Quantifying and comparing the life cycle cost of light emitted diode and conventional streetlights

A minor dissertation submitted in partial fulfilment of the degree of

MAGISTER INGENERIAE

in

ENGINEERING MANAGEMENT

at the

FACULTY OF ENGINEERING AND THE BUILT ENVIRONMENT

of the

UNIVERSITY of JOHANNESBURG

by

Tshiaba Didier Kayembe

Student number: 218016625

November 2019

SUPERVISOR: Prof. JHC Pretorius

CO-SUPERVISOR: Prof. A Marnewick

DECLARATION OF PLAGIARISM

I, Kayembe Tshiaba Didier, declare that the research “Quantifying and comparing the life cycle cost of a light emitted diode and conventional streetlights” is my own and all supporting materials used has been recognized and referenced according to the postgraduate school of engineering management requirements at the University of Johannesburg. I understand that plagiarism is improper by studying the school referencing and plagiarism policies.

ABSTRACT

Today, lighting accounts for more than 19 percent of the world electricity consumption and 6 percent of the CO_2 emissions. At the same time, streetlighting is a significant municipal duty which plays an important role in the life of a community. At present, streetlights are converted to more sustainable solutions that are energy-efficient and cost-effective for both the state and local governments.

The goal of this research is to measure and compare the cost of the life cycle of a light emitted diode (LED) and conventional streetlights. This is achieved by first determining the energy use of LED streetlights compared to conventional streetlights. Secondly, establishing the total cost of ownership of an LED streetlight compared to a conventional streetlight to encourage municipalities and key decision-makers to evaluate the merit and costs of street lighting projects.

A cost framework for the life cycle has been developed from the current literature to determine the energy use and the total cost of ownership of both streetlight technologies. The selected mathematical formulas were classified and implemented using secondary data collected from a study from a project conducted by the Greater Tzaneen municipality and the researcher's employer to calculate costs for both technologies. It is noted that post-acquisition costs are the largest part of the life cycle cost for both street lighting technologies. When comparing the calculated results, it is noted that streetlights with conventional technology use 56 percent more energy than their comparable LED streetlights. The findings also suggest cost savings of between 13 and 22 percent of the total cost of ownership over a year in favour of LED streetlights.

The findings of this study indicate that LED streetlights are the best technology to implement based on their energy consumption and total cost of ownership. Municipalities and decision-makers can use this research's framework to argue on their selected technology choice. The design of the measurement method used in this research allows users to adapt it to their context and include additional costs drivers to assist cities and key decision-makers in making literature informed decision when presented with the question of which streetlight technology to consider.

ACKNOWLEDGEMENTS

First, I would like to devote my research to Gabriel Kongolo Mpinga who died of motor neuron disease in 2015. Thank you for your contribution to this world by feeding the homeless through your organisation love without borders since 2004.

My sincere appreciation to Professor A. Marnewick and JHC. Pretorius for their inspiration, motivation, commitment and expertise. Without your contribution, this research would not be possible.

Finally, i thank my lovely wife and twin daughters for their continuous love and support.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

CBS	–	Cost breakdown structure
DPP	–	Discounted payback period
DPB	–	Discounted payback
ECA	–	Equivalent annual cost
GTM	–	Greater Tzaneen municipality
HPS	–	High pressure sodium
IRR	–	Internal rate of return
LED	–	Light emitted diode
LCC	–	Life cycle cost
LCCA	–	Life cycle cost analysis
NPV	–	Net present value
ROI	–	Return on investment

UNIT OF MEASURE

c/kWh	–	Cent per kilowatt hours
KVA	–	Kilovolt ampere
kWh	–	Kilowatt hours
W	–	Watts
R	–	Rand

CHAPTER 1: INTRODUCTION

This chapter aims to introduce the objective of this research while covering its fundamental structure. The chapter introduces the background of the investigated topic and highlights the problem statement. Ultimately, it introduces the entire design approach to this inquiry.

1.1. Background

In 1701, King James II and VII of Scotland approved the installations of public lanterns and for the first time, a streetlamp lighter was an official work. In 1881, most countries converted to electrified streetlights as a better technology than the lanterns. Therefore, the absence of lamplights (Shakhmatova and Francey, 2012).

Shakhmatova (2012) found the electrified streetlight technology to be costly and difficult to maintain. Therefore, lighting accounts for more than 19 percent of the world electricity consumption and 6 percent of the CO_2 emissions (The climate group, 2012). At the same time, streetlighting is a significant municipal responsibility that plays an important role in the life of a community (Kivimäki, 2013). At present, streetlights are converted to more sustainable solutions that are more energy-efficient and cost-effective for both the state and local governments (Schmidt, 2012).

The business environment is changing so quickly that product development and new technology innovation are among the primary strategies to retain competitive advantage and to capture rapid market share. Mévellec and Perry (2006) have recognised that product development and the value of the entire life cycle cost were key elements that decision-makers weigh before investing. The overall quantitative approach to managing the product life cycle is therefore critical to meeting the needs of customers throughout the entire cycle without increasing maintenance costs, reducing quality and performance. El-akruti, Zhang, and Dwight (2016) suggest that a quantitative analysis methodology such as the life cycle cost analysis (LCCA) can be used to optimise cost benefits by evaluating cost drivers of any system. As a cost control and estimations tool, Life cycle cost has undergone significant changes (Mévellec and Perry, 2006). Accordingly, El-akruti et al. (2016) also claimed that LCC analysis does not only relate to equipment running and repair cost but can also be used as a method to formulate maintenance strategies policies in line with the objectives of the organisation. For this reason, the cost analysis of the life cycle cost tends to be a critical method to focus on when an organisation meets the task of replacing a product with a more cost-effective one.

1.2. Life cycle cost analysis of LED streetlights background

Life cycle costing as a strategy focuses on providing the owner of the equipment with the estimated cost to be anticipated when purchasing, running, maintaining and if necessary disposing of the equipment (El-akruti, Zhang and Dwight, 2016). To accurately estimate the costs that LEDs or conventional streetlights require throughout their entire life cycle, which includes both the pre-acquisition and post-acquisition costs, the two cost categories should be combined during the cost calculation and compared during analysis.

Gidén Hember et al. (2017) researched that with LCC analysis, consumers in the market could quickly compare and realise the cost-effective impact of the LED streetlight compared to conventional streetlights already in the market. Tähkämö and Halonen (2015) carried out a study using European electricity costs to analyse the above cost-benefit impact. They noticed that most of the costs were incurred when the streetlight is in service and that LED technology has been shown to use not only less power but also reduced maintenance costs throughout its lifespan, making it the best and most reliable option. Therefore, to make a fair comparison between the two technologies with different lifespans, three years and twelve years respectively, the cost of the entire life cycle must be calculated on an annual basis to enable a just economic feasibility between the two technologies (Schmidt, 2012).

1.3. Problem statement

The light-emitting diode (LED) is an innovative technology developed in laboratories. Most researchers are looking more at how to further its performance and comprehend its added capability rather than the benefits or impacts it brings to its recipients.

This research aims to quantify and compare the energy usage and the entire life cycle cost of conventional streetlights as opposed to LED streetlights. This collation could potentially empower local municipalities to evaluate the merit and costs of street lighting projects.

1.4. Research questions and objectives

1.4.1. Research questions

The answer to research question one and two will establish guidelines and determine whether LCC analysis can be used as a tool to discuss the choice of LED streetlights as opposed to conventional streetlights in terms of pre-acquisition costs and post-acquisition costs.

- Research question 1: What is the energy use of an LED streetlight compared to a conventional streetlight?

- Research question 2: What is the life cycle costs of an LED streetlight compared to a conventional streetlight?

1.4.2. Research objectives

The objective of this research is, therefore, to measure the entire life cycle cost of conventional and LED streetlights while using current knowledge of life cycle cost calculations and analysis techniques. The research findings on the energy consumption and the total cost of ownership of conventional streetlights are compared to the results of the LED streetlights. Therefore, to make recommendations that allow local municipalities to evaluate the merits and costs of street lighting projects.

1.5. Research justification

Streetlights use about 60 percent of the total municipal electricity supply and their maintenance also accounts for a large portion of their funding (Jägerbrand, 2015). At the same time, an ineffective streetlight system is commonly referred to as conventional streetlights that include high-pressure sodium (HPS) and mercury vapour (MV) lamps (Jägerbrand, 2015). Nowadays, particularly in streetlighting, LEDs have become the preferred option because of its many advantages compared to conventional streetlights. Since the industrialisation of the first LED in 1962, the technology has undergone immense advances to (Philips Lighting Academy, 2008).

As a technology, LED streetlights are a downside in terms of the acquisition costs, but with an improvement in LED technology, the price has been significantly reduced. There is still a gap in the industry in the way that life cycle cost analysis is modelled when faced with a problem of quantifying the cost impact of using conventional streetlights as for LED streetlights. Some models concentrate on the replacement scenario, but this research takes the approach of green projects where the total cost of ownership of both technologies must be measured and compared to give decision-makers a value view on which technology to implement. With the rapid growth of LED technology, cost drivers are also evolving accordingly. Researchers must therefore always adapt their LCC analysis approach to meet the current market needs.

1.6. Research limitations

LED technology streetlights have many advantages compared to conventional streetlights. Farrington and Welsh (2002) suggest that improved street-lighting can have an indirect impact result on many things such as the reduction of crime around the city, the reduction of accidents on the roads, the reduction of the carbon footprint, and many more. Therefore, this research focuses on the impact of pre-acquisition costs and post-acquisition costs when comparing the entire life cycle of conventional and LED streetlights. The cost comparison of both technologies will focus on the acquisition costs, electricity consumption, maintenance, residual and any other cost involved in the life of the streetlight.

Life cycle costing can be applied from several points of view including the view of the supplier, the view of the consumer and the view of the client, etc. For this research, the municipality owns the asset and controls of the purchasing budget, installation and maintenance of streetlights networks.

1.7. Research design

1.7.1. Research design approach

Researchers have identified three approaches to address a research design. That includes a qualitative, quantitative and mixed-method approach (Brewer, 2019). Brewer (2019) also argues that a quantitative approach is concerned with the testing of theories while a qualitative approach focuses directly on the construction of theories based on data already collected by other researchers. Hence, Allen-meares and Allm-means (2019) found that research around the social work environment requires both techniques due to the lack of understanding of the subject.

This research focuses on a quantitative approach because it measures variables that are countable and considers all the cost drivers in the life cycle of both street-lighting technologies. The methodology and approach used are designed to allow the results to be replicable regardless of who is performing the research. Figure 1 illustrates the main body of this research. It started with introducing the objectives of the research, followed by the body of the research and lastly, conclusion and recommendations.

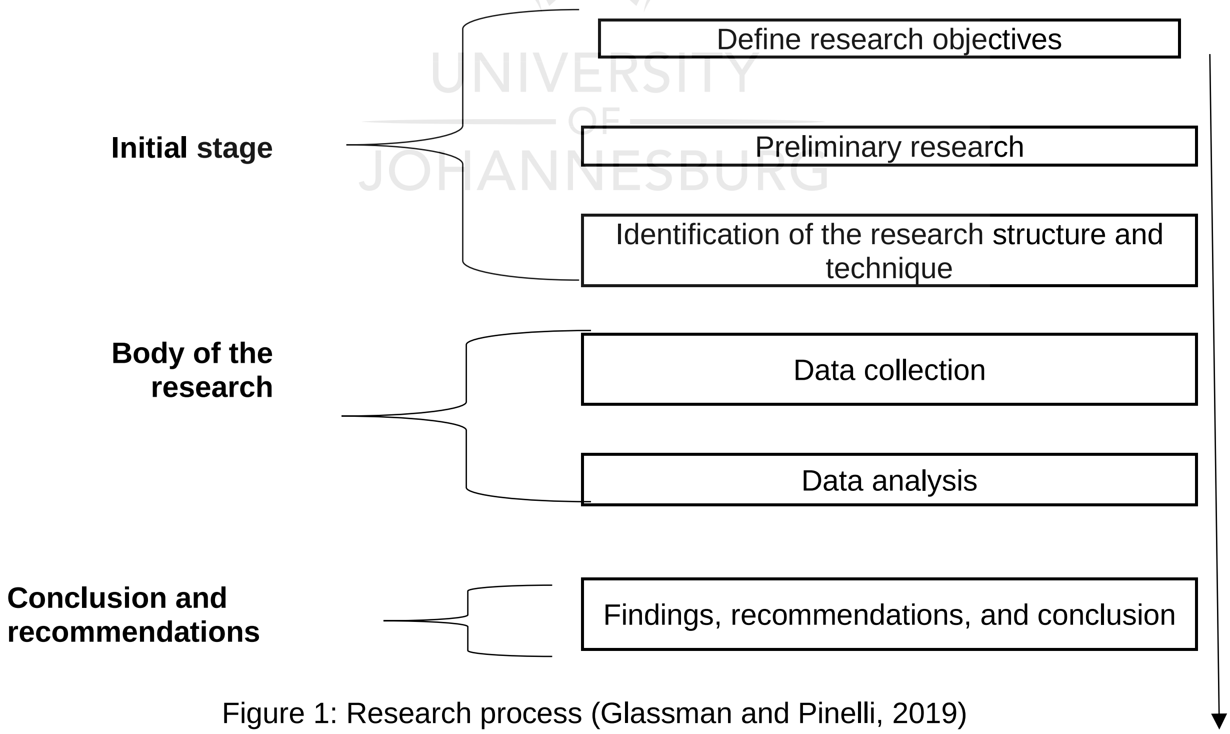


Figure 1: Research process (Glassman and Pinelli, 2019)

1.7.1.1. Initial stage

First, the initial stage of the research focuses on establishing its objectives to answer whether the use of LED streetlights is better than the use of conventional streetlights for the entire life cycle cost value. Second, it addresses the literature of different authors related to the use of LED streetlights compared to conventional streetlights. Lastly, it defines the most appropriate approach, methodology and framework to address the research questions while allowing the process to be replicated by other researchers and beneficiaries of this study.

1.7.1.2. Body of the research

This is the centre of the research in which the data collection process to answer the research questions is created. Therefore, a data collection instrument is designed based on elements that affect the life cycle of streetlights that are selected from the current literature from the initial stage. After the information has been successfully obtained, it is processed in such a way as not only to address research questions but also be delivered in a manner that allows organizations to choose easily between the two types of streetlight technologies.

1.7.1.3. Conclusion and recommendations

Finally, an appraisal is drawn up to determine whether the research carried out addressed the research questions from the initial stage and provided a framework for decision-makers to pursue.

1.7.2. Research structure

Based on the design approach outlined above, this research is divided into five chapters that address the recommendations extracted from the evaluation and conclusions from the overall objectives of the research.

Chapter one introduces the overall objectives of the research. It also displays the flow of the entire document. Chapter two draws on the literature of other researchers investigating and quantifying the life cycle value of LED streetlights compared to conventional streetlights. It also includes literature that compares the energy use between the two technologies.

Chapter three which is still in the initial phase, covers the research methodology and technique chosen to investigate and answer the research questions. It also explains the reasons behind this technique and methodology selection. Chapter four which is the core of this research includes all data collection and focuses on the analysis of the collected data. And lastly, chapter five closes with conclusions and recommendations.

1.8. Conclusion

The overall goal of chapter 1 is to describe the steps taken to undertake this research. Its early-stage provided the background to streetlight technologies and the life cycle cost as a cost calculation technique. Research questions, objectives, justification, limitations and a fundamental design approach were also discussed in the section.

Life cycle cost analysis as a cost quantifying methodology comes in different forms and can be used for different reasons, from quantifying the cost of equipment from when it produced to when it is disposed of, to a guidance tool when developing the company maintenance strategy policies to remain in line with the objectives of the organisation. The next chapter covers the literature review. It will incorporate the fundamental of the LCC concept on both conventional and LED streetlights when looking at the view of various researchers.

CHAPTER 2: LITERATURE REVIEW

Chapter two aims to provide the existing knowledge on the research topic from literature. Therefore, it includes current knowledge, research methodology, and applicable results from other researchers who have been exposed to the dilemma of which streetlight technology should be considered based on the total cost of ownership.

The chapter addresses the definition and background of the life cycle cost and it also discusses the various literature about the life cycle cost of streetlights and their impacts during the decision-making process of which streetlights technology to consider. Lastly, based on the methods and models used by other researchers to calculate the total cost of ownership, a measurement tool is built to address the research questions under this study.

2.1. Life cycle cost: Background and definition

In the United States of America, Menna et al. (2018) traced back the concept of LCC in the 1930s, when the army general, through the accounting office applied the costs of operation and maintenance into the public procurement. Before reviewing the literature of different authors, the definition of the term LCC will provide a better understanding of the concept.

Life cycle cost is defined as an overview of all the cost drivers associated with the entire life of a product or system that is paid for by the customer or the producer of the products (Ximenes et al., 2018). In its simplicity, Leena (2015) describes it as the overall cost of a product throughout its entire life cycle including production, purchase, investment, operation, maintenance and disposal. To identify similarities in the meanings of the concept, a third view of the defined concept is introduced. Barringer (2003) defined LCC as the total cost of ownership of a system or product. This includes the acquisition costs, the operating costs, maintenance costs, and the combination of decommissioning and disposal costs. Besides, the definition incorporates the time value of money and includes the significance of the idea of choosing the most cost-effective method from different alternatives to achieve the lowest cost of ownership of a product or system. Barringer's definition is the approach of this research and the next section presents the views of different authors on life cycle cost and the life cycle cost analysis of streetlights.

2.2. Life cycle cost and life cycle cost analysis of streetlights

Life cycle cost analysis in this research compares the LED streetlights as a cost-effective technology to the conventional streetlights, which constitute most of the streetlight's technology installed in South Africa's roads and streets.

Campisi et al. (2018) suggest that the cost analysis of the life cycle has been used to determine the merits of projects in the energy sector and their methodology uses the net present value approach to quantify all the costs involved throughout the lifetime of the product. However, the researchers also suggest that traditional LCCA techniques focus on direct costs and neglect indirect costs such as the management of activities and others.

Leena (2015) uses LCC analysis to compare two different technologies used in streetlights, namely high-pressure sodium luminaires considered as conventional technology and LED technology. The research also provides access to the effect of the production percentage cost of the entire life cycle of both the conventional streetlight and LED streetlight. On average, it is noted that the production of conventional streetlights represents 4 percent of its total life cycle cost based on the use of the European standard electricity rate. But the proportion varied to 34 percent when hydropower is used. The same trend was noticed in the production of LED streetlights with a 13 percent cost representation of the entire life cycle with a proportion variance of 63 percent for when hydropower is used. This shows that conventional streetlights are more cost-efficient during the production phase than LED streetlights, regardless of the source of electrical power. Nonetheless, LED streetlights have a better life cycle cost than conventional streetlights.

On that point, Mévellec and Perry (2006) introduced the theory that the price of using a product strongly depends on how the product is designed and used the example of a car and its ability to consume fuel. Figure 2 illustrates the total cost of the life cycle of a product and its cost drivers. It clearly shows that even though the percent cost of the design stage is lower than the production, usage, and recycling stages combined, it still has a significant influence on the future life cycle cost of the product.

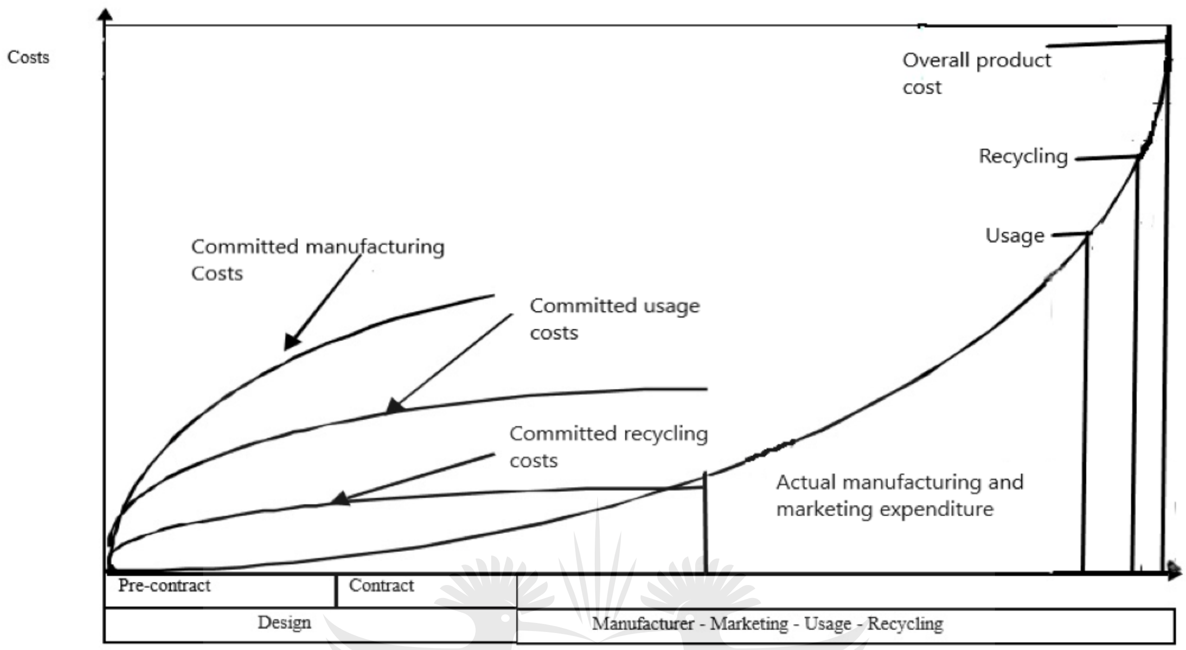


Figure 2: Overall life cycle costs (Mevellec and Perry, 2006)

A research conducted in Cyprus uses different cost calculation techniques, where life cycle cost analysis is used to access the economic viability of replacing High-pressure sodium (HPS) streetlights with LED technology streetlights. Bamisile et al. (2016) used in their calculation methodology, the minimum attractive rate of return, simple payback period and the investment ratio savings calculation techniques to calculate the cost impacts of replacing 60 000 conventional streetlights in the city. This technique involves the evaluation of costs involved from cradle to grave of streetlights.

The limitations to the above techniques are because streetlights are owned by the government and are more of a public need than revenue-oriented property. The research concluded that although the initial capital costs of the LED streetlights are higher than the conventional streetlights, the introduction of such projects will not only reduce the municipal electricity bill but, will also reduce the country's carbon emissions level. The research has further shown how the country will save on the import of fuel cells as the main driver of the electricity generator in the country. Such projects should be invigorated particularly in African countries (Bamisile, Dagbasi, and Abbasoglu, 2016).

The energy reduction during the operation life of an LED streetlight compared to conventional streetlight is between 31 percent and 60 percent (Djuretic and Kostic, 2018). As a result, Nelson, Anderson, and Cai (2017) have recognised LCCA as a feasible technique in their research on the selection methods for assessing the costs of streetlights. Their approach is illustrated on an excel sheet design to estimate the cost and payback period to replace conventional streetlights with LED streetlights. The excel sheet displays the cost drivers influencing the total cost of the life cycle which includes the acquisition costs, energy usage, maintenance costs, and installation costs.

Figure 3 shows the two main phases of a product's life cycle costing process. It includes the pre-acquisition costs and post-acquisition costs (Fieschi et al., 2015). It is normal for streetlights that most of the costs are incurred during their lifespan because they require electricity consumption and ongoing maintenance over the years.

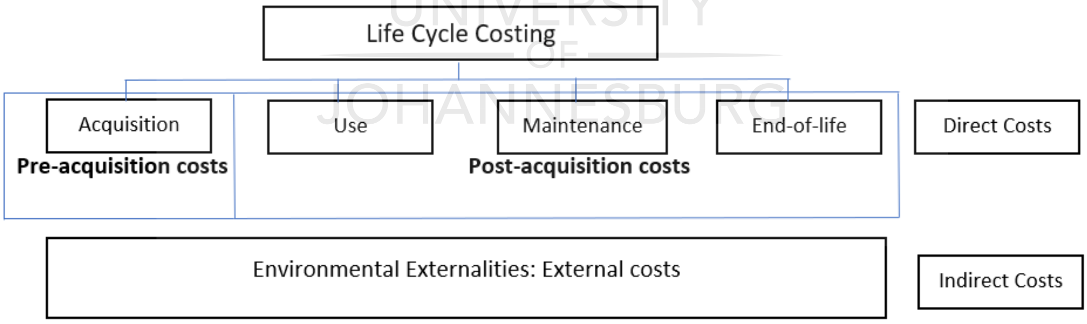


Figure 3: Life cycle costing phases (Ximenes et al., 2018)

Therefore, the cost breakdown structure (CBS) is mandatory to analyse the costs involved in the life of a product. It is a methodology that evaluates the inventory of all the costs involved during the life cycle of a product. In this research, not all the costs of replacing conventional streetlights with LED streetlights will be analysed. However, different authors used different inventories within their CBS to calculate the different stages of LCC from acquisition to end-of-life. Table 1 illustrates the different CBS used.

Table 1 – CBS life cycle inventory of streetlights

Costs / Authors		(Tähkämö, Ylinen and Puolakka, 2012)	(Nelson, Anderson and Cai, 2017)	(Campisi, Gitto and Morea, 2018)
Pre-acquisition costs	Acquisition costs	Investment costs Installation costs (LED technology)	• Streetlights purchase costs • Cost of conventional lamps • Installation costs • (acquisition costs based on conventional technology)	• Total LED streetlights investment • Installation costs
Post-acquisition costs	Use	Electricity costs	• Energy costs • Re-lamping costs • Repair/maintenance costs	• Energy costs • Maintenance cost (labour and parts)
	Maintenance	Maintenance costs Group replacement costs	• Repair parts costs: ballast, lamps, maintenance equipment costs • Re-lamping costs • Repair/maintenance costs	• Maintenance costs (labour and parts)
	End-of-life	Residual costs	• Residual costs	• Residual costs

Tähkämö, Ylinen, and Puolakka (2012) argue that post-acquisition costs dominate the life cycle cost of conventional streetlights. This is due to their energy consumption and maintenance costs over the year. Although LED technology streetlights have high acquisition costs on one hand, which include the purchasing and installation cost of streetlights, they also have lower operating and maintenance costs on the other hand because of their longer lifespan.

Nelson, Anderson, and Cai (2017) elaborate on the breakdown of the pre and post-acquisition costs of conventional streetlights in their effort to develop a lighting economics calculator. They identified four variables within the cost of a conventional streetlight which includes the streetlight cost, its life span, its re-lamping cost, and the high energy cost. The research concluded that due to their short life span, conventional streetlights budget is dominated by repair and maintenance costs while having a low acquisition costs value compared to LED streetlights. Nelson, Anderson, and Cai (2017) enforced their quantified research result by using the cost breakdown of variables to offer a sensitivity analysis where the initial investment and other variables are used to implement the analysis.

Woodward (1997) argued through his theory of the general phase cost relationship of a product that most of the costs acquired by a system during its entire life cycle are during its operation and maintenance phase.

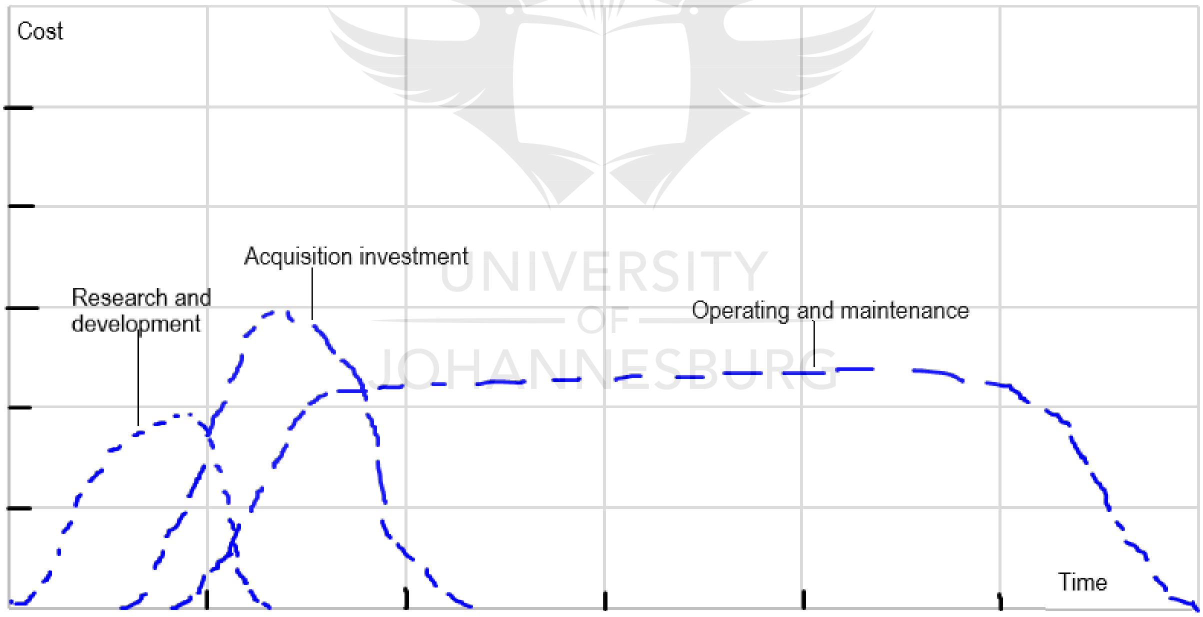


Figure 4: General life cycle cost phases (Woodward, 1997)

Hence, the next point introduces the advantages and disadvantages of LCC analysis first, before addressing the current calculation methods used to quantify the cost of drivers influencing the life cycle costing of both streetlights' technologies.

2.3. Advantages and disadvantages of life cycle cost analysis

Sacks et al. (2015) argues on the advantages and disadvantages of LCCA as a decision tool while comparing the costs of two alternatives to determine which one gives the most value for the money spent. The advantages and disadvantages of LCCA may be summarised as listed below (Sacks et al., 2015; Elmakis and Lisnianski, 2010):

2.3.1. Advantages

- It provides a clear financial view of the product initial investment and all the cost involved during its lifetime
- As a tool, it enables a comparison between various measured quantities and a choice of the greatest alternative to maximize organisational profit.
- It provides an organization with the option of estimating the cost of reparation that is capital when drafting the organization's maintenance policy.
- In the marketing strategy of a company, it is a support system as it highlights profitability.
- It shows the economic values of a system in more familiar terms such as NPV, ROI, IRR, etc.

2.3.2. Disadvantages

- The uncertainty of estimating the entire LCC of a product
- Except for the purchasing costs, the remaining are an estimation, yet, it does not mean that the tool offers wrong information
- The precision errors are difficult to point
- It is a difficult process to study and implement
- It requires the involvement of different department of the organisation to be relevant

Life cycle cost analysis of various streetlight technologies not only evaluates the pre and post acquisitions costs presented in table 1 but also describes any issue requiring an adjustment between the original and forthcoming costs (Lee, 2016). Therefore, the advantages of LCC analysis summarised by sacks et al. illustrate how decision-makers within municipalities can benefit from LCC analysis as an effective tool of cost evaluation, control, and measurement.

Nonetheless, the LCC analysis of streetlights strongly depends on the data from the inventory's costs from table 1. Hence, Ellis (2014) argues on the reliability of LCC analysis to estimate future costs since attempting to forecast costs in the future opens room for errors in calculations. At the same time, Schade (2014) argues that a reliable LCC analysis should be based on predictable data.

It is important to evaluate the existing LCC analysis representations while looking at their aptness based on streetlight requirements and the ability to advance their production and running costs.

2.4. Life cycle cost analysis representations

LCC analysis is not considered to be a standard process for all applications (Schade, 2014). Mothupi (2012) argues that the cost breakdown structure is the foundation of the life cycle cost analysis of possible replacements. As a technique, it focuses on the below points:

- Primary cost distribution
- Cost categorisation
- Monitoring and control of costs

The combined knowledge of the above three bullets allows decision-makers to align the organization's goals and tasks with the available financial resources. This enables the categorisation of costs based on tasks and major cost drivers of a system.
There are different types of LCC analysis and their operators should be aware of their pros and cons, as they are not designed as a one size fits all methodology (Schade, 2014).

The review of table 2 reveals that there are different types of economic feasibility methods for LCCA. Looking at the objectives, advantages, disadvantages, and value of the common economic feasibility techniques for LCC; table 2 slowly directs this research approach towards the NPV method without eliminating the simple payback or the discounted payback (DPB) method which shows the duration an investment will pay for itself. NPV considers the time value of money while giving decision-makers an in-depth approach to the projects.

Simple payback is driven by cost savings to make an investment return without considering the time value of money that does not include key elements such as inflation rate and interest rates. Therefore, DPB is used and calculated as follow: (Tähkämö, Ylinen and Puolakka, 2012)

$$\mathrm{DPB} = \frac{-\ln\left(1-\frac{iCi}{Co,old-Co,new}\right)}{\ln(1+i)} \qquad (1)$$

Where:

DPB = Discounted payback period

Co, old = Old installation operating cost

Co, new = New installation operating cost

i = interest rate

Ci = total investment

One of the characteristics of streetlights is that the government owns the property and manages its maintenance. They are considered as a public necessity rather than a revenue orientated asset (Bamisile, Dagbasi, and Abbasoglu, 2016). Therefore, the elimination of the internal rate of return (IRR) as an economic feasibility method for this research as it is intended for income generation investment.

Life cycle costing may include a number of presentations, including the net present values, the discounted payback, IRR, ECA, etc. the purpose of table 2 is to give decision-makers a summary of those presentations by illustrating their objectives, advantages, disadvantages, and value to enable them to choose the most appropriate approach and to use the correct formulas for their application.

Table 2 – Economic assessment technique for life cycle cost

Type	Objective	Advantage	Disadvantage	Utility
Simple Payback	To calculate the period an investment takes to pay for itself through profit. The shorter it is, the more profitable is the investment (Kim, Shim, and Reinschmidt, 2013)	Easy to understand and to calculate (Russell, 2009)	Does not account for the time value of money (Marshall, 2006)	Preliminary economic assessment when details analysis is inaccessible(Kim, Shim, and Reinschmidt, 2013)
DPB	To calculate the return on investment while considering the time value of money(Marshall, 2006)	Considers the time value of money (Marshall, 2006)	Ignore cash flow after DPP (Azar and Noueihed, 2016)	Preliminary economic assessment when details analysis is inaccessible (Kim, Shim, and Reinschmidt, 2013)
NPV	To evaluate, in present value terms, the surplus and deficit of cash flows when a financial decision is satisfied (Lin et al., 2013)	Gives decision markers a more accurate approach to project assessment and choice (Flaig, 2007)	An alternative must have the same life span. Do not consider quality costs and harvests (Flaig, 2007)	To show how an investment is affected in present value terms (Benamraoui and Madichie, 2018)
ECA	To change any cost with a particular present value lasting n year to a similar one year's cost (Collins et al., 2007)	Alternatives in comparison do not have to be of the same length of time(Schade, 2014)	If the cost of the substitute will rise over time, the concept of ECA is not effective (Lummer, 2007)	Comparison of possibilities with different life span (Schade, 2014)
IRR	To establish if the rate calculated when NPV=0 is higher or equal to the interest rate in the marketplace. (Akpan, 2010)	Results are easy to read (Schade, 2014)	Not feasible to calculate its value under conventional mathematical techniques (Akpan, 2010)	Use for income generation investment (Schade, 2014)

2.5. Life cycle cost calculations

Life cycle cost analysis focuses on comparing alternatives that satisfy the same obligation but at the same time have different acquisition and operational costs. The world bank research on energy-efficient streetlights in India suggests that LCCA should rather be introduced during the early stage of the product design procedure to allow developers an opportunity to minimize the overall product LCC. There are various costs related to the pre-acquisition and post-acquisition stage of streetlights that includes: purchase cost, repair cost, product replacement cost, residual cost, financial interest, non-monetary cost.

Table 1 introduced the life cycle cost inventory breakdown for both streetlight technologies. The following sections introduce the way to calculate these costs by using table 2 compatible representation of life cycle costing for this research.

2.5.1. Pre-acquisition costs calculations

The acquisition cost, which includes all the costs required to buy the product and fully set it to operate dominates the life cycle cost of LED streetlights (Tähkämö, Ylinen, and Puolakka, 2012). Energy and the maintenance cost dominate the life cycle cost of conventional streetlights, but the investment costs of LED streetlights are easily offset due to their low maintenance and operating costs.

2.5.1.1. Acquisition costs

The main elements considered during the acquisition of streetlights are the purchase price of the product, poles, the required installation machinery, and labour costs. they constitute the sum of acquisition costs (Tähkämö et al., 2012).

$$A_{\text{Costs}} = S_{\text{Costs}} + P_{\text{Costs}} + I_{\text{machinery, parts and labour costs}} \qquad (2)$$

Where:

A_{Costs} - The acquisition costs,

S_{costs} - The purchase price of streetlights

P_{Costs} - The poles costs

$I_{\text{machinery, parts and labour costs}}$ - The installation costs

$I_{\text{machinery, parts and labour costs}}$ - is constituted of the installation costs and all the cost of parts involved during installation.

These costs involve the following breakdown; Crane, labour to replace light fittings but for new installation, municipalities consider the cost of supply cables, foundations, control panels, and lighting cables. The assumption for this research is that the infrastructure already exists, and no additional costs are required.

2.5.2. Post-acquisition costs calculations

Post-acquisition costs constitute the largest part of the streetlight life cycle cost. Streetlights are a big part of the municipality's budget and energy consumption (Bamisile, Dagbasi and Abbasoglu, 2016). Post-acquisition costs are mainly related to operation, maintenance and disposal costs.

2.5.2.1. Operational costs

The operation costs include energy costs and maintenance costs. One of the characteristics of well-designed roads is to have streetlights that are energy-efficient and cost-effective.

2.5.2.1.1. Energy costs

Baburajan (2018) evaluates techniques for quantifying the energy consumption of streetlights and it is determined by multiplying the number of streetlights by their power consumption in watts. The answer is expressed in kW as the total energy consumed.

$$E_{\text{consumption}} = n \times W \qquad (3)$$

The total energy consumed is multiplied by the number of used hours per night. The answer is in kWh and expressed as per night energy consumption.

$$PN_{\text{consumption}} = E_{\text{consumption}} \times 12 \text{ hours} \qquad (4)$$

The per-night energy consumption is converted to annual energy consumption by multiplying $PN_{\text{consumption}}$ by 365 days in a year.

$$A_{\text{consumption}} = PN_{\text{consumption}} \times 365 \qquad (5)$$

The annual energy usage is converted to monetary value by multiplying the annual energy consumption by the price of electricity expressed in c/kWh. The calculated energy consumption is expressed in Rand/annum.

$$R_{\text{Energy consumption}} = A_{\text{consumption}} \times c/kWh \quad (6)$$

The annual energy consumption is also influenced by the client demand for electricity (Magro and Scicluna, 2017). Therefore, the concept of apparent power or demand charges is applied to formula (5). The demand fee is a part of the electricity tariff which represents the additional costs associated with customer's demand for electricity. Formula (9) reflects the true annual electricity costs by including the annual demand KVA charges.

$$\text{Monthly Energy cost (KVA)} = \text{Cost per KVA} \times \text{system power (Watts)} \quad (7)$$

$$\text{Annual Energy cost (KVA)} = \text{Monthly Energy cost (KVA)} \times 12 \quad (8)$$

the combination of formula (6) and (8) is the total annual energy consumption expressed in Rand/annum

$$\text{Total}_{\text{Annual energy consumption}} = R_{\text{Energy consumption}} + \text{Annual Energy cost (KVA)} \quad (9)$$

2.5.2.1.2. Maintenance costs

Ferrier (1997) argues on four common faults that are mostly to happen to streetlights including the replacements of cables, lamps, ballasts or the complete streetlight. The cost of all these parts is also related to the price of substitute labour.

Bamisile, Dagbasi and Abbasoglu (2016) argue that the replacement of lamps and ballasts is common for conventional streetlights because of their shorter lifespan. LED streetlights tend to reduce maintenance costs due to their longer life span. An LED streetlight can work for 50 000 hours compared to the conventional streetlight average operating hours of 12 000.

Maintenance cost is determined by combining the cost of the part and the labour costs. Although most municipalities tend to ignore labour costs due to in-house staff and their equipment, a more comprehensive evaluation should be considered. Table 3 illustrates how to calculate maintenance costs for streetlights.

Table 3 – Maintenance costs calculations (Ferrier, 1997)

Maintenance activities			
Description	Materials cost	Labour cost	Total maintenance cost
Lamp and replacement costs	$M_{\text{Cost in Rand}}$	$L_{\text{Cost in Rand}}$	$M_{\text{Cost in Rand}} + L_{\text{Cost in Rand}}$

2.5.2.2. End of life costs

The residual value shows the cost or profit produced at the end of life of a product. RV is negative if there is revenue and positive if there is cost. It may be related to the disposal of lights fittings where the company is required to outsource a disposal company at a fee. Formula (11) is an illustration of LCC with a positive RV.

Lee (2016) defines the concept as the monetary value of the outstanding life or further use of a product and its calculation can be drowned out of the outstanding service life (OSL). It is calculated as follows: (Lee, 2016).

$$\text{RV} = \frac{OSL}{total\ service}\ x\ initial\ capital\ cost \qquad (10)$$

2.5.3. Total cost of ownership

Tähkämö, Ylinen, and Puolakka (2012) focused on balancing pre and post-acquisition costs by adding all future costs to their value-avoidance. Their LCC calculation approach discounts all the returns and expenses to present value by using the interest rate and it is calculated as follows: (Tähkämö, Ylinen and Puolakka, 2012).

$$\text{LCC} = Ci + \left(\frac{1-(1+i)^{-n}}{i}\right) Co + \frac{RV}{(1+i)^n} \qquad (11)$$

Where:

Ci is the total investment cost. i is the rate of interest. n is the number of years. Co is the operating costs. RV is the residual value

Ellis (2014) argues that the cost calculations of the previous life cycle have not generated reliable future results. his theory argues that the attempt to estimate far in the future opens a room for errors to the expected results. Hence, the conclusion that LCC is not a precise science and results are an estimate. However, with realistic expectations, the cost of the life cycle is a viable instrument for estimating the cost of ownership between two products that fulfil the same obligation. Ellis (2014) argues that the net present value is the method to calculate the LCC. The net present value is the current value of an investment forecast cash flow minus the original investment and it is calculated as follows: (Ellis, 2014).

$$\text{NPV} = \sum_{t=1}^{t} \frac{CF}{(1+k)^t} - I \qquad (12)$$

Where:

NPV - net present value

CF - cash Flow

k = cost of capital (Interest rate)

t = time, years

I = investment

Schade (2014) argues that NPV or any type of capital investment decision can be used where a high investment is required to reduce the future cost requirements. It is expressed as follows: (Schade, 2014).

$$\text{NPV} = C + R - S + A + M + E \qquad (13)$$

Where:

C = Total investment cost

R = Replacement cost

S = Salvage cost at the end of life if applicable

A = Cost of operation, maintenance and repair (Recurring cost)

M= Cost of operation, maintenance and repair (Non-recurring cost)

E = Electricity cost

Different technologies acquire costs at a different stage of their life cycle. Similar costs must be brought to the same base period to facilitate comparison. Hence, the concept of time value of money and it is influenced by variables such as interest rate, interest earned, and inflation rate. Therefore, table 4 summarizes and illustrates the formulas discussed by different researchers as a basis for estimating and quantifying the LCC of streetlights.

Table 4 – LCC framework: LLC phases versus formulas breakdown (Nelson, Anderson and Cai, 2017; Baburajan, 2018; Tähkämö, Ylinen and Puolakka, 2012)

<table>
<tr><th colspan="2">Technology
LCC phases</th><th>Formulas for both LED and conventional technologies</th></tr>
<tr><td>Pre-acquisition costs</td><td>Acquisition costs</td><td>$A_{Costs} = S_{Costs} + P_{Costs} + I_{machinery, parts and labour costs}$ (2)</td></tr>
<tr><td rowspan="3">Post-acquisition costs</td><td>Usage</td><td>$E_{consumption} = n \times W$ (3)
$PN_{consumption} = E_{consumption} \times 12$ hours (4)
$A_{consumption} = PN_{consumption} \times 365$ (5)
$R_{Energy consumption} = A_{consumption} \times$ c/kWh (6)
Monthly Energy cost (KVA) = Cost per KVA x system power (Watts) (7)
Annual Energy cost (KVA) = Monthly Energy cost (KVA) x 12 (8)
$Total_{Annual energy consumption} = R_{Energy consumption}$ + Annual Energy cost (KVA) (9)</td></tr>
<tr><td>Maintenance</td><td><table><tr><th colspan="4">Maintenance activities</th></tr><tr><td>Description</td><td>Materials cost</td><td>Labour cost</td><td>Total maintenance cost</td></tr><tr><td>Lamp and replacement costs</td><td>$M_{Cost in Rand}$</td><td>$L_{Cost in Rand}$</td><td>$M_{Cost in Rand} + L_{Cost in Rand}$</td></tr></table></td></tr>
<tr><td>End-of-life</td><td>$\mathrm{RV} = \frac{OSL}{total\ service}\ x\ initial\ capital\ cost$ (10)</td></tr>
<tr><td rowspan="2">Total cost of ownership</td><td>Life cycle costing</td><td>$\mathrm{LCC} = \mathrm{Ci} + \left(\frac{1-(1+\mathrm{i})^{-\mathrm{n}}}{\mathrm{i}}\right)\mathrm{Co} + \frac{\mathrm{RV}}{(1+\mathrm{i})^{\mathrm{n}}}$ (11)</td></tr>
<tr><td>NPV</td><td>$NPV = \sum_{t=1}^{t} \frac{CF}{(1+k)^t} - I$ (12)
NPV = C + R – S + A + M + E (13)</td></tr>
<tr><td>Discounted payback</td><td>DPB</td><td>$\mathrm{DPB} = \frac{-\ln(1-\frac{iCi}{Co,old-Co,new})}{\ln(1+i)}$ (1)</td></tr>
</table>

Schade (2014) argues that the LCCA is not a one size fit all approach to quantify the life cycle cost of a product. Accordingly, each of the above formulas is based on the cost breakdown structure available to the organizational application. Although the formulas are the same for both technologies, the parameters and variables different.

The objective of generating formulas (1) to (13) is to shape the LCC framework to be used in the analysis of inventories that constitute the LCC of both streetlight technologies under this study. The LCC framework developed also aims to complement current literature by developing an applicable approach to validate the use of LED streetlights as for the conventional streetlights.

Table 4 which is derived by the researcher using formulas (1) to (13) from literature, illustrates the framework structure that analysis in chapter 4 will use to estimate the cost of using LED streetlights compared to conventional streetlights based on the selected data.

The entire LCCA, for both technologies, is based on an annual cycle with a minimum lifespan of 12 000 hours for conventional streetlights and 50 000 hours for LED streetlights. The framework can be used for different projects that cater to the needs of each municipality. The framework also requires adjustments over time due to the rapid changes in LED technology (Nelson et al., 2017). Hence, LCC calculation is a simple approach and the structuring of information can be referenced from international standards such as ISO 14040 and ISO 14044.

2.6. Life cycle cost analysis standards

The LCCA is regulated by the ISO 14040 and ISO 14044 and consists of four phases including objectives and scope; inventory assessment; impact analysis; and definition (Niu et al., 2018; Hadi et al., 2013):

2.6.1. The objective and scope description

Phase one governs the objectives and the scope of the research. It also establishes the unit of evaluation between alternatives under analysis.

2.6.2. Inventory assessment

Phase two gathers all records of all the cost drivers involved in the construction, usage and disposal of the product, including all the inputs such as raw materials and all the outputs such as CO_2 emissions.

2.6.3. Impact analysis

Phase three calculates all the environmental impacts influenced by the inputs and outputs from phase two and it shows why the intended product or system is the option to consider.

2.6.4. Interpretation

Lastly, all conclusions of the three steps are summarised to issue a recommendation to facilitate decision making. This research is also structured to comply with the four main points of the life cycle costs analysis standards. Chapter one and two covers the scope and objectives of the research which shall include identifying the research questions, structuring the research scope, and leveraging the current knowledge of the LCC of streetlights.

Chapter four covers the inventory assessment and the impact analysis section which includes the compilation of streetlight cost driver information and the analysis of those data. This section introduces chapter five which covers the interpretation of data and recommendations. The purpose is to promote decision-making during the implementation of streetlights projects within the municipalities.

2.7. Conclusion

The purpose of chapter 2 is to bring the current knowledge of this research topic to the reader's attention. It addresses the concept of LCC in general and in the context of conventional and LED streetlights. Hence, the type of LCC calculation, its standards, its advantages and disadvantages are also discussed.

From the various literature examined, the researchers brought their experiences and observations into both streetlights technologies and the factors that influencing the total cost of ownership. Energy management is the practice for public lighting in many countries. hence, LED streetlights are rapidly gaining momentum (Yoomak et al., 2018). The costs involved in the operation life of a product is crucial for an organisation. Besides, researchers have shown different methodology that one can use in the estimation of the cost involved in the life cycle of streetlights. It is vital to establish an efficient life cycle cost analysis tool for any application.

The next chapter introduces the research methodology and approach used to answers the research questions under this study.

CHAPTER 3: RESEARCH METHODOLOGY

Chapter 3 describes the methodology and process used to address the research questions. Therefore, it stipulates the chosen methodology and the type of research design applied. it also provides the type of data needed to answer the research questions while describing the data collection and analysis methodology used.

3.1. Introduction

As a researcher, the selection of an acceptable approach for your research questions to be addressed is always a challenge (Walker, 2014). At first, as a general approach, chapter 2 discussed the works of various researchers on how they have dealt with similar problems while demonstrating the existence of different approaches. Only a few works of literature have provided specific data on the chosen research methodology as they mostly focus on reporting findings.

The goal of this research is to quantify the life cycle cost of using LED streetlights as for conventional streetlights. It focuses on the life cycle cost analysis of conventional streetlights and LED streetlights while looking at the cost's drivers during the pre-acquisition and post-acquisition stages. This study aims to enable municipalities to evaluate the merit of streetlights projects based on energy use and total cost of ownership.

Walker (2014) argues that the ability to match the correct research methodology or creating a new one to answer a research problem is a mandatory skill for any researcher. Therefore, the next point will introduce the type of methodology to be used to address the research questions under this investigation and establish the most appropriate design approach.

3.2. Research methodology

3.2.1. Background

Kumar (2011) discusses the research models from three different views which include:

- Application of the results found
- Objectives of the research

- Mode of enquiry utilised to conduct the research

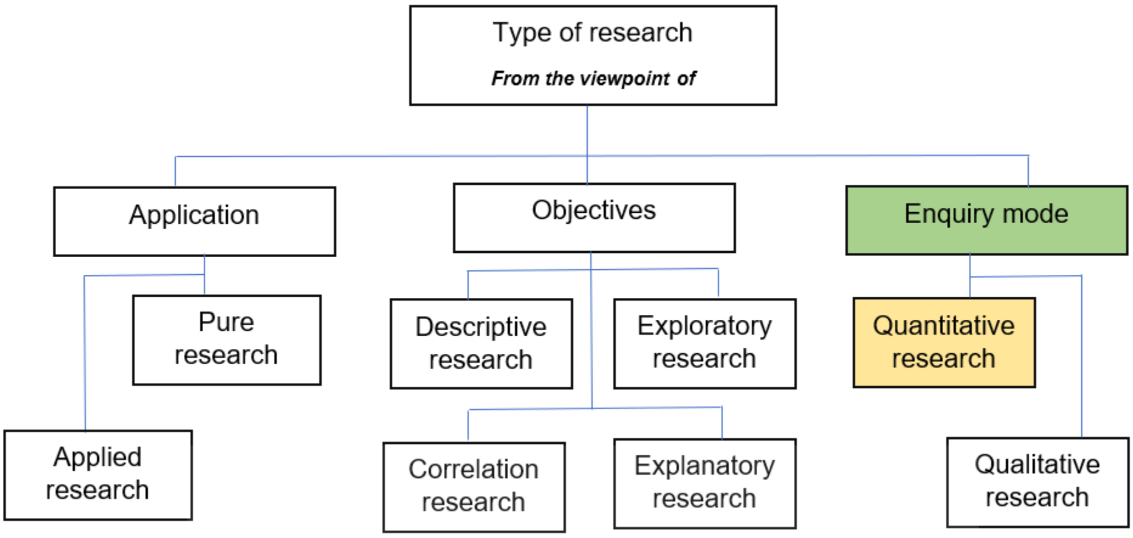


Figure 5: Research types (Kumar, 2011)

The goal of describing the different research methods in figure 5 is to introduce the highlighted approaches that this research focuses on which is the quantitative research approach.

3.2.2. Enquiry mode view and quantitative research approach

The mode of enquiry approach explores the work of researchers to find answers to the research questions under investigation. It generally follows a structured approach which has a predetermined process and an unstructured approach which is more flexible. Kumar (2011) associates the structured approach to quantitative research, where there is a need to establish the degree of the problem.

The goal of this research is to quantify and compare the LCC of conventional streetlights versus LED streetlights. Hence, the reason the quantitative research approach under the enquiry mode category is selected. the objective is to quantify and compare both streetlight technologies cost's drivers to answer research questions under this study. In other to quantify the entire life cycle cost of both streetlights' technology from acquisition to disposal. The costs during different stage of their life must be identified, collected and calculated based on formulas summarised in table 4.

The next point will introduce and elaborate the subsection of the mode of inquiry path that forms the core approach of this investigation.

3.2.3. Quantitative methodology as a selected approach for this research

Quantitative research governs the scientific literature in many disciplines, and it is characterised by measurement and data (Wang, 2010). In the context of this research and from the literature covered in chapter 2, quantitative research supports the effectiveness of LED technology solution that can be used as an alternative for conventional technology. This is achieved using quantitative data. This study's necessity of measurement addresses how the investigated research questions can be objectively addressed. Therefore, this research uses Fryer et al. (2018) 's approach to address the basics of quantitative research. it measures countable elements and gathers enough of these elements to conduct a descriptive and observational analysis since there was no experimental measurement and verification done.

The quantitative research approach under this study relies on secondary data from a study funded by the department of energy (DoE) in collaboration with the Greater Tzaneen municipality. It is also based on secondary data from past projects by the employer of the researcher and annually published reports from the Greater Tzaneen municipality. The combined sources of data utilise Fryer et al., (2018) 's approach to determine the LCC of both streetlight technologies and quantify the energy consumptions of both streetlight technologies. Nonetheless, the attributes of the quantitative research approach go by the objectives of this study. Therefore a structure or a quantitative approach is followed to generate a research process and design that guides the formulation of answers to the research questions under this investigation.

3.3. Research design and data requirements

Halverson (2014) describes the research design as an outline that focuses on data collection and analysis. Although the research concept is perceived as an immediate process of collecting and analysing data through different approaches, yet it is just a fragment of a bigger process connecting different stages both before and after. Walker (2014), through his general research process, illustrates the procedure a researcher can follow when having a potential research problem worthy to investigate. This is done by designing a hypothesis founded primarily on observation and secondly on similar literature.

In the context of this study, to answer to the research questions presented in chapter 1, a data collection tool was designed to guide the process of collecting information based on the pre and post-acquisition costs of streetlights developed in table 1. The information from secondary sources was rearranged and categorized based on table 4 structure of pre and post-acquisition costs to use the formulas selected from literature to quantify the LCC of both streetlights' technologies. The process to answer the research questions and the data required are presented in table 5 and 6 for both research questions.

Table 5 and 6 present the required data, formulas, and process followed during analysis to answer the research questions under this study.

Research question 1: What is the energy usage of an LED streetlight compared to a conventional streetlight?

Table 5 – Selected data requirement versus research design (research question 1)

LCC stage required	**LCC sub-stage required**	**Secondary data required**	**Formulas to answer research question 1**	**How the required data is used together with the formulas to answer research question 1**
Post-acquisition costs	Usage (Electricity)	• Streetlight wattage (W) • Number of streetlights (n) • Operating hours (12 hours) • c/kWh • KVA cost • Weekly energy consumption from a measurement and verification audit.	• $E_{consumption} = n \times W$ (3) • $PN_{consumption} = E_{consumption} \times 12$ hours (4) • $A_{consumption} = PN_{consumption} \times 365$ (5) • $R_{Energy\ consumption} = A_{consumption} \times$ c/kWh (6) • Monthly Energy cost (KVA) = Cost per KVA x system power (Watts) (7) • Annual Energy cost (KVA) = Monthly Energy cost (KVA) x 12 (8) • $Total_{Annual\ energy\ consumption} = R_{Energy\ consumption}$ + Annual Energy cost (KVA) (9)	• The energy consumption per streetlight network is calculated by multiplying the wattage of the streetlight by the number of streetlights in the networks. • The annual energy consumption is calculated by multiplying the total wattage by the 12 hours operating hours per day and 365 days a year. • The municipal annual report provides the c/kWh and demand kVA rates which are used to calculate the total annual energy consumption in Rand.

Research question 2: What is the life cycle cost of an LED streetlight compared to a conventional streetlight?

Table 6 – Selected data requirement versus research design (research question 2)

LCC Stages required	**LCC Sub-stages required**	**Secondary data required**	**Formulas to answer research question 2**	**How the required data is used together with the formulas to answer research question 2**
Pre-acquisition costs	Acquisition costs	• Streetlight price (S_{Costs}) • Pole costs • Lamps price	$A_{Costs} = S_{Costs} + P_{Costs} + I_{\text{machinery, parts and labour costs}}$ (2)	The sum of the streetlight's purchase costs, installation costs, machinery and all required part costs constitute the acquisitions costs
Post-acquisition costs	Usage (electricity)	As illustrated in table 5	As illustrated in table 5	As illustrated in table 5
	Maintenance	• Replacement labour costs • Lamps price	$M_{\text{Cost in Rand}} + L_{\text{Cost in Rand}}$	The material costs plus the labour costs constitute the total maintenance costs
	End-of-life	• Acquisition costs • Outstanding service life	$RV = \frac{OSL}{\text{total service}} \text{ x initial capital cost}$ (10)	The residual value of streetlights is calculated by dividing the outstanding service life or salvage life by the total service life. The answer is multiplied the initial capital cost.

The combination of the required data and formulas from table 5 and 6 is utilised to calculate the total life cycle cost for both technologies streetlights as illustrated in table 8. The analysis in chapter 4 is conducted based on the conventional streetlights of 125W with an alternative LED replacement of 54W. The reason for this choice is the secondary data collected from the municipality is based on the 125W conventional streetlights as a baseline and 54W LED streetlights used to pilot the energy-efficient project.

The discounted payback is also included in the total LCC calculation table to illustrate a scenario where the decision markers require the time frame to recoup an LED streetlights investment in terms of the return on investment on the difference between the energy consumption between the two technologies.

Table 7 – Total cost of ownership and DPB calculations

LCC and DPB descriptions		**Secondary data required**	**Formulas to answer research question 2**	**How the required data is used together with the formulas to answer research question 2**
Total cost of ownership	Life cycle costing	• Pre-acquisition costs • Post-acquisition costs • Interests rate • Residual value	$\mathrm{LCC} = \mathrm{Ci} + \left(\frac{1-(1+\mathrm{i})^{-\mathrm{n}}}{\mathrm{i}}\right)\mathrm{Co} + \frac{\mathrm{RV}}{(1+\mathrm{i})^{\mathrm{n}}}$ (11)	The combination of the pre and post-acquisition costs together with the residual costs and interest rate in formula (11) determine the total LCC for both streetlight technologies under investigation.
	NPV	• Pre-acquisition costs • Post-acquisition costs • Interests rate • Residual value	$NPV = \sum_{t=1}^{t} \frac{CF}{(1+k)^t} - I$ (12) NPV = C + R – S + A + M + E (13)	The combination of the pre and post-acquisition costs together with the residual costs and interest rate in formula (11) determine the total LCC for both streetlight technologies under investigation. This is with or without the time value of money added during the calculations.
(DPB)	Discounted payback	• Conventional streetlights operating costs • LED streetlights operating costs • I = interest rate • LED pre-acquisition costs (Ci)	$\mathrm{DPB} = \frac{-\ln(1-\frac{iCi}{Co,old-Co,new})}{\ln(1+i)}$ (1)	The required data is used in combination with formula (1) to establish how long will it take to recoup the LED streetlight investment when replacing conventional streetlights. the scenario is based on the results of this research.

3.4. Data collection

3.4.1. Data collection process

There are two main approaches to collect data to answer research questions namely primary data collection and secondary data collection techniques (Kumar, 2011). For this study, secondary data were collected from, first, a study conducted between Onga energy efficiency and management (Pty) Ltd, MVM Africa electrical engineers, and Greater Tzaneen municipality. The collected data complies with the Eskom measurement and verification process energy efficiency project protocol as per SANS 50010 standard. Secondly, the data were collected from annual reports published by the Greater Tzaneen municipality and, lastly, the data was also collected from the researcher employer. Figure 6 illustrates and summarises the data collection process used in this research.

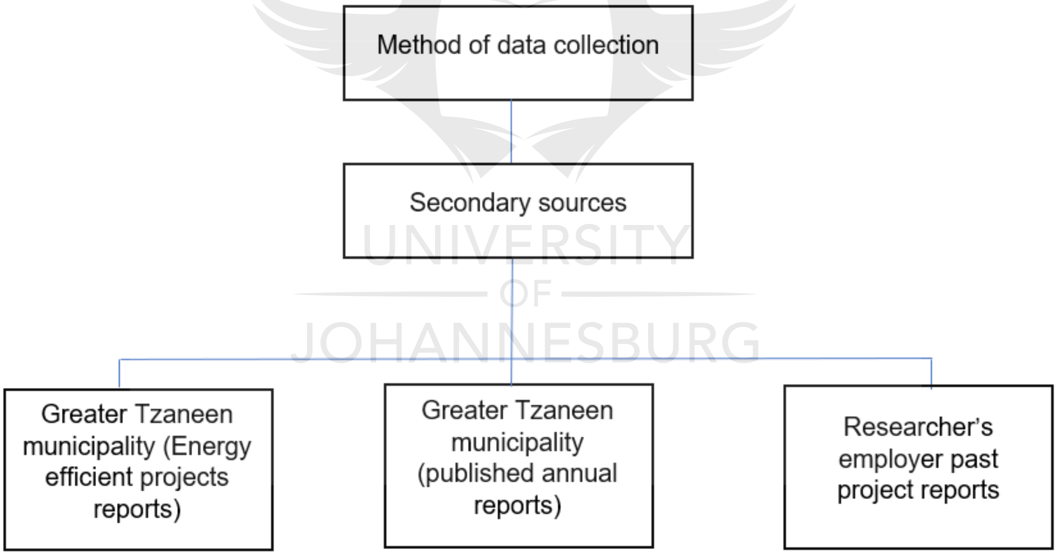


Figure 6: Data collection techniques adopted from (Kumar, 2011).

For this research, secondary sources as a data collection approach was feasible due to the availability and accessibility of information. The following point introduces the source of information collection for this research and the reason for their selection.

3.4.1.1. Greater Tzaneen municipality

As the owner of the streetlight's infrastructure, this method is backed by the availability of data from the municipality electricity department and can be found from the maintenance and operations records.

The data used for this study was made available by the University of Johannesburg's report compile during a study in the Greater Tzaneen municipality in Limpopo where data was collected during measurement and verification of streetlights during an integrated demand management intervention initiated by the municipality.

3.4.1.2. Researcher's employee past projects

This method is backed by the availability of information from the employer of the researcher. It includes past project proposals containing information such as the initial capital required for streetlight projects, feasibility study undertaken by the company to convince the government sector to use LED technology instead of the conventional technology, etc. however, the maintenance and operations data from past projects also form part of the documentation available. It contains information on energy cost and economic feasibility projections on key cost drivers affecting the entire LCC.

3.4.1.3. Chain of evidence

It is very important to validate the authenticity and traceability of the collected data to provide evidence of their source.

An official enquiry for secondary data usage was launched to the university of Johannesburg measurement and verification team and the researcher's employer. Approval was granted to the researcher to use the reports as secondary sources of data collection. The above doesn't exclude other forms of chain of evidence that include telephone calls, e-mails, database search, etc.

3.4.2. Data clean-up

The energy study undertaken by the municipality covers differents areas that include office, corridors, streetlights, etc. Therefore, firstly, the data collected was narrowed to streetlights applications. Secondly, the data were categorized by pre-acquisition and post-acquisition cost drivers to meet table 4 framework. This also applies to all the public reports published by the municipality and past project from the researcher's employer.

A summary of the selected secondary data is introduced in the next chapter to enable analysis that will quantify the LCC of conventional streetlights versus LED streetlights. Therefore, a comparison of both technologies can easily be established. This approach will identify the key cost drivers which affect the LCC of a streetlight depending on their technology and enable the analysis of these key cost drivers to quantify the LCC of both technologies streetlights which will assist municipal decision-makers to evaluate the merit of streetlight projects.

3.5. Data analysis

Once, the collection of data is completed, as a researcher, one needs to ensure the collected data analysis is feasible. In this context, the evaluation of both streetlights' technologies needs to be completed within a specific period by using available resources. Hence, not everything is predicted in advance, certain factors may change during the analysis. The analysis will need to be adapted accordingly. Langkos (2019) argues on the content analysis technique approach which not only enables the collected data to be categorized in such a way to be comparable. But, also produce results that are measurable using a quantitative approach to satisfy the research questions under this investigation.

For this research, mathematical formulas from literature in table 4 are utilised to formulate a calculation tool to quantify the LCC of both streetlights' technologies. These formulas are selected to categorize, measure, and compare key cost to answer the research questions under this study. The categorisation, measurement, and comparison aim the place key cost drivers under pre-acquisition and post-acquisition costs stages to enable analysis.

3.6. Conclusion

Chapter 3 lays out the researcher methodology and the procedure for responding to research questions in the context of this investigation. This presented the reasons why the qualitative analysis was chosen as the preferred approach. It also initiated the data collection process to be conducted by a researcher focused on secondary data. The data collected were cleaned to allow mathematical calculations to be carried out based on the selected formulas in table 4.

For this research, quantitative methodology supports the effectiveness of LED technology solution compared to conventional technology. The analysis of the collected data will be done by categorisation, measurement and comparison of the collected data. its necessity of measurement or calculation addresses how the investigated research questions can be objectively answered.

The following chapter will focus on presenting the selected secondary data, analysing it and interpreting the results.

CHAPTER 4: DATA ANALYSIS AND RESEARCH FINDINGS

This chapter provides data analysis to present the research findings deducted from quantifying and comparing the LCC of conventional streetlights versus LED streetlights. It also provides an overview of how the data are analysed and how the research findings answered the research questions under this study in a manner that generate reliable outcomes. A mathematical analysis tool is used to quantify and compare the LCC of both streetlight technologies.

4.1. Quantitative data analysis

A quantitative investigation shall pursue information in a numerical format or may be changed into a numerical format. The elementary techniques utilised to analyse numerical information are known as statistics (Sheard, 2018). These techniques are a combination of processes namely, organise, analyse, interpret and present the collected numerical data. Therefore, this section aims to give the basis of how the quantitative data was prepared and analysed as well as how the outcomes of the analysis should be understood and conveyed.

The objective of this research is to quantify and compare the total LCC of LED streetlights with conventional streetlights. For the researcher to address the following statement:

This research aims to quantify and compare the energy usage and the entire life cycle costs of conventional streetlights as opposed to LED streetlights. This study, therefore, seeks to considerably empower local municipalities to evaluate the merits and costs of street lighting projects.

Research findings must be presented in a manner that measures and compares the energy use and the total cost of ownership of the two streetlight technologies. Table 1 presents the concept of the cost breakdown structure (CBS) that is needed to evaluate the costs involved in the life of a product. It is very important to break down all streetlight technologies into sections to ensure that all the cost drivers are connected to the collected data. Hence, the subsequent sections introduce the secondary data selected for this research and proceeds to outline the process undertaken to quantify it.

4.2. Required selected data and data analysis

The secondary data identified for this research are mainly based on a study funded by the department of energy (DoE) within the Greater Tzaneen municipality. It is situated in the Mopani district municipality of Limpopo province. With a mission to ensure the effective and efficient use of existing resources, it covers an area of 3 243 000 square metres with more than 10 towns.

4.2.1. Energy usage required data and analysis

4.2.1.1. Required data

The secondary data selected was initially used to reduce the lighting load within the Greater Tzaneen municipality area. This was done by replacing the conventional technology streetlight with a more efficient one. Table 8 summarises the data required to answer research question 1.

Table 8 – Summary of data required for the total energy consumption calculation

Conventional streetlights (Onga M&V, 2014)		LED streetlights (Onga M&V, 2014)	
Type and wattage	Quantity	Type and wattage	Quantity
Mercury vapour (125W)	2161	LED (54W)	2161
The below data applies for both streetlight technologies			
Operating hours	12 Hours	(Onga M&V, 2014)	
c/kWh	47 Cents	(GTM annual report, 2014)	
Demand KVA	R 112	(GTM annual report, 2014)	

A second set of secondary data was also selected from data collected following a methodology that conforms to the measurement and verification of SANS 50010 and the Eskom standard procedure for energy efficiency and demand-side management projects. The data was collected with the assumption that the power factors of the streetlights and their operating hours were stable for 12 hours per day during weekdays and weekends.

Table 9 **–** Baseline data in (kW) for 12 hours operating time, power consumption measurement and verification. Weekdays and weekends (Onga M&V, 2014).

Technology Conventional				**Technology Conventional**			
Time	Weekday	Saturday	Sunday	Time	Weekday	Saturday	Sunday
00:00	310.46	310.46	310.46	**18:00**	**155.23**	**155.23**	**155.23**
00:30	310.46	310.46	310.46	**18:30**	**155.23**	**155.23**	**155.23**
01:00	310.46	310.46	310.46	19:00	310.46	310.46	310.46
01:30	310.46	310.46	310.46	19:30	310.46	310.46	310.46
02:00	310.46	310.46	310.46	20:00	310.46	310.46	310.46
02:30	310.46	310.46	310.46	20:30	310.46	310.46	310.46
03:00	310.46	310.46	310.46	21:00	310.46	310.46	310.46
03:30	310.46	310.46	310.46	21:30	310.46	310.46	310.46
04:00	310.46	310.46	310.46	22:00	310.46	310.46	310.46
04:30	310.46	310.46	310.46	22:30	310.46	310.46	310.46
05:00	310.46	310.46	310.46	23:00	310.46	310.46	310.46
05:30	310.46	310.46	310.46	23:30	310.46	310.46	310.46

4.2.1.2. Analysis

The energy usage data is required to answer the research question 1 under this investigation. Firstly, energy usage is an analysis based on the research process, design, and formulas introduced in table 5. Secondly, the analysis will be based on secondary data selected from the measurement and verification conducted within the municipality.

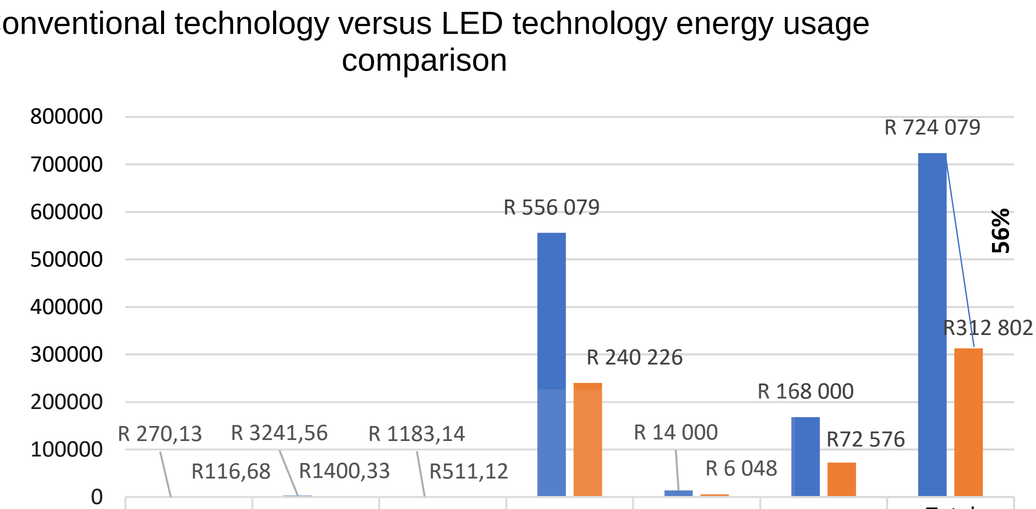
Table 10 – Energy usage calculations for conventional technology (research question 1)

LCC stage required	**LCC sub-stage required**	**Secondary data required**	**Formulas to answer research question 1**	**Energy usage results**
Post-acquisition costs	Energy Usage (Electricity)	• Streetlight wattage (W) = 125W • Number of streetlights (n) = 2161) • Operating hours= 12 hours • c/kWh= 47 cents • demand KVA = R 112	• $E_{consumption}$ = n x W **(3)**	• $E_{consumption}$ = 270,13 KW
			• $PN_{consumption}$ = $E_{consumption}$ x 12 hours **(4)**	• $PN_{consumption}$ = 3241.56 KW
			• $A_{consumption}$ = $PN_{consumption}$ x 365 **(5)**	• $A_{consumption}$ = 1183.14 MW
			• $R_{Energy\ consumption}$ = $A_{consumption}$ x c/kWh (yearly) **(6)**	• $R_{Energy\ consumption}$ = R 556 079
			• Monthly demand KVA = Cost per KVA x system power (Watts) **(7)**	• Monthly demand KVA = R 14 000
			• Annual demand KVA = Monthly Energy cost (KVA) x 12 **(8)**	• Annual demand KVA = R 168 000
			• $Total_{Annual\ energy\ consumption}$ = $R_{Energy\ consumption}$ + Annual Energy cost (KVA) (yearly) (**9)**	$Total_{Annual\ energy\ consumption}$ = R 724 079

Table 11 – Energy usage calculations for LED technology (research question 1)

LCC stage required	**LCC sub-stage required**	**Secondary data required**	**Formulas to answer research question 1**	**Energy usage results**
Post-acquisition costs	Energy Usage (Electricity)	• Streetlight wattage (W) = 54W • Number of streetlights (n) = 2161 • Operating hours= 12 hours • c/kWh= 47 cents • demand KVA = R 112	• $E_{consumption} = n \times W$ **(3)**	• $E_{consumption}$ = 116.68 KW
			• $PN_{consumption} = E_{consumption} \times 12$ hours **(4)**	• $PN_{consumption}$ = 1400.33 KW
			• $A_{consumption} = PN_{consumption} \times 365$ **(5)**	• $A_{consumption}$ = 511.12 MW
			• $R_{Energy\ consumption} = A_{consumption} \times$ c/kWh (yearly) **(6)**	• $R_{Energy\ consumption}$ = R 240 226
			• Monthly demand KVA = Cost per KVA x system power (Watts) **(7)**	• Monthly demand KVA = R 6 048
			• Annual demand KVA = Monthly Energy cost (KVA) x 12 **(8)**	• Annual demand KVA = R 72 576
			• $Total_{Annual\ energy\ consumption} = R_{Energy\ consumption}$ + Annual Energy cost (KVA) (yearly) **(9)**	$Total_{Annual\ energy\ consumption}$ = R 312 802

4.2.1.2.1. Conventional technology versus LED technology energy usage, a comparison from table 10 and 11 calculations



	E consumption (KW)	PN consumption (KW)	A consumption (MW)	R Energy consumption/ year (Rands)	Monthly demand KVA (Rands)	Annual demand KVA (Rands)	Total annual energy consumption (Rands)
Conventional technology	270,13	3241,56	1183,14	556 079	14 000	168 000	724 079
LED technology	116,68	1400,33	511,12	240 226	6 048	72 576	312 802

Figure 7: Conventional technology versus LED technology energy usage comparison

The figure above illustrates a comparison of key drivers that contribute to the energy consumption between the two technologies. The difference in the total annual energy consumption between the two technologies is of 56 percent based on the selected secondary data used. Therefore, the data used for this study indicates that LED streetlights consume 56 percent less energy compared to the conventional streetlight for the same required light output.

4.2.1.2.2. Analysis of selected data from the measurement and verification audit

Conventional streetlights require a starting time to fully illuminate and consume power to the fullest (Pliszczak, 2010). Hence, there is a significant drop in energy consumption from the usage data selected from 18:00 to 18:30 when they are initially turned on. The secondary data selected for the conventional technology recorded 310 kW power consumptions on weekdays, Saturdays and Sundays

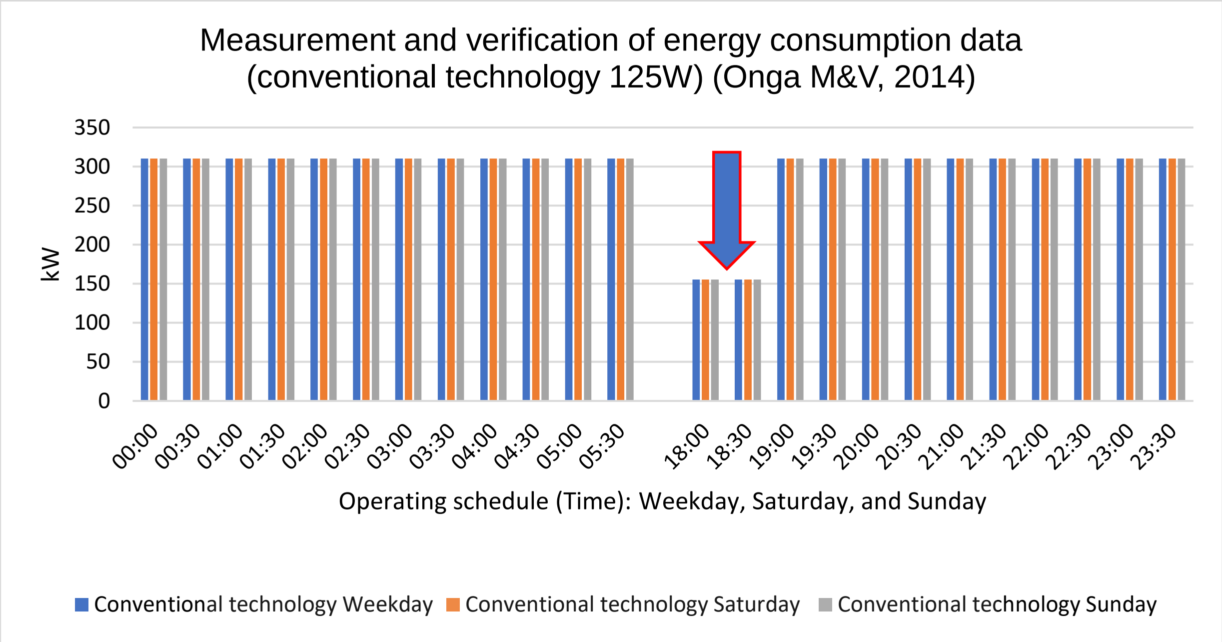


Figure 8: Weekly measurement and verification of energy consumption data (conventional technology)

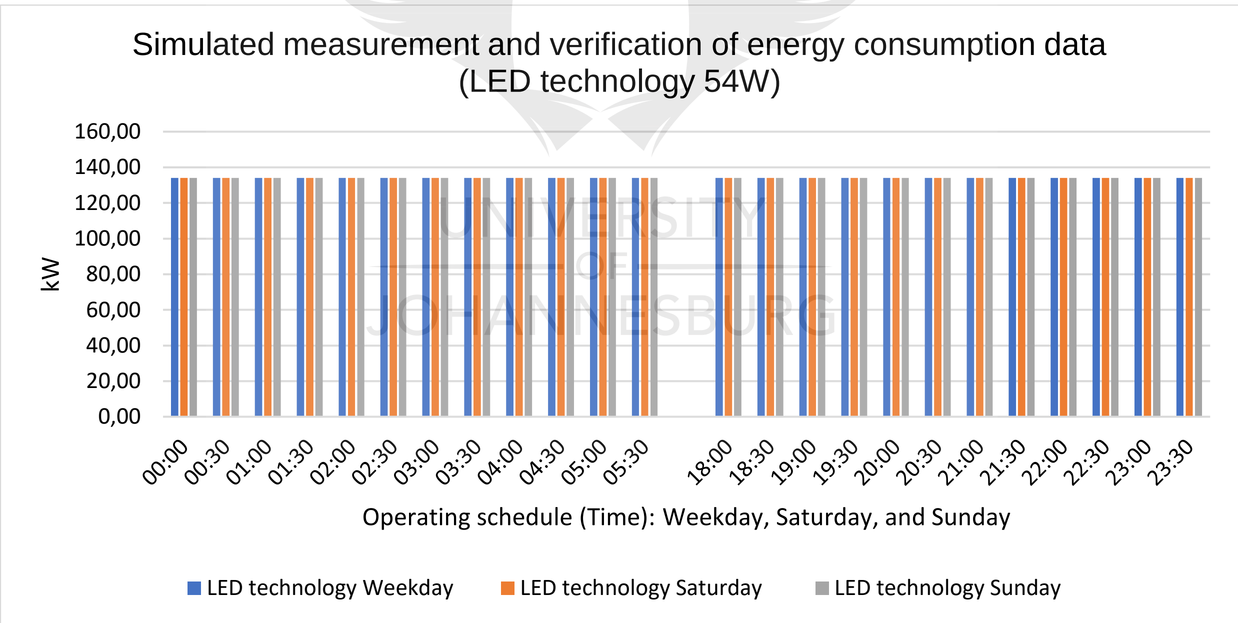


Figure 9: Simulated measurement and verification of energy consumption data (LED technology)

The municipality used a 54W LED technology as an alternative to pilot the project. A LED technology energy usage simulation is presented in figure 9 based on the 56 percent drop in power between the 125W conventional streetlight and the 54W LED streetlight. Power consumption of only 134W is recorded on weekdays, Saturdays, and Sundays. Due to their ability to light up to their full capacity, the power of LED streetlights remains constant at 134W from 06:00 PM to 5:30 AM.

Conventional technology such as mercury vapour which forms the baseline of the selected data requires stabilizers to withstand power interruption or dip. It includes the installation of additional capacitors to improve the power factor. Hence, the power factor is assumed to be stable during data collection.

The objectives of the measurement and verification are to establish the actual daily electricity usage as well as to monitor the operating environment. Therefore, the measured values can in return be compared to the electricity cost to evaluate the deviation and its reasons. The typical deviation is utilized as a baseline for unmeasured infrastructure. The selected secondary data presents the actual energy usage of the 2161 conventional streetlights.

Figure 9 illustrates the 56 percent decrease in energy usage between the conventional streetlights versus the LED streetlights. The LED streetlights power consumption is constant regardless of the operating hours. This is due to their ability to instantly reach the full operating status as compared to the conventional technology which requires starting time.

4.2.2. Total cost of ownership required data and analysis

The total cost of ownership includes all the costs incurred during the pre-acquisition and the post-acquisition phases. The next section introduces the required data to answer research question 2 under this investigation.

4.2.2.1. Required data

Tables 12 and 13 summarise the data required to answer research question 2 under this investigation. The data presented is utilised as input to quantify the LCC of the two streetlight technologies by applying the formulas presented in table 4.

Table 12 – Summary of data required for the total LCC calculations (Conventional technology)

Pre-acquisition costs data		
Conventional streetlight cost	R 2703	(Philips lighting, 2016)
Conventional lamps cost	R 48,77	(Philips lighting, 2016)
Poles costs including installation	R 1500	(Philips lighting, 2016)
Post-acquisition costs data		
Energy Usage in Rands	R 724 079	Results from table 10
Maintenance: • Lamps replacement labour costs • Lamps replacement cost	R 200 R 48.77	(Philips lighting, 2016)
End-of-life: • OSL • Total service life	0 12 000 hours	(Philips lighting, 2016)

Table 13 – Summary of data required for the total LCC calculations (LED technology)

Pre-acquisition costs data		
LED streetlight cost with Lamp (LED chips) included	R 2120.70	(Philips lighting, 2016)
LED chips or lamps cost	R 0	
Poles costs including installation	R 1500	(Philips lighting, 2016)
Post-acquisition costs data		
Energy Usage in Rands	R 312 802	Results from table 11
Maintenance: • Lamps replacement labour costs • Lamps replacement cost	R 0 R 0 (Lamps integrated)	(Philips lighting, 2016)
End-of-life: • OSL • Total service life	0 50 000 hours	(Philips lighting, 2016)

4.2.2.2. Analysis

Table 14 – Pre-acquisition and post-acquisition cost calculation for conventional technology (Research question 2)

LCC Stages required	LCC Sub-stages required	Secondary data required	Formulas to answer research question 2	Results
Pre-acquisition costs	Acquisition costs	• Streetlight cost (S_{cost}) = R 2703 • Pole costs including I, (machinery, parts and labour) = R 1500 • Lamps price= R 48.77	$A_{Costs} = S_{cost} + P_{Costs} + I_{\text{machinery, parts and labour costs}}$ (2)	A_{Costs} = R 4 252.42 For 2161 units A_{Costs} = R 9 189 479.62
Post-acquisition costs	Energy Usage (electricity)	Total annual energy consumption	Results from table 10	R 724 079
	Maintenance	• Replacement labour costs = R 200 • Lamps price = R 48.77	$M_{\text{Cost in Rand}} + L_{\text{Cost in Rand}}$	R 248.77 per lamps. At least one replacement per lamps a year. for 2161 streetlights M = R 537 591.97
	End-of-life	• Acquisition costs= R 9 189 479.62 • OSL = 0 • Total service life = 12 000 hours	$RV = \frac{OSL}{\text{total service}} \times \text{initial capital cost}$ (10)	For this research, the OSL = R 0 because after a year of operation the light output decrease below standards and cannot be utilised further. The assumption is, there is no cost acquired while disposing the lamps. Therefore, RV = R 0

Table 15 – Total cost of ownership calculation for conventional technology (Research question 2)

LCC descriptions		**Secondary data required**	**Formulas to answer research question 2**	**Results**
Total cost of ownership	Life cycle costing	Pre-acquisition costs (Ci) = R9 189 479.62 • Post-acquisition costs (Co) = (R 724 079 + R 537 591.97) = R1 261 670.97 • Interests rate (i) = 6 • Number of years (n) = 1 • Residual value = R0	$LCC = Ci + \left(\frac{1-(1+i)^{-n}}{i}\right) Co + \frac{RV}{(1+i)^{n}}$ (11)	LCC = R 9 369 718.33
	NPV	Pre-acquisition costs = R9 189 479.62 • Replacement costs = R 537 591.97 • Energy usage cost = R 724 079 • Interests rate (k)= 6 • T=1 year • CF= R 1 261 670.97 • Residual value (S) = R 0	$NPV = \sum_{t=1}^{t} \frac{CF}{(1+k)^{t}} - I$ (12) NPV = C + R – S + A + M + E (13)	Cash flows are represented as negatives value in the balance sheets. NVP (12) = R 9 009 240.91 (Time value of money considered) NVP (13) = R10 451 150.59 (A=0; M=0) (No time value of money considered)

Table 16 – Pre-acquisition and post-acquisition costs calculation LED technology (Research question 2)

LCC Stages required	**LCC Sub-stages required**	**Secondary data required**	**Formulas to answer research question 2**	**Results**
Pre-acquisition costs	Acquisition costs	• Streetlight Cost (S_{cost}) = R 2120.70 • Pole costs = R 1500	$A_{Costs} = S_{cost} + P_{Costs} + I_{machinery,\ parts\ and\ labour\ costs}$ (2)	A_{Costs} = R 3 620.70 For 2161 units A_{Costs} = R 7 824 332.70
Post-acquisition costs	Energy Usage (electricity)	Total annual energy consumption	Results from table 11	R 312 802
	Maintenance	• Replacement labour costs • Streetlight cost	$M_{Cost\ in\ Rand} + L_{Cost\ in\ Rand}$	Due to the long life of LED technology no replacements are due in a year hence, M = R 0
	End-of-life	• Acquisition costs = R 7 824 332.70 • Outstanding service life (OSL) = R 0 • Total service life = 50 000 hours	$RV = \frac{OSL}{total\ service} \times initial\ capital$ (10)	For this research, the OSL = 0 because after five years of operation the light output decrease below standards and cannot be utilised further. The assumption is there is no cost acquired while disposing the streetlights. Therefore, RV = R 0

Table 17 – Total cost of ownership calculation LED technology (Research question 2)

LCC descriptions		**Secondary data required**	**Formulas to answer research question 2**	**Results**
Total cost of ownership	Life cycle costing	Pre-acquisition costs (Ci) = R7 824 332.70 • Post-acquisition costs (Co) = (E = R 312 802 + M = R 0) • Interests rate = 6 • Number of years (n) = 1 • Residual value = 0 Rands	$\text{LCC} = \text{Ci} + \left(\frac{1-(1+\text{i})^{-\text{n}}}{\text{i}}\right)\text{Co} + \frac{\text{RV}}{(1+\text{i})^{\text{n}}}$ (11)	LCC = R 7 869 018,70
	NPV	• Pre-acquisition costs = R 7 824 332.70 • Replacement cost = R 0 • Energy usage cost = R 312 802 • Interests rate (k) = 6 • t = 1 year • CF = R 312 802 • Residual value (S) = R0	$NPV = \sum_{t=1}^{t} \frac{CF}{(1+k)^t} - I$ (12) NPV = C + R – S + A + M + E (13)	Cash flows are represented as negatives value in the balance sheets. NVP (12) = R 7 779 646.7 (Time value of money considered) NVP (13) = R 8 137 134.7 (A=0; M=0) (No time value of money considered)

For a scenario where there is an existing conventional streetlight infrastructure, the notion of a return on investment time expressed as the discounted payback (DPB) in the calculations illustrates the time required for the investment costs of a different technology as LED to pay for itself using the energy usage and maintenance costs. If the conventional technology infrastructure needs to be replaced, it will take 2 years for the money used to purchase the LED streetlights to be recouped based on the savings from the energy consumption and maintenance costs.

Table 18 – Discounted payback calculation

Discounted payback		Required data	Formula	Results
Discounted payback	DPB	• Conventional streetlights operating costs = R 724 079 Energy usage costs plus R537 591,97 Maintenance costs. Total = R1 261 670.97 (Co, old) • LED streetlights operating costs = R 312 802 (Co, new) • I = 6 Ci = R 7 824 332.70 (LED)	$\mathrm{DPB} = \frac{-\ln(1-\frac{iCi}{Co,old-Co,new})}{\ln(1+i)}$ (1)	DPB = 1.9944 years

4.2.2.2.1. Conventional technology versus energy technology total cost of ownership calculations, a comparison from table 14, 15, 16, and 17

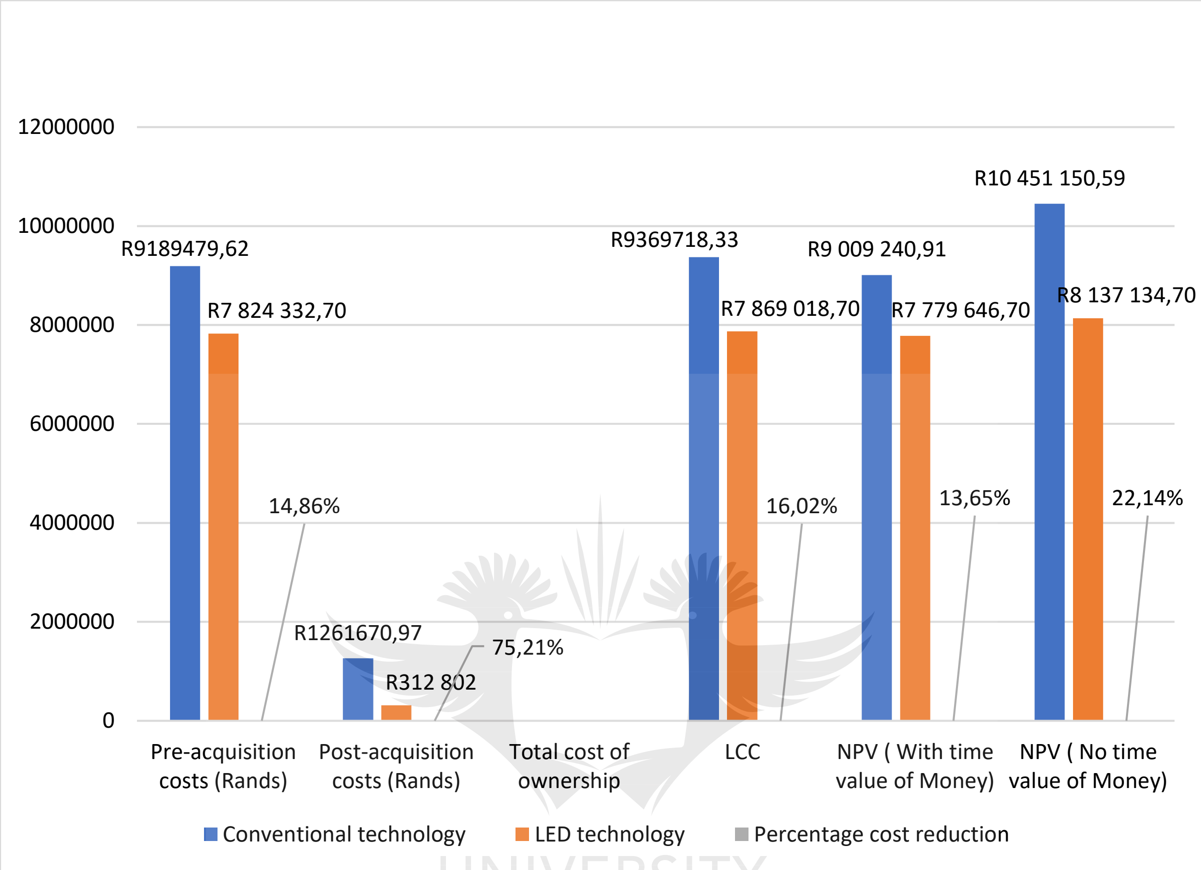


Figure 10: Total cost of ownership results comparison (Conventional versus LED)

A result summary of the total cost of ownership is presented in figure 10 that answers research question 2 under this study. The conventional technology totals pre-acquisition costs results are 14.86 percent higher than those of LED technology. First, this is because the conventional technology streetlight requires an additional cost for the lamps while in LED streetlight the option is integrated. Secondly, LED technology is becoming cheaper over the years as opposed to when it was launched.

The LED technology records post-acquisition costs saving of 75.21 percent. This is because of the high consumption energy costs of conventional technology and the maintenance costs involving the labour and parts replacement costs.

Lastly, the combination of the pre-acquisition costs and post-acquisition costs is presented in the form of LCC, NPV (with time value of money) and NPV (without time value of money). The annual cost difference between the two technologies was 16.02, 13.65, and 22.14 percent respectively. For the three scenarios, the LED technology still leads with a better total cost of ownership regardless of the different parameters used in the calculations.

The energy and maintenance costs are the main contributors to maintaining conventional streetlights based on the results of this study. South Africa has experienced a constant rise in electricity demand and streetlights are one of the biggest load contributors on the electricity grid as they operate during peak time at night. Switching to a more effective and efficient technology such LED can save municipality approximately 50 percent in energy cost based on the results of this study.

4.3. Conclusion

Chapter four presented the secondary data selected from the Greater Tzaneen municipality and other sources for analysis to answer the research questions under this investigation. The selected secondary data were categorised in a manner that aligned with formulas requirements in table 4. First, the energy usage costs between the two technologies is quantified and compared. The analysed data present that LED streetlights are more energy-efficient compared to conventional streetlights. Second, the pre-acquisition costs and other elements of the post-acquisition costs are quantified and compared to determine the total cost of ownership which is the sum of both costs. The analysed results put the LED technology as the better option with a total cost of ownership of between 13 to 22 percent less of the conventional streetlight.

This analysis aims to offer a methodology to evaluate savings, to select a more viable solution and to give proof of which option provides the most effective LCC over the year regardless of their pre and post-acquisition costs. Therefore, the adoption of LED streetlights will permit the achievement of a more efficient and effective total cost of ownership and energy consumption over the years.

CHAPTER 5: RECOMMENDATIONS AND CONCLUSIONS

Lastly, chapter 5 summarises the findings of the research and presents future recommendations in a way that incorporates ideas for future studies.

5.1. Research findings

5.1.1. Introduction

This research aimed to quantify and compare the total LCC of an LED technology streetlight versus a conventional technology streetlight. For the researcher to address the following research problem:

This research aims to quantify and compare the energy usage and the entire life cycle cost of conventional streetlights as opposed to LED streetlights. This collation could potentially empower local municipalities to evaluate the merits and costs of street lighting projects.

The literature review in chapter 2 evaluates the current LCC techniques from various researchers. Therefore, an LCC framework was developed with formulas and different cost breakdown stages which includes pre-acquisition, post-acquisition and the total cost of ownership.

The availability of secondary data was mandatory to use the LCC framework developed. Acknowledgements to a study funded by the department of energy (DoE) within the Greater Tzaneen municipality located in the Mopani district municipality of Limpopo province where secondary data could have been retrieved for a study completed in 2014.

5.1.2. Research outcomes

The research outcomes answer research question 1 which covered the energy usage and research questions 2 which covered the total cost of ownership.

i. **Question 1: What is the energy usage of an LED streetlight compared to a conventional streetlight?**

This question was addressed by firstly categorising and analysing the secondary data related to energy usage. The baseline data profile shows the cumulative profile before any energy savings program intervention, including weekdays, Saturdays and Sundays. During the measurement and verification process, assumptions were made that the power factor and the operation time of the streetlights were stable.

Upon reviewing the selected secondary data on energy usage, it is noted that the energy consumption constitutes the biggest part of the post-acquisition costs in both streetlight technologies. After comparing the results of the energy usage for both streetlight technologies, it is noticed that conventional streetlights consume 56 percent more energy than their equivalent LED streetlights will normally consume.

Most researches use energy usage as a key driver to influence decision-makers in the municipality to adopt the LED technology as compared to conventional technology. Therefore, research question 2 looks at other costs drivers that influence the total cost of ownership of both streetlighting technologies.

ii. Question 2: What is the life cycle cost of an LED streetlight compared to a conventional streetlight?

This question was answered by firstly categorising the secondary data chosen under pre-acquisition and post-acquisition costs. In one hand, the pre-acquisition costs incorporate the products and the installation costs. On the other hand, the post-acquisition costs incorporate operation, maintenance, and residual costs.

The pre and post-acquisition costs were quantified for both technologies by using the LCC framework created from the different literature presented in table 4. The results were utilised to calculate the total cost of ownership of both technologies over a year. It was concluded that over a year and based on the streetlight's lifetime of 50 000 hours for the LED technology and 12000 hours of the conventional technology, the total cost of running LED streetlights is between 13 and 16 percent less compared to running conventional streetlights. This is when the time value of money is taken under considerations in the calculations. But, without the time value of money, LED streetlight costs 22 percent less to operate annually compared to conventional streetlight.

The results also show that the 56 percent energy usage saving is increased to 75% because of the additional maintenance costs of replacing conventional streetlights due to their short lifespan. Although the post-acquisition cost savings between both technologies is spectacular (75 percent) favouring the LED technology, the total cost of ownership considering the time value of money is minimal (13 percent). The research results presented in figure 10 demonstrates that:

If the pre-acquisition and post-acquisition costs of both conventional and LED streetlights are known, municipalities can support their choice of using LED streetlights as opposed to conventional streetlights based on their total cost of ownership which is between 13 and 22 percent lower.

5.2. Recommendations

The municipality needs to look at the data collected during the audit to determine if there is any difference between the charged and measured electricity consumption paid for. The difference can be caused by the lack of monthly meter reading or else the long interval reading which results in estimating the consumption between the gaps. Therefore, it affects the actual LCC of the entire streetlight infrastructure which is mostly formed of the energy usage costs. One way to address this problem is to utilise smart streetlights system. Although it has a downfall of an added pre-acquisition costs to the investment, it also brings its own added values that include accurate metering, electricity theft detection, maintenance fault allocation, etc.

The municipality can use the smart system to reduce the energy consumption by dimming the light intensity during low traffic period between 11:00 PM and 04:00 AM. Therefore, energy consumption is conserved, and this applies only if the corporation between the local government and the electricity supplier is in a such manner that the monthly c/kWh rate cost remains unaffected until the return in investment is achieved.

Lastly, a very important factor such as the exchange rate must be included in the calculations when streetlights are imported as is the case of many African countries.

5.3. Conclusion

The LCC process is a continuous procedure. This is due to the interminable change of the different elements that influence it. Hence, it is critical for engineers, decision-makers within the municipality and managers to keep up with trends that enable them to better manage the cost of ownership of streetlights infrastructure.

The following findings of this research are summarised as follows:

- Post-acquisition costs account for a large part of the cost of the total life cycle of streetlights.
- LED technology presents lower post-acquisition costs compared to conventional technology. This is due to their lower energy and maintenance costs during the operating stage.
- Table 4 can be used and adapted to a municipal environment in terms of the cost drivers of streetlights.
- The LCC technique and formulas selected during analysis need to be relevant to the environment.

The objective of this research was to quantify and compare the cost of the total life cycle of LED and conventional streetlights. The results showed that LED streetlights are more cost-efficient based on energy consumption and the total cost of ownership

6. REFERENCES

Akpan, E.O.P., (2010). A modified internal rate of return model for capital rationing in project selection. *Production Planning and Control*, 10(8): 809-814. doi: 10.1080/095372899232632.

Azar, S. A. and Noueihed, N., (2016). The Discounted Payback in Investment Appraisal : A Case Study. *International Journal of Business Administration*, 5(5): 58-64 doi: 10.5430/ijba.v5n5p58.

Baburajan, S., (2018). Cost Benefits of Solar-powered LED Street Lighting System , Case Study-American University of Sharjah , UAE', *International Research Journal of Engineering and Technology (IRJET)*, 4: 11–17.

Bamisile, O. O., Dagbasi, M. and Abbasoglu, S., (2016). Economic feasibility of replacing sodium vapor and high pressure mercury vapor bulbs with LEDs for street lighting, *Energy and Policy Research*, 3(1): 27–31. doi: 10.1080/23815639.2016.1201442.

Campisi, D., Gitto, S. and Morea, D., (2018). Economic feasibility of energy ef fi ciency improvements in street lighting systems in Rome, *Journal of Cleaner Production*, 175: 190–198. doi: 10.1016/j.jclepro.2017.12.063.

The climate group, (c2019): relevance of lighting for socio-economic development. Available from: https://www.theclimategroup.org

Collins, J. and Singhal, R., (2007). Applications of the equivalent annual cost concept in mining, *international Journal of Surface Mining, reclamation and environment*, 9: 7–9. doi:10.1080/09208119508964708

Djuretic, A. and Kostic, M., (2018). Actual energy savings when replacing high-pressure sodium with LED luminaires in street lighting, e*nergy*, 157: 367–378. doi: 10.1016/j.energy.2018.05.179.

El-akruti, K., Zhang, T. and Dwight, R., (2016). Developing an optimum maintenance policy by life cycle cost analysis – a case study, *International Journal of Production Research*, 54(19):. 5946–5962. doi:10.1080/00207543.2016.1193244

Elmakis, D. and Lisnianski, A., (2010). Life cycle cost analysis : Actual problem in industrial management, *journal of business economics and management*, 7: 5–8. doi:10.1080/16111699.2006.9636115

Flaig, J.J., (2005). Improving project selection using expected net present value analysis, *quality engineering*, 17: 535–538. doi:10.1080/08982110500250990

Glassman, M., Pinelli, T. E., (2019). Scientific inquiry and Technical Communication : An Introduction to the Research Process*, society for technical Communication,* 32(4): 8–13.

Abdul Hadi, S., Al Kaabi, M.R., Arafat, H.A., (2013). Comparative Life Cycle Assessment (LCA) of streetlight technologies for minor roads in united arab emirates, *energy for sustainable developm*ent, 17: 438–450. doi:10.1016/j.esd.2013.05.001

Jägerbrand, A.K., (2015). New framework of sustainable indicators for outdoor LED (light emitting diodes) lighting and SSL (solid state lighting), *sustainability (Switzerland)*, 7: 1028–1063. doi:10.3390/su7011028

Kim, B.C., Shim, E., Reinschmidt, K.F., (2013). Probability distribution of the project payback period using the equivalent cash flow decomposition, *engineering economist* 58: 112–136. doi:10.1080/0013791X.2012.760696

Kivimäki, S.E.E., 2013. Sustainable infrastructure development: Assessing LED street lighting as a tool for sustainable development in São José dos Campos, Brazil. 119. Available from: https://dspace.library.uu.nl/handle/1874/287884

Lin, R., Lin, J.S. J., Julian, P.C., (2007). Note on inventory model with net present value, *Journal of Interdisciplinary Mathematics* 10: 587–592. doi:10.1080/09720502.2007.10700518

Lummer, S.L., (1986). Equivalent real annual costs: evaluating investment alternatives with unequal lives under, *engineering economist* 31: 317–326. doi:10.1080/00137918608902947

Marshall, H.E., (1985). A graphical approach to discounted payback, *construction management and economics* 3: 105–120. doi:10.1080/01446198500000009

De Menna, F., Dietershagen, J., Vittuari, M., (2018). Life cycle costing of food waste: A review of methodological approaches, *Waste Management*, 73: 1–13 doi:10.1016/j.wasman.2017.12.032

Mevellec, P., Perry, N., 2006. Whole life-cycle costs: a new approach. *International Journal of Product Lifecycle Management,* 1:1-12. doi:10.1504/ijplm.2006.011058

Nelson, M. A., Anderson, B. P. and Cai, H., (2017). Selection methods and procedure for evaluation of LED roadway luminaires, *Journal of illuminating engineering society of North America*. 13(3): 159–175. doi: 10.1080/15502724.2016.1256782.

Niu, Y., Fink, G., (2019). Life Cycle Assessment on modern timber bridges, *Wood Material Science and Engineering*, 14: 212–225. doi:10.1080/17480272.2018.1501421

Peersman, G. (2014).Overview: Data collection and analysis methods in impact evaluation, methodological briefs: Impact evaluation 10, UNICEF office of research, Florence.

Philips Lighting Academy, (2008). Basics of light and lighting, *Koninklijke Philips Electronics N.V.*,1: 1–54. doi: 3222 635 58631.

Russell, C. (2009) 'Simple Payback : The Wrong Tool for Energy Project Analysis ? Simple Payback : The Wrong Tool for Energy Project Analysis ?', 5236. doi: 10.1080/10485230809509411.

Sacks, A. *et al.* (2015). Life cycle cost analysis: a case study of Lincoln on the Lake, *journal of engineering, design and technology*, 10 (2): 228-254, doi:

10.1108/17260531211241202.

Schmidt, S. M. (2012). A feasibility analysis of retrofitting existing roadway lighting infrastructure with LED technology. Masters Theses. Available from: http://scholarsmine.mst.edu/masters_theses/5329.

Shakhmatova, K., Francey, S., (2012). A history of street lighting in the old and new towns of Edinburgh World heritage site. Available from: https://ewh.org.uk/wp-content/uploads/2017/09/Lighting-project-publication-ver-6-Feb-2012.pdf

Tähkämö, L., Ylinen, A., Halonen, L., (2012). Life cycle cost analysis of three renewed street lighting installations in Finland. *International Journal of Life Cycle Assessment*, 17: 154–164. doi:10.1007/s11367-011-0345-z

Walker, D. H. T., (1997). Choosing an appropriate research methodology, *Construction Management and Economics*, 15(2): 149-159, DOI: 10.1080/014461997000000003

Wang, L. L. (2010). Quantitative research methodology: Common pitfalls and recommended solutions, *newborn and infant nursing reviews*, 10(1): 2–4. doi: 10.1053/j.nainr.2009.12.002

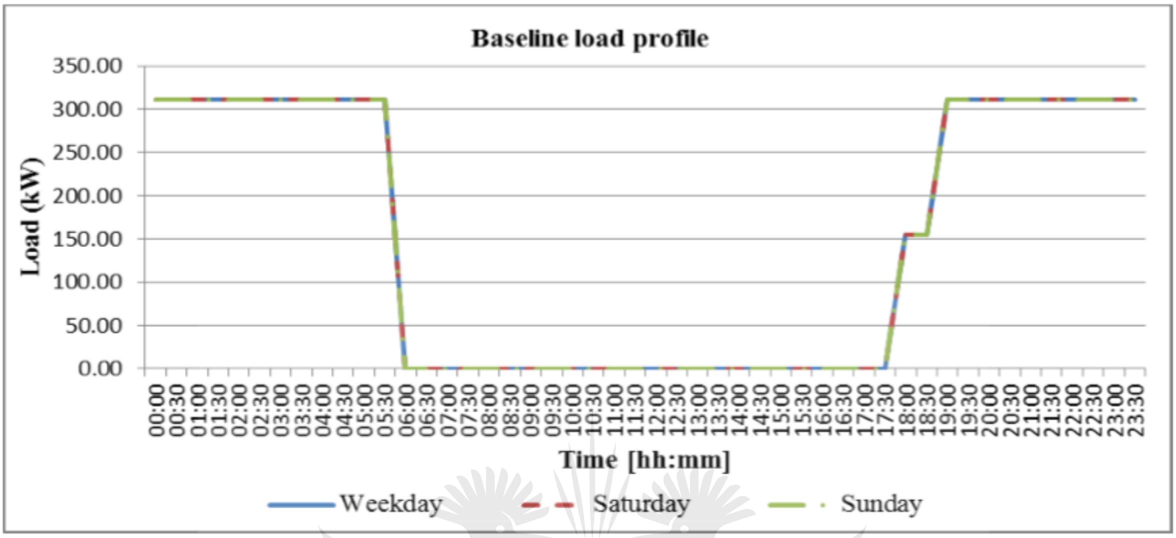
Woodward, D. G. (1997). Life cycle costing-theory , information acquisition and application, *international journal of project management*, 15(6):335–344. doi:10.1016/S0263-7863(96)00089-0

Ximenes, A. *et al.,* (2018). Life cycle costing as a bottom line for the life cycle sustainability assessment in the solar energy sector : A review, *Solar Energy*, 1(1):1–25. doi: 10.1016/j.solener.2018.04.011.

Yoomak, S. *et al.,* (2018). Comparative study of lighting quality and power quality for LED and HPS luminaires in a roadway lighting system, *Energy & Buildings*, 159: 542–557. doi: 10.1016/j.enbuild.2017.11.060.

7. APPENDIX

APPENDIX A: Baseline load profile from secondary data: Conventional technology.



APPENDIX B: Baseline half-hourly load profile data (24 hours test)

Baseline data (kW)			
Time	Weekday	Saturday	Sunday
0:00	310.46	310.46	310.46
0:30	310.46	310.46	310.46
1:00	310.46	310.46	310.46
1:30	310.46	310.46	310.46
2:00	310.46	310.46	310.46
2:30	310.46	310.46	310.46
3:00	310.46	310.46	310.46
3:30	310.46	310.46	310.46
4:00	310.46	310.46	310.46
4:30	310.46	310.46	310.46
5:00	310.46	310.46	310.46
5:30	310.46	310.46	310.46
6:00	0.00	0.00	0.00
6:30	0.00	0.00	0.00
7:00	0.00	0.00	0.00
7:30	0.00	0.00	0.00
8:00	0.00	0.00	0.00
8:30	0.00	0.00	0.00
9:00	0.00	0.00	0.00
9:30	0.00	0.00	0.00
10:00	0.00	0.00	0.00
10:30	0.00	0.00	0.00
11:00	0.00	0.00	0.00
11:30	0.00	0.00	0.00
12:00	0.00	0.00	0.00
12:30	0.00	0.00	0.00
13:00	0.00	0.00	0.00
13:30	0.00	0.00	0.00
14:00	0.00	0.00	0.00
14:30	0.00	0.00	0.00
15:00	0.00	0.00	0.00
15:30	0.00	0.00	0.00
16:00	0.00	0.00	0.00
16:30	0.00	0.00	0.00
17:00	0.00	0.00	0.00
17:30	0.00	0.00	0.00
18:00	155.23	155.23	155.23
18:30	155.23	155.23	155.23
19:00	310.46	310.46	310.46
19:30	310.46	310.46	310.46
20:00	310.46	310.46	310.46
20:30	310.46	310.46	310.46
21:00	310.46	310.46	310.46
21:30	310.46	310.46	310.46
22:00	310.46	310.46	310.46
22:30	310.46	310.46	310.46
23:00	310.46	310.46	310.46
23:30	310.46	310.46	310.46

APPENDIX C: Typical streetlight installed during the measurement and verification process (Conventional streetlight)

APPENDIX D: Typical LED streetlight as a replacement option

APPENDIX F: Data collection inquiry letter

To Whom it may concern;

In partial fulfilments of my master's degree in engineering management with the University of Johannesburg, I would like to ask for your assistance as a reliable source of maintenance and operations costs of streetlights in South Africa. please I can arrange to meet with you in person or are you willing to share the maintenance, repair and operations data on current streets or roads lights for my research study entitled:

Quantifying and comparing the life cycle cost of light emitted diode and conventional streetlights

In connection with this, I would like to ask your good office to allow me to use your materials as one of our references and to conduct our survey and interview in your vicinity if possible. Rest assured that the data I will gather will remain confidential and to be used on academic purposes only. I believe that you are with me in my enthusiasm to finish this requirement as compliance for my graduation and to develop my well-being. We hope for your positive response on this humble matter. Your approval to conduct this study will be greatly appreciated.

For further questions please contact me at: kayembe6@hotmail.com

Thank you very much!

Respectfully yours,

Student: Tshiaba Didier, Kayembe

Supervisor: Prof JHC Pretorius

Co-Supervisor: Prof A Marnewick