	1	1
Welgevonden	**0**							
Idas Valley	**564**	368	145	9	3	1	0	0
Cloetesville	**510**	280	102	3	1	1	1	0
Kayamandi	**14**	7	2	0	0	0	0	0

Table 4 Number of households per suburb with credit meter consumption per category

The tables, however, show a clear contrast between high electricity consuming suburbs and low electricity consuming suburbs. The unequal electricity consumption by citizens should be challenged. Stellenbosch Municipality has a gini-coefficient of 0.57[6] (Bureau of Economic Research, 2013). As income is a determining factor in electricity consumption, the higher the income the more electricity is being consumed and the less financial stress is being felt when electricity prices go up. Mcdonald (2009:25) states that pricing inequalities become starker if we look at these charges in relation to household incomes. He mentions an example, in 2006, that if a suburban household consumed 700 kWh at R263.50 per month (at an electricity rate of R0.376/kWh) the electricity costs would make up only a small percentage of a suburban household's income, typically in the range of R10 – 15 000 a

[6] Measured in 2011, Stellenbosch in a Nutshell

month. While for a township household using 500 kWh, R182 would make up 23% of an R800 monthly income. According to McDonald (2008), this is not uncommon for households relying on pensions and grants. As a consequence, many low income households either under-consume electricity (using paraffin as a substitute) or cannot pay their electricity bills. In Mcdonald (2009)'s example the price of electricity is significantly lower than it is now. Also, the electricity consumption for townships in this example is quite high and the usage for high-use consumers much lower than the averages for some high-consuming suburbs in Stellenbosch. A quota on electricity consumption for high-use consumers could result in redistribution of electricity consumption, allowing more citizens, businesses and industries to be connected so that economic development will not be hampered by a shortage of electricity in the short run.

Factors influencing consumption pattern

This section specifically looks at what the determining factors are for electricity consumption patterns in households and changes to consumption patterns. Is it price changes, income, affordability or accessibility that determines the amount of electricity usage?

To examine this we will look at the economics perspective of price elasticity of demand of electricity. Swilling (2014) pointed out during the meeting of the Integrated Infrastructure Committee on Friday, 2 May 2014 that the price elasticity of electricity is greater than assumed. This means that the demand for electricity is responsive to the price changes. In this paragraph this observation will be examined. The price elasticity of demand is used in economics to measure the sensitivity or responsiveness of the quantity of a product or service demanded to changes in price. The demand is inelastic if it does not respond much to changes in the price. Basic goods and necessities such as food tend to have an inelastic demand, which means the demand will stay more or less the same when prices fluctuate. Luxury goods tend to have an elastic response in demand when the price changes, which means that the demand will change a lot when the price of these goods changes. Thus the higher the price elasticity, the more sensitive consumers are to price changes (Moffatt, 2015). An article written by Inglesi-Lotz (2011) points out the sensitivity of electricity consumption to price fluctuations during different periods in time. As South Africa has experienced price increases of 25% and further electricity prices increases are still expected, it is important for energy policy makers to understand the impact of these price increases on the consumption behaviour of electricity users. Inglesi-Lotz (2011) found that an initial round of electricity increases does not impact the electricity consumption behaviour as such. The price elasticity remains fairly constant in this period. However, after multiple and structural price increases, price will play an important role in electricity consumption.

Inglesi-Lotz (2011) found out that up until the early '90s price had not played a significant role in the increase of electricity consumption. The price elasticity was significantly negative during the '80s and early '90s. However, after this period consumers were more responsive to price. The effect of income to electricity consumption has become more significant from close to zero in the '80s to almost unit elastic in the 2000s. However, these results need to be considered in the light of the history of South Africa, since before 1994, the government provided electricity in favour of whites who were, due to government laws, also wealthier than their black fellow countrymen. From 1992, each year an average of 300 000 new connections have been made, mostly to low-income households. Between 1994 and 2000, Eskom connected 2.5 million new households to the electricity grid (Mcdonald, 2009). The income of the newly connected households was significantly lower than previously advantaged households. These factors most likely influenced the price elasticity of the country significantly as a whole.

Even though electricity, from a Western perspective, is generally perceived as a basic necessity and should, according to this theory, be a price inelastic product, it is also highly dependent on accessibility to the product and the income of people. Unlike food and water, electricity is substitutable and people have for most of human existence in history and still today, lived without electricity. Even though electricity is increasingly required for certain economic activities and is critical to economic growth, people can and do lead healthy and productive lives without it (Mcdonald, 2009). Therefore, the most determining factor shall not be the price of electricity itself but more the accessibility and income (and increasingly availability since the recent load-shedding events) of households. Within the different income categories the price elasticity will differ. For low-income households, electricity up to a certain number of units might be seen as a necessity, excess electricity might be seen as luxury. This is in contrast to the perception of high-income households, who view unlimited access to and the availability of electricity as a basic necessity.

Conclusion

The differences in electricity usage between the various identified suburbs in Stellenbosch have been analysed. The top electricity using suburbs consume on average more than double the amount of the top lowest electricity consuming suburbs. Since high consumption of electricity is related to the income of households, the high electricity using suburbs are the ones that are considered viable to install solar PV system as they can afford the investment. Moreover, as the households in the high consuming areas mostly fall into block 4 of the tariff incline block system and thus pay more per electricity unit once they exceed 600 kWh per month, it will reduce their bill more than if their maximum consumption were falling into the 3 lower tariff blocks. Solar PV will shave off the top of the electricity units falling into the highest block tariffs.

However, when looking at the proportion of income that would be saved, it makes much more sense for the low-income households to have solar rooftop PV. As the low-income households have a limited budget, their proportion of expenditure on electricity will be far higher than for rich households. If low income households had solar panels, the percentage that would be spent on electricity would drop faster than for high income households, giving the low income households more to spend on other necessities.

Discussion:

It is questionable that when households can afford large amounts of electricity, as pointed out in this paragraph, it is unlikely that financial reasons will be the driver for high income households to put up rooftop PV. If they want to reduce the electricity bill, they could easily do it by energy efficiency measurements. However, an incentive could still be given. When the incentive is not financial, the municipality could put a quota system in place for people through a by-law, i.e. residents may consume certain amount per household, and if this is exceeded, they will be fined. In effect, a Notified Maximum Demand for consumers of municipal distributed electricity, to redistribute and allow more connections for not yet connected businesses and households. An alternative would be to simply insist that if residents don't cut down on electricity usage, they have to put embedded generation (rooftop PV) in place.

The municipality has to decide what is more important: the revenue implication of having people to install solar rooftop PV, or the financial implication of paying Eskom to finance an increase in Notified Maximum Demand *and* risking constraining the economic development of the town.

A few ironies:

1) Solar electricity is produced during the day when it makes the least sense financially for municipality
2) For the high-income group, electricity is only a small proportion of their income and or expenditure. The high-income group financially has the means to invest. But if one consumes 10 000 kWh a month, do you really care about reducing your bill by solar PV, if it can be reduced easily by energy efficiency measurement?

3) Financially, the poor would benefit the most from having solar panels but do not have the means to invest. If the electricity bill could be reduced for the poor households by the same 3 kWp solar investment, it would mean that in percentage terms, a larger amount of their budget would become available

4.3 Research findings 2: Grid capacity to receive embedded generation

This section discusses the grid capacity in the high-use suburbs in Stellenbosch. The calculations pointed out in this paragraph are based on NRS policy 097-2-series.

The high-use suburbs of Stellenbosch were identified and only these areas were used to analyse how much electricity from rooftop PV can go onto the grid. The reason for this is that these are the most probable areas where investments in rooftop PV are likely to happen. Rooftop PV requires a relatively high investment cost and as such, this study identified the following areas as people could afford the investment: Uniepark and Karindal, Paradyskloof, Die Boord, Onder Papegaaiberg, Dalsig and Welgevonden. Figure 15, derived from Google Earth, shows the particular areas in Stellenbosch that will be looked at in more detail in this chapter.

Figure 15 Identified high-income areas in Stellenbosch marked for research

The next step is to look at South African policy to determine how much electricity would be recommended as a maximum to be fed onto the grid by households connected to a municipal grid. A key constraint in South Africa in the process of implementing small scale grid connected renewable energy technologies, is the lack of pre-approved, generic standards for utility engineers and system promoters to apply in designing and approving the utility interface (SABS, 2014). A relevant policy to look at is NRS 097-2-series. This policy is crucial in calculating how much electricity from embedded generation can go onto the grid. This specification of the NRS is issued by Eskom on behalf of the Electricity Suppliers Liaison Committee (ESLC) and approved by it for use by supply authorities and published by South African Bureau of Standards (SABS). The document is prepared by a working group consisting of Eskom employees, municipal officials and a Manufacturers Interest Group (MIG). This document does not have the status of a South African National Standard (SABS, 2014). This standard covers utility interface requirements (NRS 097-2-1), embedded generator requirements (NRS 097-2-2), and utility framework requirements (NRS 097-2-3).

The criteria as provided in the standards serve as an indicator under which conditions low-voltage (LV) connected generators (embedded electricity generation) could be connected to the utility grid before a proper grid study is performed. The aim of this standard is to guide and increase the renewable energy share of the electricity utilised. Sustainability, future fossil price volatility, risk aversion, and utility energy shortage are among the drivers for the stimulation and guidance of grid connected renewable energy technologies. In certain circumstances, it might even alleviate local network capacity constraints or improve power reliability (Botha, 2014). Botha (2014) emphasises safety as the main reason for utilities requiring standards, in addition to safeguarding the quality of supply and network performance. He notes that municipalities need to keep a proper record and report to NERSA about newly installed grid connected rooftop PV, its capacity and location, within municipal borders.

The flow chart in Figure 16 illustrates a summary of the NRS 097-2-3:2013 standard to assess connectivity of embedded electricity generation to the municipal grid.

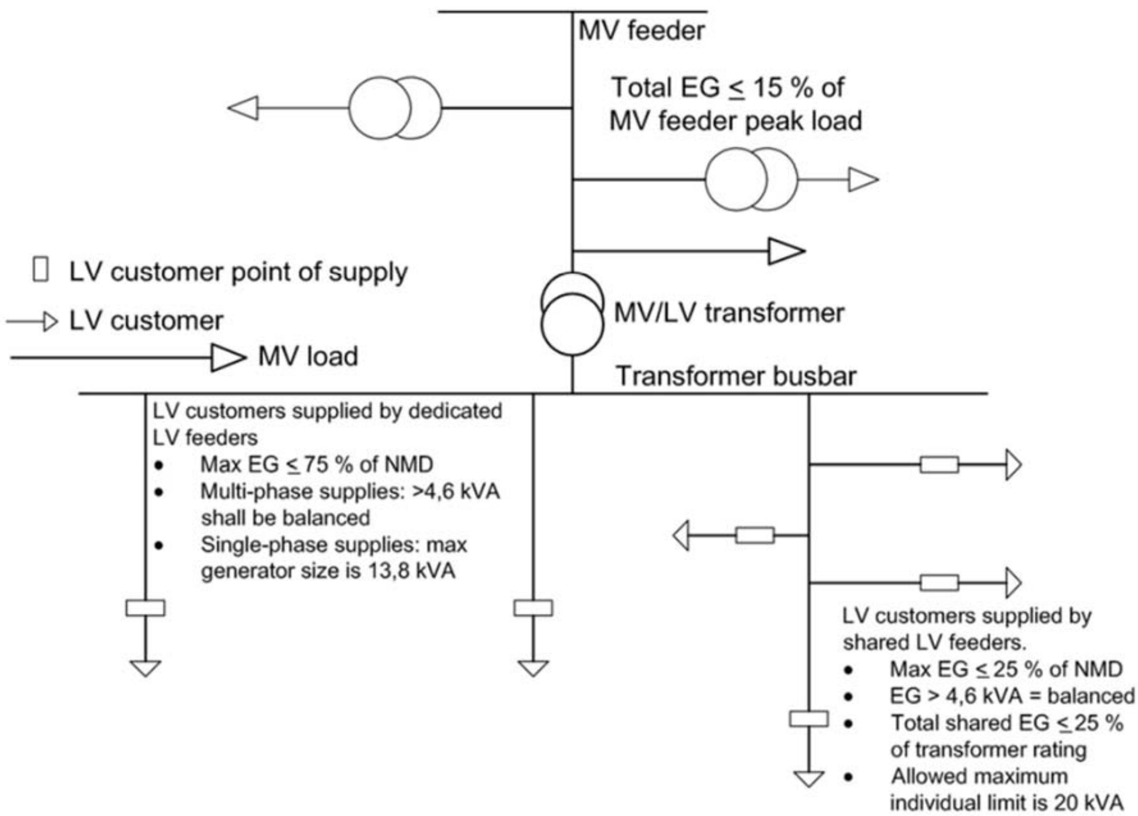

Figure 16 Flow chart of simplified connection technical evaluation criteria (NRS 097-2-3:2013)

In order to calculate the maximum installed embedded generation capacity that will be allowed per suburb, the NRS 097-2-3 will be used as a point of departure. In order to find information on how to calculate the maximum DG that can be allowed onto the grid considering the current state of the NRS 097-2- series policy, I went to speak to Bernard Bekker on 7 August. Bekker has been part of a similar study for Hessequa municipality, as documented in 'Unlocking the Rooftop PV Market in South Africa' (Reinecke et al., 2013).

According to Bekker (2014), the chart in Figure 16 is key in calculating the maximum RE capacity that could go onto Stellenbosch' electricity grid. This graph should be applied to the high-voltage and medium-voltage single line drawings from Stellenbosch Municipality that maps all the different substations and electricity distribution by the municipality to the customers. In the calculations throughout this chapter, the flow chart below from NRS 097-2-

series policy functions as a guideline. It is a simplified flow chart showing technical connection evaluation criteria.

The process of finding an answer to the question of how much embedded generated electricity can go onto the grid is again divided into three steps. We will look at the household level, transformer level and the MV feeder level. These three steps serve as a logical flow.

1) Household

First it will be determined how much embedded generated electricity can be produced and channelled back by **households** and if it is possible to use this data in order to find out what the impact would be on the municipal electricity revenue.

2) Transformers

The second step looks at each **transformer** in the residential high electricity use areas and how much maximum electricity from embedded generation it can receive according to NRS 097-2-series standards.

3) MV Cable/ MV Feeder

The third step looks at the **medium-voltage cables** coming from the substations and distributing electricity towards the transformers. The NRS 097-2-series advises a maximum of embedded generation that can be distributed via these cables. This step also serves as a control for the second step. The maximum each transformer receives may not exceed the maximum the medium-voltage cables can carry.

Household level

The first step in this process is to look at the household level. It attempts to answer the question of how much own-generated electricity can be fed back to the grid per household.

Households are connected to shared LV feeders as shown in Figure 16. Shared LV feeders are transformers or mini-substations that convert the medium-voltage electricity it receives from the substations into low-voltage to be distributed to households. It is called 'shared' because more households are sharing the same transformer that provides them with electricity. Embedded generation by households is limited to <20 kVA or 25% of the Notified Maximum Demand according to standard NRS 097-2-3:2013.

Example 1 demonstrates calculations per household of how much electricity is allowed to be channelled back and what the effect of this will be. The example is used to evaluate if it would be a useful and valid approach to look at what the maximum electricity in kW would be that households are allowed to feed back according to the NRS policy. Thus, looking from a household's perspective, not from a transformer or medium-voltage cable perspective. In this example, a supply of 60 A (Ampere) is presumed. A household is connected to a low-voltage cable, which is 230 V.

<u>Example 1:</u>

VA = A x V

A= 60

V= 230

VA = 60 x 230 = 13.800

kVA = 13.8 (= NMD)

25% of 13.8 kVA = 3.45 kVA

Conclusion: the electricity from embedded generation should not be allowed to exceed the 3.45 kVA per household.

Take the example that a transformer or mini-substation in Stellenbosch has the size of 315 kVA Notified Maximum Demand. The Notified Maximum Demand per household for general electricity is 13.8 kVA. 315 kVA/13.8 kVA is approximately 22.8. This means that only 22 houses can be supplied at peak level. However, the chance that every household will, at the same time, consume at peak level is unlikely. Therefore, electricity providers use the Diversity Factor (DF), which allows more households to be connected to the same transformer. The DF notifies how many households are allowed to be connected per transformer. If, in this example, the DF is 2, this means (315 kVA/13.8 kVA) x 2 = 45.6 households. This means 45 households can be supplied by the same transformer of 315 kVA. The higher the DF, the higher the number of households per transformer. However, per transformer, the embedded generated electricity may not exceed 25% of 315kVA = 79 kVA. 45 households multiplied with a maximum generation of 3.45 kVA per household means in total 45 x 3.45 kVA = 157 kVA. This amount exceeds the limit of 79 kVA per individual transformer.

In conclusion, looking from a household perspective leads to a problem when one wants to calculate how much total embedded generated electricity can be channelled onto the municipal grid. The total electricity supply by rooftop PV might exceed the amount one individual transformer is allowed to take up, depending on the DF. If a DF is used or the DF is unknown, it is better to look at the MV/LV transformer level. The MV/LV transformers are also called mini-substations or (shared) LV feeders. This argument takes us to the next step of calculating, per MV/LV transformer, how much electricity from Rooftop PV generated by households can be allowed onto the grid[7]. The third step focuses on the MV feeder or in other terms the medium-voltage cables that supply medium-voltage electricity to the MV/LV transformers.

[7] Note: The electricity that can be channelled onto the grid according to NRS 097-2-series. The NRS 097-2-3 is a guideline before a proper grid study has been conducted. A detailed grid study may result in allowing more embedded generated electricity onto the grid.

MV/LV transformer and MV feeder level

This section points out the second and the third steps in determining the grid capacity in order for the grid to receive embedded generation. The two are put together in this section so that both can be compared and discussed simultaneously for the different suburbs.

For every research suburb, a separate paragraph is dedicated. Maps are used to point out the location of the area. Electricity network drawings from Stellenbosch Municipality are used to indicate high- and medium-voltage lines distributing electricity from the substations to the transformers. The information in this drawing and the NRS 097-2-series standard is used to calculate the maximum embedded generated electricity transformers and the medium-voltage cables can receive[8].

Should additional information be required on the paragraphs below, refer to the detailed schedules of the calculations done per suburb in Appendix 2.

A. Uniepark

Figure 17 illustrates the high-income areas of Uniepark and Karindal. These two areas are connected to Jan Marais substation.

[8] The University's and Franschhoek substation are left out in these examples.

Figure 17 Uniepark, Rozendal, Karindal, Mostertdrift

The diagram in Figure 18 illustrates the electricity distribution from Jan Marais substation to the transformers. The red line represents the substation from which high-voltage 66 kV electricity gets converted into medium-voltage (11 kV) through transformers. The maximum peak rated load is 2 times 10 MVA. The 10 MVA represents the maximum capacity, it does not mean the Notified Maximum Demand that has been applied for to Eskom by the municipality. The Notified Maximum Demand is the maximum amount of electricity allowed to the municipality, not the actual capacity. If the electricity consumption exceeds the Notified Maximum Demand, Eskom can fine the municipality.

The thin lines show the medium-voltage lines transferring electricity to different areas and mini-substations. The mini-substations or transformers are the green-white boxes. From these transformers low-voltage electricity goes to the houses.

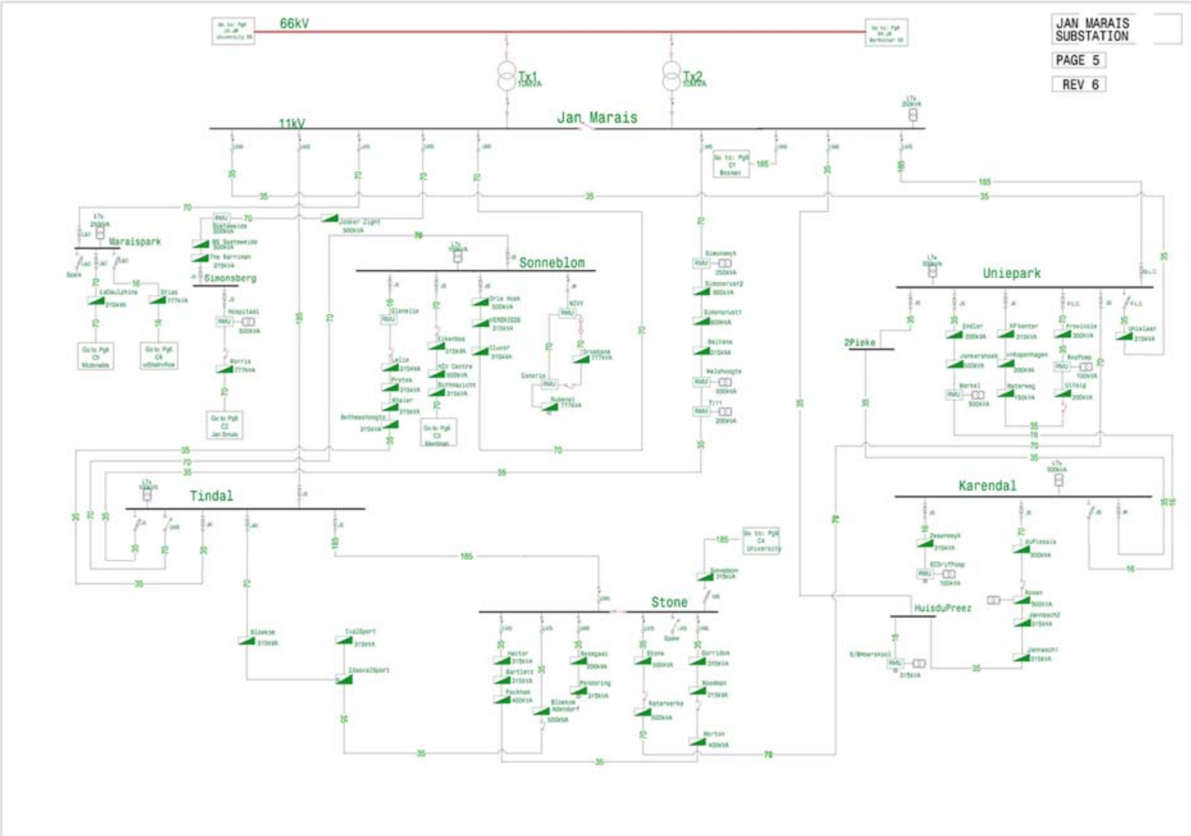

Figure 18 Jan Marais Substation high-voltage and medium-voltage single line drawing

The table on Uniepark and Karindal in Appendix B, shows the calculations of the amount of kW that can be put onto the grid per transformer (LV Feeder) connected to Jan Marais substation in the selected high-income areas of Uniepark, Rozendal, Karindal and Mostertsdrift. In the table it is indicated as Uniepark and Karindal. The maximum kVA per transformer is 25% of the Notified Maximum Demand. The Notified Maximum Demand is, in this example, the same as the maximum kVA capacity of the transformer.

The total kVA maximum embedded generation is 699 + 283 kVA = 982 kVA. The Power Factor is used to convert kVA data into kW data. According to data from Stellenbosch the power factor lies between 0.95 and 1. I used the lowest, 0.95, as a measurement to determine the kW. The reason that Rowan, Jannasch 1 and Jannasch 2 LV feeders are separated from the rest is because they are supplied by a different cable, which makes a difference when calculating how much embedded generation may not exceed a certain percentage of the maximum capacity of the MV feeder cables.

The third step looks at the MV Feeders. The MV feeders are the medium-voltage cables that supply electricity from the substations to the transformers. The second table shows the calculations for the MV feeder cables that distribute electricity to the transformers in the area Uniepark and Karindal. Two cables of 185 mm² Cu (copper) and 35 mm² Cu supply Unielaan, Provinsie, Uitsig, Endler, Jonkershoek, AP Venter, vnKopenhagen and Waterweg transformer. A separate MV feeder cable of 35 mm² Cu provides three substations Rowan, Jannasch 1 and Jannasch 2 with electricity. The standard SANS 10142-1:2006 (Ed 1.5) - *The Wiring of Premises* has been used to identify how much electricity the MV feeder copper cables can carry. According to Table 6.4(a) – Multicore PVC insulated armoured cables (SANS 1507 (SABS 1507)) Current-carrying capacity copper conductors – in the standard on page 106, a copper cable of 185 mm² can carry 348 A (Ampere). The cable voltage is 11.000V. The kVA is determined by the formula: kV x A. So 11kV x 348A = 3828 kVA. The second cable of 35 mm² can carry 125 A. This means the kVA is 11kV x 125A = 1375kVA. The embedded generation may not exceed the maximum of 15% of the total kVA which is (1375 + 3828) x 0.15 = 780 kVA. The power factor is needed to calculate the amount of kW that may not be exceeded. The power factor (PF) is in this case 0.95. This means 0.95 x 780 = 741 kW. In conclusion, the limitation on the amount of kW from potential embedded generation is 741 kW from a MV feeder cable perspective[9].

The third 35 mm² copper (Cu) cable that supplies the three remaining transformers has a maximum capacity of 11kV X 125A = 1375 kVA. 15% of 1375 kVA = 206 kVA. If the power factor is 0.95 this means 0.95 x 206 kVA = 196 kW.

[9] All the outcomes are approximate results

In conclusion, the maximum capacity of all the transformers combined in the area Karindal and Uniepark is 3 925 kVA. 25% of this can be used to feed back electricity from embedded generation, which is approximately 982 kVA. In kW, this is around 932 for a power factor of 0.95. The medium-voltage cables can handle 15% of the Notified Maximum Demand, which is around (206 + 780) = 986 kVA, and (741 + 196) = 937 in kW. The difference is only 5 kW between the second and the third step. For overall results, in this case it does not matter if one looks at the maximum embedded generation per transformer or the maximum per MV feeder cables that supply the specific transformers. However, it is still advisable to calculate the results for both the transformers and the MV cables.

B. Dalsig

Figure 19 shows the areas of Dalsig and Brandwacht that in this research are regarded as high-income areas, with people who can afford investments in solar panel installations. These areas are connected to Markotter substation, which is one of the electricity substations in Stellenbosch. The full area that is supplied by Markotter substation can be found in Appendix 1.

Figure 19 Dalsig and Brandwacht

Figure 20 diagram illustrates the electricity distribution from Markotter substation to the transformers in the Dalsig area. The red line represents the substation from which high-voltage 66 kV electricity gets converted into medium-voltage 11 kV through transformers. The maximum peak rated load is 3 times 7.5 MVA. Dalsig can be found in the right hand bottom corner of the illustration. There are transformers that will be looked at and three medium-voltage cables of each 185 mm² Cu.

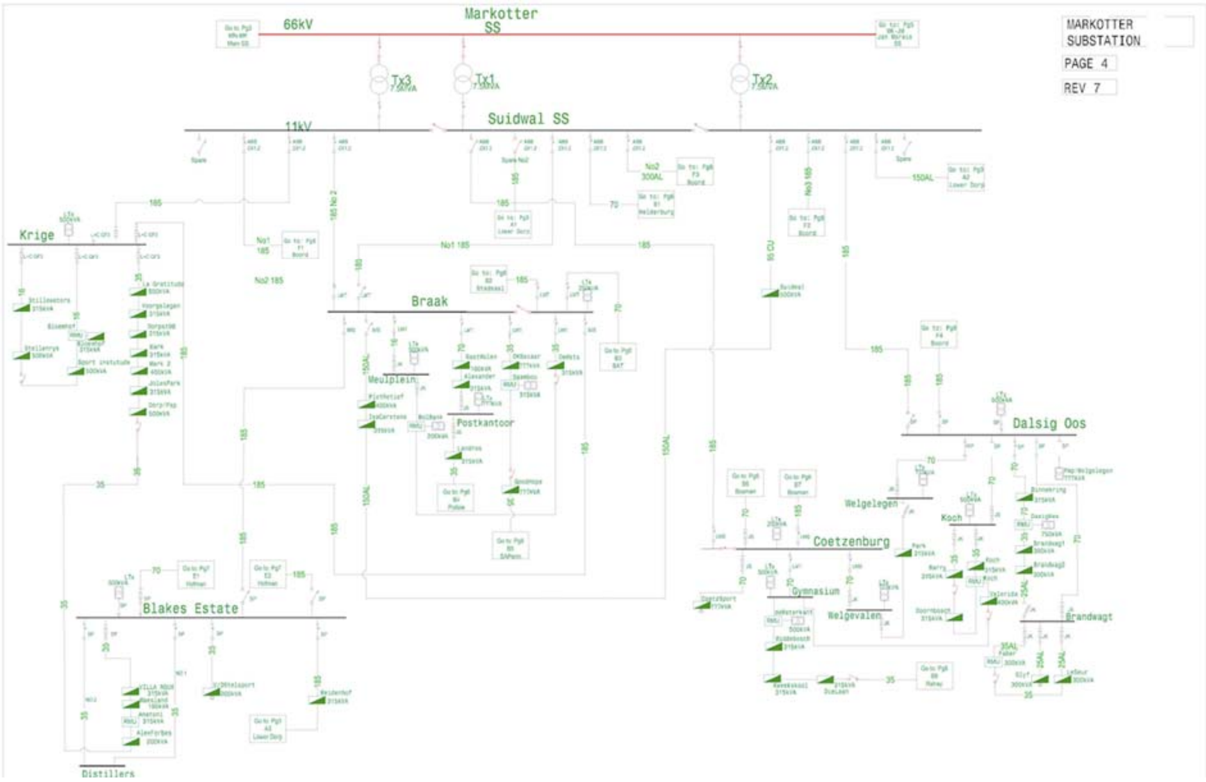

Figure 20 Markotter Substation high-voltage and medium-voltage single line drawing

The table with calculations for Dalsig can be found in Appendix 2. It shows calculations for the amount of kW that can be put onto the grid per transformer (LV Feeder) connected to Markotter substation in Dalsig and Brandwacht. The maximum kVA embedded generation per transformer is 25% of the Notified Maximum Demand. The Notified Maximum Demand is, in this example, again the same as the maximum kVA capacity of the transformer.

Looking from the transformer perspective, in the diagram step two, the total kVA maximum embedded generation is 930 kVA. This is 25 % of the maximum capacity of the transformer, which is 3 720 kVA. In terms of kW this is 884 given a power factor of 0.95. The transformers in this particular area are supplied by three medium-voltage cables, each of 185 mm^2 Cu. This brings us to step three. 185 mm^2 Cu cable can carry 348 A (Ampere). The cable voltage is 11 000 V or 11 kV. The kVA is determined by the formula: kV x A. The kVA is 11 x 348 = 3828 kVA. 15 % of (3 x 3828) is 1 723 kVA. In kW this is approximately 1 723 x 0.95 = 1 637 kW. So the maximum renewable energy from households for on the grid in step three is 1 637 kW.

In conclusion, the limit of embedded generation from a transformers perspective is around 884 kW. The cables would allow approximately 1 637 kW onto the grid. In contrast to the Uniepark and Karindal area, the difference between the two calculations is much larger. If one only looks at the medium-voltage cables, there would be around 752 kW more allowed onto the grid than when looking at the transformers. It is, therefore, important to be careful which calculation is used to determine how much DG can be allowed and how many licenses can be given to households to install renewable energy installations. To be safe, both calculations need to be conducted. The lowest result in kW should be used as a point of departure. This means that in this case 884 kW would be the maximum.

C. Die Boord and Paradyskloof

The framed area in Figure 21, derived from Google Earth, illustrates Die Boord and Paradyskloof. These suburbs are supplied by the Golf Club substation.

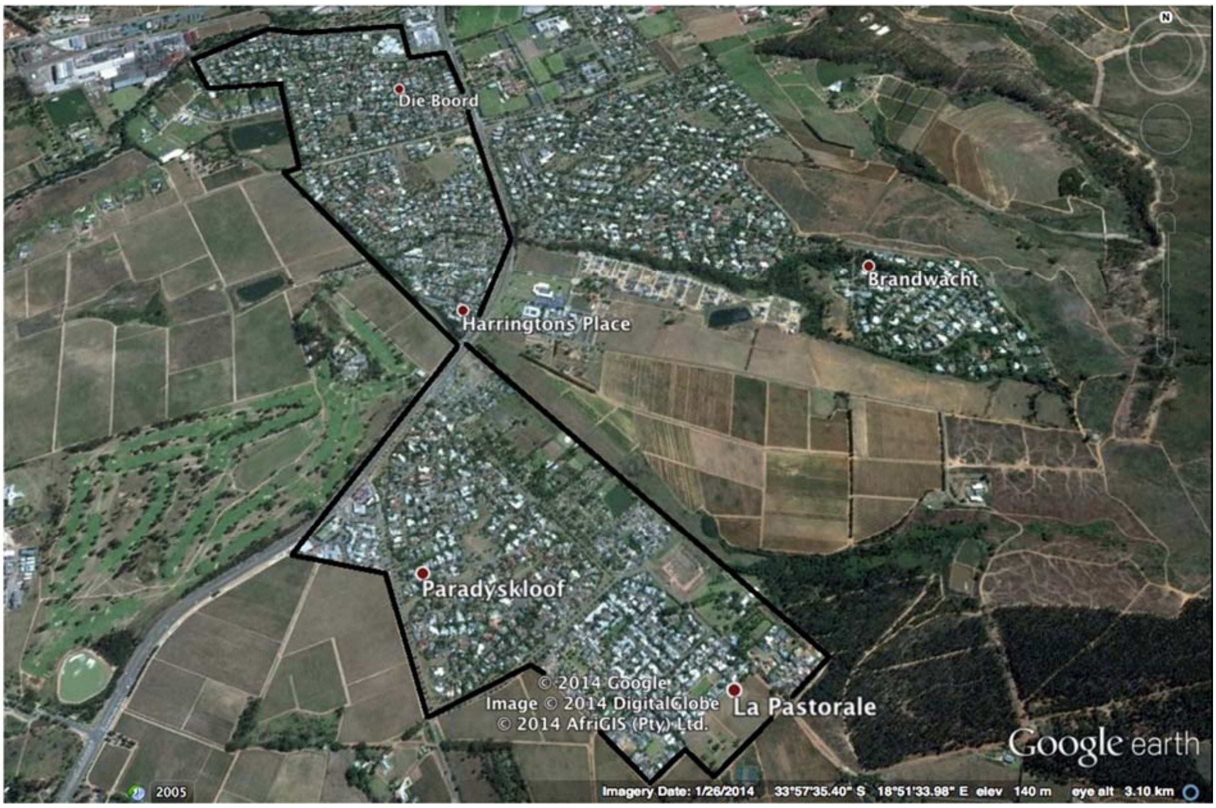

Figure 21 Paradyskloof and Die BoordParadyskloof and Die Boord

Figure 22 illustrates the electricity distribution from the Golf Club substation to the transformers in the Paradyskloof and Die Boord areas. It is quite a large high electricity use area that is connected to this substation and this substation supplies a significant number of transformers. It is the largest high-income settlement that will be researched in this thesis. 19 Transformers will be looked at for Paradyskloof and 15 transformers for Die Boord. The maximum peak rated load is 2 times 20 MVA. Paradyskloof and Die Boord are supplied by the upper transformers in the schedule. Technopark is not considered in this investigation, as this is a commercial and/or industrial area. Paradyskloof is supplied by four 95 mm² Cu medium-voltage cables. Die Boord is also supplied by four 95mm² Cu medium-voltage cables, which will be looked at in step three. The four 95 mm² Cu cables are the thickest and main cables that supply these areas. The greater the diameter of the cable, the more Ampere electricity it can carry. The thick cables are again split into smaller cables supplying the transformers, e.g. 35 mm² Cu and 70 mm² Cu. There are also aluminium cables marked, for example 50 AL. In the guidelines, there is a different schedule showing how much

Ampere the aluminium cable can carry. However, in this calculation I only looked at the main cables supplying the group of transformers. The reason is to avoid double calculations. What needs to be considered is that there are losses when the main cables are split into smaller cables. However, these losses are left out in these calculations.

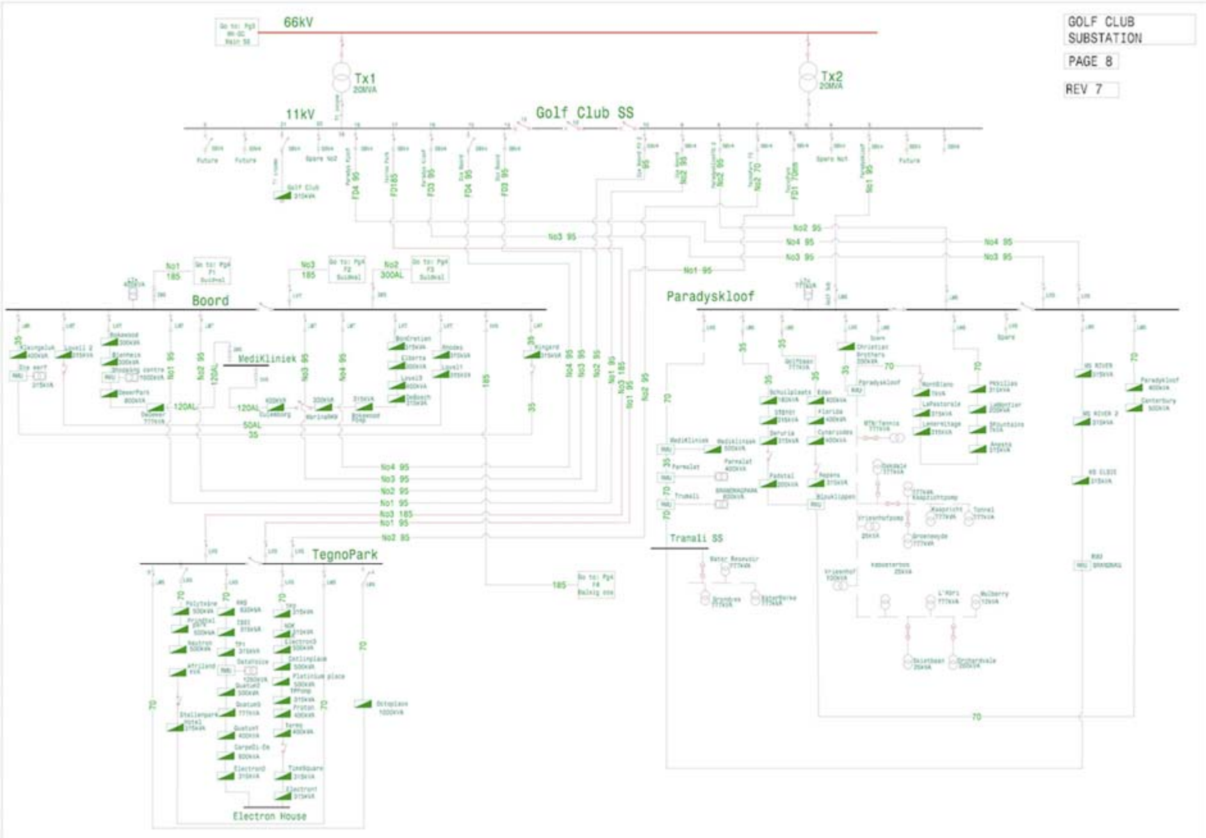

Figure 22 Golf Club Substation high-voltage and medium-voltage single line drawing

The table with extensive calculations concerning Paradyskloof and Die Boord can be found in Appendix 2. The table shows the calculations of the number of kW that can be put onto the grid per transformer (LV Feeder or mini substation) in the area Paradyskloof and Die Boord connected to Golf club substation.

The maximum kVA embedded generation per transformer is 25% of the Notified Maximum Demand. The Notified Maximum Demand is, in this example, again the same as the maximum kVA capacity of the transformer.

The total kVA maximum embedded generation produced by households that the transformers can handle according to the policy is approximately 1 503 kVA for Paradyskloof and 1 351 kVA for Die Boord. This makes a combined maximum of around 1 503 + 1 351 = 2 854 kVA. This is 25 % of the maximum capacity of the transformer, which is 11 415 kVA. Given a power factor of 0.95, in kW this is approximately 0.95 x 1 503 = 1 427 for Paradyskloof and 0.95 x 1 351 = 1 284 for Die Boord. The transformers are supplied by four 95 mm^2 copper cables in Paradyskloof and also four 95 mm^2 copper cables in Die Boord. This brings us to step three of calculating how much embedded generation the medium-voltage cables can carry. As per standard, a copper cable of 95 mm^2 can carry 231 Ampere electricity. The kVA for this is 11 kV x 231 A = 2 541 kVA. Four times 2 541 kVA is 10 164 kVA. The medium-voltage cables can only carry 15% EG of the Notified Maximum Demand. In this example, it is the total capacity of the transformer. In reality the Notified Maximum Demand is usually lower but we use the worst-case scenario. 15 % of 10 164 kVA is approximately 1 525 kVA. In terms of kW this would be approximately 1 448 kW for a power factor of 0.95. Both Paradyskloof and Die Boord are supplied by four copper cables with a diameter of 95 mm^2. The limit of DG for both areas is thus 1 448 kW for the medium-voltage cables.

In conclusion, the limit of embedded generation from a transformer perspective is around 1 427 kW for Paradyskloof and 1 284 kW for Die Boord. This makes a combined limit of 2 711 kW for the transformers. The medium-voltage cables for Paradyskloof and Die Boord combined would allow around 2 897 kW onto the grid. The difference between the two approaches is around 186 kW, which is less than the previous area but still significant. Care must also be taken here when considering which approach to take. In this case, looking at the transformers would be best as this gives the lowest DG allowance and this would be considered safest. This means that for these two areas the maximum would be 2 711 kW.

D. Welgevonden

The area lined with black in Figure 23 is called Welgevonden. It is the newest high-income suburb that will be looked at. This area is connected to Cloetesville substation.

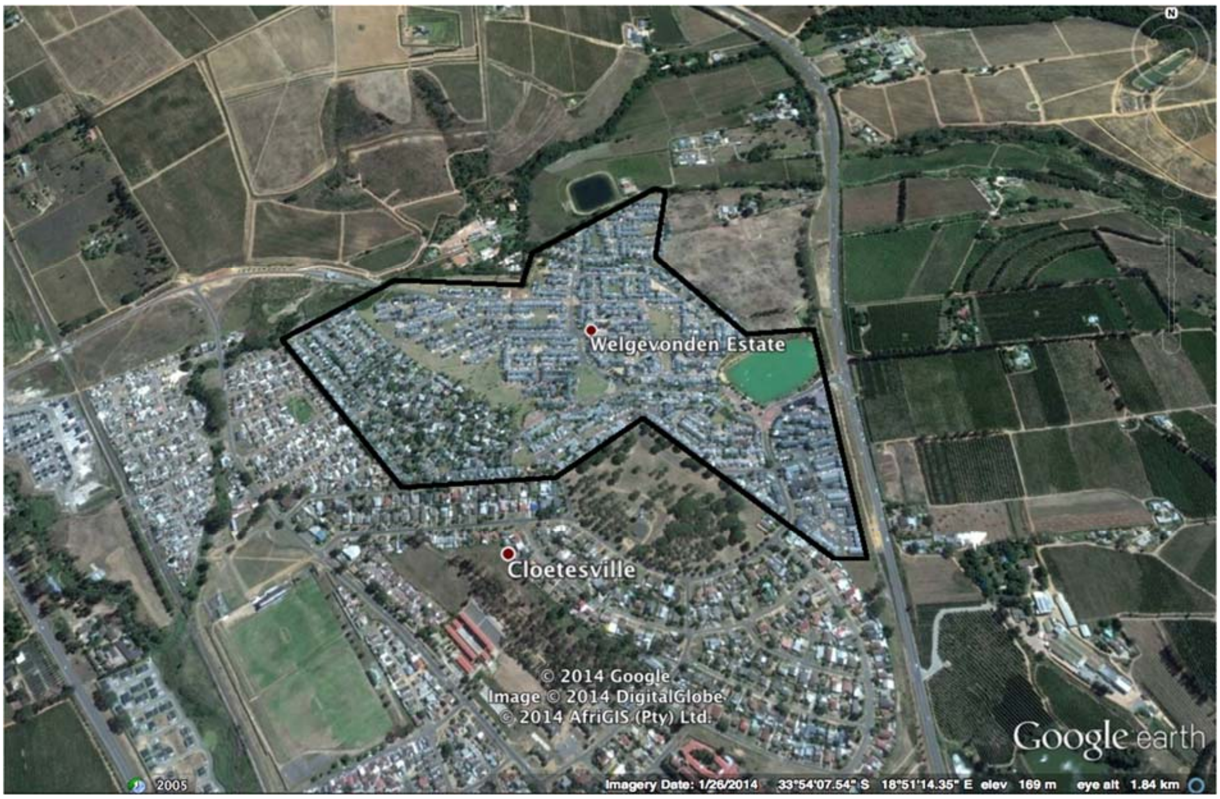

Figure 23 Welgevonden

Figure 24 illustrates the electricity supply from Cloetesville substation to several places in the surrounding area. The considered high electricity consuming area of Welgevonden is only a small area that is connected to this substation. Welgevonden is pointed out at the left side of the diagram. Other areas like Kayamandi and Cloetesville demonstrated in the diagram are considered low to medium electricity use areas and not taken into account in the calculations. Welgevonden is supplied by 13 different transformers. These transformers are supplied by two 185 mm^2 medium-voltage copper cables.

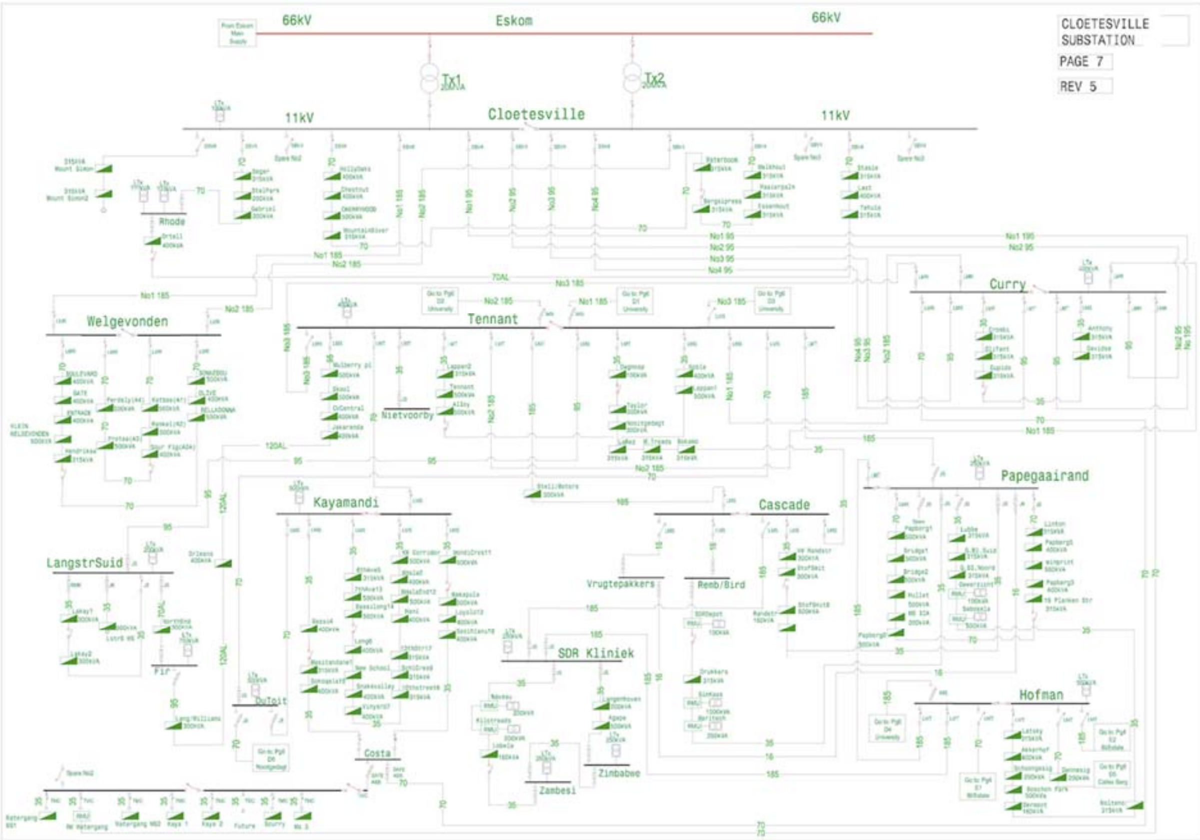

Figure 24 Cloetesville Substation high-voltage and medium-voltage single line drawing

The table with detailed calculations concerning Welgevonden can be found in Appendix 2. This table shows the calculations that have been conducted to measure the maximum amount of kW embedded generation that can be produced in this area. This process is the same as the previous examples, divided into step two that looks at the capacity of the transformers and a third step that evaluates the capacity of the medium-voltage cables.

The total kVA maximum embedded generation produced by households that the transformers can handle according to the policy is approximately 1 454 kVA for Welgevonden. This is 25% of the maximum capacity of the transformers supplying Welgevonden area, which is 5 815 kVA. In terms of kilo Watt this is 1 381 kW, given a power factor of 0.95.

After establishing the amount of kW allowed per transformer in step three, it is necessary to do a double check by calculating what the maximum is per medium-voltage cables that supply electricity to the transformers. This takes us to step three in which we look at the maximum EG the medium-voltage cables can carry as per DG South African standards. Two 185mm² Cu medium-voltage cables supply the transformers. The standard indicates that a medium-voltage copper cable of 185mm² can carry 348 Ampere electricity. The maximum capacity in kVA is 11 kV x 348 A = 3 828 kVA. Two times 3 828 kVA is 7 656 kVA, this is the total kVA capacity for the two medium-voltage cables that supply the transformers in Welgevonden. The maximum embedded generation for these cables is 15% of the total capacity. This is 15% of 7 656 kVA is 1 148 kVA. Given the power factor of 0.95, the kW is 0.95 x 1 148 is 1 091 kW. The limit DG for the two medium-voltage cables is thus 1 091 kW.

In conclusion, the limit of embedded generation in Welgevonden for the transformers is approximately 1 381 kW. The limit of embedded generation as per medium-voltage cables in Welgevonden is 1 091 kW. In this area, the medium-voltage cables can carry less embedded generation as per standard than the transformers. The difference is 290 kW. This example has also proved that there might be differences between the two approaches. It is, therefore, advisable to calculate the maximum DG from both perspectives. In this example, the results from the medium-voltage cable calculations should be used, as this gives the lowest results. This would be considered as the safest approach as the other approach might exceed the limit of the medium-voltage cables. This means that the absolute maximum, before a grid study has been performed, would be 1 091 kW for Welgevonden area.

E. Onder Papegaaiberg

The final high-income area that will be looked at is Onder Papegaaiberg. **Error! Reference source not found.** shows this area. This area is connected to and supplied by the Main substation.

Figure 25 Onder Papegaaiberg

Figure 26 shows the electricity distribution from Main substation to the transformers in the area. Tortelduif and Begraafplaats as indicated are the areas where the transformers supply the residential area of Onder Papegaaiberg. The other transformers supply industrial or commercial activities as well as a residential area in Stellenbosch's lower *dorp*. The residential area in Onder Papegaaiberg is supplied by 13 different transformers. The transformers around Begraafplaats are supplied by one 70 mm² medium-voltage copper cable and one 185 mm² copper cable. The transformers in Torteldui are supplied by one 70 mm² medium-voltage copper cable.

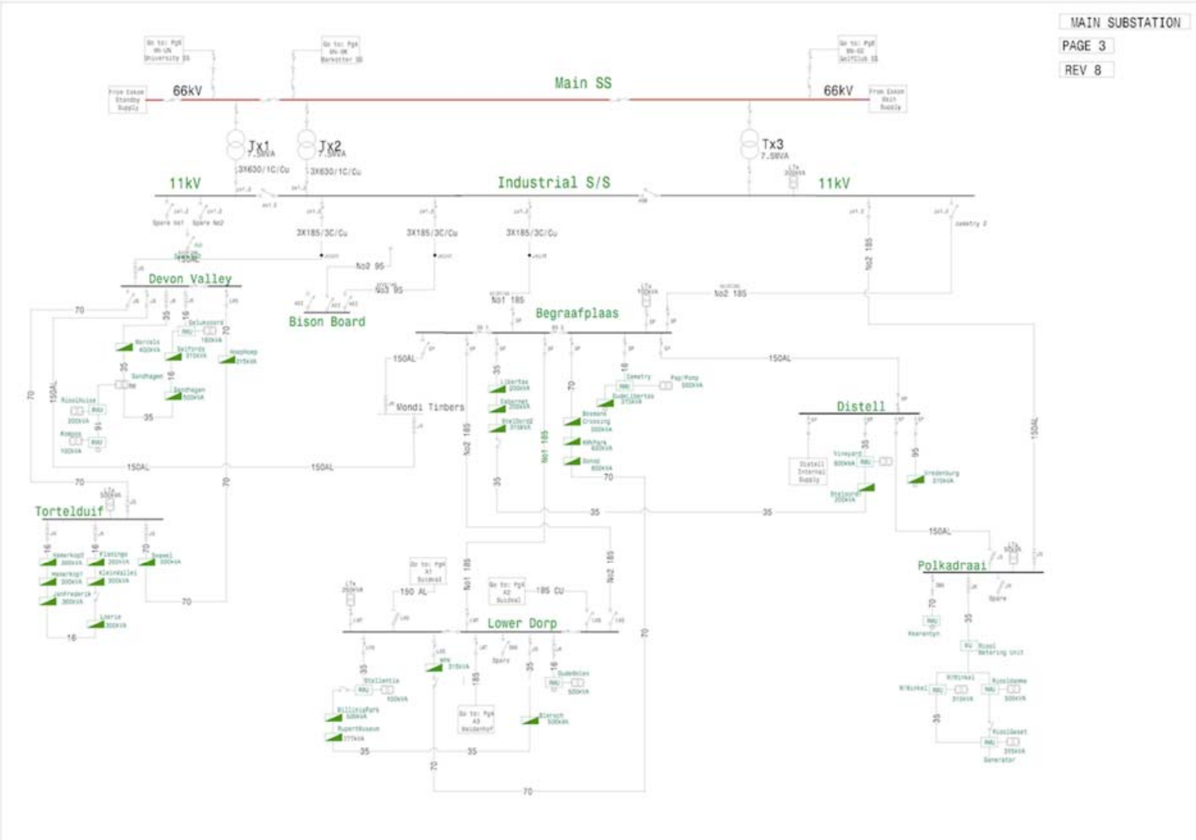

Figure 26 Main Substation high-voltage and medium voltage single line drawing

The table with detailed calculations concerning Onder Papegaaiberg suburb can be found in Appendix 2. This table shows the calculations and results that have been conducted to measure the maximum amount of kW embedded generation that is advised as an absolute maximum as per standards in Onder Papegaaiberg. This process is like the previous examples, divided into step two that looks at the capacity of the transformers, and a step three that evaluates the capacity of the medium-voltage cables.

The total kVA maximum embedded generation produced by households that the transformers can handle according to the policy is approximately 4 945 kVA for the residential area of Onder Papegaaiberg. This is 25% of the maximum capacity of the transformers supplying Onder Papegaaiberg, which is 1 236 kVA. In terms of kilo Watt this is 1 174 kW, given a power factor of 0.95.

After establishing the number of kW allowed per transformer in step three, it is necessary to do a double check by calculating what the maximum is per medium-voltage cables that supply electricity to the transformers. This takes us to step three, in which we look at the maximum EG the medium-voltage cables can carry as per EG South African standards. Two medium-voltage cables supply the transformers from Begraafplaats. One is a 185 mm^2 Cu cable and the second one is a 70 mm^2 Cu cable. The standard indicates that a medium-voltage copper cable of 185 mm^2 can carry 348 Ampere electricity. The maximum capacity in kVA is 11 kV x 348 A = 3 828 kVA. A 70 mm^2 Cu cable can carry 192 Ampere. In kVA this is 11kV x 192 A = 2 112 kVA. The maximum embedded generation for these cables is 15% of the total capacity. This means 15% of 3 828 kVA and 15% of 2 112 kVA = 574 kVA and 317 kVA. Given a power factor of 0.95 this is in kW, 0.95 x 574 is 545 kW and 0.95 x 317 kW = 301 kW. The total kW maximum embedded generation is 545 + 301 = 846 kW.

The area connected to Tortelduif is supplied by one 70 mm^2 Cu cable that can also carry 192 Ampere. In kVA this is 11kV x 192 A is 2 112 kVA. The maximum embedded generation for these cables is 15% of the total capacity. This means 15% of 2 112 kVA = 317 kVA. Given a power factor of 0.95 this is 0.95 x 317 = 301 kW.

The total limit in embedded generation as per medium-voltage cables for Tortelduif and Befgraafplaats in Onder Papegaaiberg is 846 kW + 301 kW = 1 147 kW.

In conclusion, the limit of embedded generation in Onder Papegaaiberg for the transformers is approximately 1 174 kW. The limit of embedded generation as per medium-voltage cables in Onder Papegaaiberg is 1 147 kW. In this area, the medium-voltage cables can carry less embedded generation as per standard than the transformers. The difference is only 27 kW. Although the difference is small and relatively insignificant, this example has also proven that there might be differences between the two approaches. It is, therefore, still necessary to calculate the maximum EG from both perspectives. In this example, the results from the medium-voltage cables calculations should be used as this gives the lowest result. This would be considered as the safest approach as the other approach might exceed the limit of the medium-voltage cables. This means that the absolute maximum; before a grid study has been performed, would be 1 147 kW for the residential area in Onder Papegaaiberg.

Summary of Results

This section gives a summary of all the calculated results. Table 5 and Table 6 show the maximum embedded generation in kW that households in the five different high-income areas can feed back to the grid. The maximum, as Table 5 shows, if one looks at the capacity of the mini-substations / transformers in the areas, is around 7 082 kW. The maximum, as Table 6 shows, looking at the capacity of the medium-voltage cables, is approximately 7 709 kW. In the entire town of Stellenbosch this means the absolute maximum, without doing an extensive grid study, would be 7.7 megawatt. However, the safest approach is to take the lowest value as point of departure. This means that if the transformers have a lower capacity than the medium-voltage cables, the point of departure should be the transformers.

Substation	Area	Transformer kVA	kVA (25% NMD)	kW PF = 0,95
Jan Marais	Uniepark & Karindal	3925	981,25	932,1875
Markotter	Dalsig & Brandwacht	4665	930	883,5
Golf Club	Paradyskloof & Die Boord	11415	2853,75	2711,0625
Cloetesville	Welgevonden	5815	1453,75	1381,0625
Main	Onder Papegaaiberg	4945	1236,25	1174,4375
Total		30765	7455	7082,25

Table 5 Summary of results of transformer's capacity to carry DG in high-income areas in Stellenbosch

Substation	Area	MV Feeder kVA	kVA (15% NMD)	kW PF=0,95
Jan Marais	Uniepark & Karindal	6578	986,7	937,365
Markotter	Dalsig & Brandwacht	11484	1722,6	1636,47
Golf Club	Paradyskloof & Die Boord	20328	3049,2	2896,74
Cloetesville	Welgevonden	7656	1148,4	1090,98
Main	Onder Papegaaiberg	8052	1207,8	1147,41
Total		54098	8114,7	7708,965

Table 6 Summary of results of medium-voltage cable's capacity to carry DG in high-income areas in Stellenbosch

Discussion

The concern of municipalities over revenue loss because of rooftop PV penetration is realistic but there is a limit to the amount of rooftop PV generated electricity that the current distribution network can receive. Per MV feeder, or in other terms, the MV cables coming from the electricity substations distributing electricity to the transformers, the maximum installation size of rooftop photovoltaic is less than 15% of the MV feeder peak load. Furthermore, per particular transformer, the maximum allowed embedded generation is 25%. The limit of 15% is needed to avoid instability when, for example, a cloud comes over and the generation of electricity of the rooftop PV installations would drop because it doesn't receive sunlight. A further point is that only the high-income class can afford to invest in solar panel installation for their rooftop, which puts another limit on investing in large-scale rooftop PV.

However, what is also evident is that citizens invest in solar PV installations and connect them to the grid without permission of the municipality. In the City of Cape Town, it is estimated that the illegal connections number at least 1 000 (Janisch, 2014). At the time of writing, it is unknown if there are illegal connections of embedded generation to the municipal grid in Stellenbosch. However, if the municipality does not come up with a municipal policy regarding embedded generation in time or makes it extremely difficult and costly for people to connect, chances are that citizens will connect without informing the municipality.

Moreover, the NRS policy only provides guidelines and can be used for the current situation. After grid studies have been done the maximum capacity RE the transformers and cables can carry might change. Furthermore, since there is a trend in connecting illegally as can be seen in the City of Cape Town, the NRS guideline will become less valuable as citizens are not considering these policies whilst connecting.

Conclusion

This section has pointed out what the grid capacity is for embedded generation as a share of the total maximum grid capacity for electricity according to NRS 097-2-series. It was calculated that the maximum capacity, if the minimum values between the transformers and MV electricity grid cables are used as point of departure, is 6 765 kW or approximately 6.7 MW. If all households considering rooftop PV were to install a 3 kWp system, this would equate to 6 765 /3 = **2 255 rooftop PV systems**. Therefore, when looking from a grid capacity point of view, 2 255 households living in the high electricity use areas, would theoretically be able to put up a 3 kWp rooftop system. In section 4 of the research findings, the financial impact as a result of DG, criteria are set to determine for which households it would make financial sense to invest in rooftop PV. The maximum number of households that can put up rooftop PV in this section will be compared to the households that could invest in Rooftop PV according to the criteria in section 4. The next section will look at the impact of Rooftop PV on the load profile based on the results of this chapter.

4.4 Research findings 3: Impact of Distributted Generation on load profile

This section of the case study provides the findings on what part of the electricity load profile would be taken up by distributed generation, indicated as an averaged kW value over an hour on the y-axis. A simulation approach is used to model possible future extreme case scenarios based on the maximum grid capacity for embedded generation and based on the solar penetration in the specific identified high electricity use suburbs. The solar penetration is based on recorded data from a total of 1.68 MWp solar PV system that has tracked the exact solar penetration on every day of the year between July 2013 and June 2014. To keep data collection and tracking consistent and to achieve consistent results, the 2013/2014 municipal financial year is used as a point of departure throughout the research. The grid capacity results from the previous section are used as a basis for the results in this section.

This set of findings is structured as follows: it will initially show and analyse the findings for the impact of solar rooftop PV from the suburb Welgevonden that is connected to the substation Cloetesville. Secondly, the findings and analyses of the findings for the suburbs Uniepark and Karindal, Onder Papegaaiberg, Die Boord and Paradyskloof, Dalsig and Brandwacht are given. These are connected to Stellenbosch Main substation. As the suburb Welgevonden is connected to a different substation from the other high user residential areas, the results for this suburb are plotted in a separate graph.

Figure 27 and Figure 28 serve as an example of the potential maximum impact of solar PV from households. The graphs show the impact of households when the maximum PV is installed and before grid studies are needed in the high electricity use suburbs. Figure 27 shows the impact of solar rooftop PV from the residential suburb Welgevonden, on a particular day in the month of August 2013. The red coloured field represents the electricity that will be substituted by grid connected embedded generated electricity in an extreme case scenario from the residential sector based on the grid capacity as calculated in the previous chapter. Industry, the commercial sector, and the agricultural sector etc. are left out of the calculations for rooftop PV even though they consume a part of the electricity load profile of the substations represented in the graphs.

Figure 28 shows the impact from solar rooftop PV in the residential suburbs Uniepark and Karindal, Dalsig and Brandwacht, Paradyskloof and Die Boord, and Onder Papegaaiberg, all marked with different colours.

The y-axis of the graph presents the averaged kW over an hour that is being demanded by electricity consumers connected to the specific substation and the x-axis shows at which specific hour the electricity is demanded. As the two substations have different capacities and different amounts of electricity are being demanded per substation, the graphs are plotted on different margins. The maximum on the graph for Cloetesville substation is 14 000 kW. The maximum on the graph for Stellenbosch Main substation is 45 000 kW. The electricity load profiles per substation differ, which represents the difference in the amount of electricity output per hour of the day. These differences in electricity load depend on the type of electricity consumers and the number of electricity consumers that are connected, and the amount they consume at different times. The range of electricity consumers will, in absolute terms and in percentages, differ per substation and therefore, differences in hourly consumption figures are experienced. Industry, residential, agricultural and commercial sectors each have a different typical electricity demand profile. The Stellenbosch Main substation is closest to industry and could therefore have a more industrial load profile, displayed in a table mountain shape. This is in contrast to Cloetesville substation that, apart from having less electricity demand from the consumers that are connected to this substation, also has a different electricity load structure throughout the day. The findings show that the Cloetesville load profile has a clear morning peak and a spike in electricity usage in the evenings. A predominance of residential areas that are connected to this substation in comparison to other consumer categories can explain this. The residential load typically occurs early morning and in the evening when people are at home.

Technical losses of electricity on the grid have also been calculated and are shown in the legends. These were calculated assuming a power factor (PF) of 0.95. However, as almost invisible in the graphs, the technical losses are negligible.

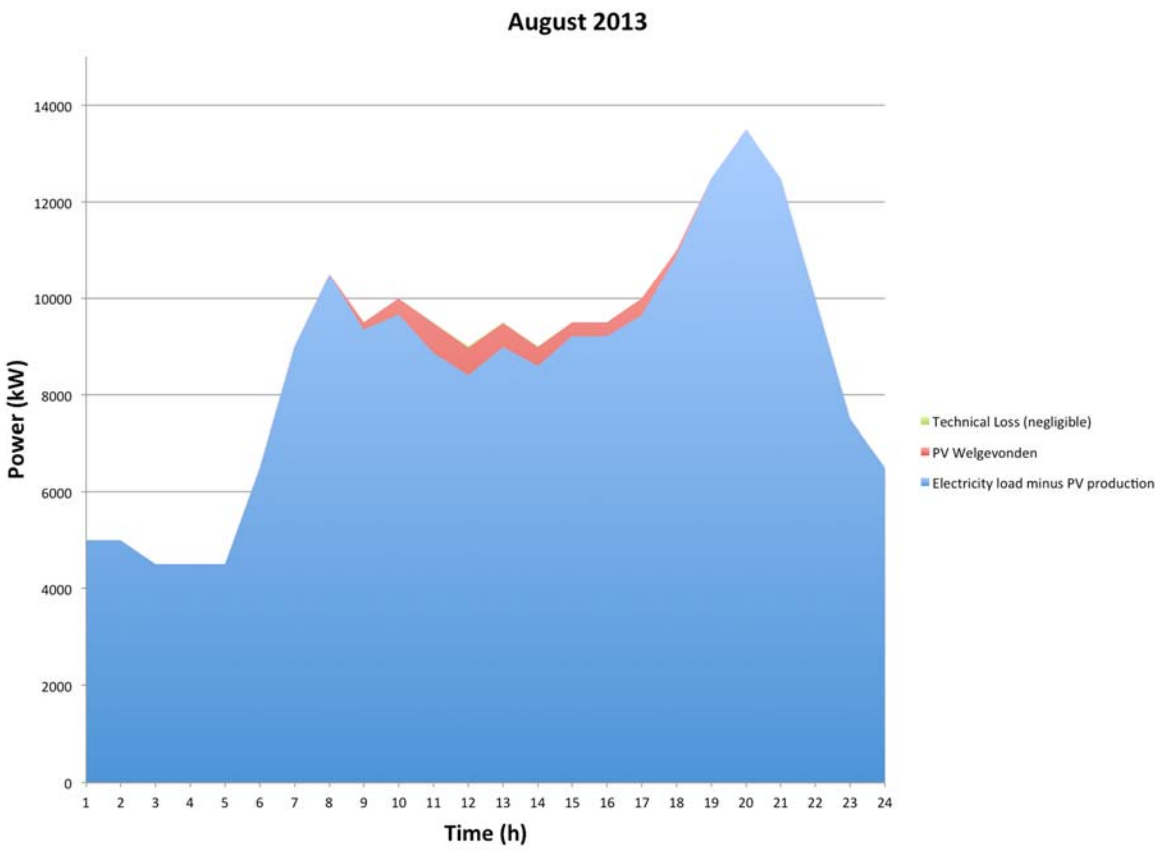

Figure 27 Example graph of the impact of rooftop PV in Welgevonden on the Cloetesville substation load profile[10]

[10] Instantaneous power values for an hour is averaged over the hour, resulting in the kW value indicated on the y-axis

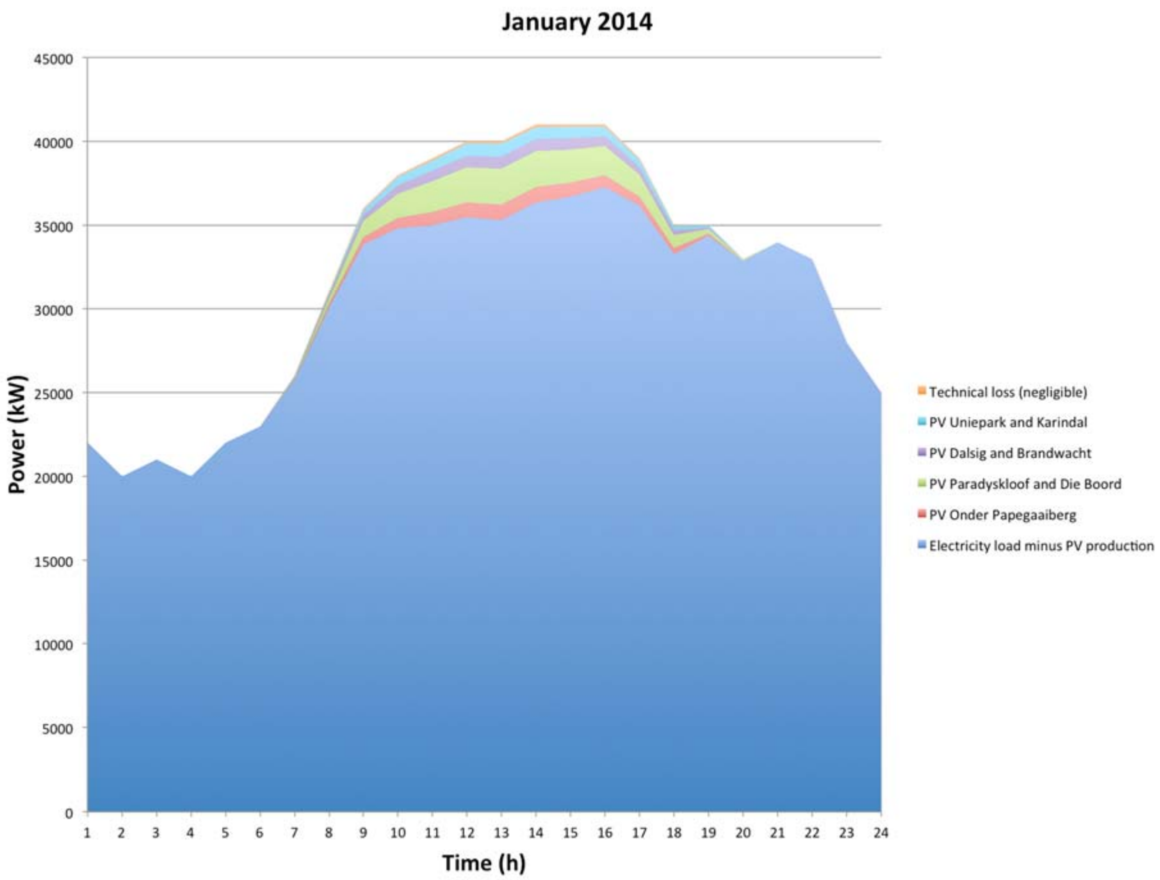

Figure 28 Example graph of the impact of rooftop PV in Other Suburbs on the Stellenbosch Main substation load profile[11]

[11] Instantaneous power values for an hour is averaged over the hour, resulting in the kW value indicated on the y-axis

Findings and analysis

The graphs in Figure 29 and Figure 30 represent the results of section three of the case study chapter. It gives an overview of the impact of PV on the electricity load profiles of Cloetesville and Stellenbosch Main substations for the 2013/2014 municipal financial year. For every month, typical days with weather results representable for that season where chosen to display the results. Only weekdays have been used.

Figure 29 show that the Cloetesville load profile has a clear morning peak and a spike in electricity usage in the evenings. As solar PV is generated during sun hours, this falls mostly in between the morning and evening peak. However, in a few spring / summer months (October, November, December, January, February, March and April) a slight shaving of the morning peak is projected. The research findings in section four will point out if it is financially beneficial, as electricity for municipalities is more expensive during peak hours than standard or off-peak hours.

Figure 30 shows an overview of the impact of potential embedded generation in the suburbs Uniepark and Karindal, Paradyskloof and Die Boord, Dalsig and Brandwacht, and Onder Papegaaiberg on the electricity load profile of Stellenbosch Main substation in the 2013/2014municipal financial year. In contrast to the Cloetesville substation, the electricity load profile of the Stellenbosch Main substation has a rather table mountain profile during the spring / summer months (October – April). This is beneficial as it reduces the top of the electricity load profile and allows for more room until NMD has been reached.

Both figures show an extremely low impact in June as one of the least sunny days was used as the point of departure. Also the electricity usage is, on average, more during winter months, which reduces the impact of PV as a percentage of the total electricity demand.

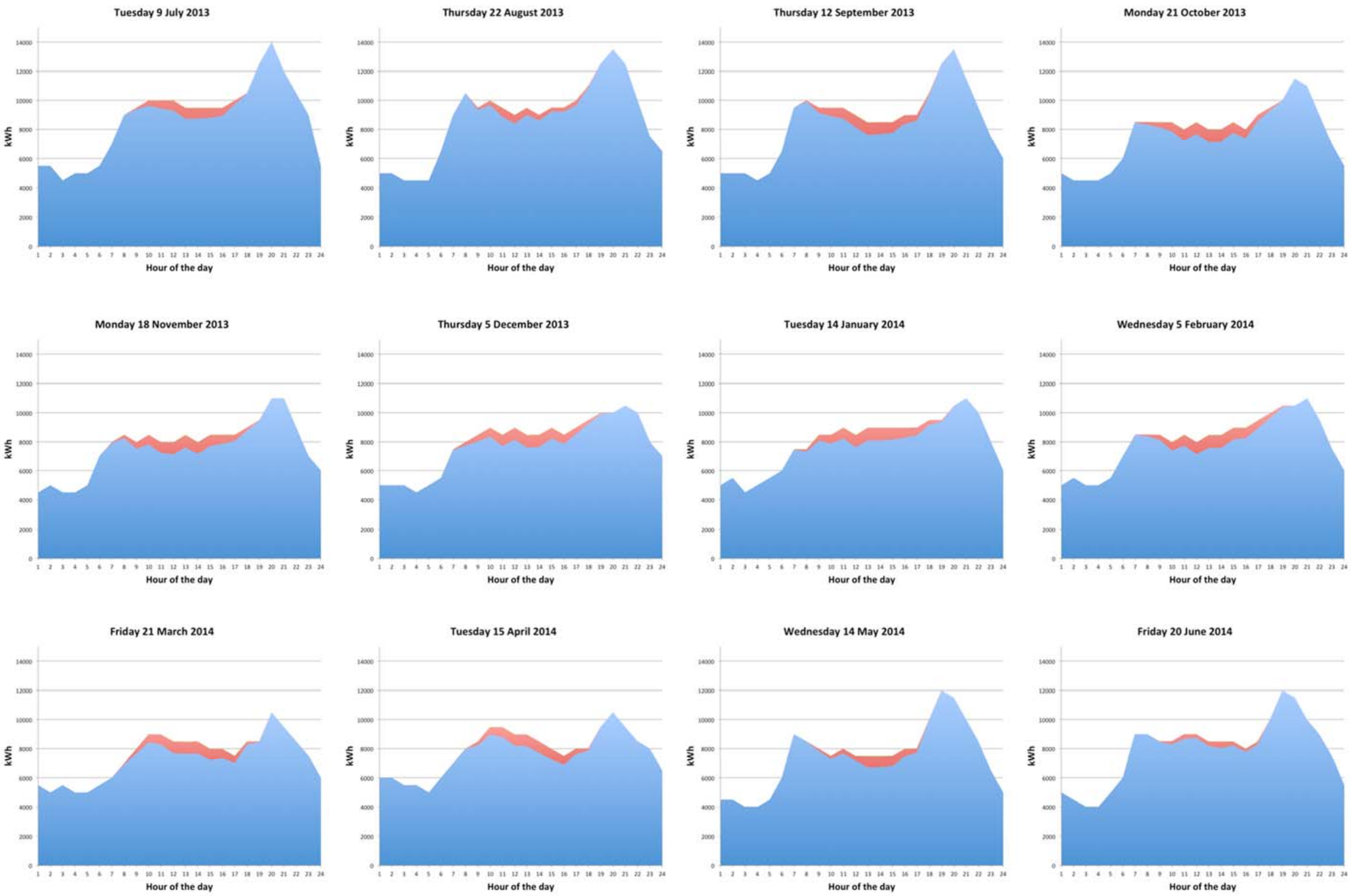

Figure 29 Impact EG on Cloetesville substation load profile for a typical day each month in financial year 2013/2014

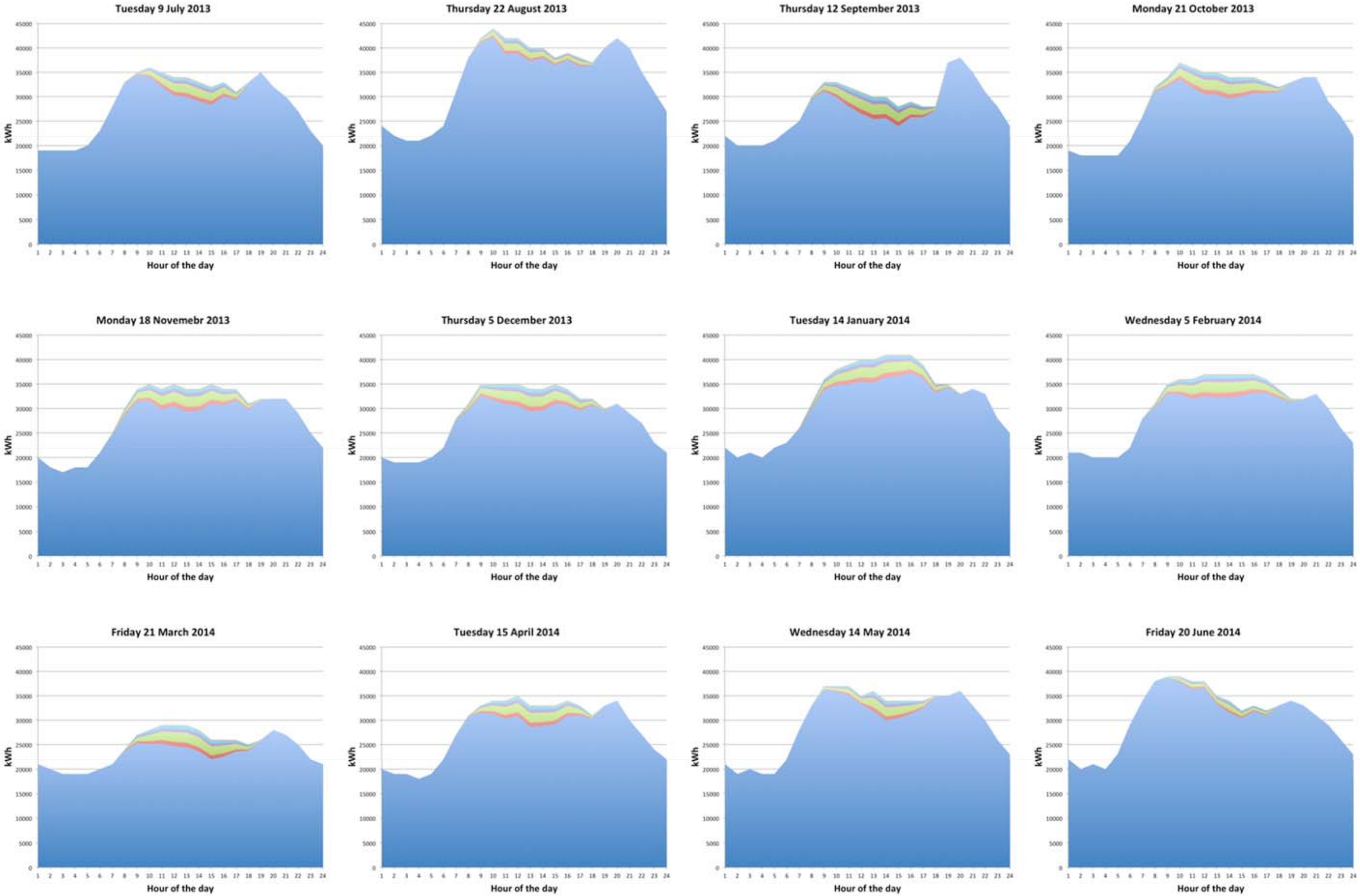

Figure 30 Impact EG on Stellenbosch Main Substation load profile for a typical day each month in financial year 2013/2014

4.5 Research findings 4: The financial impact as a result of embedded generation

Since section three showed the impact in averaged kW over an hour of the electricity load profile, section four presents the final set of findings: the financial impact as a result of embedded generation presuming an extreme case scenario. This section is structured as such:

It will first present and discuss the tariff and payment structure of both Eskom and the municipality as this lays the foundation for the calculations. Secondly, the savings for the municipality as a result of household rooftop PV electricity generation will be presented and discussed. Thereafter the financial reduction on the electricity revenue (loss of income for Stellenbosch Municipality) will be given. These two different approaches were needed as different tariff and payment structures apply from municipality to citizens and from Eskom to municipality. The two outcomes will be deducted from each other that will give the net loss of income to the municipality.

Note:

- The calculations are conducted without considering feed-in tariffs because there is no feed-in tariff structure available in Stellenbosch.
- Possible subsidy structures for PV are also omitted from consideration

The results will differ if potential feed-in tariffs or subsidy structures are considered in the calculations. The results will also deviate, as tariffs are different per municipality. Some municipalities in South Africa have introduced feed-in tariffs and pay a fee per unit of electricity received from licensed embedded generation. Some people who have a credit meter installed manage to let it run backwards.

Payment / tariff structures and implications

In order to find out what the impact is of residential rooftop PV is it important to understand the payment and tariff model of electricity for South African municipalities, and in this regard, specifically Stellenbosch Municipality. Municipalities buy electricity from Eskom and resell it to consumers within its legal jurisdiction. Exceptions in this example are Pniel and Johannesdal that are located within Stellenbosch's border, but are supplied and billed by Drakenstein municipality. A proportion of the electricity in Stellenbosch, approximately 10%, is supplied and billed directly by Eskom.

According to tariff principles as stated in Stellenbosch' tariff policy 2013/2014 "tariffs should reflect the costs reasonably associated with rendering the service, including capital, operating, maintenance, administration, replacement costs and interest charges. Tariffs are set at levels that facilitate the financial sustainability of the service, taking into account subsidisation from sources other than the service concerned. A service is financially sustainable when it is provided in a manner that would ensure its financing from internal and external sources is sufficient to cover the costs of the initial capital expenditure required, operating the service, maintaining, repairing and replacing the physical assets used in its provision" (Stellenbosch Municipality, 2013). In summary, these tariff principles state that services provided by the municipality should be financially sustainable and therefore recover the initial capital expenditure, either internally or from external sources. Some services, however, are able to generate more than what is required to cover their own costs. Water and electricity are examples of such services, which are classified by Stellenbosch Municipality as trading services (Stellenbosch Municipality, 2013). According to the tariff policy of 2013/2014, these services must generate a surplus, which will be used to subsidise community services other than economic services, meaning services that are not able to generate own revenue (Stellenbosch Municipality, 2013). In previous years, the electricity department managed to generate a surplus on electricity sales. It is this surplus that the municipality endeavours to protect as it, in the current model, is an indispensable income source used to supplement other departments. According to Coetzee (2015) the cost recovery model on electricity must stay like this. If this is not possible, then other departments must get resources from elsewhere or rates and taxes should be increased.

A critical point to note is that the tariff policy is not specific on how much the surplus has to be in relative or absolute terms, in order for it to become a sufficient source to supplement other services.

Tariff structures

Eskom – Municipality

In this section, we zoom in on the tariff structure of electricity and its benefits / implications and the relation to solar rooftop PV. The payment and tariff structure will determine for the larger part what the income and expenditure is of the municipality on electricity. Stellenbosch Municipality pays Eskom according to the Megaflex for Local Authority rates for the electricity it receives. The Megaflex indicates a Time-of-Use (TOU) and seasonal electricity tariff for customers with an NMD greater than 1 MVA who are able to shift their load. Eskom charges in c/kWh for active energy including losses, based on the voltage of supply and the transmission zone. Most of Eskom's coal-fired power stations are located in Mpumalanga province in the north-east of the country. As the Western Cape is the furthest province from where the electricity is generated in the north-east of the country, the transmission zone for Stellenbosch is >900 km (Eskom Tariff, 2014). This means that Stellenbosch Municipality falls into the highest payment category of the Megaflex for Local Authorities. A map of the high-voltage transmission lines and coal-fired power plants is included in Appendix C. The municipality faces additional charges in the event of exceeding the NMD in accordance with the NMD rules (Eskom Tariff, 2014).

Table 7 shows the different prices Eskom charges the municipality for using electricity during different tariff hours during high and low season. As the case study focuses specifically on the 2013/2014 municipal financial year, the prices for this specific year are given. The amounts are given in Rands per kWh. High season represents the winter months June, July, August and low season represents the summer months Sept – May.

High Season	Tariff Hour	Tariff
Week	Off Peak	0.3383
	Standard	0.623
	Peak	2.0566
Saturday	Off Peak	0.3383
	Standard	0.623
Sunday	Off Peak	0.3383
Low Season		
Week	Off Peak	0.2929
	Standard	0.4617
	Peak	0.6708
Saturday	Off Peak	0.2929
	Standard	0.4617
Sunday	Off Peak	0.2929

Table 7 Tariff charges from Eskom to Stellenbosch Municipality per kWh per tariff hour and per season for 2013/2014 municipal financial year

Municipality to consumers within own borders of jurisdiction

The Council of Stellenbosch Municipality adopts and implements a tariff policy on the levying of tariffs for municipal services in accordance with section 74 of the Local Government Municipal Systems Act, Act 32 of 2000. The tariffs represent the charges levied by Council on consumers for the utilisation of services provided by the municipality (Stellenbosch Municipality, 2013).

In 2009, the block incline tariff was introduced (Kruywagen, 2014). Therewith the tariff structure changed drastically. It was an incentive to remove load-shedding and to put more pressure on the high-use consumers to reduce their consumption (Kruywagen, 2014). At that time the municipality advertised for people to consume less electricity. The target was a 10% decrease in electricity consumption (Kruywagen, 2014). If this were to be achieved the municipality would not have to implement load-shedding to bring the consumption down in a forced way (Stellenbosch Municipality, 2014).

Municipalities pay different prices to Eskom at different times of the day. Since electricity is more expensive during the ‘normal’ peak hours the municipality has the choice of less margin on electricity, or running at a loss. In summer, electricity units during peak hours cost R0.6708 for the municipality, which is still lower than the price consumers of municipal electricity pay on average. However, during the winter months, electricity during peak hours costs the municipality R2.0566 which is often higher than prices consumers pay to the municipality. However, as the municipality’s tariff structure (prepaid and credit block system) is fundamentally different from Eskom’s tariff structure (TOU) these cannot simply be compared to each other.

If people were to invest in rooftop photovoltaic, this could potentially have a negative impact on the revenue of municipalities. From net consumers, people are going to consume less or become zero consumers. In a ‘worst’ case scenario through the lens of a municipality they become net suppliers during the day when electricity for the municipality would be profitable. This scenario results in not only a loss in income for the municipality but the municipality also needs to pay for the electricity of the supplying household and for the grid maintenance. On top of this, photovoltaic only generates during the day when the sun shines. This is, however, also the time that municipalities pay less to Eskom per kWh than at other times and generates a higher margin than during the peak hours.

Savings

This paragraph discusses the savings for Stellenbosch Municipality as a result of grid connected embedded generation. Table 8 shows the outcomes of the calculations done to get an answer on the sub-question of how much the municipality would save when people start investing in solar panels. The savings are calculated as what the municipality does not need to pay to Eskom due to the reduction in electricity demand. The calculations are based on the maximum grid capacity for EG and the solar penetration in Stellenbosch based on a 1.68 MWp system. This is divided as a proportion over the week, Saturday and Sunday during peak, off-peak and standard hours. The total EG produced is 11 144 917 kWh. The proportions of EG generated during the TOU are multiplied with the tariff charged by Eskom to the municipality. This leads to a total of R5 465 182 savings for 2 255 households installing a 3 kWp solar PV.

Table 8 shows that almost 60% (48.5 + 11.3) of the total EG electricity is generated during the week in standard hours, when electricity is bought against relatively cheaper prices. During the peak hours, 11.7% (10.2 + 1.5) electricity is generated by EG. In addition, the saving in proportion to the standard hours is 60% (45.6 + 14.4). The saving during peak hours as part of the total is higher than the electricity generated, due to influence of a higher tariff. The saving during peak hours is 20.3% (14 + 6.3).

High Season	Tariff Hour	Tariff in Rand	Maximum PV in Stellenbosch sample system	Electricity produced per kWp	EG produced for kWp	Proporation EG produced per tariff hour	Savings on Eskom bill for municipality in Rand	Proporation of savings
Week	Off Peak	0,3383	0	0	-	0%	R -	0%
	Standard	0,623	313 574	187	1 262 722	11%	R 786 676	14%
	Peak	2,0566	41 431	25	166 837	1%	R 343 116	6%
Saturday	Off Peak	0,3383	41 632	25	167 646	2%	R 56 715	1%
	Standard	0,623	26 345	16	106 089	1%	R 66 094	1%
Sunday	Off Peak	0,3383	75 560	45	304 272	3%	R 102 935	2%
Low Season								
Week	Off Peak	0,2929	0	0	-	0%	R -	0%
	Standard	0,4617	1 340 991	798	5 399 993	48%	R 2 493 177	46%
	Peak	0,6708	282 819	168	1 138 877	10%	R 763 959	14%
Saturday	Off Peak	0,2929	182 136	108	733 439	7%	R 214 824	4%
	Standard	0,4617	134 487	80	541 561	5%	R 250 039	5%
Sunday	Off Peak	0,2929	328 663	196	1 323 481	12%	R 387 648	7%
Total			2 767 638	1647	11 144 917	100%	**R 5 465 182**	100%

Table 8 Savings on Eskom bill for Stellenbosch Municipality

Reduction in revenue

This paragraph points out the reduction in the municipality's revenue. This reduction is calculated for the group that is further refined as identified potential investors.

The criteria I have used to determine these potential investors:

- Household
- Located in identified high-user suburb
- Consuming 600 kWh or higher per month + the amount in kWh embedded generation would generate for a 3 kWp PV system in a month

In the approach, it is assumed that households make a rational monetary decision and will only invest in rooftop PV if they get the maximum saving. Therefore, it is assumed that only households who will, for every month of the year not dip below 600 kWh electricity usage after PV is installed. Below a usage of 600 kWh the price per kWh is much less and therefore fewer savings will be experienced by the rooftop PV consumer. The number of households per suburb that can invest in rooftop PV differ according to the set criteria. Table 9 shows the results of the calculation based on the criteria above for households with a prepaid meter. Table 10 presents the results of the calculations for credit meters. The lowest number of households that can have solar PV in a particular month is marked in yellow. This number is used for every month during the 2013/2014 municipal financial year. The lowest value is taken, as it is then certain they would fit the criteria in the other months as well to invest in rooftop PV. Table 11 and Table 12 use the lowest values to get to the maximum kWh produced by rooftop PV in the suburbs.

An example:

As Table 9 indicates, in the suburb Uniepark, the number of kWh produced in the month of January 2014 by a 1 kWp system in the most favourable weather condition is 177 kWh. This has been determined by the use of a yield assessment of the photovoltaic power plant with the program SolarGIS PV Planner. The solar installation is positioned facing north, with an inclination of 29°. The coordinates of the site are: **33° 55' 43.64" S, 18° 53' 6.04" E.** The annual average electricity production for this system is approximately 1 636 kWh with a performance ratio of 78.1%. In order to be as accurate as possible, the same assessment has been done for the area Karindal, connected to Uniepark, as there are differences in landscape relief. However, the assessment results showed the differences are insignificant in influencing the amount of kWh production in a month. This controlling approach has also been done for the other research suburbs to avoid inaccuracy.

Assumed in the research is that potential investors will install a 3 kWp system, in this example leading to a PV output of 303 kWh. A monthly electricity usage of potential investors of 600 kWh + the PV output in the month is used as a criterion. The reason for this is because when consuming over 600 kWh the highest tariff of the block system counts. By using the criteria, the lowest number of households willing to invest is in January 2014. For January 2014 it is determined that 28 households are able to put up a solar PV system producing a total of 868 kWh.

The same approach as depicted above is used for every research suburb, for both the prepaid and credit meters during the 2013/2014 municipal financial year. This is also the reason why the first column starts with the month July, as it is the first month of the municipal financial year. The totals can be found in the right hand column of Table 11 and Table 12.

Note

The criteria, however, can be changed as necessary, which will lead to changes in the financial impact. The last criterion has the default that it is not always the same households consuming 600 kWh plus the extra amount their solar system would generate. In some months some households may meet the criteria and not in other months. It was decided to look at a monthly basis, as even though not all households might always meet the criteria, they are still identified as potential investors as the other months can compromise. The other reason is that these criteria were seen as the most logical for now with the data available. New field research with questionnaires would be more precise in establishing how many households are actually considering or willing to invest in rooftop PV. Once this number is clear, as well as the amount of kWh the households consume, and the size of the rooftop installation, more accurate results can be predicted.

Pre Paid meters	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13	Dec-13	Jan-14	Feb-14	Mar-14	Apr-14	May-14	Jun-14
Uniepark & Karindal												
kWh produced per month for 1 kWp system	101	111	130	157	158	169	177	156	161	128	102	89
kWh produced per month for 3 kWp system	303	333	390	471	474	507	531	468	483	384	306	267
600 + kWh produced per month for 3 kWp system	903	933	990	1071	1074	1107	1131	1068	1083	984	906	867
household viable to put up rooftop pv according to above criteria	58	69	64	48	37	35	28	33	46	36	67	81
Welgevonden												
kWh produced per month for 1 kWp system	102	111	131	157	159	169	177	157	161	128	103	89
kWh produced per month for 3 kWp system	306	333	393	471	477	507	531	471	483	384	309	267
600 + kWh produced per month for 3 kWp system	906	933	993	1071	1077	1107	1131	1071	1083	984	909	867
household viable to put up rooftop pv according to above criteria	41	72	38	14	12	11	7	16	11	21	39	93
Dalsig & Brandwacht												
kWh produced per month for 1 kWp system	101	110	130	157	158	169	176	156	160	127	102	89
kWh produced per month for 3 kWp system	303	330	390	471	474	507	528	468	480	381	306	267
600 + kWh produced per month for 3 kWp system	903	930	990	1071	1074	1107	1128	1068	1080	981	906	867
household viable to put up rooftop pv according to above criteria	64	73	63	41	36	36	28	34	41	50	55	75
Onder Papegaaiberg and Kleinvallei												
kWh produced per month for 1 kWp system	102	111	131	158	160	170	178	157	161	128	103	89
kWh produced per month for 3 kWp system	306	333	393	474	480	510	534	471	483	384	309	267
600 + kWh produced per month for 3 kWp system	906	933	993	1074	1080	1110	1134	1071	1083	984	909	867
household viable to put up rooftop pv according to above criteria	23	29	23	8	6	8	7	11	10	14	30	38
Paradyskloof & Die Boord												
kWh produced per month for 1 kWp system	101	111	130	157	159	169	177	156	160	128	102	89
kWh produced per month for 3 kWp system	303	333	390	471	477	507	531	468	480	384	306	267
600 + kWh produced per month for 3 kWp system	903	933	990	1071	1077	1107	1131	1068	1080	984	906	867
household viable to put up rooftop pv according to above criteria	132	129	116	72	60	64	65	68	74	84	118	162

Table 9 Analysis of maximum households to invest in embedded generation for pre paid meters

Credit meters	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13	Dec-13	Jan-14	Feb-14	Mar-14	Apr-14	May-14	Jun-14
Uniepark & Karindal												
kWh produced per month for 1 kWp system	101	111	130	157	158	169	177	156	161	128	102	89
kWh produced per month for 3 kWp system	303	333	390	471	474	507	531	468	483	384	306	267
600 + kWh produced per month for 3 kWp system	903	933	990	1071	1074	1107	1131	1068	1083	984	906	867
household viable to put up rooftop pv according to above criteria	291	271	287	282	272	155	116	163	110	154	187	249
Dalsig & Brandwacht												
kWh produced per month for 1 kWp system	101	110	130	157	158	169	176	156	160	127	102	89
kWh produced per month for 3 kWp system	303	330	390	471	474	507	528	468	480	381	306	267
600 + kWh produced per month for 3 kWp system	903	930	990	1071	1074	1107	1128	1068	1080	981	906	867
household viable to put up rooftop pv according to above criteria	278	221	246	252	220	105	127	154	117	175	207	247
Onder Papegaaiberg & Kleinvallei												
kWh produced per month for 1 kWp system	102	111	131	158	160	170	178	157	161	128	103	89
kWh produced per month for 3 kWp system	306	333	393	474	480	510	534	471	483	384	309	267
600 + kWh produced per month for 3 kWp system	906	933	993	1074	1080	1110	1134	1071	1083	984	909	867
household viable to put up rooftop pv according to above criteria	122	106	114	112	89	38	30	55	32	52	57	95
Paradyskloof & Die Boord												
kWh produced per month for 1 kWp system	101	111	130	157	159	169	177	156	160	128	102	89
kWh produced per month for 3 kWp system	303	333	390	471	477	507	531	468	480	384	306	267
600 + kWh produced per month for 3 kWp system	903	933	990	1071	1077	1107	1131	1068	1080	984	906	867
household viable to put up rooftop pv according to above criteria	647	258	530	430	369	185	167	251	170	245	319	455

Table 10 Analysis maximum households to invest in embedded generation for credit meters

Pre Paid meters	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13	Dec-13	Jan-14	Feb-14	Mar-14	Apr-14	May-14	Jun-14	Total
Uniepark & Karindal													
kWh produced per month for 1 kWp system	101	111	130	157	158	169	177	156	161	128	102	89	1639
kWh produced per month for 3 kWp system	303	333	390	471	474	507	531	468	483	384	306	267	4917
600 + kWh produced per month for 3 kWp system	903	933	990	1071	1074	1107	1131	1068	1083	984	906	867	12117
household viable to put up rooftop pv according to above criteria	28	28	28	28	28	28	28	28	28	28	28	28	28
Total kWh produced by EG per month	8484	9324	10920	13188	13272	14196	14868	13104	13524	10752	8568	7476	137676
Welgevonden													
kWh produced per month for 1 kWp system	102	111	131	157	159	169	177	157	161	128	103	89	1644
kWh produced per month for 3 kWp system	306	333	393	471	477	507	531	471	483	384	309	267	4932
600 + kWh produced per month for 3 kWp system	906	933	993	1071	1077	1107	1131	1071	1083	984	909	867	12132
household viable to put up rooftop pv according to above criteria	7	7	7	7	7	7	7	7	7	7	7	7	7
Total kWh produced by EG per month	2142	2331	2751	3297	3339	3549	3717	3297	3381	2688	2163	1869	34524
Dalsig & Brandwacht													
kWh produced per month for 1 kWp system	101	110	130	157	158	169	176	156	160	127	102	89	1635
kWh produced per month for 3 kWp system	303	330	390	471	474	507	528	468	480	381	306	267	4905
600 + kWh produced per month for 3 kWp system	903	930	990	1071	1074	1107	1128	1068	1080	981	906	867	12105
household viable to put up rooftop pv according to above criteria	28	28	28	28	28	28	28	28	28	28	28	28	28
Total kWh produced by EG per month	8484	9240	10920	13188	13272	14196	14784	13104	13440	10668	8568	7476	137340
Onder Papegaaiberg and Kleinvallei													
kWh produced per month for 1 kWp system	102	111	131	158	160	170	178	157	161	128	103	89	1648
kWh produced per month for 3 kWp system	306	333	393	474	480	510	534	471	483	384	309	267	4944
600 + kWh produced per month for 3 kWp system	906	933	993	1074	1080	1110	1134	1071	1083	984	909	867	12144
household viable to put up rooftop pv according to above criteria	6	6	6	6	6	6	6	6	6	6	6	6	6
Total kWh produced by EG per month	1836	1998	2358	2844	2880	3060	3204	2826	2898	2304	1854	1602	29664
Paradyskloof & Die Boord													
kWh produced per month for 1 kWp system	101	111	130	157	159	169	177	156	160	128	102	89	1639
kWh produced per month for 3 kWp system	303	333	390	471	477	507	531	468	480	384	306	267	4917
600 + kWh produced per month for 3 kWp system	903	933	990	1071	1077	1107	1131	1068	1080	984	906	867	12117
household viable to put up rooftop pv according to above criteria	60	60	60	60	60	60	60	60	60	60	60	60	60
Total kWh produced by EG per month	18180	19980	23400	28260	28620	30420	31860	28080	28800	23040	18360	16020	295020

Table 11 Potential total kWh produced by embedded generation for the different research suburbs for pre paid meters

Credit meters	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13	Dec-13	Jan-14	Feb-14	Mar-14	Apr-14	May-14	Jun-14	Total
Uniepark & Karindal													
kWh produced per month for 1 kWp system	101	111	130	157	158	169	177	156	161	128	102	89	1639
kWh produced per month for 3 kWp system	303	333	390	471	474	507	531	468	483	384	306	267	4917
600 + kWh produced per month for 3 kWp system	903	933	990	1071	1074	1107	1131	1068	1083	984	906	867	12117
household viable to put up rooftop pv according to above criteria	110	110	110	110	110	110	110	110	110	110	110	110	110
Total kWh produced by EG per month	33330	36630	42900	51810	52140	55770	58410	51480	53130	42240	33660	29370	540870
Dalsig & Brandwacht													
kWh produced per month for 1 kWp system	101	110	130	157	158	169	176	156	160	127	102	89	1635
kWh produced per month for 3 kWp system	303	330	390	471	474	507	528	468	480	381	306	267	4905
600 + kWh produced per month for 3 kWp system	903	930	990	1071	1074	1107	1128	1068	1080	981	906	867	12105
household viable to put up rooftop pv according to above criteria	105	105	105	105	105	105	105	105	105	105	105	105	105
Total kWh produced by EG per month	31815	34650	40950	49455	49770	53235	55440	49140	50400	40005	32130	28035	515025
Onder Papegaaiberg & Kleinvallei													
kWh produced per month for 1 kWp system	102	111	131	158	160	170	178	157	161	128	103	89	1648
kWh produced per month for 3 kWp system	306	333	393	474	480	510	534	471	483	384	309	267	4944
600 + kWh produced per month for 3 kWp system	906	933	993	1074	1080	1110	1134	1071	1083	984	909	867	12144
household viable to put up rooftop pv according to above criteria	30	30	30	30	30	30	30	30	30	30	30	30	30
Total kWh produced by EG per month	9180	9990	11790	14220	14400	15300	16020	14130	14490	11520	9270	8010	148320
Paradyskloof & Die Boord													
kWh produced per month for 1 kWp system	101	111	130	157	159	169	177	156	160	128	102	89	1639
kWh produced per month for 3 kWp system	303	333	390	471	477	507	531	468	480	384	306	267	4917
600 + kWh produced per month for 3 kWp system	903	933	990	1071	1077	1107	1131	1068	1080	984	906	867	12117
household viable to put up rooftop pv according to above criteria	167	167	167	167	167	167	167	167	167	167	167	167	167
Total kWh produced by EG per month	50601	55611	65130	78657	79659	84669	88677	78156	80160	64128	51102	44589	821139

Table 12 Potential total kWh produced by embedded generation for the different research suburbs for credit meters

Table 13 summarises Table 11 and Table 12 and provides the financial impact. It points out the total number of households that are able to invest in PV according to the criteria. This totals **541 households**. As seen in section 2 of the results chapter, if the maximum grid capacity is used a point of departure, 2 255 households would be able to invest in rooftop PV. Even though 2 255 households with a 3 kWp solar system could connect to the grid before grid studies are needed, these potential households do not exist when purely looking at monetary criteria. When using the monetary criteria only, 541 households would potentially invest in solar panels to get the maximum benefits. This is four times less than the 2 255 households that could potentially connect to the grid with a 3 kWp system.

The column next to the households shows the total kWh produced by embedded generation. The total kWh multiplied by R1 3803 provides the financial impact. R1 3803 is the amount per unit in block 4 of the Block-incline-Tariff (BiT) system for 2013/2014. When adding all the amounts per suburbs, the total financial impact would be R3 671.016.

		Households	Total kWh produced by EG	Financial Impact	
Pre Paid					
1,3803	Uniepark & Karindal	28	137 676	R	190 034
	Welgevonden	7	34 524	R	47 653
	Dalsig & Brandwacht	28	137 340	R	189 570
	Onder Papegaaiberg	6	29 664	R	40 945
	Paradyskloof & Die Boord	60	295 020	R	407 216
Credit					
1,3803	Uniepark & Karindal	110	540 870	R	746 563
	Dalsig & Brandwacht	105	515 025	R	710 889
	Onder Papegaaiberg	30	148 320	R	204 726
	Paradyskloof & Die Boord	167	821 139	R	1 133 418
Total		541	**2 659 578**	**R**	**3 671 016**

Table 13 Total financial reduction in municipality's electricity revenue

4.6 Concluding remarks

This section provides concluding remarks on the financial impact on the electricity revenue of Stellenbosch Municipality. This also leads to an answer on the research question of this study. Lastly, a discussion is provided on the economic implications and potential benefits of embedded generation.

1. Net loss using monetary criteria – households

The saving is R5 465 182 for 2 255 households, using the maximum grid capacity as criteria.

The financial reduction on income is R3 671 016 for 541 households.

The savings for 541 households is then:

(R5 465 182 / 2 255) x 541 households = R1 318 429.

This leads to a **net loss** of R3 671 016 - R1 318 429 = **R2 352 587**

2. Net loss using maximum grid capacity criteria

The financial reduction on income is R3 671 016 for 541 households.

The savings for 2 255 households is R5 465 182.

This means the financial reduction for 2 255 households is (R3 671 016 / 541) x 2 255 = R 15 301 555.

This leads to a **net loss** of R15 301 555 - R5 465 182 = **R9 836 373**.

Impact for the 2013/2014 municipal financial year:

Total electricity revenue:	R413 698 000
Total electricity expenditure:	R381 089 000
Surplus:	R32 609 000

Net loss **R2 352 587 (0.6% impact on electricity revenue)**

Net loss **R9 836 373 (2.4% impact on electricity revenue)**

If fixed charges would need to cover for the net- losses this comes down to the following fixed monthly charges to solar PV consumer:

<u>For monetary criteria approach:</u>

R2 352 587 / 541 = R362.4 per month

<u>For maximum grid capacity approach:</u>

R9 836 373 / 2255 = R363.5 per month

<u>Discussion – economic implications and benefits:</u>

What needs to be considered is the cost to increase the Notified Maximum Demand in relation to the cost of allowing grid-connected embedded generation. According to Jan Coetzee (2015), an application has been submitted to Eskom to increase the NMD of the MVA of the Franschhoek substation from 9 to 10 MVA and is supposed to be upgraded at the time of writing (Wednesday, 29 July 2015). The cost to upgrade the NMD with 1 MVA was R1 331 507. In 2013, Stellenbosch Main substation received an upgrade from 55 MVA to 60 MVA Notified Maximum Demand. This upgrade cost the municipality R4 007 100. The Cloetesville substation got upgraded in 2010 from 15 MVA to 16 MVA. At that time, the upgrade cost the municipality R395 580. This is a significant difference to the price for the upgrade in 2015. The reason for this is the steep price increases in the cost of electricity. In general, applications to Eskom to increase the MVA NMD need to be submitted a year in advance. Up until now, despite Eskom's challenges to meet the electricity demand in the country, no application to upgrade the MVA NMD for a substation has been declined.

Costly to increase NMD: PV has a potential to reduce the load profile by flattening the high use times. This is beneficial as it gives the municipality more room before they have to apply to increase the NMD again, which is becoming more and more costly as electricity prices are rising. Moreover, there is less chance of exceeding NMD, which could result in fines by Eskom. Thirdly, it hampers economic activity in town if electricity connections were held back because of electricity shortages.

What is important to take into consideration is what the economic benefits would be for the municipality of regulating renewable energy and stimulating energy efficiency. The current load-shedding events do have economic consequences for South Africa as a whole. It is, however, not certain what exactly the economic implications are on the municipal level. Stellenbosch Municipality has a high rate of development due to the university, with high demand for student accommodation, and due to its business environment (Stellenbosch Municipality, 2014). The municipality applied for extra MVA for the electricity distribution substations to meet the demands of new developments. Eskom, however, already cannot meet the current national electricity demand and it is therefore unlikely that Stellenbosch can apply for even more electricity. There could, therefore, be a limit on future consumption of electricity and new developments that can be connected. However, according to Stellenbosch Municipality (2014), electricity connections are at this moment not a problem in terms of development. More challenging though, are wastewater and potable water connections.

Discussion in comparison with other studies

The last section of the discussion focuses on the comparison of the thesis study to other similar studies in the world. Satchwell et al. (2015a) have conducted a similar study in the United States. The rapid expansion of customer-sited photovoltaic in the United States over the recent years have caused heated debates about the impact of this development on utility shareholders and ratepayers. Progress in the solar industry to grow and for government and environmental advocates to achieve their sustainability goals, has been hampered by lack of research on the financial impact on utilities and other stakeholders as a result of PV. Also the conditions under which the impacts would become more or less significant are not clear. In response to this debate Satchwell et al. (2015a) have conducted a similar study to the study of this thesis in the United States. The difference is however that the study of Satchwell et al. (2015a) examines the situation including net-metering tariffs. Thus, for every electricity unit sold back to the grid an equal amount of money is returned as what the consumer would have paid the utility for electricity. Furthermore, in the study the analysis results are based on the characterization of two prototypical utilities: a vertically integrated model in the South West of the US (SW utility) and a wires-only utility and default service supplier in the North East of the country (NE utility). In contrast to the specialised focus of the thesis study on the financial impact of PV on the revenue and surplus of the municipality's electricity revenue, the US study involves a more broader scope including the impact of net-metered PV on utilities cost, average rates, and utilities shareholders earnings and return-on-equity. It also examines the sensitivity of the financial impacts on the utility's regulatory and operating environment such as the cost growth, electricity load growth and frequency of general rate cases. A pro forma financial model has been used to calculate utility cost and revenues based on specific assumptions about its physical, financial, operating, and regulatory characteristics. Satchwell et al. (2015a) analysed their results under various assumptions regarding the operating and regulatory environment of utilities. They also found that the impact of PV could vary greatly depending on the specific context of the utility.

Satchwell et al., (2015a) found that customer sited PV in general reduce the collected revenues by utilities more than reductions in costs which leads to a net revenue loss and lost future earnings opportunities. They also conclude that on average, retail rates increased as a result of on-site distributed PV generation, as utility costs are spread over a relatively smaller customer base. This thesis study of Stellenbosch Municipality concludes similarly that, in case of the current operating business model, Stellenbosch Municipality will experience a net loss as a result of increases of household solar PV. However, in South Africa it cannot be argued that increases in electricity prices is a result of household PV or renewable energy effort in general. The uptake of renewable energy across the country, although increasing, is still too small. The dramatic increases of electricity prices over the last years have a number of other reasons, mainly the under-capacity of the state electricity utility Eskom to meet the electricity demand in the country. This does however not mean that PV will not contribute to electricity price increases when keeping the current business model. If the business model of utilities and municipalities operating as utilities would be changed whilst incorporating PV wisely in that model, the electricity service could be run financially more balanced and environmentally more sound. This will be discussed in the concluding chapter.

The study for Stellenbosch Municipality does not include a net-metering tariff or any other form of rate for distributed generation PV that would be channelled onto the municipal electricity grid. Policies that indicate a return rate for excess PV production are not in place at the time of writing. As becomes clear from various studies in other places, net-metering would not be the best option as it increases the financial impact on municipal or utility electricity revenues and induces fixed costs being unfairly distributed from PV owners towards non-PV owners and utilities. The study done for Stellenbosch Municipality could be expanded in future studies by using an academically credible and suitable financial model that includes a broader study area than the financial impact on revenue and surplus on electricity. Although the US study is more broadly focussed on financial impact such as on the costs of electricity, it has not outlined the types of consumers in the area of study and the effect of net-metered PV on consumers from different consuming and income classes remain unclear. The outlining of different consumer types in Stellenbosch could be taken further through developing measurement systems that indicate what the exact impact would be on different consumer categories.

Based on the results of the study the researchers highlight potential implications for policy makers and provide key issues justifying further research. As acknowledged by Satchwell et al. (2015a) the model that the researchers used for their study did not have the capability to represent more complex rate designs, such as time-of-use (TOU) pricing or tiered (i.e., inclining or declining block) rates. This is another point where this thesis academically contributes towards the knowledge in this particular field.

Chapter 5: Conclusion

5.1 Introduction

This chapter merges the findings and arguments developed throughout the study. Firstly, a summary of findings is provided, structured around the research objectives as stated in the introductory chapter. The summary of findings will give the findings and sub-conclusions that form the building blocks around the main conclusion. Thereafter, the main conclusion is given that provides an answer to the research question of this study. Lastly, suggestions are made for further research that could make useful contributions to existing knowledge around the topic of this research.

5.2 Summary of findings

Worldwide electricity utilities are facing financial challenges as a result of a boom in the uptake of embedded generation by the residential sector. It has been pointed out that it is in fact not embedded generation as a disruptive technology that is the problem, but the inherent unsustainable business model of utilities based on volumetric sales. There was discussion as to whether the increased uptake of distributed generation would lead to a Death Spiral – a reduction in electricity sales, causing grid electricity prices to rise to cover fixed costs, resulting in more incentives to uptake distributed generation. Although the Death Spiral theory might be somewhat extreme in reflecting the current utility's business model challenge, it is evident that factors have created a 'perfect storm' for utilities (Faruqui & Grueneich, 2014). Utilities will be required to re-examine their traditional business models, especially the unsustainable design of revenue collection, through volumetric sales. Decoupling, which breaks the link between a utility's recovery of fixed costs and kWh sales, is suggested as an alternative tariff system rather than calling a halt to the development of rooftop PV (Xue et al., 2014). However, decoupling through raising fixed tariffs for all consumers might be politically sensitive as it could place higher burdens on poorer households. It is also not evident as to whether decoupling will be enough to mitigate the effects of distributed generation on electricity revenue. Moreover, raising fixed charges might be a disincentive for households to manage electricity effectively and sustainably, as the economic incentive would be reduced. More in-depth research will be needed to propose a more balanced rate design. Furthermore, a sustainable and fair rate design will be needed to compensate for electricity being fed to the grid by distributed generation (DG) owners. Under a net-metering system, the utility is required to purchase excess PV-generated electricity at the same retail rate they charge for electricity provision. Although net metering might be the easiest, least costly and least time-consuming policy to implement, net metering may result in two shortcomings: firstly, it will distribute costs from relatively wealthier DG electricity consumers to non-DG electricity consumers. Secondly, when utilities pay the full electricity tariff for DG electricity they are not able to cover the fixed costs and are not appreciated for providing a constant back up system (Cai et al., 2013; Kirsch & Morey, 2015). The Value of Solar Tariffs (VOST) is being discussed as an alternative system to net metering (Costello, 2015). In contrast to net metering, the VOST system bills customers for using electricity from the grid and separately credits solar PV owners for all generated electricity fed to the grid. In this way, a fair compensation for solar electricity is provided whilst avoiding over-payment of non-PV owners. The price paid for solar electricity from DG owners by the utility should reflect the actual avoided cost (generation costs such as fuel and capacity costs) (Costello, 2015). The final action utilities or municipalities could take is to invest in ownership of renewable energy assets to also benefit from the energy transition (Richter, 2013a). A study by Richter (2013b) showed that German utilities lost an estimated 97% of the distributed generation market to investors and households from outside the electricity industry. In order to benefit from the changing energy market, utilities should adjust their business model by finding new ways of value creation and value capture by building up assets and knowledge in the field of renewable energy (Richter, 2012). As pointed out in the literature review, Funkhouser, Blackburn, Magee, & Rai (2015) suggest Community Solar as a solution to mitigate the concerns of revenue loss by utilities. Community Solar, administered by the utility or a third party entity in which multiple customers can participate, serves as an alternative deployment model for PV whilst integrating distributed generated solar PV. Kritzinger, Meyer, Van Niekerk, & Scholtz (2015), proposed municipally generated and owned electricity through investments in rooftop solar PV to Drakenstein municipality. Stellenbosch municipality could take similar suggested approaches to mitigate revenue loss, whilst supporting Stellenbosch Municipality's sustainability and innovation agenda.

Many South African municipalities used to generate and provide electricity before it was centralised (Eberhard, 2004). Currently, municipalities rely on Eskom for electricity provision before they can distribute it to the consumers (Eberhard, 2004). However, since the introduction of distributed generation a decentralisation shift is happening again. The South African PV market has experienced enormous growth over the last few years due to the very successful REIPPPP project (Baker et al., 2014). Despite this success, the residential rooftop PV market still experiences many challenges (PV Insider, 2014a). However, the residential market is not insignificant. 95% of the connections are residential and they contribute to 75% of the national variable load. More importantly, they contribute 35% to the peak demand (Ijumba et al., 2008), which is undesirable as the grid is already under constraint and it is expensive to generate electricity during this time. This study has shown that embedded generation will reduce peak demand almost insignificantly, as most PV electricity is generated during the day. Stellenbosch generates 30% revenue on electricity provision. The surplus, revenue minus expenditure, is however much less – approximately 8% of the total revenue generated on electricity. The surplus fluctuates per financial year for Stellenbosch municipality for which the reasons are uncertain. Furthermore, the impact of residential rooftop PV on the revenue should not be seen in isolation but in a wider context, especially in terms of financial management. Technical and non-technical energy losses have an impact on revenue as well.

5.2 Conclusion

The results as discussed and analysed led to a finding on the following main question:

What will be the impact on Stellenbosch Municipality's electricity revenue if households in identified high electricity use suburbs are using the maximum capacity for embedded generation according to NRS standard to feedback electricity produced by rooftop PV to the grid?

An extreme case scenario was used in this research to arrive at an answer to this question. Two ways of approaching the problem were set out.

Firstly, from a maximum grid capacity view, calculations were made to find out how many households could connect to the grid and what the impact would be. If households were to invest in a 3 kWp solar rooftop PV system and install the maximum capacity as guided by NRS standard, then 2 255 households could potentially connect to the grid. This would result in a financial reduction on electricity revenue of R15 301 555. It would also result in a municipal expenditure saving of R5 465 182 on the electricity bill from Eskom. The **net loss** on the electricity for the municipality would then be **R9 836 373.** This would lead to a percentage loss figure of 2.4% on the total revenue on electricity of R 413 698 000 in 2013/2014.

Secondly, monetary criteria were set to evaluate how many households would invest in rooftop PV if they wanted to achieve the maximum financial benefits. This was done by selecting households that would not dip below a monthly usage of 600 kWh of electricity after installing rooftop PV. When using these criteria only 541 households from high-electricity use areas would invest in rooftop PV. This would result in a financial reduction on the electricity revenue of R3 671 016. The savings on the municipality's annual bill for the procurement of electricity from Eskom as a result of fewer electricity sales would be R1 318 429. This would lead to a **net loss** of **R2 352 587**. It would mean a 0.6% loss on the total revenue on electricity of R 413 698 000 in the 2013/2014 municipal financial year.

If the municipality would consider to charge distributed generation owners to cover for the net loss of **R9 836 373**, this comes down to **R9 836 373 / 2255 = R363.5** fixed monthly charge. An approximate similar amount is calculated to cover a net loss of **R2 352 587.** This comes down to **R2 352 587 / 541 = R362.4** monthly charge. However, fixed charges can be very counter-productive and a real disincentive for people to invest in solar PV installations. People are investing in embedded generation because it is financially attractive. By charging high fixed amounts on a monthly basis will take away the financial incentive to invest in solar PV. Moreover, as pointed out in the literature review, it is also a disincentive to manage electricity as efficiently as possible. Charging high fixed amounts on a monthly basis to solar PV customers could hamper a sustainable energy transition.

5.3 Summary of contributions

This research has contributed to informing municipal decision makers and planners in policy development through analytical research. The aim was to deepen the knowledge on practical questions that an energy transition brings regarding embedded generation. What deserves attention is that the approach and results of this research in Stellenbosch Municipality is useful for other municipalities in South Africa, but not representative or a blueprint for other municipalities. Stellenbosch is unique, faces different challenges, and copes with varied social and economic dynamics.

5.4 Further research

This thesis has looked specifically at what the impact is of rooftop PV on the municipality's revenue on electricity. It has only touched lightly on options for how to deal with this revenue reduction in the literature review. It would be highly valuable to conduct in-depth research in designing new business models in which the aim of energy efficiency and distributed generation is not lost, whilst maintaining enough income to supplement the municipal coffers. Not only will the tariff structure based on volumetric sales need to be changed, but investment in new value proposition is also needed if the municipality aims to benefit from the energy transition. The question for municipalities is not *if* a transition is going to happen, but *how* municipalities are going to respond to the challenges and how they should transition to a sustainable model. If municipalities are to be sustainable and resilient in future, they have no other choice but to look for a sustainable finance and electricity model to run the municipality. It would be highly beneficial to the existing knowledge, planning practises and policy development.

Furthermore, the entire financial management model of municipalities in South Africa could be investigated of which surplus on trading services such as water and electricity is a part. Research could be done to see if it is sustainable and feasible in the future to rely on these trading services for cross-subsidisation of other services that are underfunded.

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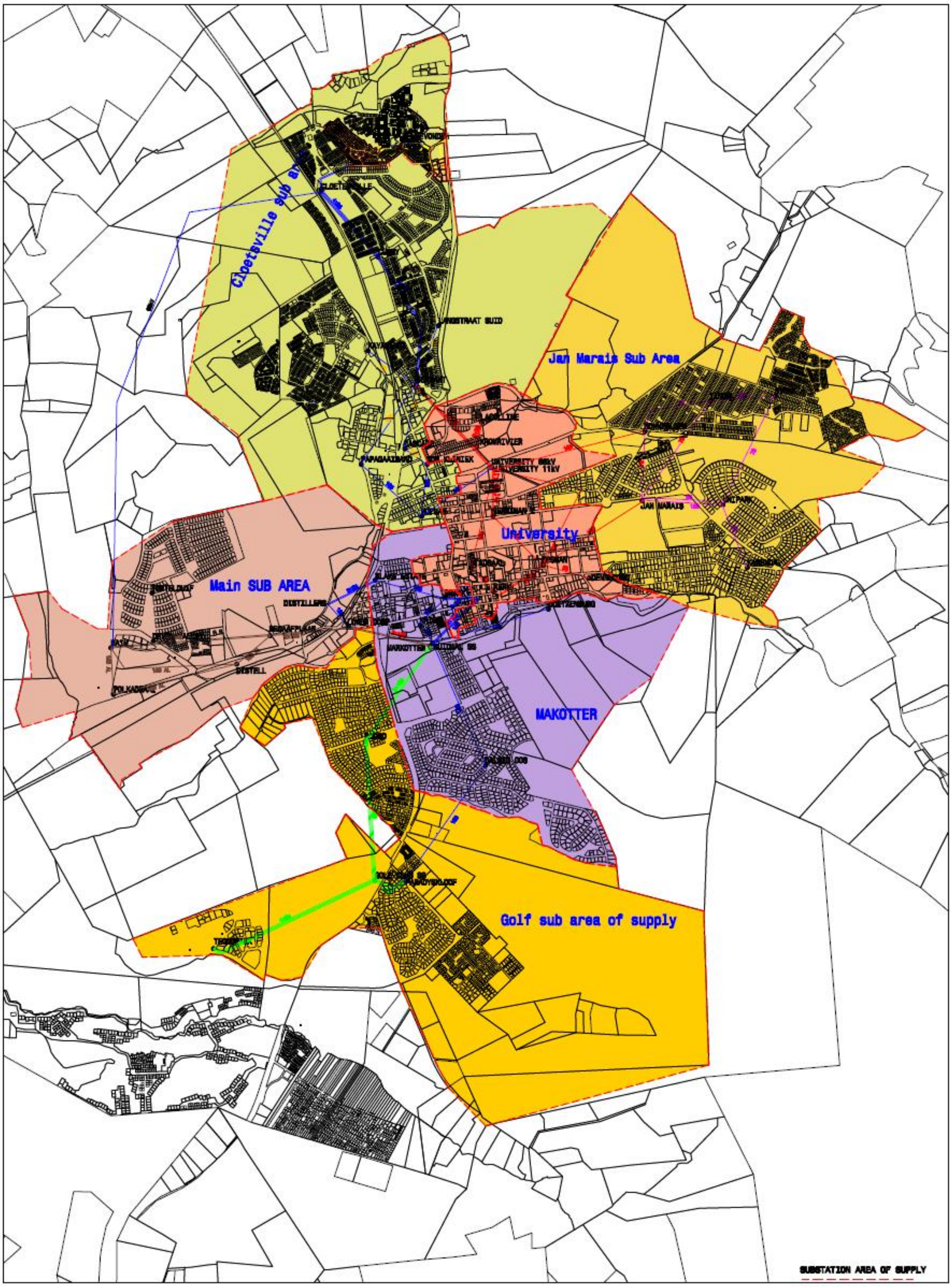
Appendix A: Areas of electrical supply by different substations

STELLENBOSCH MUNICIPAL AREA OF ELECTRICAL SUPPLY



Appendix B: Calculations of maximum EG for transformers and MV cables in high-use areas

Uniepark and Karindal

Jan Marais Substation			
Step 2 MV/LV transformer (shared LV feeders, EG max. 25% of NMD)			
Uniepark			P(kW)=S(kVA) x PF
Transformer	**NMD kVA**	**EG kVA** (25% of NMD)	**kW** PF= 0,95)
Unielaan	315	78,75	74,8125
Provinsie	300	75	71,25
Uitsig	200	50	47,5
Endler	200	50	47,5
Jonkershoek	500	125	118,75
AP Venter	315	78,75	74,8125
vnKopenhagen	200	50	47,5
Waterweg	150	37,5	35,625
Karindal			0
du Plessis	300	75	71,25
Zwaanswyk	315	78,75	74,8125
Total	2795	698,75	**663,8125**
Rowan	500	125	118,75
Jannasch 2	315	78,75	74,8125
Jannasch1	315	78,75	74,8125
Total	1130	282,5	**268,375**
Total	3925	981,25	**932,1875**
Step 3 MV Feeder cables			
supplied by same 185 mm2 Cu + 35 mm2 Cu underground cable			
Uniepark	185 mm2 = 348 A		
Unielaan	348 A x 11.000V = 3828 kVA		
Provinsie	Cable can carry up to 3,828MVA		
Uitsig	35 mm2 = 125 A		
Endler	125 A x 11.000V = 1375 kVA		
Jonkershoek	Cable can carry up to 1,375 MVA		
AP Venter			
vnKopenhagen	EG: 15% of (3,828 + 1,375) =		
Waterweg	0,78045 MVA = 780,45 kVA		
Karindal	PF (0,95): 0,95x 780,45 = **741,4275 kW**		
du Plessis			
Zwaanswyk			
supplied by 35 mm2 Cu underground cable			
Rowan	35 mm2 = 125 A		
Jannasch 2	125 A x 11.000V = 1375 kVA		
Jannasch1	Cable can carry up to 1,375 MVA		
	EG 15% of 1375 kVA = 206,25 kVA		
	PF=(0,95): 0,95x 206,25 = **195,9375 kW**		

Dalsig

Markotter Substation			
Step 2 MV/LV transformer (shared LV feeders, EG max. 25% of NMD)			
Dalsig Oos			
Transformer	**NMD kVA**	**EG kVA** (25% of NMD)	**kW** (PF = 0,95)
Le Seur	300	75	71,25
Olyf	300	75	71,25
Brandwag1	300	75	71,25
Brandwag2	300	75	71,25
Binnekring	315	78,75	74,8125
Koch	315	78,75	74,8125
Barry	315	78,75	74,8125
Doornbosch	315	78,75	74,8125
Park	315	78,75	74,8125
Middebosch	315	78,75	74,8125
Kweekschool	315	78,75	74,8125
Die Laan	315	78,75	74,8125
Total	3720	**930**	**883,5**
Step 3 MV Feeder cables			
supplied by three 185 mm2 Cu underground cables			
185 mm2 = 348 A		EG: 15% of (3x 3828) = 1722,6 kVA	
348 A x 11.000V = 3828 kVA		PF (0,95): 0,95x 1722,6 = **1636,47 kW**	
Cable can carry up to 3,828MVA			

Conclusion			
Step 2 Max. Transformer	kVA	kVA (25% NMD)	kW PF= 0,95
Total	4665	**930**	**883,5**
Step 3 Max. MV Feeder	kVA	kVA (15% NMD)	kW PF= 0,95
Total	11484	**1722,6**	**1636,47**
Difference between totals	6819	**792,6**	**752,97**

Paradyskloof and Die Boord

Golf Club Substation			
Step 2 MV/LV transformer	(shared LV feeders, EG max. 25% of NMD)		
Mini-substation/ transform	NMD kVA	EG kVA (25% NMD)	kW (PF= 0,95)
Paradyskloof			
Paradyskloof	400	100	95
Canterbury	500	125	118,75
MS River	315	78,75	74,8125
Ms River2	315	78,75	74,8125
MS Elsie	315	78,75	74,8125
PKVillas	315	78,75	74,8125
LeMontier	200	50	47,5
Anesta	315	78,75	74,8125
LeHermitage	315	78,75	74,8125
LaPastorale	315	78,75	74,8125
Christian Brothers	200	50	47,5
Eden	400	100	95
Florida	400	100	95
Cynariodes	400	100	95
Repens	315	78,75	74,8125
Padstal	200	50	47,5
Seruria	315	78,75	74,8125
STB101	315	78,75	74,8125
Schuilplaats	160	40	38
Total	6010	1502,5	1427,375
Die Boord	NMD kVA	EG kVA (25% NMD)	kW (PF= 0,95)
Wingerd	315	78,75	74,8125
Rhodes	315	78,75	74,8125
Lovel1	315	78,75	74,8125
Lovel2	315	78,75	74,8125
Bon Cretien	315	78,75	74,8125
Elberta	300	75	71,25
Lovel3	400	100	95
De Bosch	315	78,75	74,8125
Bokewood Pomp	315	78,75	74,8125
Marina RKW	300	75	71,25
Culemborg	400	100	95
Oewer Park	800	200	190
Blenheim	300	75	71,25
Rokewood	300	75	71,25
Kleingeluk	400	100	95
Total	5405	1351,25	1283,6875

Paradyskloof and Die Boord

Step 3 MV Feeder cables	
Paradyskloof supplied by four 95 mm2 Cu underground cables	
95 mm2 Cu = 231 A 231 A x 11kV = 2541 kVA Cable can carry up to 2,541 MVA	4x 2541 = 10164 EG: 15% of (4x 2541) = 1524,6 kVA PF (0,95): 0,95x 1524,6 = 1448,37 kW
Die Boord supplied by four 95 mm2 Cu underground cables	
95 mm2 Cu = 231 A 231 A x 11kV = 2541 kVA Cable can carry up to 2,541 MVA	4x 2541 = 10164 EG: 15% of (4x 2541) = 1524,6 kVA PF (0,95): 0,95x 1524,6 = 1448,37 kW
231 A x 11kV = 2541 kVA Cable can carry up to 2,541 MVA	EG: 15% of (4x 2541) = 1524,6 kVA PF (0,95): 0,95x 1524,6 = 1448,37 kW

Conclusion			
Step 2 Max. Transformer	kVA	kVA (25% NMD)	kW PF= 0,95
	6010	1502,5	1427,375
	5405	1351,25	1283,6875
Total	11415	**2853,75**	**2711,0625**
Step 3 Ma. MV Feeder	kVA	kVA (15% NMD)	kW PF= 0,95
	10164	1524,6	1448,37
	10164	1524,6	1448,37
Total	20328	**3049,2**	**2896,74**
Difference between totals	8913	**195,45**	**185,6775**

Welgevonden

Cloetesville Substation			
Step 2 MV/LV transformer (shared LV feeders, EG max. 25% of NMD)			
Transformer	NMD kVA	EG kVA (25% NMD)	kW PF= 0,95
Welgevonden			
Sonnedou	500	125	118,75
Olive	400	100	95
Belladonna	500	125	118,75
Katbos	500	125	118,75
Rankel	500	125	118,75
Sour Fig	400	100	95
Protea	500	125	118,75
Perdely	500	125	118,75
Boulevard	400	100	95
Gate	400	100	95
Entrance	400	100	95
Klein Welgevonden	500	125	118,75
Hendrikse	315	78,75	74,8125
Total	5815	1453,75	1381,0625
Step 3 MV Feeder cables			
supplied by two 185 mm2 Cu underground cables			
185 mm2 = 348 A 348 A x 11.000V = 3828 kVA Cable can carry up to 3,828MVA		2x 3828 = 7656 kVA EG: 15% of 7656 = 1148,4 kVA PF (0,95): 0,95x 1148,4 = **1090,98 kW**	

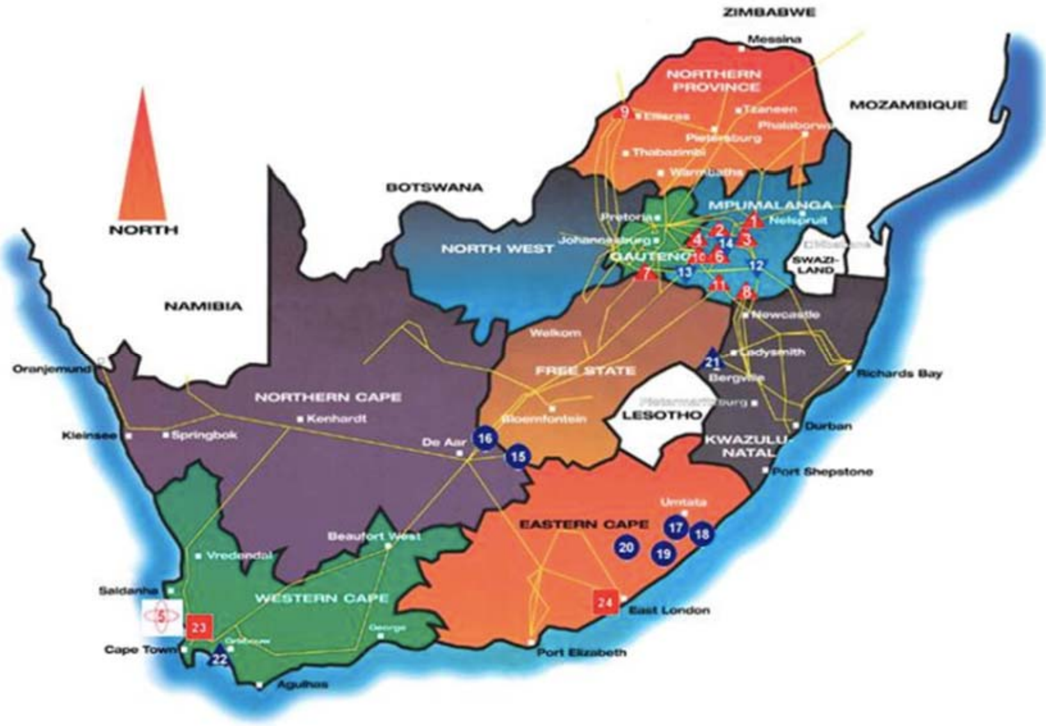
Conclusion			
Step 2 Max. Transformer	kVA	kVA (25% NMD)	kW PF= 0,95
Total	5815	**1453,75**	**1381,0625**
Step 3 Max. MV Feeder	kVA	kVA (15% NMD)	kW PF= 0,95
	7656	**1148,4**	**1090,98**
Difference between totals	1841	**-305,35**	**-290,0825**

Onder Papegaaiberg

Main Substation			
Step 2 MV/LV transformer (shared LV feeders, EG max. 25% of NMD)			
Transformer	NMD kVA	EG kVA (25% NMD)	kW (PF= 0,95)
Onder Papegaaiberg Begraafplaats			
Libertas	200	50	47,5
Cabernet	200	50	47,5
Steloord2	315	78,75	74,8125
Bosmans Crossing	500	125	118,75
KWVPark	630	157,5	149,625
Sonop	800	200	190
Total	2645	661,25	628,1875
Onder Papegaaiberg Tortelduif			
Swawel	500	125	118,75
Flamingo	300	75	71,25
Klein Vallei	300	75	71,25
Loerie	300	75	71,25
JanFrederik	300	75	71,25
Hamerkop1	300	75	71,25
Hamerkop2	300	75	71,25
Total	2300	575	546,25
Step 3 MV Feeder cables			
Onder Papegaaiberg Begraafplaats supplied by 185 + 70 mm2 Cu			
185 mm2 = 348 A 348 A x 11.000V = 3828 kVA		EG: 15% of 3828 = 574,2 kVA PF (0,95): 0,95x 574,2 = **545,49 kW**	
70 mm2 Cu = 192 A 192 A x 11kV = 2112 kVA		EG: 15% of 2112 = 316,8 kVA PF (0,95): 0,95x **300,96 kW**	
Onder Papegaaiberg Tortelduif supplied by 70 mm2 Cu			
70 mm2 Cu = 192 A 192 A x 11kV = 2112 kVA		EG: 15% of 2112 = 316,8 kVA PF (0,95): 0,95x **300,96 kW**	

Conclusion			
Step 2 Max. Transformer	kVA	kVA (25% NMD)	kW PF= 0,95
	2645	661,25	628,1875
	2300	575	546,25
Total	4945	**1236,25**	**1174,4375**
Step 3 Ma. MV Feeder	kVA	kVA (15% NMD)	kW PF= 0,95
	3828	574,2	545,49
	2112	316,8	300,96
	2112	316,8	300,96
Total	8052	**1207,8**	**1147,41**
Difference between totals	3107	**-28,45**	**-27,0275**

Appendix C: South African electricity supply map



Appendix D: Eskom's TOU Tariffs