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Assessment of Geographical Based Load Forecast Approach in Distribution Planning

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Dissertation Presented for the Degree of Master of Science in Engineering, in Electrical Engineering, Department of Electrical Engineering, University of Cape Town

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DISSERTATION SUMMARY

ASSESSMENT OF GEOGRAPHICAL BASED LOAD FORECAST APPROACH IN DISTRIBUTION PLANNING

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Prior to the year 2007, Eskom Distribution followed a method of load forecasting (now referred to as legacy method in this report) that was based on collecting customer applications, historical load trending, and relied on the planner's knowledge of the area to a large extent. It was based in a conventional Microsoft Excel spreadsheet. On seeking to improve its load forecasting approach, the utility adopted a technique that was based on spatial forecasting. This new technique was called a geographical based load forecasting (GLF) technique which was performed by using a custom based tool, called PowerGLF.

The aim of this research was to assess any improvements (or lack thereof) that were brought about by adopting the GLF method as compared to the legacy method that was used previously.

The hypothesis to be tested was declared as: "*The use of the GLF method that was introduced to Eskom Distribution Planning brings about the improvement on the planning process of infrastructure that is adequate, reliable and economic, when compared to the legacy method that was used before it*."

To carry out this assessment, a case study method was followed. Real network studies that were compiled in 2006 and 2007 were used. These network studies were based on GLF method and the legacy method. The load forecasts from the case studies were evaluated on forecast accuracy, how

they influenced the planning of adequate, reliable and economic (ARE) network infrastructure and their impact on the procurement and construction of the network infrastructure (which represent the actual utility expenditure on infrastructure). The statistical comparative analysis was done.

The research results revealed that the legacy method was more accurate than the GLF method in both the case studies that were evaluated. However, regarding the ability of a load forecast method to support the planning process, the GLF method showed to be supporting the planning of adequate, reliable and economic infrastructure better than the legacy method. It was found that the forecast error for the GLF and legacy method do not affect the utility infrastructure procurement and construction.

Based on the test results, the study reached a conclusion that *the use of the GLF method that was introduced to Eskom Distribution Planning brings about the improvement in the planning process of infrastructure that is adequate, economic and reliable when compared to the legacy method that was used before it.*

The author wishes to express that the results of this study must not be taken as a generic conclusive finding regarding the evaluated load forecasting methods; they are applicable to the tested case studies. To get to a general conclusive result, more case studies would need to be carried out where clear and consistent evidence on performance of these load forecasting methods will be seen. The findings of this study can be used as part of a larger sample if such a larger population of case studies was to be evaluated. The methodology followed in this research can be repeated and followed when similar assessments are done in future.

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DECLARATION

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Signed by candidate

Monde Soni

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ABBREVIATIONS

AAV	Absolute Average Value
BECOUE	Break Even Cost of Unserved Energy
CIC	Customer Interruption Cost
COUE	Cost of Unserved Energy
DG	Distributed Generation
FEM	Financial Evaluation Model
GLF	Geographical Load Forecast
HV	High Voltage (Nominal Voltage > 33kV)
IDP	Integrated Development Plan
IRR	Internal Rate of Return
kVA	Kilo Volt Ampere
LLCC	Least Life Cycle Cost
LM	Legacy Method
LV	Low Voltage (Nominal Voltage < 1kV)
MADM	Multi Attribute Decision Making
MAPE	Mean Absolute Percentage Error
MCDM	Multi Criteria Decision Making
MIRR	Modified Internal Rate of Return
MTS	Main Transmission Station
MV	Medium Voltage (1kV≤ Nominal Voltage ≤33kV)
MVA	Mega Volt Ampere
NDP	Network Development Plan
NMP	Network Master Plan
NPV	Net Present Value
NPW	Net Present Worth
PI	Profitability Index
RMSE	Average of Sum-Squared Errors
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SDF	Spatial Development Framework
SPLUMA	Spatial Planning and Land-use Management Act
UAP	Universal Access Plan

1. INTRODUCTION

This chapter gives the background information on the origin of this research. The context is introduced as well as the research hypothesis and research questions.

1.1. Study Background

Eskom is a state owned utility company in South Africa which is the majority producer, transmitter and distributer of energy in the country. The utility is divided into 3 main business units; Generation, Transmission and Distribution for electric power. As part of continuous monitoring and improvement, Eskom went through a process to change its planning operation in 2007. Part of the business improvement was changing the way the old load forecast method that Eskom Distribution used and the new method called Geographical Based Load Forecast (GLF) method was adopted.

Prior to adopting the GLF method, Eskom used a method of load forecasting that was not standardised in a documented standard or guide. In this research, this method has been given a name “legacy method”. Though the legacy method was performed in different ways by different planners, the generic description has been arrived at by consulting old network planning studies that were carried out at Eskom in years prior to 2007, as well as interviewing some of the planners who were working for Eskom during the time of legacy method.

When performing the legacy method, the load forecast was done per equipment area, the lowest level being a medium voltage (MV) feeder level. In the main, the feeder loading history would be studied using the meter readings from the previous years and, based on history; the feeder would be trended to forecast the future.

Due to its nature as a small area based load forecast, GLF was believed to be a better replacement that would bring improvement to the way load forecasting was done. This is mainly because, the GLF method gives detailed load analysis at higher spatial resolution than the legacy method as one is able to read and analyse the load at sub-feeder (MV) level.

In line with Eskom mandate (Eskom, 2013) and (Eskom, 2015), and the Eskom Network Planning Methodology Standard (Bunge & du Preez, 2007), planning must aim to achieve network that is reliable and economic. In addition, Eskom mentioned the importance of ensuring regulatory compliance and working with the government to achieve its aspiration of providing all citizens (100%) with electricity, thus provision of adequate supply. Therefore, the network would be considered adequate if it allows for connection of the whole community in the study area and the quality of supply is maintained within regulatory limits.

This research shall evaluate whether or not, the GLF method assists Eskom Distribution to achieve its goal as stated in the mandate, compared to the legacy method. In essence, this research is an appraisal of the GLF and it will be compared to the legacy method in order to identify the improvements that were aimed for when GLF was adopted.

1.2. Thesis Statement

With the understanding that Eskom's objective is to plan networks that are reliable, economic and adequate, the research hypothesis was declared to be:

"The use of GLF method that was introduced to Eskom Distribution Planning brings about the improvement on the planning process of infrastructure that is adequate, reliable and economic when compared to the legacy method that was used before it."

1.3. The Research Questions

To focus the research efforts towards testing the hypothesis, the following research questions were formulated:

- *Describe the distribution network planning process?*
- *What role does the load forecast (GLF or LM) play in a distribution network planning process?*
- *What are the key differences between the legacy method and GLF method?*
- *What is the cost associated with performing each load forecast method?*
- *Does one load forecast method have innate forecast accuracy over the other?*
- *How is the load forecast error measured?*
- *How does the accuracy or lack thereof, of a load forecast method affect the planning of infrastructure that is adequate, reliable and economic?*
- *On what basis (matrix) is the adequate, reliable and economic network from each load forecast method compared?*
- *What point of reference is used to compare the two load forecast methods?*
- *How does the forecast accuracy by GLF and legacy method affect the infrastructure procurement and construction?*

Why forecast accuracy is important: before the load forecast can be evaluated on how it improves the planning of infrastructure, it is critical to know how well or bad does it *get it right*. Basically, how close the predicted values (forecast) were from the actual measured load, the inverse of that is error.

Equally important, as accuracy, is how the load forecast method supports the business mandate of planning the infrastructure that the business aspires to have.

A statistical scoring system was used on the appraisal, and it was followed by a qualitative analysis that seeks to look at the contextual differences and non-quantifiable differences between the two load forecast methods being studied.

1.4. Chapter Overviews

Chapter 1 is an introduction of the research, it states the origin of this research and it declares the context, hypothesis and research questions. Chapter 2 reviews the literature relevant to the posed research questions. Chapter 3 develops the theory base for this study; it mainly concentrates on the matrices and formulas to be used in the research. Chapter 4, 5 and 6 describe the method used for the hypothesis test in three aspects being tested; load forecast error evaluation, load forecast impact on the distribution planning process and the impact of the load forecast error on the procurement and construction of network infrastructure respectively. Chapter 7, 8 and 9 list the results of the tests carried out in the preceding chapters, in the same order. Chapter 10 discusses the results against the context of the case studies as well as comparing the results to the literature stance. Chapter 11 gives more attention to the research questions by answering them in details, making reference to relevant parts of the report for evidence. Chapter 12 is a conclusion of this research and it states the extent to which the whole research has gone in testing the hypothesis.

1.5. Conclusion

The research objective is to appraise the GLF method against the legacy method in distribution planning. The hypothesis has been stated along with the research questions that will be addressed to test the hypothesis.

The next chapter reviews the relevant literature as a step towards the testing of the validity hypothesis.

2. LITERATURE REVIEW

This chapter reviews the literature pertinent to the hypothesis and research questions. The first section describes the planning process and the role played by the load forecasting in the planning process. A review of literature with regard to planning methods, specifically looking at the methods used for evaluation of economics, adequacy and reliability of infrastructure networks is carried out. Then the GLF and the legacy method are described in the context of this research. They assist the reader to understand the meaning and the context to which these terms are used and will avoid confusion going forward. Later, works on techniques used for evaluation of forecast methods and the relevant findings made from them are reviewed. The literature shows to have covered some areas in regard to the answering of research questions.

2.1. Describing the Distribution Network Planning Process and the Role of Forecasting as Part of the Planning Process

An Australian consulting company noted that planning of utility networks is about meeting customer expectations for a reliable and quality supply, while maintaining compliance to regulatory requirements, and ensuring economical and profitable operations (ADEA Power Consulting Pty Ltd, 2015).

Willis (2004) defined the planner's goals as, "to meet criteria while maximizing attributes". He defined *criteria* as, "aspects of performance that a utility wants to assure to satisfy a target of requirement", and he pointed out the service voltage as an example of criteria that the utility needs to assure that it falls within the defined limits. He further described *attributes* as "aspects of performance that a utility wants to achieve as extreme a value as possible", and he said the cost is an example of such attributes as it is always desired that it must be minimized.

Tanwar & Khatod (2015) asserted that, "the objective function of the [distribution network expansion] models is normally the minimization of economic cost function". They also state that, "the objective function of the problem formulated may be single or multi-objective problem within minimization or maximization in nature".

Different network infrastructure plans have different driving goals and objectives. The master plan presented by Aden*, et al*. (2016) highlighted its target as ensuring "the security of supply at every moment of the year for each generation mix possible". Meanwhile, Celli*, et al*. (2006) described their goal as ensuring that the "requirements on service quality and system security" are met while complying with the "constantly increasing budget restrictions" from the utility point of view.

The Georgian National Energy and Water Supply Regulatory Commission (GNEWSRC, 2016) described what entails planning on their Distribution Network Rules as ensuring that, "adequate measures [are taken] to ensure high quality and reliable power supply to customers". This statement was further broken down into the actual planning criteria for Georgia which includes these aspects: safety, reliability, quality of supply, reduction of network losses, integration of renewable generation, improvement of the environment and distribution automation. GNEWSRC (2016) enforces that every network plan must be evaluated and scored on how it performs according to the said criteria. The Georgian regulator (GNEWSRC, 2016) dictates that the planning studies shall include; load flow studies, line load optimisation, reactive power studies, losses, reliability, voltage and short-circuit current levels.

It became clear, from the reviewed literature, that the infrastructure planning process is a goal driven process that is adapted to the different utilities according to their respective goals. The planning process involves evaluating the network infrastructure against the criteria based on the existing conditions of the network and the future conditions. The latter requires a forecast to be done.

- **Role of Forecasting in Planning:**

The role of a load forecast in planning, according to Willis (2002), is to support the planning process. Willis (2002) says, "every [load] forecast must be judged by how well it supports the planning process in correctly identifying future T&D needs". Tanwar & Khatod (2015) lamented that the planner is to ensure that the forecasted load is supplied, while the reliable and economic operation of the power system is maintained.

Du, *et al.* (2007) expressed the importance of load forecasting in the planning process by saying that an, "accurate forecasting method can be helpful in developing [utility] power supply strategy and development plan". They also intimated that load forecasting plays a critical role in the utility budget allocation process. Similarly, Daneshi, *et al.* (2008)referred that, "power system planning starts with a forecast of load requirement". Adding that, the forecast carries information which is important for the expansion planning of, "generation, transmission and distribution".

Espie, *et al.* (2003) demonstrated a proposed network planning methodology showing load forecasting as an input into the process at the early stage of the process. They also demonstrated that while the planning process may be based on selected criteria for network assessment, the load forecast is an input that is required regardless of the preferred sets of utility criteria. On identifying network capacity constraints; Espie, *et al.* (2003) suggested that load growth [forecast] scenarios can be used to evaluate the network for solutions where the envisaged load is greater than the network capacity. They added that, "the consequence of the adverse [load growth] scenario is determined by performing power load flow calculations [on the network being studied]".

According to the Eskom Planning Methodology Standard (Bunge & du Preez, 2007), the load forecast plays a role of informing the planning process of the expected future changes on the demand side. This information is fed into the network evaluation tools (load flow tools) and is also used for strategic servitude and site selection for power lines and substations.

In light of the above reviewed works, the planning process can be defined as a multi-faceted approach that seeks to study the existing network infrastructure capacity against the forecasted load and proposes solutions where the network is unable to supply the load. The different utilities may use different criteria for assessing the network violations. The selected criteria may be informed by the regulatory compliance as well as utility aspirations [Willis (2004) Tanwar & Khatod (2015) Aden, *et al*. (2016) Celli, *et al*. (2006) and GNEWSRC (2016)]. The role of a load forecast in the planning process is that it is used as an input variable against which the network abilities are evaluated through load flow analysis. Therefore, the problem statements of an infrastructure development plan, as well as the solutions (network investment) are informed by the load forecast, as it supports the planning process [Willis (2002), Tanwar & Khatod (2015), Du, *et al.* (2007), Daneshi, *et al.* (2008), Espie, *et al.* (2003) and Bunge & du Preez (2007)].

The sections that follow discuss the objective functions used in multi criteria decision making, and have been selected in line with the hypothesis of this research: reliability, economics and adequacy (combines both electrification and quality of supply).

2.1.1. Network Investment Economics

Khatib (1996) defines economic evaluation of a project as a holistic evaluation of the project finances, and its economic and environmental implications. He made reference to non-financial viable projects such as rural electrification and said that they can be economic in a sense that they bring economic and social improvements to the communities being electrified. "Economic evaluation should take into account the true cost, benefits to economy and other impacts and costs such as environmental impacts" (Khatib, 1996).

Khatib (1996) and Schlabbach & Rofalski (2008) expressed that in the context of infrastructure planning, project economics is used to compare alternatives. An alternative may be declared economic when compared to another alternative by using an economics index.

The specifications by the National Energy Regulator of South Africa (NERSA), documented in the Republic of South Africa Distribution Network Code version 8 (NERSA, 2010), say that an economic investment is the one that has a least life cycle cost, meets the minimum power quality requirements according to the NRS 048 and the minimum reliability and operational requirements as stated by NERSA.

A number of methods that seek to minimise the total project cost have been documented [Willis (2004), Guillermo A, *et al*. (2010) and Hasselfield, *et al.* (1990)]. They all demonstrate a certain level of trade-off between project cost and other objective functions such as technical, environmental, social and regulatory requirements.

2.1.1.1. Distribution Network Economic Models

For an alternative to be declared more economic to another, the economic models are used. The list below contains the most common economic models used in the evaluation of planning proposals.

- **Present worth method**

"Cash inflows and outflows are converted in terms of the present value". The selection of a best alternative is based on the least Net Present Worth (NPW), which is the difference between the inflows and outflows of cash associated with such an alternative. This method is expanded upon in references: Seifi & Sepasian (2011, p. 36), Willis (2004) chapter 5 and Hidalgo, *et al*. (2011), who demonstrated the application of both the net present value (NPV) and the internal rate of return (IRR) in their case study.

In a case study by Hidalgo, *et al*. (2011), the NPV, IRR and Payback period have been used for economic evaluation of the project. They concluded that a project is economically justified when it gives a high and positive NPV, and a higher IRR than the alternative(s) it is being compared to. This is subject to all the alternatives being technically viable, meaning that they do not lead to power quality violations as well as violations of network reliability.

According to Khatib (1996), "the present value method discounts the capital and future running costs of each considered alternative to its present value using the already agreed discount rate". An NPV > 0 means that the project is profitable.

- **Annual cost method**

Cash flow (input and output) are converted into uniform annual input and a uniform annual output. The Net Equivalent Uniform Annual Cost (NEUAC) is used as the indicator when doing economic assessment. The criteria for selecting a more suitable alternative is such that the project must have a less uniform annual output as compared to its input, or, simply the least NEUAC value (Seifi & Sepasian, 2011, p. 38). Seifi & Sepasian (2011) explained that this method may be used in select instances as, "this method is especially attractive if the plans economic lives are different".

The annual cost method can be used instead of the PV method and vice versa according to the Planner's preference, as these methods will eventually show similar outcomes, asserted Khatib (1996).

- **Project Profitability Index (PI)**

The profitability index (PI) is defined as the ratio of the present value of cash inflows to the present value of cash outflows, Eskom-FEM-Model (2012).

- **Rate of return method**

Rated by Khatib (1996) as the most commonly used method for profitability evaluation, the IRR can be defined as, "the interest rate that leads to the NPV of the project to be zero; meaning that the costs and benefits of the project are equal" (Khatib, 1996).

An Interest Rate that results in the (Input Cash Flow – Output Cash Flow = Zero), is called Rate of Return (ROR). The formula is also written as (Present Worth Cost = Present Worth Benefit).

The best alternative selection criteria is where the, ROR > MAROR (Minimum Attractive Rate of Return) and where the alternative with the highest ROR is preferred (Seifi & Sepasian, 2011, p. 38).

By definition, IRR is an interest rate that would lead to an NPV of zero. Linking this to Eq. 15, this condition can be formulated in Eq. 1 (modified from Yin-Xiang (2013)).

$$\sum_{t=0}^{n} \frac{CF_t}{(1+IRR)^t} = 0 \qquad \text{Eq. 1}$$

Where:

CF_t if the cash flow at year t

IRR is the Internal Rate of Return

t is the period in years

n is the total number of years

The value of IRR for a project can be calculated using the Microsoft Excel "IRR" function.

Lefley (2018) identified that there is a general conflict with regard to the use of the NPV versus the IRR, pointing out that the two may easily give conflicting results when two dissimilar projects are being compared. NPV may be in favour of project 'A' while the IRR is in favour of project 'B'. He further stated that there may be limitations with the use of the IRR method. One of the limitations was expressed as a, "major weakness of the IRR is the basic assumption that the interim cash flows from a project can be re-invested to earn a return equal to the IRR of that project". Lefley (2018) referred that the solution to the shortcomings of the IRR method was the introduction of the modified internal rate of return (MIRR). He expressed that, "the MIRR which assumes an outflow in year zero and a single inflow in the final year is said to give more realistic results". Lefley (2018) warned that the difference in project lives for the projects being compared on the basis of the MIRR can however have a significant impact on the investment decision.

- **LCC Method**

"Life cycle cost (LCC) refers to the overall costs of equipment, systems or projects of which long-term economic benefits being considered, during the whole life cycle period in the planning, design, manufacture, purchase, installation, operation, maintenance, replacement, and finally discarding" (Luo, *et al*., 2014, p. 1140), are included in the evaluation process. The preferred alternative project selection criteria is the Least Life Cycle Cost (LLCC), as it incorporates all the stated elements.

2.1.2. Network Reliability

Willis (2004, p. 3) introduces reliability by looking at the history of power systems. He reviewed work by Abbott (1895) where the reliability was mainly focused on ensuring that the utility maximises its revenue. Each outage would then be associated with the load and revenue lost. Reliability has evolved from that initial stand point to the present, where the customer who is inconvenienced by the outage is also involved in the quantification of impact associated with reliability. Koval & Chowdury (1996) describe the value based reliability, as the one where the cost incurred by the utility to achieve reliability is evaluated against the benefit received by the customer as a result of the reliability of the supply. This is also known as "benefit to cost" evaluation. In other words, the network would need to be strengthened in order to achieve a certain level of reliability. In case of network failure, the customer incurs a cost/loss on their normal day-to-day production, which is equated to the customer interruption cost (CIC). The reliable network is the one in which the sum of these costs (utility and customer interruptions) is minimised (Koval & Chowdury, 1996). The graph on Figure **1** below demonstrates the typical relationship between the utility cost and the customer interruption cost.

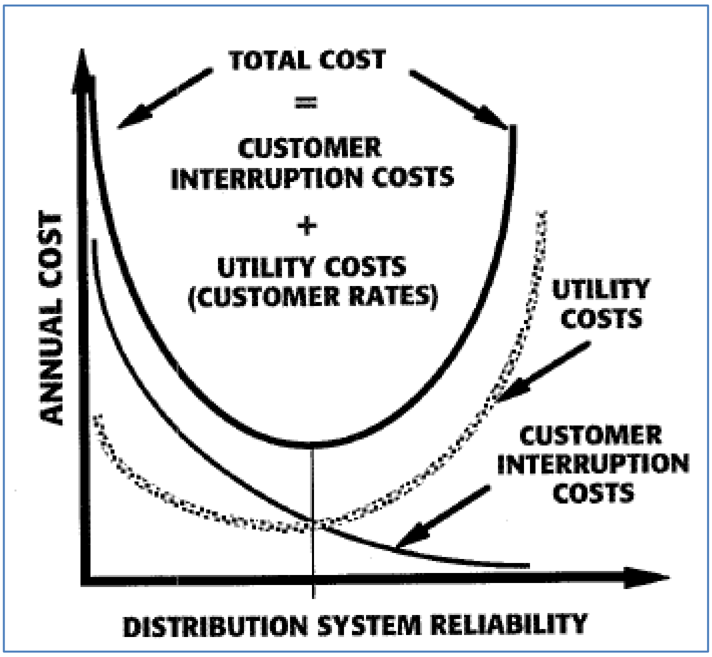

Figure 1: Reliability vs. Cost (Koval & Chowdury, 1996).

As revealed by Figure **1**, the total cost has two extreme sides where the customer interruption cost is too high and utility cost is low; as well as where the utility cost is too high and customer cost of interruption is lower. The optimum investment is the one where the "total cost" is minimum. This means that the sum of the costs (utility cost and customer interruption cost) is at its lowest.

Reliability can be categorised into two aspects:

- Customer-centric: mainly concerned about the losses incurred by the customer in case of an outage as it relates to the general customer inconvenience. It is mostly indicated as a measure of SAIDI, SAIFI, COUE (or Customer Damage), etc. These indicators are discussed more in section 2.1.2.1 below.
- Balanced perspective: normally measured by evaluating the benefit to cost ratio. Basically it answers the question, "at what cost does the utility try to avoid the customer-centric loss or inconvenience".

A number of works have been published on the subject of reliability in distribution planning. Koval & Chowdury (1996) studied the relationship between load growth and customer interruption cost, and the reliability worth. They also established and demonstrated that the customer interruption cost (CIC) is a function of a customer class. Vrey (2006) suggested the use of a GLF method to assist in calculating customer damage factors for the purpose of planning. Similarly, Brown, *et al.* (1999) performed a study where the spatial forecast method results were used to perform reliability assessments on existing and planned networks using customer points. The authors Teansri, *et al.* (2011) carried out a survey to determine the customer damages for different customers and found that the individual customer damages can be summed up using customer weightings to come up with the composite customer damage factor in any intended area of concern (study area). This was also confirmed by the Eskom Standard for Reliability that was compiled by Kleynhans, *et al*. (n.d.). Smith & Joubert (2002), Herman & Gaunt (2008), Herman & Gaunt (2010) and Kleynhans, *et al*. (n.d.)

carried out surveys and found that the CIC is a function of different customer classes, outage durations and outage frequencies.

2.1.2.1. Distribution Network Reliability Models

IEEE Guide 1366 (IEEE-Std:1366, 2012, p. 19) has indicated that there are four commonly used reliability indices: SAIDI, SAIFI, CAIDI and ASAI, as discussed below.
NRS 048-6 (2009)uses the same indices as the IEEE 1366, to evaluate and report reliability from the Regulator's perspective. Most of the indices are customer-centred, showing the fact that customer impact is part of reliability evaluation of the network.

SAIDI – System Average Interruption Duration Index
SAIDI is a function of the number of customers and the total duration of power interruptions. The IEEE guide (IEEE-Std:1366, 2012) points out that the SAIDI index is preferred, as it caters for the duration of the interruption, which is also indicative of the cost to the customer and a measure of the total cost of the interruption. According to IEEE-Std:1366 (2012), SAIDI does account for the change in customer numbers when it is calculated. The role of load forecasting is thus crucial, as the change in customer numbers may have a profound impact on the SAIDI measure, as the customers increase over time on a specific network.

SAIFI - System Average Interruption Frequency Index
SAIFI is a measure of the frequency of interruptions. In other words, it is defined as the number of interruptions that customers experience in a given period. A lower value of SAIFI indicates a better level of reliability of a network.

CAIDI - Customer Average Interruption Duration Index
CAIDI is a customer based model, as opposed to SAIDI and SAIFI that are system based. It represents the average time required to restore service (IEEE-Std:1366, 2012). The shortfall of this index is that it does not reveal the effect of the outage at the system level, but only shows the customer impact.

ASAI - Average Service Availability Index
ASAI is the duration of time that the customer has had access to electricity (IEEE-Std:1366, 2012).

The load based indices are also of importance:
ASIFI and ASIDI are both load based indices that show the frequency and duration of load interruption, respectively. ASIFI is the Average System Interruption Frequency Index, and ASIDI is Average System Interruption Duration Index. Both these indices are applicable in a network that has very few customers (a typical large power user customer point), as it would be inappropriate to use customer based indices in such a situation.

MSLI – MV Supply Loss Index
It is defined as the MV transformer unavailability indicator (in hours per month) (NRS 048-6, 2009). Similar to ASIFI and ASIDI, MSLI is a load-based indicator.

Another commonly used reliability index is the **Cost of Unserved Energy** or the cost to customer. The IEEE 1366 Guide attested that this index is difficult to calculate accurately in practice.

The reliability indices discussed above provide the basis for evaluation and quantification of reliability of the power system network. The index/indices to be used for testing the hypothesis in this research will be selected and developed further under theory development (chapter 3) to prepare for the evaluation of the network which will be performed later in chapter 4.

2.1.3. Defining Adequate Supply

This section reviews the meaning of the word *adequate* in general and in electricity utility business. Using Eskom corporate visions, the meaning of adequacy in the context of this research was described.

The Merriam-Webster online dictionary defined adequate as, 1: “sufficient for a specific requirement”, and 2: “lawfully and reasonably sufficient”.

The North American Electric Reliability Corporation (NERC, 2007)defined adequacy in power system reliability as, “the ability of the electric system to supply the aggregate electric power and energy requirements of the electricity consumers at all times, taking into account scheduled and reasonably expected unscheduled outages of system components”. They further clarified that the specifics with regards to *acceptable limits*, *acceptable performance*, *and expected unscheduled outages* are stipulated in their reliability standard.

The Eskom Distribution Division has defined its mandate as, “to service the customer, provide reliable electricity by building, operating and maintaining distribution assets, while also acting in the national interest, by actively partnering with the wider industry to resolve distribution industry issues while enhancing stakeholder relations” (Eskom, 2015).

The Corporate Business Plan for 2013/14-2017/2018 for the Eskom Distribution Wires Business outlined their mandate and strategic objectives as: reducing network interruptions, ensure quality of supply compliance (power must be delivered within regulated quality while the customer expectations are managed), grow the network responsibly (grow network capacity in a sustainable manner to supply the increasing demand, efficient capital expansion programme and effective delivery of electrification program), reduce restoration time (reduction of SAIDI and SAIFI), enable IPP connections(connection of independent Power Producers without compromising the Interconnected Power System), legislative (influence legislation that impacts the business), and: regulative (create internal regulatory environments and work with the regulator for common purpose), social (support the government’s objective of universal access to electricity) and standards.

It has been learnt from the Eskom Corporate Business Plan, that the utility, in partnership with the government have put electrification as one of their key objectives. Section 2.1.4 below deals with the aspects of electrification from the perspective of network planning.

While it is the corporate plan to connect all South African citizens with electricity, the acceptable quality of power to the customer must be complied with. The minimum and maximum voltage limits applicable in South Africa are stipulated in the specification NRS 048-2 (2007).

Similar to the description of multi-criteria decision making, the selection of objective functions and the supply adequacy in any utility area is case-specific. However, as highlighted at the beginning of this section, for the supply to be adequate, it must be sufficient to cater for the customer needs within regulated limits. In this research the adequate supply refers to the supply that caters for all citizens, in any study area, at acceptable voltage levels.

2.1.4. Electrification

According to the survey by Statistics South Africa (2016), South Africa in 1996, had poor access to electricity, with only 58.1% of its citizens having access to electricity. This number climbed to 69.7% in 2001. By this time, the South African Government introduced the Integrated National Electrification Programme (INEP) to give special attention to ensuring that all citizens get access to electricity (100% access). This was named Universal Access Plan (UAP). The INEP was first mentioned in the Energy White Paper in 1998 and came into effect in 2001, according to the presentation by Department of Energy (Barnard, n.d.).The government, via the Department of Energy (DoE), became a funder for this program and the electricity distributers (Eskom and municipalities) played the role of implementers (INEP). In 2016, 90.3% South Africans enjoyed access to electricity as they use it for lighting and other purposes, according to Statistics South Africa (2016).

Eskom (as one of the implementers of the INEP) also included electrification as a target in their Corporate Plan, in alignment with the Government (the funder) focus areas. As such, electrification is also embedded in the Eskom Network Planning Standard (Bunge & du Preez, 2007). Each network study carried out must cater for universal access to electricity in their midst.

From a technical viewpoint, the Guide to Planning and Designing of Economic and Reliable Electrification Infrastructure, emphasizes that for the adequate load modelling for the purpose of electrification of households [dwellings], "these three parameters must be described: location, dispersion and shape" (NRS 034-1, 2007). The importance of these three parameters is demonstrated in Figure **2** below.

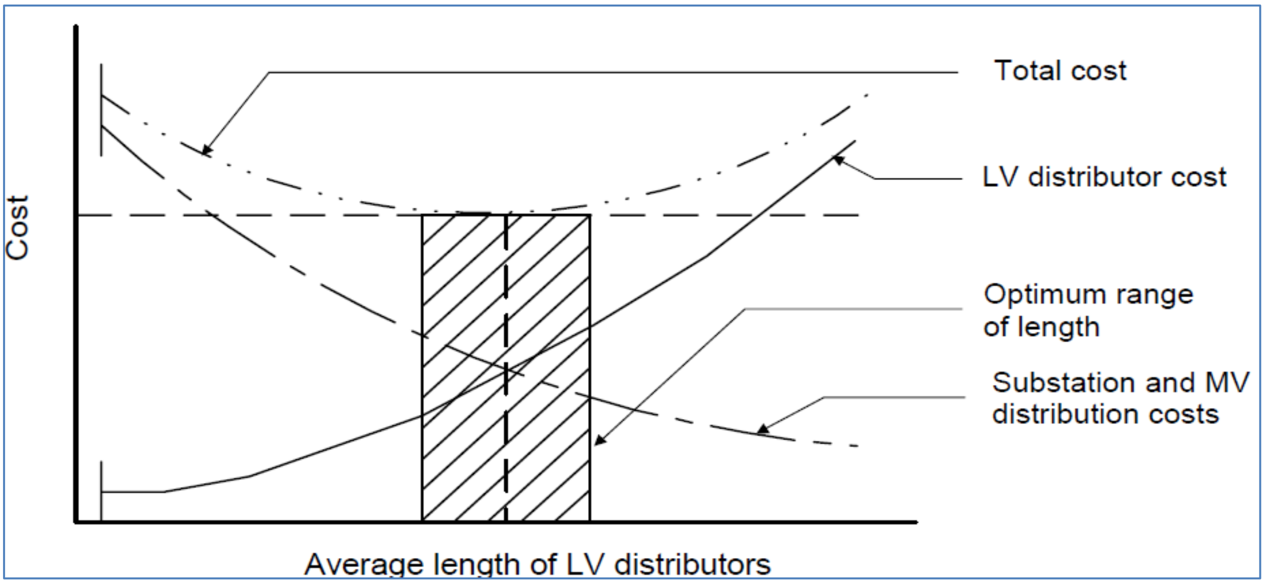

Figure 2: Cost of electrical infrastructure (NRS 034-1, 2007)

Figure 2 shows the impact on total cost with two extremes that may result from excessively long LV network design or a high cost due to inadequate MV and substation design. The optimum design is indicated by the shaded area in Figure **2**. The area where the total network infrastructure cost is lower.

Iosfin, *et al*. (2007) demonstrated the importance of economic electrification network design. They pointed out the importance of developing a spatial forecast when doing a rural electrification project. Iosfin, *et al*. (2007) confirmed that determining, among other things, the *load type*, *magnitude* and *location* is important. This is consistent with NRS 034-1 (2007). Determining the load type, magnitude and location gives the planner the ability to size and position the network infrastructure (LV and MV) optimally. Figure **3** shows a relationship between the design capacity and the associated cost.

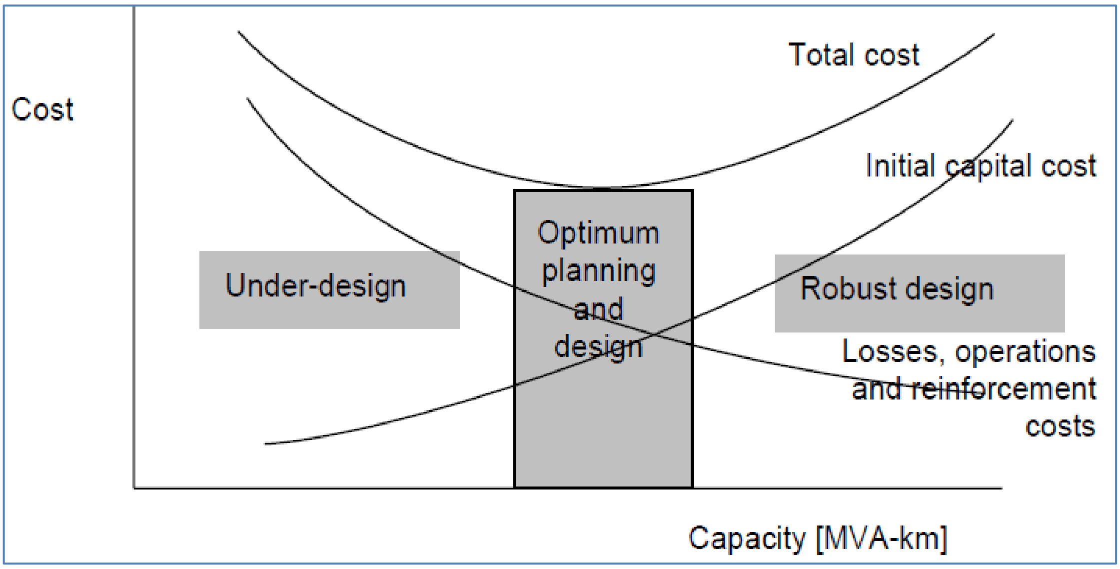

Figure 3: Capacity Design and Associated Costs. Iosfin, *et al*. **(2007)**

This relationship (Figure 3) shows that under-design and robust-design have extreme costs associated with them and the optimum total cost can be achieved by balancing these two (under-design and robust-design).

While providing access to electricity for all citizens is of importance, the provision thereof in an adequate manner is of equal importance. NRS 048-2 (2007) states that the voltage at the customer point of supply must be less or equal to 110% and greater or equal to 90% of nominal value for voltage level of less than 500V. The limits for voltages greater than or equal to 500V are +/-5% of the nominal voltage. This user specification is applicable to all electricity distributers in South Africa (Eskom and municipalities).

The work done in this research, to test adequacy, will be bounded by these two main objectives; the plan must ensure 100% electricity access while voltage variations are kept within +/-10% nominal.

Iosfin, *et al*. (2007) and NRS 034-1 (2007) have agreed on the importance of forecasting the three important load aspects: position, type and magnitude. This sentiment aligns with the description of the GLF method, which was discussed in 2.2 of this report.

2.1.4.1. Electrification Index

The objective of Eskom in partnership with the South African government has been stated as to provide access to electricity for all citizens of the country, the universal access, according to the corporate business plan for 2013/14-2017/2018 for Eskom Distribution Wires Business.

The measure of access to electricity is the percentage of connected households to the total number of households in the study area.

2.1.5. Evaluation of Network Planning Alternative Solutions for Network Investment Decision Making

Methods for selecting the best network planning alternative out of a number of candidate solutions during the planning of the network are reviewed.

Saulo, *et al*. (2010) discussed a vision driven planning approach for distribution planning. The paper shows the multi-criteria decision making planning approach in a country that has a vision (such as universal access to electricity for all citizens by 2030). It discusses how this can be done, while adhering to the regulatory requirements in terms of power quality, reliability and environment, and ensuring that the infrastructure expansion is done in an economic and financially viable manner. Thus, “the analysis and evaluation [of alternatives] are carried out with regard to network reliability, annual energy losses and environmental impact [as evaluation criteria]. The decision score for a solution depends on its performance relative to the other alternative solutions” (Saulo, *et al*., 2010).

The multi-criteria decision making method (MCDM) was also used by Espie, *et al*. (2003). They made use of *desirability scores* in order to decide on the best combination of objective functions that the utility may have chosen as their focus areas. However, Espie, *et al*. (2003) mentioned that the most contentious issue about the MCDM is the allocation of weightings of the objective functions. Adding that this must be discussed with senior planners before the weightings can be adopted as it is invariably a subjective process.

The Eskom methodology for planning, compiled by Bunge & du Preez (2007) stipulates that the method adopted by the utility for planning is via a multi-criteria decision making process. It states that network analysis aims to test compliance with the following minimum requirements: [technical] Thermal loading, Fault levels, Large Motor Starting, Non Linear Loads, [regulatory] Voltage standards, Contingency and Reliability criteria. Environmental compliance is included as part of the criteria, as it enables servitude and site acquisition, and is addressed as a separate outcome. When this methodology is followed, the preferred alternative must solve the technical network problem first and then compared to other alternatives in terms of cost (how economically viable the alternative is).

The multi-criteria decision making approach is also influenced by social objectives and by the rules applicable to the utility. Government regulations and the corporate responsibility of a Utility such as achieving 100% access to electricity by a certain year, as in the case of Kenya (Saulo, *et al*., 2010) and South Africa (Bunge & du Preez, 2007) can be used in the MCDM. Manalo & Manalo (2010) followed a case study to show the importance of incorporating the business’s corporate vision in a multi-criteria decision making model such that when the best network alternative is selected, it caters for all key business objectives and not only the technical perspective.

Georgilakis & Hatziargyriou (2015) investigates the state of the art power distribution planning models and lists a number of recent multi-criteria decision making algorithms that were released from 2004 and later. The authors discussed 77 works with deferent algorithms in their review.

According to Chicco, *et al.* (2012), “decision making problems in distribution systems generally refer to the selection of the most convenient alternative(s) to be practically operated in a given framework”. Chicco, *et al.* (2012) defined a non-dominated network solution as the one where, “no other solution exists with better values for all the individual objective functions”, and this is a balance between objective functions. They mentioned that the non-dominated solution can be derived by using a multi-criteria decision making (MCDM) tool. Chicco, *et al.* (2012) used three MCDM methods to rank the network alternatives, and they are:

> 1) Analytic Hierarchy Process (AHP): the authors expressed that this MCDM method is guided by three main levels. Level 1: defining the global goal (objective) for the decision process, level 2: the criteria for evaluation of the objectives, level 3: alternatives (solutions) to rank. Chicco, *et al.* (2012) explained that these three levels are handled by the pair comparison matrix (for partial ranking of alternatives) and the decision making matrix (which judges each solution according to its proximity to the ideal solution).
>
> 2) Technique of Order Preference by Similarity to Ideal Solution (TOPSIS) which is achieved by first modelling the *non-ideal* solution and then the best solution of the optimisation problem is one furthest from the *non-ideal* solution.
>
> 3) Decision-theory-based method which applies minimum expected value criterion (applicable where the objective function is to be minimised); minimax weighted regret criterion (where the utility wants to minimise the maximum regret) and the optimistic criteria (“applied by determining the overall minimum value of the indicator, corresponding to the best possible outcome for each scenario”).

Chicco, *et al.* (2012) concluded that all three methods resulted to the same ranking outcome when they were evaluated against each other in a case study.

While Kamble, *et al.* (2017) describe the AHP method in line with Chicco, *et al.* (2012), they further expressed that the AHP method has the capability to combine both tangible quantities and non-tangible quantities that are largely subjective. In their work, Kamble, *et al.* (2017) proposed a new method called the Analytic Hierarchy Process - Preference Ranking Organisation Method for Enrichment Evaluation (AHP-PROMETHEE). They achieved this method by modifying the AHP method such that the ranking of alternatives is performed from best to worst using the net flows as the deciding factor. It is demonstrated that, when using the AHP-PROMETHEE method, each criterion has its own matrix where the preference degrees between the alternatives is interrogated separately. It is not clear whether the proposed method is better than the existing ones or not, as the authors did not analyse the comparison results between the AHP-PROMETHEE and other methods such as the simple AHP.

Zhang & Yuan (2005) argue that there is a flaw in the decision making process for infrastructure planning which emanates from the capital cost having the possibility to mask the technical attributes that are also considered in that process. They mentioned that an alternative with better technical attributes but higher capital cost can be easily ranked lower than the one with bad technical attributes at a lower capital cost. To this end, Zhang & Yuan (2005) proposed a multi-attribute decision making (MADM) method called ELECTRE III which, they say, is widely used in Europe. ELECTRE III makes use of a "weightings and thresholds" approach to overcome the dominance of capital cost during the decision making process. However, Zhang & Yuan (2005) do concede that the weightings and thresholds are subjective and are assigned to reflect the preferences of the decision maker. "It is a contentious issue", they added. They compared ELECTRE III to another MADM method called SMART and concluded that ELECTRE III is good in overcoming the aforementioned masking introduced by the capital cost.

Ochoa, *et al.* (2006) applied a multi-objective index method for assessment of the best alternative for distributed generation (DG) to be accommodated in the network. As also highlighted by others (such as Zhang & Yuan (2005) and Chicco, *et al.* (2012)) , the authors reiterated the fact that the allocation of weights (also called relevance factors) to the indices being compared is a subjective exercise and it depends on what the utility deems important at the time. Ochoa, *et al.* (2006) presented a simple method where the ranking of alternatives is done by using the multi-objective index (IMO) as shown in Eq. 2 below.

$$IMO^k = w_1 IL_P^k + w_2 IL_q^k + w_3 IVD^k + w_4 IVR^k + w_5 IC^k + w_6 ISC3^k + w_7 ISC1^k \qquad \text{Eq. 2}$$

Where:

w_i is the assigned weighting for each technical issue (criterion),

IVD^k is the maximum voltage drop,

IVR^k is the voltage regulation (referring to minimum and maximum load conditions),

IL_P^k and IL_q^k are active and reactive power losses respectively,

$ISC3^k$ and $ISC1^k$ and three-phase fault current and single phase fault current respectively.

k is the network configuration state.

It can be noticed, from Eq. 2, that some of the terms of the equation are desired to be lower while some are desired to be higher. There is a negative proportionality that needs to be managed. For example, losses are preferred lower while the voltage regulation is preferred closer to 1 per unit of nominal voltage. To deal with this possible disjuncture, Ochoa, *et al.* (2006) expressed the losses according to Eq. 3.

$$IL_P^k = 1 - \frac{Re\{Losses^k\}}{Re\{Losses^0\}} \qquad \text{Eq. 3}$$

Where:

$Losses^k$ represents the total losses on the proposed network configuration k, and $Losses^0$ represents the original network losses without reconfiguration.

Eq. 3 removes the disjuncture between the terms of Eq. 2 that occurs when some attributes are desired low while others are desired high.

Ochoa, *et al.* (2006) noted that the indices in the multi-objective matrix must be expressed as per unit values (without dimensions) in order to make it easy to add them, and it was observed that Tanaka, *et al.* (2010) and Ochoa, *et al.* (2006) have also handled the indices the same way.

The authors; Tanaka, *et al.* (2010), Zhang & Yuan (2005), Ochoa, *et al.* (2006) and Kamble, *et al.* (2017) have all used the multi-criteria decision making method in trying to find the most optimum solution under differing attributes that are sometimes contradictory. They have shown care in allocating weights and scores to the attributes that make the basis for the evaluation of their alternatives. It is evident from these works that both weight allocation and scores can be tackled in different ways, however, it must be explained and there must consensus between the decision makers.

2.2. Geographical Based Load Forecast

The aim of this section is to describe the GLF process and also to clarify the context within which the research is done.

"Spatial forecast methods based on forecasting consumer type and density have been used since the 1930s and computerized since the middle of the 1960s" (Willis, 2002, p. 30). GLF is a technique that falls under spatial forecasting methods and is performed using a software tool called PowerGLF amongst others.

The essence of the GLF technique as reviewed from the practice document used in Eskom (see reference Hashe (2012)) is summarised below:

> The GLF technique is a derivative of spatial forecast method. It combines the land-use forecast and Gompertz-curve fitting algorithms on a small area basis. As it has been especially derived for the South African utility planning environment, the GLF technique has the so-called customer based forecast algorithm, which is a manual capturing of electrification plans and conversion into a load forecast.
>
> The customer based forecast assumes that the domestic load increases in a similar manner as shown in Figure **4** below.

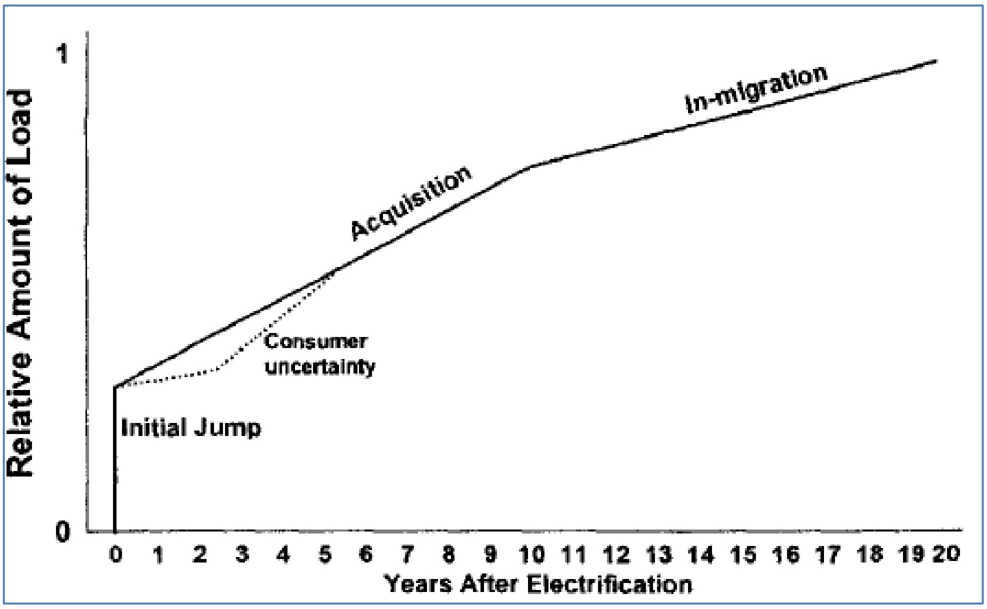

Figure 4: Customer based forecast (also called electrification forecast) (Willis, 2002).

The set of customised growth curves that align to different economic sectors and the constant percentage growth calculations are used to align the electric forecast to the econometrics study. The computer based tool called PowerGLF is used to perform the forecast. According to the review by Willis & Aguero (2007), PowerGLF is a tool mainly used to store the load forecast; the actual forecasting is performed, mostly, manually.

The spatial load forecast is defined as, "a prediction of future electric demand that includes location (where) as one of its chief elements, in addition to magnitude (how much) and temporal (when) characteristics" (Willis, 2004, p. 909). Willis (2004) pointed out that locating the load growth can be accomplished by dividing the supply area into smaller subdivisions. The GLF method includes an additional component named *what*, leaving the forecast with four components in total, they are; ***where***, ***how much***, ***when*** and ***what*****.**

2.2.1. Load Position Forecast – the "Where"

The capability to forecast the load position is one of the reasons why Eskom adopted the GLF method. This component of the GLF gives details of where the forecasted load will be situated and it makes it possible to secure sites and servitudes for the future infrastructure timeously, Hashe (2012) and Bunge & du Preez (2007) alluded. In the South African context, the development of the land is guided by the government policies through the spatial development frameworks (SDF) according to the Spatial Planning and Land-Use Management Act (SPLUMA) (Rural Development and Land Reform, 2013) .

2.2.2. Load Magnitude Forecast – the "How Much"

The forecast magnitude refers to the forecasted load size (in kVA, MVA, etc.). It is particularly important as it guides the infrastructure planning process with regard to the size of the infrastructure needed (Willis, 2004). Cartina, *et al*. (2000) stated that the load forecast magnitude is a function of customer class, the number of customers/connections, month (of the year or simply a season), day (of week) and load diversity.

2.2.3. Time Forecast – the "When"

The time component of a load forecast refers to the time indicating when the forecasted load can be expected. The load existence is with reference to time; it could be existing currently, or will be in the future. The *when* component of the load forecast is the indication of time in that sense. When viewed from the infrastructure investment planning perspective, the *when* component can be used to place orders for long lead equipment such as transformers (Willis, 2004).

2.2.4. Load Type Forecast – the "What"

The *what* component of a load forecast refers to the load type, such as domestic, commercial, etc. categories. For GLF, the load classes were developed according to their characteristics and in line with NRS 034-1 (2007) specification. Willis (2002)mentioned the consumer class forecast as one of the requirements for a transmission and distribution load forecast, and emphasised the importance of consumer classification whenever there is a study that involves "consumer side assessment". He added that consumer classification plays an important role in working out the load densities as different customer classes will have different kW/ha loads.

2.3. Legacy Method of Forecasting

The method that was used by Eskom before the GLF adoption was not structured and documented in a Standard. In this research, it has been termed the "legacy method".

To investigate the legacy method, network studies that were done during that period have been reviewed. The Polokwane North Network Development Plan[1] (Eskom Distribution, 2003) and Mokopane NDP[2] (Eskom Distribution, 2007) are referred to in this report. The referred Eskom Distribution NDP's showed that the load forecasts were done by making use of a trending method. The load forecasts were based on a constant percentage trend with reference to the history of the equipment area load (feeder or transformer area). The studies also show that customers were classified according to the main classes in order to assign different growth rates for the future years; for example, residential and industrial customers.

The former Eskom Planning Study Committee Chairman, Carter-Brown, C. [3](personal communication, 2015) described the legacy method as a "trending of feeder maximum load readings based on historical maximum demand". In addition, he mentioned that customer applications were recorded as a load forecast in this approach.

After the survey of the network planning studies that were done in absence of the GLF method at Eskom, Mokopane NDP (Eskom Distribution, 2007) and Polokwane North NDP (Eskom Distribution, 2003), the step by step guide to perform load forecasting using the Legacy Method can be summarised as follows:

---

[1] The Polokwane North Network Development Plan (PN NDP) has been chosen by the author to illustrate the approach that was used prior GLF. The PN NDP was chosen due to the fact that it has a report that details the approach rather than the presentation only. PN NDP report has been appended.

[2] This NDP was used because it also has the report and the data for historical load readings for the NDP area is accessible.

[3] Dr. Clinton Carter-Brown was the Chairman of the Planning Study Committee that was responsible for governance of technological developments in Planning. He was a planner before GLF was introduced to Eskom Planning and he was in the group that introduced GLF to Planning in Eskom.

- Collection of the historical loading data for each equipment area (feeders and transformers) in the study area.
- Identification of the industrial customer points on the network.
- Collection of the customer applications for both new supply and upgrades of existing customers and their locations (usually MV line pole numbers).
- Collection of electrification applications and their locations (usually MV line pole numbers).
- Use of the historical data to trend the forecast for existing customers.
- Use of informal information sources to decide on load growth. Information sets such as:
    - The Planner's experience of the study area – this assists the planner in vetting the trends drawn from history for suitability of application into the load forecast. Experience would also give a planner the "gut feel" with regard to the likelihood of certain customer applications/developments materialising.
    - Interviews of the local community – planners used the informal interviews to assess what the locals were expecting versus what the local authorities were planning.
- Adding the customer applications to the abovementioned load forecast.
- Diversifying the forecasted load according to the diversity factor of the equipment.

Lastly, Willis & Aguero (2007) evaluated the trending method against the spatial method (and others), and noted that it has a good short range accuracy which can be done with low labour involvement. They also highlighted that the legacy method can be of extremely poor accuracy for long range forecasts, and where historical data includes abnormal switching, cleaning the data up can take considerable time and effort. One of the stated downfalls is the fact that if the historical load is zero, the forecast will be zero as well.

It is observed that while the legacy method was chiefly based on trending of historical loading, the planner's knowledge about the area being forecasted added value to the load forecast.

2.4. Data Sources for GLF and Legacy Method

According to the Eskom GLF Standard document (Hashe, 2012), the GLF method needs the following information to be gathered for the outcomes to be performed: GIS data sets (mainly municipal and provincial data sets from policy documents and Deeds office, electrical networks, roads/streets); demographics (mainly from Statistics South Africa); electrical loading data, town planning, load classification, plans (electrification and developments). All data sets to be used as input into the GLF must be converted to digital shape files.

The legacy method was observed to be making use of the following data sets: historical loading data, customer/electrification applications, and to a limited extent, customer types, municipal integrated development plans and largely the planner's knowledge of the area were integrated into the load forecasts ((Eskom Distribution, 2003), (Eskom Distribution, 2007)).

The majority of data used for the GLF is sourced from external sources, whilst the legacy method primarily depends on the data within the utility.

2.5. Forecast Evaluation

The literature review carried out by Alfares and Mohammad (2002) to compare forecasting methods against others has cited a number of works that are critical when comparing forecast methods. The comparison discussed in this work is primarily looking at forecast accuracies and data requirements.

One of the methods used for forecast error measurement, is called the Mean Squared Error and is defined as the average of the sum-squared errors (RMSE) (Chockalingam, 2009):

$$RMSE = \sqrt{\frac{(\sum(Actual - Forecast))^2}{Number\ of\ Takes}} \qquad \text{Eq. 4}$$

Where: “Actual” refers to the measured load for a particular area being studied, “Forecast” refers to the load forecast for a particular area being studied and the “Number of Takes” is the number of data points. RMSE in Eq. 4 quantifies the difference between the load forecast and the measured load for the same area over the same period of review.

Chai & Draxler (2014) describe the bias forecast error, as the error that results from a forecaster deciding to “up” their forecast in order to, for example, send a message that more capacity is needed; meaning that there is human intervention and it is intentional.

Mean Absolute Error (MAE) is an indication of deviation between the forecast, and the actual values and it has units (like MVA in case of load forecast). See Eq. 5 that was rewritten from Chai & Draxler (2014).

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|Actual_i - Forecast_i| \qquad \text{Eq. 5}$$

Where: “$Actual_i$” and “$Forecast_i$” are the measured load and forecasted load in year “i”, respectively.

MAE and RMSE are expressed in actual dimensions of quantities for forecast and measured values. These indicators are only applicable when two or more forecast methods have been applied to forecast the same “area” and the comparison is done between the forecasts and a single set of actual values.

Willis (2002) (chapter 17) compares 19 spatial load forecasting techniques. He selected a number of aspects that he would test in order to establish the differences between the load forecasting techniques. The aspects that were selected by Willis (2002) for comparative purposes were stated to be; load forecast accuracy, load forecast applicability, data needs, and resource requirements. Each load forecast method was scored on how it performed on each aspect. Willis (2002) made the following findings:

- the average absolute value (AAV) method is not a recommendable error measure for spatial forecast evaluation. He suggested a spatial error method (U_x) that evaluates the forecast impact on infrastructure planning.
- Willis (2002) further found that the trending method does not demand as much data as other spatial forecast methods (like land-use), and it has high error and negative impact to planning than other methods (that are based on land-use).

He made a general observation that the more comprehensive methods tend to be expensive, time consuming, data intensive, but tend to be more accurate than their simpler counterparts.

Lifeng and Zhenyu (2005) compared 6 load forecasting methods in order to test a load forecasting method they developed. They compared these load forecasting methods by looking at their accuracy (how close the load forecast is to the actual measured load) using an Average Absolute Error (AAE) method. On their assessment, they found that the proposed method gives the lowest AAE error. Based on this, they conclude by pointing out that the proposed method is fit for load forecasting when there are limited computing resources. They further outlined the difference between the land-use method and the trending method. They propose to replace the land-use method as the land use method requires a lot of data as compared to the trending method, which may only require the historical loadings that are internally accessible to the utility. The datasets required for the land use based forecast are not always accessible to the utility.

Willis, *et al*. (1995) took on an assessment to examine their newly developed load forecasting tool against its potential competition. At first, the writers compared two methods quantitatively on how they perform in rural and urban areas. It was found that the simulation method is superior to the simple trending method in both rural and urban areas. However, the simulation method is more accurate in urban than in rural areas. To carry out comparison, the percentage error was calculated between the load forecast and the actual loading (deviation).

The second part of the evaluation by Willis, *et al*. (1995) examined an area that had historical load data for more than 15 years and they forecasted this area from scratch. They collected the data that was available and used it to create a load forecast. They employed the different load forecasting techniques for the same area and recorded the results. Upon coming up with different load forecasts, they compared these load forecasts to the known measured load over the evaluated 15 years. The comparison was based on a percentage deviation of a forecast from the actual recordings. Du, *et al.* (2007) used a similar method to perform forecast evaluation for their improved load forecast method. In their case, Du, *et al.* (2007) used input data of 1990 to 2000, which was used to forecast the “future years” from 2001 to 2005. In this case, their base year was 2000.

The findings by Willis, *et al*. (1995) were that, firstly, different methods perform better in different situations such as urban versus rural. Secondly, over and above the load forecast accuracy, Willis, *et al*. (1995) expressed that there are other trade-offs such as computational capability requirements and data requirements that must also be compared when determining the overall veracity of a load forecast.

One of the critical points with regard to forecast evaluation that was mentioned by Willis, *et al*. (1995) is that the land use method showed to have a higher forecast error when applied in rural areas compared to when it was applied in urban areas. This is attributed to the dispersed nature of the rural development. The proximity algorithms do not perform well when exposed to a village set up in a rural environment. This can also be the case in the South African context. The sources of information that are mostly used in the GLF are related to municipal policy documents that guide and define the development of the land in the urban areas (mostly within the urban edge).

Willis & James (1983) and Willis (2002) discussed the error associated with the location in a spatial forecast and they agreed that the locational error analysis and minimization is most important. They called it a *spatial error*. The writers claim that this error method is meant to evaluate the spatial forecast accuracy, instead of using the statistical methods that have been employed by other writers (also reviewed above). The spatial error is described as the ultimate impact that forecasting a load position incorrectly will have on the planning of the actual infrastructure. They (Willis & James (1983) and Willis (2002)) showed the relationship between the locational error and the magnitude error, and found that the higher spatial resolution tends to minimise the overall magnitude error. They recommended that for distribution planning, the accuracy of network infrastructure plans were influenced by the relative granularity of the area under review, and that smaller areas would lead to greater accuracy of such development plans.

Melo, *et al*. (2014) weighed in on the spatial error measurement and suggested that the spatial error is as a result of input data, making specific mentioning of the grouped data and aggregated data, which showed dependency and sensitivity of a spatial forecast to input data.

Willis & Aguero (2007) undertook a study to compare load forecasting methods with respect to their forecast error. They warned that forecast error evaluation at feeder level can be worsened by loading data instability that results from continuous feeder operational switching. Mostly, a feeder load forecast does not take into consideration the changes in switching. This poses a possibility of counting the network operational switching as an error as it deviates from the forecast. To alleviate the impact of switching, Willis & Aguero (2007) suggested that when the evaluation is done on a certain feeder, the immediate feeders adjacent to it must be included, as according to them, this has shown to reduce the overall forecasting error. Willis & Aguero (2007) argued that, while the statistical error calculations such as RMS and AAV methods give an idea of how the load forecast method performed, it is also critical to use spatial error correlation methods for the assessment of spatial forecast evaluation. The spatial error correlation is a measure of the locational difference between the actual development and the forecast, and not only the error in forecast magnitude.

At the end of their forecast evaluation study, Willis & Aguero (2007) made two findings:

- The first was that the GLF is more accurate than the trending method. The trending method was performed using an INSITE tool while GLF was done using PowerGLF.
- Secondly, the higher the cost (which is a combination of data requirements, complexity and need for higher specification computer processor) of the forecast application (model) used, the lower the forecast error.

This is in line with the load forecast evaluation that was undertaken by Carvallo, *et al.* (2016). GLF was found to have a lower error but higher cost of forecasting, while the trending method gave a higher error at a lower cost.

Carvallo, *et al.* (2016) reviewed a number of network planning reports that were compiled through different methods of load forecasting. They compared forecasting accuracy using the Absolute Average Value (AAV) error method. They then compared the infrastructure plans to the actual procurement outcomes. Some of the findings indicate that most load forecasts are overstated and, whilst the actual procurement does not seem to be following the actual load, it still closely follows the initially planned infrastructure. They noted that the latter finding was not expected.

Shahida, *et al.* (2014) compared three long-term forecasting methods, which are trend analysis, end-use and econometric forecasting. They found that each method has its advantages as well as disadvantages and recommended that a combination of these methods would give better and more accurate results. Shahida, *et al.* (2014) pointed out that the trend analysis method is, "quicker, simpler and cheaper, and does not require much historical load data". The authors did not comment on its accuracy. Regarding the end-use analysis, the authors declared that its shortcoming is the fact that it assumes a certain relationship between the usage of power and the end-user, which they added, will not remain the same for years to come. Lastly, they commented on the econometric analysis by saying that it provides information regarding how the various economic factors will affect the load growth. However, similar to the end-use, they complained that the econometric measures assume that future changes in economics will affect the load in similar vein to its historical past. It is observed that the comparison performed by Shahida, *et al.* (2014) is qualitative in nature.

Willis & Northcote-Green (1984) compared 14 load forecasting methods on the basis of accuracy and how they improve the planning of infrastructure. Load forecasts were performed in two areas by using different forecasting methods and the forecast results were compared to the actual load, by using statistical methods. To evaluate the planning impact of these forecasting methods, three network plans were used to compare the outcomes:

- "hindsight plan", which is a plan that was derived using the actual measured end-state load;
- "forecast derived plan", which was based on the forecasted load; and
- "modified plan", which was the network infrastructure plan required to change the forecast derived plan to be the same as the hindsight plan.

Two critical precautions were taken to ensure a fair comparison throughout; the same computer based network planning programme was used to perform planning for all cases, and the same computer based load forecasting tool was used to perform load forecasts for the thirteen load forecasting methods that were proposed, with the exception of one.

From their comparison, Willis & Northcote-Green (1984) made these findings:

- A high statistical forecast error associated with the particular method does not automatically lead to a higher negative impact of that load forecast method in planning of infrastructure.
- Few load forecasting methods yielded a high absolute average value error but a smaller negative impact to planning.
- They also expressed that the test results presented do not generally mean that there is a load forecasting method that is better than the other, adding that each method must be tested for the specific application before it can be judged suitable or not.

The findings by Willis & Northcote-Green (1984) are synonymous with those made by Rajab & Sharma (2015) below.

Rajab & Sharma (2015) compare two forecast methods. While the actual forecasting methods being studied are not related to this research, the process followed in performing this comparison is of importance. Rajab & Sharma (2015) started by discussing the similarities and differences between the two forecasting methods in aspects such as architecture, data requirements, and application. The methods were applied to forecast the stock market and the sales. Results showed that one method performed in one application while the other method outperformed it on the second application. No one method showed to universally outperform the other in both applications. The performance was based on an error evaluation using the RMSE method for both applications. Based on the presented results, neither method could be rated as superior to the other, based on the two elements that were being tested by Rajab & Sharma (2015).

Laouafi, *et al.* (2015) compared the performance of six load forecasting models by comparing their accuracy. To perform this comparison, MAPE and RMSE methods were used as indicators of accuracy. It is seen from this comparison that, Laouafi, *et al.* (2015) ensured that these models are assessed by using the same study area and under the same data availability conditions.

The study by Hossa, *et al.* (2014) evaluates medium term energy forecasting methods. They used the real life data, which presented a challenge of gaps where field data was not consistently available. Dealing with data, Hossa, *et al.* (2014), made assumptions to fill up the gaps where data was not available. They made use of calculated averages as a way to fill up these gaps. This data would then be used for all load forecasting methods being evaluated in the study. This was done to ensure data consistency.

For forecast error quantification, Hossa, *et al.* (2014) used the mean square error (MSE) and the relative error (RE) method. Both these indicators are expressed in energy demand units and not percentages, as it is the case with other indicators. The forecast with the lowest error was then declared superior to others competing with it.

Minhas, *et al.* (2017) undertook a study to evaluate the performance of their forecasting algorithm. The authors demonstrated due diligence in ensuring that the performance evaluation was fair by;

1) Applying their algorithm to the same area as the other method being tested against it,

2) Splitting the different days according to their daily power consumption characteristics.

This was to ensure that "like gets compared to like" for the evaluation to be fair for both forecasting methods being evaluated. In addition to the commonly used MAPE, Minhas, *et al.* (2017) also used probability distribution curves to show and analyse the forecast error.

Tsekouras, *et al.* (2003) developed a load forecasting method which relies on the data mining procedures and the correlations between the selected variables that are used to perform the forecast. They called this proposed method a hybrid non-linear regression method. Tsekouras, *et al.* (2003) compared the performance of the proposed method to two other methods called simple regression and multiple regression models. The comparison was carried out by using MAPE as one of the indicators. Two cases were used to perform the evaluation; domestic load and industrial load areas. In the domestic load case study, the proposed hybrid non-linear regression method showed superior performance against the other two methods. However, in the case of the industrial area the following outcomes become apparent;

- Firstly, the comparison results are not shown for all the three methods, one of them was not shown.
- Secondly, the proposed hybrid non-linear regression method does not outperform the multiple regression method in all evaluated areas. It is not discussed on the paper as to why the second test case does not encompass all the forecasting methods as was done in case one.

The most common method of evaluating a forecasting method is to make it compete with another method, especially the one you are aiming to replace or improve. Though a number of references have evaluated load forecasting methods based on how well/badly they have predicted the load, some work has been done to take this evaluation further than just measuring the forecast accuracy. Spatial accuracy is one of the examples that go beyond only getting the numbers right. Evaluating the impact on the network procurement is another one. These outcomes form the basis on which this research is aiming to expand upon. In this research, the forecast evaluation will also incorporate the load forecast impact on planning and procurement of network infrastructure, as well as impact on power quality of supply.

2.5.1. Using the Rubric Method for Evaluation

Rubrics have been used in education assessments. According to Mertler (2001), “[rubrics] are a form of scoring instrument used when evaluating student performances or products resulting from a performance task”. Mertler (2001) states that there are two types of rubrics; the holistic rubric and the analytic rubric. They further expressed that the holistic rubric is normally used to assess a single dimensional issue while the analytic rubric is for application in an evaluation consisting of multiple dimensions. They highlighted that the analytic rubric is more detailed in a way the information is presented when compared to the holistic one. The scoring system can be qualitative or quantitative when using rubric method, it depends on the application at hand (Mertler, 2001). Mertler (2001, p. 3) presented detailed “steps [to be followed] in the designing of scoring rubrics”.

Moskal (2000) says that, “scoring rubrics are typically employed when a judgement of quality is required and may be used to evaluate a broad range of subjects and activities”. The author explains that the use of a rubric removes the subjectivity that may arise from the evaluator when different evaluators are examining essays, as the essays are typically open to subjective assessments. “By having a description of the characteristics of responses within each score category, the likelihood that two independent evaluators would assign the same score to a given response is increased” (Moskal, 2000). They call this concept “rater reliability”.

Mertler (2001) and Moskal (2000) suggested a checklist method as one of evaluation methods that can be used instead of rubrics. However checklists are not as flexible as the rubrics, as they are “limited to the determination of whether specific criteria have been met”, added and Moskal (2000).

Care must be exercised when selecting the criteria and scoring in rubrics to ensure that there is no overlap between the criteria being evaluated (Moskal, 2000). The overlap can lead to skewed results such as “unintentionally severely penalising the student” for the same mistake (Moskal, 2000).

2.6. Effect of Load Forecast Error on the Procurement and Construction of Network Infrastructure

The expectation is that, the infrastructure procurement should follow the infrastructure plan which is based on a load forecast. According to the Eskom Planning Methodology (Bunge & du Preez, 2007), the load forecast paves a way for the infrastructure plan, which then gets constructed to ensure continuity of supply to the envisaged load. Therefore, a positive deviation (error) of a load forecast from the actual load would be expected, at the very least, to lead to an over-planning (planning more infrastructure than actually needed) and, the ultimate construction of the excess capacity. This scenario was observed to have happened in a number of case studies surveyed by Carvallo, *et al.* (2016), where the over-forecast led to over-planning and therefore over-procurement. Their analysis showed no relationship between forecast accuracy, and the accordant accuracy of infrastructure procurement and construction. The infrastructure procurement largely followed the initial plan regardless of the error of a load forecast.

Engel & Dyson (2017) found that, on average, network planners have overstated their load forecasts. They also alluded that, "today, as a result of poor forecasting in past decades, U.S.[United States of America] electricity customers are spending billions of dollars each year for power plants they don't need because they were built to serve electricity demand that never materialized" (Engel & Dyson, 2017). They stated that over-forecasting was not an issue in the past, as the load would still materialise, albeit a few years later. The changing customer behaviour (most declining consumption patterns) make over-forecasting more costly to the utility going forward, Engel & Dyson (2017) asserted.

Shahida*, et al.* (2014) explained that, "the future generation and distribution is influenced by an accurate long term forecast".

Regarding the effect that the load forecast error has on infrastructure planning and construction, Laouafi, *et al.* (2015) specified that, "overestimation of future load, results in excess supply". They further explained that, "underestimation of load leads to a failure in providing enough reserve and implies high costs in peaking unit".

To test the impact that the load forecast accuracy has on the planning of the distribution infrastructure, Willis & Northcote-Green (1984) presented a method that used the "hindsight" infrastructure as a point of reference to which other distribution infrastructure plans were compared. The "forecast based" infrastructure plans were compared to the hindsight plan and the larger deviations were taken as an indication of poor performance of a load forecast method in improving infrastructure planning.

Another method for testing the load forecast accuracy impact on the planning and procurement of infrastructure is presented by Carvallo, *et al.* (2016), where the constructed infrastructure was compared to the initially planned infrastructure in order to evaluate the deviation between the two. The methods used by both Willis & Northcote-Green (1984) and Carvallo, *et al.* (2016) can be applied, based on the data availability as well as the computing capability that the researcher has access to.

Most of reviewed works suggest that the over-forecast is likely to lead to over-planning that would result to over-procurement and construction, a view that Willis & Northcote-Green (1984) do not share. Willis & Northcote-Green (1984) found that there is no direct correlation between the load forecast accuracy and the infrastructure procurement. Their evaluation was done using a hypothetical hindsight network, as discussed above.

The two methods used to test the impact of a load forecast on infrastructure procurement and construction, are the *hindsight* method presented by Willis & Northcote-Green (1984) and the use of *actuals* that was presented by Carvallo, *et al.* (2016).

2.7. Legacy Method versus the GLF Method: Summarised Characteristics

Based on the review of the collected information discussed under the GLF (section 2.2) and the legacy method (section 2.3), Table **1** below presents a simplified comparison between these load forecasting methods

Table 1: Critical aspects that differentiate the legacy method from the GLF method

Aspect	**GLF**	**Legacy**
Forecast horizon	Flexible up to 20 years	Flexible, has been used for 20[4] years' forecast
Smallest area of application	Typically smaller than an MV feeder (load cells)	Normally an MV feeder
Level of forecast aggregation	National system level	National system level can be achieved through collaboration of spread sheets
Data input	Spatial datasets	Historical loading data
Software requirements	PowerGLF software	Microsoft Office Excel
Computing requirements	Requires servers due to large data sets	Requires Microsoft Office enabled computer as Microsoft Excel spread sheets are used
Presentation of forecast results	Load growth graphs and spatial maps	Load growth graphs
Method of forecasting	Small area method	Feeder trending method
Load classification	Forecasts based on load subclasses	Forecast growth according to feeder history

As can be seen from Table **1** above, the legacy method and the GLF are far apart from each other with regard to data aspects and computing. As indicated, these methods are discussed in detail earlier in this report.

2.8. Reflecting on Research Questions

The reviewed literature has paved a way towards answering the research questions that are listed under section 1.3 of this report. The extent to which the literature has gone in trying to answer the research questions is summarised below (each research question has been rewritten for ease of reference):

- *Describe the distribution network planning process?*

[4] The for the Windmill Area Network Development Plan (Eskom Distribution, 2005) and the Mokopane Network Development Plan (Eskom Distribution, 2007) that are later used as sources of data in this report are both based on 20 year legacy method forecasts.

The planning process was described as a multi-faceted approach that seeks to study the existing power system network infrastructure capacity against the forecasted load and proposes solutions where the power system network is found not being able to supply the load. The different utilities may use different criteria for assessing the power system network violations. The selected criteria may be informed by the regulatory compliance as well as utility aspirations [Willis (2004) Tanwar & Khatod (2015) Aden*, et al*. (2016) Celli*, et al*. (2006) and GNEWSRC (2016)].

- *What role does the load forecast (GLF or LM) play in the distribution network planning process?*

The role of a load forecast in the planning process is that it is used as an input variable against which the power system network abilities are evaluated through a load flow analysis. Therefore, the problem statements of an infrastructure development plan, as well as the solutions (network investment) are informed by the load forecast, as it supports the planning process [Willis (2002), Tanwar & Khatod (2015), Du, *et al.* (2007), Daneshi, *et al.* (2008), Espie, *et al.* (2003) and Bunge & du Preez (2007)]

- *What are the key differences between the legacy method and GLF method?*

GLF method is a spatial based load forecast method with emphasis on load position, while the legacy method is network based and is built on historical load trending and the planner's knowledge about the study area.

- *What is the cost associated with performing each load forecast method?*

It has been discussed that the GLF technique is performed using a special software called PowerGLF, and it uses GIS data – meaning that raw data needs to be converted into a GIS format for use. The legacy method uses Microsoft Excel as a tool, and no specific data format required. GLF is understood to be more expensive, complex and data intensive than the trending method.

- *Does one load forecast method have an innate forecast accuracy over the other?*

GLF has been said to be more accurate than the legacy method, particularly in long range planning. Due to its trending nature, the legacy method is expected to be accurate in a short term forecast (Willis & Aguero, 2007). However, this is not conclusive as the legacy method is also based on the planner's knowledge, and not only refers to trending methods. Some works have alluded that no one load forecasting method can be declared more accurate than the other, as it all depends on the application and each case must be judged on its merit ((Rajab & Sharma, 2015), (Willis & Northcote-Green, 1984)).

- *How is the load forecast error measured?*

The load forecast error is a measure of how far the forecasted values are from the actual measured values. AAV, Ux, RMS, MAPE and other statistical error measures (inverse which is accuracy) have been found through a literature survey ((Chockalingam, 2009), (Chai & Draxler, 2014), (Willis, 2002)). These measures give an indication as to how accurately the forecast method predicts the load.

- *On what basis (matrix) is the adequate, reliable and economic network from each load forecast method compared?*

In section 2.1.5 of this report, it was found that the MCDM gives objective balance between the utility's vision, regulatory requirements (including environmental), technical requirements and economic requirements when comparing more than one project alternative. A number of MCDM models were also discussed ((Espie, *et al*., 2003), (Chicco, *et al*., 2012), (Kamble, *et al*., 2017)). In this research, the objective functions were chosen to be reliability, adequacy and project economics.

- *How does the load forecast accuracy by GLF and legacy method affect the infrastructure procurement and construction?*

Previous assessments have shown that the over-forecast leads to over-procurement and over-construction. The procurement seems to ignore the actual load growth and it follows the initial load forecast ((Engel & Dyson, 2017), (Shahida, *et al*., 2014), (Laouafi, *et al*., 2015)). However, a viewpoint conflicting this assertion was presented. The opposing viewpoint suggests that there is no correlation between the load forecast error and the impact on infrastructure planning and procurement (Willis & Northcote-Green, 1984).

2.9. Conclusion

The legacy method has been reviewed by collecting the steps that were followed as a norm in performing load forecasting at Eskom prior to GLF and there is no published work that replicates this method. The key differences between these two load forecasting methods have been discussed.

The literature has presented a few techniques that are used to evaluate the performance of a load forecasting method. The methods used for evaluating the impact of a load forecast on the planning and procurement of the network infrastructure have been reviewed together with results from previous similar assessments.

While the literature could not be expected to address the hypothesis entirely, it has assisted in setting up a series of expectations regarding the outcomes of this study and also presented usable test methods from previous studies.

3. THEORY DEVELOPMENT

This chapter defines the formulas and relationships that will be used as a theory base for the test to be carried out in the next chapter.

3.1. Adequacy, Reliability and Economic Assessment Matrix

For assessing multiple objectives of the project, the literature suggested a multi-criteria decision making (MCDM) method (Espie, *et al*. (2003), Chicco, *et al*. (2012), Kamble, *et al*. (2017), among others).

For this research, the MCDM will consist of adequacy, reliability and economics (also referred to as ARE) as the criteria. The desirability scores will be used to assess and compare the power system network plans from the GLF based network planning study and the legacy method based network planning study.

Weightings justification: the weightings were allocated to each criterion according to the order of importance – refer to Table **2** for allocated weightings. The weighting scale of 1 to 10 was adopted. 1 shows the least importance of the criterion while 10 shows higher importance. The allocation of weights is relative in that, the weighting of one criterion is allocated in comparison to the others in the matrix. Also, it must be noted that weightings are case specific and not universal. For another utility, for example, in a developed economy, the MCDM attributes and weightings would be different from the ones shown in Table **2**.

The approach to the weight allocation is such that, the government and utility priorities have been rated higher than other attributes. These are followed by regulatory requirements in terms of quality of supply and reliability. The economic attributes have been ranked lower compared to the aforementioned attributes. While the economic solutions are sought, the project must prioritise the government and utility priorities first and ensure regulatory compliance in terms of quality of supply and reliability.

It was discussed in the literature review, that a utility together with the government are working towards ensuring 100% access to electricity for all its citizens. This is to ensure socio-economic emancipation for all South Africans. This has therefore been declared to be of higher importance than the other aspects in the MCDM. In a scale of 1 to 10, it has been given the weight of 9. This means that, for a power system network strengthening study being carried out in any study area, the infrastructure plan must accommodate the electrification of all citizens in that study area (100%). The voltage quality is important, more so as it caters for the customer needs in terms of the quality of supply and it is regulatory requirements. It has been assigned a weight of 8.

The power system network reliability is, similar to the power quality, a regulatory requirement that also protects the utility customers from poor supply reliability. For this reason, it has been given the same weight as the voltage quality which is 8. The initial intention was to represent the reliability with two attributes in the MCDM; however, the only data available for the case studies (discussed in chapter 5) was the Cost of Unserved Energy (COUE). For this reason, only the COUE was used to represent reliability. To ensure that there is consistency in the number of attributes per criterion, the COUE was weighted as two attributes of 8 each, which gave it an overall weight of 16.

Lastly, the economic weight was assigned the lowest rating within the group. The decision was based on the fact that, although it may be important to have projects that are financially viable, in the case study that will used in this research, the project would not get blocked based on the financial viability, but the *inadequacy* would lead to the project being blocked if not complied with. Also, the economics is less critical than the compliance with reliability. Therefore, the criteria followed in this study are that a power system network alternative must be adequate, reliable and economic, in that order (ARE network).

The "ARE" network criteria: As a general rule, each criterion was broken down into two indicators. However, the unavailability of data led to only one indicator being used for reliability, the COUE. The adequacy, as defined in the previous chapter, has two aspects to it, viz. the power quality aspect and the universal access plan for electrification. Table **2** shows the MCDM matrix that will be used to test the hypothesis.

Table 2: MCDM weightings

Criteria		**Weight**
Adequacy	Electrification Coverage	9
	Voltage Quality	8
Reliability	COUE	8*2
Economics	Project Profitability Index	5
	Modified Internal Rate of Return	5

The makeup of each objective on the MCDM presented in Table **2** is discussed in the following sections.

3.2. Network Adequacy

As described in the literature, adequate power system network shall be regarded as the one that addresses the universal access of the community to electricity (the one that promotes access of electricity to all) at the acceptable level of power quality.

The measure of access created is the number of connections catered for by the network infrastructure plan, and the supply quality refers to voltage levels as measured against NRS 048-2 (2007). The concept is depicted in Figure **5**.

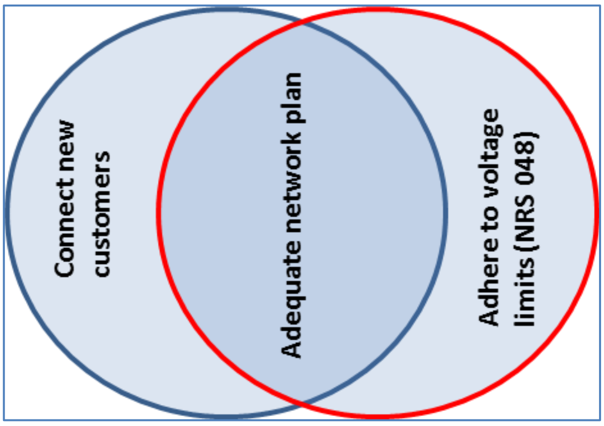

Figure 5: Adequate network concept

For the power system network to be adequate, it must have both aspects of connecting new customers, whilst adhering to the voltage limits. The area where these two intersect represents the adequate plan that is shown in Figure **5**.

The electrification coverage which is a measure of how many households have been catered for by the strengthening study as a percentage of the total households (backlog) without electricity in the study area was chosen as one aspect of adequate power system network.

$$\%connections = \frac{Number\ of\ Connections\ Planned\ for}{Total\ Number\ of\ Households\ Backlog\ in\ the\ Study\ Area} \times 100\% \qquad \text{Eq. 6}$$

Where:

- Number of Connections Planned for = number of household connections that the network plan (either GLF based or legacy method based) has planned for.
- Total Number of Households Backlog in the Study Area = number of households as reflected in the Statistics South Africa (Stats SA) in the study area, that do not have access to electricity.

The electrification measure can be used in areas with large number of electrification and in areas where there are fewer houses without electricity, it is not biased towards a certain situation, hence the use of a percentage and not actual numbers.

3.2.1. Using the Rubric Method for Electrification Evaluation

In absence of the actual numbers of electrification that can be plugged into Eq. 6 above, a rubric scoring method can be used. The rubric (discussed in section 2.5.1 of this report) can be used to evaluate how the network development plan or master plan covers the aspect of electrification. The rubric scores will then be used instead of the actual electrification statistics.

The rubrics are especially applicable in a scenario where the actual numbers are not available as, “they support the examination of the extent to which the specified criteria has been reached”, and “they provide feedback to students concerning how to improve their performances”, they are descriptive in nature (Moskal, 2000).

Following the process presented by Mertler (2001, p. 3), the "steps [to be followed] in the designing of scoring rubrics", the following rubric is proposed.

Step 1: Task objectives: the objective is to compare two studies, one based on GLF forecast and the other based on LM forecast, on how they cover electrification.

Step 2: Attributes: the following attributes will be scored

- Electrification assumptions presented by the study
- Sources of information used for electrification forecast
- Activities undertaken to perform the electrification forecast

Performing the steps 3 through to 7 as presented by Mertler (2001, p. 3), the rubric shown in Table 3 was developed.

Table 3: Rubric for electrification evaluation

Question	**Insufficient/Not evident (Score=1)**	**Sufficient (Score=2)**	**Good (Score=3)**
Electrification assumptions comprehensive?	No information presented about electrification	Information presented takes into account all existing electrification applications	Information presented shows scientific methods of forecasting electrification needs
The sources of information used for electrification forecast.	No sources of information shown or discussed in the study report.	Basic electrification backlog from the municipality was used.	Advanced methods that go beyond the known municipality applications were used.
Activities undertaken to perform electrification forecast.	No activities evident towards electrification forecast	Direct addition of connection applications from the municipalities/ customers/ tribal authorities	Scientific (such as statistical) or other means of comprehensive predictive algorithms are presented.
Sub-Total			
Total			

Each study will be evaluated and scored in accordance with the rubric in Table 3 and the total scores (per study) will be populated in the MCDM matrix against the respective study. The studies in question are the GLF based power system network study and the legacy method (LM) based power system network study.

3.2.2. Voltage Level Evaluation Matrix

Voltage level was chosen as an additional indicator of power system network adequacy. This is done in order to cater for the quality of supply inclusion. The voltage level in this evaluation will be shown in line with NRS 048-2 (2007) which allows voltage levels to be -10% (minimum) and +10% (maximum) of nominal voltage. 100% of nominal will be awarded a score of 100, which decreases as you move towards the lower and upper limits. Any voltages out of the said limits will be given a score of zero. Figure **6** below shows how the scores vary as the voltage level changes from 100% to 90% and 110%.

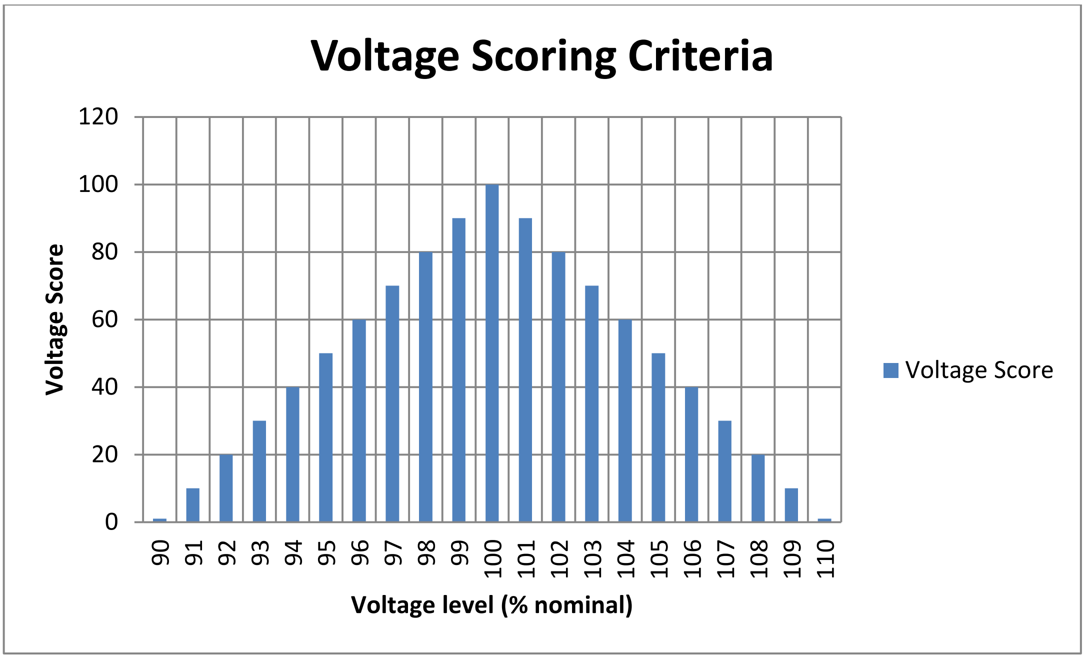

Figure 6: Voltage level scoring criteria

The relationship in Figure **6** can be represented mathematically as follows.

$$Volt\ Score = 10\ VoltLevel - 900, \{91\% \leq \text{VoltLevel} \leq 100\%\} \quad \text{Eq. 7}$$

$$Volt\ Score = -10\ VoltLevel + 1100, \{100\% \leq \text{VoltLevel} \leq 109\%\} \quad \text{Eq. 8}$$

$$Volt\ Score(90\%) = 1, \{\text{VoltLevel} = 90\%\} \quad \text{Eq. 9}$$

$$Volt\ Score\ (110\%) = 1, \{\text{VoltLevel} = 110\%\} \quad \text{Eq. 10}$$

$$Volt\ Score = 0, \{\text{elsewhere}\} \quad \text{Eq. 11}$$

Where (referring to Eq. 7 to Eq. 11):

"Volt Score" is the score to be associated with a voltage level as measured on the network,

"Volt Level" is the voltage on the network in percentage of nominal voltage

Eq. 7 and Eq. 8 show a linear relationship between the voltage level (in % nominal) and the voltage score. This relationship was calculated using Microsoft Excel software to cater for voltage levels that are not shown in the graph (Figure **6**). An example of such voltage level is 95.75%, which cannot be read directly from the graphs. The limits applicable to each equation are introduced to ensure that the voltage levels lower than 90% are regarded as an unfit solution, and therefore will be allocated a score of zero. This is done to ensure that all network strengthening solutions remain within the NRS

048-2 voltage level limits. If the voltage level of the proposed network strengthening plan is at the extreme limit (lower or upper), the matrix is designed such that it will get a score of 1. Eq. 11 alludes to the fact that voltage violating solutions shall be awarded a score of zero. The volt score value associated for a network strengthening plan will be used in the MCDM matrix (Table 5) next to the "voltage quality" criteria.

3.3. Network Reliability

The cost of unserved energy (COUE) also known as customer interruption cost (CIC) by Koval & Chowdury (1996) and customer damage by Teansri, *et al*. (2011), among others, was chosen to represent reliability assessment in the MCDM matrix. The cost of unserved energy is an indication of cost incurred by the customer and impact to economy in case of an outage, and it is a good indicator of the impact of the load and the duration of outage. The FEM model (Eskom-FEM-Model, 2012) uses two outputs to indicate a decision regarding project reliability assessment; the weighted cost of unserved energy (denoted as COUE) and the breakeven cost of unserved energy (BECOUE).

The parallels can be drawn between the FEM model and the description by Koval & Chowdury (1996) as cited under the literature, "the value based reliability as the one where the cost incurred by the utility to achieve reliability is evaluated against the benefit received by the customer as a result of the reliability". The proposed reliability evaluation model for this research compares the *cost of unserved energy* (COUE) to the cost that the utility must incur in order to safeguard the load at risk. The utility capital cost per kWh load served by the distribution network is termed *break even cost of unserved energy* (BECOUE). While the literature differed in actual values of the COUE, it largely suggested that the COUE values vary according to the customer classes [Smith & Joubert (2002), Herman & Gaunt (2008), Herman & Gaunt (2010) and Kleynhans, *et al*. (n.d.)]. In line with the literature, the FEM model has a library for COUE values per customer class. According to the FEM model user's manual instruction, the values of COUE for different load types in FEM are based on surveyed information. The COUE per customer class gets updated annually on the FEM library. Table 4 shows the FEM library for COUE values in 2012.

Table 4: COUE values per customer class. Source: Eskom-FEM-Model (2012)

Customer Class (C. Class)	**Energy Mix$_{C.Class}$ (%)**	**COUE$_{C.Class}$ (R / kWh)**
Industrial / Mining	%	**R 27.58**
Commercial	%	**R 21.48**
Agricultural / Rural	%	**R 6.31**
Residential	%	**R 3.13**
Traction	%	**R 1.69**
Percentage Check (must be 100%)	**100%**	

The COUE per customer class values shown in Table 4 are then used to calculate the weighted cost of unserved energy for the complete study area. The weighted COUE for the study area is calculated using Eq. 12:

$$COUE = \frac{\sum_1^n Energy\ Mix_{C.Class} \times COUE_{C.Class}}{100} \qquad \text{Eq. 12}$$

Where:

COUE is the weighted cost of unserved energy in the study area;

n is the number of customer classes under the study area;

Energy $Mix_{C.Class}$ is the percentage portion of a specific customer class. The portion of each customer class in the study area depends on the load composition for that study area;

$COUE_{C.Class}$ is the value of the cost of unserved energy associated with the specific customer class.

Using FEM, the weighted COUE for the study area is compared with the BECOUE, which is calculated using Eq. 13:

$$BECOUE \ = \ cost\ p.a./expected\ energy\ not\ served\ p.a \qquad \text{Eq. 13}$$

Where: *cost p.a.* (*cost per annum*) refers to the reliability capital expenditure over the 25 year power system network equipment lifecycle in Rand and the *expected energy not served p.a.*(per annum) refers to the load that would be affected by the outage if the power system network does not have redundancy and is expressed in kWh. The *expected energy not served p.a.* is made up of the load existing in the base year as well as the forecasted load in a particular study area.

The FEM model compares the BECOUE to the COUE such that; if BECOUE is less than the COUE, then the reliability project is justifiable, but if not, then the project in question is not justifiable (Eskom-FEM-Model, 2012). This comparison is normally carried out between two or more power system network investment alternatives in order to get to the one that is better than the others.

The example result of a typical cost-benefit analysis using FEM model is presented in Figure 7 below. The values are only hypothetical and are not based on the real power system network.

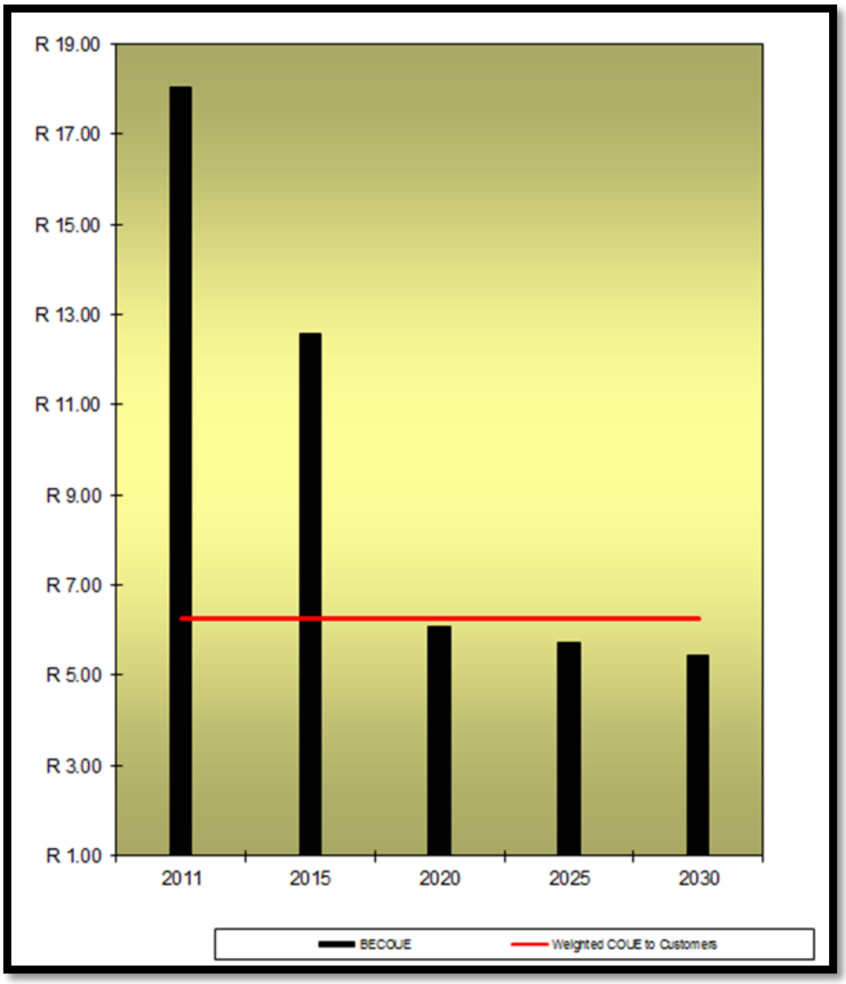

Figure 7: A plot of BECOUE and COUE. Hypothetical values used for demonstration only.

The graph in Figure 7 shows a constant weighted COUE value for a selected study area which is reflective of the load mix in that area and the decreasing BECOUE. The BECOUE typically decreases over the forecast period if the load in the study area concerned is forecasted to increase. This means that the denominator of Eq. 13 increases. This specific "hypothetical" case can be interpreted as follows regarding the reliability cost-benefit results. The proposed reliability strengthening is not justifiable in years prior to 2020 (approximately); it is only justifiable from year 2020 onwards. In other words, the favourable condition of "BECOUE<COUE" takes place from the year 2020 onwards.

It must be noted that both the BECOUE and COUE are expressed in Rand per kilowatt-hour (R/kWh) and they may vary according to the size of the load and the infrastructure investment in the study area. This situation makes it difficult to compare two dissimilar study areas as performed later in this report. To ensure consistency in comparison of reliability assessment results from the two studies, one forecasted using the GLF method and the other forecasted using the legacy method, the percentage difference between BECOUE and COUE will be used instead of the actual values with units. For this percentage difference calculation, Eq. 14 is introduced.

$$Sensitivity = \frac{COUE - BECOUE}{COUE} \times 100\% \qquad \text{Eq. 14}$$

With Eq. 14 being dimensionless, it becomes possible to evaluate two dissimilar power system network reliability investment decisions of different sizes, and compare the results accordingly.

The introduction of Eq. 14 above will also help to deal with the disjuncture caused by the concept of negative desirability. In the literature, Ochoa, *et al.* (2006) used Eq. 2(page 29 of this report) as an MCDM. As it is noted in section 2.1.5, not all attributes of the MCDM have a positive desirability. To close such a gap, Ochoa, *et al.* (2006) introduced the second equation that would then change the sign of the negative desired attributes into positives and therefore enable them to be used in the MCDM matrix, that they introduced Eq. 3. Adapting this approach to this study would lead to the following: If the COUE is less than the BECOU, the sensitivity in Eq. 14 will give a negative sensitivity percentage value and that means the reliability project is not justifiable. However, in a case where the two projects being compared against one another both have positive “sensitivities”, then the one with the highest % value will be more desirable than the other. The bigger the positive sensitivity value means that the viability of that project over another is preferred.

Therefore Eq. 14 makes the reliability desirability to be a positive one in nature. . Therefore, the value of sensitivity will be used directly in the MCDM as a score.

3.4. Network Economics

Using ideas drawn from Hidalgo, *et al*. (2011), where NPV, Internal Rate of Returns (IRR) and the payback period were used as economic indicators in a project economic evaluation, this research has adopted the indicators; Project Profitability Index (PI) and the Modified Internal Rate of Returns (MIRR) as the criteria for economic evaluation. The choice of these two indicators was also informed by the fact that they are significantly different from one another. The PI reflects the project profitability for each Rand that is spent on that project, while MIRR reflects the rate of returns that will get the project to break-even and also relates to the project payback period. Also, both these indicators are per unit values which make it easy to compare projects from different areas and different capital sizes. These indicators have a positive desirability score contribution.

In line with the approach used by Hidalgo, *et al*. (2011), FEM calculates the project profitability index using Eq. **15** and Eq. **16**:

$$PI = \frac{Cash\ inflows}{Cash\ outflows} \qquad \text{Eq. 15}$$

$$PI = \frac{\sum_{t=0}^{n} \frac{CIF}{(1+r)^t}}{\sum_{t=0}^{n} \frac{COF}{(1+r)^t}} \qquad \text{Eq. 16}$$

Where:

CIF is the project cash inflow

COF is the project cash outflow

r is the interest rate

t is the period in years

n is the total number of years

Yin-Xiang (2013) and the FEM model manual (Eskom-FEM-Model, 2012) highlighted disadvantages with the use of the IRR method to evaluate the economic viability of a project. Hence the FEM model adopted the modified rate of return (MIRR) method.

Giordani, *et al*. (2017): presented Eq. **17** to demonstrate the MIRR

$$\sum_{y=0}^{n} \frac{NCF_y}{(1+R_f)^y} = \frac{\sum_{y=0}^{n} PCF_y (1+R_i)^{n-y}}{(1+MIRR)^n} \qquad \text{Eq. 17}$$

Where (Giordani, *et al*., 2017):

NCF_y = negative cash flow in year y

PCF_y = positive cash flow in year y

y = year

R_i = reinvestment rate

R_f = funding rate

n = number of cash flow periods

Replacing terms of Eq. **17** with words as described by Lefley (2018), Eq. **17** can be rewritten as Eq. **18**.

$$Negative\ Cashflow(financing\ rate) = \frac{Positive\ Cashflow\ (investment\ rate)}{(1+MIRR)^n} \qquad \text{Eq. 18}$$

Then,

$$(1+MIRR)^n = \frac{Positive\ Cashflow\ (investment\ rate)}{Negative\ Cashflow(financing\ rate)}$$

Multiply by $1^{1/n}$ on the left and right,

$$(1+MIRR)^{n*1/n} = \left(\frac{Positive\ Cashflow\ (investment\ rate)}{Negative\ Cashflow(financing\ rate)}\right)^{1*1/n}$$

Therefore,

$$MIRR = \left(\frac{Positive\ Cashflow\ (investment\ rate)}{Negative\ Cashflow(financing\ rate)}\right)^{1/n} - 1 \qquad \text{Eq. 19}$$

In addition to Eq. **19**, MIRR can be calculated using Microsoft Office Excel function “MIRR”. Also, the FEM model is set to calculate the MIRR as well.

The economic evaluation for this research will be done using the MIRR and the PI. Reflecting on the issue that was pointed out by the literature (Lefley, 2018), citing problems regarding the IRR method, it is believed that the MIRR will produce better results, as Lefley (2018) argued that “MIRR does produce more realistic results when compared to the IRR method”. These indicators will be used directly in the MCDM matrix as scores.

3.5. Development of a Multi Criteria Decision Making Matrix

After the weightings for attributes and indices were defined, the MCDM matrix was designed. The MCDM design used concepts from the reviewed literature (Espie, *et al*. (2003), Chicco, *et al*. (2012) and Kamble, *et al*. (2017)). Eq. 2(page 29 of this report) was suggested by Ochoa, *et al.* (2006), and converted into a matrix using a Microsoft Excel spreadsheet as presented in Table **5** below.

Table 5: Complete MCDM matrix

Criteria		**Weight**	**GLF**		**LM**	
			Actual Score	**Weighted Score**	**Actual Score**	**Weighted Score**
Adequacy	Electrification Coverage	9	%connections	9*%connections	%connections	9*%connections
	Voltage Quality	8	Voltage Score	8*Voltage Score	Voltage Score	8*Voltage Score
Reliability	COUE	8*2	COUE(sensitivity)	8*2COUE(sensitivity)	COUE(sensitivity)	8*2COUE(sensitivity)
Economics	Project Profitability Index	5	PI	5*PI	PI	5*PI
	Modified Internal Rate of Return	5	MIRR	5*MIRR	MIRR	5*MIRR
Desirability score				Sum(Scores)		Sum(Scores)

As shown in Table 5 above, the complete matrix takes into account all the components discussed above. The “Actual Scores” are the values extracted from the evaluation of an alternative; they are real values without units. The “Weighted Values” give the assigned weight to the scores by multiplying the scores by the assigned weights according to their relative importance. The simple addition of these weighted scores gives an indication of desirability of the overall method, and the “Desirability Score” for each method. An outcome with a higher score will be deemed to be more desirable than the other.

3.6. Load Forecast Error Evaluation

The theory regarding the methods for load forecast error evaluation and load forecast error measurement (quantification) are discussed in this section.

3.6.1. Load Forecast Error Evaluation Method

The literature presented two load forecast error evaluation methods; hindsight method [(Du, *et al*., 2007), (Willis, *et al*., 1995), (Willis & Northcote-Green, 1984)] and an actuals method (Carvallo, *et al*., 2016).

The **hindsight method** requires the evaluator to forecast the study area in the present, whilst referring to the past. How it works is that, if a load forecast error evaluation is to be carried out for the period 2000 to 2010, the evaluator would use 1999 as a base year, and forecast the study area using the different load forecasting methods that are being compared. This means that the evaluator must gather the data as though it is year 2000, and forecast the years 2000 to 2010 as though the actual load growth for that period is not known. After forecasting the study area, the load forecasts for 2000 to 2010 would then be compared to the actual load for the same period and the error would be quantified for each method.

The major issue with the hindsight method is that, the evaluator forecasts the area whose actual load they already know, but they forecast it as though they do not know the actual load for the period being forecasted. The evaluator can thus sway the results to favour the prefered load forecast method.

The **actuals method** requires that the evaluator collect the forecast report for the load forecast that was performed in the past, and compares the original load forecast to the actual load that materialised after the forecast study was done. If for example, the load forecast error evaluation is done for the period 2000 to 2010 using the actuals method, the evaluator would need to source the forecast report that was compiled in 2000 and the actual load that was measured from 2000 to 2010 for the study area. The evaluator would then compare what was forecasted (from the load forecast report) in 2000 for the following ten years, to what actually happened in terms of the load growth in the same period.

The actuals method was chosen as a prefered method for this research due to its transparency and objectivity. It is believed that the evaluator takes himself/herself out of any potential conflict of interest, by using this method for load forecast error evaluation. The evaluator does not have to perform the forecast wherebythe outcome of the evaluation could potentially be influenced.

3.6.2. Load Forecast Error Quantification

To quantify the deviation of a load forecast from the actual load, a number of indicators were discussed in the literature review(section 2.5). Some indicators used the actual load units (MVA) to quantify the error, while others used per unit values and percentage velues. It was learnt that the mean absolute percentage error(MAPE) was widely used [Laouafi, *et al.* (2015), Minhas, *et al.* (2017) and Tsekouras, *et al.* (2003)]. The fact that MAPE is a percentage based error indicator makes it possible to compare error analyses from different case studies that may have different load magnitudes.

Mean Absolute Percentage Error (MAPE)

Chockalingam (2009) stated that, to work out one error metric for a group of items, one must calculate the average error across the population being evaluated. To calculate the MAPE associated with a forecast, Eq. **20** (rephrased from Laouafi, *et al.* (2015) and Minhas, *et al.* (2017)) is used.

$$MAPE = \frac{\sum |(Actual - Forecast)|}{\sum Actual} \times 100\% \qquad \text{Eq. 20}$$

MAPE gives undefined results in instances where the actual data has values equal to zero.

If,

$$Actual = Forecast, \text{ then}$$

$$MAPE = 0$$

$$Accuracy = 100\% - Error\%$$

$$\therefore Accuracy|_{MAPE=0} = 100\%$$

However,

$$Accuracy|_{MAPE \geq 100} = 0\%$$

The above equations are expressing that while an error can be more than 100%, accuracy can only range between 0 and 100%.

3.7. Measuring the Difference between Planned and Constructed Infrastructure to Determine the Forecast Error Effect

On the question of whether the load forecast accuracy does affect the procurement and construction of infrastructure, the literature carried two opposing views; Engel & Dyson (2017), Shahida, *et al*. (2014) and Laouafi, *et al*. (2015) are of the view that the accuracy of a load forecast does affect the procurement, as the procurement is informed by the load forecasts. This view was also shared by Bunge & du Preez (2007). However, Willis & Northcote-Green (1984) shared a view that the load forecast does not affect the procurement and construction of network infrastructure.

These two differing views necessitated that this assessment be carried out in this research, to establish where a comparison between the GLF vs LM results will point towards.

Carvallo, *et al.* (2016) presented a method that uses actual *constructed* network infrastructure compared to the *planned* infrastructure by means of percentage deviation between them. This evaluation can be carried out using Eq. **21**.

$$Total\ \%\ plan\ constructed = \frac{\sum Constructed}{\sum Planned} * 100\% \qquad \text{Eq. 21}$$

Where:

Constructed = Constructed infrastructure that is in operation at the time of assessment

Planned = Infrastructure appearing on the capital expenditure plan of the power system network study being assessed.

A large infrastructure deviation implies that what was planned is not in line with what was eventually constructed. Also, the smaller error means that the plan was closely aligned to the constructed outcomes.

3.8. Conclusion

The theory has been developed to clarify the relationships (formulas) to be used in the actual test/method. The following aspects have been dealt with:

- Load Forecast Error: the “actuals” method was defined, which will be followed when evaluating load forecast errors for the GLF and the LM. The load forecast error will be quantified using MAPE.
- ARE: a matrix named ARE was developed to test each load forecast method, and how it supports the planning of adequate, reliable and economic power system network in a multi criteria decision making approach.
- Effect of load forecast accuracy on infrastructure procurement and construction: The effect of the load forecast errors associated with each load forecast method will be evaluated by comparing the infrastructure plan to what was actually procured and constructed.

The next chapters (4 to 6) describe the methodology for testing the above mentioned aspects.

4. TEST1: LOAD FORECAST ERROR FOR GLF VERSUS LEGACY METHOD

Previous work that has been done on forecast evaluation has shown the importance of assessing a forecast method based on its error (Alfares and Mohammad (2002), Willis (2002) (chapter 17), Lifeng and Zhenyu (2005), Willis, *et al*. (1995) and Willis & Aguero (2007)). This chapter discusses the test procedure and data used for the test. The test is performed between the GLF method and the legacy method, to evaluate their accuracy. This is the first of the three test cases that are performed in this research. The rest of these tests are: load forecast impact on the planning process and the load forecast impact on the procurement of the infrastructure – see Figure **8** below.

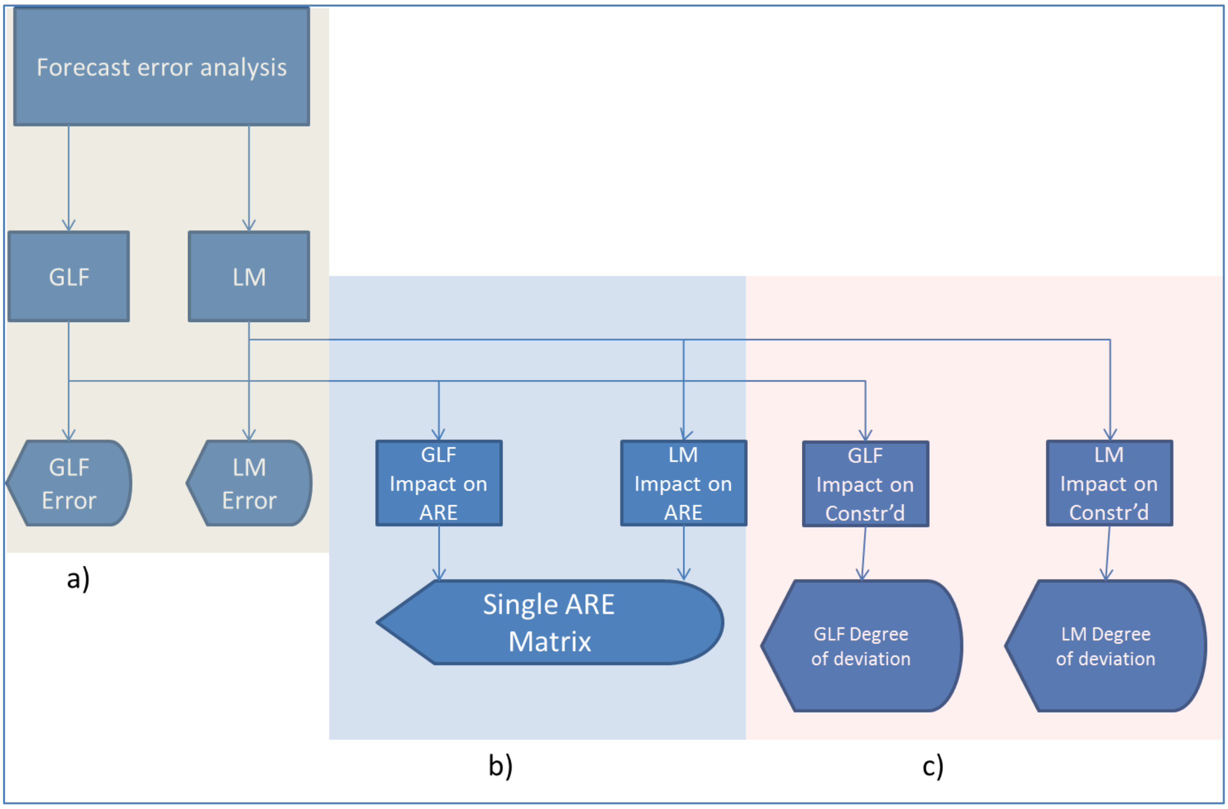

Figure 8: a) Forecast error test, b) forecast impact on the planning of ARE network and c) forecast impact on the constructed network.

Refer to Figure 8 above:

a) Is the load forecast error evaluation that is being carried out in this chapter, chapter 4,
b) The evaluation of the impact of a load forecast method (GLF and LM) on the planning of infrastructure that is adequate, reliable and economic is discussed in chapter 5, and
c) The impact assessment of a load forecast method on the constructed power system network will be carried in chapter 6 by comparing the planned network infrastructure to the actually constructed network infrastructure.

This chapter presents three load forecast error evaluation case studies. The first one is carried out using the Stellenbosch area, followed by the Franschhoek area and lastly, the Mokopane area.

The forecast evaluation model (MAPE) discussed under theory for error analysis,) has been used for this purpose.

4.1. Forecast Error Evaluation: The Actuals Method

To evaluate the error of each load forecast method, the load forecasts from the power system network planning studies were compared to the actual load growth that took place between their time of compilation (say 2006/2007) and 2016 in an *ex post* approach. The method followed is similar to the one used by Carvallo, *et al.* (2016), see section 3.6.1 of this report. This method is referred to as the actuals method.

The load forecast error will be calculated using the mean average percentage error method (MAPE) that was used by Laouafi, *et al.* (2015) and Minhas, *et al.* (2017). The MAPE calculation will be based on Eq. **20** (page 57 of this report).

4.2. Case study 1: Stellenbosch Area Forecasts (GLF versus Legacy Method)

The first comparison between the GLF and the legacy method is based on the Stellenbosch area, where both methods were assessed.

4.2.1. Data Sources Used

It can be mentioned that data availability that would ensure fair and consistent comparison between the two load forecast methods being studied was one of the challenges experienced during this research. A Network Development Plan (NDP) for the Windmill area (Eskom Distribution, 2005) that was compiled using the legacy method was used as a source of data for the LM. This NDP encompasses the Stellenbosch Area. The GLF based Stellenbosch Master Plan (Stellenbosch Municipality, 2006) was used as a source of the GLF data. The actual Stellenbosch loading data (sourced from Stellenbosch Local Municipality (2015)) was used as reference data for the error calculations between the respective methods. Both the GLF and LM data cover a period of 10 years, which gives a duration that is fair for both to assess the load forecasts against.

The GLF forecast from the Master Plan (Stellenbosch Municipality, 2006) covers a 20 year forecast horizon, from 2005 to 2025. The legacy method forecast from the NDP (Eskom Distribution, 2005) covers a 10 year forecast horizon, from 2005 to 2015. The actual measured data is from 2005 to 2015 and was received from the local municipality (Stellenbosch Local Municipality, 2015).

4.2.1.1. Data Discrepancies and Solutions

In the Stellenbosch area, after collecting the data for the measured load readings and the load forecast from the Master Plan, it was found that the starting loads were not the same for these two sets of data. According to the Eskom load forecast standard (Hashe, 2012), the base load scaling of a load forecast is one of the steps that are part of forecasting in GLF. Also, the base load is defined as the highest peak of the year as read from the measuring meters (Hashe, 2012). Having a forecast base load that is different from the measured peak is inconsistent with this description.

Upon investigating the source of this deviation, it was found that the substation peak load forecasts for the study area were added up to give the total area load forecast, and that the individual load characteristics of the substation loads were ignored in the Master Plan. The Stellenbosch area consists of different load types with very different load characteristics viz. farming, business/commercial, university and domestic loads. All these load types have different consumption patterns for a complete day, week and a year (or 4 seasons). The different load profiles tend to diversify themselves according to their different peak times. The PowerGLF tool has a database for load subclasses that carries different subclasses with profiles and attributes. However, as stated, it seems that the direct addition of substation peaks was done in the case of the Stellenbosch NMP, instead of utilising the underlying profiles.

To correct this situation, the scaling factor, as shown in Eq. **22**, was calculated and applied to diversify the load forecast.

$$Load\ Scaling\ Factor = \frac{Measured\ Load}{Forecast\ Base\ Load} \qquad \text{Eq. 22}$$

Measured load (2005) = 54.6 MVA

GLF Assigned Base Load (2005) = 67.3 MVA

$$Factor\ used\ to\ scale\ the\ Assigned\ Base\ Load\ down\ (GLF) = \frac{54.6MVA}{67.3MVA}$$

= 0.812

The rest of the load forecast was then scaled down by this factor. This correction improved the error for GLF.

When reviewing the LM forecast for Stellenbosch, the disjuncture between the forecast base load and the actual load was also found. The base load was represented as 60MVA. Thus, the forecast base load was scaled down in a manner similar to the GLF forecast discussed above. Using Eq. **22**, the load scaling for LM is as follows:

$$Factor\ used\ to\ scale\ the\ Assigned\ Base\ Load\ down\ (LM) = \frac{54.6MVA}{60MVA}$$

= 0.910

The scaling exercise performed above led to the data shown in Table 6

Table 6: Stellenbosch area actuals and forecasts' data

Year	Actual (MVA)	LM Forecast (scaled) (MVA)	GLF Forecast (scaled) (MVA)
2005	54.62	54.62	54.62
2006	51.75	55.53	57.78
2007	55.49	60.08	61.03
2008	56.89	61.90	64.27
2009	55.74	62.81	67.68
2010	55.73	63.72	71.17
2011	55.17	64.63	74.66
2012	57.40	64.63	78.23
2013	57.11	66.45	81.88
2014	59.68	68.27	85.62
2015	59.54	71.00	89.43

The error analysis for GLF and LM was done based on the data shown in Table 6.

4.2.2. Methodology

The annual actual loading data for the Stellenbosch area was compared to the annual LM forecast and the annual GLF forecast. The LM and the GLF errors were quantified using the MAPE method. The load forecast errors resulting from the two load forecasting methods were observed and compared to each other. The flow diagram in Figure **9** shows the process followed.

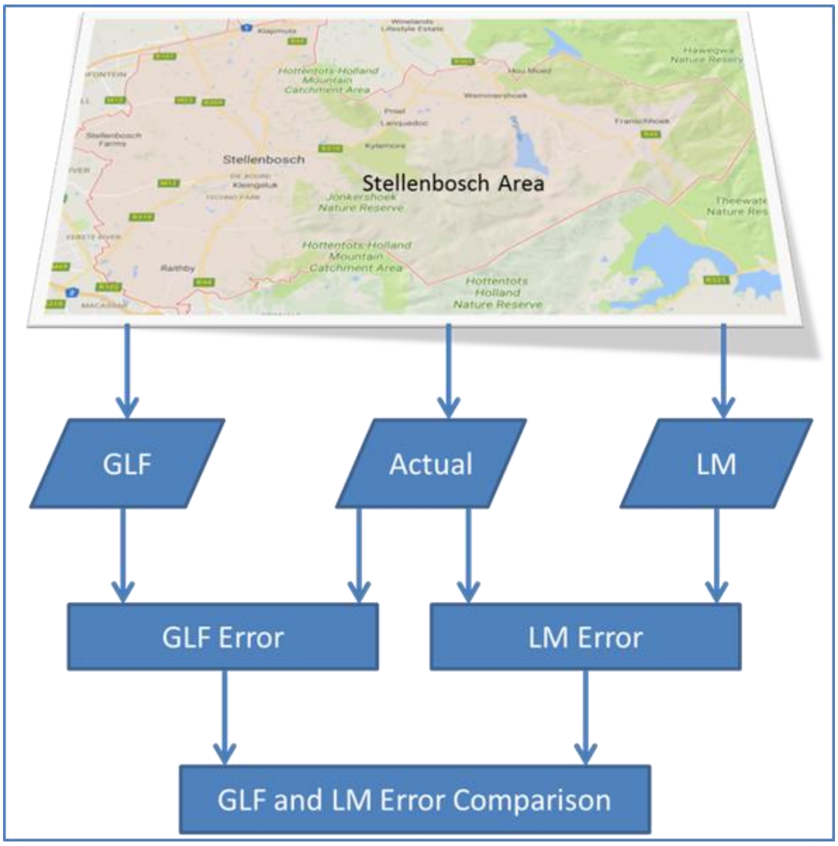

Figure 9: Forecast error comparison flow diagram

As can be seen from the diagram in Figure **9**, the GLF forecast was compared to the actual data and the GLF error was quantified. The legacy method forecast was also compared to the actual data and the LM error was quantified. The two calculated errors were compared to rank the forecasts according to their error performance.

For consistency on the tests, all data used was for the same area. The first test was done for the Stellenbosch area and the second test was done for the Franschhoek area.

4.2.3. Forecast Assumptions

Forecasts for load change (usually growth) are linked to predicted events that may lead to such a change. The assumptions made at the time, provide the perspectives of the forecaster at the time that the load forecast was done.

4.2.3.1. GLF Method Assumptions

The GLF assumptions were based on municipal studies and plans. The Stellenbosch Municipal Spatial Development Framework (SDF) was mentioned to be the basic building block of the load forecast in the GLF area. Attempts were made to get hold of this document (SDF) but it was not found. The SDF document was not found, even though, and according to the Spatial Planning and Land-use Management Act (SPLUMA) (Rural Development and Land Reform, 2013), the municipality is compelled to publish this document and ensure that the public has access to it.

SPLUMA (Rural Development and Land Reform, 2013) describes the SDF as:

- **Long-term strategic planning** mechanism for ensuring better designed, more efficient, more sustainable and more equitable spaces (regions/municipalities/cities/provinces)

- Must show **what** should develop, **where** and **how much** of it should be developed **when.**

These characteristics make it compatible with the GLF approach as the GLF approach is also based on *what*, *where*, *how much and when* – as was discussed in detail in the literature review of this report.

4.2.3.2. Legacy Method Assumptions

The LM forecasts for the Stellenbosch and Franschhoek areas were based on known major developments plus a constant percentage growth that was observed in years prior 2005.

For the Stellenbosch area, 2.5% annual load growth plus inputs received from interviews with the local authorities were used as a base for the projections.

4.3. Case study 2: Franschhoek Area Forecasts (GLF versus Legacy Method)

The approach for the Franschhoek area load forecast was largely similar to the Stellenbosch area, as both areas were sub- sections of the Stellenbosch Master Plan (2006), and Windmill NDP (Eskom Distribution, 2005). The key aspects of the load forecast error evaluation for the Franschhoek area are discussed below.

Data Sources Used: The load forecasts (GLF and LM) for the Franschhoek area were based on the studies; the Stellenbosch Master Plan (Stellenbosch Municipality, 2006) for GLF and the Windmill Network Development Plan (Eskom Distribution, 2005) for LM forecast.

To correct the forecast base loads for both GLF and LM, Eq. **22** was used. Using data from the Stellenbosch Master Plan (Stellenbosch Municipality, 2006),

$$GLF\ Scaling\ Factor\ = \frac{6.07}{6.10}$$

= 0.995

Using data from the Windmill Network Development Plan (Eskom Distribution, 2005),

$$LM\ Scaling\ Factor\ = \frac{6.07}{6.00}$$

= 1.012

The data in Table 7 was used for the Franschhoek area load forecast error evaluation for GLF and LM.

Table 7: Franschhoek area actuals and forecast data

Year	Actual (MVA)	LM Forecast (scaled) (MVA)	GLF Forecast (scaled) (MVA)
2005	6.07	6.07	6.07
2006	6.41	6.38	6.47
2007	7.00	6.70	6.87
2008	7.71	7.03	7.36
2009	7.95	7.38	8.16
2010	8.43	7.75	9.15
2011	8.40	8.14	10.45
2012	8.76	8.54	11.64
2013	8.50	8.97	12.84
2014	8.79	9.42	13.73
2015	9.00	9.89	14.53

Methodology: the same methodology discussed in section 4.2.2 and demonstrated using Figure **9** was followed in the Franschhoek area.

Forecast assumptions: the municipal SDF was used as a basis for the GLF forecast. To compile the legacy method forecast, it was learnt from the NDP (Eskom Distribution, 2005) that a 5% annual growth rate was used for the Franschhoek area load forecast.

4.4. Case Study 3: Mokopane Area Forecast (Legacy Method Forecast)

4.4.1. Case Study Back Ground

The two case studies discussed in sections 4.2 and 4.3 above refer to the Stellenbosch and Franschhoek areas respectively, for both the GLF and legacy method error evaluations. Stellenbosch and Franschhoek are both municipal areas of supply, under the jurisdiction of the Stellenbosch Local Municipality. As such, the infrastructure plans for these areas are the responsibility of the municipality. While the legacy method forecast was done for both areas by Eskom, they do not have the mandate to carry out any infrastructure planning within the said areas. With this in mind, the research aims to evaluate the impact of the load forecast in the planning process, and as indicated earlier, evaluate how the load forecast leads to the planning of adequate, reliable and economic (ARE) infrastructure. The fact that the load forecasting methods reviewed in the case studies do not have the accompanying infrastructure plans, against which the forecast impact can be evaluated, necessitated an additional case study to be evaluated, that is based on the Mokopane NDP, in an Eskom area of supply.

The Mokopane NDP (Eskom Distribution, 2007) was done based on the legacy method. The load forecast horizon starts from 2005, and extends to 2025. This NDP was chosen because it presents the load forecast data, infrastructure plans and the data regarding the actuals for both the loading and the network infrastructure was also accessible from Eskom. The idea behind the evaluation of this case study is that the legacy method will be assessed independently, as the data is only available for the legacy method forecast. The load forecast error for the legacy method and the impact on the planning of the ARE power system network will be tested. At a later stage, the planned infrastructure versus the procured infrastructure analysis will be done.

Ideally, if the data were available, the following would have been done. Consider a hypothetical study area named Area 1. Area 1 has an NDP that was compiled based on the GLF method as well as legacy method. Both the NDP's have network infrastructure plans that are outcomes of the studies and they were compiled independently of each other. There is one set of data for historical data, as well as the network infrastructure constructed post the compilation of the said NDP's for Area 1, also referred to as the actual data. This means that the load forecasts would be evaluated against the same historical data for error adjudication, and the infrastructure plans from each NDP would be assessed against the same group of constructed infrastructure. However, the unavailability of data that would lead to such a setup necessitated an additional case study to be considered that carries data, in order to better assess the evaluation of the legacy method.

4.4.2. Mokopane Area Data

Mokopane Network Development Plan (Eskom Distribution, 2007) covers the Mokopane Municipal area in Limpopo. Its load forecast covers a 20-year window. The load forecast of this study was based on the legacy method, see Table **8**. The authorisation to use Eskom data is appended in this report.

Table 8: Base year correction for Mokopane area forecast (LM)

Initial Years	2007	2012	2017	2022	2027
Corrected Years	2005	2010	2015	2020	2025

It was learnt, from the NDP study, that the base year assigned according to the report was 2007 (denoted as "initial Years" in Table **8** above). Considering that the bulk of this study was carried out in 2006 and ultimately was approved in 2007, the base year for the load forecast was corrected to 2005. If the study was performed in 2006, it is highly probable that the base load could have been taken as the maximum load reading of the year prior to the study year (which is 2005 in this instance). Therefore, the load forecast data was shifted by two years to align with this actuality. For this research, the "corrected years" were used in the analysis. As can be seen from Table **8**, the load forecast from this study was presented in five year intervals and not annually, as is the norm.

The actual loading values for the Mokopane area were extracted from the 2016 network development plan compiled for this area and are presented in Table **9**.

Table 9: Actual loading data for Mokopane area

Year	**2005**	**2012**	**2013**	**2015**
Actual max load (MVA)	154.3	233.76	238.51	251.9

Table 9 presents historical loading that is not annualised, but is shown in discrete years.

The lack of correlation in the study area and the power system network extent in the Mokopane NDP, presented a data challenge. Willis & Aguero (2007) undertook a study to compare load forecasting methods with respect to their forecast accuracy. They warned that forecast error evaluation at feeder level can be worsened by loading data instability that results from continuous feeder operational switching. Mostly, a feeder load forecast does not take into consideration these switching events and abnormalities, and hence the possibility of counting the switching abnormality as a forecast error, as it will create deviations from the normal forecast. To alleviate the impact of switching, Willis & Aguero (2007) suggested that when the evaluation is done on a certain feeder, the immediate feeders adjacent to it must be included, as this has shown to reduce the overall load forecast error. The Mokopane NDP area presented a problem similar to the one identified by Willis & Aguero (2007). In the Mokopane NDP area, as shown Figure **10**, one of the data challenges was that, there were two Transmission injection stations that supply the study area, and part of the network in the study area shares the Transmission supply with other networks.

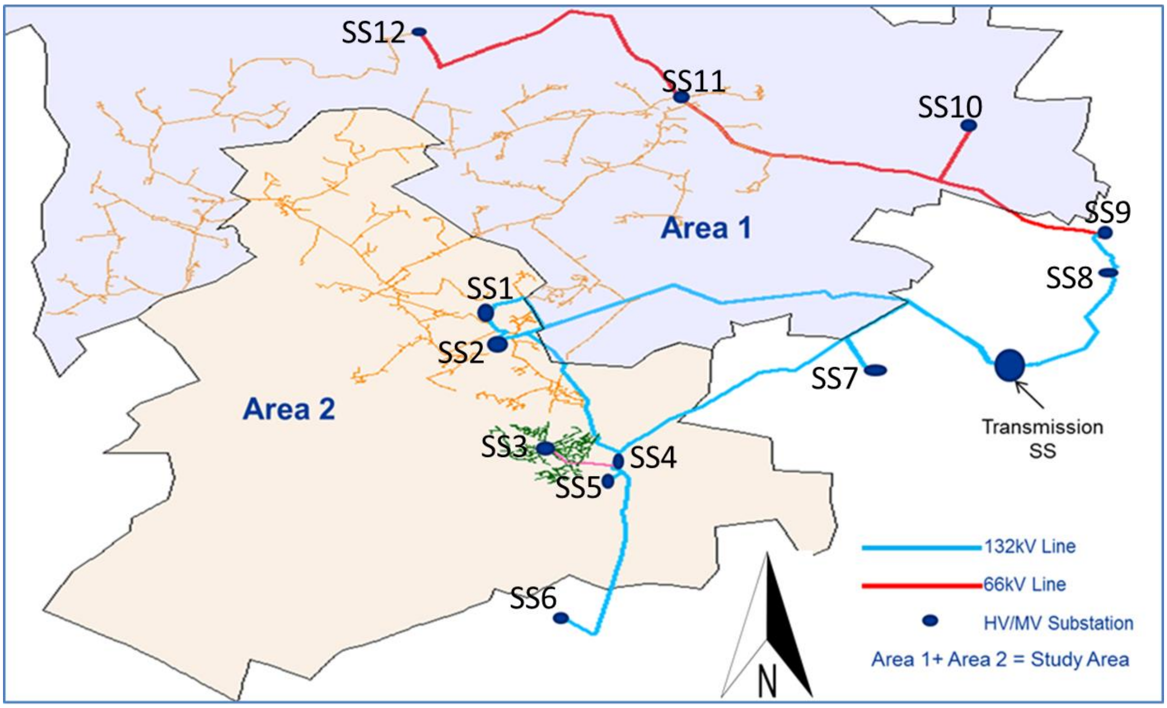

Figure 10: Legacy method study area network

In Figure 10, substation SS6 is linked to another power system network which links to another Transmission substation. Also, some of the substations (SS7, SS8 and SS9) are actually out of the study area and there was no load forecast data as they were not part of the initial study (the 2007 NDP). This situation presented a challenge as one cannot simply download the metering data from the Transmission supply lines upstream.

To resolve this challenge, the load forecast and actual load data were gathered per substation and added up directly. Only forecasted substations that are in the study area were considered for comparison with the actuals.

4.4.3. Mokopane Area Forecast Assumptions

The main load driver in this area was platinum mining. The assumption set of the power system network development plan report alluded to the fact that, "due to the confirmed platinum deposits in the area, it is expected that extensive exploration and beneficiation will take place soon

('Engineering News' 26 January 2007). The load forecast was accordingly to be updated with new loads as and when customers sent in their applications" (Eskom Distribution, 2007), see Figure **11** for mining location.

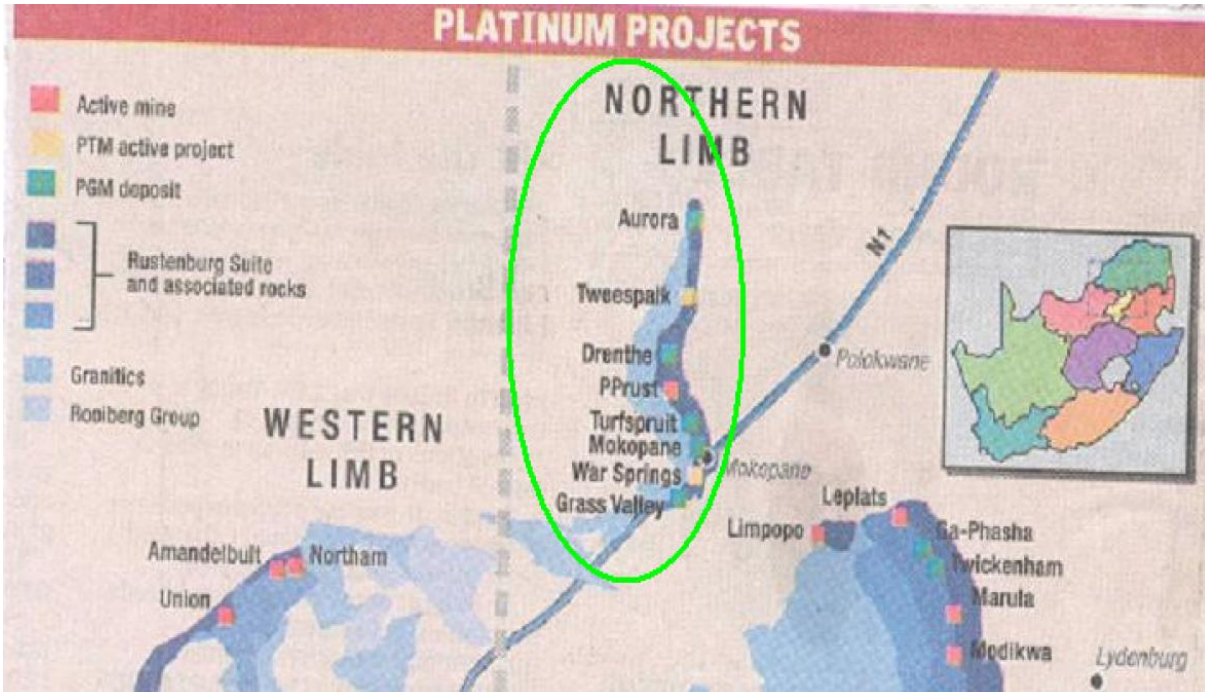

Figure 11: Platinum Deposits, Mokopane Network Development Plan (Eskom Distribution, 2007)

According to the Mokopane NDP, Figure **11** was sourced from Sunday Times' 27 May 2007 release. Figure **11** shows active mines and mineral deposits on which the load forecast assumptions were built, the area under study is the area within the highlighted green oval.

It was further stated that, household electrification was expected to pick up in this area due to the hike in population that would be caused by the new job opportunities in the mines (Electrification is discussed in more detail in section 5.3 of this report).

4.5. Forecast Error Evaluation Methods not Used

4.5.1. Forecasting in Retrospect

Forecasting in retrospect, is a process where a forecast method of interest (being evaluated) is used to forecast a load that has already taken place, popularly used by H. Lee Willis ((Willis & James, 1983) (Willis & Aguero, 2007) (Willis, 2002)). For example, two or more methods can be used to forecast an area from 1990 to 2000, with 1990 being the base year. The actual loading data (the eventuality) is known to the person doing the evaluation. They must however, pretend that they do not know while doing the forecast. The forecasts from the two methods would then be compared to the actual load from 1990 to 2000 and their accuracy quantified.

This method was not used in this research as it is open to bias by the person doing the evaluation. It would be easy to setup one method to fail over another, which may compromise the results of the evaluation.

4.5.2. Backcasting

Defined by Armstrong (2001) as *forecasting backwards*; this method, if used to evaluate forecasting methods for an area (similar setup as in 4.5.1 above), 2000 would be taken as the base, and the forecast be performed back to 1990. Similar to retrospective forecasting, this method is open to manipulation, leading to results that may not be trusted.

4.6. Conclusion

The backdrop to this chapter was the research question, "*How is the load forecast error measured?*".

The case studies and available data that were used for the error evaluation were discussed. Two case studies where the GLF and the legacy method were used to forecast the same area were discussed and an additional case study where only the legacy method was used was also discussed. The additional case study is meant to cater for the tests that will be carried out in the chapters that follow.

This chapter acts as a precursor to the results presented in Chapter 7.

5. TEST2: LOAD FORECAST IMPACT ON THE DISTRIBUTION PLANNING PROCESS

According to Willis (2002), "a forecast must be [evaluated on] how well it supports the planning process". The literature (Tanaka, *et al.* (2010), Zhang & Yuan (2005), Ochoa, *et al.* (2006) and Kamble, *et al.* (2017)) have suggested a multi-criteria decision making matrix as a way of evaluating a planning outcome against another. This is normally used for evaluation of network planning alternatives. The MCDM for this research was constructed in Chapter 3 as part of theory development and the criteria used were adequacy, reliability and economics, shortened as ARE. Each load forecast method will be evaluated based on how it supports the planning process and will be measured using the ARE matrix.

This chapter makes use of two case studies, as dictated by the availability of data, to assess the impact GLF and legacy method have on the planning of the ARE power system network characteristics.

5.1. Methodology

The impact comparison that the GLF and legacy method have on the planning of adequate, reliable and economic power system network is shown in Figure 12 below.

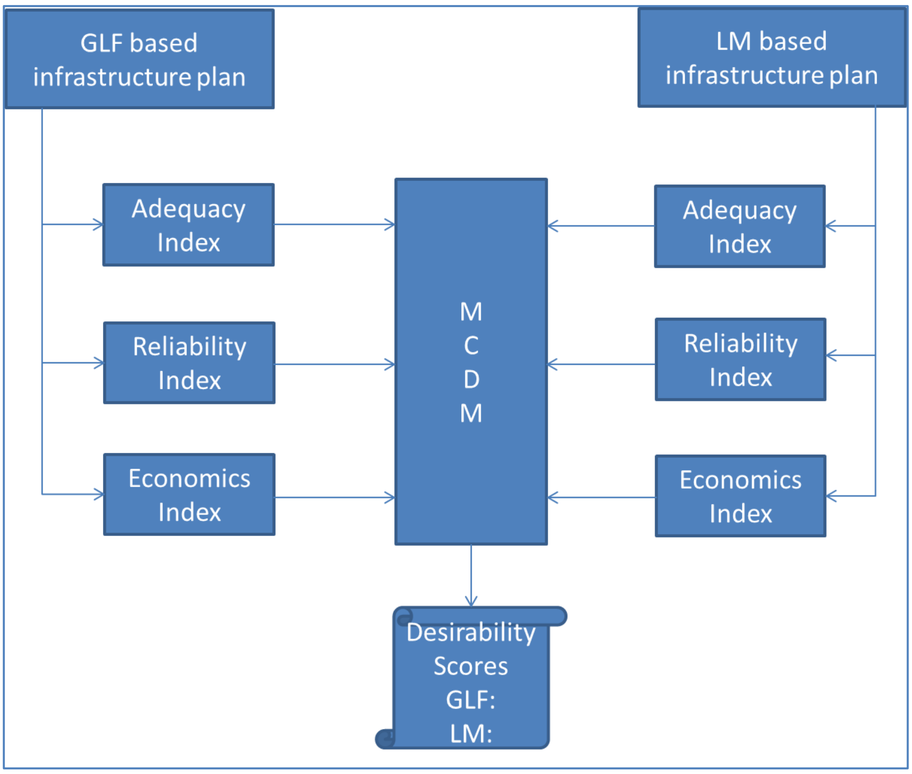

Figure 12: flow diagram for the evaluation of the GLF and LM forecasts impact on the planning of ARE network

As shown in Figure 12, two different network infrastructure plans are used; one based on the GLF method and the other based on the legacy method, as a basis on which it was derived. The criteria consisting of indices of adequacy, reliability and economics were used to equally weight these network plans against one another in an MCDM. The results will be the outcome values of desirability that will be calculated from the MCDM.

5.2. Data Sources Used

The GLF derived plan was extracted from the Stellenbosch Municipality Electrical Infrastructure Master Plan (Stellenbosch Municipality, 2006). Ideally, it would have been proper to use the same study area for this assessment (GLF based plan versus LM based plan), however, data that would allow for that was not found. Municipalities are responsible for the infrastructure planning in their areas of supply while Eskom has a responsibility in its own area of supply. This situation compelled the author to use an infrastructure plan from a study called the Mokopane Network Development Plan (Eskom Distribution, 2007) as a source for the legacy method based infrastructure plan data.

While these studies are named differently, the Master Plan (for Stellenbosch) and Development Plan (for Mokopane), they are both based on 20-year load forecasts and have associated detailed infrastructure development plans. They therefore cover the same objectives. The fundamental difference between the studies is the load forecasting method followed. As such, both power system network plans will be "put on the same scale" to ensure a fair comparison between the two areas. An attempt has been made to align the comparative aspects, to allow for an appraisal on the same platform, e.g. the economic evaluation was performed using the same platform for both studies to ensure that the main difference between the studies is the load forecast approach followed.

Both the power system network plans used as data sources, cover a similar period of historical data. The Stellenbosch Master Plan was compiled in 2006 and the Mokopane NDP in 2007, and this evaluation is carried out approximately a decade after the studies were compiled. It must be appreciated that they were both compiled without prior knowledge that there would be a global recession in 2008. Therefore, the impact of the global recession is expected to have affected both areas equally.

The level of expertise of the planners that compiled these power system network studies is believed to be at an advanced level for both development plans; as the Stellenbosch Master Plan was compiled by Netgroup SA Pty LTD which is a company that developed the GLF method and the software PowerGLF, and the Mokopane NDP was compiled by a Senior Engineer from Eskom. It is assumed for the purposes of this assessment that the level of skills required to develop such an NDP, would be of an equal standing.

5.3. Network adequacy

As described in the literature and theory, an adequate power system network shall be regarded as the one that addresses the universal access to electricity (the one that promotes access of electricity to all) at the acceptable level of power quality.

5.3.1. Electrification Perspective

The data was not available in order for the percentage connections made to be calculated. In the case of the Stellenbosch area, the load forecast report does not make reference to the number of connections that are forecasted. The Mokopane NDP does not stipulate such figures either.

The unavailability of statistics means that the second option for the electrification assessment (refer to the theory development chapter), the qualitative analysis based on the rubric, must be used. The rubric was developed in section 3.2.1 (theory development) based on literature from Mertler (2001, p. 3).

The referred rubric is presented in Table 10 for ease of reference.

Table 10: Rubric for evaluation of electrification; redrawn for ease of reference

Question	**Insufficient/Not evident (Score=1)**	**Sufficient (Score=2)**	**Good (Score=3)**
Electrification assumptions comprehensive?	No information presented about electrification	Information presented takes into account all existing electrification applications	Information presented shows scientific methods of forecasting electrification needs
The sources of information used for electrification forecast.	No sources of information shown or discussed in the study report.	Basic electrification backlog from the municipality was used.	Advanced methods that go beyond the known municipality applications were used.
Activities undertaken to perform electrification forecast.	No activities evident towards electrification forecast	Direct addition of connection applications from the municipalities/ customers/ tribal authorities	Scientific (such as statistical) or other means of comprehensive predictive algorithms are presented.
Sub-Total			
Total			

The allocation of scores on Table 10 is discussed under the results chapter (in section 8.1 of this report).

5.3.2. Power Quality Perspective

To complete the power system network adequacy evaluation, the second attribute after electrification, namely the voltage quality, will be assessed for each of the two network plans being studied. The lowest voltage that is subsequent to a proposed network plan (from the Stellenbosch NMP or Mokopane NDP) will be captured as “volt level” and the graph in Figure **6** and/or the equations (Eq. 7 to Eq. 11) (page 48) will be used to calculate the “volt score”. The results for each network infrastructure plan will be updated on the MCDM for comparative purposes.

5.4. Network Reliability

In section 3.3, the basis for reliability assessment for this research is developed by using two critical indicators; the breakeven cost of unserved energy (BECOUE) and the weighted cost of unserved energy (COUE). These are used for the reliability cost-benefit evaluation.

On reviewing both the reports; the GLF- based Stellenbosch Master Plan and legacy method based Mokopane NDP, it was found that the reliability target for these studies was to ensure that there is sufficient back-feeding capability on the power system network. This means that, in case one part of the network is out of service, due to emergency or planned maintenance, there must be an alternative supply option available to ensure continuity of supply to the customers. This phenomenon is referred to as an (n-1) criterion. This was found to be the case in both the Stellenbosch NMP and the Mokopane NDP.

The approach followed in this research to compare the reliability of the plans was that, the cost incurred to bring about the supply contingency was compared to the cost of losing the load at risk. The model used for this examination was the FEM (also used for the economic evaluation in Section 5.5). This approach is called reliability cost-benefit assessment and was discussed by Koval & Chowdury (1996); see section 2.1.2 under literature review.

The cost of unserved energy for the study areas (Stellenbosch and Mokopane areas) was calculated using the load class compositions, and the percentage loads for each area were populated based Table 4 (page 49). The weighted cost of unserved energy was calculated using Eq. 12 (page 50). The actual values are presented under the results chapter (section 8.2).

To calculate the breakeven cost of unserved energy, the "reliability capex" was extracted from each plan; basically, all infrastructures meant for an (n-1) supply compliance were grouped. The reliability capex is then spread throughout the 25 year equipment lifecycle and it is termed *cost per annum (cost p.a.)* as shown in Eq. 13 (page 50). The *expected energy not served per annum*, which is the denominator of Eq. 13 is calculated using Eq. **23** below.

$$Expected\ energy\ not\ served\ p.a. = LoadFactor \times PowerFactor \times LoadatRisk\ (kVA) \times OutageDuration \times OutageFrequency \qquad \text{Eq. 23}$$

Where:

- The "load factor" and "power factor" used are the same values that were used under economic evaluation; these are related to the load composition for the area.
- The "load at risk" was extracted from the load forecasts – only for the substations affected by (n-1).
- The "outage duration" and "outage frequency" were derived from the existing power system network statistics from Eskom:

Eq. **23** is the equation used by the FEM model when calculating the Expected Energy not Served p.a. This equation requires, among other inputs, the outage duration and outage frequency. Ideally, the actual distribution network performance data (outage duration and frequency) for each area (Stellenbosch and Mokopane), as it was in 2006/2007 would have been used if it was available. However, these statistics were not available for the said years. To close this gap, a power system network whose performance data was accessible was used in order to derive these figures. All the outage events were extracted from the records and were summed up over one year period. The total number of failure events was divided by the number of high voltage assets to get the average failure rate per asset per annum, see Eq. **24** below.

To derive the average outage duration, the total duration of failure events was divided by the number of failures in the power system network as shown in Eq. **25**.

The following statistics were received from the operator:

- Total number of HV Assets = 590, this shows that the statistics were received for a relatively larger area, and this is important to know when the averages are going to be used.
- HV Assets Affected by Faults = 98
- Total count of events = 276
- Total Duration of Events = 10002.41 hours

$$Average\ Failure\ Rate(outage\ frequency) = \frac{Total\ Count\ of\ Events}{Total\ Number\ of\ HV\ Assets} \quad \text{Eq. 24}$$

And,

$$Average\ Failure\ Duration = \frac{Total\ Duration\ of\ Events}{Total\ Count\ of\ Events} \quad \text{Eq. 25}$$

- The following values were derived:
    - Outage duration = 36.24hr per annum
    - Outage frequency = 0.45times per annum

The two network case studies were compared against each other on how justifiable their reliability projects were. The gap between BECOUE and the weighted COUE were compared.

The sensitivity analysis was done to compare BECOUE to the weighted COUE and Eq. 14 was used for quantification of results. The sensitivity % results were used directly in the MCDM matrix.

The weakness of this evaluation was noted to be the fact that the outage statistics for the Stellenbosch and Mokopane areas during the time the NMP and NDP were compiled were not available. However, the realistic statistics derived from the existing power system network were gathered for use in absence of the specific areas' statistics.

5.5. Network Economics

The objective of this test was to evaluate the impact that a load forecast would have towards the planning of economic network infrastructure. This is the last criterion of the ARE matrix. This assessment draws from the work presented by Willis & Northcote-Green (1984), where steps were taken to ensure a fair comparison between the network infrastructure plans. In their case, Willis & Northcote-Green (1984) used the same network planning tool to ensure that the network infrastructure plans being compared, are put on the 'same scale'. However, in this research, the unavailability of data that can make reference to the same area dictated that two different areas be used. Steps taken to avoid unfair comparison in this regard are presented in section 5.5.4.

Linking to the developed theory, this test is carried out based on the Project Profitability Index (PI) and Modified Internal Rate of Return (MIRR). While the theory base for these indices was discussed in section 3.4, the Eskom-FEM-Model (2012) software was used to perform the calculations for these indices

5.5.1. Procedure for Economic Evaluation

Keeping a consistent approach with the adequacy and reliability tests, the economic evaluation was carried out between the Stellenbosch NMP, which is based on GLF and the Mokopane NDP which is based on legacy method. To perform this analysis, a financial evaluation tool that was previously used by Eskom, called FEM (Eskom-FEM-Model, 2012) was used in this research.

The original power system network study reports (Stellenbosch and Mokopane) have economic evaluation sections included in them. However, due to the differences that lead to inconsistency between these analyses, the author decided to redo the economic evaluation in a manner that will be consistent for both case studies. The issues found on the reviewed case study reports are expressed in more detail below.

5.5.2. Issues within the reports (case studies)

The inconsistencies that were found in the reports would lead to an assessment that is not robust and it would be difficult or impossible for others to repeat the assessment and critique it, if these figures were used. The Mokopane NDP report refers to the total capital expenditure plan to be R222.7 million (distribution component) and R246 million (customer component). These give a total of R468.7 million. However, later in the same report, under financial analysis, the report refers to a total capital expenditure of R552.7 million.

The Mokopane NDP stated that the strengthening cost portion and the cost for swinging substations from the old Transmission station to the new have been excluded from the financial analysis (this is an assumption that has been stated by the report). The thinking behind this selective exclusion is that this expenditure is not initiated by new loads that may lead to the utility making money out of the additional loads from new customers in a form of tariffs. Lastly, the financial evaluation sheet appended in the Mokopane NDP report did not make sense for use in such a robust comparison.

The Stellenbosch Master Plan study mentioned that the load characteristics were taken from the lowest level of the GLF model (from the load zones) and the energy and sales were calculated based on those parameters. However, the details of these calculations are not shown in the report, only the mentioning that it was done. It was further found that, in the Stellenbosch Master Plan, the actual results of the financial evaluation were not included. The report explained, in detail, the principles behind financial evaluation and the assumed rates (like inflation, technical losses, etc.) but these did not get applied to populate economic evaluation results for this Master Plan.

5.5.3. Issues between the reports

The financial assumptions stated in the reports were not aligned. As stated, the Mokopane NDP ignored the strengthening and load swinging costs in the financial evaluation, while the Stellenbosch Master Plan did not mention disregarding any possible expenditure.

The Stellenbosch Master Plan clearly stipulated their assumptions in terms of inflation, percentage maintenance cost, losses, etc. While these were also taken care of by the FEM model used in the Mokopane NDP, they may not be the same.

The two power system network plans were not based on the same economic evaluation model.

5.5.4. Approach followed to Ensure Fair Evaluation

Having come across the issues stated above, the approach was taken to ensure a robust assessment that is not biased, and which will be possible to be repeated by future researchers working on a similar topic. Key lessons were drawn from Willis & Northcote-Green (1984). What is of key importance is to ensure that there is a fair comparison between the case studies, in that; none of them seem to have been given an unfair advantage/disadvantage over the other. This could be achieved by putting the two studies on the "same scale". The same model had to be used so that the similar economic indices could be compared. A Microsoft Excel based computer programme called Financial Evaluation Model (FEM) was used to do financial evaluation on both case studies.

FEM evaluates projects on bases of their profitability. The input information used is:

- Load forecast values;
- Tariff types;
- Capital expenditure plan;
- Customer upfront payment (if any).

The economic indicator outputs are (refer to literature review (2.1.1.1) for descriptions):

- NPV: Net Present Value
- PI: Project Profitability Index
- MIRR: Modified internal rate of return
- Discounted Payback Period

To set up the model for the two case studies, the indicators listed in Table 11 were used.

Table 11: Assumptions used for economic evaluation. Source: Eskom-FEM-Model **(2012)**

Indicator	Assumed Figure
Discount Rate / Hurdle rate (i)	10.30%
Tax Rate	28.00%
Depreciation period for lines & cables	20 years
Depreciation period for all other plant	4 years
Dominant Load/Tariff Type	
Stellenbosch	Agricultural; Commercial
Mokopane	Mining/Quarying; Rural
Tax is deducted in the year of expenditure (resulting in a conservative approximation of NPV).	
Negative taxation ALLOWED for loss making periods	

The "indicators" in Table 11 were adopted from the FEM software as a default and were applied in both the Stellenbosch NMP and Mokopane NDP for fair and consistent comparison. The load characteristics (Dominant Load/Tariff Type) were taken from the load analysis and forecast that were presented in the original reports (Stellenbosch NMP and Mokopane NDP).

The energy profiles used are the ones readily defined in the FEM tool library and are shown in Table **12**.

Table 12: Tariff energy characteristics. Source: Eskom-FEM-Model **(2012)**

Tariff Type	**Time of Use Energy Ratios**			**Load Characteristics**	
	Peak	Standard	Off-Peak	Load factor	Power Factor
Agricultural	15%	41%	44%	0.3	0.95
Wholesale & Retail Trade (Commercial)	16%	42%	42%	0.4	0.95
Mining & Quarrying	15%	37%	48%	0.93	0.95
Domestic - Low Consumption	15%	42%	43%	0.15	0.97

The version of FEM used for this test was based on the 2012 tariff rates. This is the only template that was available during this study. For consistency, both studies were based on this template. This means that for both areas, the base year for this evaluation is assumed to be 2012.

To deal with the challenge of inconsistency in capital expenditure; the list of proposed infrastructure was taken from each study alongside its cost and this was added up to give the total capital expenditure on each case study. This total capital expenditure was used instead of the lumped figures that were mentioned in the case study reports.

5.6. Application of MCDM

It was ventilated in the literature as well as theory development, that the MCDM is a matrix used to compare more than one network planning alternatives when different attributes must be considered at the same time. These attributes may positively or negatively correlate.

For this research, the MCDM matrix was developed in section 3.5 and is presented in Table **5** (page 55). This matrix is later utilised to tabulate the results and compare GLF plan to the LM plan in section 8.4 (page 104).

For scoring of each method (GLF plan and LM plan), the scores will be sourced from the attribute performance evaluation of the load forecasting method as follows:

Electrification coverage score: the actual score will be taken from the rubric discussed in 5.3.1 above.

Voltage quality score: the actual score will be based on the lowest voltage on the power system network that will be assessed using the method discussed in 5.3.2 above.

COUE: the score for the two methods being studied will be taken directly from the results of the reliability evaluation that has been discussed in section 5.4 above.

Project profitability index: the index that will be associated with each network infrastructure plan will be used as the actual score; this index will result from the method discussed in 5.5 above.

Modified Internal Rate of Return: following the method discussed in 5.5 above, the MIRR for each power system network plan (GLF and LM) will be calculated, the results for each method will be populated on the MCDM matrix directly, for comparison.

The MCDM with the scores resulting from the evaluation of adequacy, reliability and economics of the GLF and LM methods has been presented in the results chapter (8.4).

5.7. Conclusion

The matrices that were developed in the theory chapter have been used as part of the test methodology. However, the reliability matrix was re-adapted due to the lack of data.

It became apparent that the case studies used for the test were based on 20 year load forecasts and the assessment is being carried out halfway through the forecast period.

Some data could not be directly extracted from the case study reports due to inconsistencies which make it impossible to compare them without disadvantaging either of them. In those cases, data was "corrected" and some evaluations were re-worked to ensure a fair comparative analysis. It can be concluded that the method for the evaluation of how the GLF and legacy method support the planning process was successfully set up with all the sources of data identified.

The test results are detailed in Chapter 8 of this report.

6. TEST3: PLANNED INFRASTRUCTURE VERSUS PROCURED AND CONSTRUCTED INFRASTRUCTURE

The research question, "How does the load forecast accuracy by GLF and legacy method affect the infrastructure procurement?" posed under section 1.3 of this report forms the basis for the test being carried out in this chapter. The aim is to lay bare the method and data. The results will be presented in chapter 9. In other words, this chapter is a build up towards answering the said question and will not completely provide the answer as such.

The Eskom Network Planning Standard (Bunge & du Preez, 2007) states that the role of a load forecast in distribution infrastructure planning is to give direction to the utility and puts the utility in a favourable position to procure long-lead material, acquire strategic servitudes and to ensure continuous supply to the current and envisaged load. The aspect being tested in test 3 is; to what extent did the GLF and the LM forecasts affect the procurement and ultimate construction of the infrastructure in the study areas: Stellenbosch for the GLF and Mokopane for the LM.

The literature was divided into two opposing views regarding the impact of a load forecast on the procurement and construction of infrastructure that follows as a result of the planning process. Engel & Dyson (2017), Shahida, *et al*. (2014) and Laouafi, *et al*. (2015) suggested that the load forecast error affects the procurement and construction of network infrastructure, while Willis & Northcote-Green (1984) believed that there is no correlation or impact between the load forecast and the procurement and construction program that follows.

6.1. Method

To carry out this assessment, the literature suggested two methods; the 'hindsight' method by Willis & Northcote-Green (1984) and the 'actuals' method by Carvallo, *et al*. (2016).

The actuals method that was based on the lessons from Carvallo, *et al*. (2016) was adopted, as the available data allows for such analysis. The main drawback of the hindsight method is that it is based on hypothetical "actual infrastructure" and doing planning for the network infrastructure that readily exists, as if it does not exist. This can open it up to criticism and may be vulnerable to a form of bias, if someone is driving a specific agenda. It can easily be set up to give a preconceived outcome.

The infrastructure comparison is done between the planned infrastructure and the actual infrastructure procured and constructed, by using the Stellenbosch NMP data for GLF based study and the Mokopane NDP for the LM based study. The reason for performing this comparison is to investigate how the load forecast error from the forecasting methods used, affected the procurement of the infrastructure in these areas.

To test how the two case studies deviate from the plan, a statistical measurement was done, using the MAPE method, as in the case of load forecast accuracy test.

6.1.1. Assessment approach

The infrastructure plans from each study were reviewed. A snapshot of the infrastructure at the base year was recorded. The list of the planned infrastructure was recorded as it was extracted from the capital expenditure plans of the two case studies. The existing infrastructure of 2016 was reviewed (from recent studies). The base infrastructure was "subtracted" from the 2016 infrastructure, in order to get the list of network that was commissioned between the study base year and 2016. This was taken as the actual commissioned network and was compared to the planned network, and the results were recorded. The comparison was based on Eq. **21** (page 57) which is part of the developed theory.

The difference between the planned network infrastructure and the actually procured and constructed network infrastructure was then quantified as per the MAPE.

6.1.2. Data

In the case of the Stellenbosch area, due to the lack of detailed information on the reports, the number of lines was used instead of the length of lines.

With regard to network infrastructure data, the infrastructure as it existed in 2006 and 2007 before any plans were proposed was extracted from both power system network studies and used as the base. The list of planned infrastructure was also drawn from each study. Table **13** lists the data for the Stellenbosch area that was used for this assessment.

Table 13: Stellenbosch area network infrastructure statistics, Stellenbosch NMP (2006) and (2016)

	2006 TRFR Capacity (MVA)	**Planned TRFR Capacity (MVA)[5]**	**2016 Actual TRFR Capacity (MVA)**	**2006 HV Lines (number of lines)[6]**	**Planned HV Lines (number of lines)**	**2016 Actual HV Lines (number of lines)**
Totals	230	262.5	230	13	19	17

As shown in Table **13**, the 2006 as well as 2016 data were gathered.

To establish the difference between the base years (2006 in case of Stellenbosch NMP and 2007 in the case of Mokopane NDP), the network infrastructure as it exists at present(2016), was reviewed. The differences between the 2016 network and the base network were listed, and taken as the actual infrastructure that was constructed in this period. A similar procedure and approach was followed for the Mokopane area, see Table 14 below.

Table 14: Mokopane area infrastructure - planned and actual

	New Planned TRFR Capacity (MVA)	**2016 Actual TRFR Capacity (MVA)**	**New Planned HV Lines (km)**	**2016 Actual HV Lines (km)**
Totals	600	160	306	60

[5] This value represents the total transformer capacity planned for the study area.
[6] All HV Line quantities represent the number of lines and not the line length.

It is evident from the gathered data shown in Table **13** and Table **14** that the available data in these case studies were not completely the same. For example, in the case of the Stellenbosch area, the line lengths were not available on the original report, whereas in the case of Mokopane area, the line lengths were quoted in the original report. This does not pose a threat to the assessment as the gist of the evaluation for each case study is to compare the planned infrastructure with the infrastructure that was in fact constructed in the assessment period. If the available data makes reference to, for example, 50km of lines planned, then the constructed outcomes must also be expressed in km's for the particular case study.

The two power system network studies did not cover the medium voltage level in detail. As information was not available to sufficient levels of detail, no comparison was attempted for MV networks.

6.2. Conclusion

In this test, the methodology and data were discussed. While two different case studies have been used, the process followed is the same, to ensure fair comparison. The available data makes it possible to follow the method presented by Carvallo, *et al*. (2016) when they were doing a similar assessment.

The results of this assessment are presented in Chapter 9 of this report.

7. RESULTS1: FORECAST ERROR EVALUATION

Following the test setup discussed in Chapter 4 of this report, the results subsequent to that, have been presented in this chapter. Templates and data discussed in Chapter 4 are used. The results are not discussed in this chapter, but will be elaborated on in Chapter 10.

7.1. Results for Case study 1: Stellenbosch Area Forecasts (GLF versus Legacy Method)

The load forecast error evaluation results for the Stellenbosch area case study are shown in Table **15** below.

Table 15: Stellenbosch area data: LM, GLF and Actual Loading

Year	Actual (MVA)	LM Forecast (scaled) (MVA)	LM |Actual-Forecast| (MVA)	GLF Forecast (scaled) (MVA)	GLF|Actual-Forecast| (MVA)
2005	54.62	54.62	0.00	54.62	0.00
2006	51.75	55.53	3.78	57.78	6.04
2007	55.49	60.08	4.59	61.03	5.54
2008	56.89	61.90	5.01	64.27	7.38
2009	55.74	62.81	7.06	67.68	11.94
2010	55.73	63.72	7.99	71.17	15.45
2011	55.17	64.63	9.46	74.66	19.49
2012	57.40	64.63	7.23	78.23	20.84
2013	57.11	66.45	9.33	81.88	24.77
2014	59.68	68.27	8.59	85.62	25.94
2015	59.54	71.00	11.46	89.43	29.89

Table **15** was plotted in a graph shown in Figure **13** below.

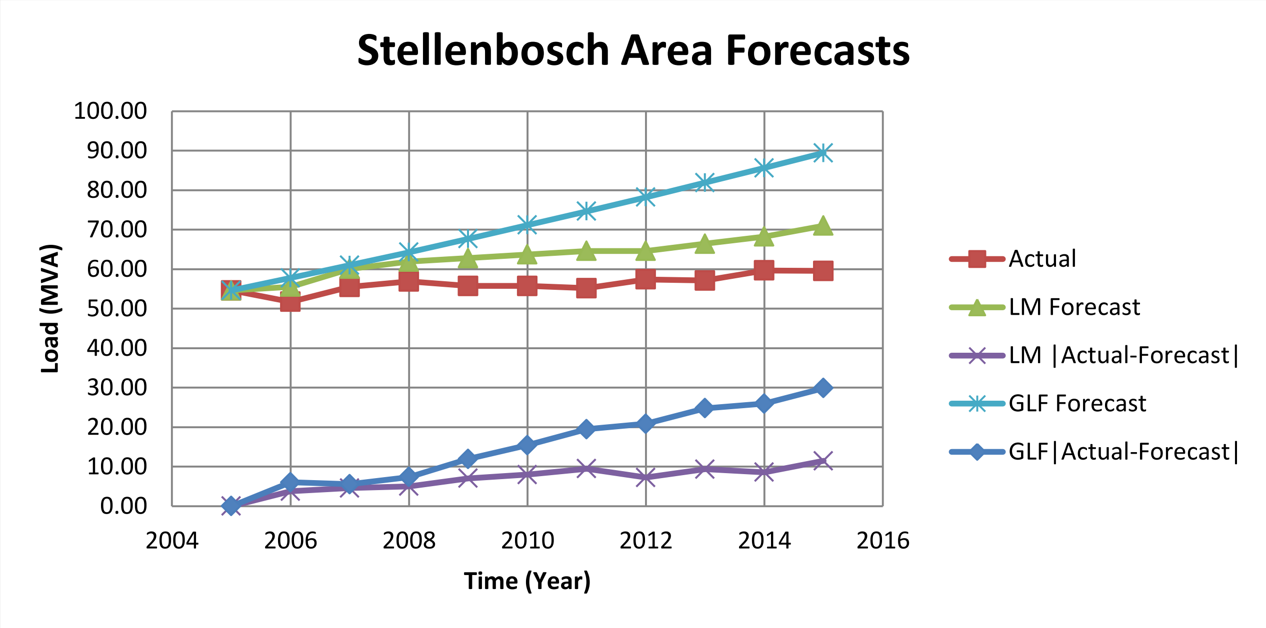

Figure 13: Graph for Stellenbosch area forecasts for GLF, LM and actual load

The load forecast error evaluation results for the legacy method and GLF method are shown in Table **16**.

Table 16: Summary results for Stellenbosch area forecast error evaluation

	LM	**GLF**
Sum(Actuals) - MVA	619.10	619.10
Sum(Error) - MVA	74.52	167.27
MAPE - %	**12.04**	**27.02**
Correlation (Forecast, Actual)	0.86	0.83

The load growth was forecasted to be **30.00%** in the period under assessment (2005 to 2015). However, the actual load for Stellenbosch grew by **9.01%** over the period of 2005 to 2015.

7.2. Results for Case study 2: Franschhoek Area Forecasts (GLF versus Legacy Method)

For the Franschhoek area, the load forecast error results are shown in Table 17.

Table 17: Franschhoek area data: LM, GLF and Actual Loading

Year	Actual (MVA)	LM Forecast (scaled) (MVA)	LM |Actual-Scaled Forecast| (MVA)	GLF Forecast (scaled) (MVA)	GLF|Actual-Scaled Forecast| (MVA)
2005	6.07	6.07	0.00	6.07	0.00
2006	6.41	6.38	0.03	6.47	0.06
2007	7.00	6.70	0.30	6.87	0.13
2008	7.71	7.03	0.68	7.36	0.35
2009	7.95	7.38	0.57	8.16	0.21
2010	8.43	7.75	0.68	9.15	0.72
2011	8.40	8.14	0.26	10.45	2.05
2012	8.76	8.54	0.22	11.64	2.88
2013	8.50	8.97	0.47	12.84	4.34
2014	8.79	9.42	0.63	13.73	4.94
2015	9.00	9.89	0.89	14.53	5.53

Plotting the data from Table 17 above, the graphs in Figure **14** resulted.

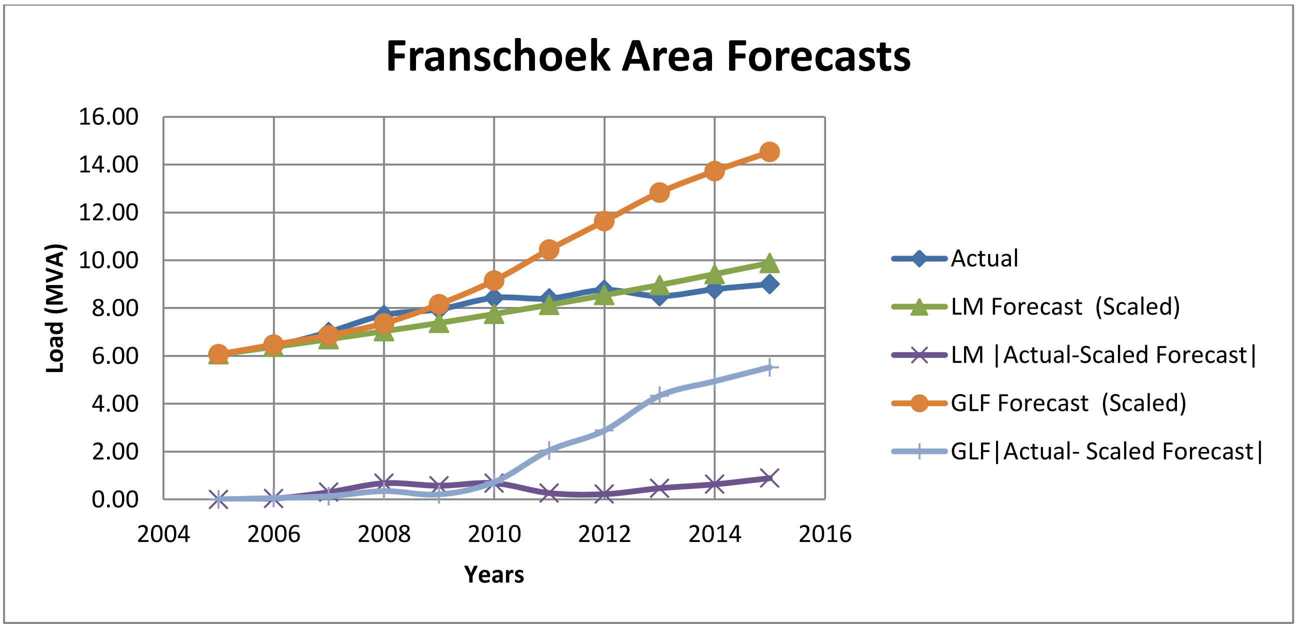

Figure 14: Graph for Franschhoek area forecasts for GLF, LM and actual load

The summary of the load forecast error evaluation for the Franschhoek area is shown in Table 18.

Table 18: Summary results for Franschhoek area forecast error evaluation

	LM	GLF
Sum(Actuals) – MVA	87.02	87.02
Sum(Error) – MVA	4.73	21.21
MAPE - %	**5.44**	**24.37**
Correlation (Forecast, Actual)	0.92	0.88

7.3. Results for Case Study 3: Mokopane Area Forecast (Legacy Method Forecast)

The comparison of the load forecast to the actual peak load for the Mokopane area gave the results shown in Table 19.

Table 19: Comparison results for the forecast and actual data for legacy method – Mokopane area

Year	Forecast	Actual	|(Forecast-Actuals)/Actuals|
2005	154.30	154.30	0.000
2010	380.90	210.00	0.814
2012	480.00	233.76	1.053
2013	530.00	238.51	1.222
2015	629.70	251.90	1.500
MAPE			**91.8%**
Correlation (Forecast, Actuals)			**0.990**
Forecast Growth Rate (Over 10 years)			**408.10%**
Actual Growth Rate (Over 10 years)			**63.25%**

The results of Table 19 are plotted graphically in Figure 15 below.

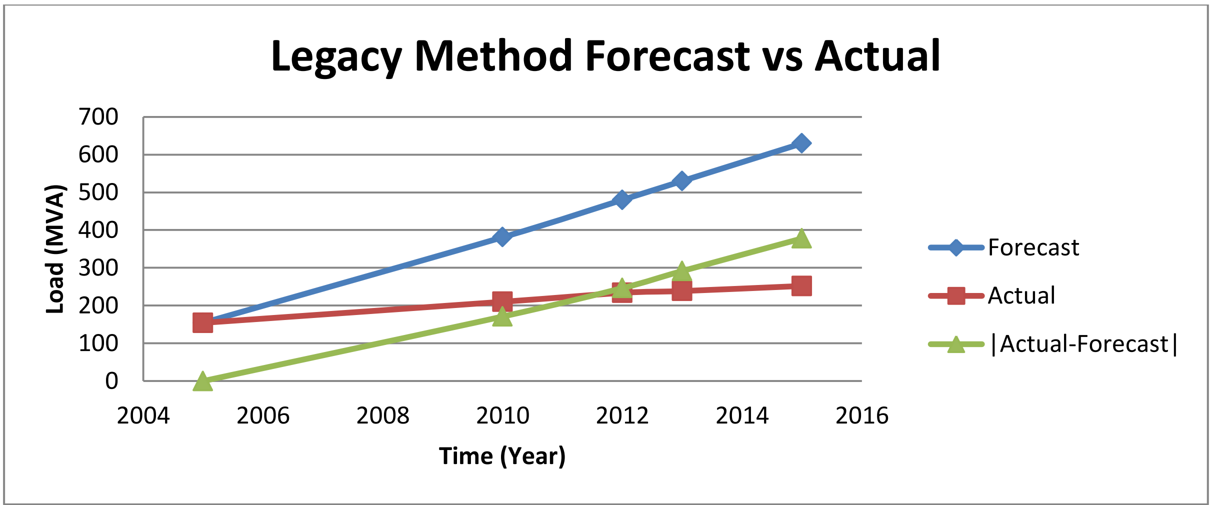

Figure 15: Graph of the legacy forecast results and actual load on the same set of axis for Mokopane study area

7.4. Conclusion

The load forecast error evaluation results have been presented. The results for Stellenbosch and Franschhoek areas showed the legacy method to have a smaller load forecast error than the competing GLF method.

The literature (Willis & Aguero, 2007) suggested that the spatial forecast methods are generally of better accuracy than trending methods, the results observed in this assessment where the same area was used for both tests are contradicting this stated expectation.

The additional test case results were also presented. For this, Mokopane study area load forecast and historical data were used. The LM forecast error for this area was recorded for the purpose of evaluating the load forecast impact on infrastructure planning, and procurement and construction.

A detailed review and discussion of these results is carried out in Chapter 10 of this report.

8. RESULTS2: LOAD FORECAST IMPACT ON DISTRIBUTION PLANNING PROCESS

The test methodology described in Chapter 5 of this report was followed to produce the results presented in this chapter. The results of the "load forecast impact on distribution planning process" are listed in this order; adequacy, reliability and lastly, economics.

8.1. Network adequacy Results

The adequate network infrastructure plan was described as the network plan that caters for connection of all customers while keeping the voltage quality within the acceptable level stated in NRS 048-2 (2007). Thus, the electrification and voltage level were selected as measures of adequacy.

8.1.1. Stellenbosch Area Case Study (GLF Forecasted)

The adequacy results regarding the GLF-based network infrastructure plan which was an outcome of the Stellenbosch Network Master Plan have been listed in the sections below.

8.1.1.1. GLF Electrification Results

The rubric method discussed in literature and adapted under theory development was used as reflected under the test set up discussed in section 5.3.1. Three criteria listed in the rubric are:

- Are Electrification assumptions comprehensive?
- Rating the sources of information used for electrification forecast.
- Rating the activities undertaken to perform the electrification forecast.

Each criterion is scored below, with justifications in line with the rubric scoring levels.

a. **Electrification assumptions comprehensiveness: *Good (3)***

The electrification assumptions and projections for the GLF forecast were based on the economic development study which was the key input into the GLF. Some of the information sets used as input to the GLF forecast are municipal SDF's and IDP's. These help to incorporate the municipal policies and plans into the study. Also, the economic development study looks at the economy in general, population growth and mortality rate. These inputs help to build up the assumption set for electrification. The economic development study gets converted using the GIS software tools to a GLF forecast. The culmination of these different inputs enables the planner to forecast the electrification load according to the customer type (such as domestic high or low income), customer position (in line with the dictates of the municipal SDF), the expected period and magnitude or a number of connections expected. The conversion of all input information into load (MVA) is based on the GLF subclass data which is in line with NRS 034-1 (2007). Based on the fact that a wide range of the information sets are used to come up the assumptions for electrification, this outcome was regarded as good, and thus the score of 3 was awarded in the rubric.

b. **Rate the sources of information used for electrification forecast: *Good (3)***

The approach followed when compiling the Stellenbosch Master Plan was that, the development perspective of the area was studied separately and, by using spatial shape files, its results were used as input to the load forecast.

Fundamentally, the development perspective is a study on how the area is likely to grow in future. The study takes into account the area demographics, macroeconomics, local economics and area spatial profile. One of the main sources that were consulted when compiling the development perspective was the municipal Spatial Development Framework (SDF).

The report, "Social Survey 2005: Stellenbosch Municipality (2005)", provided a key component input to the SDF. The Social Survey (Stellenbosch, 2005) states that, "although 92.5% and 88.2% [of the population in Stellenbosch Local Municipality] use electricity for lighting and cooking respectively, there are areas where substantial numbers use paraffin and candles. For example, on the Franschhoek Farms 15.2% use paraffin for lighting and 23.5% for cooking. Far fewer households use electricity for heating. Only 67.5% used electricity for heating. In Khayamandi, for example, 45.5% households still use paraffin for heating and in Jamestown 23.8% use wood", as indicated in the 2005 survey report (Stellenbosch Municipality, 2005). This means that, only 7.5% of the population in the municipal jurisdiction did not have access to electricity. It can be noted that this number was higher in Franschhoek as stated. These households were then included into the total load forecast (Stellenbosch Municipality, 2005).

Therefore, the forecast for domestic load was based on the following information sets, as stated by the Stellenbosch Network Master Plan (Stellenbosch Municipality, 2006):

- "Development perspective, which was also centred on the following
  - Municipal Spatial Development Framework
  - Social survey
  - Econometrics
  - Municipal IDP
- Previous planning reports,
- Historical billing information for key customers: Key Customer information (KWh and KVA readings for 2005) was obtained in hard copy for both Stellenbosch and Franschhoek. These were documented in an excel spread sheet.
- Meter factor information was obtained from the financial department and used to calculate Key customer maximum demand figures for 2005.
- Mini-substation readings for Stellenbosch were obtained and documented in an excel spread sheet,
- Load data for distribution substations and feeders were obtained from the telemetry system for both Stellenbosch and Franschhoek.
- Historical Eskom supply information (three years),
- Land-use information was obtained from GIS Global Image as well as TV3.
- Discussions with regard to new developments were also conducted with Dennis Moss and Partners.
- Development initiatives as discussed with Town Planners,
- Spatial development Framework for Franschhoek developed by Taylor, van Rensburg and van der Spuy,
- Existing power system network single line diagrams for Stellenbosch HV / MV networks.
- Ortho photos (Obtained from the Department of Land Affairs),
- Cadastral information, and

- Basic topological information".

The information sources consulted for the GLF domestic load forecast make a comprehensive list. The municipal IDP covers the short range forecast, while the SDF covers a longer range. The other sets of data that are mentioned are additional information sets that may assist the forecaster during the load forecast process. The sources are therefore regarded as the ones that go beyond the known municipal applications. A score of 3 is thus allocated according to the developed rubric.

c. Rate the activities undertaken to perform electrification forecast: *Good (3)*

The GLF method relies on the software for data conversion and forecasting.

Software

Mapping: The Stellenbosch Network Master Plan (Stellenbosch Municipality, 2006) stated that the following tools were used for mapping:

- "All mapping and geographical presentation of information and data was done using ESRI ArcMap 9" and
- Microstation CAD Ver8.0.

These information sets were consolidated by means of geographic information system (GIS) shape files in order to accurately work out the position and magnitude of the associated load forecast in PowerGLF.

The SDF process starts by identifying and showing the vacant land which will potentially be developed in the future. To demonstrate the process, the existing SDF which was compiled in 2007 for Klapmuts town which is situated in the Stellenbosch municipal demarcation area, was used. See Figure **16** below.

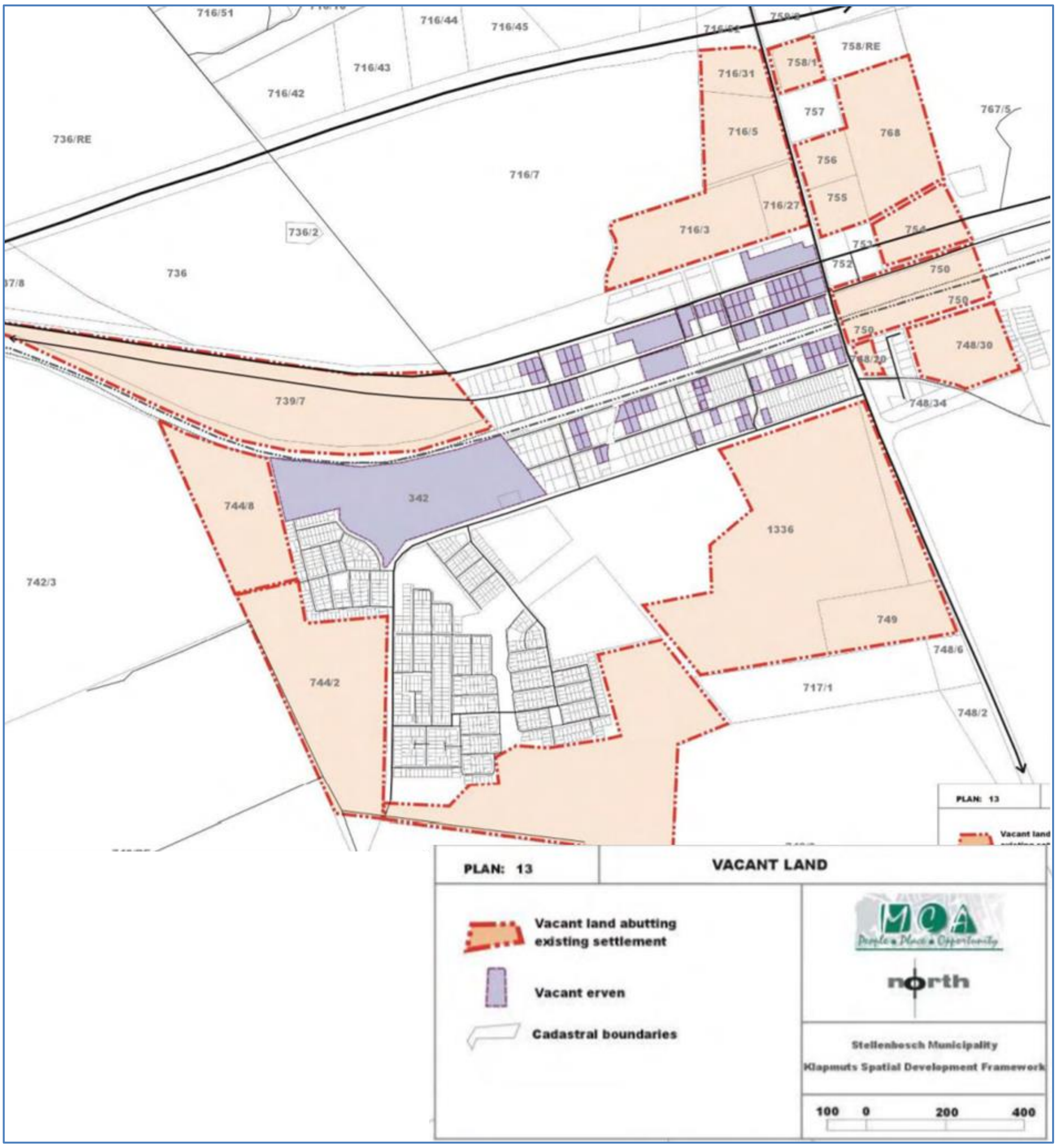

Figure 16: Vacant land map for Klapmuts SDF (2007)

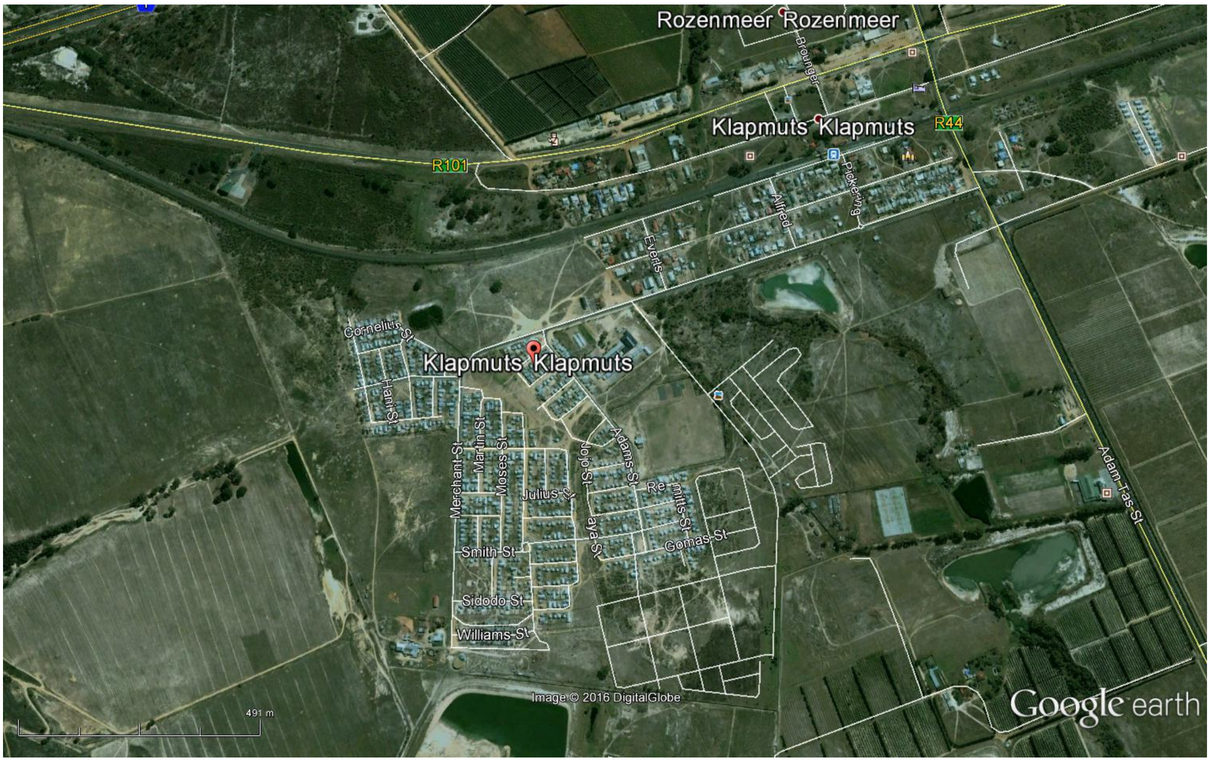

Figure 17: Google Earth map for Klapmuts showing the 2005 view

Figure **16** profiles the area in terms of development space still available. This is at the beginning of the SDF process. The satellite imagery for the same area in 2005 is shown in Figure **17**.

After carefully studying the area, and comparing the development needs versus the available land and also ensuring that the development of the land is done in a sustainable manner that caters for social, economic and environmental needs, the spatial proposals (the framework) are completed and released. This is demonstrated in Figure **18** below (Stellenbosch Municipality, 2007).

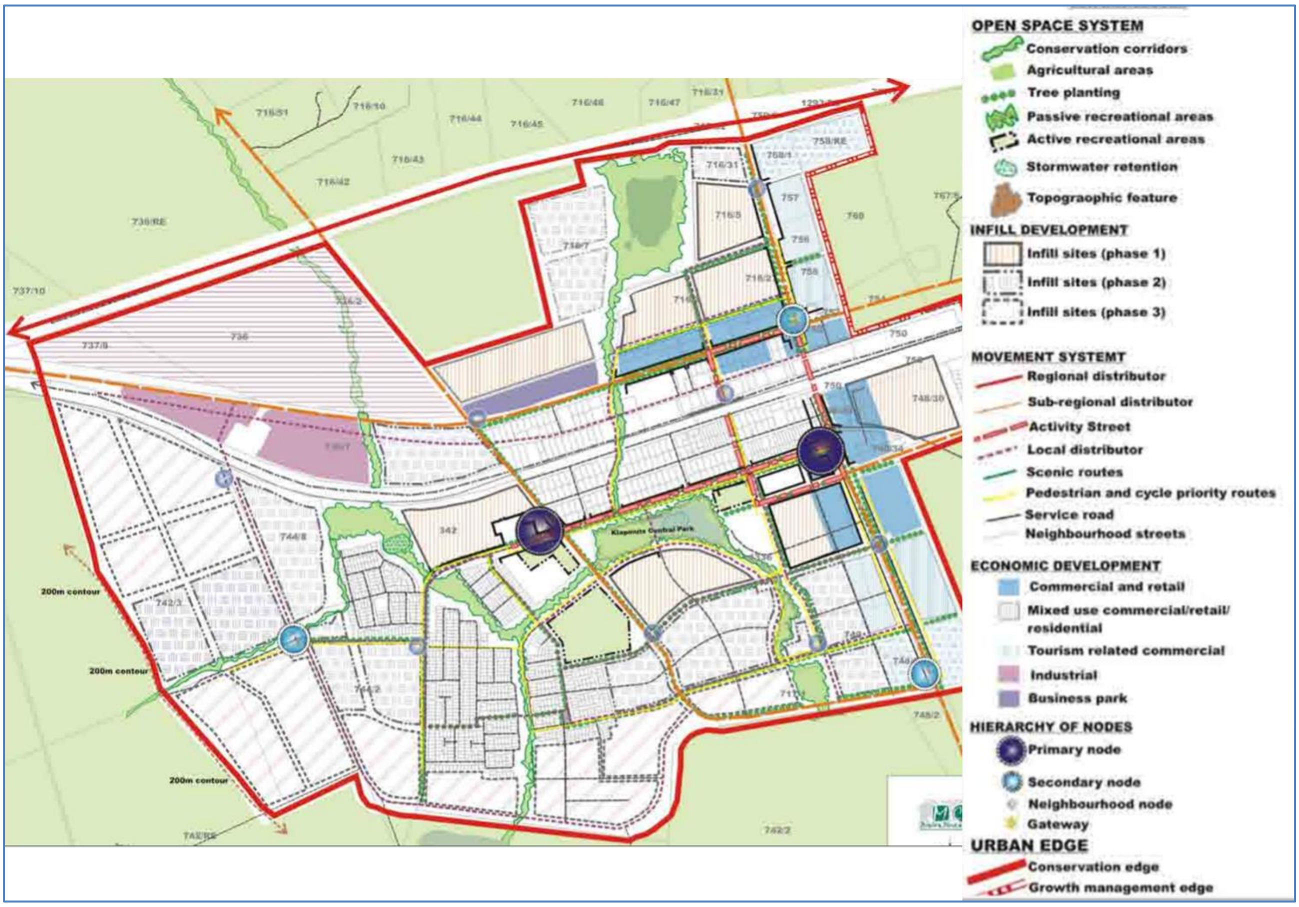

Figure 18: Spatial proposals for Klapmuts SDF, Stellenbosch Municipality (2007)

Figure 19: Google Earth map for Klapmuts showing 2016 view

The data set above (Figure **18**) shows development type (load type), position of the development and the extent of the development (load magnitude). For accuracy, this information is used in a GIS shape file format or .dgn format, and used as input to the PowerGLF. More details on how the information gets converted into a load (MVA) were discussed in the literature review of this report. Figure **19** shows the actual 2016 satellite view for Klapmuts.

However, if Figure **18** can be assumed to be the forecast (as it was stated that the load forecast was based on the SDF) then Figure **19** can be taken as the actual development that was built during the period under review. When these views are compared by means of a visual inspection, it can be seen that the developments on the south of the urban edge have materialised according to the forecast, and the river stream buffer has been complied with as shown in the forecast. However, the actual percentage accuracy cannot be calculated as these data sets are shape files and are not physical quantities.

The use of digital GIS shapefiles, the inclusion of environmental sensitivity considerations at forecasting level as well as at the ultimate development construction level, and the use of the software tools mentioned above, show that the activities undertaken to perform the electrification forecast have scientific merit. This is assigned a score of 3 according to the rubric.

In summary, the following scores were allocated to the GLF using the rubric, see Table 20 below.

Table 20: Rubric scoring for GLF's electrification assessment

Question	Insufficient/Not evident (Score=1)	Sufficient (Score=2)	Good (Score=3)
Electrification assumptions comprehensive?	No information presented about electrification	Information presented takes into account all existing electrification applications	Information presented shows scientific methods of forecasting electrification needs ✓
The sources of information used for electrification forecast.	No sources of information shown or discussed in the study report.	Basic electrification backlog from the municipality was used.	Advanced methods that go beyond the known municipality applications were used. ✓
Activities undertaken to perform electrification forecast.	No activities evident towards electrification forecast	Direct addition of connection applications from the municipalities/ customers/ tribal authorities	Scientific (such as statistical) or other means of comprehensive predictive algorithms are presented. ✓
Sub-Total			9
Total	9		

The total score for the rubric assessment was calculated to be 9, as reflected in Table 20 above.

8.1.1.2. GLF Quality of Supply

The criteria followed in the Stellenbosch Master Plan with regard to the voltage quality was that the voltage at the customer point shall not exceed 105% of nominal voltage, and not fall below 95% of nominal voltage during normal operational and maintenance conditions. The study allows for the maximum voltage deviation of +/-10% during unplanned outages (Stellenbosch Municipality, 2006).

These limits were used as input information into the study, meaning that, if the power system network alternative violated these conditions, then it was not considered a feasible alternative.

When the power system network constraints were reviewed, it was learnt that none of them related to voltage issues. This is mainly due to the fact that the power system networks in the study area were made up of relatively short MV lines, and therefore no significant voltage drops that may lead to voltage deviations contravening NRS 048-2 (2007), were experienced on these power system networks. The highest voltage from the 2006 Master Plan was simulated to be 11.5kV (105%). This was the voltage simulated with the recommended additional strengthening in place. Thus, according to the voltage scoring matrix (Figure **6** on page 48), the voltage score for this power system network is:

$$Voltage\ Score_{105\%} = 95$$

This score was captured in the MCDM matrix for comparison with the Mokopane NDP (LM based).

8.1.2. Mokopane Area Adequacy Assessment Results

The Mokopane NDP was done based on the legacy method of load forecasting. The outcomes regarding adequacy of the infrastructure plans from this study are listed in the subsections below.

8.1.2.1. Legacy Method Electrification Results

Following the developed rubric as done in the case of Stellenbosch NMP, the following results were achieved.

a. Electrification assumptions comprehensive: *Good (3)*

The Mokopane Network Development Plan forecasted the population to increase at a rate of 1.5% as had been the case in the years prior to the study. The review also expected more residential load growth as a result of the mines that were foreseen to start operating in the near future as stated in their electricity connection applications. The NDP mentioned that a domestic load of 10.5MVA was to have been expected within the 10 year forecast period.

The assumptions for the electrification forecast went beyond existing electrification program, and the trending method was accordingly used. The gravitational impact of the forecasted mining developments was also factored into the load forecast. Based on this assertion, it can be declared that the assumptions presented in the Mokopane NDP study shows scientific methods of forecasting for the electrification needs. Therefore, a score of 3 is awarded on the rubric.

b. Rate the sources of information used for electrification forecast: *Good (3)*

The NDP took the municipal Integrated Development Plan (IDP) into account when forecasting the domestic load. The forecast also incorporated the house connection applications as per the electrification plan, and which is revised on an annual basis.

The domestic load projections were therefore based on the following information sources:

- Population projections from previously known STATS SA figures (indicate a 1.5% growth per annum),
- Municipal Integrated Development Plan,
- Electrification Planning information from within Eskom,
- Planners knowledge of the study area,
- After Diversity Maximum Demand (ADMD) planning assumptions of 1.5kVA for all domestic connections.

It can be noted that the IDP and Electrification Planning department reflect the current parameters and electrification growth forecasts as found in the municipal records. The Planner's knowledge of the area is a source of information that cannot be repeated if another Planner were to be doing a forecast in the same study area. The projections based on STATS SA are however repeatable and can be traced back to the source information. The only additional source of information that goes beyond the basic backlog data from the municipality, as presented by the NDP, is the STATS SA projection. According to the rubric, a score of 3 is accorded to this item.

c. Rate the activities undertaken to perform electrification forecast: *Good (3)*

To forecast the electrification load growth, the following activities were undertaken in the Mokopane NDP:

- Collection of backlogs from the municipality and Eskom Electrification Planning department
- Addition of the backlogs to create a forecast
- Factoring an annualised growth of 1,5% into the existing population (based on the trends from STATS SA)
- Application of the planner's knowledge of the area
- Multiplication of the number of forecasted households by the ADMD of 1.5kVA.

The above listed activities show that the forecast was not done by simply adding electrification applications. Population studies and forms of trending were used to carry out the long term predictions. According to the proposed rubric, a score of 3 is awarded in this instance.

The scoring rubric for the electrification aspect of the Mokopane NDP is presented in Table 21.

Table 21: Rubric scoring for legacy method electrification assessment

Question	**Insufficient/Not evident (Score=1)**	**Sufficient (Score=2)**	**Good (Score=3)**
Electrification assumptions comprehensive?	No information presented about electrification	Information presented takes into account all existing electrification applications	Information presented shows scientific methods of forecasting electrification needs ✓
The sources of information used for electrification forecast.	No sources of information shown or discussed in the study report.	Basic electrification backlog from the municipality was used.	Advanced methods that go beyond the known municipality applications were used. ✓
Activities undertaken to perform electrification forecast.	No activities evident towards electrification forecast	Direct addition of connection applications from the municipalities/ customers/ tribal authorities	Scientific (such as statistical) or other means of comprehensive predictive algorithms are presented. ✓
Sub-Total			9
Total	9		

The total score for the legacy method on electrification is 9, as shown in Table 21 above.

8.1.2.2. Quality of Supply

The Mokopane Network Development Plan study is based on the specification that the voltage shall not deviate by more than +/-10% of the nominal level. These are the limits that are set as non-negotiable when the study is being setup. This is specified by NRS 048-2 (2007).

Mokopane NDP (Eskom Distribution, 2007) states that, to study the future voltage levels on the power system network, the power system network was modelled on a load flow simulation tool. The existing network was populated with the envisaged load (which was forecasted using the LM forecast method). After realising overloading in certain parts of the power system network and low voltages in other parts, as a direct result of the envisaged load increase, new substations and lines were proposed to mitigate these constraints. This is the network whose adequacy is being evaluated by this research, the planned power system network.

With the proposed network strengthening, the lowest simulated voltage on the power system network is said to be 94.8% (Eskom Distribution, 2007). The lowest voltage is anticipated to take place at the end of the 20 year forecast period of the NDP. Also, the anticipated 94.8% voltage is said to be on the 33kV network, resulting from a high number of electrification connections that are forecast to be connected on these networks. The 66 kV network in the study area, starts off with a voltage level of 86% at SS3, but improves to 101.5% due to the proposed network upgrade that is proposed by the NDP, see Figure **20** for orientation.

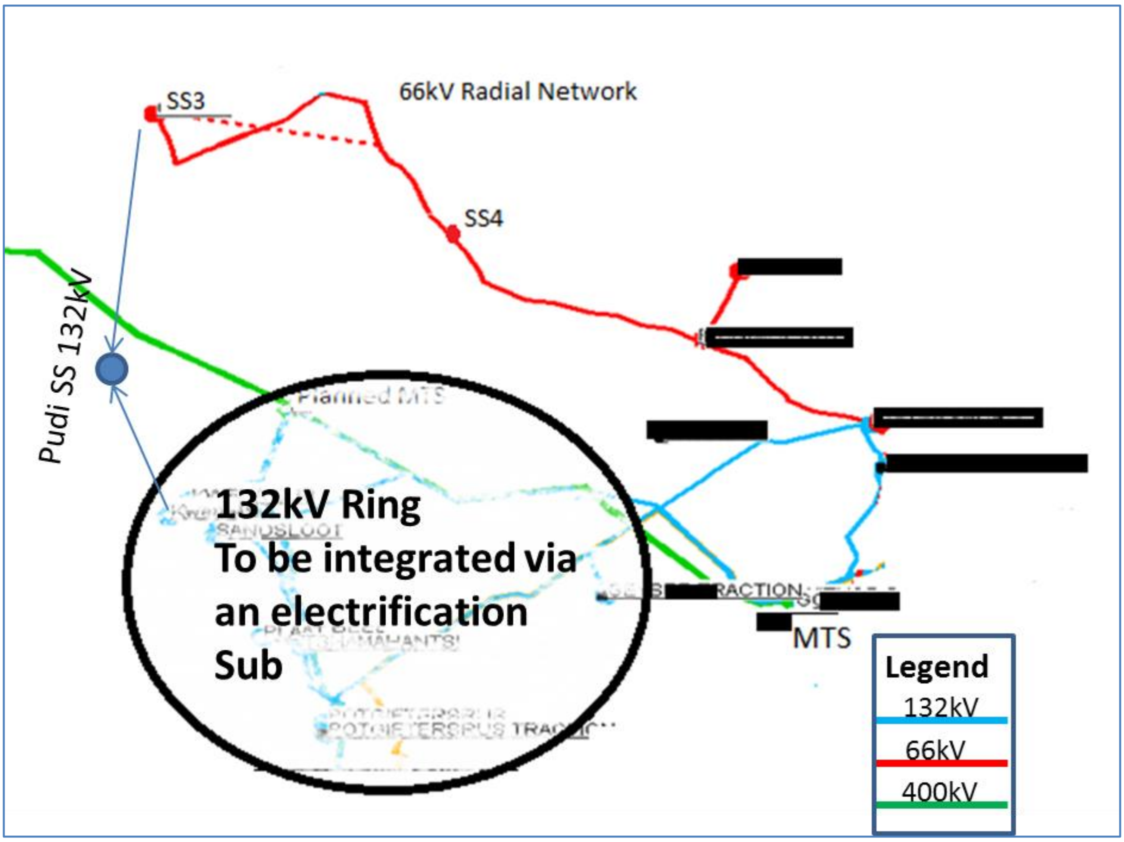

Figure 20: Geographical view of the constrained network with proposed substation

Therefore, according to the NDP, the lowest voltage level simulated on the power system network, having implemented the proposed solution, is 94.8%. In terms of scoring this performance, reference is made to (Figure **6** on page 48). Using Eq. 7, then

$Volt\ Score = 10\ VoltLevel - 900$, {91% ≤ VoltLevel ≤ 100%}

= 10*94.8-900

=48

This value was then captured in the MCDM (Table 30) alongside the legacy method for voltage quality.

8.2. Network Reliability Results

The results of the reliability analysis follow after the test setup is discussed in section 5.4.

8.2.1. GLF Forecasted Area Results for Reliability Assessment

The load data for the Stellenbosch area is shown in Table 22 below. This load data was used as input into the FEM model for reliability evaluation.

Table 22: Load data for Stellenbosch area for reliability assessment

Customer Class (C. Class)	Energy Mix$_{C.Class}$ (%)	COUE$_{C.Class}$ (R / kWh)
Industrial / Mining	0%	R 27.58
Commercial	**60%**	**R 21.48**
Agricultural / Rural	**40%**	**R 6.31**
Residential	0%	R 3.13
Traction	0%	R 1.69

Table 22 was extracted from the FEM model and populated with the data applicable in the Stellenbosch area. The "Energy Mix$_{C.Class}$" column represents the load mix in the Stellenbosch area and the COUE$_{C.Class}$ column shows values or COUE as per customer class as available in the FEM library.

The aggregate load and power factors, respectively, as extracted from the economic analysis model library are:

Average Total Load Factor = 0.40

Average Total Power Factor = 0.95

The capital expenditure for the reliability as shown on the Stellenbosch NMP report:

Capex (in 2012/13 Rand value) R 36 131 800

Risk Alleviated (also known as load at risk):

Table 23: Details of the risk to be alleviated for the Stellenbosch area

Scenario name (Years)	**5**	**10**	**15**	**20**	**25**
Risk Alleviated (kVA)	47 400	61 300	77 500	93 900	103 500
Outage Duration (Hrs)	36	36	36	36	36
Outage Frequency per annum	0.45	0.45	0.45	0.45	0.45
kWh lost per annum	**293 740**	**379 879**	**480 271**	**581 902**	**641 394**

In Table 23, the "Risk Alleviated" is actually the load forecast of the substations under the evaluation. It was extracted from the Stellenbosch NMP load forecast. Scenario name (Years) refers to the years under study (forecast years). The "Outage Duration" and "Outage Frequency per Annum" were derived in section 5.4. The model uses Eq. 23 (page 73) to calculate the "kWh lost per annum" and it is also termed "expected energy not served". The discussed data was used by the FEM model to calculate BECOUE.

The model calculated the weighted cost of unserved energy from Table 22 using Eq. 12 as follows:

$$COUE = \frac{60 * 21.48 + 40 * 6.31}{100}$$

= 15.41 R/kWh

The results for BECOUE and the weighted COUE for the Stellenbosch area are tabulated in Table 24.

Table 24: BECOUE and COUE results for the GLF area

BECOUE (R / kWh)	R 6.46	R 5.00	R 3.95	R 3.26	R 2.96
Weighted COUE (R / kWh)	R 15.41	R 15.41	R 15.41	R 15.41	R 15.41

Both Table 23 and Table 24 are standard tables extracted from the FEM model and populated with the data for the Stellenbosch area.

As shown in Table 24, the final results of the reliability assessment for the Stellenbosch NMP show that the weighted cost of unserved energy is less than the BECOUE.

Calculating the sensitivity % for the purpose of the MCDM, Eq. 14 (page 52) was used as follows:

The sensitivity of the results can be expressed as:

$$Sensitivity = \frac{COUE - BECOUE}{COUE} \times 100\%$$

$$Sensitivity = \frac{15.41 - 6.46}{15.41} \times 100\%$$

= +59.83%

This value will be populated in the MCDM matrix for comparison with the Mokopane area NDP.

8.2.2. Legacy Method Forecasted Area Results for Reliability Assessment

The reliability assessment was carried out using the Mokopane NDP which was compiled using the legacy method. The load mix and corresponding COUE per customer class for the Mokopane area are tabulated in Table 25.

Table 25: Load data for Mokopane area for reliability assessment

Customer Class (C. Class)	Energy Mix$_{C.Class}$ (%)	COUE$_{C.Class}$ (R / kWh)
Industrial / Mining	**90%**	**R 27.58**
Commercial	0%	R 21.48
Agricultural / Rural	0%	R 6.31
Residential	**10%**	**R 3.13**
Traction	0%	R 1.69

The Mokopane NDP area is predominantly a mining area with some residential customers that mainly work in the mines.

Using the data in Table 25 and Eq. 12, the weighted cost of unserved energy was calculated by the FEM model as follows:

$$COUE = \frac{90 * 27.58 + 10 * 3.13}{100}$$

COUE = 25.14 R/kWh

The aggregate load and power factors, respectively, as extracted from the economic analysis FEM model library:

Average Total Load Factor = 0.92

Average Total Power Factor = 0.95

The reliability capital expenditure for Mokopane NDP is as follows:

Capex (in 2012/3 Rand value) = R192 600 000

Risk Alleviated:

Table 26: Details of the risk to be alleviated for the legacy area

Scenario name (Years)	2005	2010	2015	2020	2025
Risk Alleviated (kVA)	80 800	158 800	290 400	355 300	393 900
Outage Duration (Hrs)	36	36	36	36	36
Outage Frequency per annum	0.45	0.45	0.45	0.45	0.45
kWh lost per annum	1 151 658	2 263 407	4 139 127	5 064 159	5 614 332

From Table **26** above:

- Scenario name (Years) refers to the years under study (forecast years).
- Risk Alleviated (kVA) refers to the load forecast for the substations for which n-1 is being proposed.
- Outage Duration (Hrs) is the value for the average outage duration that was derived in a real power system network for the purpose of reliability assessment.
- Outage Frequency is the value for the average outage frequency that was derived in a real power system network for the purpose of reliability assessment.
- kWh lost per annum is the total energy that can be lost per annum based on the forecasted annual peak, outage duration and outage frequency. These values are calculated by the model.

The model was used to calculate the BECOUE for the Mokopane area and the results are tabulated alongside the weighted cost of unserved energy in Table **27**.

Table 27: BECOUE and COUE results for the legacy area

BECOUE (R / kWh)	R 8.78	R 4.47	R 2.44	R 2.00	R 1.80
Weighted COUE (R / kWh)	R 25.14	R25.14	R 25.14	R 25.14	R 25.14

The sensitivity % was calculated as follows:

$$Sensitivity = \frac{COUE - BECOUE}{COUE} \times 100\%$$

$$Sensitivity = \frac{25.14 - 8.78}{25.14} \times 100\%$$

$$\text{Sensitivity} = +65.07\%$$

The value will be used in the MCDM to represent the reliability evaluation attribute for the legacy method.

8.3. Results of Economic Evaluation

The outcomes of the economic evaluation of the Stellenbosch NMP (GLF based) and the Mokopane NDP (legacy method based) areas have been listed in this section.

8.3.1. Economic Input Data

The following data was used as input to the FEM model for economic evaluation.

a) Load Growth: as per load forecasts for the 2 areas. Figure 21 and Figure 22 show the load forecasts for Mokopane area and Stellenbosch area respectively.

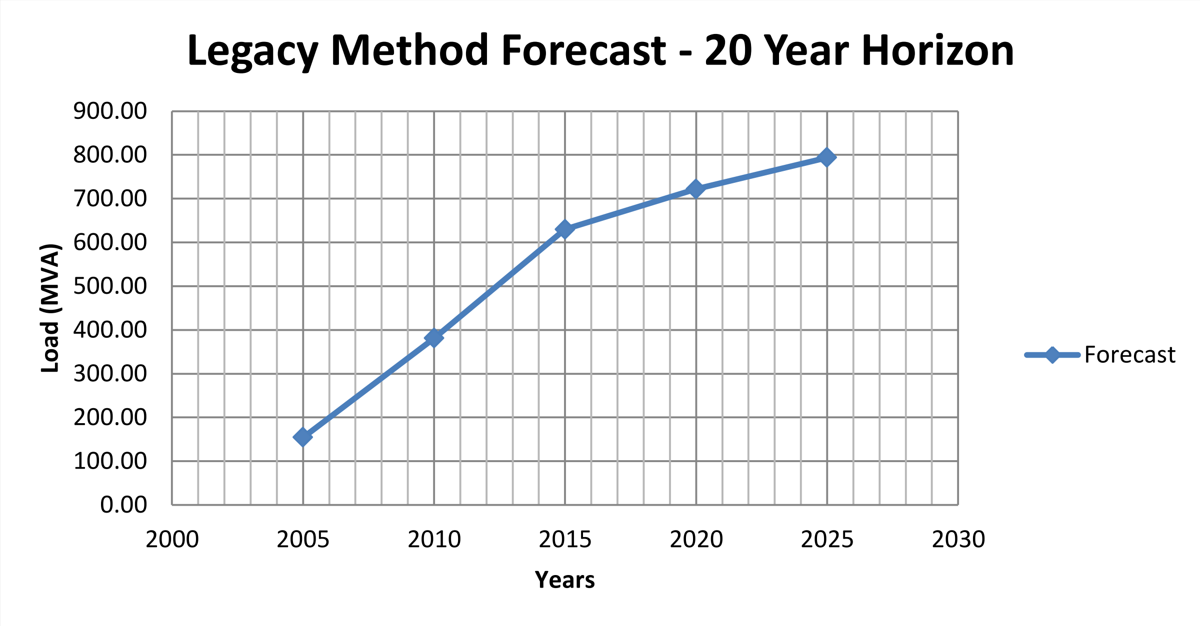

Figure 21: Load forecast for the legacy method area (Mokopane) covering 20 years

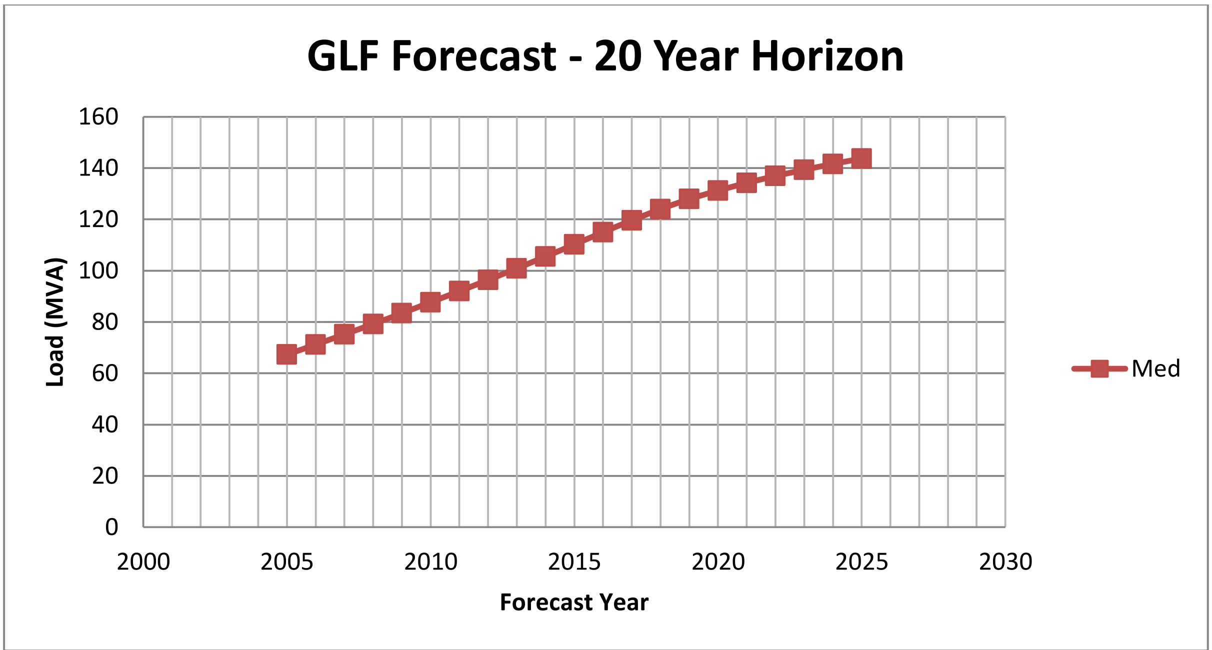

Figure 22: Load forecast for the GLF method area (Stellenbosch) covering 20 year forecast horizon

The FEM model converts these load forecasts into energy and sales based on the tariff and energy characteristics discussed under the Methodology chapter.

b) Capital Expenditure Plan for the 2 areas was used.

Mokopane area capex total = R 706 700 000.00

Figure 23 and Figure 24 show the capital expenditure plan as projected by the Mokopane NDP and Stellenbosch NMP respectively.

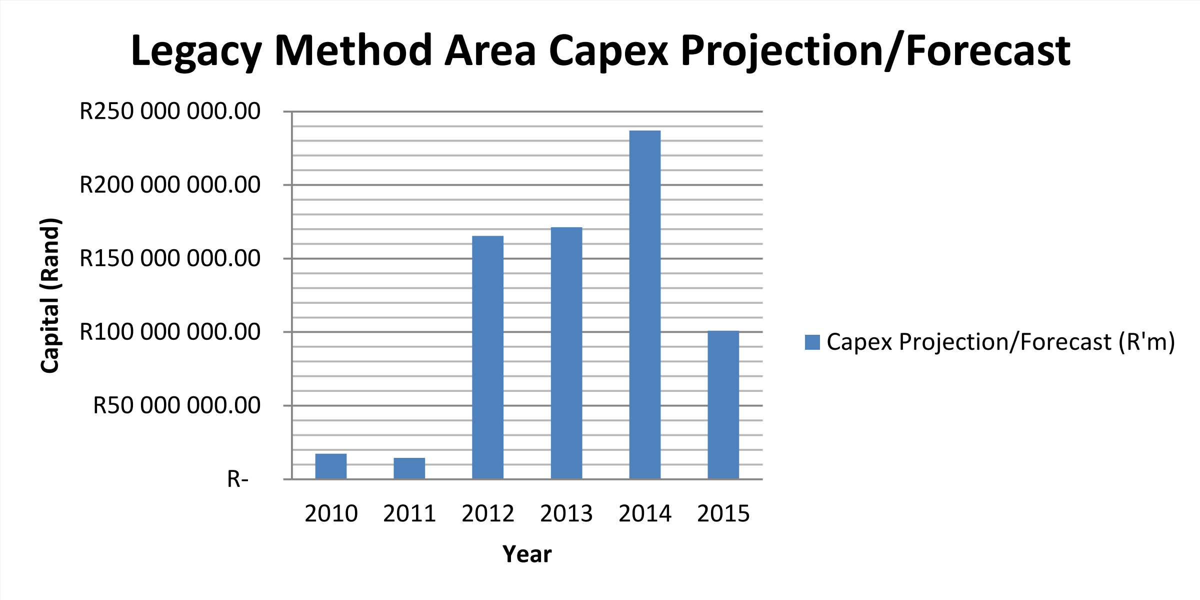

Figure 23: Legacy area capital expenditure plan

Stellenbosch area total capex = R 78 868 360.00

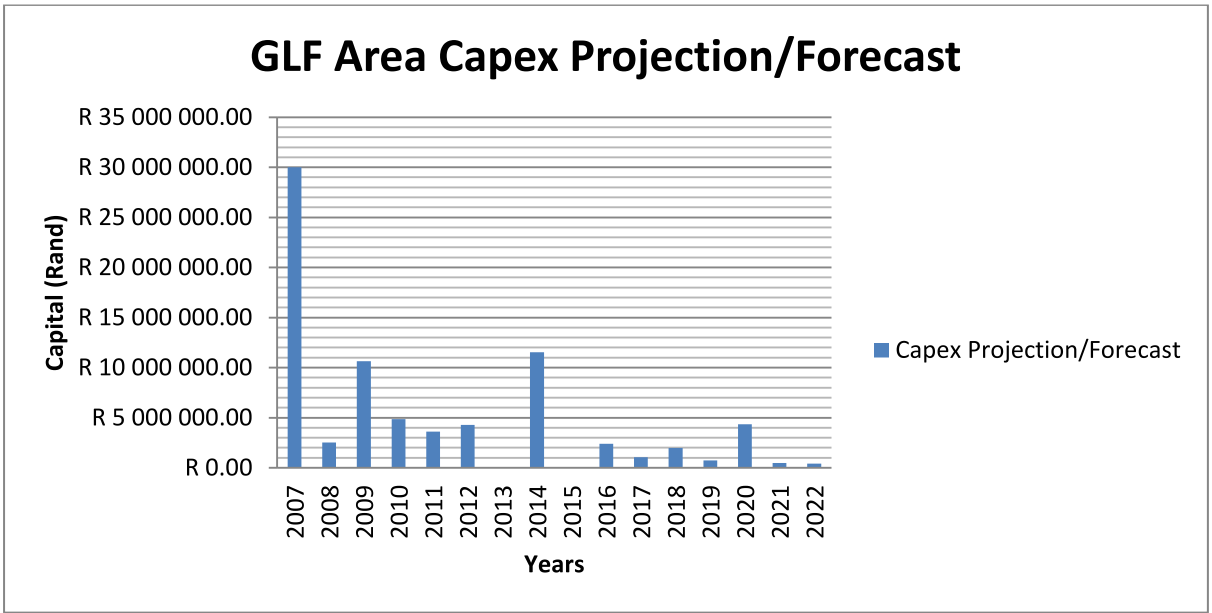

Figure 24: GLF area capital expenditure plan

The capital expenditure plan (capex) accounts for the largest cash outflow.

c) Customer Upfront Payment: this amount refers to the customer contribution towards the capex fund and is the infrastructure that is financed by the customer. The customer upfront payment amount could not be established for the GLF area as it is not stipulated in the

Stellenbosch NMP report. This amount has thus been assumed to be zero in both areas to ensure a fair comparison. The evaluation will now assume that the capex will be funded by the utility in full. This is not expected to affect the integrity of the assessment, and if one were to repeat the assessment, it could be done with or without the customer upfront payment allocation.

8.3.2. Economic Model results

Results for the Mokopane (legacy forecast) area is shown in Table 28 below:

Table 28: Economic results for the legacy area

Project PI	1.5
Project MIRR	12.0%

The Stellenbosch (GLF) area infrastructure plan economic evaluation results are shown in Table **29**:

Table 29: Economic results for the GLF area

Project PI	1.0
Project MIRR	10.5%

As was explained under theory (section 3.4), the results for the PI and MIRR for the case studies being evaluated will be used directly as scores in the MCDM. Both these indices have positive desirability with regard to the MCDM matrix.

8.4. Consolidated Multi Criteria Decision Making Matrix Results

After each of the attributes of the ARE matrix was derived under the theory development in Chapter 3, the method and data to be used to evaluate it was described in Chapter 5, and the results presented in this Chapter (8), the MCDM was then populated with the scores (results) from each of the attributes.

- **Adequacy**: The *electrification coverage* results as presented in 8.1.1.1 and 8.1.2.1 were populated in the matrix. The actual scores for electrification coverage are 9 for the GLF study and 9 for the LM study. The *voltage quality* scores as presented in 8.1.1.2 and 8.1.2.2 are 95 for GLF and 48 for LM.
- **Reliability**: The COUE (sensitivity) values presented in 8.2 were used in the MCDM matrix; the actual scores are 59.83 for GLF and 65.07 for LM.
- **Economics**: the PI and MIRR for each network investment plan were calculated and results presented in 8.3.2. The PI for the GLF study was 1.00 and 1.50 for the LM study. These values were populated into the MCDM matrix. The MIRR was calculated to be 10.50 for the GLF study and 12.00 for the LM study.

All attributes presented in the matrix have a positive desirability. The resulting MCDM is shown in Table 30 below.

Table 30: MCDM results for the ARE Matrix

			Evaluation Criteria Scores			
Criteria		**Weight**	**GLF**		**LM**	
			Actual Score	**Weighted Score**	**Actual Score**	**Weighted Score**
Adequacy	Electrification Coverage	9	9.00	81.00	9.00	81.00
	Voltage Quality	8	95.00	760.00	48.00	384.00
Reliability	COUE	16	59.83	957.28	65.07	1041.12
Economics	Project Profitability Index	5	1.00	5.00	1.50	7.50
	Modified Internal Rate of Return	5	10.50	52.50	12.00	60.00
Desirability score				1855.78		1573.62

Refer to Table 30 above; the desirability score is a sum of weighted scores for the respective power system network investment plans.

8.5. Conclusion

The results of evaluating how the load forecasting methods support the planning of adequate, reliable and economic infrastructure network plans were listed. Each criterion was evaluated separately and later combined in the same matrix, called the multi criteria decision making (MCDM) to assess the net effect of the different attributes. The results are discussed in detail in Chapter 10 of this report.

9. RESULTS3: PLANNED NETWORK INFRASTRUCTURE VERSUS PROCURED NETWORK INFRASTRUCTURE

The comparison of the planned infrastructure against the actual procured and constructed infrastructure was performed and the results for the two case studies are listed in sections below.

9.1. GLF Area

The statistics regarding planned and constructed infrastructure were gathered and listed in Table **31**. This table has been copied from Table **13** for convenience of reference.

Table 31: Stellenbosch area planned and constructed infrastructure record

	2006 TRFR Capacity (MVA)	**Additional planned TRFR Capacity (MVA)**	**2016 Actual TRFR Capacity (MVA)**	**2006 HV Lines (number of lines)[7]**	**Additional planned HV Lines (number of lines)**	**2016 Actual HV Lines (number of lines)**
Totals	230	32.5	230	13	6	17

Refer to Table **31**:

According to the Stellenbosch NMP, the total transformer capacity on the base year (2006) was 230MVA. An additional transformer capacity of 32.5MVA was planned. However, in 2016, the total transformer capacity for the study area was still 230MVA (same as 2006). This means that none of the planned new capacity was procured and constructed.

With regard to HV lines, the total number of HV lines in the study area in 2006 was recorded to be 13. The plan was to build 6 new HV lines. In 2016, a total of 17 HV lines existed. This means that out of 6 planned HV lines planned, 4 were actually procured and constructed. This translates into 66.67% construction of the planned lines. For the whole study area, the comparison between the planned and procured network infrastructure can be calculated using Eq. **26** which was introduced as part of the theory:

$$Total\ \%\ plan\ constructed = \frac{\sum Constructed}{\sum Planned} * 100\% \qquad \text{Eq. 26}$$

$$= \frac{0+4}{32.5+6} * 100$$

= 10.39%

It can be concluded that only 10.39% of the GLF-based network infrastructure plan was in fact procured and constructed.

[7] All HV Line quantities represent the number of lines and not the line length.

9.2. Legacy Method Area

The extraction of network infrastructure statistics for the Mokopane area is presented in Table **32** below.

Table 32: Mokopane area planned and constructed infrastructure record

	New planned TRFR Capacity (MVA)	2016 Actual TRFR Capacity (MVA)	New planned HV Lines (km)	2016 Actual HV Lines (km)
Totals	600	160	306	60

As summarised by Table **32**, the Mokopane NDP alluded to the fact that there was 600MVA of planned new transformer capacity, and it was found that 160MVA of that was constructed in the period 2007 to 2016. This means that 26.67% of the planned transformer expansion capacity was actually constructed in Mokopane.

With regard to HV line capacity expansion, the Mokopane NDP stated that 306km of new HV lines were planned of which 60km was actually constructed. This amounts to 19.61% of the planned lines that were constructed within that period.

Using Eq. **26** to calculate the overall percentage of the planned network infrastructure that was constructed as per the plan,

$$Total\ \%\ plan\ constructed = \frac{160 + 60}{600 + 306} * 100$$

= 24.28%

Therefore, 24.28% of the LM-based network infrastructure plan was actually constructed in Mokopane area.

9.3. Conclusion

The results for comparison of planned infrastructure versus procured and constructed have been listed.

The GLF based network infrastructure plan saw 10.39% of itself being procured and constructed, while the LM based plan had its 24.28% actually constructed.

10. DISCUSSION

This research evaluates the GLF against the legacy method in three main aspects; the load forecast error, ARE and network infrastructure procurement and construction. The test procedures for each aspect were discussed in chapters 4 to 6; followed by the results in chapters 7 to 9. The overview of the test setup for this research is shown in Figure 8 on page 59. Additionally, the cost comparison between the GLF method and the LM method is carried out in Section 10.5.

This chapter interprets and discusses the results. It also reviews the results by comparing them to the literature and known practices.

10.1. Forecast Error

The literature regarding differences between load forecasting methods could not identify which method can be expected to be more accurate than another, in all situations.

Willis, *et al*. (1995) established that the simulation method was more accurate than the simple trending method. Willis (2002) also found that the spatial forecast method was more accurate than the trending method. Consistent with these two works, Willis & Aguero (2007) did a survey of forecasting methods, and suggested that the GLF approach was more accurate than the use of the trending method.

The opposing view from Lifeng and Zhenyu (2005) suggested that a trending method that they developed was more accurate than the spatial method. Shahida, *et al.* (2014) simply pointed out the downfalls of the end-use method and econometrics methods, but they did not present a comprehensive comparison in terms of the relative load forecast errors between the end-use method and the trending method.

The forecast error evaluation results for the two case studies that were evaluated in this research are listed in Table 33.

Table 33: Forecast error results for Stellenbosch and Franschhoek area

	LM	GLF
MAPE (%) (Stellenbosch Area)	12.04	27.02
MAPE (%) (Franschhoek Area)	5.44	24.37

It is evident, as presented in Table 33, that the LM forecast method has a lower MAPE when compared to the GLF. For both case studies, the forecasts being compared are for a 20 year horizon; with both being evaluated approximately 10 years after the forecasts were done.

The results are consistent in the two case studies, that the LM forecast was more accurate than the GLF forecast with regard to load forecast error.

While the global recession that took place in 2009 did not have a visible impact on the load (read from the historical values) for the study areas, it was observed from the load forecasts that none of them considered its possibility. As a result, while the error magnitudes differed, both forecast methods in Stellenbosch and Franschhoek study areas overstated their forecasts.

10.1.1. Over-forecast and higher error on the side of legacy method in the Mokopane NDP area

It must be noted that the additional load forecast error evaluation that was carried out for the Mokopane study was not meant for comparison between GLF and LM forecast error. This area was originally forecasted using the legacy method only. In this research, the load forecast error evaluation for the Mokopane NDP forecast was done for the purpose of ARE matrix as well as the comparison of planned infrastructure versus the procured and commissioned build program. However, the author feels that there are aspects of the load forecast error evaluation and results that are worth discussing in order to contextualise the results.

Due to its reliance on the customer connection applications, the legacy method did not seem to be catering for long range planning well. It states that a customer may be included in a load forecast after the customer has applied to the utility for connection (this becomes a confirmation and improves the confidence of the business).

The possible source of over-forecast: There are two sources of economic slowdown that are suspected to have contributed to the high error margins in this area, these are discussed below.

One source of slowdown that is evident from the main Transmission substation loading data that is supplying the Mokopane study area and other substations outside the study area shows that there was a load decline from 2012 and it reached the lowest point towards the end of 2013 – see Figure **25**. This may be attributed to the mining strike that caught global attention in 2012, and ultimately investors losing confidence and withdrawing their investments.

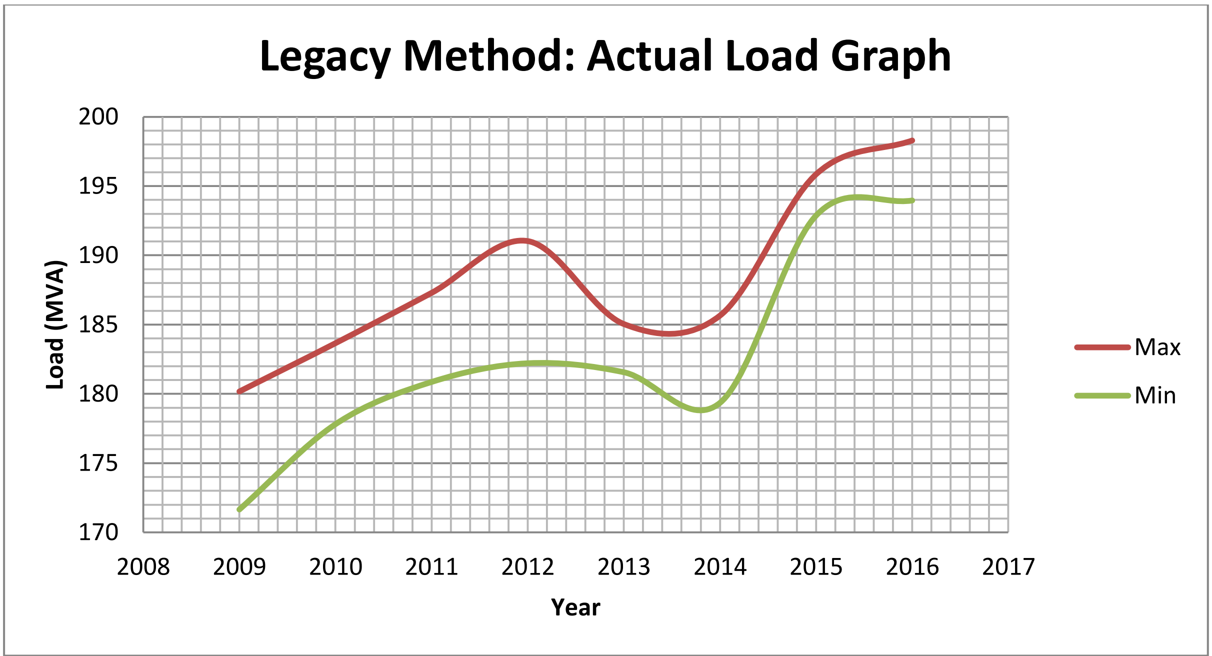

Figure 25: Mokopane area historical measured load

It is also evident, from Figure **25**; that the load was on a road of recovery after the 2008/2009 recession, when the 2012/2013 dip occurred. Though there was no annual measured load data available in this area for the period prior 2009, the report by Housing Development Agency (HDA) of

South Africa (2014) shows that the municipality (Mogalakwena Local Municipality) was also affected by the global recession as shown in Figure **26**.

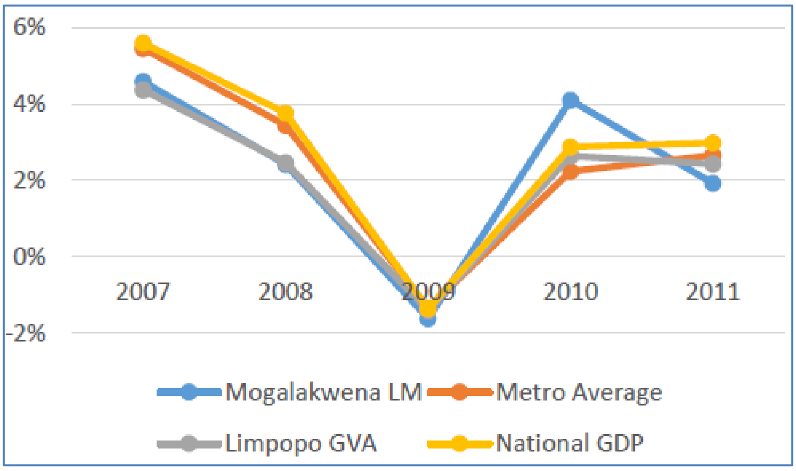

Figure 26: Comparison of Economic Growth Rates (2007 -2011). (Housing Development Agency of South Africa, 2014)

HDA (2014) also states that mining contributed 32.77% to the Gross Value Add (GVA) of the municipality. It was the main contributor. Therefore the decline shown in Figure 26 was expected to be felt in the mining sector as well.

The huge error (**MAPE of 91.8%,** see Table 19 on page 85) in the Mokopane area was realised as the stated economic downturns, which were never expected, hit the country by surprise.

Arguably, the error margins could have been bigger if, for example, based on the expected mining growth, more smelters were projected, and perhaps even some rail lines for transportation predicted, but the more conservative approach that the legacy method adopted, (making use of the applications more than the “what could come”) assisted in making the situation less than what it could have been.

10.1.2. If Mokopane was to be forecasted in GLF, would it have made a difference (better or worse)?

In trying to get an answer to this question, an investigation was done to assess if there were effects of the 2008/2009 recession on the Stellenbosch load, as this was to be compared to the load forecast, to verify if the load dip was forecasted. It was found that there was no dip on the Stellenbosch load (see Figure **13** on page 83, the graph labelled “actual”) and therefore one cannot tell whether GLF method would assist to “detect” the dip based on such an assessment.

A further investigation was done to check if there were any characteristics of the GLF method that could make it possible to forecast an economic recession. The document mentioned as the main source of information for use in the GLF is a municipal spatial development framework (SDF). The SDF that is reviewed in this research is for the Klapmuts area (Stellenbosch Municipality, 2007) , and it does not make any mention of the economic downturn. It does, however, state the economic profile of the area and demarcates the area in accordance with the type of development allowed in demarcated areas.

Based on this discussion, there is no clear indication that the use of the GLF method to forecast the Mokopane study area would have detected the economic downturn. However, the quantitative result to compare the two load forecast methods was not available, as this study area was only forecasted by using the legacy method.

10.2. Network Adequacy

The adequacy of a network infrastructure plan is a tricky criterion as it consists of two attributes that may work against each other. When the number of customer connections on a feeder increase, the power system network becomes strained and the voltage levels get affected. Hence these two attributes may work against one another in that way. However, the aim of the adequacy test was to ensure that both attributes are achieved without compromising one another. The test for adequacy of the network infrastructure plans gave the results shown in Table **34**.

Table 34: Network adequacy results summary

	Electrification Coverage	Voltage Quality	Total
GLF	81	760	841
LM	81	384	465

The two case studies proved to be covering the electrification aspect well, as measured using the developed rubric method. The extent of information gathering and the detailed process that the GLF method adopts in order to forecast the electrification growth, was noted as good and comprehensive. Its ability to incorporate municipal spatial development frameworks, while also including short term plans from the municipal IDPs in the form of digital shape files, allows for a more detailed load forecast. The legacy method also follows a comprehensive approach in gathering relevant information with regard to electrification, but was generally was observed to be conservative in its approach in this instance.

The Mokopane NDP (legacy method area) (Eskom Distribution, 2007), when dealing with electrification, started by giving the following context about the study area:

- 1.5kVA per connection will be taken as a blanket ADMD
- Population growth forecast from 330 000 to 500 000
- An annual 1,5% population growth
- Growth in population due to the opening of new mines

The process followed by the legacy method shows to be working well for electrification. This is judged by the high accuracy of the load forecast compared to actuals as shown in Table 35.

Table 35: Legacy method: 2006 electrification forecast and 2016 actuals

	Forecast for Electrification Substations					Actual Readings
Substation	**2007**	**2012**	**2017**	**2022**	**2027**	**2016**
SS1	15.4	20.1	23.8	25.8	27.7	19.5
SS2	11.1	15.3	17.9	20.6	22.5	14.2
SS3	8.4	10.9	12.8	13.6	14.9	16.4
SS4	10.0	11.0	12.3	13.1	15.9	16.2
Total Area (MVA)	44.8	57.4	**66.7**	73.2	81.0	**66.3**

The substations listed in Table 35 are electrification dominated substations. It can be observed that their total forecast (which is electrification) for 2017 was forecasted at 66.7MVA and the actual loading for these substations in 2016 was read to be 66.3MVA.

The approach by GLF based network study covers both the short term and long term electrification plans, as it is based on the municipal SDF. It takes into account the open land that is planned for low cost domestic developments, which later become electrification projects.

From the assessment for an adequate power system network supply for the GLF and LM plans, it can be concluded that both network infrastructure plans showed to be adequate in terms of electrification coverage. It was noted that none of the infrastructure plans led to voltages outside the +/-10% nominal range. The GLF based network plan, however showed to be better than the LM plan in the voltage assessment.

While the results for adequacy are in favour of the GLF method, there is no confidence that these results can be generalised. It was learnt from the case studies that the Mokopane area has long MV lines that supply electrification villages, while the Stellenbosch area has short urban MV lines. Stellenbosch is not prone to large voltage drops. It is for this reason that, the results cannot be generalised. Should however, sufficient data and sample sizes be made available for such a comparative assessment based on similar areas, a conclusive result may be reached.

10.3. Network Reliability

The reminding summary results of the reliability assessment that was carried out between the GLF based infrastructure plan and the LM based infrastructure plan is shown in Table 36 below.

Table 36: Reliability evaluation results for GLF and LM network infrastructure plans summarised

	GLF (Weighted Score)	LM(Weighted Score)
COUE (Sensitivity)	957.28	1041.12

Two observations were made from the literature;

1) COUE is a function of customer type [Smith & Joubert (2002), Herman & Gaunt (2008), Herman & Gaunt (2010) and Kleynhans, *et al*. (n.d.)]. The GLF method forecasts the load according to the load type, the forecast component named "what". Vrey (2006) and, Brown *et al*. (1999) demonstrated that the GLF can be used to do reliability analysis for future power system network based on its capability to

forecast the load type. From this analysis, a better network investment decision would be expected to be made, as detailed information about the location and type of the load would be known to the planner (from the forecast).

2) With regard to the LM forecast; the load forecast is network based. The forecast is performed by, mainly, trending of feeder historical loading data and the addition of customer applications. This means that the LM does not present as much detail as the GLF regarding load position (spatial aspect) and load type.

Drawing from 1) and 2) above, it would be expected that the GLF based infrastructure plan be the one that makes better investment decisions for reliability as it has more information to assist in that decision making. However, in the assessment carried out in this research, the results do show that the LM based infrastructure plan was superior to the GLF based infrastructure plan in regard to the COUE assessment that was done. In this assessment, the literature-created expectation was proven to be erroneous.

Like the test of adequacy discussed above; the weakness of this reliability test is the fact that two dissimilar study areas were used. The load composition in Mokopane is said to consist of a predominant mining load type, which has a higher weighted COUE compared to the commercial and agricultural load seen in Stellenbosch. Therefore, while the approach of this assessment can be useful for a similar study in the future as a reference point, these results cannot be assumed to portray the future outcomes of similar assessments.

Based on the case studies used in this research, it can be surmised that the GLF method did not lead to the planning of a more reliable power system network, when compared to the legacy method in the context as discussed above.

10.4. Network Economics

The economic investment decisions for the case studies, evaluated using the project profitability index (PI) and the modified internal rate of return show that the LM based network infrastructure plan was more economic than the GLF based network infrastructure plan, see Table 37 below.

Table 37: Summary of economic evaluation results for GLF and LM network plans

	GLF (Weighted Score)	**LM(Weighted Score)**
PI	5.00	7.50
MIRR	52.50	60.00
Total	57.50	67.50

It is clear, from the two case studies under review (Stellenbosch and Mokopane), that the economic evaluation of the infrastructure plans were not taken as an important part of the power system network studies, albeit that it was mentioned in the literature review as being a critical component. It is evident that the economic studies were not given much attention in the planning reports for both areas. Perhaps this could be justified by the fact that most projects were not profit driven, but that they were meant to address the regulatory compliance in terms of accepted voltage and reliability standards. In other words, whether the projects are profitable or not, they still need to be done to ensure compliance with the accepted Distribution Network Code requirements.

The economic assessment for the projects was done at the high voltage level, as was explained under the test methodology. However, if the utility wanted to do an economic assessment for their projects at a medium voltage level, the legacy forecast would not make it possible for the planner to make a detailed decision, as the minimum resolution for the legacy method is at a feeder level. The detailed spatial nature of the GLF method would make detailed load modelling possible and the economic assessment would be done at any level of the power system network, including at a sub-feeder level.

While it is understood that both the PI and MIRR are dimensionless quantities, the impact of the difference between the study areas can be mentioned as a weak point on this assessment. As such, the results can be taken to be case specific, instead of being classified as a generic outcome.

10.5. Cost Comparison between Using GLF and LM Forecasts

A complete and detailed cost comparison is beyond the scope of this dissertation, and the following assessment is intended to indicate the overall cost of implementing each approach in the context of the overall research.

The cost of using the GLF and LM forecasting method refers to the amount of money it takes to do a successful load forecast using each method, from scratch. This is a cost per single forecaster or workstation. This amount is summarised in Table 38 below and then discussed further in this section.

Table 38: Cost of using GLF compared to LM method

Cost Source	Cost Category	GLF	LM
Software License	Once-off	R 42 500.00[8]	R 1 899.00[9]
User Training	Once-off	R 9 500.00[10]	R 0.00
Computer cost (PC)	Once-off	R 11 999.00[11]	R 2 199.00[12]
Data cost (sourcing and preparation)	Running (per annum)	R 204 096.00[13]	R 0.00
Software Maintenance	Running (per annum)	R 7 437.50[14]	R 0.00

NB: permission to use the above information was granted by Aurecon in writing.

A comparison similar to this one was carried out by Shahida, *et al.* (2014), and they concluded that the cost for a trending method was much lower than that of the end-use method. They looked at the data requirements as well, citing that the trending method does not require as much data as the end-use application such as GLF.

[8] Source: Aurecon
[9] Source: Microsoft website: https://products.office.com/en-za/office-system-requirements.Accessed 18 July 2018.
[10] Source: Aurecon
[11] Source: HiFi Corporation: https://www.hificorp.co.za/computing-and-cellular/computing/notebooks. Accessed on the 18 July 2018
[12] Source: HiFi Corporation: https://www.hificorp.co.za/computing-and-cellular/computing/notebooks.Accessed on 18 July 2018.
[13] Source: https://www.indeed.co.za/salaries/GIS-Analyst-Salaries.Accessed on 10 September 2018.
[14] Source: Aurecon

Regarding the application installation; in the case of the GLF method, PowerGLF license cost was used. This cost is compared to a basic Microsoft Office license as it was used to perform the LM forecasting. The user training is required for PowerGLF software while there is no special training required for using Microsoft Office Excel. The computer specifications for PowerGLF installation were provided by Aurecon and the price of such a computer was looked up on the HiFi Corporation website. The same website was used to check the price of a computer required to run Microsoft Excel. Use of the same source of information was done to ensure consistency in prices. The total once off payment price associated with the GLF added up to R63,999.00, while it worked out to be R4,098.00 for the LM. Data sourcing and preparation is a requirement when one is performing a detailed GLF forecast. This refers to data sets such as IDP's and SDF's that are normally made available in hard copies and .pdf formats. These datasets need to be interpreted and converted into GIS data that can be used in a spatial platform, including PowerGLF. The cost for data sourcing and preparation was assumed to be equal to one GIS Analyst's annual average salary. In the case of LM, most of the data used is metering data which is predominantly owned by the utility. While there is a maintenance cost for the GLF software, no maintenance cost is anticipated for the Microsoft Excel tool.

To conclude, the cost of using the LM method is lower than the cost of using the GLF method. The LM's once off cost is 93.6% lower than the one expected to be paid to get the GLF forecast running, per user. The GLF has a running cost of R211, 533.50 per annum, while there is no running cost associated with the LM forecast.

This cost comparison assumes that the forecaster is a power systems planner in both cases; GLF and LM personnel are thus assumed to be paid on the same salary scale.

10.6. Relationship between the Forecast Error and ARE Network

Willis (2002)was quoted in the literature review when he stated that a forecast method must be tested on how it supports the planning process. A load forecast method can be accurate in predicting the load, but it is more critical to evaluate how it supports the planning of power system network infrastructure. However, other works, most of which were reviewed in the literature (such as Hossa, *et al*. (2014), Laouafi, *et al.* (2015), Lifeng & Zhenyu (2005) and Willis & Aguero (2007), among others), evaluated their load forecast methods only by evaluating their load forecast errors. This research evaluated the two competing methods (GLF and LM) in three aspects; load forecast error, how they support the planning process in terms of the ARE power system network as well as their impact on the procurement and construction of infrastructure network. The latter is discussed in section 10.7 below.

Load forecast error evaluation and comparison, without a doubt showed that the legacy method was more accurate than the GLF method in this research. Testing how the load forecast methods support the planning of adequate, reliable and economic power system network led to a competition between the competing methods where, in certain attributes, the LM based infrastructure plans would outperform the GLF based plans and visa-versa. The attribute specific performance showed to be highly variable (unstable). This instability was resolved by the use of MCDM method. The MCDM is meant for decision making in instances where there are a number of attributes that may act against one another at times, and to come up with one overall preferred solution or network investment decision. The weakness of this evaluation is the fact that two different power system network studies were used. However, the indicators used for scoring the attributes were chosen to be dimensionless, such as percentages or just dimensionless numbers. While the test procedure can be repeated in future, the results cannot be generalised.

Using the MCDM, the GLF method outperformed the LM method; see the MCDM matrix in Table 30 on page 105. From this result, it can be concluded that, the accuracy of a load forecast does not, by default, mean that it can support the planning process better.

Looking back at the literature, this finding is in line with the finding made by Willis & Northcote-Green (1984) and Rajab & Sharma (2015), who were both reviewed in the literature review of this report.

The following section discusses how the load forecast methods being tested affected the procurement and construction of the network infrastructure.

10.7. Comparing the Planned Infrastructure to the Constructed Infrastructure in the Presence of a Forecast Error

This evaluation was formulated with the basic understanding from the literature review, that two opposing views were presented. One view suggested that the inaccuracy of a load forecast (for example over-forecast) leads to procurement and construction of infrastructure that is not required, and which was misled by the load forecast. The opposing view suggested that load forecast inaccuracy does not affect the actual procurement and construction of power system network infrastructure.

The weak point of this evaluation is the fact that two different areas were used as a means of comparison. This is because of the unavailability of data that would make it possible to perform this evaluation in the same area. Therefore, the results from this test are primarily applicable to the used case studies. When data becomes available in the future, an analysis using the same methodology and approach, in the same study area, may however yield more accurate results.

Table 39 presents the summary of the results for the percentage of the planned infrastructure that was constructed for both the Stellenbosch NMP and the Mokopane NDP areas. Also shown in Table 39 are the corresponding load forecast errors for the two case studies.

Table 39: Summary results showing the percentage of the network plan constructed and forecast errors for the case studies

	GLF Based Study (Stellenbosch)	LM Based Study(Mokopane)
%infrastructure constructed	10.39	24.28
Forecast error (MAPE)	27.02	91.8
Actual load growth (%)	9.01	63.25
Forecast load growth rate (%)	30.00	408.10

As shown in Table 39, the Stellenbosch NMP forecasted a load growth of 30.00% over the period of 10 years. Only 9.01% load growth was realised. The infrastructure plan in the NMP document was proposed to ensure that the forecasted load is supplied when it comes to pass. However, only 10.39% of that infrastructure plan was procured and constructed.

The Mokopane NDP forecasted a load growth of 408.10% over the 10 year period. Looking at the actual measured load, it was learnt that the actual load growth in that area was 63.25%. While the proposed infrastructure plan was based on the envisaged high load growth, it became apparent that only 24.28% of that infrastructure plan was in fact procured and constructed by the utility.

There are parallels that can be drawn between these two case study results. The huge variance between the infrastructure plans that are based on load forecasts and the actually constructed infrastructure suggest that the plans were only partially translated into constructed assets. In both cases, less than 30% of the planned infrastructure was constructed. Also, in both cases, the load forecast was overstated (forecast error was discussed in section 10.1 above). The question is what may have informed the utilities not to proceed and procure the infrastructure plans? A periodic review of the infrastructure plans is understood to have assisted the utilities not to over-procure and construct; this is elaborated in 10.7.1 below.

The results from both case studies reveal that the over-forecast did not lead to over procurement. The procurement and construction rather followed the slower than anticipated growth of the actual load.

10.7.1. Impact of network development plan periodic review on planned infrastructure versus constructed

All South African licenced electricity distributors are required to have network infrastructure development plans that cover a minimum of five future years and these development plans shall be reviewed every 3 years, according to the South African Distribution Network Code (NERSA, 2010).

This rule compels the distributors, regardless of the load forecasting method followed, to revise their infrastructure plans in 3 yearly intervals. The GLF and LM studies reviewed in this research are expected to have been reviewed in later years in line with the Grid Code requirements.

This periodic review gives the utility a chance to evaluate their previous power system network studies, including the forecasts. In cases where the load forecast was overly optimistic, which seems to be common in the case studies reviewed in this research, the utility assesses where the previously envisaged load did not materialise. Also, this creates an opportunity for the utility to change and adjust their infrastructure procurement to align with realistic load forecasts. If the Grid Code is followed by the distributors, the chance of over-procurement and over-construction resulting from over-forecasting should be minimised.

The context of the load forecast error results and the percentage of constructed infrastructure shown in Table 39 indicate that it is highly likely that the adherence to the 3 yearly revision cycle for their development planning allowed the utilities to adapt to an infrastructure construction plan which was more aligned to the actual load growth requirements. This assertion is based on the assumption that the utilities who compiled the case studies used in this research did comply with the Grid Code and reviewed their power system network plans every 3 years following these studies.

With regard to the impact of a load forecast error in the procurement and construction of power system network, it can be concluded, based on the tested case studies with the results shown in Table 39, that the load forecast error did not affect the procurement and construction of the infrastructure. Also, the periodic review of network infrastructure development plans, in compliance with the Grid Code, gave the utilities a chance to review their investment decisions and adjust them according to the eventuality, which could be different to that which was envisaged by the load forecasts.

10.8. Conclusion

The load forecast error evaluation between the GLF and LM forecasting methods in Stellenbosch and Franschhoek areas showed the LM to be more accurate than the GLF. The ARE matrix results between the GLF based network infrastructure plan and the LM based network infrastructure plan showed that the GLF based network was adequate, reliable and economic when evaluated using the MCDM desirability score. It was learnt that the load forecast error did not impact the procurement and construction of network infrastructure, and that the 3 year review of the infrastructure development plans gave utilities an opportunity to revisit their infrastructure plans and adjust them according to what they saw happening, and not what was originally forecasted. Due to the intensive data and computing requirements, the GLF method was found to be more expensive than the LM method.

It has been mentioned that the test results of the respective case studies cannot be viewed as generic sample. A larger variety of cases would need to be assessed before such a general conclusion could be drawn. Rajab & Sharma (2015) and Willis & Northcote-Green (1984) warned that certain forecasting methods may be found to be performing better in different contexts.

The test method followed in this research could be replicated and repeated for similar studies elsewhere.

The summary of the tests carried out in this research is shown in the infographic in Table **40** below.

Table 40: Infographic: Overall research test results summary

	GLF Case Study	LM Case Study
Forecast Error		
Adequate, reliable, economic network		
Forecast Cost		
Forecast error impact on construction		

11. UNPACKING ANSWERS TO RESEARCH QUESTIONS

The research questions posed in section 1.3 of this report have been discussed below. The objective is to show the extent to which the research has gone in answering each research question. References are also made to sections that carry more details regarding the research question in the report.

11.1. Describe the distribution network planning process?

To describe the distribution power system network planning process, the literature was used. The reviewed literature expressed different variations of the description of the distribution network planning process which was generally summarized as follows:

> The planning process was described as a multi-faceted approach that seeks to study the existing network infrastructure capacity against the forecasted load, and proposes solutions where the network is found not able to supply the load. The different utilities may use different criteria for assessing the power system network violations. The selected criteria may be informed by the regulatory compliance as well as utility aspirations [Willis (2004) Tanwar & Khatod (2015) Aden*, et al*. (2016) Celli*, et al*. (2006) and GNEWSRC (2016)].

In this research, the planning criteria used were network adequacy, network reliability and network economics, all of which, each network infrastructure alternative must be evaluated against.

11.2. What role does the load forecast (GLF or LM) play in a distribution network planning process?

The role of a load forecast in the distribution planning process was investigated using literature. Conference papers and utility standards were consulted in order to derive a description:

> The role of a load forecast in the planning process is that it is used as an input variable against which the power system network abilities are evaluated through load flow analysis. Therefore, the problem statements of an infrastructure development plan, as well as the solutions (network investment) are informed by the load forecast, it supports the planning process [Willis (2002), Tanwar & Khatod (2015), Du, *et al.* (2007), Daneshi, *et al.* (2008), Espie, *et al.* (2003) and Bunge & du Preez (2007)].

The case studies that were used for the tests carried out in this research, namely: Stellenbosch NMP (Stellenbosch Municipality, 2006), Windmill NDP (Eskom Distribution, 2005) and Mokopane NDP (Eskom Distribution, 2007)demonstrated the role of a load forecast, regardless of the forecast method used, to be in line with the literature description.

11.3. What are the key differences between the legacy method and GLF method?

The information gathered with regard to the GLF method, which was mainly from the Eskom Load Forecasting Standard (Hashe, 2012), described that the GLF method is a spatial-based load forecast method. The information on the legacy method was collated in consultation with the distribution network planners that were using this method during its time (prior to 2007) and network development studies that were compiled during that time. These sources described the legacy method as being trending based, which builds a forecast by trending MV feeder historical load, whilst adding known new customers.

Therefore, the key difference between these two methods was the fact that the GLF method is a small area based load forecasting method that is built from a land use model. The legacy method was found to be a feeder based forecast that was built from the level of the feeder, and was based on trending of historic load and the planner's knowledge about the area. The GLF was found to be data intensive, as it requires a lot of data for the load forecasting while the legacy method depends on historical trends and the planner's knowledge and experience.

11.4. What is the cost associated with performing each forecast method?

The literature highlighted that the spatial forecast methods are data intensive and they require data that may not be available to the utility doing network infrastructure planning, in-house. This was not deemed to be the case for trending methods, which mainly depended on the historical loading data that was normally housed within the utility itself. This difference was noticed when the case studies were reviewed, where the GLF was said to have made use of a municipal SDF as one of its sets of input data. The GLF input data required conversion and processing in a digital spatial form called a geographic information system (GIS). The processing of different datasets for GLF required a computing power that would enable such activity. On the other hand, the LM depended on Microsoft Excel, which required minimal computing power and less complex forms of data inputs.

To quantify the costs associated with these load forecast methods, information was requested from the developers of the PowerGLF tool and was compared to the Microsoft Excel.

The findings were that the cost associated with performing a forecast using the LM method was R4,098.00 for the initial cost and zero for running cost. The GLF initial cost was worked out to be R63,999.00 for the initial cost and R211,533.00 per annum for its maintenance and support costs. The LM initial cost is 93.6% less than the GLF initial cost and the LM also has no running costs associated with it.

As highlighted earlier, this finding was expected based on the literature review.

11.5. Does one forecast method have an innate forecast accuracy over the other?

The review of the literature regarding the matter of load forecast accuracy gave mixed viewpoints. One view suggested that the GLF was more accurate than the trending methods (Willis & Aguero, 2007). This was backed up by Willis, *et al*. (1995) who compared spatial forecast methods with trending methods, and found the spatial method to be more accurate. The opposing view from Lifeng and Zhenyu (2005) suggested that a trending method that they developed was more accurate than the spatial method. Also, a more neutral view suggested that no one load forecasting method can be declared more accurate than the other, it all depends on the application and each case must be judged on its own merit ((Rajab & Sharma, 2015), (Willis & Northcote-Green, 1984)).

The findings of this research are based on the tested case studies (Stellenbosch and Franschhoek) where the legacy method was found to be more accurate on load prediction than the GLF method.

The error evaluation was based on the MAPE method. However, more case studies where the two methods have been used would need to be reviewed before it can be concluded if there is a method that is innately more accurate than the other.

11.6. How is the forecast error measured?

Two methods of forecast error evaluation were reviewed; the “hindsight” method and the “actuals” method. The actuals method was used in this research. The measurement of the forecast error was quantified using the mean absolute percentage error (MAPE).

11.7. How does the accuracy or lack thereof, of a forecast method affect the planning of infrastructure that is adequate, reliable and economic?

This research question came at the back of what was stated by Willis (2002), that the load forecast method must be evaluated and judged on how it supports the planning process. In this research, the goal of planning was defined to be ensuring adequate, reliable and economic (ARE) infrastructure.

The load forecast error tests carried out in this research showed the legacy method to be more accurate than the GLF. However, the MCDM evaluation using ARE matrix showed GLF to be a method that led to the planning of an adequate, reliable and economic power system network. Therefore, there was no evidence that the accuracy of a load forecast method leads to the planning of an ARE power system network.

11.8. On what basis (matrix) is the adequate, reliable and economic network from each forecast method compared?

A method that was overwhelmingly suggested by the reviewed literature was the use of a multi criteria decision making method (MCDM). Using desirability scores and attribute weights, this method gives a balanced assessment that is able to consider a multifaceted problem. The MCDM literature is discussed in section 2.1.5. The theory base that was developed for this research, in section 3.5, was ultimately used for the evaluation of adequate, reliable and economic network infrastructure plans in section 8.4.

11.9. What point of reference is used to compare the two forecast methods?

In all reviewed works, when there is a new forecasting method being proposed, it gets compared to the one it replaces or its potential competition in the market. For this research, in all aspects that were evaluated and compared the two load forecasting methods were compared solely against each other. Even if they, for example, both show positive results on a certain aspect being tested, they would still be compared to one another to review their relative performance against each other.

11.10. Does the forecast accuracy by GLF and legacy method affect the infrastructure procurement and construction?

Two competing views from the literature review were *for* and *against* the posed question (refer to 10.7 for the discussion).

The infrastructure procurement and construction has shown to be following the actual load growth instead of an overstated load forecast (in both case studies tested).

12. CONCLUSION

The objective of this research study was to evaluate the GLF method against the method it replaced named the legacy method in this research, as it has no official name. The following hypothesis was adopted as a basis for the research: "*The use of GLF method that was introduced to Eskom Distribution Planning brings about the improvement on the planning process of infrastructure that is adequate, reliable and economic when compared to the legacy method that was used before it*."

To test the hypothesis, the test methodology was developed to compare GLF to the legacy method in three main aspects:

- Load forecast accuracy
- How the load forecast supports the planning of adequate, reliable and economic power system network infrastructure
- Impact of the load forecast accuracy on the procurement and construction of the power system network infrastructure

These findings were made, based on the evaluated case studies:

- The GLF proved to be less accurate than the legacy method
- The GLF supports the planning process better than the legacy method
- The load forecast error associated with the GLF and LM showed not to affect the procurement and construction.

This research concludes that the hypothesis holds true; the GLF does *bring about the improvement on the planning process of infrastructure that is adequate, reliable and economic when compared to the legacy method that was used before it*.

It was qualified that these results, however, cannot be taken as a generic outcome but rather as applicable to the tested case studies. To reach a generic conclusion, more case studies would have to be surveyed where both load forecasting methods were used. At this stage, this data is not available. The methodology followed in this study can be used when a similar study is done in future, depending on the availability of data.

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APPENDIX A: "POLOKWANE NORTH NDP", (LOAD FORECAST), BY SIBANDA S. (2003)

4.0 LOAD FORECAST

4.1 INTRODUCTION

The load forecast is primarily aimed at highlighting possible future development expressed on load basis i.e. maximum demand and notified demands. The load is forecasted over a 20-year period, which necessitates constant revision and update at least annually to keep abreast with ongoing developments.

4.2 LOAD FORECAST MODEL

The load-forecast is compiled in Napoleon access database. The maximum demand is obtained from statistical metering. The actual recorded maximum demand from the last three years, are used to determine the percentage annual load growth.

On industrial loads the notified maximum demand is used to determine the customer load growth. Specific customer requirements and anticipated growth are based on customer request through feasibility quotes.

Domestic load-growth is determined from the electrification five year masterplan, and particularly on the Lebowakgomo Supply zone reticulation network reinforcement plan.

4.3 LOAD FORECASTING TECHNIQUES

The following steps were followed:

- The supply zones are categorised per substation loads.
- The substation loads are further categorised per feeder.
- Loading per feeder is obtained from statistical metering data.
- The actual recorded maximum demand per feeder is obtained.
- The electrification master plan data is obtained to determine future loads.
- The bulk loads and industrial loads maximum demands are obtained from BDS contract agreement.
- Customer new loads application with anticipated future loads are obtained.
- The power factors, load factors and diversity factors are determined per substation feeder.
- After diversified loads, with appropriate power factors and load factors are summed up to get the total substation load.

- The current year substation loading and the previous two years actual loading are extrapolated to determine the average annual percentage growth; the average growth ranges between 1-3% were no specific developments are highlighted.
- The various substation loads are further summed up to determine the MTS loads.

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APPENDIX B: LEGACY AREA RELIABILITY EVALUATION MODEL SHEET

FEM2012-01 (Apr 2012) **FEM Evaluation Summary - Cost of Unserved Energy Project**

Basic Input Data | Print COUE Sheet | Image Dump | Help

This model determines the weighted outage cost to the customers (called Cost of Unserved Energy or COUE) and compares this to the cost Eskom has to incur (called Break Even Cost of Unserved Energy or BECOUE) to eliminate the potential loss risk.
The bar graphs show the BECOUE in relation to the weighted COUE to the customers and whether a project can or cannot be justified in the 'national economic' interest. The YES / NO table at the bottom presents the same result.
The project is justified in the national economic interest when the BECOUE is less than the COUE.

Project Name: Mpumalanga

Date: 2012/04/25

COUE to Customers:

	Energy Mix (%)	R / kWh
Industrial / Mining	90%	R 27.58
Commercial		R 21.48
Agricultural / Rural		R 6.31
Residential	10%	R 3.13
Traction		R 1.69
Percentage Check (must be 100%)	100%	

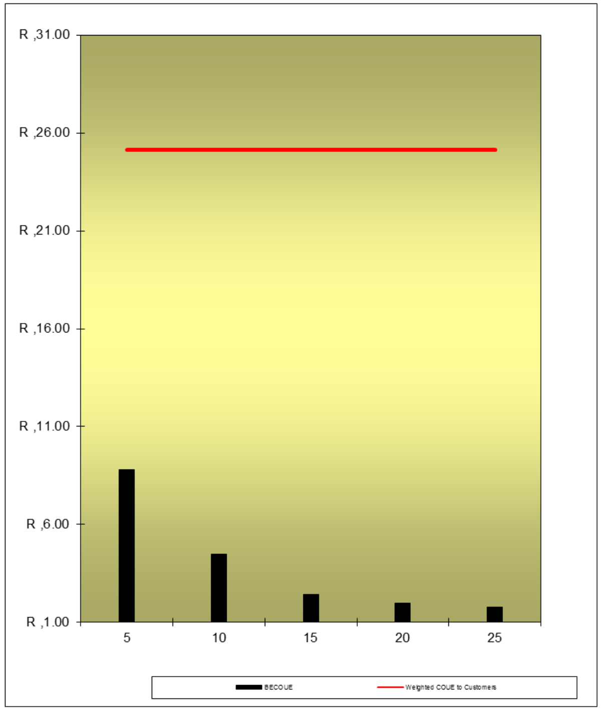
Weighted COUE to Customers: R 25.14

Total Capex (in 2012/3 Rand value)		192 600 000
Discount Rate (i)		10.3%
PPI		7.9%
Economic life of equipment (n)	years	25
Levelisation Factor		0.0525
Levelised Cost	R/Year	R 10 115 578
Average Total Load Factor		0.92
Average Total Power Factor		0.95

Notes/Assumptions:
qwerty

Risk Alleviated:

Scenario name:		5	10	15	20	25
Risk Alleviated	kVA	80 800	158 800	290 400	355 300	393 900
Outage Duration	Hrs	36	36	36	36	36
Outage Frequency	per annum	0.45	0.45	0.45	0.45	0.45
kWh lost	per annum	1 151 658	2 263 407	4 139 127	5 064 159	5 614 332
BECOUE:	R / kWh	R 8.78	R 4.47	R 2.44	R 2.00	R 1.80
		R 25.14	R 25.14	R 25.14	R 25.14	R 25.14
Is project justified ?		Yes	Yes	Yes	Yes	Yes



APPENDIX C: GLF AREA RELIABILITY EVALUATION MODEL SHEET

FEM2012-01 (Apr 2012) **FEM Evaluation Summary - Cost of Unserved Energy Project**

Basic Input Data | Print COUE Sheet | Image Dump | Help

This model determines the weighted outage cost to the customers (called Cost of Unserved Energy or COUE) and compares this to the cost Eskom has to incur (called Break Even Cost of Unserved Energy or BECOUE) to eliminate the potential loss risk.
The bar graphs show the BECOUE in relation to the weighted COUE to the customers and whether a project can or cannot be justified in the 'national economic' interest. The YES / NO table at the bottom presents the same result.
The project is justified in the national economic interest when the BECOUE is less than the COUE.

Project Name: Westen Cape

Date: 2012/04/25

COUE to Customers:

	Energy Mix (%)	R / kWh
Industrial / Mining		R 27.58
Commercial	60%	R 21.48
Agricultural / Rural	40%	R 6.31
Residential		R 3.13
Traction		R 1.69
Percentage Check (must be 100%)	100%	

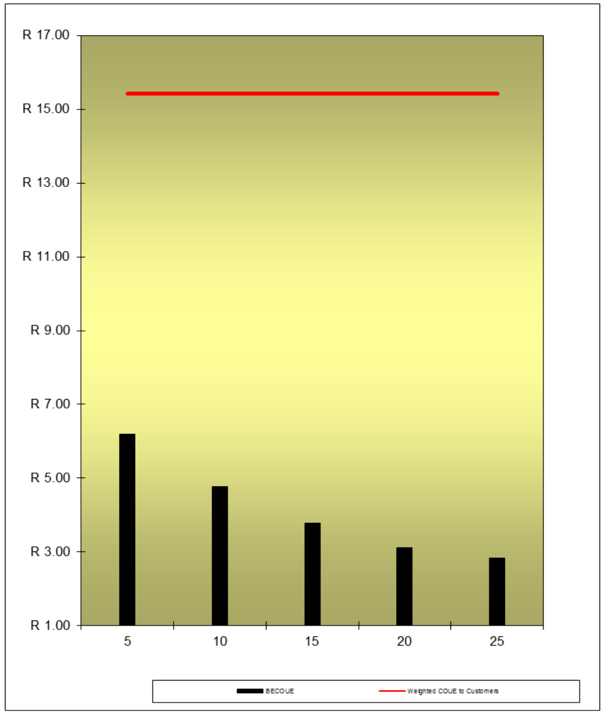
Weighted COUE to Customers: R 15.41

Total Capex (in 2012/3 Rand value)		36 131 800
Discount Rate (i)		10.3%
PPI		7.9%
Economic life of equipment (n)	years	25
Levelisation Factor		0.0525
Levelised Cost	R/Year	R 1 897 684
Average Total Load Factor		0.40
Average Total Power Factor		0.95

Notes/Assumptions:
qwerty

Risk Alleviated:

Scenario name:		5	10	15	20	25
Risk Alleviated	kVA	47 400	61 300	77 500	93 900	103 500
Outage Duration	Hrs	36	36	36	36	36
Outage Frequency	per annum	0.47	0.47	0.47	0.47	0.47
kWh lost	per annum	306 795	396 762	501 616	607 764	669 900
BECOUE:	R / kWh	R 6.19	R 4.78	R 3.78	R 3.12	R 2.83
		R 15.41	R 15.41	R 15.41	R 15.41	R 15.41
Is project justified ?		Yes	Yes	Yes	Yes	Yes



APPENDIX E: DATA CLEARANCE

Letter of authorisation for the use of unpublished Eskom data has been attached. The Stellenbosch data is openly published on the municipality website and, in this report, it is referenced accordingly.

Eskom

Mr Mfundi E. Songo
Senior Manager Group Technology
Planning and GIS CoE
PO Box 1091
Johannesburg
2000

Date:
2 August 2017

Enquiries:
Mfundi E. Songo
Tel +27 11 800 4795

Dear Sir/Madam

Authorization to Use Eskom Data for MSc. Eng. Studies for Monde Soni

This is to confirm that the employee, Monde Soni (Senior Engineer, Planning), has been granted the right to use Eskom data for his Masters Dissertation as it relates to Eskom Network Planning. However, the employee is not allowed to use Eskom customers' details such as company names, addresses and owners.

The title of the dissertation is: *Assessment of Geographical Based Load Forecast Approach in Distribution Planning*.

Yours sincerely

Mr Mfundi Eramus Songo Pr Eng
SUBJECT MATTER EXPERT: Power Systems Planning

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1923-2013

APPENDIX D: ETHICS CLEARANCE APPROVAL

Application for Approval of Ethics in Research (EiR) Projects
Faculty of Engineering and the Built Environment, University of Cape Town

APPLICATION FORM

Please Note:
Any person planning to undertake research in the Faculty of Engineering and the Built Environment (EBE) at the University of Cape Town is required to complete this form **before** collecting or analysing data.The objective of submitting this application *prior* to embarking on research is to ensure that the highest ethical standards in research, conducted under the auspices of the EBE Faculty, are met. Please ensure that you have read, and understood the **EBE Ethics in Research Handbook**(available from the UCT EBE, Research Ethics website) prior to completing this application form: http://www.ebe.uct.ac.za/usr/ebe/research/ethics.pdf

APPLICANT'S DETAILS		
Name of principal researcher, student or external applicant		Monde Soni
Department		Electrical Engineering
Preferred email address of applicant:		sonim@eskom.co.za
If a Student	Your Degree: e.g., MSc, PhD, etc.,	MSc Eng (Electrical)
	Name of Supervisor (if supervised):	Prof. C.T. Gaunt
If this is a researchcontract, indicate the source of funding/sponsorship		Student
Project Title		Assessment of Geographical Based Load Forecast Approach In Distribution Planning

I hereby undertake to carry out my research in such a way that:

- there is no apparent legal objection to the nature or the method of research; and
- the research will not compromise staff or students or the other responsibilities of the University;
- the stated objective will be achieved, and the findings will have a high degree of validity;
- limitations and alternative interpretations will be considered;
- the findings could be subject to peer review and publicly available; and
- I will comply with the conventions of copyright and avoid any practice that would constitute plagiarism.

SIGNED BY	Full name	Signature	Date
Principal Researcher/ Student/External applicant	Monde Soni		**06 Jun 2017**

APPLICATION APPROVED BY	Full name	Signature	Date
Supervisor (where applicable)	GAUNT. Click here to enter text.		20 June 2017 Click here to enter a date.
HOD (or delegated nominee) Final authority for all applicants who have answered NO to all questions in Section1; and for all Undergraduateresearch (Including Honours).	SUNETRA Click here to enter text. CHOWDHURY	Sunetra Chowdhury	25/8/17 Click here to enter a date.
Chair : Faculty EIR Committee For applicants other than undergraduate students who have answered YES to any of the above questions.	Click here to enter text.		Click here to enter a date.

Page **1** of **1**