National University of Lesotho

Energy Audit and Management Opportunities for a Diamond Mine: A case for Lets'eng Diamond Mine

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ABSTRACT

The mining sector is highly energy intensive. Undertaking mining activities at a geographic location bearing extremely cold temperatures like Lets'eng in Lesotho exacerbates the situation as abundant energy is required to provide the comfort needed by employees. Nonetheless, there exists ample waste in energy use within the mining sector which can be avoided by bringing forth energy management strategies. The study firstly identifies areas of energy waste and their cause. Both simple and technical energy management strategies are employed in correcting ways of energy use in order to utilise the least possible energy. The aim of the study is to minimize energy costs at the mine and reduce environmental damage associated with electrical energy use while also integrating renewable energy technologies where it is possible to do so. Monthly energy consumption profiles from electrical meters at the mine were used to analyse the consumption patterns of different energy processes. The study identified energy management opportunities in the energy processes of lighting, space heating, water heating and poor power factor. Energy management interventions for all the opportunities identified were economically assessed in terms of their cost of implementation and operation against the associated energy savings they would yield. All the recommendations proved to be economically viable as they resulted in a positive Net Present Value (NPV) and all Payback Period in years were within the remaining life of the mine which spans until 2034. Modelling gives a total of 41 903.14 tonnes of greenhouse gases averted from emission to the environment as a result of implementation of energy management opportunities.

Keywords:

Energy Audit, Energy Efficiency, Renewable Energy, Power Factor, Lighting, Space Heating, Water Heating, Lets,eng

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I would like to thank the management of Lets'eng Diamond Mine for giving me the opportunity to undertake this project in their organisation and offering me all the necessary commodities during my visits to the mine. Special thanks to M. Foloko who organised everything that I needed during the visits and also gave an insight about the energy setting of the mine. I am also grateful to all the staff that I interacted with as they helped in all I needed.

I dedicate this work to my nieces and nephews, this is a fulfilling journey which I hope they take when their time is due.

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1.0 INTRODUCTION

1.1 BACKGROUND

Energy is necessary for our survival on Earth; energy is the driver of all economic activities [1]. Mankind lived negligently for the past centuries as they could acquire food, have shelter and be transported by more than adequate supplies of energy that were very cheap and easily available. This continued until the 1970s when energy prices hiked and the whole world had to think differently regarding energy issues. Prices of energy especially oil, skyrocketed to the detriment of economic activities [2].

One of the measures which countries sought to was to try and achieve energy security which means being energy self-sufficient and ensuring that states are able to satisfy their energy demand regularly[3]. However, Lesotho like most Sub-Saharan African countries gets additional energy supplies from outside its borders to meet its demand. Concerned with electricity alone, Lesotho currently imports power from South Africa and Mozambique from their respective utilities Eskom and *Electricidade de Mocambique* to complement the local main supply which is the 72 MW ‘Muela Hydropower Station of the Lesotho Highlands Development Authority (LHDA) [4],[5].

Importations of power from outside the country lead to high prices of electricity. Lesotho’s load keeps increasing due to high electrification rate and the extent of growth in the industry such as mining, water and medical cannabis projects [6]. Since industries take a bigger share of electricity consumption, their energy expenses constitute a larger part of their total operating expenses [7]. Demand side energy management is eminent to ensure use of the least possible energy to undertake production in order to reduce operating costs and curb national demand as industries are accountable for a great deal of the national energy demand.

Lets’eng Diamond mine is fed by supplementary power from Eskom through Lesotho Electricity Company’s 33 KV transmission line that is independent from the national grid as it comes from South Africa specifically to the mine site. The mining sector is energy intensive with Lets’eng Diamond Mine’s peak consumption hitting above 11 MW in 2019 as a single entity against Lesotho’s peak load which has never reached 170 MW [6]. The mining sector uses huge electrical equipment like motors to do work that consume the most power. Lets’eng Diamond mine is located in the highlands of Lesotho in Mokhotlong District where it is extremely cold. The need for heating to provide comfort for the human resource is one energy challenge which leads to high energy consumption. Space heating alone gulped up to 11184330 MWh only in 2019.

Lets'eng Diamonds is found at the coordinates 29°0'01"S, 28°51'43"E. It is the highest diamond mine in the world as it is found at the altitute of 3100 m above sea level. As the mine is situated in the highlands, Lets'eng mine therefore experiences extremely cold temperatures throughout the year. Nonetheless, the worst temperatures are recorded during the winter season. In Lesotho, the true winter months are May, June and July and the true summer months are November, December and January and the other months bear intermediate characteristics of winter and summer but predominantly of the season to which they are mostly inclined to. This has led to a significant hike in electrical load hence more energy consumption for the winter season as a consequence of space heating. Extremely low temperatures have rendered it unnecessary for the use of full-functioning of Heating, Ventilation and Air Conditioning (HVAC) equipment. It is only heaters present at the mine but not cooling devices.

1.2 PROBLEM STATEMENT:

The mining sector is energy intensive. Moreover, not all the energy procured for production and support within the mine is finally useful. Demand side management is necessary at mine operations sites to alleviate high and unnecessary energy consumption. There are many avoidable energy uses in the diamond mining sector which can be reduced by simply applying energy management strategies.

1.3 GOALS:

To lower energy consumption at the mine which in turn ensures lower energy costs and minimal environmental degradation.

RESEARCH QUESTIONS:

1. Which activities consume the most energy and what is their timing?
2. Which energy management opportunities are best suited to avoid or reduce energy consumption?
3. Are energy management solutions proposed economically viable?
4. What is the cost and environmental impact of each energy management solution?

OBJECTIVES:

- To identify the energy uses and their timing at the mine.
- To identify the “low hanging fruits” in terms of reducing energy use at the mine.
- To identify energy management interventions that involve technical solutions and financial outlay to implement, including renewable energy solutions.
- To recommend the best way of implementing the energy management solutions.

1.4 THESIS STRUCTURE

The thesis is a structure of five chapters. The first chapter is the introduction which gives a background on Lesotho’s power sector. An outline of the problem statement which gives justification to the study also forms the introduction. The aim is also stated which will be realised by meeting the goals through well-articulated objectives. The second chapter revisits existing literature surrounding energy management and the processes of lighting, heating and power factor correction. The third chapter describes the general methodology of performing an energy audit and unique methodologies for identification of opportunities from different energy processes, further outlay of methodologies adopted in the implementation of measures of energy management. The fourth chapter presents the results, identified energy management opportunities and proposed interventions are discussed. The fourth chapter further assesses the economic and environmental implications of undertaking the measures proposed in chapter 3. The fifth and final chapter is the conclusion.

2.0 LITERATURE REVIEW

2.1 ENERGY MANAGEMENT

Capehart defines energy management as "*the efficient and effective use of energy to maximise profits (minimise costs) and enhance competitive positions*"[1]. This definition is adopted here as the study is concerned with energy management within an industrial entity with the primary aim of making huge profits.

2.2 ENERGY AUDIT

Thurman A. defines energy audit as "*a process of determining the types and costs of energy use in a building, evaluating where a building or plant uses energy, and identifying opportunities to reduce consumption*" [8],[9]. When conducting an energy audit, the cost measured and the amount of data collected for analysis is related directly to the extent of identifiable energy management opportunities [8],[10], [11]**.** An energy audit is eventually accomplished by submission of a technical report outlining recommendations for implementation to achieve reduced energy consumption within an entity under study[12],[13], [14].

There are two types of energy audits; a *preliminary audit* and a *detailed audit*. An audit type is influenced by the type and function of an industry and the degree to which a reduction of costs is desired [15],[8]. An energy audit can also be referred to as industrial, commercial, or residential depending on the setting to which it is conducted [8],[1].

A *preliminary energy audit* is a quick approach that identifies energy processes in the organisation[8]. Small immediate data is used with more observations to identify energy saving opportunities and interventions that are easy to implement [8], [16]. A *detailed energy audit* is a comprehensive energy audit that follows a thorough, often complex analysis of energy processes and patterns in an organisation. Detailed analysis of energy use are executed, waste and savings calculations are made [8],[17].

2.3 ENERGY EFFICIENCY

Energy efficiency is the proportion of the energy that actually gets used to do work to the total input energy[12], [18]. Not all the input energy can be converted to useful energy. It is important to fully understand energy efficiency to know the amount of energy that gets lost. Electrical equipment can be compared against one another for efficiency performances[16]. For electricity specifically, this ratio is called the power factor; the total input power is called the *apparent power*, the useful power is the one that finally does work and it is called the *active power*, a fraction of the apparent power that is not useful (that is lost) is referred to as the *reactive power*. The proportion of the active power to the apparent power is therefore referred to as power factor[19].

2.4 GEOGRAPHIC PLACEMENT

The location of an entity undergoing an energy audit should be given utmost consideration together with its meteorological data[19]. This information helps auditors to understand energy needs for cooling and heating. The daily temperatures will be helpful in assessing the energy demand for thermal applications[20]. Lets'eng location is one that is characterised by low temperatures prevalent on the site which surely prompt the mine to acquire more energy for heat generation.

2.5 FACILITY ARCHITECTURE

Plans or blueprint documents which have details about the design of the facilities should be available and studied to look at the size of the facility. Other features like construction materials, insulation extent, entrance area and ventilation systems should also be explained within the blueprints. All these features influence the quantity of energy consumption. Further assurance should be made that the plan has not altered from the original which was previously constructed[7].

2.6 SHIFT SCHEDULING

It is very important to critically look at the production scheduling of the industry. Registration of the number of shifts in a day and processes that take place under each shift should be considered. Shifts can therefore be rescheduled so that some loads are shifted to off peak hours or rescheduling be done to shave congested load to eased load at particular time of the day to avoid high power consumption because maximum power consumption (demand) is one of the components of electrical billing[7],[20].

2.7 SELF GENERATION AND RENEWABLE ENERGY INTEGRATION

One intervention for consideration for industrial energy cost reduction is by incorporating self generating renewable energy systems. This allows for use of energy that is free and helps avoid increasing prices of fossil fuels and transportation costs of such conventional fuels [21],[22]. Costs are saved from Renewable Energy (RE) integration by reducing both energy use and demand magnitude. RE systems add convenience as they provide a system not subject to production interruption caused by power cuts [23]. It provides for a transformation of the mining sector towards a greener energy market with reduced carbon emissions and thereby achieving minimal environmental pollution [21], [23]. Solar Photovoltaics (PV) constitutes the highest share of self generated power distributed for consumption in industries [23],[24].

2.8 MAIN ENERGY USE PROCESSES IN MINING

ELECTROMECHANICAL ENERGY CONVERSION

Electromechanical energy conversion occurs when a device converts electrical energy to mechanical energy or vice versa[25]. But since an electrical energy audit is under place here. Concern is on the former conversion. In the mining sector, a great deal of energy is used in electro-mechanical conversion. In order to do work of ore extraction, crushing and mineral processing in the plants. Machines that use electricity to do kinetic work to fulfill a task are used. These include small to huge pumps and inductive motors [25].

MOTORS

An electric motor is a machine doing work by converting electrical energy into rotational mechanical energy to drive equipment that does work [25]. Examples of motor driven equipment may be conveyor facilities, pumps and fans. Electric motors are responsible for approximately 40% of worldwide power consumption, in industrial settings their share of energy consumption can go as high as two thirds of the total industrial electricity use[25]. The capital cost of acquiring an electric motor is only a small factor considering expenses it accrues over time [26].

For energy to be saved, a motor has to be turned off when there is no work needed to be done. A soft starter enables the stopping and starting of motors often. A motor uses much current from the supply when starting, it can even consume power above its rated power. To control the current during a start, installation of a soft starter device is needed to limit the current that a motor uses during a start-up, in this manner a gradual acceleration profile is maintained. Advantages of soft starting include a prolonged motor life due to reduced wear on the components doing work mechanically and protects the electrical parts from overheating. Increased frequency of motor starts and stops also leads to energy savings in an hour [26].

The life of an electric machine driven on the load will similarly be extended because of eased acceleration that stresses the machine during start-up. Information shown on the motor nameplate stipulates the maximum allowed starts per hour. Another benefit is that controlling the current hike during start-ups reduces the kVA demand thereby curbing power charges [7].

POWER FACTOR

The current needed by induction motors, fluorescent lights, transformers, resistance welders and induction furnaces, is made up of three kinds of current:

1. Power producing current
2. Magnetizing current
3. Total current[1],[16]

Power producing current (Real power)

It is the current which is converted by the equipment into useful work such as pumping water, doing a weld and driving a conveyor. This power is measured using the kilowatt (kw)[1],[27].

Magnetising current (Reactive current)

This current is needed to produce the magnetic field necessary for the induction equipment to operate. Without this current, inductive devices could not do work. The unit of this reactive power derived from magnetising current is the kilovar (kvar) or kilovolt amperes reactive [1], [28].

Total current (current producing apparent power)

This is the current that an ammeter reads on the circuit. It is all the current that is sent to an electrical appliance. It is the vector sum of the reactive current and the real current. It is measured by the unit kilovolt ampere (kVA). A majority of alternating current (ac) powered loads need both kilowatts (active power) and kilovars (reactive power) to do useful work[1].

Power Factor Definition

It is the ratio of real power (power that actively does work) in a circuit to the apparent power supplied on the power line (kW/kVA). The relationship of real power (kW), reactive power (kVAR) and apparent power (kVA) in an electrical system can be shown by scaled vectors to quantify the magnitude of each power[1],[16],[29].

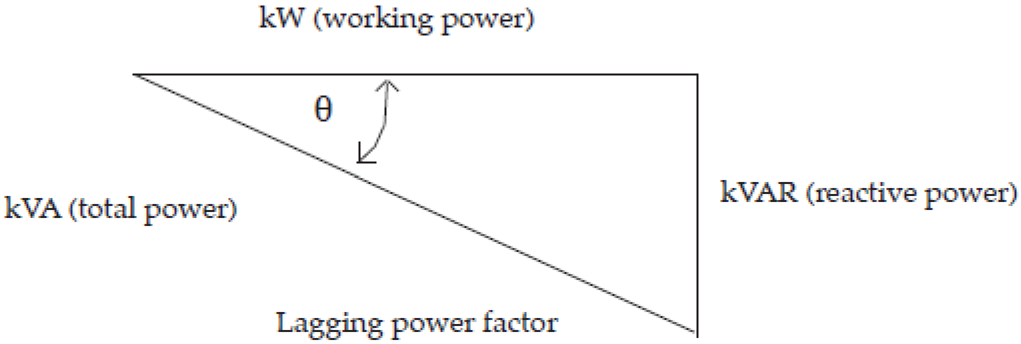


Figure 1: power vectors of a lagging power factor

[29]

kVAR vector is at a right angle to that of kW, the vectorial sum of these quantities yields the kVA vector. The angle where the vectors kW and kVA intersect is the phase angle, the cosine of this angle is equal to the power factor and it is (kW/kVA)[29].

$$kVA = \frac{kW}{cos\theta} = \frac{kW}{PF} = \sqrt{(kW)^2 + (kVAR)^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

When billing, demand is determined in kVA, a higher power factor closest to unity or (one) leads to reduced kVA which definitely leads to decreased energy costs. A power factor closer to one means that reactive power (losses) is minimal.

POWER FACTOR FLUCTUATIONS

In most cases, motors do not usually drive a matched load. The power factor also fluctuates depending on the load a motor is driving. When a motor drives a relatively smaller load, then power factor also falls because motors work more efficiently at a higher load factor[8]. In essence, to save electricity, adjustable and variable drive speed devices are necessary in order to match the load driven by the motor[1]. Adjustable and variable speed drives can be used as control mechanisms that are incorporated to reduce the energy used by a motor when it is not pushing a full load.

Therefore, Adjustable Speed Drives (ASDs) and Variable Speed Drives (VSDs) controls help in improving efficiency of motor operation, the working principle of ASDs and VSDs is that the sizing of the motor is based on the maximum load it drives[30]. These electronic devices vary the rotational speed of the motor so that the speed matches the load driven by a motor. This is achieved by adjusting the voltage or current of the motor input so that motor output always matches the load[8]**.** When introduced to the electrical system, VSDs are able to achieve energy savings exceeding 50%, improve power factor and process precision[26]

Peak demand often occurs when motors start simultaneously often after power cuts when the power comes back. Normally when motors start, they consume power that exceeds their rated capacity for a few seconds. This implies that a lot of power is consumed when a population of motors start at the same time. Soft and sequential starting control mechanisms of motors are necessary to avoid high demand during start-ups [25].

POWER FACTOR IMPROVEMENT

At low power factor, the reactive power compensation requirement is very high, it increases closer to the requirement of real power. This calls for a means of power factor improvement in industrial facilities[31],[32],[29]. Power factor of a system or within an operation unit can be lagging or leading. The direction of flow of the real and reactive power can be used to tell whether power factor is lagging or leading. When both the reactive and active power in the same direction, the power factor is said to be lagging, but if the reactive and the active power flow in opposite directions, then the power factor is leading. An example of a lagging power factor load is an inductive motor and an example of a leading power factor is a capacitor[33]. Because the load within the mine is inductive, principally because of inductive motors, power factor within the mine is lagging therefore requires capacitors for improvement.

There are three major reasons for power factor improvement in industries:

1. To reduce electricity consumption in a plant
2. To reduce electricity costs only
3. Reduce both electricity cost and electricity consumption

Reduce electricity Consumption

Any method of power factor correction will minimise losses and ease current loadings on equipment of supply which are generation facilities, transformers, cables and switchgears. Therefore when correction is executed within a plant, electricity consumption will drop and electricity costs. In most cases, losses arising as a result of unattended power factor are undermined. This is the principal reason why there is a claim that power factor correction affects only costs where the utility charges a tariff that incorporates reactive power or poor power factor. Correction of power factor will result in reduced electricity consumption if carried out locally at equipment or centrally at the control centre. Consumption will however not be decreased if a plant is supplied by a grid and executes correction at incoming voltage level just to reduce reactive power drawn from the grid. There will be reduction in cost not consumption[29], [1].

Reduce electricity costs only

Improvement of power factor will only reduce electricity cost when a generation plant for example, which is supplied by a grid corrects power factor at a supply point to compensate for reactive power consumed from the grid. But improving power factor at this point may not always lead to reduction in costs. It is only governed by contractual obligations between the two parties. A minimum kVA value may be stipulated for a certain charge, therefore a further reduction in kVA may not necessarily bring cost reductions[29].

Reduction of both electricity cost and electricity consumption

In all power factor correction endeavours, both consumption and costs are reduced except for the case above where a plant corrects against reactive power drawn from the grid. Importantly, payback on power factor correction depends on the method of installation, power tariff, and loading pattern equipment[8].

SHUNT CAPACITOR BANKS

One of the common techniques for power factor correction when the power factor is lagging is the use of shunt capacitor banks (SCBs)[34],[35],[36]. These devices when installed correct power factor by providing compensation for reactive power. SCBs have several merits in that they improve voltage on the load, make voltage regulation easy, and reduce power losses. Capacitors are static devices with no moving parts therefore wear out after a relatively long time and do not require regular maintenance. Because shunt capacitors provide reactive power that is leading , the power factor is improved in overall[35],[33],[37].

The need for capacitor banks

Contemporarily, economical management of power systems require voltage support that is highly distributed. High reactive power (VAR) compensation is an eminent requirement along the power system. Capacitor banks provide the most economical technique in injecting (VARs) to the power system. Shunt capacitor banks can be installed centrally or locally to ameliorate power factor[38],[29]. Centrally, they can be installed at the bus bar, feeder and at high voltage distribution systems. They can also be installed locally at individual or grouped branch locations. Capacitors may be switched or fixed on the system.

LOCATING CAPACITOR BANKS

As it has been mentioned, shunt capacitors can correct power factor either when installed locally or centrally. Therefore, they can be placed at high voltage bus, on the distribution or at the load which may be individual or grouped. Below are common power factor improvement installations.

GROUP CAPACITOR BANK

In this case a power factor correction is undertaken in unison to a group of loads at only one location. This approach is more appropriate for industrial utilities with loads that are widely distributed. When loads are grouped together they can be essentially be switched on and off together. If a distinguished load was to be switched independently, it would not be suitable to adopt this technique, perhaps it would lead to a malfunction in power factor correction. For instance, the sizing of a capacitor in kVAR would be distorted. The advantage of having a larger capacitor bank for reactive power compensation is that it is economical compared to having smaller multiple units.

BRANCH CAPACITOR BANK

In some industrial operations, loads are based on shifts and are switched at different times. These loads may be connected to individual feeders or branch circuits. It is here that a specific capacitor bank may be installed for a particular branch. However losses in a main circuit will not be reduced in this setting[29].

LOCAL CAPACITOR

This technique is mainly employed when individual equipment operates at their own independent timing. Correction is made at the load on the individual equipment. The local power factor correction is quite expensive as many power factor correction units have to be purchased[29].

LIGHTING

Energy used for lighting accounts for only 5-25% of all the energy used in industries[1] . Nonetheless, lighting energy management also has to be executed to take the little energy saving opportunities. Lighting energy management interventions require less technical and financial interventions compared to other energy processes [1], [16]. While undertaking lighting energy management, workplace personnel productivity and safety should be highly considered. Fortunately, retrofits in lighting often lead to increased productivity and also improving employee amenities in the workplace [1].

The commonly available types of light bulbs are [39]:

- Incandescent lamp
- Fluorescent lamps
- Light emitting diode (LED) lamps

Incandescent lamps

This type of lamps is made with a tungsten filament attached inside a glass bulb which has a noble gas inside it. They exhibit many varied shapes and sizes and are a common sight in most households [40]. They are the most traditional lamps and have the lowest efficiency[39]. Incandescent light bulbs are currently widely replaced by contemporary fluorescent bulbs and LEDs because of their poor efficiency.

Table 1: incandescent bulb characteristics

Advantages	Disadvantages
• Relatively cheap • High colour rendition • They start immediately • Affordable dimming • Excellent light focusing • Portable size • Easy maintenance	• Efficiency is less than 10% – other energy produces heat • Low efficacy – less than 20 lumens per watt • Non durable • Filament prone to detachment from shocks and vibrations

Fluorescent lamps

These lamps have a mercury vapor and other several gases. They emit ultraviolet light which is transformed into light that is visible through a phosphorus coated surface on the inside wall of the glass tube. Efficiency of fluorescent lamps is four to five times higher than that of incandescent lamps. They also come in many shapes. Efficiency of fluorescent lamps increases with length but decreases with higher tube radius. Fluorescent lamps can last up to nine times the life of incandescent bulbs.

Table 2: fluorescent bulb characteristics

Advantages	Disadvantages
• Fair lumen output per watt (30-80/W) • Relatively affordable • Around 25% of input energy is useful/visible light • Long life from 6000 to 20 000 hours	• Need large heavy fixtures with ballast (additional costs) • Dimming needs special costly ballasts, magnetic ballasts cause noise • Lumen output drops at low temperatures • Cannot start/light immediately, requires warming • Mercury leads to disposal obligations

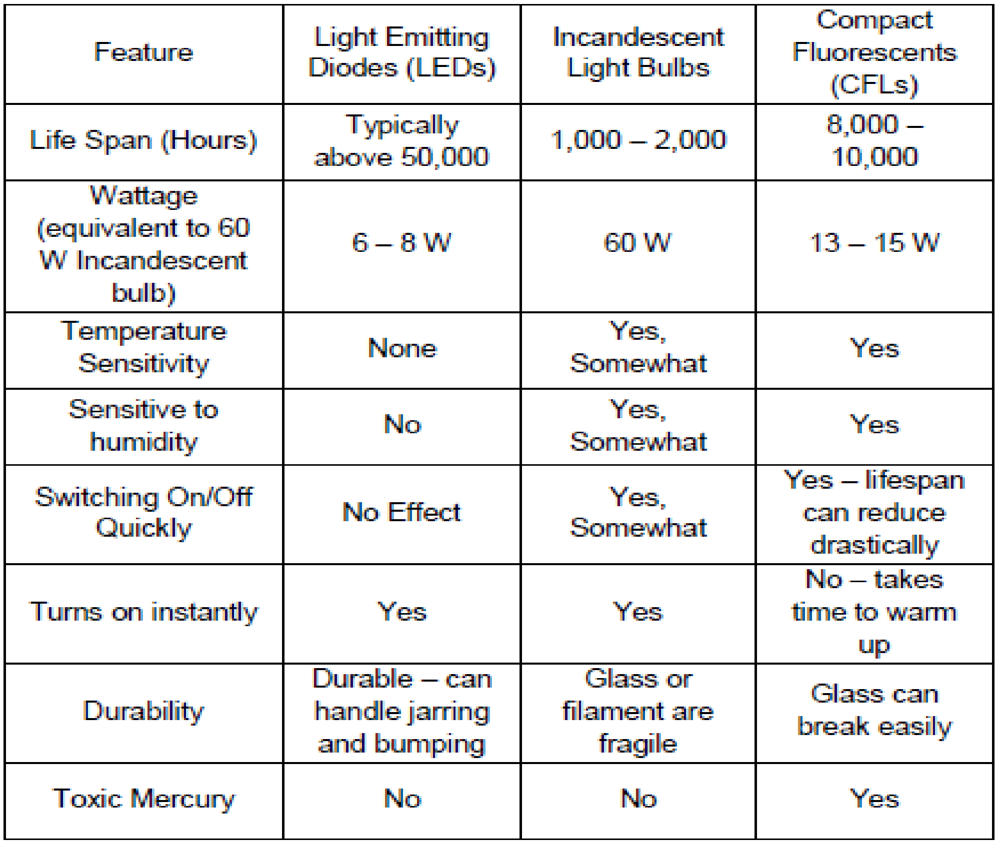
Light Emitting Diode (LED) lamps

These are electronic devices that are semi-conductor sources of light when current is allowed to flow through them. When electron holes recombine with electrons in the semi conductor, energy is released in the form of photons thereby producing light [39].

Table 3: LED bulb characteristics

Advantages	Disadvantages
• Uses up to 60% less energy compared to traditional lamps • Long lifetime – up to 50 000 hours • No warm up period – immediate lighting • Light can be directed/focused (no light waste) • Excellent light rendition • Environmentally friendly – no mercury • Easy light control/dimming	• Recently the most expensive on capital costs than other preceding light technologies • Performance of LED bulbs is mainly influenced by accurately configuring the fixture to control heat generation

Table 4: comparison of different bulb type characteristics



Feature	Light Emitting Diodes (LEDs)	Incandescent Light Bulbs	Compact Fluorescents (CFLs)
Life Span (Hours)	Typically above 50,000	1,000 – 2,000	8,000 – 10,000
Wattage (equivalent to 60 W Incandescent bulb)	6 – 8 W	60 W	13 – 15 W
Temperature Sensitivity	None	Yes, Somewhat	Yes
Sensitive to humidity	No	Yes, Somewhat	Yes
Switching On/Off Quickly	No Effect	Yes, Somewhat	Yes – lifespan can reduce drastically
Turns on instantly	Yes	Yes	No – takes time to warm up
Durability	Durable – can handle jarring and bumping	Glass or filament are fragile	Glass can break easily
Toxic Mercury	No	No	Yes

[40]

SPACE HEATING

Open pit mining does not have needs for HVAC systems[24], Lets'eng Diamond mine is an open pit mine with a very high requirement of heat for comfort. It is usually cold even in summer as temperatures can go fall as low as 9^0C during midday. HVAC is therefore not necessary even for cooling amenities beside the mining processes as the employees never experience the need for cooling. Lets'eng requires very efficient heating systems as heating energy is needed for nearly of the time of the day irrespective of the season.

SOLAR WATER HEATING

ENERGY BALANCE OF A SOLAR WATER HEATING SYSTEM.

For a solar heating system, which has a storage tank of mass M and a water specific heat capacity of *Cp*, an energy balance for the system can be shown by the differential equation (2):

$$(MC_P)_s \frac{dT_s}{dt} = Q_u - L_s - U_s A_s [T_s - T_a] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Equation (1) denotes that the change in energy within the storage tank is equal to the interactions of energy ongoing within time intervals [41], [42].

These interactions are heat input Qu generated by the solar collector, heat removal rate (Ls) and heat energy losses from the storage tank *(UsAs[Ts-Ta])* [43]. Euler integration can be employed but first expressing temperature derivatives as $(T_s^+ - T_s)/\Delta T$ and re-writing the equation in terms of the tank temperature gives:

$$T_s^+ = T_s + \frac{\Delta T}{(MC_p)_s} (Q_u - L_s - U_s A_s [T_s - T_a]) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

In equation (3), solar energy input Qu can be found for a collector with area Ac receiving incident solar irradiance G_T. the thermal energy that is useful is gained at a rate given by the Hottel-Whillier-Bliss equation:

$$Q_u = A_c \{ G_T K \tau\alpha F_R (\tau\alpha)_n - F_R U_L (T_s - T_a) \} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Where:

- $(\tau\alpha)_n$ is the normal incidence transmittance absorptance product of the collector.
- $k\tau\alpha$ incident angle modifier
- A_c is the collector
- G_T is the solar irradiance
- $F_R(\tau\alpha)_n$ is the y-intercept of the collector efficiency curve
- $F_R U_L$ is the slope of the efficiency curve
- T_s is the storage tank temperature
- T_a is the environmental temperature [41], [42]

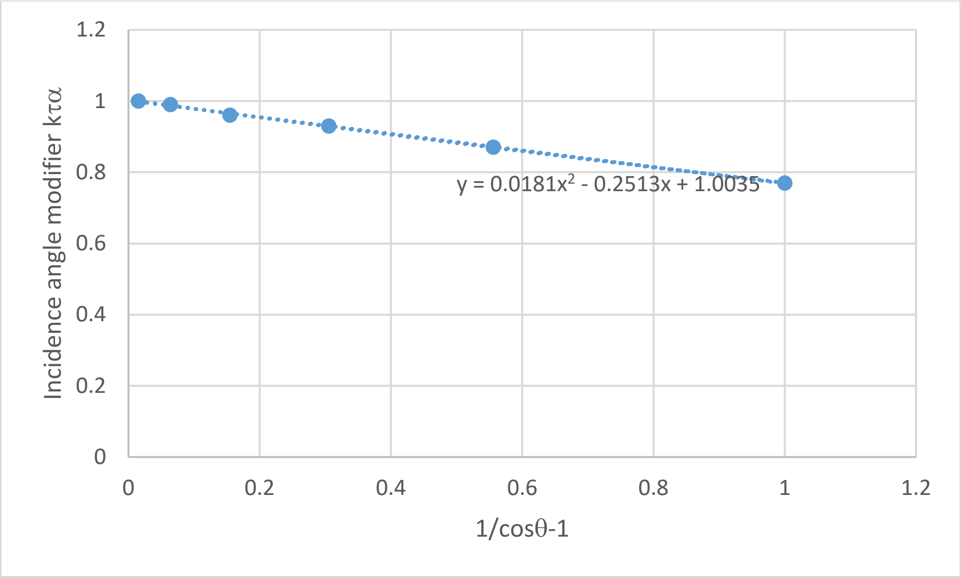


Figure 2: incidence angle modifiers for Sunmaxx collector

Proceeding with the modifications of equation (2), the rate of heat removal from the solar system *(L_s)* is thought of. This rate of heat displacement from the solar concerned storage tank is given by:

$L_s = M_s C_p (T_s - T_{mains})$……………………………(5) [42]

Where:

- M_s is the rate of water mass withdrawal
- C_p is the specific heat capacity of water
- T_s is the temperature of the storage tank
- T_{mains} is the temperature of supply water coming from the municipals.

The mass rate of abstraction of water is influenced by the amount of water that is taken out of the tank for use, *(M_{load})* at the load temperature, *(T_{load})* and the ratio between T_s and T_{load}. That is, if the storage temperature is greater than the load temperature, then the mass of water for abstraction will be less than the exact requirement for use and that the required water will be met by diluting the less but hotter water with colder water to bring it to the required mass and required load temperature[44]. Similarly, when tank contents temperature is less than the temperature of the load, then water will be withdrawn at its temperature and its temperature will be enhanced to the load temperature by the auxiliary heater, leading to equation (6)[41].

$M_s = MIN\left\{\frac{T_{load}-T_{mains}}{T_s-T_{mains}};\frac{1}{1}\right\} \times M\_load$…………………………….(6)

One aspect which properly communicates the performance of a solar heating system is the solar fraction. It is the ratio of energy contribution by solar to the total energy contribution of energy to the system [45]. The instantaneous solar fraction can be written as:

$S_F = \frac{M_s(T_s-T_{mains})}{M_{load}(T_{load}-T_{mains})}$……………………………………….(7)[42]

OVERVIEW OF ENERGY PER DOLLAR OF A SOLAR COLLECTOR AND THE NET PRESENT VALUE OF SOLAR SAVINGS

The computation of the discount rate *(D)*, in investment economics where the prevalent interest rate *(i)* per year and inflation rate *(j)* per year are known is given by:

$D = \frac{1+i}{1+j} - 1$……………………………………………….(8)

The annualized cost of a solar collector array with area A_c *(*m^2*)*, which is cost per unit area C_c *(*$\$/m^2$*)*, with annual operation and maintenance cost *(OM)* over *(w)* warranted operating years, is given by:

$C_{annual} = A_c C_c \frac{d}{1-(1+d)^{-w}} + OM$…………………………………..(9)

In equation (9), the fore cost of the collector A_cC_c is multiplied by the cost regaining factor $\frac{d}{1-(1+d)^{-w}}$ and the quotient is summed together with the yearly operation and maintenance cost. To attain the whole annualized cost [42].

The yearly heat yield of solar water heating system Q_{annual} is the timely rate Q_u interpolated for the entire year. Heat productivity per unit area diminishes as the collective area of collectors increases within a closed system. The solar fraction also behaves similarly with a diminishing increase as area is increased. The solar fraction curve creates an elbow where diminishing is first obviously observed. It is an engineering rule of thumb that the elbow of this curve must be clearly referenced by coordinates so that its coordinates become the design point as seen in chapter 4 on *Figure 20* [42].

The preferred measure to deploy in comparing the level of cost effectiveness of the chosen collectors is the energy per dollar criterion. It is found by dividing the annual energy yield of the collectors by the annualized life cycle cost (warranty life) at the point of the optimal design.

$$Energy\ per\ Dollar = \frac{Q_{annual}}{C_{annual}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(10)$$

The location of the optimal point of design is made in such a manner that the highest value of the Net Present Value of Solar Savings (NPVSS) is achieved. The Net Present Value of Solar Savings substituting electricity as the powering fuel is given by:

$$NPVSS = \frac{(L_{annual} \times PE)}{\eta_E} \frac{(1+d]^{-n}}{d} - (A_cC_c + V_sC_s + C_{BOS}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(11)[41],\ [42],\ [44]$$

Where:

- P_E is the price of electricity *($/kWh)*
- η_E is the electric to heat efficiency
- V_s hot water storage volume
- C_s is the cost of storage tank per unit volume

The cost of balance of system components C_{BOS} (includes installation labour costs) which is a percentage of own conviction of the cost $A_cC_c + V_sC_s$ [46].

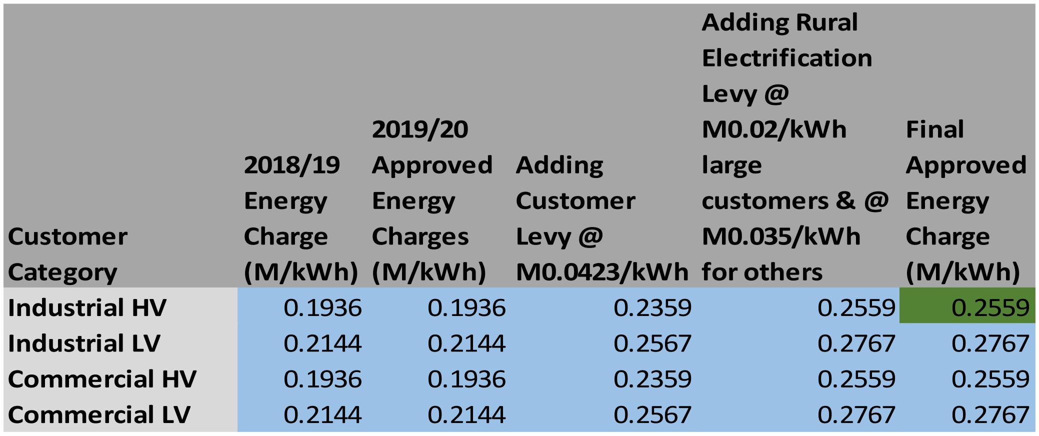
To obtain the optimal design point of solar fraction, the collector area is iteratively varied, thereby varying the storage tank temperature T_s and the solar fraction. The *NPVSS* changes with increase in collector area initially increasing as collector area increases, and finally decreasing when the area has been increased beyond the optimal design [42].

ELECTRICAL BILLING

To best understand electric billing by the utility, it is advisable to scrutinise the costs encountered by the utility. These costs are associated with the physical plant, transmission and distribution infrastructure, substations, meters, administrative costs, energy and fuel costs, interest on debt and finally the utility must make profit which is the surplus of revenue exceeding the costs[1]. Once costs contributing to the electric bill are well comprehended, customers together with the utility can reduce these behaviourally. Customers impose the utility to costs of varying magnitude depending on nature of the customer, customer are therefore categorised for the billing purpose[16].

Major conventional categories of customers are residential, commercial and industrial. In Lesotho, billing for industries is composed of only *energy* and *demand* charges, and a mine falls under customer category *Industrial High Voltage* (HV) as categorised on *Table 5*. Energy charge is for the total electrical energy (kWh) used over a month. The utility charges its industrial customers for energy use at the same rate as opposed to some utilities which have different charges for different blocks of energy uses [1],[16]. One kilowatt hour is charged at $0.017 [47]. ***(All rates from Lesotho have been converted to US$ at a rate US$1 = M14.98)***

Table 5: Energy charge prices approved by LEWA for 2019/20

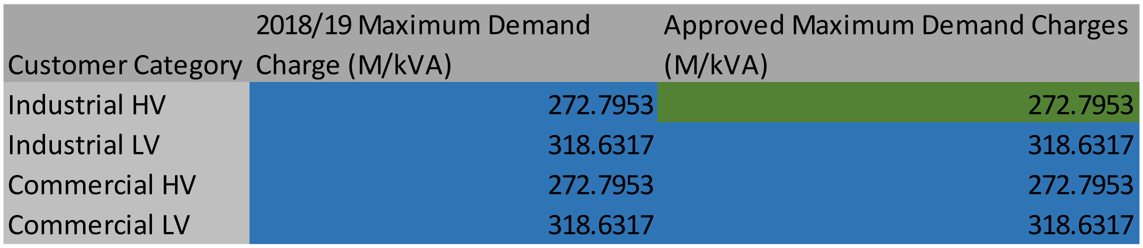


Customer Category	2018/19 Energy Charge (M/kWh)	2019/20 Approved Energy Charges (M/kWh)	Adding Customer Levy @ M0.0423/kWh	Adding Rural Electrification Levy @ M0.02/kWh large customers & @ M0.035/kWh for others	Final Approved Energy Charge (M/kWh)
Industrial HV	0.1936	0.1936	0.2359	0.2559	0.2559
Industrial LV	0.2144	0.2144	0.2567	0.2767	0.2767
Commercial HV	0.1936	0.1936	0.2359	0.2559	0.2559
Commercial LV	0.2144	0.2144	0.2567	0.2767	0.2767

[47]

Demand charge is based on the industry's maximum or peak power demand occurrence each month. Some industries may require high power for a short period of time while others may require a steady supply at a relatively lower level. These industries may consume the same kWh over a month but the one which had the higher peak demand stresses the utility to have higher generating and transmission capacity for that particular time. Demand is measured in KVA since it is the rate of energy consumption. In some countries utilities do not charge small industries for demand if it is less than a stipulated benchmark power, 50 KVA for instance [16],[1] [2]. In energy management, to achieve reduced energy bills, the load profile should be near even because peak demands that are way above the base load lead to very high costs [48]. The utility in Lesotho charges industries $18.21 per KVA on the maximum monthly demand [47]. **(Rates are converted to US$ at a rate US$1 = M14.98)**

Table 6: maximum demand prices approved by LEWA for 2019/20



Customer Category	2018/19 Maximum Demand Charge (M/kVA)	Approved Maximum Demand Charges (M/kVA)
Industrial HV	272.7953	272.7953
Industrial LV	318.6317	318.6317
Commercial HV	272.7953	272.7953
Commercial LV	318.6317	318.6317

[47]

ECONOMIC ANALYSIS

After identification of an array of energy management opportunities (EMOs), it is at this point where considerations are made about methods of analysing economically competing investments in terms of cost effectiveness [8],[1]. The winning investment may then be presented to the organisation's management for implementation. There are several methods of assessment in order to find one implementation opportunity. Simple payback period is the simplest method often used; other methods are the Net Present Value (NPV), Internal Rate of Return (IRR) and the Discounted Payback Period [12].

Payback Period

Payback period is the time in years it takes to recover an initial capital cost from annual savings, the cost of investment or retrofit is divided by the annual savings on energy to yield the number of years which denote after how long the investment will have repaid itself. Simple payback does not look at savings beyond the payback period, thus, it favours investments that have huge initial savings based on investments costs rather than long service life projects that take a long time to recover costs[12]. Simple payback can be computed using equation:

$$Payback = \frac{First\ Cost}{Annual\ Energy\ Savings} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(12)$$

The Net Present Value

The Net Present Value is a measure that will be adopted to assess economically the performance of proposed investments that are meant to save energy. Net Present Value is the most common and modern economic valuation method. Its main principle is the discounting of all the cash flows of the future, both the inflowing and the outflowing by a known discount rate and adding them together to find the net cash flows as presented by the equation (13)[12]:

$$NPV = \sum_{t=0}^{n} \frac{NCF_t}{(1+r)^t} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(13)$$

NPV = Net Present Value

NCF_t = Net Cash Flows in year t

r = discount rate T

The other principle of NPV method is that it asserts that a risky unit of money today is less valuable than a sure unit of money today [8]. It caters for the time value of money. The discount rate is interest on a firm's investment or interest it pays for a debt borrowed [49]. Net Cash flow is the sum of the cash inflows and cash outflows over the life of the investment. Cash inflows examples are gains from the investment or savings and could sometimes be the salvage value of an investment at its expiry if a there is a value of a commodity left. Cash flows are time to time expenses to maintenance costs, depreciation and capital costs of the investment [1].

ENERGY SAVINGS AND ASSOCIATED EMISSIONS REDUCTIONS

Saving electrical energy comes with avoiding excessive greenhouse gas emissions to the environment. There is a correlation between energy saved (kWh) to greenhouse gases emitted to the environment [50]. A programme named AVoided Emissions and geneRation Tool (AVERT) is used which is a Greenhouse Gas Equivalencies Calculator. AVERT uses the U.S. national weighted average carbon marginal emissions rate to convert reductions in kWh to units of carbon dioxide emissions warded off[51]. Millstein et al used the same tool in assessing the impacts of wind and solar plants on the U.S. air emissions [52].

Since electricity fed to Lets'eng Diamond Mine comes from South Africa which mostly generates power from coal-fired power plants, the calculator helps in seeking equivalencies for electricity bound emissions. It therefore, gives out equivalencies for emissions reductions that arise as a result of energy efficiency (EE) or renewable energy (RE) techniques. This is done by quantifying the amount of fossils used in generation and emissions that are avoided by introducing energy efficiency or renewable energy. EE and RE are presumed not to affect baseload generation emissions but peak generation that is only introduced at particular times to meet demand.

The emissions factor provided by AVERT when energy efficiency and renewable energy programs are introduced is [51]:

$$7.07 \times 10^{-4}\ tonnes\ CO_2/kWh$$

3.0 METHODOLOGY

3.1 General Energy Audit

During the first visit to the mine, an introduction with the energy management head was convened. Further introductions to other relevant personnel within the department were also undertaken. Electrical processes within the mine were discussed. Visits to the metering stations were made and data for monthly electrical energy consumption profiles for due months of 2019 was provided. Metering at the mine was only introduced in September 2018, so data for 2019 was gathered. Billing receipts of previous years however reflect an even annual consumption pattern.

From the preliminary data and mere observations, energy intensive processes together with easily identifiable Energy Management Opportunities (EMOs) were observed. This is where a walk through audit was undertaken to evaluate consumption information and analyse the quantities of energy use patterns. Most of the sites of the mine were visited during this period especially the offices and accommodation sites. No visits to the plants were arranged as there are strict obligations hindering access. Plant consumption analysis relied on data and interviews.

Data was accessed from the energy department about electricity consumption profiles starting from the month of September 2018 which is the time when metering in the mine was first introduced. Data for 2019 was sequentially provided after months were due. Billing receipts were also provided to be familiar with the industrial billing method and to establish how different charges contribute to the total bill. Meteorological data of the site was provided by the utilities department with data from January 2015 to June 2019.

From the Sites Accommodation department, data collected was about all the residential blocks within the mine, the total number of rooms and number of people occupying the rooms. Sites were also visited to gather information about electrical appliances in the blocks, their quantities, power ratings and hours of use. This was achieved through examination of such equipment and oral interviews with the users. The offices were also visited together with facilities like, kitchen, clinic, laundry and the gymnasium. It is during these visits when different energy use processes were profiled like lighting, heating, etc. Visits to sites only allowed making a count of electrical equipment and observations about electrical equipment power ratings. Measuring of any parameter like light intensity and temperature was prohibited as it was deemed to be against the security obligations of the mine.

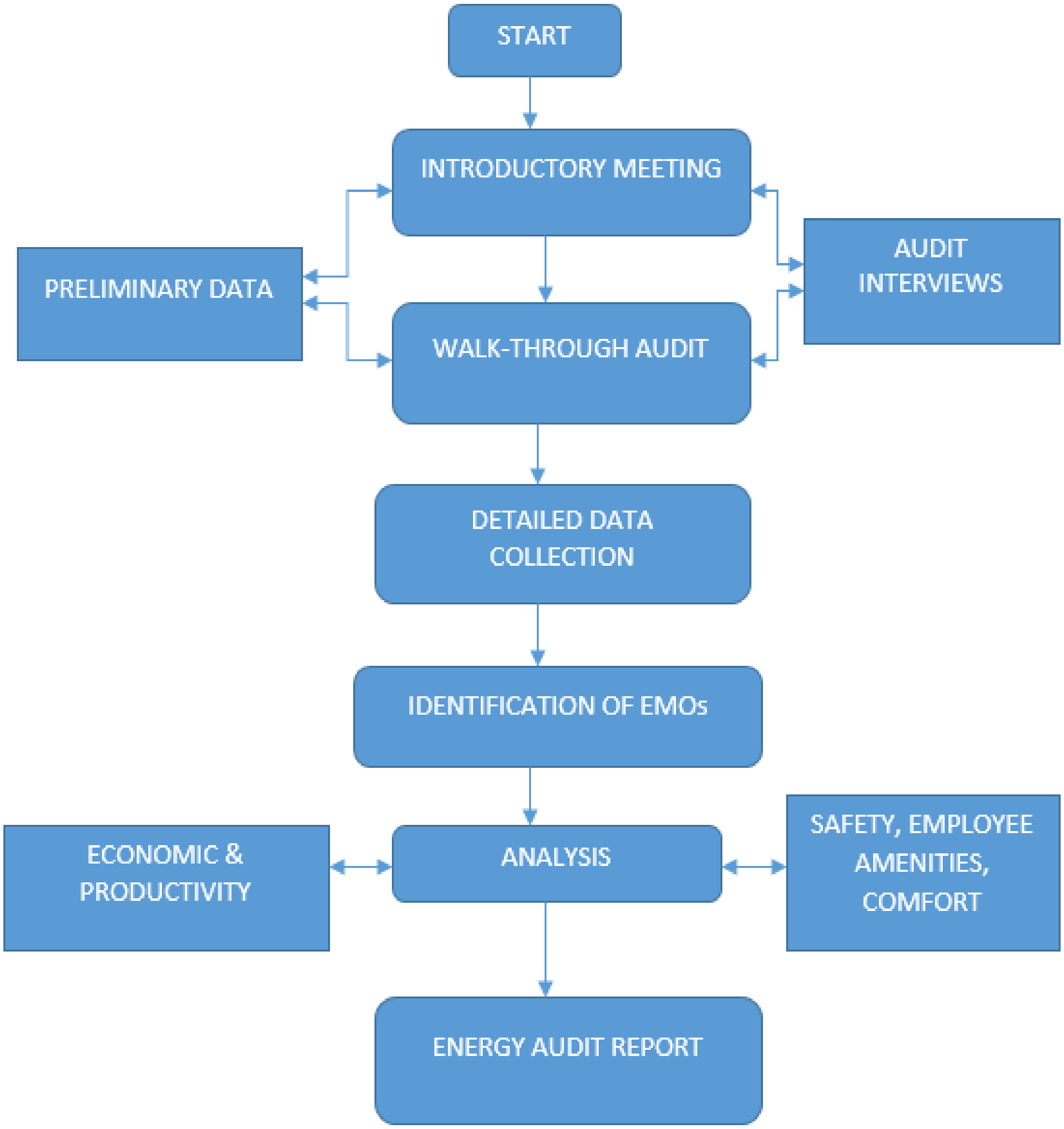


Figure 3: generalised energy audit methodology

There were shortcomings encountered as per the adopted methodology. Metres installed at the residential blocks and other apartments measure electrical energy passing at a point and it is consumed for different processes. It therefore rendered a tedious process of registration of all electrical equipment type, their time of use, duration of use and their number of such equipment to establish the amount of energy used by each process. It would have been ideal if more local metres were installed to measure energy consumption for a distinguished process.

3.2 Power Factor Correction Methodology

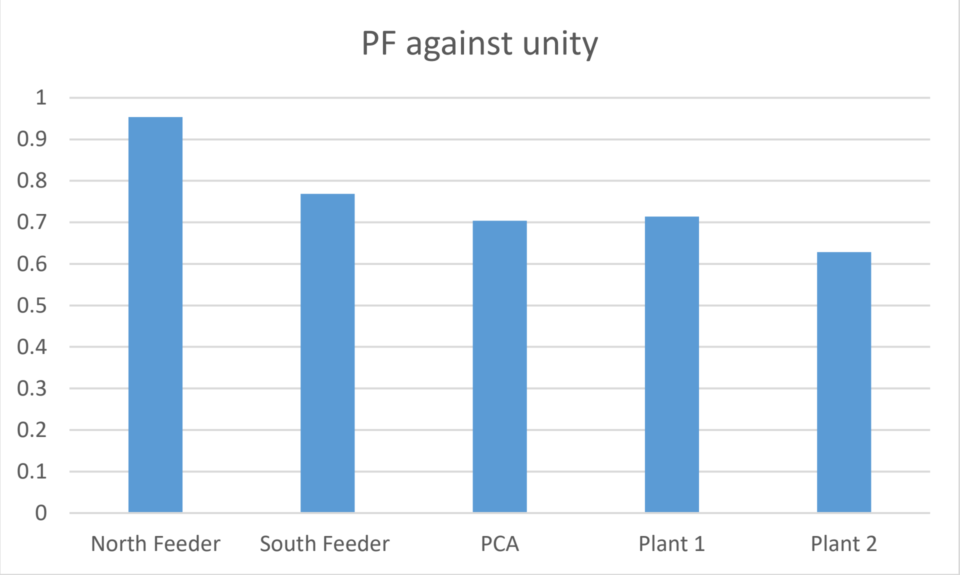


Figure 4: feeder average power factors

Figure 4 shows a plot of the average power factor readings from the five feeder metres, the data is half hourly and the averages were attained by computing half hourly data for the whole year of 2019. The lowest values are found in Plant 2, PCA and Plant 1 with 0.63, 0.70 and 0.71 respectively where inductive motors are found. South Feeder the power factor is 0.77 and the greatest power factor 0.95 for North Feeder. Improvement of the power factor at the loads is necessary to minimise power losses. The power factor should be improved so that it is one or closest to 1.

Because the power factor in this case of inductive loads is improved by compensating reactive power with capacitors; it is necessary to verify whether capacitance needed to achieve different better power factor values is linear for all the improvement percentages from the current actual power factor to the different target values or if the percentage increment or improvement diminishes when higher power factors are attempted.

Therefore, from the current actual power factor to the best power factor of 1, different values of power factor between the current power factor and 1 were plotted against the percentage reactive compensation needed to achieve such desired power factor values. This was done for the five feeders and the results were the same as it is shown on *Figure 5* for Plant 1 and *Figure 6* for Plant 2 that power factor improvement beyond a power factor value of 0.95 requires more from reactive power compensation as the curves execute an elbow denoting a high need of reactance compensation for a power factor increment above 0.95.

Since power improvement will require the procurement of capacitors and economical implications will be of concern, it will make sense to improve the power factor to 0.95 and not above, as such ambition means that capacitors in (kvar) needed to compensate reactive power for such power factor values will be relatively higher compared to improvement aimed at 0.95. Since the power factor for the North Feeder is already 0.95, power factor improvement will only be undertaken in the other four feeders..

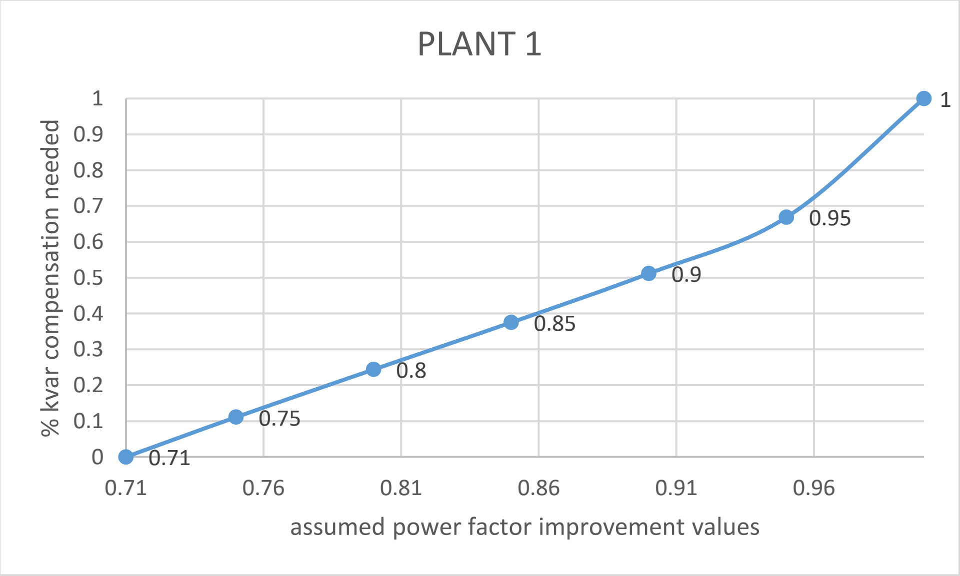


Figure 5: determination of a new power factor value

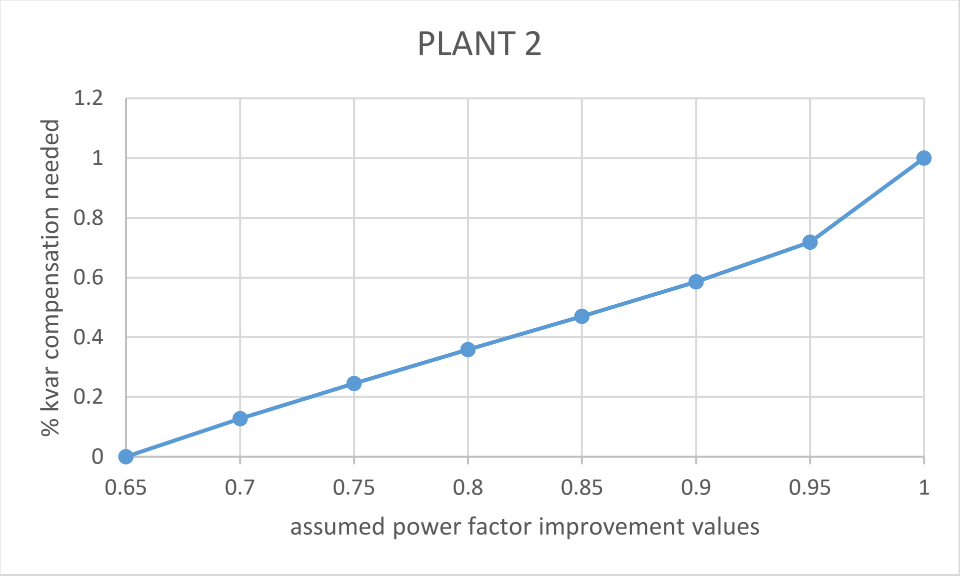
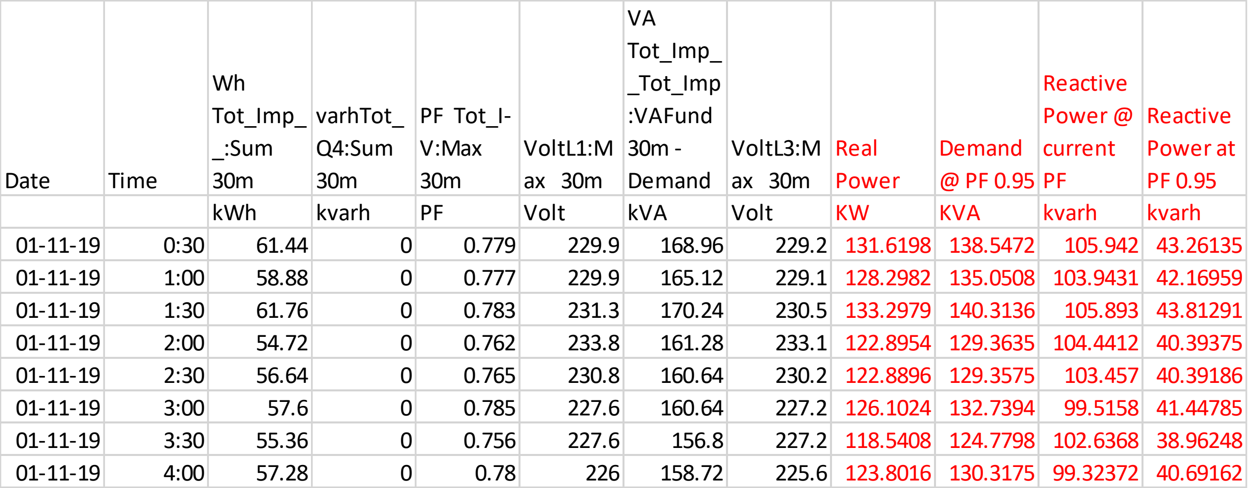


Figure 6: determination of a new power factor value

To calculate the load (kw) in each 30 minute interval, the apparent power (kVA) was multiplied by the corresponding power factor in the same 30 minute interval.

$kw = kva * pf$ ……………………………..(14)



Date	Time	Wh Tot_Imp_ _:Sum 30m	varhTot_ Q4:Sum 30m	PF Tot_I-V:Max 30m	VoltL1:Max 30m	VA Tot_Imp_ _Tot_Imp :VAFund 30m - Demand	VoltL3:Max 30m	Real Power	Demand @ PF 0.95	Reactive Power @ current PF	Reactive Power at PF 0.95
		kWh	kvarh	PF	Volt	kVA	Volt	KW	KVA	kvarh	kvarh
01-11-19	0:30	61.44	0	0.779	229.9	168.96	229.2	131.6198	138.5472	105.942	43.26135
01-11-19	1:00	58.88	0	0.777	229.9	165.12	229.1	128.2982	135.0508	103.9431	42.16959
01-11-19	1:30	61.76	0	0.783	231.3	170.24	230.5	133.2979	140.3136	105.893	43.81291
01-11-19	2:00	54.72	0	0.762	233.8	161.28	233.1	122.8954	129.3635	104.4412	40.39375
01-11-19	2:30	56.64	0	0.765	230.8	160.64	230.2	122.8896	129.3575	103.457	40.39186
01-11-19	3:00	57.6	0	0.785	227.6	160.64	227.2	126.1024	132.7394	99.5158	41.44785
01-11-19	3:30	55.36	0	0.756	227.6	156.8	227.2	118.5408	124.7798	102.6368	38.96248
01-11-19	4:00	57.28	0	0.78	226	158.72	225.6	123.8016	130.3175	99.32372	40.69162

Figure 7: screenshot of electrical energy consumption data

To compute new demand in kVA for the 30 minute intervals over a month, the half hourly load values (KW) were all divided by 0.95 to give lower kVA demand compared to the one on the data which is uncorrected. This was done to show the difference in quantity of kVA demand before power factor correction and after correction to a value of 0.95. Comparisons of the resulting new kVA demand to the former kVA demand can be seen on *Figure 16*, *Figure 17*, *Figure 18* and *Figure 19* for each of the four feeders. The maximum demand (kVA) at uncorrected power factor and at 0.95 in a month for each feeder can therefore be identified.

Since the power factor is improved to a higher, better value of 0.95, resulting new kVA Monthly demands at power factor 0.95 are all lower compared to the actual demand at uncorrected power factor. Hence, a deduction can be made in monetary terms to calculate the savings as each kVA is charged at $18.21 for the maximum demand charge (peak monthly demand in kVA). Thus, the difference between the sum of the four feeders' maximum demand at uncorrected power factor and the sum of the four feeders' at a power factor of 0.95 multiplied by $18.21 will be the monthly total savings from peak demand. *Table 8* in the next chapter shows aggregated savings for each month of 2019 derived from power factor improvement.

Sizing of the capacitor bank needed to correct the power factor to 0.95 requires computation of the difference in the reactive power (kvar) between the scenario of uncorrected power factor and when the power factor is corrected [29],[35]. Therefore, the (kvar) at uncorrected power ($kvar_1$), should be determined, then ($kvar_2$) at the desired power factor. The difference between the two reactive power values is the size of the capacitor bank needed to correct power factor to a desired power factor. Thus: at uncorrected power factor, the reactive power is [35]:

$$Kvar_1 = \sqrt{(KVA_1)^2 - (KW)^2} \text{.......................................(15)}$$

Then, at the desired power factor, the reactive power is:

$$Kvar_2 = \sqrt{(KVA_2)^2 - (KW)^2} \text{..(16)}$$

The capacitor rating is the quantity of reactive power (kvar) at uncorrected power factor minus the quantity of reactive power at a desired corrected power factor:

$$capacitor\ rating\ (kvar) = kvar_1 - kvar_2 \text{...............................(17)}$$

But since the power factor fluctuates half houly over the month, the worst (kvar) value at uncorrected power factor ($kvar_1$) was taken and the best (kvar) value at a power factor of 0.95 was also recorded, the difference between the two values gives the size or the range to which a capacitor will compensate reactive power in order to correct power factor adequately to a power factor of 0.95.

3.3 Lighting and Space Heating

Both the methodology for lighting EMOs and space heating EMOs followed similar steps. There are meters installed to measure distinguished lighting and heating energy consumption. Therefore, a profile of heating and lighting appliances was established. The profiles recorded all the heating and lighting appliance properties and their energy consumptions pattern and timing.

Appliance efficiency properties are scrutinised in order to make an assessment if appliances are up to date. Their power wattages are considered in making such decisions. A record of hours of appliance operation per day with respect to each day of the week was registered to estimate appliance's daily, monthly and annual energy consumption. Each residential block and facility unit was studied to determine the times which are truly necessary for lighting and heating appliance operation.

The relevant times for heating and lighting will be used to make an adjusted scenario to attain annual energy savings derived from reduced hours of operation. Also high wattage old inefficient appliances are replaced by lower wattage appliances in the second constructed scenario to achieve annual savings derived from efficient appliances and reduced hours of operation.

3.4 Solar Water Heating

A Microsoft Excel computer-based programme developed by Tawanda Hove was utilised to compute the energy balance and economic calculations required for designing an accurately sized solar water heating system. For each average day of each month, calculations are executed on hourly intervals. The start-up feeding data which is monthly-average daily global horizontal irradiation was obtained from [42].

The programme incorporates Collares-Perreira and Rabl models which automatically computes hourly-average GHI for each month. The programme was specially built for modelling of Zimbabwean region, therefore, it was necessary to edit the in-built equations for diffuse ratio to the clearness index correlation characteristic to the mine site. The programme is able to compute ambient hourly temperatures from the fed average monthly minimum and maximum ambient temperature as executed in the model [53]

The surface area of the tank for heat losses is calculated as the necessary formulae needed are also built within the model. It generates a demand profile for hot water abstraction in boarding schools using a model founded by Rousseau and Rankin. Weiss model was used to calculate the daily hot water demand[54]. The spreadsheet also has the hourly consumption patterns of a boarding school as presented in *Figure 8*, which is adopted from Rosseau model which was undertaken in assessing hot water consumption in different industrial buildings in South Africa [55]. The model has three different consumption profiles types*; boarding school, hotel and a residential home,* boarding school was chosen as water consumption at accommodation blocks of the mine corresponds to water abstraction at a boarding school

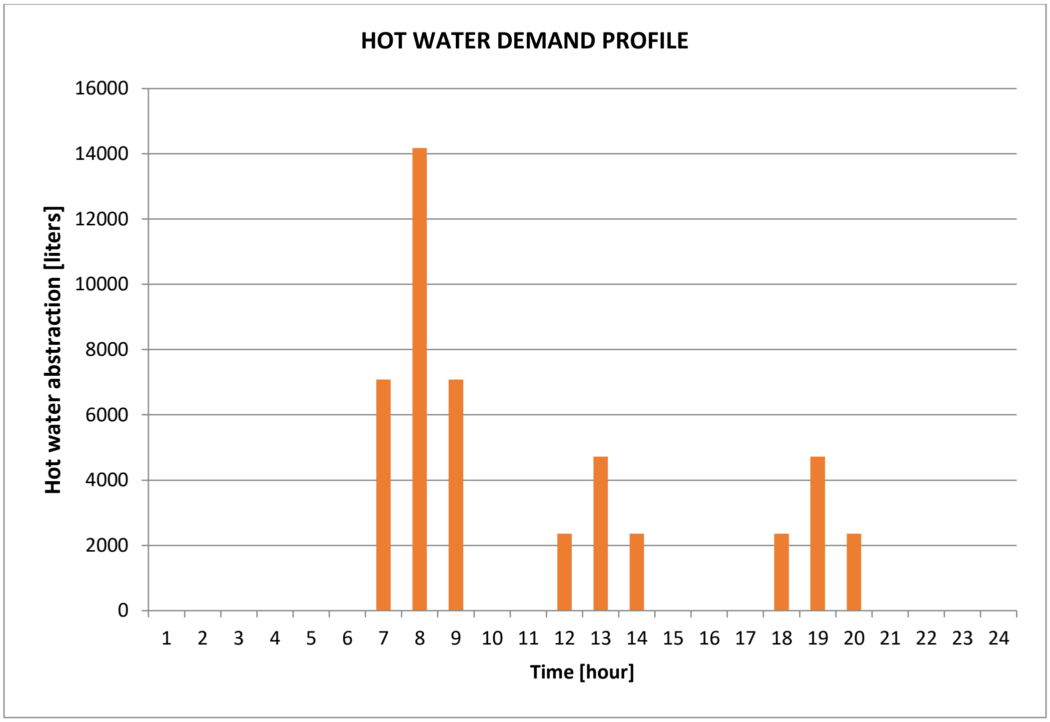


Figure 8:daily hot water consumption profile

4.0 RESULTS AND DISCUSSIONS

4.1 OVERVIEW OF ELECTRICITY DISTRIBUTION AT THE MINE

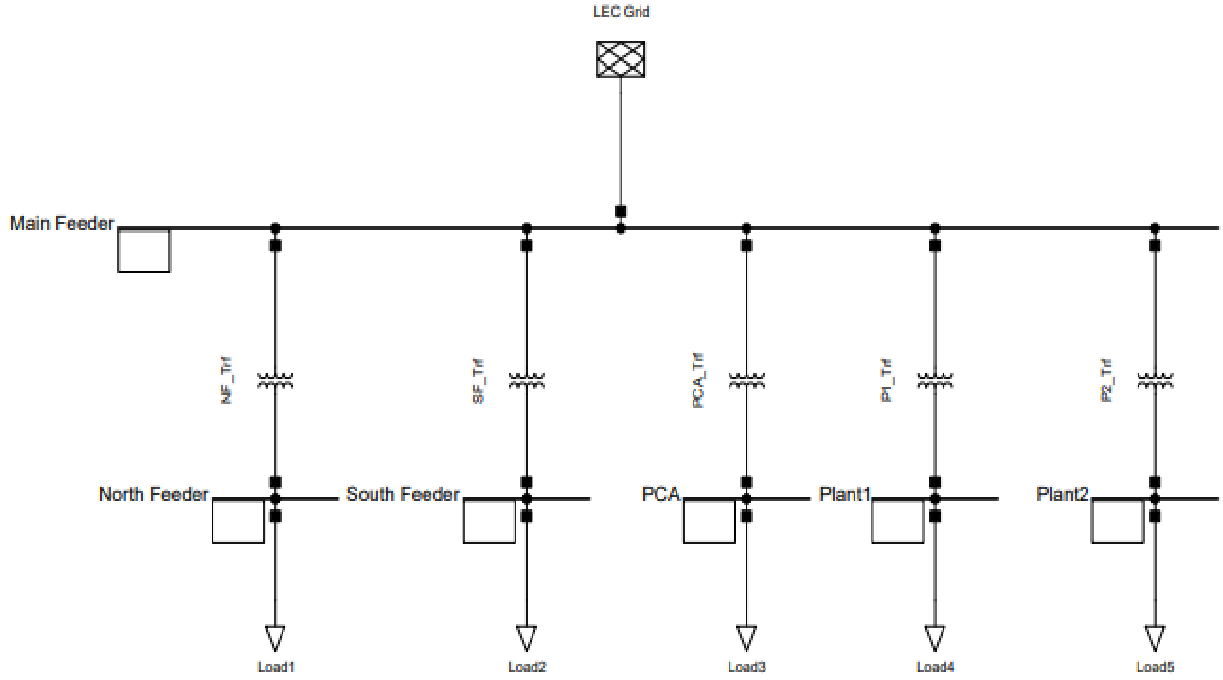


Figure 9: Distribution of power at the mine

Electricity that is incoming on the site of Lets'eng Diamond mine is from a 33 KV transmission line and is distributed through the main feeder to the five feeders at the mine's sub station as observed from *Figure 9*. These feeders distribute power to different loads within the mine. The feeders are Plant 1, Plant 2, South Feeder, North Feeder and the Primary Crushing Area (PCA). Therefore, there are six metres at the sub station, one for the whole incoming electricity and five for the distribution feeders.

There is a huge variance from the five metres at the bus bar in terms of the quantity of power being distributed at any instant. This is because of the type of electrical equipment that is powered under each feeder and quantity of such power using equipment. Also the average power factor within the feeders differs significantly as *Figure 15* shows. There is no local or branched power factor correction at the loads in the mine but only undertaken centrally at the main feeder.

Table 7: Major equipment fed in each section

PLANT 1	**PLANT 2**	**NORTH FEEDER**	**SOUTH FEEDER**	**PCA**
Inductive motors	Inductive motors	Office equipment	Office equipment	Inductive motors
Pumps	Pumps	Domestic equipment	Pumps	Office equipment
			Inductive motors	

4.2 MONTHLY ENERGY AND PEAK DEMAND

Figure 10 shows the monthly energy use by the mine and monthly peak power demand. The graph shows that energy use is more intensive during the winter months as it reaches over 6000 MWh for the months of April, May, June, July, August and September and drops between 4000 MWh and 6000 MWh for the summer months of January, February, March, October, November and December. Since it is very cold at Lets'eng Diamond Mine, more energy is being used in winter months because of highly escalated use of heating equipment as compared to the summer months. All the other electrical equipment at the mine use power at a stable rate seasonally except for heaters. To a not so great extent, lighting also consumes more energy in winter months due to the increased number of hours necessary for lighting as the daylight hours are decreased in winter. Peak Power demand occurrences do not show any noticeable trend that is dependent on the seasons. The highest peak power demand of March was caused by the failure of the central power factor correcting device at the bus bar because currently the mine only corrects power centrally at the sub station.

The histogram on *Figure 13* shows peak occurrence frequencies for the 12 months of 2019 distributed on the hours of the day. These occurrences are observed between 04:00 hours and 07:00 hours and between 19:00 hours and 22:00 hours only. The morning and evening hours which experience peak demand reflect the time when most of the power equipment is in use in the mine. The plants and workshops operate 24 hours a day. Offices consume energy during the day hours while the residences experience their own peak operation to the time corresponding with the overall peak occurrence of the mine mainly because of heating and lighting. During this time the offices do not use much power, however their withdrawal from peak contribution does not lead to shifting of peak occurrences to hours of the day or night as load from the residences highly offsets the load withdrawn due to the closure of offices. Loads from the residences and plants that lead to peak occurrences at these times are mainly lighting and heating. During these times almost all the lamps and heaters are switched on.

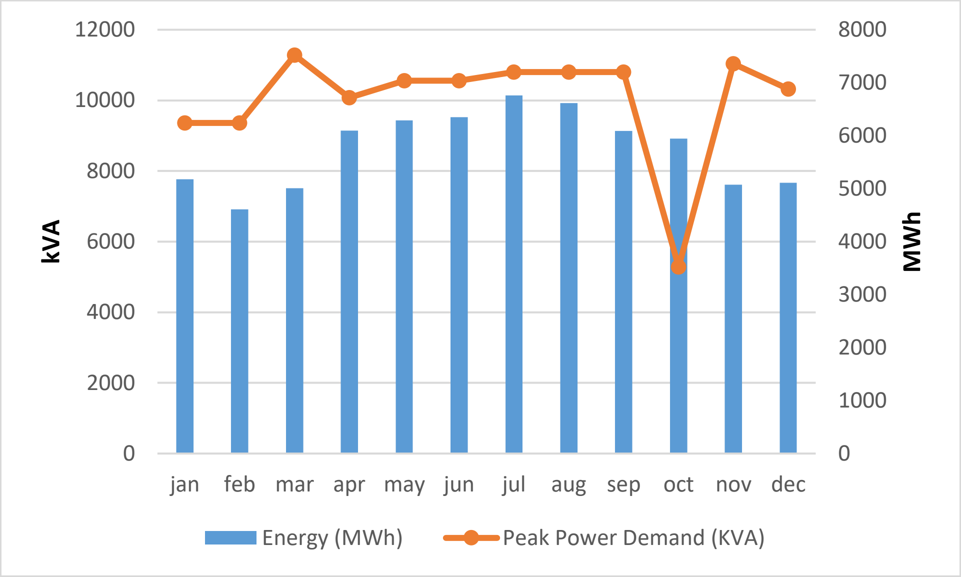


Figure 10: 2019 monthly energy consumption and peak power demand profiles

Figure 11 shows the load profile of the mine for the year 2019. The normal load profile of the mine ranges between 8000 KVA and 11000 KVA. *Figure 11* clearly shows that time to time KVA demand in winter is higher than that of summer. Therefore, higher KVA demand for the months of March and November which are essentially summer months in this context have been a consequence of a fault (power factor control fault) and negligence or bad energy management such as uncontrolled starting of machines respectively.

Load below the base load of the industry does not reflect the normal load of the mine, below the base load, it signifies technical obligations that can be power cuts in some operations or sections of the mine. Power trips are a common instance. Load below the base load cannot be viewed as savings but rather as a negative impact to the productivity of the industry. A distinguished load is observed on the graph below the baseload which is evenly distributed around 5000 KVA; that represents the month of October to November when maintenance was being undertaken in the plants.

In essence, an ideal load profile should show an evenly distributed curve above the base load without significant spikes that extend very far above the base load which cost the industry higher monthly peak demand charges.

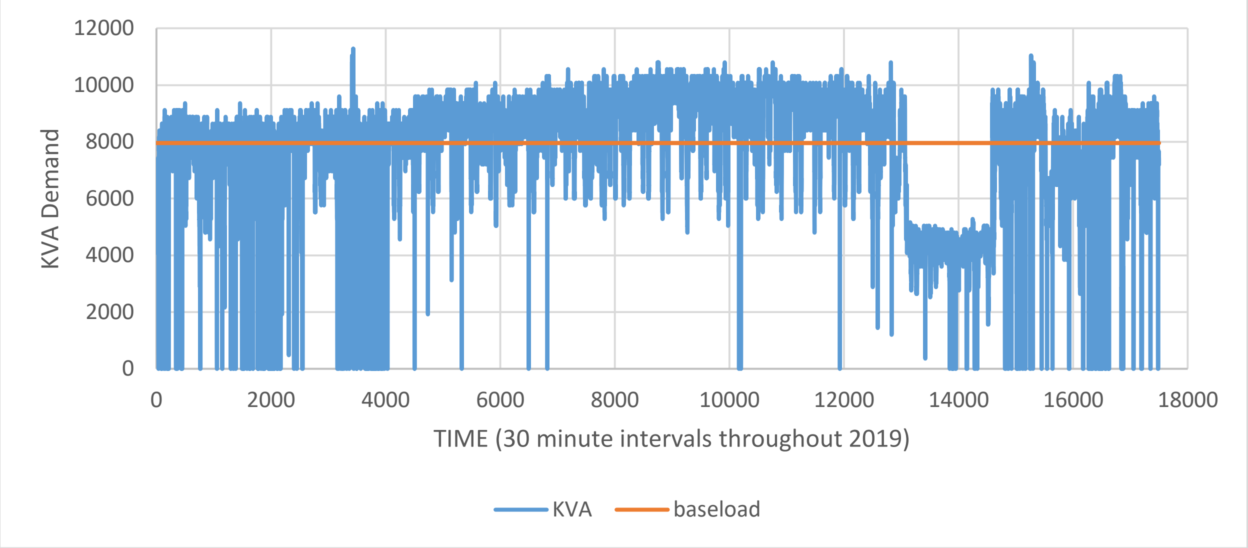


Figure 11: 2019 load profiles

Since the industrial monthly bill in Lesotho is composed of the monthly peak demand (kVA) and monthly energy (kWh), it is worth assessing how much each charge component constitutes to the total monthly bill. Figure 12 shows the average monthly ratio of the peak demand charge to the energy charge for the year 2019. Maximum demand charge is therefore seen to claim a large proportion of the electricity bill thereby drawing more scrutiny for energy management in order to lower costs.

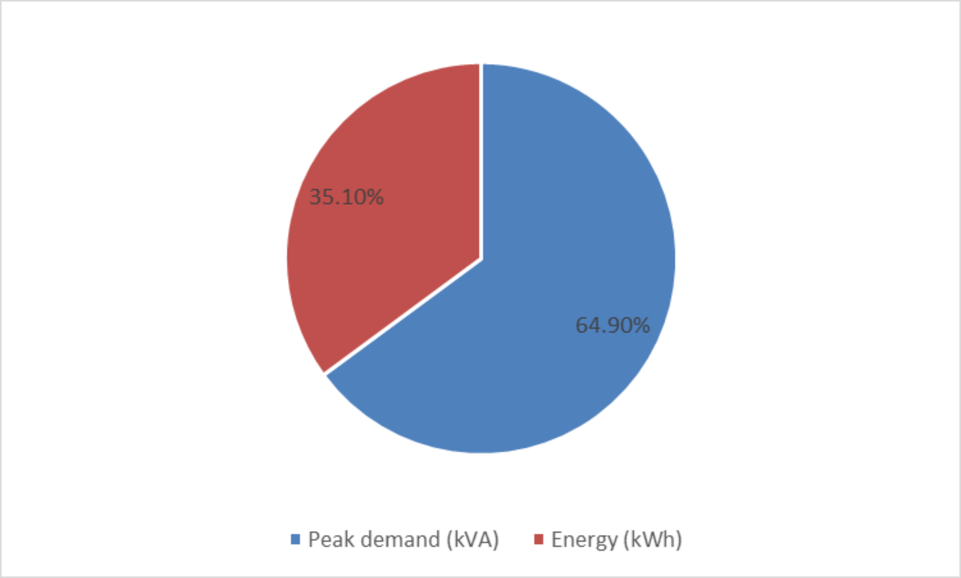


Figure 12: monthly average electrical energy bill composition

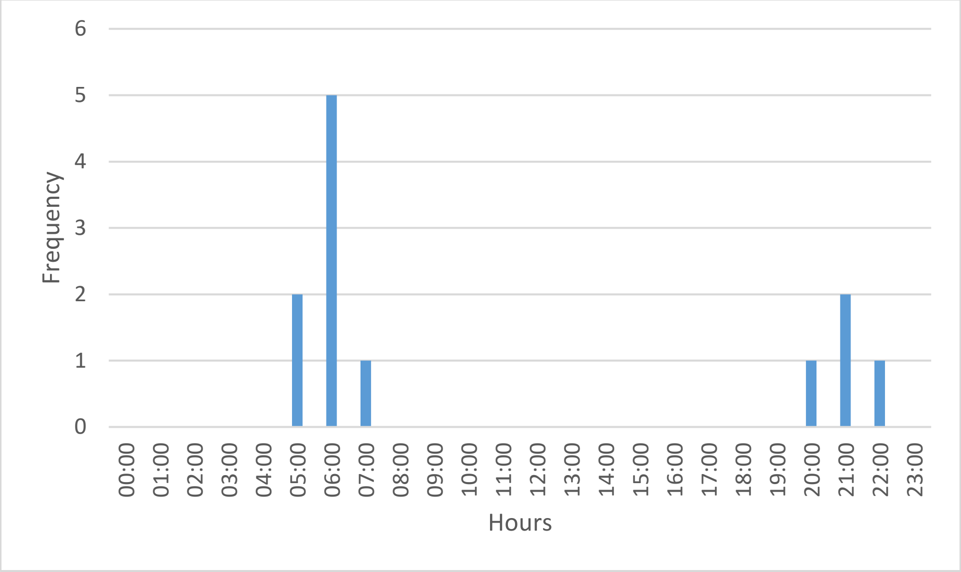


Figure 13: monthly peak power occurrences distribution over hours of the day

4.3 ELECTRICAL ENERGY FLOW PROCESSES

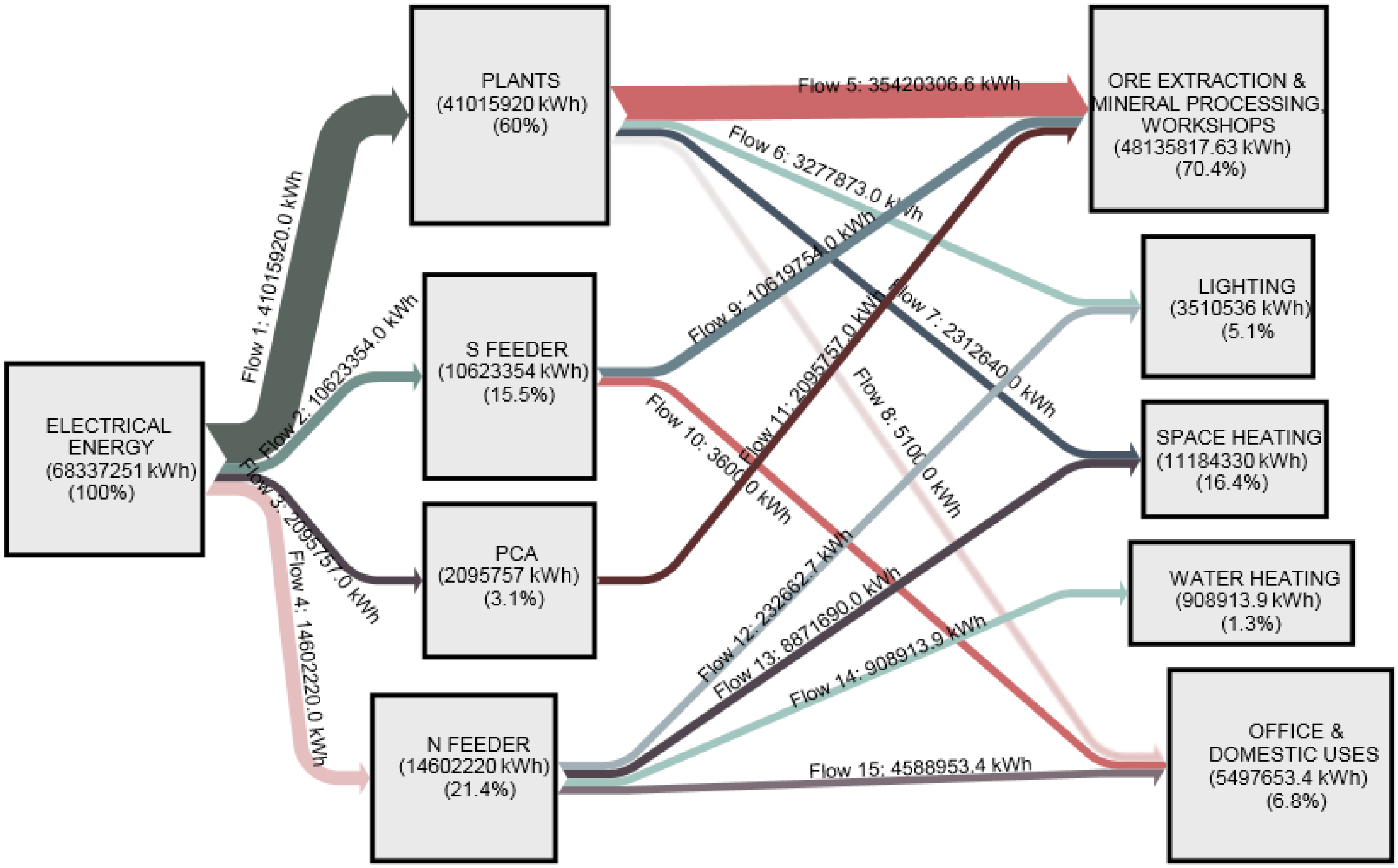


Figure 14: electrical energy flow processes in the mine

All the electrical energy that was consumed by the mine in 2019 is 68337251 kWh. This energy was distributed through the five feeders which further distributed different quantities of electrical energy to different processes. Plant 1 and Plant 2 Feeders jointly distributed 41015920 kWh which is 60% of the total mine's electrical energy. Of all the electrical energy distributed from the plants, 86% of it was utilised for the mine's production processes of ore extraction, mineral processing and workshops. Lighting, space heating and office use in the plants were fed from the Plants by 8%, 5.99% and 0.01% respectively.

South Feeder distributes electrical energy to the plants but particularly to the workshops. The South Feeder distributed 10623354 kWh which is 15.5% of the mine's electrical energy. 99.9% of this energy was supplied to the workshops and the remainder supplied for office use in the workshops. The PCA feeder distributed 2095757 kWh which is 3.1% of the mine's energy. All this energy is solely used for rock crushing.

The North Feeder distributed 14602220 kWh which constitutes 21.4% of the industry's electrical energy. Since the North Feeder supplies energy to residential blocks, offices and other specialised facility apartments like the clinic and the laundry, 60.8% of this energy was used for space heating, followed by 31.4% which was used for office and other unclassified domestic uses in the residential blocks. Water heating and lighting consumed 6.2% and 1.6% from the North Feeder respectively.

The production processes of ore extraction, mineral processing and support services of the workshops together used 70.4% of the mine's electrical energy. These processes and services do work with the use of large inductive motors. Space heating follows with 16.4% consumption of the mine's total electrical energy. Office equipment and other unclassified domestic uses consume 6.8%, lighting electrical consumption is at 5.1% and lastly water heating at 1.3%.

Energy management opportunities are considered based on the electrical energy end-use processes on *Figure 14*. Energy management opportunities from all the processes are discussed later in this chapter except for "*office and domestic use*". Electrical office equipment and domestic equipment in the accommodation rooms use more energy than water heating and lighting as observed of *Figure 14*. It was however left out when undertaking energy management opportunities because these equipment only operate for a short period of time when needed. Their standby or idling consumption is almost negligible and they are efficient in energy consumption as they are the type of equipment which are easy to replace frequently without major economic obligations.

4.4 POWER FACTOR

CURRENT SCENARIO

Power factor correction is only performed centrally at the main feeder. It is not undertaken locally at the loads where the feeder branches eventually distribute power. The time-steps average power factor values within the feeders is shown on *Figure 15*. The values of power factor are influenced by the type of load exhibited by the type of equipment found in feeders as shown on

Table 7. Only the power factor for the North Feeder is very close to one (unity) whilst power factor values for the other feeders are below 0.8 and therefore are deemed poor. Determination of a new power factor value was found to be 0.95 for all the four feeders and the verification of the results for two feeders are shown on *Figure 5* and *Figure 6*.

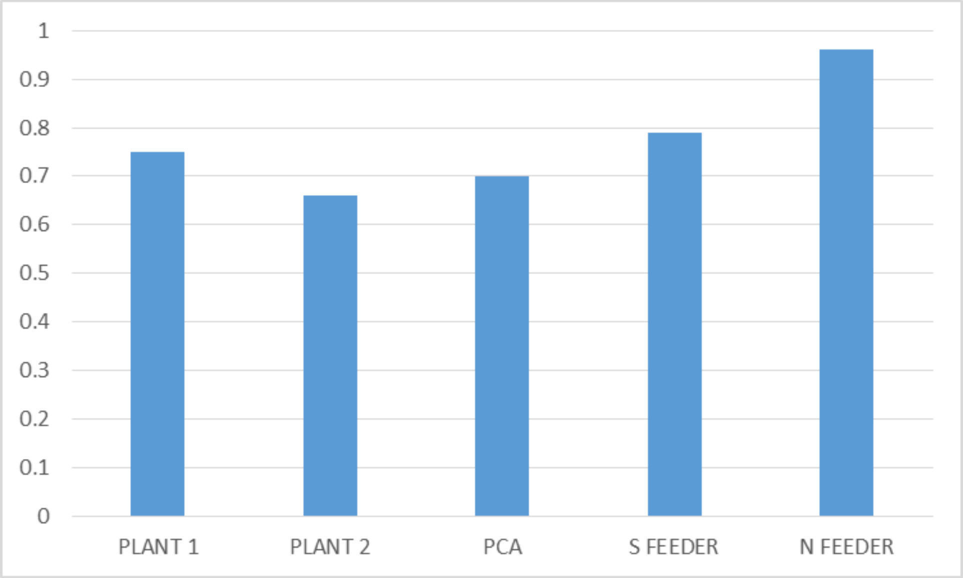


Figure 15: Feeder power factor analysis

The times of peak demand occurrence for each month were recorded and the kVA demands at the corresponding times in the four feeders with the poor power factor were also noted. *Figure 16*, Figure *17*, *Figure 18* and *Figure 19* show kVA demand at the times of monthly peak when the current poor power factor in the four feeders prevailed against the lower kVA demand that would have been if the power factor was corrected to 0.95.

OPPORTUNITIES

Correction of power factor at the individual or grouped loads will ensure reduced demand of incoming electricity .The difference in kVA demand from the current power factor and the desired power factor at 0.95 in the four feeders each month can be translated into monetary value as shown on *Table 8*. Using the demand charge of $18.21 per kVA, the total monthly savings from the four feeders are shown which add up to the annual savings of $405 769.36.

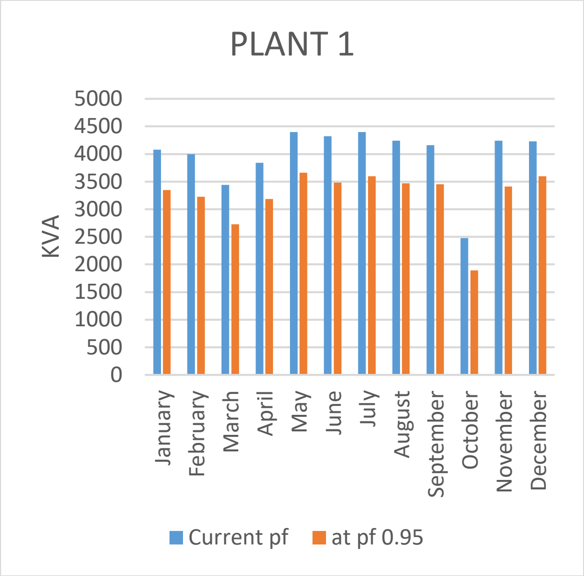


Figure 16: current and desired power factor comparison

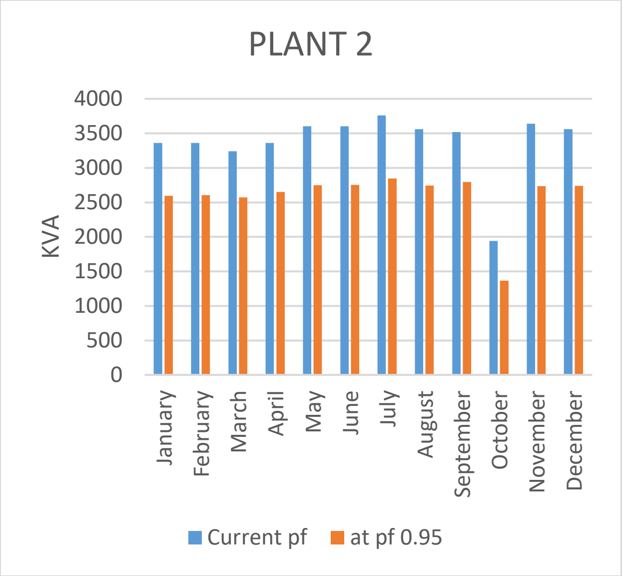


Figure 17: current and desired power factor comparison

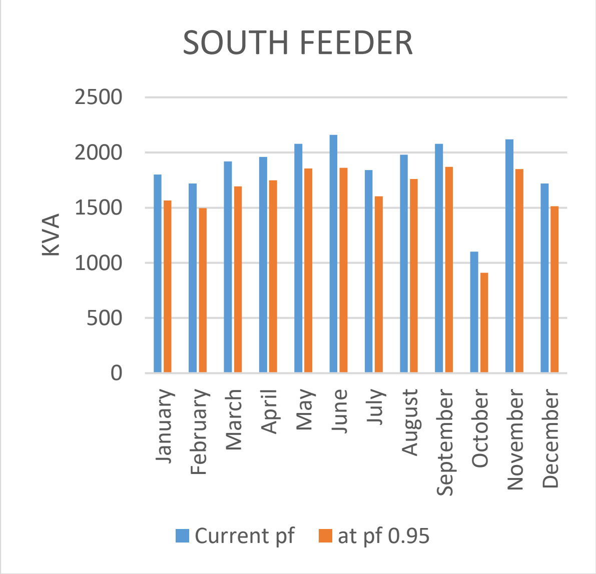


Figure 18: current and desired power factor comparison

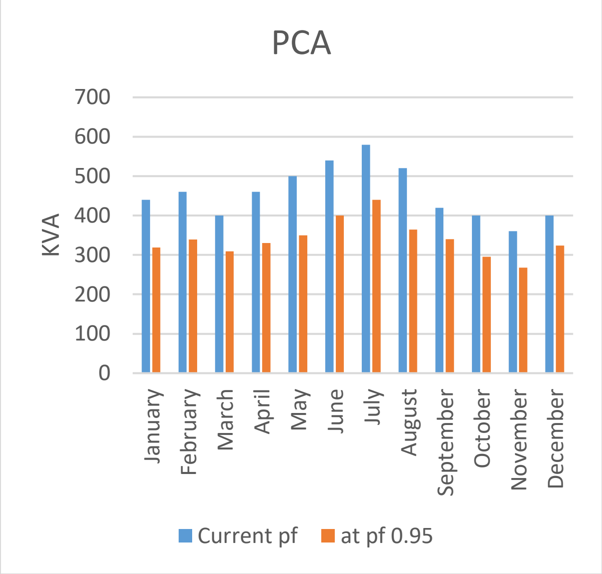


Figure 19: current and desired power factor comparison

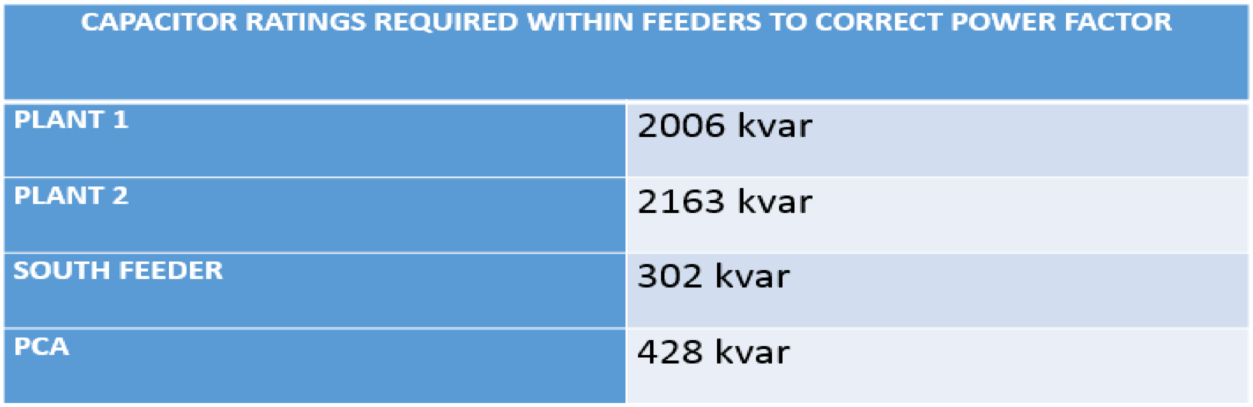
Table 8: presumed monthly savings from power factor improvement

MONTH	**PLANT 1 ($)**	**PLANT 2 ($)**	**SOUTH F ($)**	**PCA ($)**	**MONTHLY SAVINGS ($)**
January	13293.8	13912.9	4279.5	2203.5	**33689.7**
February	14040.4	13785.5	4097.4	2203.5	**34126.7**
March	12984.2	12182.9	4152.0	1657.2	**30976.3**
April	11928.0	12874.9	3878.9	2367.4	**31049.1**
May	13494.1	15533.7	4115.6	2731.6	**35874.9**
June	15242.3	15388.0	5426.8	2549.5	**38606.5**
July	14568.5	16644.5	4334.1	2549.5	**38096.6**
August	13985.8	14878.1	3988.1	2840.9	**35692.8**
September	12911.3	13220.9	3824.2	1456.9	**31413.3**
October	10689.6	10489.3	3441.8	1912.1	**26532.9**
November	15042.0	16462.4	4916.9	1675.4	**38096.6**
December	11527.3	14950.9	3751.4	1384.0	**31613.6**
ANNUAL SAVINGS					**405769.36**

INTERVENTIONS

The maximum kvar requirement for reactive power compensation necessary for power factor in the four feeders are reflected on *Table 9*. Capacitor banks of the required kvar capacity will have to be purchased and installed at the loads.

Table 9: required capacitor sizing for power factor correction



CAPACITOR RATINGS REQUIRED WITHIN FEEDERS TO CORRECT POWER FACTOR	
PLANT 1	2006 kvar
PLANT 2	2163 kvar
SOUTH FEEDER	302 kvar
PCA	428 kvar

4.5 LIGHTING

CURRENT SCENARIO

The residential blocks, offices and other facilities are equipped with LED and fluorescent lamps. There are LEDs of 8 W, 18 W, 22 W, 24 W and 26 W while the fluorescent lamps are of wattage 36 W and 58 W. 36 W and 58 W fluorescent are mostly found at relatively old residential blocks and facility buildings and are steadily being phased out with LEDs even though this is only done after fluorescent lamps break-up as a maintenance routine.

8 W 18 W and 22 W are used in the rooms at the residential blocks, 24 W and 26 W do exist but they are relatively fewer in the blocks and offices. 8 W LED lamps are the most common at the residential blocks, they are the only type of lamps used for outdoor lighting above doors at residential and office building. They are also fitted in the rooms of the newer blocks. 18 W, 22 W and 24 W are also observable in the new blocks, again, 24 W and a few of 26 W in large facilities like the kitchen, gymnasium and the laundry.

OPPORTUNITIES

During the counting of bulbs, it was observed that occupants frequently leave the lights on, an average of 36% of rooms were left lit during the day for the three days of bulb profiling. Blocks that have side and front outdoor bulbs above doors are usually left switched on 24 hours with no one bothering to attend their control. Some of the new blocks do not have outdoor lights, these were constructed after the erection of apollo towers with lambs that light the mine site at night. However, old blocks close to these new blocks have not been outdoor de-lamped. Their outdoor lights are often left switched on as a consequence of negligence. It was surprising that some blocks which are identical in terms of structural properties and design we fitted with LEDs of differing wattages, most are installed with 8 W LEDs but some 18 W, 22 W and some 24 W.

INTERVENTIONS

Major measures taken to conserve lighting energy include managing the lighting hours in a day when it is necessary for lights to be on, de-lamping light bulbs that are deemed unnecessary and replacing inefficient or higher wattage lamps with lower wattage lamps which could give necessary light intensity for the space they are meant to light.

For the residential blocks, only 8 W lamps are used in the rooms and outdoor for blocks not in the vicinity of apollo lights. Ninety one (8 W) outdoor lamps were removed which are in the proximity of apollo lighting. In other facilities and offices, the only lamps used are 8 W and 18 W. In the plants, some lamps which operate 24 hours a day are to be dimmed during the day hours so that they do not always consume energy to their maximum capacity as only half of their light intensity is required and the rest is complemented by natural light. So, on *Table 11* the lamps in the plants are shown in the blue box, these represent those bulbs which operate 4380 hours in a year (12 hours a day) to their maximum potential, the same bulbs are denoted again in a grey color to show that for the other 4380 hours of the year they are dimmed (another 12 hours a day).

The use of light intensity sensors for outdoor lamps on the buildings and for apollo lights will be adopted to assist in achieving the minimum hours when light is considered inadequate for lighting. Occupancy sensor switches in the rooms are necessary to ensure that lights are on when there are people inside the rooms and they switch off automatically once the rooms are vacated. *Table 10* shows the current scenario before lighting energy management interventions while *Table 11* was constructed after lighting energy management interventions of de-lamping, dimming, replacement of bulbs with more energy efficient ones and installation of sensor switches to correctly match the hours of daily lighting which are presented on *Table 11*.

SAVINGS AFTER LIGHTING ENERGY MANAGEMENT INTERVENTIONS

The amount of energy used for lighting in 2019 is shown on *Table 10* as 3510536 kWh. As a result of lighting energy management interventions, the annual energy used would have been 2476236 kWh as seen on *Table 11* which is much less than the former value. The difference between the two energy values which is 1034300 kWh is the annual energy saved from lighting. Since the utility charges $0.0171 per kilowatt hour of energy used, then the savings translate to annual savings of $17 668.72 from lighting only.

Figure 13 shows the frequency distribution of peak demand occurrence over the hours of the day. Peak demand seemingly occurs only in the morning and evening hours from 04:00 hours to 07:00 hours and 19:00 hours to 22:00 hours respectively even though a greater frequency belongs to the morning hours. It is important to note that at these times, most of the bulbs are expected to be on expect a small fraction of lamps inside the offices. Almost all facilities operate 24 hours but even those that do not are open at these times like the kitchen and the gymnasium. At the residential blocks in those morning hours occupants prepare to go to work and they are usually not asleep in the evening hours until 22:00 hrs.

Therefore, on both *Table 10* and *Table 11* the total on the column showing the Power (kW) represents a condition during peak times except that for *Table 10* where 1.6 kW of indoor office lights is subtracted as they would be off. The difference between the two totals from the two tables in kilowatts represents peak power shaving by 11. 486 kW which can automatically be estimated to 11.486 KVA as LED lamps load exhibit properties of a resistive load. This is the lighting power's contribution to the monthly peak demand and because peak demand is charged $18.21 per KVA monthly; the savings in monetary terms amount to $209.17. This amount is multiplied by 12 to get annual savings of $2,510 since it influences peak monthly demand charge.

Adding the total annual energy saving with the total peak demand savings gives annual savings of $20,178.73.

Table 10: current scenario of the lighting energy processes

	Lamp Type	Quantity	Rating W	Power kW	Operating hours	Energy kWh
Residential Blocks	LED Compact	1685	8	13.48	4380	59042
	LED tube	120	18	2.16	4380	9461
	LED tube	136	22	2.992	4380	13105
	LED tube	30	24	0.72	4380	3154
	LED tube	3	26	0.078	4380	342
	Fluorescent tube	114	36	4.104	4380	17976
	Fluorescent tube	80	58	4.64	4380	20323
Kitchen	LED Compact	12	8	0.096	6570	631
	LED tube	246	24	5.904	6570	38789
	Fluorescent tube	32	58	1.856	6570	12194
Gymnasium	LED Compact	7	8	0.056	1825	102
	LED tube	24	24	0.576	1825	1051
Laundry	LED Compact	1	8	0.008	8760	70
	LED tube	14	24	0.336	8760	2943
Clinic	LED Compact	28	8	0.224	8760	1962
	LED tube	44	24	1.056	8760	9251
All Offices	LED Compact	205	8	1.64	4380	7183
	LED tube	86	18	1.548	4380	6780
	LED tube	165	22	3.63	4380	15899
	LED tube	118	24	2.832	4380	12404
Plants	LED	398	15	5.97	3650	21791
	LED	281	17.5	4.9175	3650	17949
	LED	440	125	55	8760	481800
	LED	498	150	74.7	8760	654372
	LED highbay	305	200	61	8760	534360
	LED	423	400	169.2	8760	1482192
Apollo Lights	LED	60	300	18	4745	85410
TOTAL		**5555**		**436.7235**		**3510536**

Table 11: scenario after lighting EMOs interventions

	Lamp Type	**Quantity**	**Rating W**	**Power kW**	**Operating hours**	**Energy kWh**
Residential Blocks	LED Compact	2077	8	16.616	2555	42454
Kitchen	LED Compact	2	8	0.016	4015	64
	LED tube	278	24	6.672	4015	26788
Gymnasium	LED Compact	7	8	0.056	1825	102
	LED tube	24	24	0.576	1825	1051
Laundry	LED Compact	1	8	0.008	4380	35
	LED tube	14	24	0.336	4380	1472
Clinic	LED Compact	13	8	0.104	4380	456
	LED tube	44	24	1.056	4380	4625
All Offices	LED Compact	175	8	1.4	3650	5110
	LED tube	86	18	1.548	3650	5650
	LED tube	165	22	3.63	3650	13250
	LED tube	118	24	2.832	3650	10337
Plants	LED	398	15	5.97	3650	21791
	LED	281	17.5	4.9175	3650	17949
	LED	440	125	55	4300	236500
	LED	498	150	74.7	4380	327186
	LED highbay	305	200	61	4380	267180
	LED	423	400	169.2	4380	741096
	LED	498	75	37.35	4380	163593
	LED highbay	305	100	30.5	4380	133590
	LED	423	200	84.6	4380	370548
Apollo Lights	LED	60	300	18	4745	85410
TOTAL		**5409**		**423.6375**		**2476236**

Table 12 shows the difference in the number of bulbs between *Table 10* (scenario 1) and *Table 11* (scenario 2). The negative difference means that more bulbs of that type would need to be purchased to achieve the investment in scenario 2 while the positive difference denotes excessive bulbs that will be kept for replacing burned out lamps.

Table 12: difference of bulbs between the two scenarios

	8W	15W	17.5W	18W	22W	24W	26W	125W	150W	200W	300W	400W
scenario 1	1937	398	281	206	301	476	3	440	498	305	60	423
scenario 2	2275	398	281	86	165	478	0	440	498	305	60	423
Difference	-338	0	0	120	136	-2	3	0	0	0	0	0

4.6 SPACE HEATING

CURRENT SCENARIO

All the concrete built halls of residence, facility and office apartments are installed with 1.5 kw underfloor heaters per room. The residential and office rooms are relatively small as they are about 3m by 3m by mere observation. In residential places and offices which are not concrete built, 3000 W oil heaters are for safety considerations as these apartments are mostly park-homes which bear a risk of catching fire. In some facilities like the gymnasium 2500 W bar heaters are mounted on the wall because underfloor heaters could not be installed as some equipment is mounted on the floor and oil heaters would occupy the space needed for exercising in the gymnasium.

OPPORTUNITIES

Underfloor heaters operate even when rooms are vacant in offices and accommodation rooms. All underfloor heaters on site are preset to operate for 18 hours a day once they are switched on. Each underfloor heater is controlled by a local switch. The control system is deceivable as occupants are able to make heaters operate 24 hours a day by switching the heater on and off immediately so that it starts afresh a count of up to 18 hours. When leaving the rooms for work, employees deliberately leave the rooms heating so that they find them warm when they get back, this also happens when they vacate their offices. The 2500 W radiation bar heaters and 3000 W oil heaters are significantly old and were purchased before better insulated accommodation rooms were built.

INTERVENTIONS

One central control system for each block and facility is proposed so that heaters under one apartment are switched on simultaneously. This is complemented by the fact that people working under one roof have similar hours of work. The employees are also allocated the same blocks by a criterion that they have similar work shifts and leave schedules to allow for maintenance and cleaning; this also complements the use of a sole central switch in residential blocks. It therefore helps save significant energy when all the people within a block jointly leave the block for a few leave days. The 3000 W oil heaters will be replaced by 2000 W oil heaters, 2500 W bar radiator heaters will be replaced by 1200 W halogen bar heaters. It is proposed that operation of heaters be cut from 18 hours to 7 hours which is four in the evening (between 5 pm and 9 pm) and three in the morning (between 5 am and 8 am), it is proposed that electric blankets be purchased for employees to be used when occupants are asleep between 9 pm and 5 am. Electric blankets have a wattage of about 200 W.

SAVINGS AFTER SPACE HEATING ENERGY MANAGEMENT INTERVENTIONS

For savings derived from the energy charge (kWh) used over the year as shown by the difference between the two values from *Table 13* and *Table 14*. The difference shows that after interventions, annual savings of 5389959.5 kWh will be achieved. This translates to monetary value of $92,075.5.

For savings derived from monthly peak demand, *Table 13* and *Table 14* are scrutinised on the total kW based on the hours of peak occurrences as illustrated by the frequency histogram on *Figure 13***.** Since *Table 13* shows what used to happen before interventions, the total kW will be used as it is presumed from evidence that heaters were negligently on in the hours of peak demand occurrence. However, to find the impact of the presumed interventions, the total on *Table 14* which shows heating energy use after interventions will be considered but first a subtraction representing office heating power will be made because it does no contribute to peak demand as offices would be vacant in the morning and or evening hours of peak occurrence.

Therefore, the peak monthly demand savings will be calculated as:

$$1462.5kW - (1186.7Kw - 18kW - 18kW) = 239.8kW$$

Because the heating load is purely resistive, the power savings of 239.8 kW can also be deemed to be exactly 239.8 KVA. Therefore, as governed by the peak demand charge monthly, these savings translate to a value of $4,366.91 which will be $52,402.92 annually.

The total annual savings together from energy and peak demand add up to $144,478.42.

Table 13: current scenario of space heating energy processes

	Heater type	Wattage	Quantity	Daily hours of operation	KW	Annual hours of operation	Annual kWh
Residentials	Underfloor	1500	509	20	763.5	7300	5573550
	Oil heater	3000	62	24	186	8760	1629360
All offices	Underfloor	1500	88	18	132	6570	867240
	Oil heater	3000	17	18	51	6570	335070
Plant offices /24 hour shift	Underfloor	1500	130	24	195	8760	1708200
	Oil heater	3000	23	24	69	8760	604440
Gymnasium	Halogen radiator	2500	6	18	15	6570	98550
Laundry	Underfloor	1500	3	24	4.5	8760	39420
Clinic	Underfloor	1500	13	24	19.5	8760	170820
Kitchen	Underfloor	1500	18	16	27	5840	157680
Total					**1462.5**		**11184330**

Table 14: scenario after space heating EMOs interventions

	Heater type	Wattage	Quantity	Hours of operation/day	KW	Hours of operation/ year	Annual kWh
Residentials	Underfloor	1500	509	7	763.5	2555	1950742.5
	Oil heater	2000	62	7	124	2555	316820
	Electric blankets	200	816	8	163.2	2820	460224
All offices	Underfloor	1500	88	10	132	3650	481800
	Oil heater	2000	17	10	34	3650	124100
Plant officies /24 hour shift	Underfloor	1500	130	24	195	8760	1708200
	Oil heater	2000	23	24	46	8760	402960
Gymnasium	Halogen radiator	1200	6	8	7.2	2920	21024
Laundry	Underfloor	1500	3	24	4.5	8760	39420
Clinic	Underfloor	1500	13	24	19.5	8760	170820
Kitchen	Underfloor	1500	18	12	27	4380	118260
Total					**1186.7**		**5794370.5**

4.7 SOLAR WATER HEATING

CURRENT SCENARIO

Hot water at the mine is currently heated using bought electricity. For the year 2019, 908913.9 kWh electrical energy was used only for water heating.

OPPRTUNITIES

Take advantage of solar water heating which uses free solar energy and reduce the amount of energy used for water heating depending on the performance of solar water heater on the site.

INTERVENTIONS

Install Solar Water heaters.

SAVINGS FROM SOLAR WATER HEATING ENERGY MANAGEMENT INTERVENTIONS

*Figure 20***,** shows that Solar Fraction *(SF)*, Storage *(V_s)* and Net Present Value *(NPV)* change as a function of the total area of collectors in order to heat water to a load temperature *(Tload*) of 55°C at Lets'eng site. It helps in making a rationale design decision as the area of collectors has to be chosen at a point corresponding to the highest *NPV* regarded as the optimal area. In this case, the optimal area is 1000 m^2. At this point, the Solar Fraction is 91.8%. It is worth observing that increasing the collector area beyond 1000 m^2 would increase the Solar Fraction but unfortunately the Net Present Value diminishes beyond 1000 m^2 hence it is the optimal point.

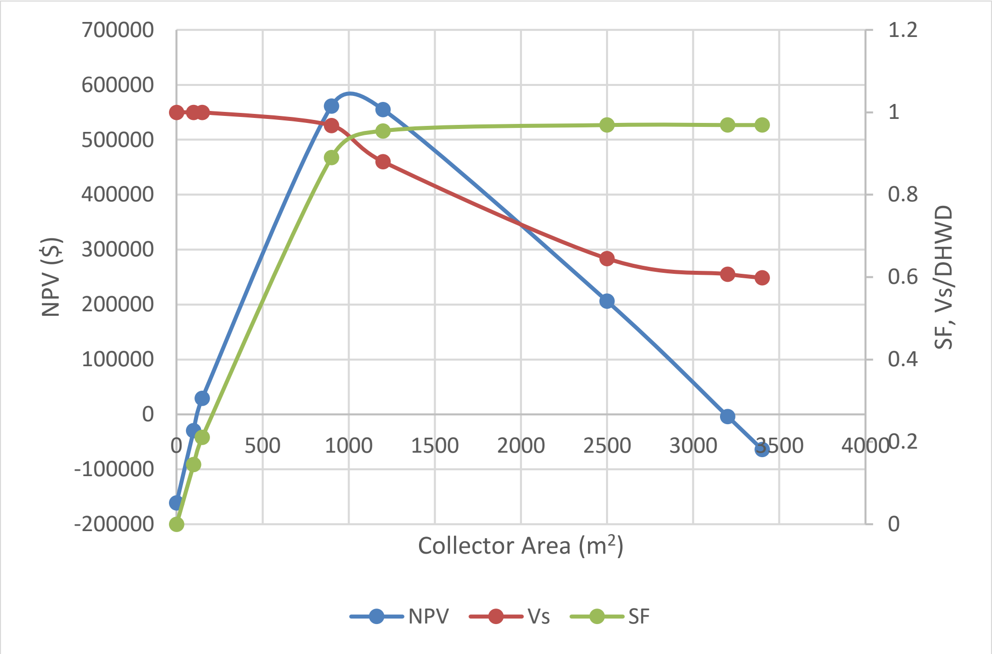
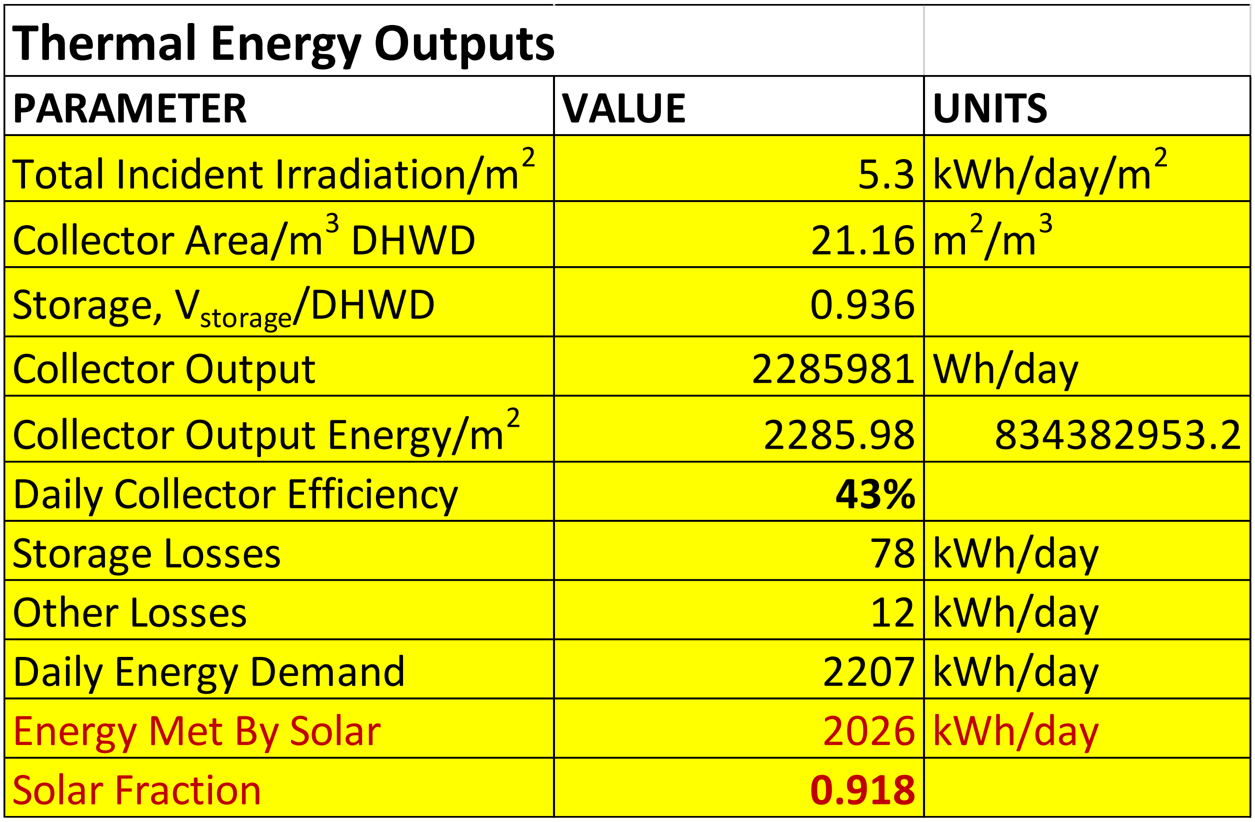


Figure 20: determination of an optimal collector area

Table 15: thermal energy outputs of the solar water heater



Thermal Energy Outputs

PARAMETER	VALUE	UNITS
Total Incident Irradiation/m^2	5.3	kWh/day/m^2
Collector Area/m^3 DHWD	21.16	m^2/m^3
Storage, $V_{storage}$/DHWD	0.936	
Collector Output	2285981	Wh/day
Collector Output Energy/m^2	2285.98	834382953.2
Daily Collector Efficiency	**43%**	
Storage Losses	78	kWh/day
Other Losses	12	kWh/day
Daily Energy Demand	2207	kWh/day
Energy Met By Solar	2026	kWh/day
Solar Fraction	**0.918**	

Table 16: inputs of the solar water heater model

PARAMETER	VALUE	UNIT	PARAMETER	VALUE	UNIT
Average month	June	[-]	Collector FRUL	3.92	W/m2°C
Latitude	-28.988	Degrees	Tank heat loss	2.5	W/m2/°C
Longitude	28.86	Degrees	Electric heat efficiency	75	%
Collector tilt	33.988	Degrees	Collector cost	220	$/m²
Horizontal irradiation	12.6	kWh/m²/day	Tank cost	2000	$/m³
Diffuse irradiation		kWh/m²/day	installation/capital cost	12 909	%
Maximum monthly Ta	19.7	˚C	maintenance/capital cost	1	%
Minimum monthly Ta	8.9	˚C	Electricity price	0.1	$/kWh
Daily hot demand	47250	litres	Interest rate	11	%/annum
Tmains	15	˚C	Inflation rate	4	%/annum
Tload	55	˚C	Collector warranty period	10	years
Collector Frta	0.739		Economic time horizon	20	years

4.8 ECONOMIC AND ENVIRONMENTAL ANALYSIS

4.8.1 Investments in Power Factor Correction

For power factor correction, capacitors have to be procured to the site and installed by a reputable contractor. VSD devices will also have to be incorporated to ensure the load sizing. There are large industrial capacitor bank units suitable for industries in the market that are rated 100 kvar. The sizing of these capacitors is suitable as they could be clustered to form a larger bank if reactive power compensation of such magnitude is necessary, it is also flexible if a smaller capacitor needed for a smaller target individual load in the plant. A total of 4899 kvar from the four feeders (plant1, plant 2, south feeder and PCA) has to be considered for compensation. Therefore, 490 units of 100 kvar capacitors are necessary to effectively improve power factor to 0.95. A target of 89 machines of different sizes will have to be mounted with VSD devices.

The cost of procuring a 100 kvar capacitor to the site is estimated to $5,533.44 hence the total cost of 490 units of 100 kvar capacitors to the site will be $2,352,000.00. The total procurement of VSDs will amount to $355,250.00. Their total cost will therefore amount to $2,707,250.00. The contract value due to the consultancy company for the installation of the capacitors and VSDs is estimated to be 60% of the cost of procuring the capacitors and VSDs. The total amount of the installations together with the charge of procuring equipment will finally be $4,331,600.00. This value is the capital on investment and it is the cash outflow in year zero on the investment. The investment analysis is based on the capacitors' and VSDs lifetime which is about fifteen years [56].

From the year 2019, it was observed from *Table 8* that annual savings if the power factor was corrected would have amounted to $405,769.36. This money is the cash inflow for the first year and it was assumed that these savings would increase by 10% annually as the electricity prices also increase. Other general expenses were assumed to be 0.2% annually also calculated from the value of purchasing the capacitors. Maintenance is 1% of the cost of purchasing capacitors and VSDs after every three years excluding the final year.

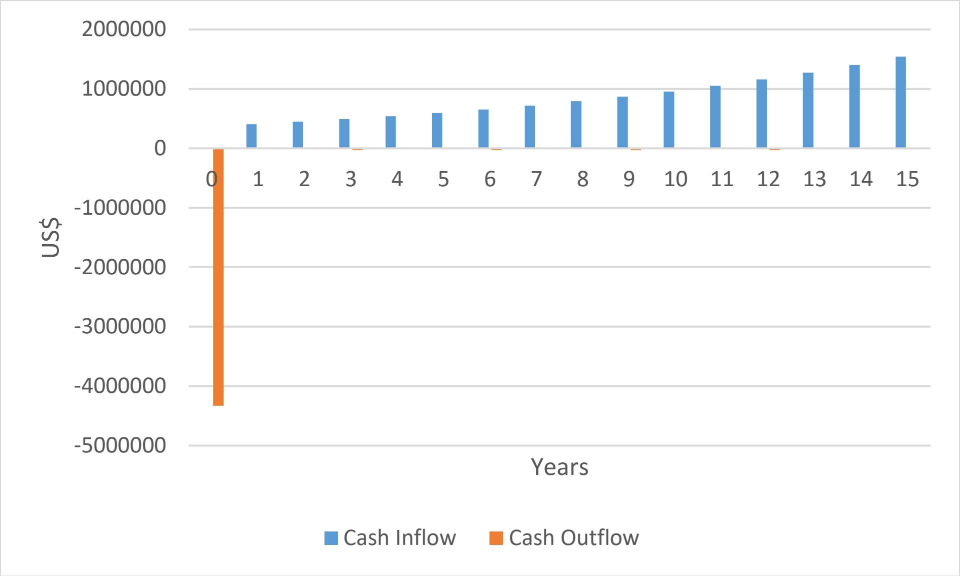


Figure 21: cash flows for power factor improvement investment

Table 17: cash flows for power factor improvement investment

Year	Cash Inflow ($)	Cash Outflow ($)	NCF ($)	Present Values ($)	Cumulative Present Values ($)
0	0	-4331600	-4331600	-4331600	-4331600
1	405769	-5415	400355	366290	-3965310
2	446346	-5415	440932	369089	-3596221
3	490981	-32487	458494	351134	-3245087
4	540079	-5415	534665	374628	-2870459
5	594087	-5415	588672	377375	-2493084
6	653496	-32487	621009	364231	-2128853
7	718845	-5415	713431	382834	-1746019
8	790730	-5415	785315	385552	-1360467
9	869803	-32487	837316	376104	-984363
10	956783	-5415	951368	390973	-593390
11	1052461	-5415	1047047	393681	-199709
12	1157707	-32487	1125220	387075	187366
13	1273478	-5415	1268064	399097	586464
14	1400826	-5415	1395411	401809	988273
15	1540908	-5415	1535494	404525	1392798
NPV				**1392798**	

An investment in power factor correction is acceptable since it achieved a positive net present value of $1392798 and a cumulative payback period of 11 years and 7 months which falls within 2034 which is the year the life of the mine is expected to run until.

4.8.2 Investments in Lighting

Table 18 shows description of new equipment required for energy management interventions in lighting together with their quantities and costs. The total initial investment cost for undertaking energy management opportunities in lighting is $72,916.00.

Table 18: purchased new lighting equipment and costs

Lighting component	**Quantity**	**Unit Price ($)**	**Total Price ($)**
Light sensor switches	42	8	336
Occupancy sensor switches	981	30	29469
8w LED bulbs	338	2	564
24w LED Bulbs	2	5	9
8w Fixtures	338	2	790
24w Fixtures	2	11	21
Dimmable LED bulbs 150	498	20	9973
Dimmable LED bulbs 200	305	30	9162
Dimmable LED bulbs 400	423	53	22590
Total Investment Cost			**72916**

[57],[58]

The investment aimed at achieving energy management opportunities in lighting is based on the life of occupancy and light sensor switches which is ten years [40]. Within the ten years some bulbs will have to be replaced as they would have reached the 50 000 hours of operation as their life in years differs as a consequence of being operational over the year by distinguished number of hours as shown in *Figure 22***.** The cost of one bulb depending on their wattages is shown on *Table 19* [58].

Table 19: bulbs to be replaced after ten years

LED BULB Wattages	price ($)
8	1.668892
18	4.00534
22	4.339119
24	4.672897
15	3.671562
17.5	4.00534
125	20.0267
150	20.0267
200	30.04005
300	40.0534
400	53.40454

[59]

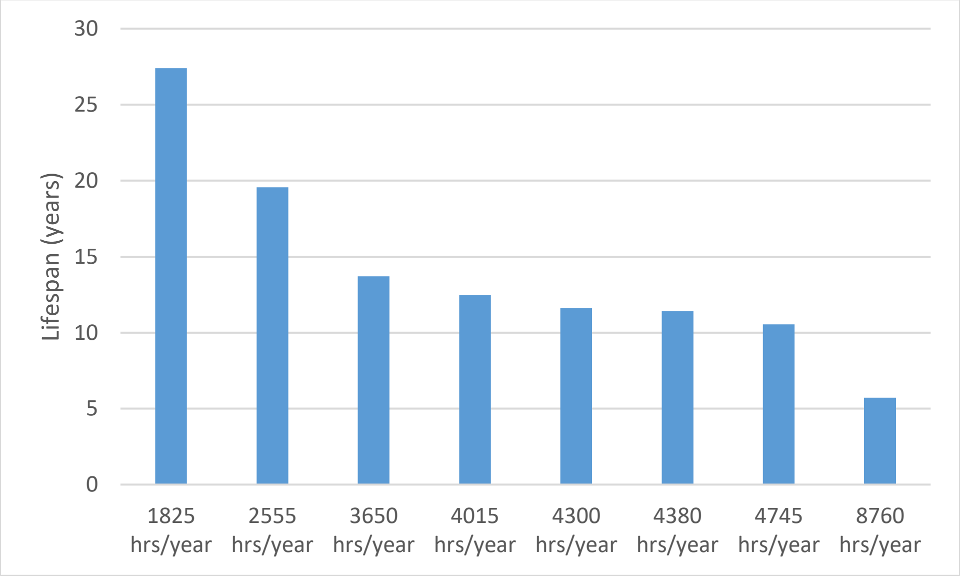


Figure 22: lifespan of bulbs depending on the hours they operate in a year

These bulbs are grouped by the number of hours they operate in a year on *Figure 22*. It is important to note that within the ten years of the investment which is based on the live of sensors, only on the sixth year will the replacement of bulbs take place while the other bulbs will not be replaced as their life lapses beyond the investment period. Therefore, a cash outflow will only be seen on the sixth year.

Table 20: life of bulbs for replacement

Operational hours/year	Wattage	Quantity	Life (years)	Cost of replacement ($)
1825	8,24	7,24	27	124
2555	8	2077	20	3466
3650	8,18,22,24,15.17.5	175,86,165,118,398,281	14	4491
4015	8,24	2,278	12	1302
4300	125	440	12	8812
4380	8,24	14,58	11	294
4745	300	60	11	2403
8760	150,200,400	498,305,423	6	41726

[59]

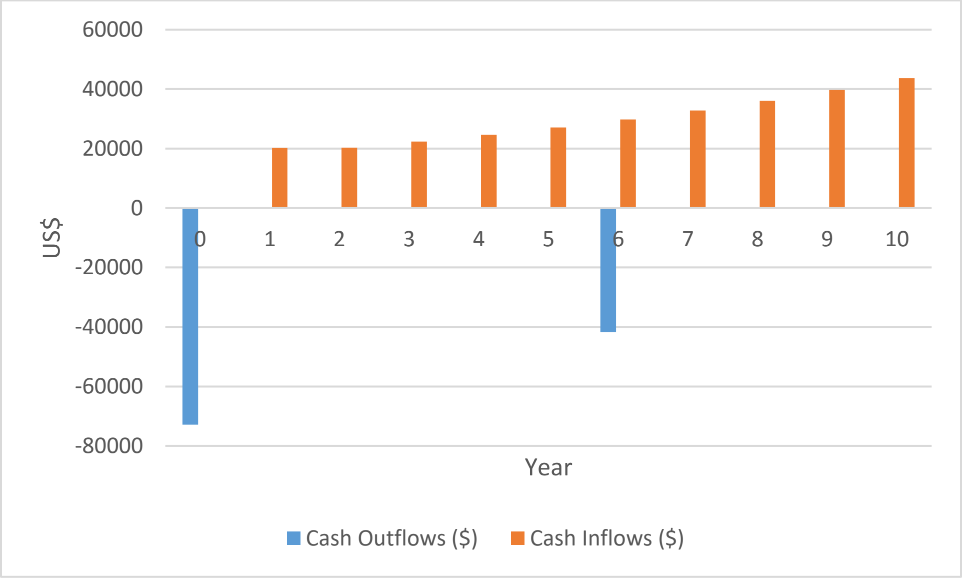


Figure 23: cash flows for lighting EMOs investment

Table 21: cash flows for the lighting EMOs investment

Year	Cash Outflows ($)	Cash Inflows ($)	NCF ($)	Present Values ($)	Cumulative Present Values ($)
0	-72916	0	-72916	-72916	-72916
1		20179	20179	19993	-52923
2		20381	20381	20007	-32916
3		22419	22419	21805	-11112
4		24660	24660	23764	12652
5		27126	27126	25900	38552
6	-41726	29839	-11887	-11244	27307
7		32823	32823	30764	58071
8		36105	36105	33528	91599
9		39716	39716	36541	128140
10		43687	43687	39825	167965
NPV				**167965**	

Energy management interventions in lighting are worth implementing as their economic assessment resulted in a positive Net Present Value of $167965 and a cumulative payback period of 3 years 6 months.

4.8.3 Investments in Space Heating

Table 22 shows the initial investment costs undertaken in heating Energy Management Opportunities. The number of electric blankets does not coincide with the number 816 used for water heating energy modelling in chapter 3. This is because there are 1020 employees on site but there can only be a maximum of 816 on site due to leave schedules, therefore the solar water heating system was designed for a maximum of 816 people. 1.5 kW underfloor heaters were installed in 2018 before the energy audit that is why the cost of their purchase is excluded here.

Table 22: space heating retrofits and their costs

Desciption	Quantity	Life (Years)	Unit Price ($)	Total Price ($)
1200w Halogen bar heater	6	8	27	160
2000w Oil heater	102	18	40	4085
Timer Switches	84	10	27	2299
Electric blankets	1020	7	23	23827
Total				**30372**

[60]

It is evident that space heating energy management interventions provide the best results relative to the cost of implementation as the cash flows show that outflowing cash is too little against the monetary savings acquired from interventions as observed from *Figure 24.* Replacement of electric blankets after seven is the only significant cost that will be encountered over the life of the investment even though it is still little to offset more money from energy savings.

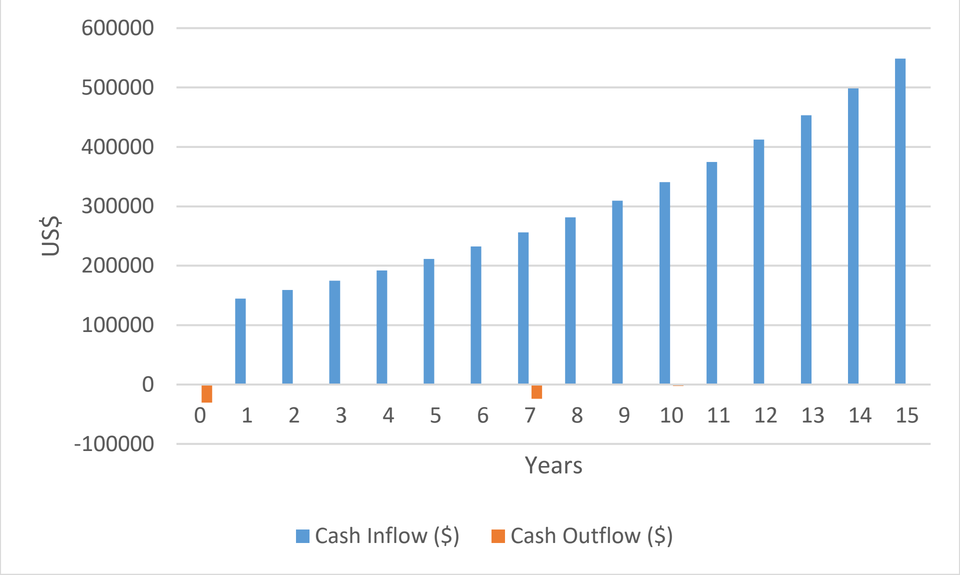
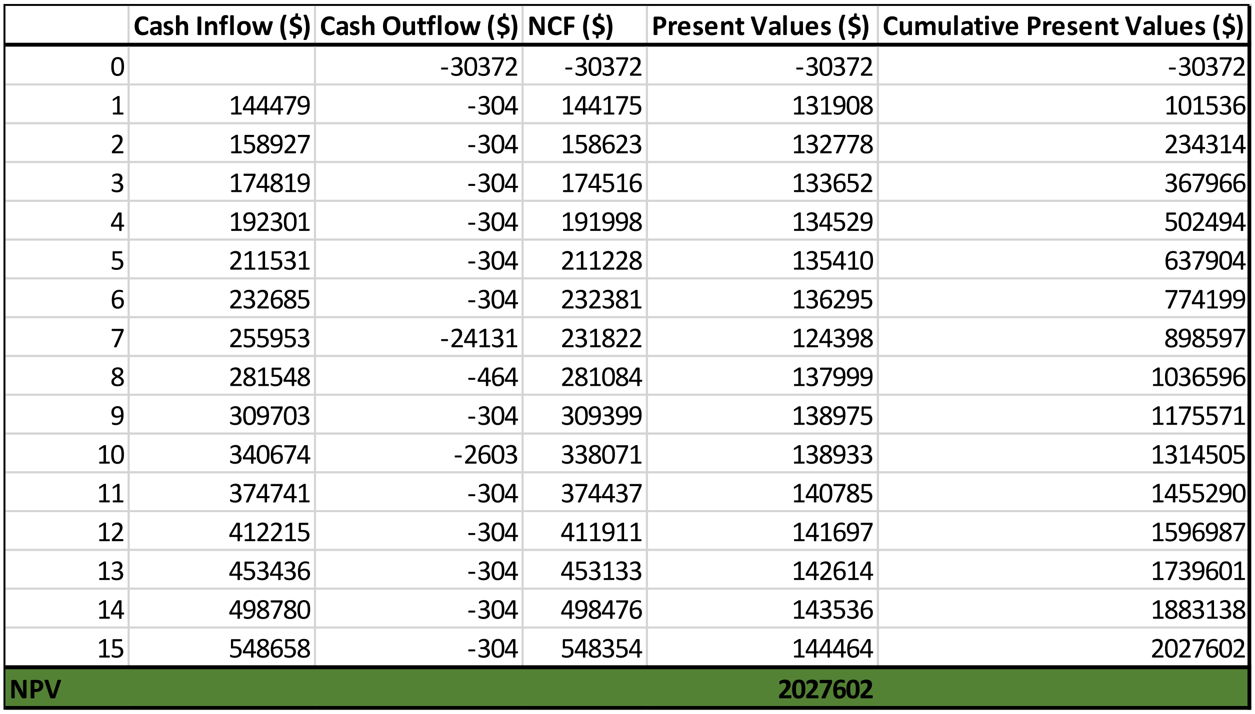


Figure 24: cash flows for space heating EMOs investment

Table 23: cash flows for space heating EMOs investment

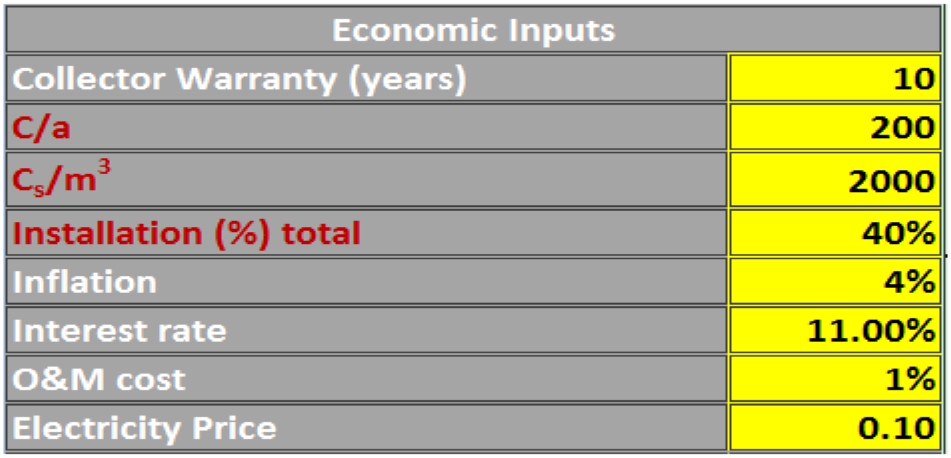


	Cash Inflow ($)	Cash Outflow ($)	NCF ($)	Present Values ($)	Cumulative Present Values ($)
0		-30372	-30372	-30372	-30372
1	144479	-304	144175	131908	101536
2	158927	-304	158623	132778	234314
3	174819	-304	174516	133652	367966
4	192301	-304	191998	134529	502494
5	211531	-304	211228	135410	637904
6	232685	-304	232381	136295	774199
7	255953	-24131	231822	124398	898597
8	281548	-464	281084	137999	1036596
9	309703	-304	309399	138975	1175571
10	340674	-2603	338071	138933	1314505
11	374741	-304	374437	140785	1455290
12	412215	-304	411911	141697	1596987
13	453436	-304	453133	142614	1739601
14	498780	-304	498476	143536	1883138
15	548658	-304	548354	144464	2027602
NPV				**2027602**	

Investments in Space Heating are very attractive and are therefore highly encouraged. They yield a Net Present Value of $2027602 and a cumulative payback of just 3 months.

4.8.4 Investments in Solar Water Heating

Table 24: economic inputs to the model

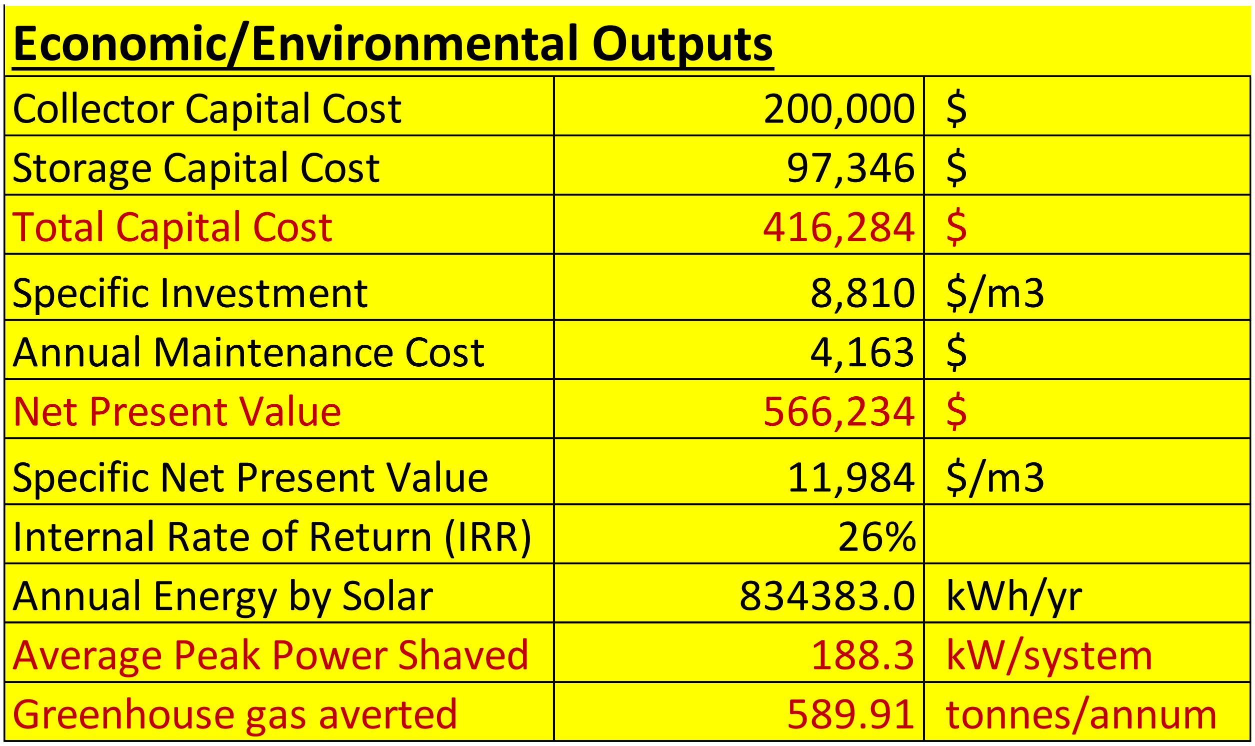


Economic Inputs	
Collector Warranty (years)	10
C/a	200
C_s/m^3	2000
Installation (%) total	40%
Inflation	4%
Interest rate	11.00%
O&M cost	1%
Electricity Price	0.10

Table 24 shows the prices of components of the solar heating system, the cost of a collector per m^2 *(C/a)*, Storage cost per Cubic metre, (C_s/m^3), and economic parameters such as installation cost to acquisition of equipment ratio, inflation, interest rate, operation and maintenance cost *(O&M cost)*, and the price of electricity. Environmental, meteorological characteristics of the site and performance parameters of the collector are given in *Table 16*.

Economic and environmental outputs are displayed by the model on *Table 25* after computation using inputs from *Table 16* and *Table* 24.

Table 25: Economic and environmental results from the model



Economic/Environmental Outputs		
Collector Capital Cost	200,000	$
Storage Capital Cost	97,346	$
Total Capital Cost	416,284	$
Specific Investment	8,810	$/m3
Annual Maintenance Cost	4,163	$
Net Present Value	566,234	$
Specific Net Present Value	11,984	$/m3
Internal Rate of Return (IRR)	26%	
Annual Energy by Solar	834383.0	kWh/yr
Average Peak Power Shaved	188.3	kW/system
Greenhouse gas averted	589.91	tonnes/annum

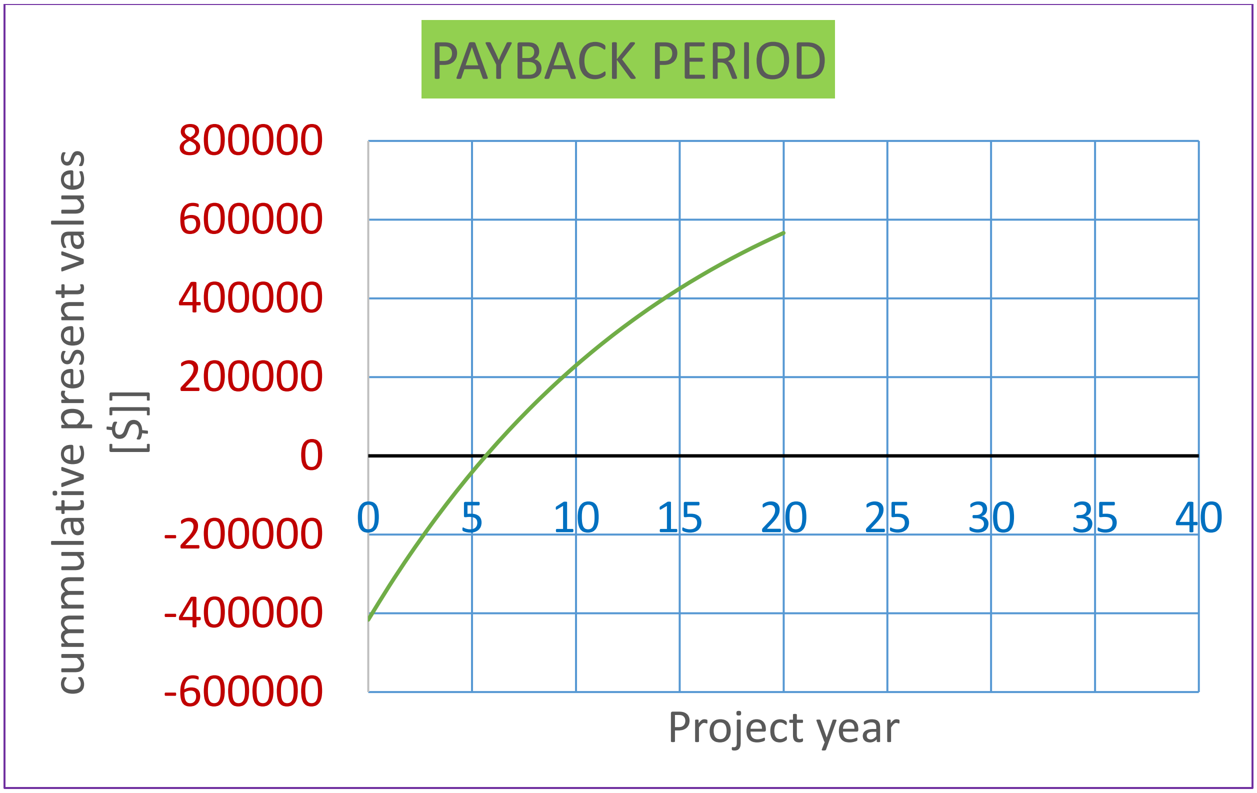


Figure 25: computation of payback period

Investments in Solar Water Heating are economical viable with a Net Present Value of $566234 and a cumulative payback period of 6 years.

4.9 ENVIRONMENTAL ANALYSIS

Power Factor Improvement

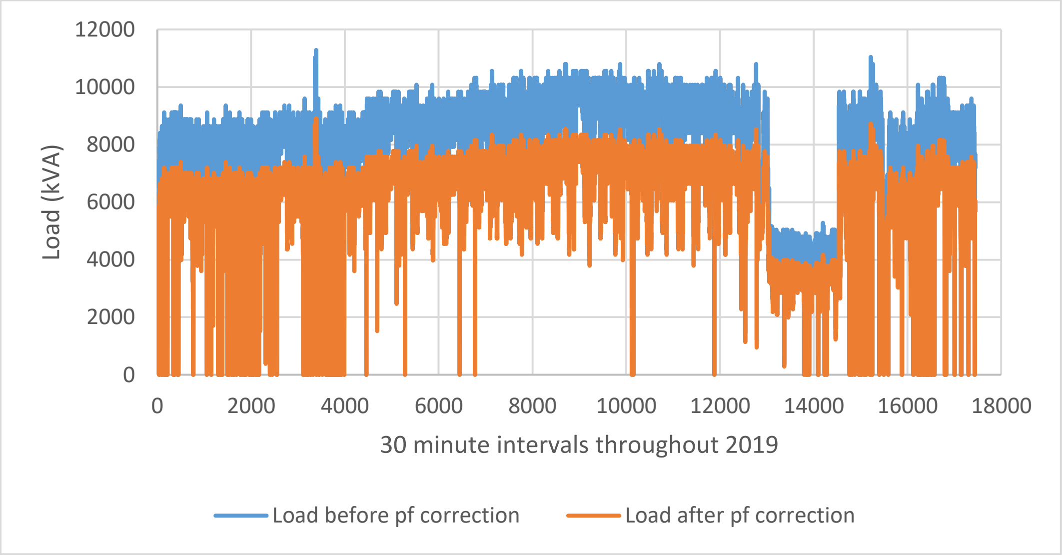


Figure 26: Mine's load comparison based on power factor

The mine used electrical energy of 69185590 kvah or 68337251 kWh. This discrepancy is brought by the power factor not being one at the power station where it is incoming. The 0.99 proportion of kWh to kvah represents the average power factor at the sub station for the period of 2019. If power factor correction to 0.95 in the four feeders was undertaken prior, time to time demand of power for the mine would have been different as witnessed on *Figure 26*, it would have dropped significantly. The annual energy used would have been 52535600 kvah which could be corrected to 52010244 kWh if the power factor at the sub station is still not improved. Energy savings of 52010244 kWh therefore have associated emissions that would have been avoided. Emissions factor from AVERT is used to quantify emissions that would have been avoided as shown on *Table 26*.

Lighting and Space Heating

Using the emissions factor adopted from AVERT, 731.24 and 3 810.70 tonnes of carbon dioxide were successfully warded off as result of both lighting and space heating EMOs respectively. The fluorescent light bulbs that were replaced with LED bulbs should be sent for recycling as their disposal to the environment brings the risk of contaminating the environment with toxic mercury.

Solar Water Heating

The model by Tawanda Hove used for solar water heating automatically calculates the emissions averted as it is evident from *Table 25*.

Table 26: Averted emissions from energy savings

Process	**Energy Savings (kWh)**	**Emissions averted (Emisisions factor: 7.07 x 10^{-4} tonnes CO_2/kWh**
Power factor improvement	52010244	36 771 tonnes/annum
Lighting	1034300	731.25 tonnes/annum
Space Heating	5389959.5	3 811 tonnes/annum
Solar Water Heating	834383	589.9 tonnes/annum
TOTAL EMISSIONS AVERTED		**41 903.15 tonnes/annum**

4.9.1 DISCUSSIONS

Electromechanical energy conversion in the mine from operation of motors for ore extraction, mineral processing and workshops is responsible for a great deal of energy use within the mine. It accounted for 70% of the mine's total energy use. The most energy saving opportunities were also found from electromechanical energy conversion as a whooping 52010244 KWh savings are realized only from power factor correction. Annual financial savings of $405769.36 were achieved from peak power shaving alone as a result of power factor correction. Power factor correction requires technical interventions and the whole process is capital intensive but the resulting economic outputs make it worth undertaking.

Lighting provides the "low hanging fruit opportunities" for energy management as identification of opportunities and implementation of interventions do not require vast technical expertise. Even though lighting used only 5.1% of the total electrical energy in 2019, 1034300 KWh energy savings is significant considering the ease of implementation and the relatively low cost of investment.

Space heating poses a major challenge to the energy needs of the mine due to the cold climate of the place. Space heating consumed 16.4% of the total energy use (11184330 KWh). Energy savings of up to 5389959 KWh were achieved through energy management. Interventions were not essentially technical. Old higher wattage heaters were replaced with modern heaters which have the same heat output with the heaters being replaced. Complex heating controls which respond to daily weather changes were ignored due to the stochastic nature of Lets'eng's climate which could not meet immediate heating needs of a sudden requirement of heat if necessary.

Solar water heating provides the best energy management opportunities as it substitutes the available electrical energy by integrating free renewable energy sources from solar. The model shows that solar energy was used to substitute electricity by 834383 KWh. Solar water heating is also environmentally good as its integration directly averts fossil fuel emissions.

Shift scheduling

The daily load of the mine shows higher consumption in the morning and evening hours from 0400 hours to 0700 hours and from 2000 hours to 2200 hrs. This is because most of the mining activities which consume the most energy run for 24 hours a day. Higher consumption therefore occurs in the morning and evening when lighting and heating energy becomes necessary and thereby added to the load. Notable savings from peak demand would be realised if production did not run for 24 hours a day, then peak production hours would be eased by shifting some production to leisure hours. Since maximum consumption is brought by addition of lighting and heating energy requirements, shifting of load to achieve notable peak demand is not possible as lighting and heating times are influenced by nature.

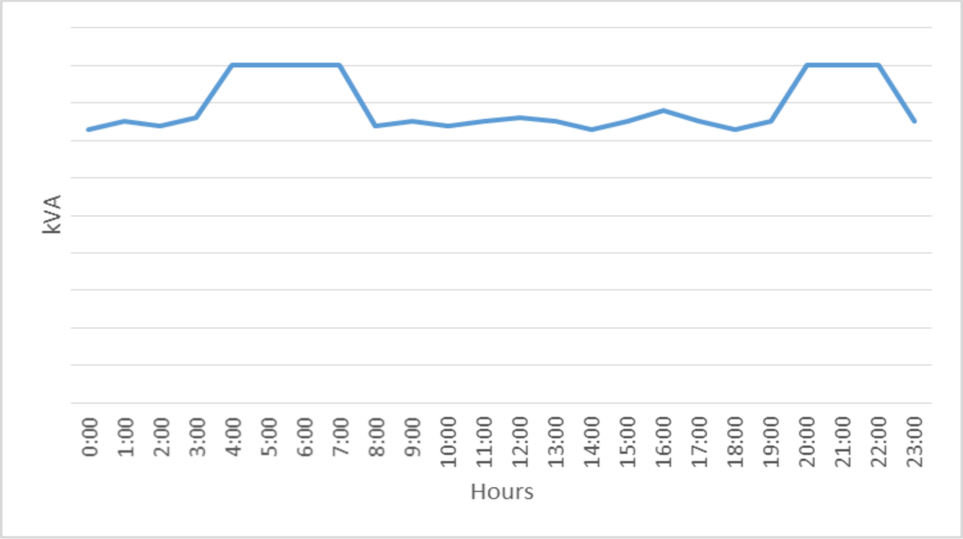


Figure 27: Normal daily load of the mine

Soft Starting

In order to avoid high peak demand as motors start simultaneously post an event of a power cut when the power comes back, it is recommended that a single control that restricts machines from re-starting is installed to ensure that the motors will manually be re-started by personnel in sequence as the employees are always overseeing the plants. Sophisticated control systems that would otherwise be used for automated soft starting control would require higher initial costs to implement and also costs of maintenance that is why a simple manual control is encouraged.

5.0 CONCLUSION

Energy use and power consumption can be managed in an industry but that cannot be accomplished beyond a certain extent. Under this study, an endeavour was to correct high rate of energy consumption that is not necessary and to halt excessive energy use that leads to energy waste. Peak demand charge is more expensive to the energy charge and therefore constituted nearly two thirds of the total electricity costs. The high kVA demand was a consequence of the poor power factor. The capital costs of implementing EMOs at the mine are very high but fortunately they are offset by the great savings derived from implementation of energy management interventions. Investments on power factor correction are worth executing as they yield a positive NPV, and a cumulative payback period of 11 years 7 months.

Motors and other huge machinery in the plants run 24 hours. Peak power consumption consequently occurs in the morning or evening hours when lighting, space heating and water heating loads add to the plants load. It is difficult to disperse shifts from morning and evening peak hours since most of the employees need to go to work in the morning and therefore turn on lights and heaters. Peak times sometimes occur in the evening for some months even though it happens rarely. This is also attributed to employees switching heating and lighting appliances when they get to their residences.

Space heating investments give great returns as the cumulative payback period is accomplished before the lapse of the first year as it realised after only three months. This tells that energy management opportunities cost less to implement against the higher cash inflows resulting from the savings. Lighting energy management interventions give a cumulative payback period of 3 years 6 months. The payback period from lighting interventions is by far longer than that of heating, this is because the annual savings from this interventions are not huge in terms of offsetting the capital costs of the initial year.

The final investment is on solar water heating which substitutes the role of heating water by 91.8% which is the Solar Fraction after installation of solar water heaters. The Solar Fraction simply implies 91.8% of the bathing water requirement was met by solar. The cumulative payback period is 6 years. It is quite longer than space heating for instance because under solar water heating all the equipment was new whereas under space heating there were already energy efficient heaters and only some other devices were bought and a few new heaters. Nonetheless, the annual savings from solar water heating are still high given a 91.8% solar penetration which almost wipes off electricity from water heating.

Renewable Energy penetration amongst the energy management interventions in the study is very minimal as it only appeared in solar water heating. There are constraints that hindered incorporation of RE technologies. The baseload of the mine at 7957 kVA would require building a wind farm of about 40 MW to cover all the mine electricity needs given the 25%-40% capacity factor for onshore African wind power projects [61]. An amount of US$ 1.4 million for a one megawatt turbine[47], and all the other costs associated with the putting in place of a wind farm yield a payback period of a very long time when considering the cash flows that would be gained as avoided annual costs of electricity.

The main challenge to generation of electricity by solar is the spatial are needed for mounting solar panels. To generate a capacity of 1 MW for instance, 3330 panels of 300 watts and dimensions 2m x 1m would cover 6660 m^2 area. Even the roofing area on the site cannot provide this area. Furthermore, to generate electricity of that capacity by solar would only happen at the environmental standard test conditions which rarely occur. As it has been observed that the monthly electricity costs are mainly attributed by peak power demand, solar electricity cannot solve the peak power problem as peak occurs early in the morning or in the evening unless a battery backup is incorporated. Incorporation of a battery backup in a solar project may escalate the cost of a project by over half the project costs.

The limitation of this study on power factor which is, it does not explain thoroughly how the whole intensively technical process of optimally placing capacitors and incorporating VSDs. This limitation can nonetheless be overcome by a completely different independent study that analyses the motor distribution network of the mine and performing simulations to identify the best solution for power factor correction.

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