An integrated energy management strategy for the deep-level gold mining industry

JIG Bredenkamp

21082294

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Promoter: Prof M Kleingeld

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YUNIBESITI YA BOKONE-BOPHIRIMA
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ABSTRACT

Title:	An integrated energy management strategy for the deep-level gold mining industry
Author:	Mr JIG Bredenkamp
Supervisor:	Prof M. Kleingeld
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In recent years, the South African deep-level gold mining industry experienced a rapid decline in gold production figures. Numerous challenges – such as lower ore-grade mining, low commodity prices and higher-than-inflation operating costs – played a crucial part in the production decline. Because of these challenges, gold mining in South Africa has become a marginal operation with very little contribution to the country's gross domestic product.

Most of the abovementioned challenges experienced are beyond the control of the gold mining industry. The expenditure on electricity, which forms part of a gold mine's largest operating costs, is one of the challenges offering large potential for reduction. Although electricity is not the largest capital expense in gold mining, it remains one of this industry's biggest concerns. This is mainly due to electricity prices increasing more than inflation in South Africa and the gold mining industry's electrical intensity for sustainable production.

The challenges in modern day gold mining and the high electricity cost rates present an opportunity for electrical energy management. Effective energy management would help to reduce capital expenditure on the electricity portion of a gold mine's operating costs. In turn, this would contribute to increased profitability and help gold mines to remain operational and competitive within global markets throughout less favourable times.

Research proved that there are no existing energy management strategies in the South African gold mining industry. However, numerous initiatives contributing to the concept of electrical energy management in the gold mining industry were found. The research mainly highlighted the implementation and maintenance of load shifting, peak clipping and energy efficiency projects on the energy-intensive components of gold mines such as pumps, compressors, refrigeration machines, ventilation fans and winders. Energy services companies mainly implemented these projects as part of the Eskom Demand Side Management intervention.

Some studies also focused on ISO 50001-compliant techniques for project implementation, maintenance and energy savings reporting. All of these studies contributed to optimised techniques for implementing energy savings initiatives in the gold mining industry. Combining all of the abovementioned initiatives within a comprehensive energy management strategy for the gold mining industry is, however, a scarce topic in literature.

Therefore, the aim of this study was to develop an integrated energy management strategy (IEMS) for the deep-level gold mining industry. The strategy would serve as a sequenced framework for gold mining groups to practise effective energy management at shaft level and consequently reduce the electrical energy consumption of the entire group. The strategy was also developed to comply with the requirements of the ISO 50001 energy management standard to ensure continual energy performance improvements.

The IEMS was implemented at one of South Africa's largest gold mining groups (Group A). The implementation commenced at Group A's most electricity-intensive mineshaft (Mineshaft B). The sequenced approach of the IEMS provided the energy management team of Mineshaft B with an energy management framework that resulted in an 18.5% electrical energy cost reduction within 12 months (January–December 2015). The improved electrical energy performance accumulated to an annual financial cost saving of approximately R75 million for Mineshaft B.

Due to the positive impact on Mineshaft B's electrical energy performance, the IEMS was expanded to all the other mineshafts of Group A. The IEMS implementation is also ongoing at Mineshaft B as the strategy complies with the continual improvement Plan-Do-Check-Act cycle of ISO 50001. Assuming an 18.5% reduction (Mineshaft B result) at all the other shafts of Group A, an annual financial cost saving of approximately R220 million is possible. However, it is important to note that this figure only applies for the first year after implementation. The IEMS implementation is a continual process and substantial cumulative cost savings are viable.

Keywords: South African deep-level gold mining industry, Challenges, Higher-than-inflation operating costs, Marginal operation, Electrical intensity, Modern day gold mining, Electrical energy management, Competitive, Less favourable times, Concept of electrical energy management, ISO 50001-compliant techniques, Integrated energy management strategy (IEMS), Sequenced framework, Continual energy performance improvements, 18.5% electrical energy cost reduction within 12 months, R75 million, Plan-Do-Check-Act cycle, R220 million

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LIST OF SYMBOLS

Symbol		**Description**
#	-	Denotes a mineshaft: 1# refers to number one shaft
$	-	United States Dollar
A	-	Cross-sectional area
C	-	Discharge coefficient
Cp	-	Specific heat
C_V	-	Flow coefficient
D	-	Distance
f	-	Darcy–Weisbach friction factor
g	-	Gravitational acceleration
h	-	Height
k	-	Specific heat ratio for air
L	-	Length
$\dot{m}$	-	Mass flow rate
n	-	Polytrophic constant
p	-	Pressure
P	-	Electrical power
Q	-	Volume flow rate
R	-	Gas constant for air
T	-	Temperature
v	-	Specific volume
Δp	-	Pressure difference
ΔT	-	Differential temperature
η	-	Efficiency
μ	-	Joule–Thompson coefficient
ρ	-	Density

LIST OF UNITS

Unit		**Description**
°C	-	Degrees Celsius
c/kWh	-	Cents per kilowatt-hour
g/t	-	Gram per tonne
GWh	-	Gigawatt-hour
K	-	Kelvin
K/Pa	-	Kelvin per pascal
kg	-	Kilogram
kg/m^3	-	Kilogram per cubic metre
kg/s	-	Kilogram per second
kJ/kg.K	-	Kilojoule per kilogram Kelvin
km	-	Kilometre
kPa	-	Kilopascal
kW	-	Kilowatt
kWh	-	Kilowatt-hour
kWh/m^3	-	Kilowatt-hour per cubic metre
kWh/Ml	-	Kilowatt-hour per mega litre
kWh/t	-	Kilowatt-hour per tonne
m	-	Metre
m^2	-	Cubic metre
m/s^2	-	Metre per square second
m^3/h	-	Cubic metre per hour
m^3/kg	-	Cubic metre per kilogram
m^3/s	-	Cubic metre per second
Ml	-	Megalitre
MW	-	Megawatt
MWh	-	Megawatt-hour
Pa	-	Pascal
R/kg	-	Rand per kilogram
R/t	-	Rand per tonne
t	-	Tonne

LIST OF ABBREVIATIONS

Abbreviation		**Description**
3-CPF	-	Three-chamber Pipe Feeder
BAC	-	Bulk Air Cooler
CFL	-	Compact Fluorescent Light
COP	-	Coefficient of Performance
CPI	-	Consumer Price Index
DSM	-	Demand Side Management
ECS	-	Energy Conservation Scheme
EEI	-	Energy Efficiency Incentive
EES	-	Energy Efficiency Strategy
EMT	-	Energy Management Team
EnMAP	-	Energy Management Action Plan
EnMP	-	Energy Management Plan
EnMS	-	Energy Management System
EnPI	-	Energy Performance Indicator
ESCO	-	Energy Services Company
FEMP	-	Federal Energy Management Program
GDP	-	Gross Domestic Product
IDM	-	Integrated Demand Management
IEMS	-	Integrated Energy Management Strategy
IGV	-	Inlet Guide Vane
IPMVP	-	International Performance Measurement and Verification Protocol
ISO	-	International Standardization Organization
LED	-	Light Emitting Diode
M&V	-	Measurement and Verification
MCEP-LF	-	Manufacturing Competitiveness Enhancement Programme Industrial Financing and Loan Facilities
MCEP-PI	-	Manufacturing Competitiveness Enhancement Programme Production Incentives
NCPC	-	National Cleaner Production Centre
NERSA	-	National Electricity Regulator of South Africa
OECD	-	Organisation for Economic Co-operation and Development
PCM	-	Performance-centred Maintenance
PDCA	-	Plan-Do-Check-Act
REMS	-	Real-time Energy Management System
SANS	-	South African National Standards
SCADA	-	Supervisory Control and Data Acquisition
TOU	-	Time-of-use
VSD	-	Variable Speed Drive

CHAPTER 1

[1]

"Confidence does not come out of nowhere. It is a result of something … hours and days and weeks and years of constant work and dedication." – Roger Staubach

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[1] http://www.constructionweekonline.com/article-24033-omans-electricity-output-rises-by-64-in-2013.

1 INTRODUCTION AND BACKGROUND

1.1 The South African gold mining industry

1.1.1 Productivity and influence to the economy

The mining industry remains a very sensitive topic when considering the future growth and sustainability of the South African economy. Not only does the mining industry provide employment to over a million South Africans, but it also plays a crucial part in South Africa's export revenue and foreign exchange earnings [1]. Therefore, it is important for the South African mining industry to sustain its contribution to the economy and ensure a stable future for the country.

The magnitude of the mining industry's contribution to the South African gross domestic product (GDP) has declined over the years. The contribution declined from 21.3% of GDP in 1970 to 4.9% of GDP in 2013 [1], [2]. One of the contributing factors to the negative trend can be ascribed to the significant decline in mineral production over this period. The gold mining sector alone, one of the South African mining industry's largest financial contributors, experienced a major decline in its production output [3]. The production of gold declined from 675 tonnes (t) per annum in 1980 to 168 tonnes per annum in 2014 [4], [5]. Figure 1 displays the significant decline in gold production.

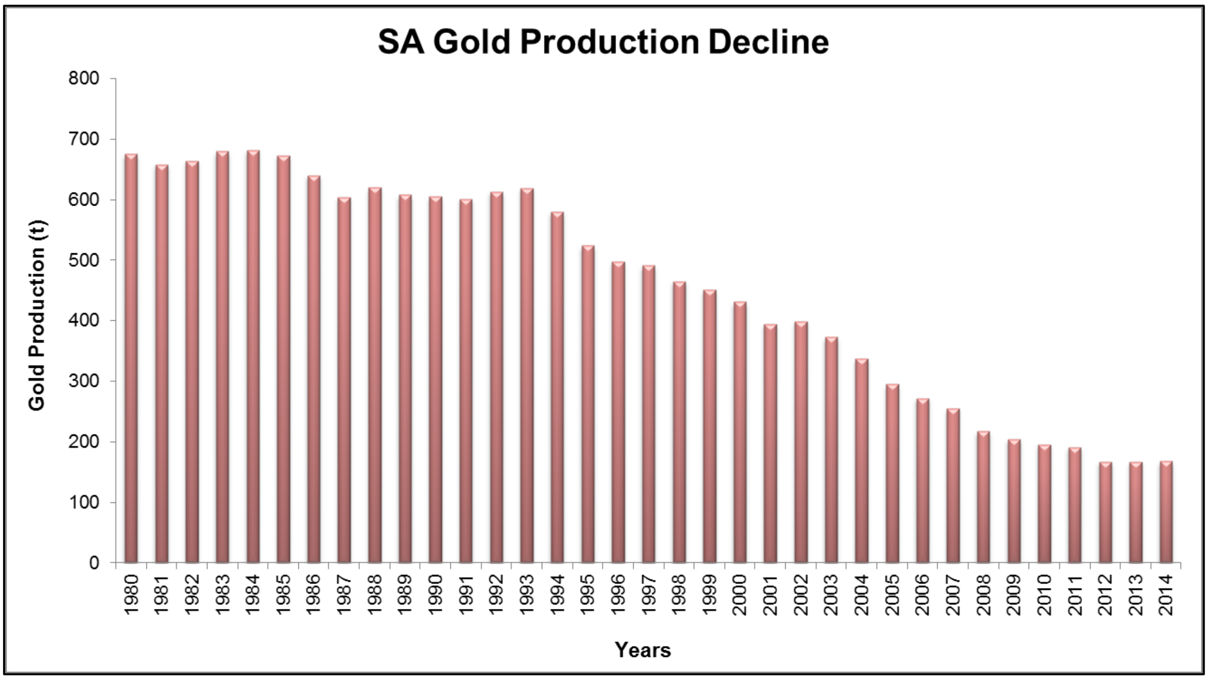

Figure 1: Declining South African gold production for the period 1980–2014

Figure 1 shows that South Africa produced 75% less gold in 2014 than it did in 1980. In January 2015, Statistics South Africa reported the lowest level of gold ever produced by the South African gold mining industry [3]. Production declined with 87% when compared with the same month in 1980 [3]. Less than a decade ago, South Africa was the global leader in gold production, but by the end of 2014 South Africa had fallen to the sixth spot globally [3].

The decline in gold production influences gold sales and has a significant impact on the South African economy [1]. South African gold sales comprised 67% of all mineral sales in 1980. By 2014, gold sales declined to 12.5% of total mineral sales [6]. Gold is one of South Africa’s most valuable commodities, but its contribution to GDP has diminished in part due to lower production. The negative influence on the South African economy as a result of declining gold production becomes evident.

This brings up the question why South African gold production gradually decreased over the years (refer to Figure 1). As of 2013, South Africa is known for having the most gold ore reserves, comprising 27% of the world total [7]. It is unusual for a country, which has almost a third of the global gold ore deposits, to contribute so little to global gold production and sales (5.5% in 2013) [5], [8], [9]. This opens up the discussion to possible factors that could have contributed to the systematic decline in gold production.

1.1.2 Factors influencing South African gold production

During the course of 2013, the South African Department of Mineral Resources and Deloitte South Africa reported on factors influencing South African gold production. The factors include declining ore grades, ever-falling gold prices, industrial action (strikes), falling productivity and escalating input costs [8], [9], [10]. These factors were investigated to determine the validity of the allegations made by these well-known South African institutions.

In 2014, the South African Chamber of Mines published a report that indicated a gradual decline in the grade[2] of mined ore since 2004. The grade per tonne of mined ore declined from 5.15 g/t in 2005 to 2.91 g/t in 2013 [5]. This is equal to an overall decrease of 44% over a period of nine years. Figure 2 gives the gradual decline in gold ore grade from 2004 to the end of 2013 [5].

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[2] Constituent gold mass per mass unit of rock measured in grams per tonne (g/t).

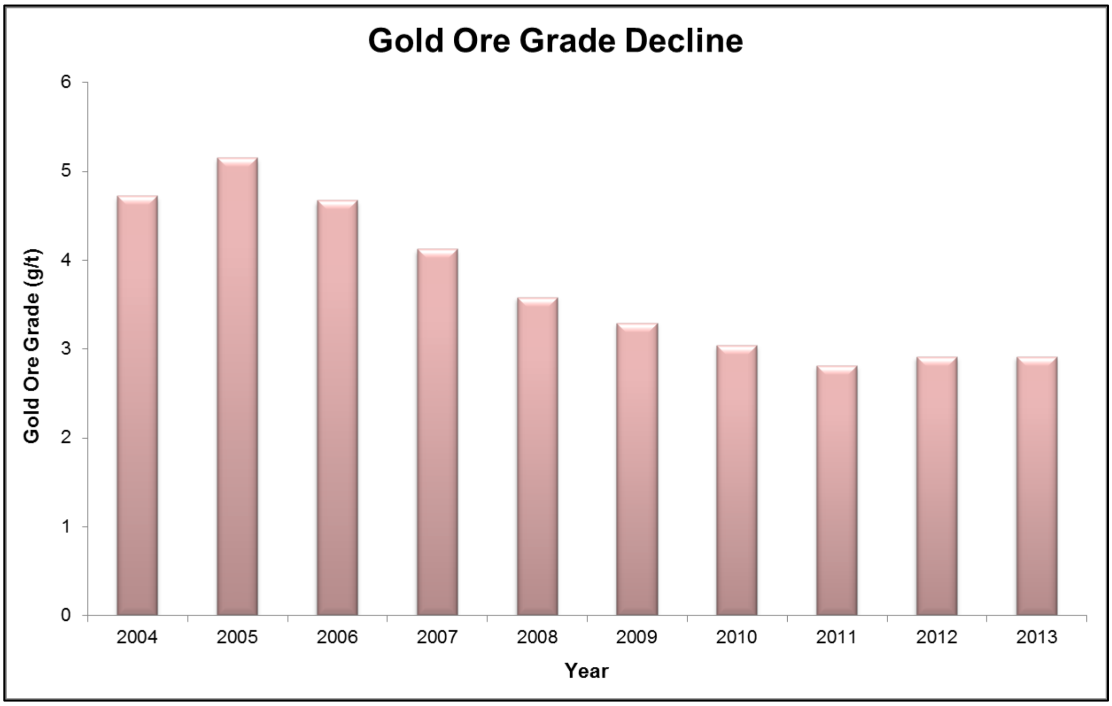

Figure 2: Declining gold ore grade for the period 2004–2013

By the end of 2013, the South African gold mining industry processed 19% more gold-containing ore than the same period in 2004 [5]. The gold produced from this ore, however, followed the opposite trend. Approximately 53% less gold was produced during 2013 than in the corresponding period in 2004 [5]. Figure 3 indicates the decline in gold production despite the increase in processed ore [5]. This is an effect of processing lower grade ore.

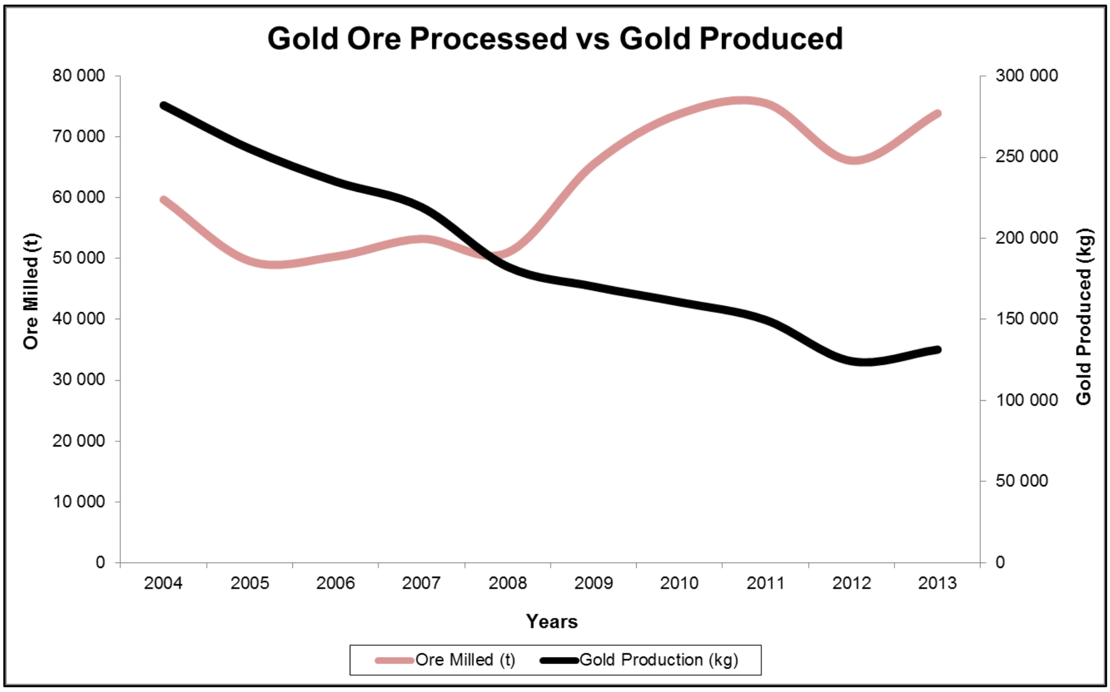

Figure 3: Annual processed ore against gold produced for the period 2004–2013

Processing lower grade ore induces higher input costs as more ore needs to be processed to ensure sustainable levels of gold production [9]. Gold mines are also obliged to mine deeper in an attempt to reach richer ore deposits, which further increases input costs [9]. Deeper mining presents additional safety risks, which may result in frequent shaft closures for safety audits [4], [9]. During safety audits mineshafts are closed temporarily, which results in lost production time [11].

In the past, higher gold prices made mining of low-grade ore economically viable [4]. Gold mines were able to cover overhead costs and remain relatively competitive in the mining industry, even when mining lower grade ore. However, the gold price has declined significantly over the last couple of years [12]. It has become uneconomical to mine gold beyond a certain commodity price threshold [4]. It is logical that by mining low-grade ore, this "uneconomical point" will be reached much sooner than when mining higher ore grades. The risks of mining low-grade ore on the profitability of gold mines become evident.

The profit margin of a gold mining group is dependent on the price of its commodity and the input costs related to deliver the final product [5], [11]. If gold prices decrease beyond a certain point (uneconomical point), it may become non-viable to mine the gold [4]. Some mining groups may have a capital surplus (previous earned profit) to continue producing gold below this point. Alternative options such as closing shafts, cutting jobs, selling capital-intensive shafts and halting projects become inevitable if the commodity price remains low. Figure 4 indicates the average annual South African gold price from 2004 to 2013 [5]. All the values are displayed in real 2013 money terms.

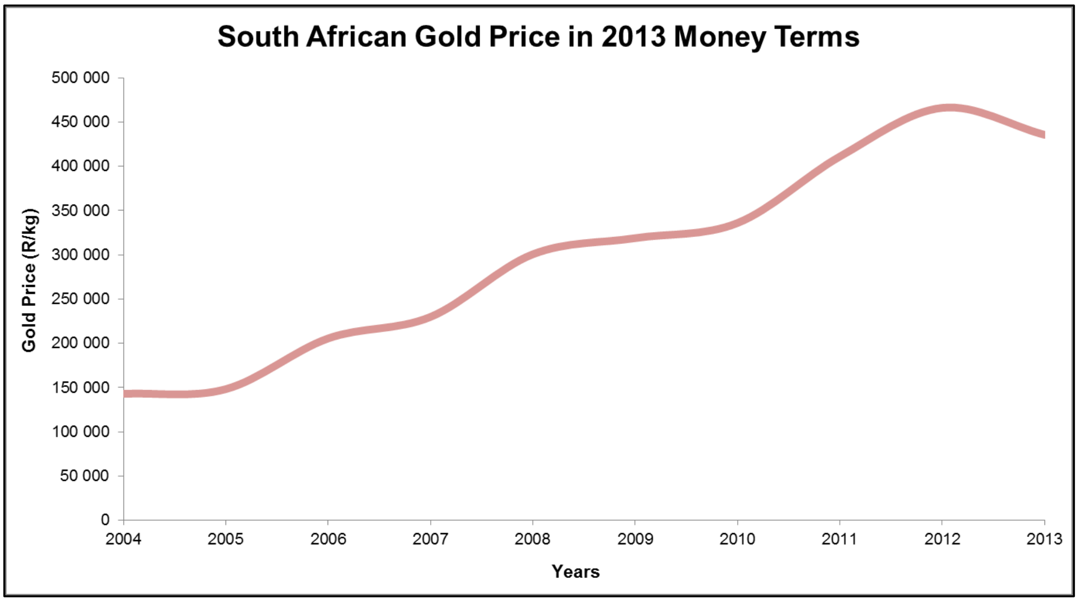

Figure 4: Gold price in South African rand for the period 2004–2013

The gradual increase in the price of gold is evident from Figure 4, with a maximum growth of 60% from 2004 to 2012 [5]. In 2013, the price of gold experienced an average annual price decrease of 6.5% from 2012 [5]. From 2013 onwards, the South African gold price never showed any signs of recovering to a positive trend. During July 2015, the gold price plummeted to a five-year low since March 2010 [13]. The mining of low-grade ore also showed no signs of improving by July 2015 [13].

Gold mining operating costs, however, increase year-on-year at a higher-than-inflation rate [11]. Figure 5 illustrates the impact of the gold price decrease, processing of low-grade ore and higher-than-inflation operating costs [5], [11]. The profit margin per tonne of ore milled decreased with 18% from R323/t (2012) to R264/t (2013) [5], [11]. This is while the operating cost increased with 1.2% over the same period [5]. The influence of the commodity price, ore grades and operating costs on the profit margin is evident.

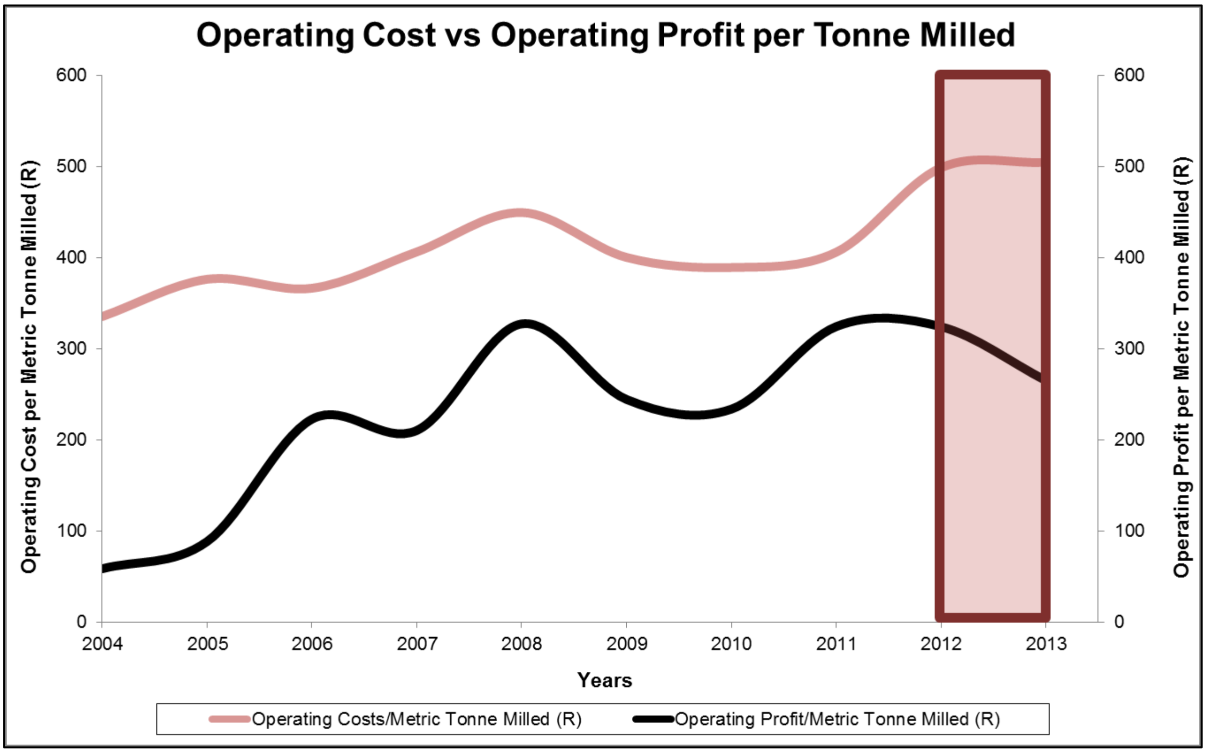

Figure 5: Gold mining operating cost versus profit per tonne of ore milled (2004–2013)

By the end of 2014, one of South Africa's leading gold mining groups had not shown any profit since 2012 [12]. Management of this particular mining group stated that the combination of falling gold prices and high input costs would force them to close down all of their non-profitable operations [12]. This gold mining group has the option to either drastically cut its overhead costs or close down its operations. This is a major concern for the South African mining sector and economy as gold mining is becoming a marginal operation.

Industrial action (strikes) is another major concern that contributes to the predicament the gold mining industry finds itself in. According to the South African Chamber of Mines, strikes limit the industry's potential to maximise its return on capital investment [11]. No income is generated from production during a strike while mines still incur costs to keep crucial components operational [11], [14]. Strikes also have a long-term effect on gold mining production as it takes a while for mines to get back to full production after a strike [15]. The impact of strikes on the profitability of gold mines, especially in conjunction with the factors discussed in preceding paragraphs, becomes evident.

The South African gold mining industry is probably facing their toughest challenge yet, which is remaining operational during this difficult era of South African mining. Mining of low-grade ore, very low commodity prices, higher-than-inflation operating costs and the continuous possibility of strikes are all factors influencing sustainable gold production. Some argue that the combination of these factors is a perfect storm waiting to emerge [15].

If gold prices remain low and gold mining groups fail to develop solutions to remain profitable throughout these difficult times, the South African gold sector and the economy may face serious repercussions. One aspect that may improve the gold sector's chance of survival is managing operating costs effectively. Reducing operating costs may increase profit margins and ensure sustainability in less favourable conditions. The next section scrutinises typical expenditures and operating costs within the South African gold mining industry.

1.2 South African gold mining operating costs

1.2.1 Preamble

Most of the challenges discussed in the previous section are beyond the control of the gold mining industry [16]. The influence of operating costs on the profit margin can, however, be addressed. Reducing operating costs would improve the viability of mining marginal shafts within a gold mining group. Mining of more shafts at lower operating costs would further increase profit margins and ensure a sustainable future for the South African gold mining industry.

The following section discusses typical operating costs gold mines incur on a daily basis. These costs are analysed to determine the effect of each cost on the profit margin of a gold mine. It is also critical to highlight and identify possible solutions to mitigate each operating cost to ensure an overall reduced capital expenditure.

1.2.2 Gold mining operating costs

The total annual expenditure for a typical South African gold mining group may range from R15 billion to R20 billion, depending on the magnitude of its operations [12], [17]. Figure 6 provides a simplified breakdown of a typical gold mining group's total expenditure on operating costs [5], [11], [12], [17]. According to Figure 6, major expenses are wages and salaries, consumables, capital expenditure and electricity. The electricity portion of the expenses is highlighted in Figure 6 as it forms the focus of this study.

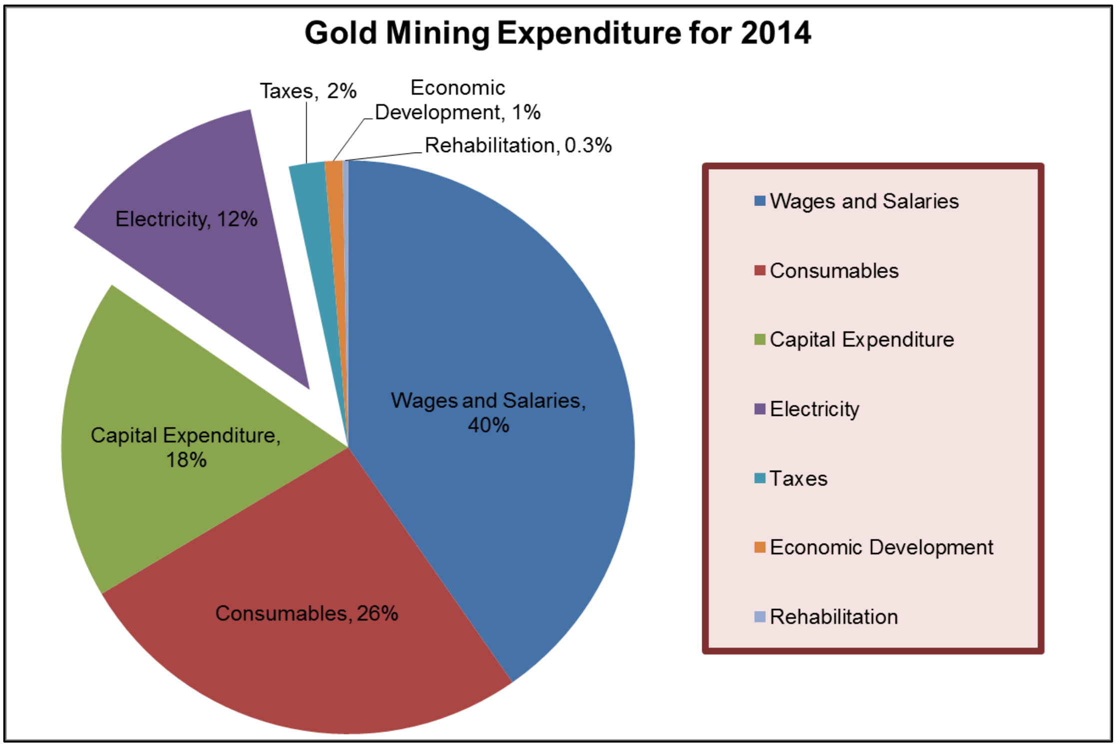

Figure 6: Typical expenditure for a gold mining group

Wages and salaries is by far the leading expense in the gold mining industry, comprising 40% of the total [5], [16]. One would typically argue that the cost reduction focus should be on these expenses. However, the gold mining industry has already been reducing its capital spend on wages and salaries for a couple of years [5]. By the end of 2014, the gold mining industry showed a 29% reduction in the number of employed personnel since 2004 [5], [11].

The gold mining industry has, however, witnessed wage increases of at least 10% per annum since 1999 [16]. The reduction in employees, therefore, only ensured that the wages and salaries portion of the expenditure remained relatively stable over this period (2004–2014). According to the Chamber of Mines' annual report, there is not much room left to reduce the capital spend on wages and salaries by retrenching employees [11], [13]. This is understandable as the gold mining industry's operations rely heavily on the human factor for sustainable production [16]. It is important for the gold mining industry to manage this portion of the expenditure effectively to remain in the vicinity of 40% of the total expenses.

According to the Gold Mine Economics Services, consumables and capital expenditure are uncontrollable expenses [16]. Consumables are one of the few relatively fixed costs due to its necessity in sustainable gold production, while capital expenditure is seen as an ongoing staying-in-business expenditure [16]. There is, therefore, not much scope to reduce expenditure on these portions of the operating costs [13], [16]. This leaves electricity as the only portion of the major expenses in gold mining with possible scope for reduction.

Although electricity is not the highest expense in gold mining, it remains one of this industry's biggest concerns [10], [18], [19]. Particularly, these concerns can be ascribed to the price of electricity and its higher-than-inflation increasing rate. In other words, electricity usage in the gold mining industry has major potential for influencing the profitability and sustainability of its operations [20]. Thus, it is a necessity to address the gold mining industry's concerns and manage electricity consumption and expenses effectively. The following section examines electricity as a major expenditure in the gold mining industry.

1.2.3 Electricity as major expenditure

For decades, South African electricity costs posed no threat to the gold mining industry as the tariffs remained relatively low. This statement becomes obvious when comparing the average electricity tariff from 1978 to 2008 in real 2011 money terms [21]. The average price of electricity decreased from 39.7 c/kWh in 1978 to 22.7 c/kWh in 2008 [21]. This is equal to an overall decrease of approximately 43% over this period. It was in 2008 when the electricity tariff trend turned towards higher-than-inflation increases – one of the main reasons being the electricity supply shortfall and Eskom[3] embarking on massive building programmes to increase the power supply capacity [10], [21].

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[3] South Africa's national electricity provider.

From 2008 onwards, the electricity tariff never showed any signs of decreasing nor stabilising. Figure 7 shows the average year-on-year increase in mining operating costs from 2008–2014, compared with the consumer price index (CPI) over the same period [11]. The average year-on-year increase in the South African CPI was 6.5% between 2008 and 2014 [1]. During the same period, the majority of operating cost components in the mining industry exceeded the CPI with quite a margin, with electricity at a leading average of 19%.

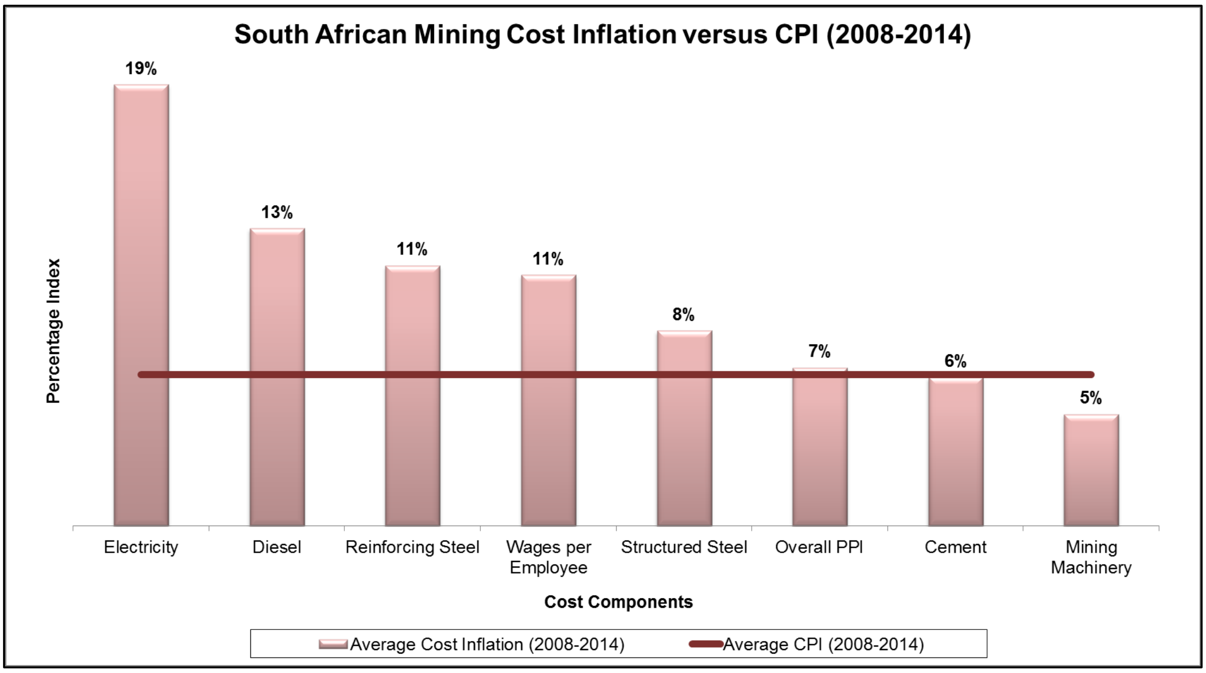

Figure 7: Mining expenditure inflation versus CPI for the period 2008–2014

Between 2008 and 2011, the average electricity tariff rose with 78% [21]. During 2013, the National Energy Regulator of South Africa (NERSA) furthermore granted an average electricity tariff increase of 8% for a consecutive five-year period [18]. This meant that the electricity tariff would increase with at least 8% per annum until 2018. By the end of 2014, NERSA approved a further 4.69% (total of 12.69%) tariff increase for the 2015/2016 financial year [10]. This figure remains 6.19% higher than the average CPI for the 2015/2016 period (refer to Figure 7). This is a major concern for the gold mining industry, as electricity is significantly related to the mining industry's production [21], [22].

Deloitte South Africa conducted a study where they determined the vulnerability of electricity-intensive[4] industries to rising electricity tariffs [21]. It was found that the larger the contribution electricity had to overall operating costs, the more vulnerable the industry would be to rising electricity tariffs [21]. Prior to determining the gold mining industry's vulnerability

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[4] Measure of an industry's reliance on electricity to produce a certain given output [21].

to these rising tariffs, one needs to thoroughly understand the industry's electricity intensity and reliance on electricity for its operations. The impact of electricity costs and the gold mining industry's vulnerability to rising costs are discussed in the following section.

1.3 Impact of electricity costs on South African gold mining

1.3.1 Electricity intensity of the gold mining industry

The more electricity-intensive (reliant on electricity) an industry is, the more sensitive it will be to electricity cost fluctuations [21]. From the gold mining industry's point of view, it is also important to consider the proportion of electricity's contribution as an input cost to deliver the final product [21]. If the gold mining industry is electricity-intensive and mostly reliant on electricity for its outputs, it becomes very vulnerable to the higher-than-inflation electricity tariff increases.

The South African mining industry is well-known for its intensive electricity consumption trends [23], [24]. Mining consumed an average of 14.9% of Eskom's total electricity sales over the last ten years (2004–2014), thus making it the third-largest consumer of electricity in South Africa [25], [26], [27], [28], [29], [30]. Figure 8 depicts the average consumption of electricity in South Africa by customer type over the last ten years [25], [26], [27], [28], [29], [30]. The mining sector is highlighted.

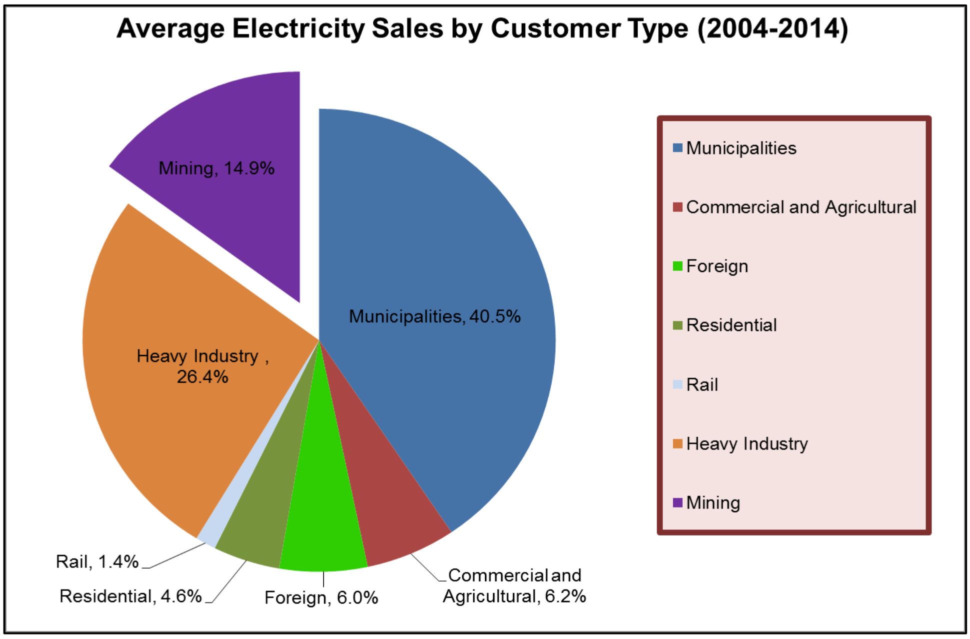

Figure 8: Average Eskom electricity sales by customer type for 2004–2014

Deloitte South Africa conducted a study in which the electricity consumption patterns of all the different South African heavy industry sectors were identified and analysed. The electricity consumption by each sector was expressed as a percentage of the total electricity supplied by Eskom. Figure 9 depicts the results from the largest to the smallest heavy industry consumer [21].

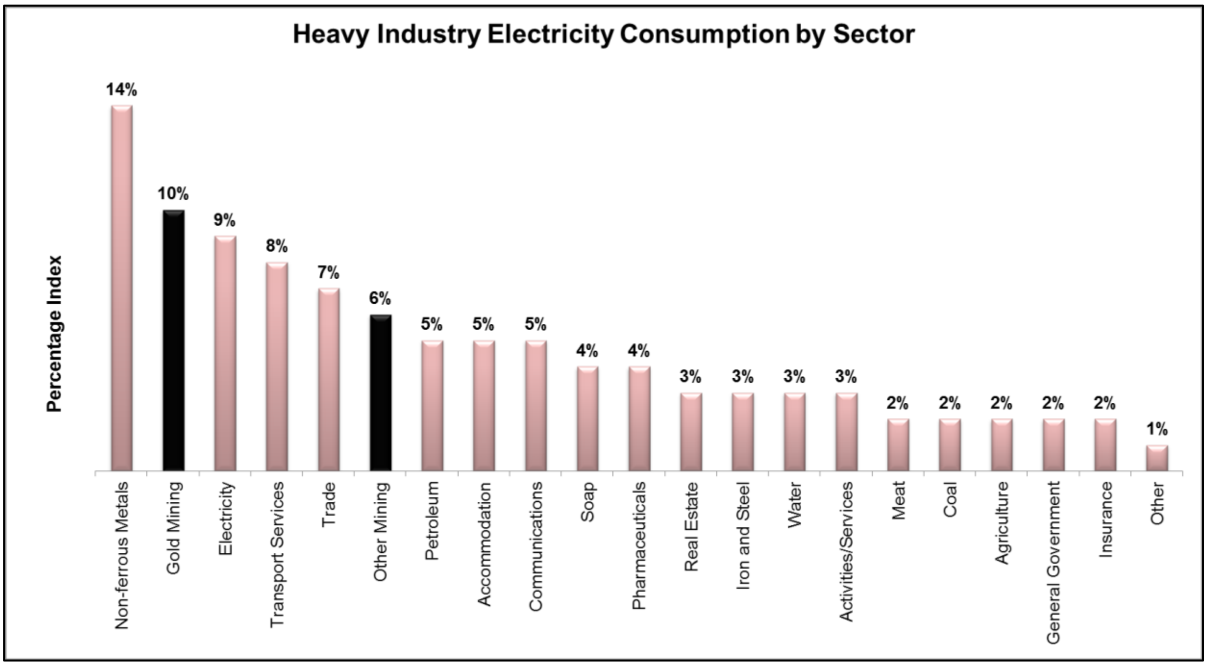

Figure 9: Electricity consumption by the South African heavy industry sectors

Figure 9 shows that gold mining consumes approximately 63% of the total electricity consumed by the mining industry [21]. Gold mining is also the second-largest electricity consumer within the South African heavy industry [21]. The electricity intensity of the gold mining industry and its reliance on electricity for its operations becomes evident. These figures are also an indication of the gold mining industry’s vulnerability to extravagant electricity tariffs, which was discussed in the preceding section [21].

In order to grasp the concept of an “electricity-intensive gold mining industry”, one needs to investigate the components and operations that contribute to high electricity consumption. The following section gives a background on the electricity-intensive components and operations of gold mines.

1.3.2 Electricity-intensive operations of gold mines

Electricity is a very important energy source for South African gold mines as most production-related operations and equipment are electricity-driven [31], [32], [33], [34]. It is stated that in some instances the electrical energy usage may comprise up to 90% of a gold mine's total energy demand [34]. This, once again, highlights the gold mining industry's reliance on this expensive energy source for sustainable production. The question, however, arises why the gold mining industry does not seek alternative solutions to power production-related equipment and operations.

Some of the existing operating gold mines in South Africa date back to the 1950s [32], [35]. As discussed in previous sections – prior to 2008, electricity was a relatively cheap form of energy for many years. Mines were, therefore, designed to accommodate electricity as the primary driver of production-related equipment and operations [32], [35]. It would be a cost- and time-consuming process for gold mines to upgrade their entire designs to accommodate cheaper operating alternatives [32]. Time and money are resources that gold mines do not necessarily have. This leaves the industry with no other alternative than utilising existing infrastructure.

According to research, four vital systems are incorporated during the initial design and development of a typical gold mine [32]. These systems comprise ventilation, cooling, dewatering and compressed air [32]. These systems are also part of the major consumers of electricity at a typical gold mine as they are regarded as continuous processes. Figure 10 categorises a typical gold mine's average electricity consumption by each operating system [36], [37]. It is important to note that the consumption trends may vary according to different gold mineshafts, depending on numerous factors [33].

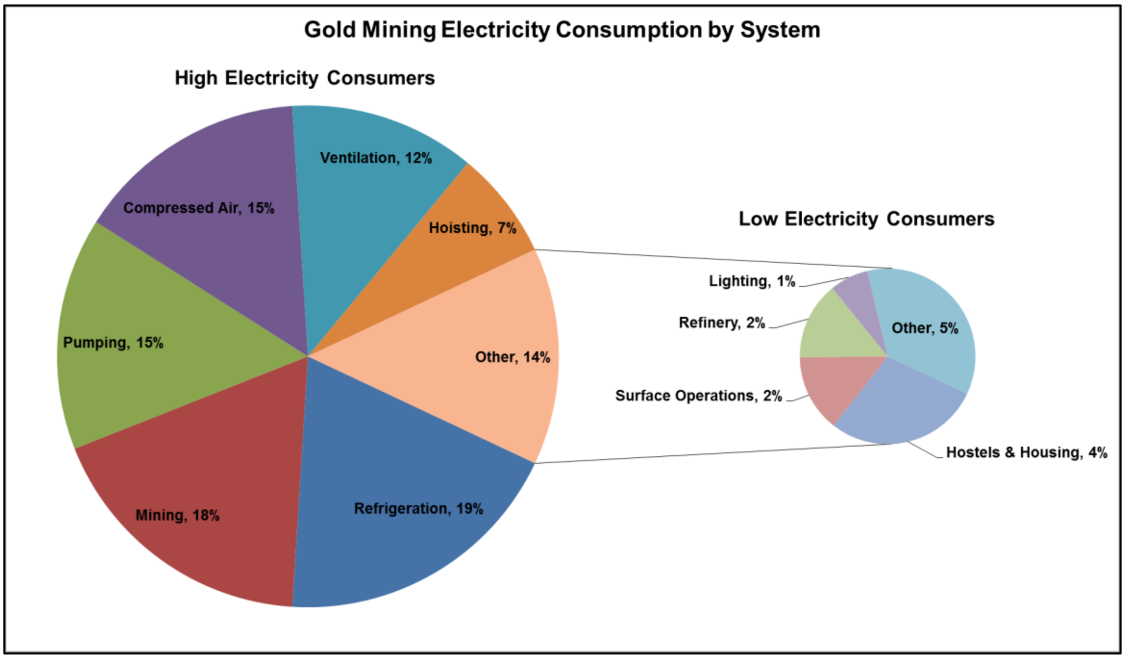

Figure 10: Average electricity consumption by system for a typical gold mine

Cooling and ventilation are very important aspects when it comes to deep-level gold mining. Underground virgin rock temperatures can reach up to 70 ºC and proper cooling is essential for creating a safe and convenient mining environment [31], [36], [37]. It is also important to keep underground ambient temperatures within safety regulations set by the relevant mining authorities [31]. Thus, gold mines will consume as much electricity as required to remain within these margins [31]. This makes cooling and ventilation, combined, the largest consumer of electricity in the gold mining industry (refer to Figure 10) [31], [33], [38].

South African gold mines are among the deepest mines in the world [36], [37]. The air-cooling provided by refrigeration and ventilation systems becomes less efficient at certain distances below surface [31], [37]. Chilled water, produced by the refrigeration system, is used to cool the environment at the deeper levels [36], [37]. Chilled water is also used continuously for drilling, cleaning and dust suppression [31], [36]. This water, together with fissure water, accumulates in large underground storage dams and needs to be pumped to the mine’s surface via cascading dewatering systems (pumping systems). It is not unusual for gold mines to pump up to 25 Ml of water during a single mining weekday [36], [37].

Dewatering systems also prevent flooding of underground levels and play a crucial part in sustaining a safe working environment for mine employees. Pumping of water is, therefore, a continuous process [39]. Energy-intensive dewatering pumps are required to move the water against large heads due to the depth of underground levels [36]. Figure 10 proves the validity of this statement as pumping consumes, on average, approximately 15% of a typical gold mine’s electricity consumption.

Compressed air generation is another vital component when it comes to deep-level gold mining. Gold mines use an extensive range of pneumatic equipment – mainly due to already installed infrastructure, reliability, safety and ease of operation [32], [40], [41]. According to Figure 10, compressed air generation comprises, on average, approximately 15% of the total electricity consumption. Some sources state that compressed air generation can consume up to 21% of the total electricity demand – depending on the magnitude of the operations [22], [33], [42].

According to Figure 10, another large electricity consumer is mining. Although mining seems to be the second single largest consumer of electricity in gold mining, it is not actually the case. Mining is a combination of several activities and components that add up to be quite a significant electricity consumer. Mining includes equipment such as booster pumps, mud pumps, submersible pumps, blowers and winches, which are all used during underground mining operations [37].

As depicted by Figure 10, hoisting is classified as a high electricity consumer although its contribution is much smaller than the continuous processes mentioned previously [39]. Hoisting occurs when mined ore is transferred from underground silos to the mine's surface and consequently consumes less electricity. Hoisting systems are also used by gold mines as a transportation medium for transferring mine personnel from underground to surface and vice versa [43].

As illustrated by Figure 10, the lower electricity consumers of South African gold mines are grouped as the Other category. This category includes components and operations such as hostels and housing, lighting, surface operations and refinery. The Other category grouped under the low electricity consumers include change houses[5], workshops etc. [37].

Some mineshafts may also have processing plants as part of the facility. In such instances, processing plants, also known as gold plants, may consume up to 14% of the mine's total electricity consumption [33]. This is a significant figure and considering the consumption of the other components (Figure 10), processing plants may be classified as one of the major electricity consumers at gold mines.

This section provided background on the electricity intensity of deep-level gold mining systems and operations. At some South African gold mines, electricity may comprise approximately 90% of the mine's total energy demand. It was also found that the majority of the electricity-intensive systems are operated continuously and are essential for safe and sustainable gold mining. Migrating to alternative and cheaper energy sources is also not an option as it is a cost- and time-consuming process.

Alternative solutions are required to mitigate the cost of electricity expenditure of major consumers at gold mines. Thus, the electricity-intensive gold mining industry and its sensitivity to higher-than-inflation electricity tariffs present electrical energy management opportunities. Effective energy management would reduce gold mining operating costs and help the industry to remain profitable and survive through the unfavourable times discussed in previous sections. The following section discusses the possibility for the gold mining industry to mitigate the high electricity related costs of gold mining.

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[5] Ablution facilities for mine personnel.

1.3.3 Mitigating expenditure on electricity costs

Other than consumables and capital expenditure (refer to Figure 6), electricity is classified as a controllable input cost [16]. In other words, there is a possibility to control a gold mine's electricity consumption and contribute positively to less spend on input costs, while delivering the same amount of product. The question now arises of how the gold mining industry could mitigate these ever-growing costs. This question can be answered in the form of the industry's capability to comply with the following criteria [21]:

1. using other energy sources instead of electricity;
2. transferring the electricity cost;
3. scoping energy efficiency; and
4. managing the use of energy holistically.

The gold mining industry's ability to migrate to other cost-effective energy sources is limited. It is possible for gold mines to use other energy sources to generate their own electricity, but the capital expenditure involved is very high [12], [21].

An easy outcome for the gold mining sector would be to pass on the electricity costs to the consumers of the commodity. In other words, increasing the price of their product to mitigate high input costs by letting the consumers pay for it. This sounds like a very feasible option, but gold is a homogeneous commodity [21]. This implies that gold mines have very little influence over the price of the delivered product. The price is usually determined by highly competitive global markets [21]. It is, therefore, not possible for the gold mining industry to pass on these costs.

The only two remaining criteria are the scope for energy efficiency and holistic energy management. Due to its electricity intensity, the gold mining industry offers large potential for the implementation of energy efficiency measures [21], [22]. There is also significant scope for electrical energy management techniques to help implement energy efficiency initiatives effectively and sustain the performance of these initiatives [21]. With decreased gold production, low gold prices and high electricity tariffs, measures such as these become a necessity for the struggling gold mining industry.

The following section scrutinises electrical energy management practices in the industrial environment with the aim of identifying any energy management strategies already implemented in the gold mining sector.

1.4 Energy management in the industry

1.4.1 Global energy management

Schulze et al. compiled extensive research on available academic journals in the industrial electrical energy management field. According to Schulze et al., a wide variety of work has been published over the years, but a comprehensive review was absent [44]. The study objective was, therefore, to conduct a systematic review of all available scientific research and publications in the field of industrial electrical energy management [44]. The research was used by Schulze et al. to develop an integrative conceptual framework for managing energy in the industry [44].

Schulze et al. investigated approximately 950 articles from 1979–2014. He found only 44 applicable to industrial energy management [44]. The study by Schulze et al. contains extensive detail on the research contained in the articles, the approach in analysing the gathered literature and the development of the conceptual framework. For the purposes of this study, the focus is rather on the following aspects devised from the study by Schulze et al.:

1. concepts of electrical energy management addressed by the study;
2. contribution to electrical energy management in the mining industry; and
3. geographical origin of the studies.

Schulze et al. divided the 44 applicable studies into different categories representing overarching themes of different energy management concepts in the industrial field [44]. The categories are as follows [44]:

1. **planning or strategic** energy management development;
2. **implementing or operating** energy management;
3. **controlling** energy efficiency improvement through energy management;
4. **organising** energy management resources and structures; and
5. creating an energy management **culture**.

The second step was identifying how studies were classified according to industrial sector. It was found that most studies were conducted on the energy-intensive sectors of the industrial sector [44]. The author, however, noticed that none of the 44 studies included electrical energy management techniques implemented in the mining industry, although this is an energy-intensive industry.

The third part of the author's review entailed background on the distribution of the geographical origin of the studies. The reason was to obtain an overall idea of each country's interest and contribution to the global concept of industrial electrical energy management [44]. The author found that none of the 44 investigated studies originated from South Africa. This is very concerning from a South African perspective. At the same time, this leaves large potential for electrical energy management opportunities in the South African industrial sector, especially mining.

1.4.2 Electrical energy management in the South African mining sector

At the beginning of 2005, a target was set for the mining industry to reduce its electricity demand by 10–15% within the next ten years [28], [33], [36], [45]. This meant that the mining industry had until the start of 2015 to achieve the target of at least 10%. The reduction target was part of the South African Energy Efficiency Strategy (EES) and Eskom Energy Conservation Scheme (ECS) to reduce the country's electrical demand and ensure a sustainable electricity reserve margin [28], [33]. Figure 11 shows the outcome of the mining industry's commitment towards the EES and ECS between 2005 and the end of 2014 [25], [26], [27], [28], [29], [30].

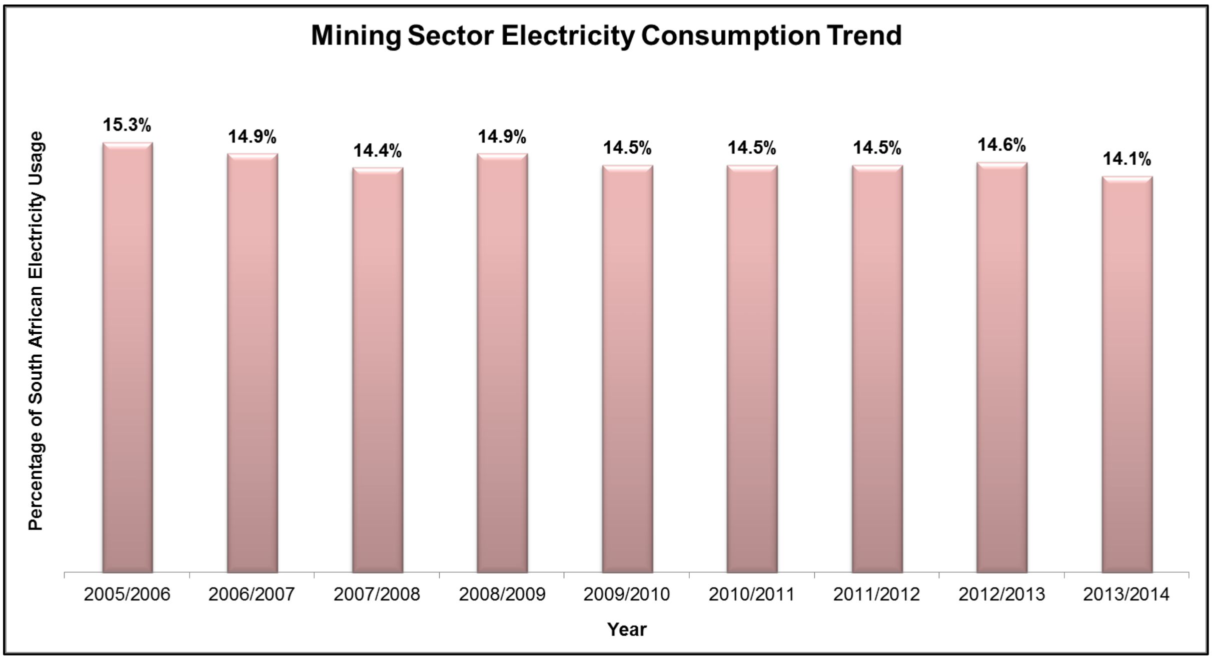

Figure 11: Mining sector electricity consumption trend for the period 2004–2014

During the 2005/2006 financial year, the mining industry consumed approximately 15.3% of South Africa's total supplied electricity. Approximately ten years later, the consumption declined to 14.1%. When calculated, this adds up to a total demand reduction of approximately 7.8%, while the target was set at a minimum of 10%. Although the mining industry came close to reaching its target, answers need to be provided to why the shortfall occurred.

As part of the ECS, Eskom developed a Demand Side Management (DSM) funding model to provide the required financing for implementing projects on major electricity consumers [30]. Since then, energy services companies (ESCOs) have capitalised on this funding model and helped Eskom with implementing energy savings projects on these consumers. The mining industry benefits from Eskom DSM projects as there are no implementation costs involved in exchange for large electricity cost-saving potential [40].

The major problem with the Eskom DSM model was, however, that ESCOs were only responsible for successfully implementing initiatives and proving the viability in terms of energy savings[6] [46]. After this period, the responsibility for maintaining the savings was signed over to the client and the ESCOs lost interest. It was not beneficial for ESCOs to maintain project performances on behalf of their clients [46]. ESCOs rather invested their time and money in scouting for new projects and initiatives to propose to Eskom in an attempt to make their businesses more profitable [46].

For this reason, and due to the mining industry's lack of energy savings expertise, performances of most of these implemented projects have deteriorated over time [10], [31]. Groenewald also mentioned that DSM projects perform well during their performance assessment phases when ESCOs prove the feasibility of energy savings [10]. It is after the handover to clients that the performance of the implemented projects deteriorates due to a lack of sustainable energy management strategies, which include proper maintenance [10].

To prove the validity of these statements, an investigation was conducted on 96 implemented projects in the South African gold mining industry. The projects were all implemented on the high electricity consumers of gold mines (refer to Figure 10) during the period 2004–2015. Table 1 gives a summary of the implemented projects [46], [47]. For the purposes of this study, the particulars and history of each project were divided into three different categories, namely:

1. date the project was handed over from the ESCO to the client;
2. date the electricity cost savings started to deteriorate; and

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[6] Savings are proven over consecutive three-month performance assessments.

3. whether the implemented project formed part of an energy management strategy (links up with the study of Schulze et al. [44]).

Table 1: Implemented energy savings projects during the period 2004–2015[7]

Implemented Energy Savings Projects in the Gold Mining Industry															
Mineshaft	**Refrigeration**			**Pumping**			**Compressed Air**			**Ventilation**			**Hoisting**		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Mineshaft A	2006-03-01	Start 2008	No	**2004-03-31**	**Never**	**No**	2009-02-01	Mid 2012	No	**2015-05-01**	**Never**	**No**	2007-03-01	Mid 2009	No
	2012-01-30	**Never**	**No**				**2013-06-21**	**Never**	**No**						
Mineshaft B	2008-08-31	End 2009	No	2004-06-01	End 2004	No	2013-01-31	End 2014	No	2014-04-01	Mid 2014	No			
	2012-04-20	**Never**	**No**	2011-07-01	Mid 2012	No									
Mineshaft C	**2015-02-19**	**Never**	**No**	2004-07-01	End 2008	No	**2013-07-15**	**Never**	**No**				2014-06-28	End 2014	No
Mineshaft D				**2004-07-01**	**Never**	**No**	**2012-06-19**	**Never**	**No**	**2015-05-01**	**Never**	**No**	**2014-10-28**	**Never**	**No**
Mineshaft E	2013-01-31	Mid 2013	No	**2005-07-30**	**Never**	**No**	2008-02-29	Mid 2012	No						
				2011-07-01	Mid 2011	No									
Mineshaft F				2006-03-31	Mid 2009	No	2011-12-01	End 2013	No	2012-07-01	Start 2013	No			
				2013-01-31	Mid 2013	No									
Mineshaft G	2007-12-05	Mid 2010	No	2006-05-31	Start 2009	No	2009-12-01	Start 2013	No	2014-09-30	Mid 2015	No			
	2012-09-28	Mid 2013	No				2013-02-01	End 2014	No						
Mineshaft H				2006-06-30	End 2006	No	2009-03-01	Mid 2010	No	2013-12-01	Start 2014	No			
							2011-09-01	Mid 2012	No						
Mineshaft I				2006-12-20	Start 2008	No	2007-12-31	End 2010	No				2008-08-01	Mid 2009	No
							2012-12-14	Mid 2013	No						
Mineshaft J	2013-01-31	Mid 2013	No	2005-09-13	Mid 2010	No							2014-05-28	Mid 2014	No
Mineshaft K				2006-06-30	End 2006	No									
Mineshaft L	2007-10-01	Start 2008	No	2006-05-01	Start 2009	No	2009-02-01	Mid 2009	No	**2015-05-01**	**Never**	**No**	2014-05-28	Mid 2014	No
	2015-03-19	**Never**	**No**				2013-09-03	End 2014	No						
Mineshaft M				2009-07-01	End 2009	No	2013-02-28	Mid 2015	No	2013-12-01	End 2014	No			
				2012-04-01	Start 2014	No				2009-06-01	End 2010	No			
Mineshaft N				2008-12-01	Start 2009	No	2011-05-01	Start 2014	No						
Mineshaft O							2009-02-01	End 2009	No						
Mineshaft P				2009-06-01	Mid 2010	No									
Mineshaft Q				2009-02-01	Start 2011	No				2009-06-01	End 2010	No			
Mineshaft R	**2014-01-01**	**Never**	**No**	2009-08-01	Mid 2012	No									
Mineshaft S				2013-02-11	Start 2015	No	2010-02-01	Mid 2010	No	2013-12-01	End 2014	No			
				2011-06-01	Mid 2013	No	**2013-06-11**	**Never**	**No**						
Mineshaft T	2012-10-01	Start 2014	No	**2013-08-10**	**Never**	**No**				2013-12-01	End 2014	No			
				2012-11-01	Start 2013	No				2009-06-01	End 2010	No			
Mineshaft U							2012-02-02	Mid 2012	No	**2015-05-01**	**Never**	**No**			
Mineshaft V				**2015-05-29**	**Never**	**No**	2012-02-01	Mid 2012	No				2014-05-28	End 2014	No
Mineshaft W	2014-02-18	Mid 2015	No	**2014-06-01**	**Never**	**No**									
				2008-02-01	Mid 2012	No									
Mineshaft X													2014-05-28	Start 2015	No
Mineshaft Y	2012-06-01	End 2012	No	2006-02-01	Start 2011	No									
MineshaftZ	2012-06-01	Mid 2012	No	2012-04-01	Mid 2012	No	2011-04-01	Mid 2012	No	2012-06-01	Start 2010	No			
										2013-12-01	End 2014	No			
Mineshaft AA				2009-03-01	Start 2012	No									
Mineshaft BB										2015-05-01	Mid 2015	No			
Mineshaft CC										2013-12-01	End 2014	No			

Legend
A - Client Takeover
B - Savings Deterioration
C - Implemented through Energy Management Strategy

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[7] Eskom and HVAC International are acknowledged for the assistance in obtaining data and performance tracking reports of the projects.

From Table 1 it can be seen that only 20 projects (highlighted in grey) of the 96 investigated projects proved a sustainable performance from the client handover date to the time of this study. It was further found that the average performance lifespan of the remaining projects was only 17 months after handover. The performance of 47 projects started to deteriorate in less than one year after handover. It is evident that something went wrong after handover from the ESCOs to the clients, as the ESCOs performed well in achieving the targeted savings during the performance assessment periods.

After further investigations, it was found that none of the identified projects were implemented as part of an electrical energy management strategy (which validates the study by Schulze et al. [44]). This means there was no framework for clients after handover to at least attempt to sustain the performance of the implemented projects. However, 20 projects were identified that never deteriorated in performance after handover. The next step was, therefore, to determine the possible reasons for sustainable performance after the handover dates. Table 2 gives a summary of these 20 projects [46], [47], [48]. The projects are arranged according to the client handover dates – oldest to most recently implemented.

Table 2: Sustainable energy savings projects after implementation for the period 2004–2015

Sustainable Energy Savings Projects After Implementation

Mineshaft	Project Type	Client Takeover	Months after Handover	Maintenance Agreement	Automatic Control (REMS)	Manual Control (Operators)	Awareness
Mineshaft A	Pumping	2004-03-31	138	May-13	√		
Mineshaft D	Pumping	2004-07-01	135	Dec-12	√		√
Mineshaft E	Pumping	2005-07-30	123		√		
Mineshaft A	Refrigeration	2012-01-30	45	May-13	√		
Mineshaft B	Refrigeration	2012-04-20	42	Mar-13	√		
Mineshaft D	Compressed Air	2012-06-19	40	Jun-13	√		√
Mineshaft S	Compressed Air	2013-06-11	28		√		
Mineshaft A	Compressed Air	2013-06-21	28	Jul-13		√	
Mineshaft C	Compressed Air	2013-07-15	27	Aug-13		√	
Mineshaft T	Pumping	2013-08-10	26		√		
Mineshaft R	Refrigeration	2014-01-01	22	Jul-14		√	
Mineshaft W	Pumping	2014-06-01	17		√		
Mineshaft D	Hoisting	2014-10-28	12			√	√
Mineshaft C	Refrigeration	2015-02-19	8	Feb-15		√	
Mineshaft L	Refrigeration	2015-03-19	7	Apr-15	√		
Mineshaft A	Ventilation	2015-05-01	6		√		
Mineshaft D	Ventilation	2015-05-01	6		√		√
Mineshaft L	Ventilation	2015-05-01	6		√		
Mineshaft U	Ventilation	2015-05-01	6		√		
Mineshaft V	Pumping	2015-05-29	5	Jun-15		√	

The procedure for determining the sustainable performance of the projects after implementation was based on the following criteria:

1. number of months after client handover;

2. maintenance agreement between the ESCOs and the clients;
3. presence of fully functional Real-time Energy Management Systems (REMS[8]); and
4. the gold mine's energy savings awareness[9].

By the time of this study, nine of the projects displayed in Table 2 were still within the average lifespan of performance (17 months) range, as discussed in the previous paragraphs. This means that it is highly likely that some of these projects would deteriorate in performance in the future.

From Table 2 it can be seen that 11 of the 20 projects formed part of a maintenance agreement between the ESCOs and their clients. The maintenance agreements on Mineshaft A and Mineshaft D's pumping projects were, however, only established during 2013 and 2012, while these projects were implemented during the course of 2004. The performance of these projects was sustained with the help of a REMS system, which automatically controls the mines' systems without relying on human factor. The effectiveness of a well implemented REMS system becomes evident [31], [32], [38]. The sustainable performance of eight of the nine remaining projects can, therefore, be ascribed to using fully functional REMS systems.

The project implemented on Mineshaft D's hoisting system is the only identified project that showed sustainable performance without the effect of a maintenance agreement or REMS system. After consulting with the engineering manager of Mineshaft D, it was confirmed that energy awareness is a high priority at this mine [49]. According to Table 1, none of the projects implemented at Mineshaft D deteriorated in performance after implementation, which proves this statement. The effect of making a mind shift to an energy conscious mining environment becomes evident.

The influence of maintenance, using REMS systems and energy awareness proved to have a significant impact on the performance and sustainability of implemented projects. An energy management strategy that contains the abovementioned initiatives must, therefore, be in place for the gold mining industry. Only 20 of the 96 (21%) investigated projects experienced the positive impact of the initiatives, while all the other projects underperformed as a result of poor energy management or a total lack thereof. The author is of the opinion that if all of the investigated projects were implemented as part of an energy management

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[8] Fully automated energy management systems eliminating the influence of human errors.

[9] Conscious of electricity impact, savings potential and the benefits related to reducing electricity consumption.

strategy, which includes the initiatives highlighted in Table 2, the performances would have been more sustainable. This statement is motivated by the information provided in Table 1 and Table 2.

The investigation proves that the Eskom funding model eventually resulted in disorganised implementation of energy savings initiatives and projects in the industry, which includes the gold mining environment [10], [31], [40]. These projects were implemented with no form of energy savings sustainability plan considered for the clients. New initiatives were constantly implemented on the energy-intensive equipment and operations of clients, while older projects were neglected and deteriorated in performance. The clients did not necessarily have the time, experience or guidance to sustain these initiatives [10], [50]. This was one of the main reasons for the mining industry not meeting its reduction target by 2015.

This section identified the absence of electrical energy management strategies in the deep-level gold mining industry and the impact on sustainability of energy savings initiatives. The following section formulates the need for energy management in the gold mining environment.

1.5 Need and objective for an energy management approach

In the modern day era, the South African gold mining industry is experiencing challenges that halt sustainable production. In conjunction with these challenges, gold mines struggle to remain profitable as a result of low commodity prices and high operating costs. The electricity portion of operating costs is one of the major expenses increasing year-on-year with higher-than-inflation rates. Considering the electricity intensity of gold mines in South Africa, this leaves large potential for electrical energy management for improved performance and sustainability.

Research worldwide revealed the scarcity of electrical energy management addressing the electrical energy management potential in the mining industry. However, literature is available on numerous energy savings projects implemented over the years in the South African gold mining industry. These projects formed part of the Eskom DSM model and were implemented by ESCOs on the energy-intensive components of gold mines such as pumps, compressors, refrigeration machines, ventilation fans and winders.

An investigation on projects implemented in the gold mining industry revealed that energy savings performance is deteriorating continuously due to a lack of energy management. Initiatives such as energy awareness, maintenance agreements and REMS systems have, however, played a significant role in sustaining the performances of some of these projects. Although these initiatives contributed positively to the concept of energy management, no clear indication was provided that these initiatives were part of an energy management strategy.

Underperforming projects cost gold mines large amounts of money. ESCOs also charge gold mines a monthly fee for rendered maintenance services to sustain project performance [10]. In some cases, these monthly fees are equal or more than the amount of capital saved through electricity cost savings [10]. This means that a mine actually does not benefit from an implemented project as all the saved capital is transferred directly to the ESCO.

The most recent concern for the gold mining industry is the availability of funds provided by Eskom for the implementation of DSM projects. During 2015, Eskom confirmed a funding cut of approximately 60% from the previous model [26], [40], [51]. This means that ESCOs have limited budgets to work with and mines need to contribute financially when implementing energy savings initiatives. In the past, gold mines carried almost no risk with the implementation of energy savings projects. Suddenly, the implementation cost payback periods become much more important.

In future, gold mines will have to start implementing energy savings initiatives at their own cost. The risk in implementing and maintaining these initiatives will, therefore, shift from the ESCOs to the gold mines. In the modern day era of mining in South Africa, gold mines cannot afford poor return on investments through underperforming initiatives. An energy management framework will, therefore, be required by the gold mining industry as guidance to implement energy savings initiatives and to maintain such initiatives effectively.

Research proved that there is a need for developing an energy management strategy for the deep-level gold mining industry. This strategy will contribute to optimised implementation of energy savings initiatives and provide gold mines with a framework to sustain the performance of such initiatives without the assistance of ESCOs. Additional benefits through an energy management strategy entail the elimination of paying maintenance fees to ESCOs and the ability to realise high return on investments on energy savings initiatives. This will ultimately reduce the electricity portion of gold mine operating costs and increase profitability in the difficult era of South African gold mining.

The following section discusses the contributions of the study by developing an integrated energy management strategy (IEMS) for the deep-level gold mining industry.

1.6 Contributions of the study

1.6.1 Overarching contribution

AN INTEGRATED ENERGY MANAGEMENT STRATEGY FOR THE DEEP-LEVEL GOLD MINING ENVIRONMENT

Problem statement

The gold mining industry experiences several challenges in modern day mining. High electricity usage and the cost thereof is one of the major challenges that ultimately affect mines' sustainability and profit margins. These high operating costs result in non-profitable mining, which ultimately leads to gold mines closing. One method to increase the profit margins of gold mines is to reduce the cost of electricity.

Existing research

Extensive research proved the scarcity of electrical energy management in the global mining environment [44]. A wide variety of electrical energy savings projects and individual energy management initiatives have, however, been implemented over the years on the electricity-intensive components and operations of the gold mining industry. These projects and initiatives positively contributed to a reduction in electricity consumption and energy management concept in the gold mining industry. The author, however, highlights that the target reduction of 10% set through the EES and ECS to the mining industry was missed by 2015 [33].

Limitations of existing research

ESCOs implement energy savings projects with the main aim being to prove the viability to the investor (mostly Eskom). After completion, the projects are handed over to their clients and the ESCOs shift their focus to identifying new projects. Table 1 indicated that this results in existing projects' performances deteriorating. Research further showed that not having an IEMS results in energy savings initiatives not delivering an overall sustainable benefit [46], [47].

Table 2 was used to illustrate the small portion of projects that sustained their performances over the years. It was found that the performance of the majority of these projects is linked to having maintenance agreements with ESCOs and using REMS systems. Table 1 and Table 2 are an indication of the inability of the gold mining industry to maintain the performances of energy savings initiatives without an IEMS [46], [47].

Research further indicated the absence of a holistic approach, which integrates individual energy management initiatives within a comprehensive energy management strategy for the gold mining industry [10], [19], [20], [31], [40], [44], [52], [53], [54]. The impact of these individual implemented initiatives eventually deteriorates and results in ineffective management of electricity consumption patterns of gold mines.

Contribution of this study

There is a need for an energy management framework for gold mines to optimise the implementation of energy savings initiatives and to sustain the performance thereof. Due to the cost of electricity in South Africa, a need also exists to manage electricity consumption effectively and ultimately contribute to profitable gold mining. In order for any institution to accomplish this task, an IEMS needs to be in place [55], [56].

Therefore, the aim and main contribution of this study is developing an IEMS for the deep-level gold mining industry. The main contribution is, however, divided into several sub-contributions. The inner detail of the contributions is provided in the following section.

1.6.2 Classifying the overarching contribution

CONTRIBUTION 1: INTEGRATING EXISTING ENERGY MANAGEMENT BEST PRACTICES WITHIN A NEW COMPREHENSIVE STRATEGY

Problem statement

Individual energy savings and management initiatives are implemented on the electricity-intensive components and operations of the gold mining industry. These initiatives are implemented haphazardly without a structured approach to optimise the benefits from implementation. Without a structured energy management framework the complexity of managing energy is increased and results in inefficient implementation of energy savings initiatives with non-sustainable electrical energy performance.

Existing research

Studies have been compiled on different initiatives and technologies that positively contributed to the concept of energy management in the gold mining industry. Table 3 provides a summary of the studies and the portion of energy management in the gold mining industry addressed through each study. The details of each study and its incorporation within the integrated energy management strategy are discussed in Chapter 2 and Chapter 3.

Table 3: Studies contributing to energy management in the gold mining industry

Gold Mining Energy Management Initiatives		
Citation	**Study**	**Portion of Energy Management Addressed**
[10]	A performance-centred maintenance strategy for industrial DSM projects	Planning, ISO 50001, Maintenance
[19]	Improving DSM project implementation and sustainability through ISO standards	Planning, ISO 50001, Implementing new initiatives
[20]	Modelling of electricity cost risks and opportunities in the gold mining industry	Planning, ISO 50001, Systems analysis, Reporting
[31]	An integrated energy-efficiency strategy for deep-mine ventilation and refrigeration	Implementing new initiatives, System inefficiencies
[32]	Reconfiguring mining compressed air networks for cost savings	Systems analysis, Reconfiguring designs
[37]	Optimising the demand of a mine water reticulation system to reduce electricity consumption	System inefficiencies
[40]	An integrated approach to optimise energy consumption of mine compressed air systems	Implementing new initiatives, System inefficiencies
[52]	Development of a supervisory system for maintaining the performance of remote energy management systems	Reporting
[53]	Measurement and verification of industrial DSM projects	Measurement & verification
[54]	A structured approach to select energy efficiency incentives applicable to industry	Optimisation
[57]	Verification procedures to ensure consistent energy metering	System inefficiencies, Measurement & verification
[58]	Sustaining compressed air DSM project savings using an air leakage management system	System inefficiencies
[59]	Converting an ice storage facility to a chilled water system for energy efficiency on a deep-level gold mine	Reconfiguring designs
[60]	Energy savings on mining compressed air networks through dedicated process plant compressors	Reconfiguring designs
[61]	A customisable data analysis interface for an online electrical energy information system	Planning, ISO 50001, Reporting

Limitations of existing research

From Table 3 it can be seen that each study focuses on individual electricity-consuming systems or addresses portions of energy management within the gold mining industry. There is no structured approach available in literature that integrates these initiatives within a comprehensive energy management strategy.

Contribution of study

For the first time, these individual energy management initiatives are combined within an IEMS. Figure 12 represents the IEMS and the contribution of each study to the development of the strategy.

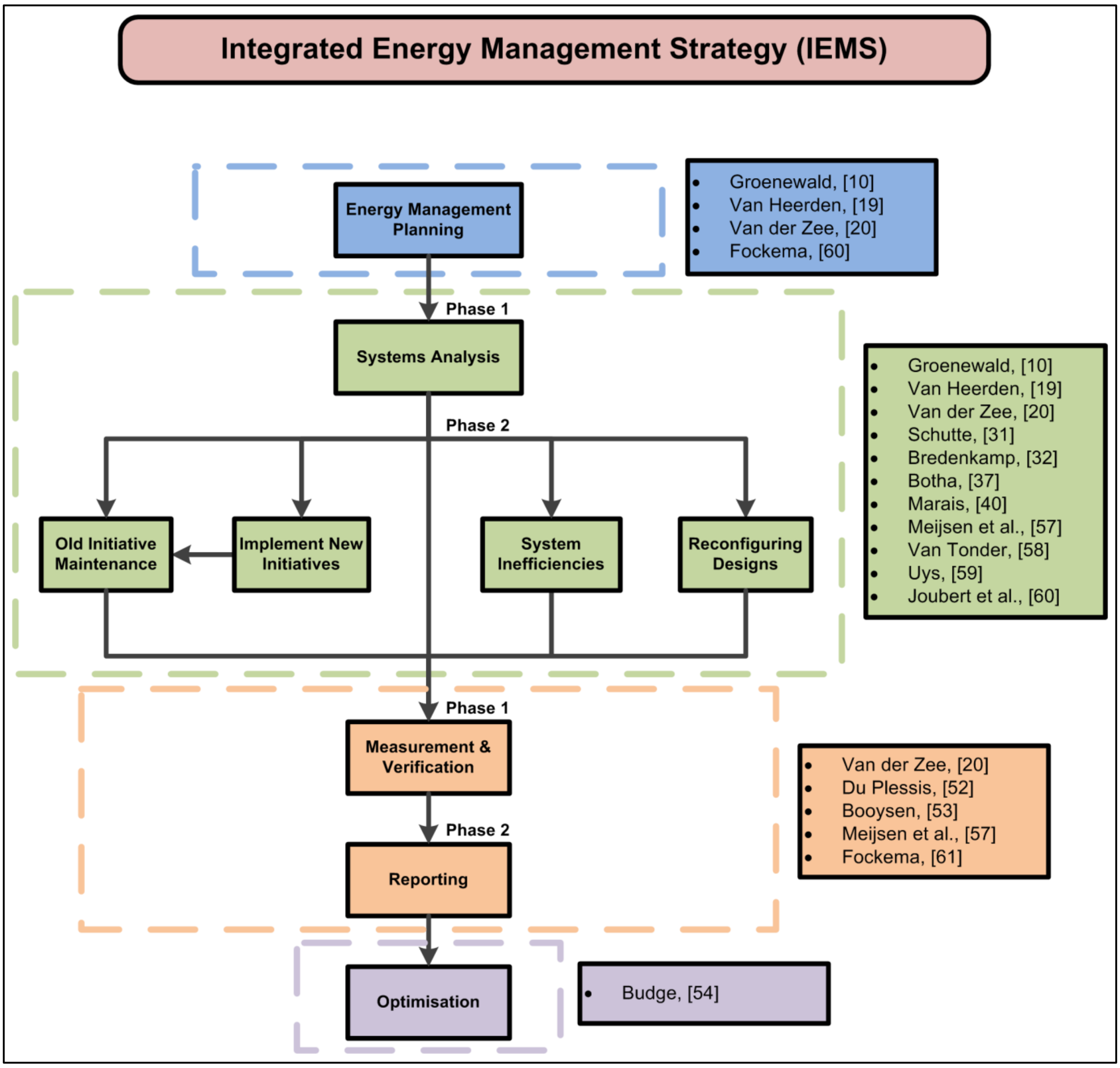

Figure 12: Integrating energy management initiatives within a comprehensive strategy

As depicted by Figure 12, the different contributions to energy management in the gold mining industry were structured to form a holistic approach. The holistic approach ensures a link between the initiatives and provides a structured procedure for electrical energy management in the gold mining industry.

CONTRIBUTION 2: STRATEGIC DEVELOPMENT OF A NOVEL ENERGY MANAGEMENT STRATEGY IN LINE WITH THE ISO 50001 STANDARD

Problem statement

Organisations around the globe are increasingly using the ISO 50001 energy management standard to improve electrical energy performance [62]. This is mainly due to the effectiveness of the ISO 50001 framework in reducing energy consumption patterns. Research, however, proved the scarcity of ISO 50001-compliant energy management in South Africa [63]. By 2013, only four[10] ISO 50001-certified sites have been identified in South Africa. For the South African gold mining industry, in particular, ISO 50001-compliant energy management and certification is a vague topic [19], [20].

Existing research

Referring to Table 3, some of the studies align with the Plan-Do-Check-Act (PDCA) cycle of the ISO 50001 standard. The incorporation of ISO 50001 within these initiatives can be summarised as follows:

1. Van Heerden implemented DSM projects using ISO 50001 standards [19], [56].
2. Groenewald developed a performance-centred maintenance (PCM) strategy according to the continuous PDCA cycle of ISO 50001 [10], [56].
3. Van der Zee developed an ISO 50001-compliant electrical energy reporting procedure for the gold mining industry [20], [56].
4. Fockema designed a data analysis system, which satisfied the “Check” and “Act” phases of the PDCA cycle [61], [56].

Limitations of existing research

The PDCA cycle was used to realise continual improvement of individually implemented initiatives that are not applicable to electrical energy management as a whole. ISO 50001-compliant energy management of a gold mining group entails much more than,

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[10] Data received from the “ISO Survey 2013” for the period 2011–2013.

for example, improving a reporting process continually. Furthermore, no evidence was found in literature regarding attempts to obtain ISO certification for these processes.

Contribution of this study

There is a shortfall in available research to incorporate all of the abovementioned initiatives within a single ISO 50001-compliant energy management strategy. The author will develop the strategy according to the continual improvement PDCA cycle of ISO 50001 and incorporate all available energy management initiatives in the different phases of the strategy. Figure 13 illustrates the development of the IEMS aligned with the ISO 50001 energy management standard.

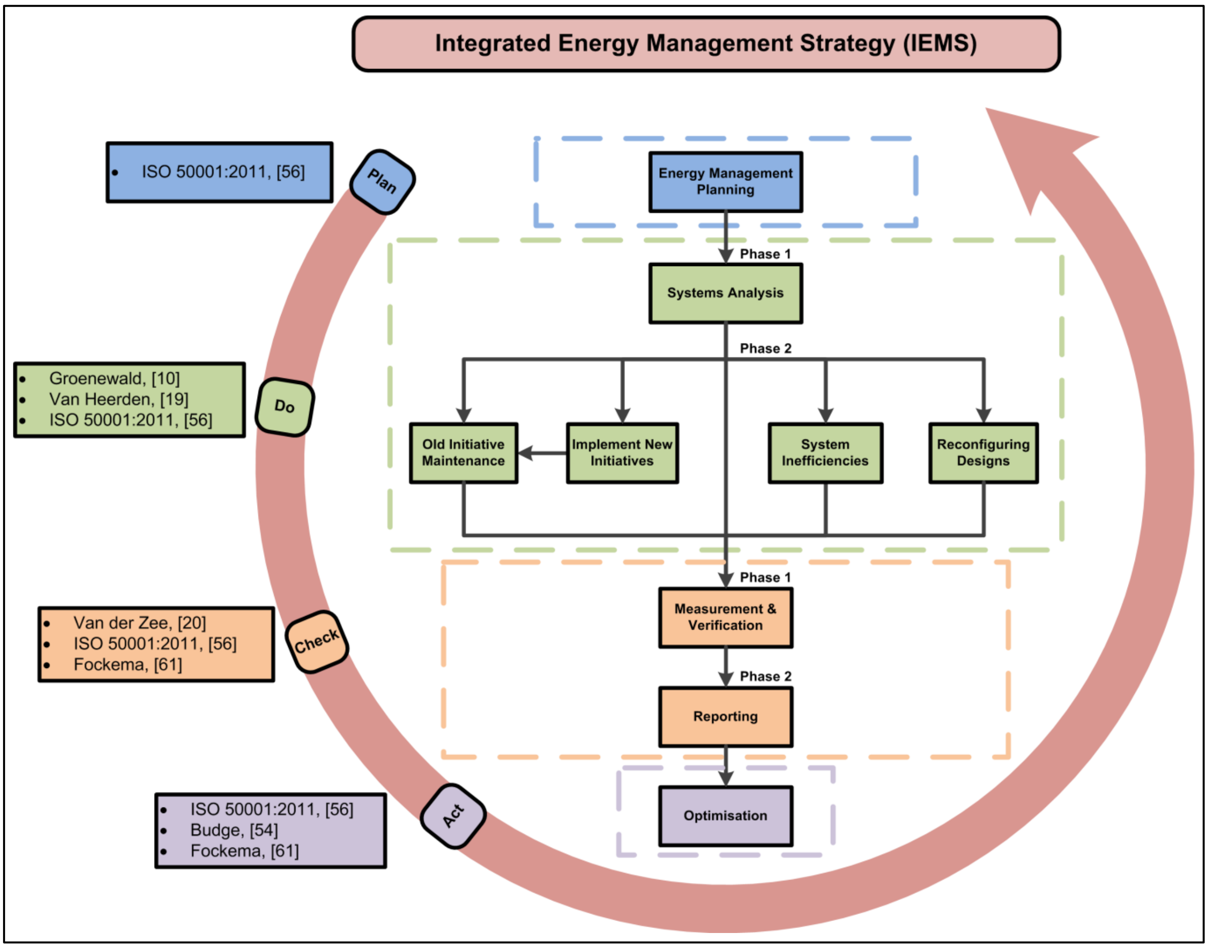

Figure 13: IEMS in line with the ISO 50001 energy management standard

Developing the strategy according to ISO 50001 standards not only enables gold mining groups to manage their energy effectively, but also allows them to become eligible for ISO 50001 certification.

CONTRIBUTION 3: NOVEL STEP-BY-STEP PROCEDURE FOR GOLD MINE ENERGY MANAGEMENT TEAMS TO IMPLEMENT THE INTEGRATED ENERGY MANAGEMENT STRATEGY

Problem statement

According to literature, the core aspect of implementing successful energy management is to have a well-documented plan [44], [62]. Gold mining groups only have limited energy management plans (EnMPs) in place to counter ever-growing electricity costs [20]. Energy management teams (EMTs), therefore, do not have frameworks or guidelines for implementing energy management effectively. Without guidance, it is also difficult for EMTs to commence with energy management without any assistance or guidance along the way.

Existing research

No literature could be found on sequenced procedures as a guideline for gold mine EMTs to practise effective electrical energy management.

Limitations of existing research

The research compiled through Table 1, Table 2 and Table 3 proves the absence of energy management in the gold mining industry, hence, the absence of documented step-by-step procedures.

Contribution of this study

The IEMS provides the EMTs of gold mineshafts with a step-by-step procedure for implementing and maintaining effective electrical energy management. The PDCA cycle of the strategy also ensures continual improvement of energy performance and sustainability of implemented initiatives. The procedure will also enable gold mining groups to function without the involvement of ESCOs.

The IEMS also adheres to a documented process. In cases where new EMTs are appointed, the documented procedure will ensure an efficient transition from the predecessors to newly appointed team members. In turn, this will ensure sustainable energy performance.

CONTRIBUTION 4: UNIQUE BENCHMARKING MODEL FOR SEQUENCING THE IMPLEMENTATION OF THE INTEGRATED ENERGY MANAGEMENT STRATEGY AT MINESHAFTS

Problem statement

During the IEMS implementation, the challenge arises for a gold mining group to identify shafts for electrical energy improvements that would realise the largest impact in the shortest period.

Existing research

Van der Zee is of the opinion that one would typically commence with electrical energy performance improvements at the mineshaft with the highest electrical input per tonne of processed ore (kWh/t) [20].

Limitations of existing research

This conventional method is not always sufficient as numerous factors such as mine depth, ore grades, magnitude of operations and electricity intensity influence the productivity and energy efficiency of gold mines. Although kWh/t is an accurate estimation of the shafts' energy performance, it does not necessarily mean that maximum financial benefits will be obtained from these shafts.

Contribution of this study

The author developed a benchmarking model for gold mining groups to easily sequence the IEMS implementation at different mineshafts. The model considers the kWh/t, operating cost, operational size and electricity intensity of mineshafts for the most beneficial implementation sequence of the IEMS within a mining group. Figure 14 depicts a simplified layout of the developed benchmarking model.

The benchmarking model is based on identifying the mineshaft with the largest cost-savings potential within a mining group for the implementation of the IEMS. The remainder of the shafts are then sequenced from those with the largest potential for implementation to those with the least potential for implementation. The inner details of the model's functionality are discussed in Section 3.3.2 of this document.

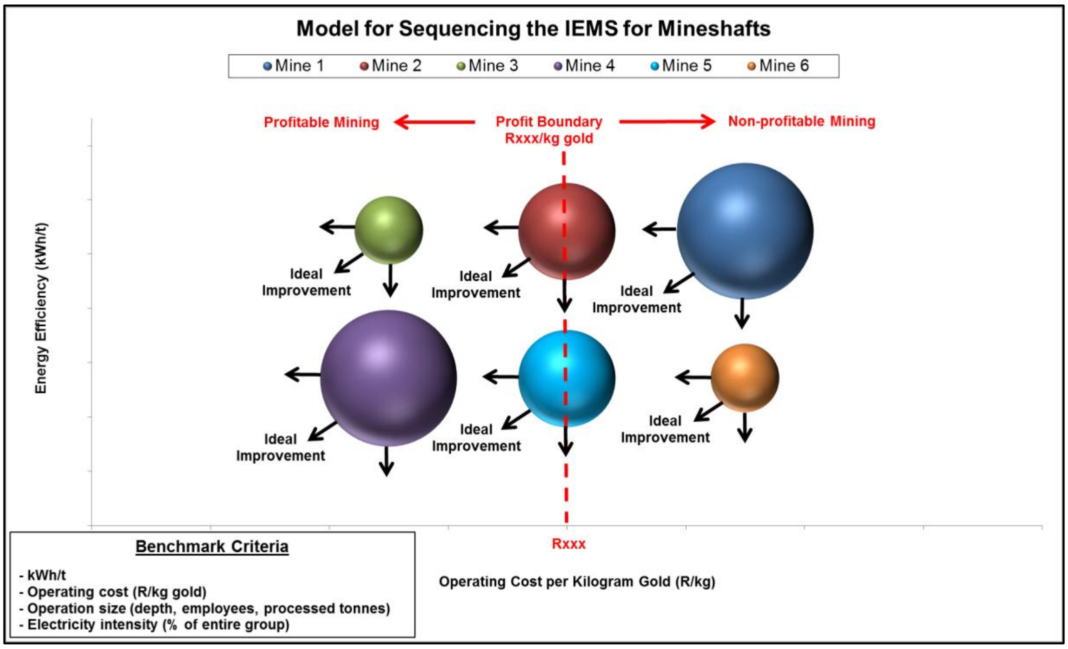

Figure 14: Benchmarking model for sequencing the IEMS at mineshafts

The model proved that the maximum benefits for a gold mining group are not necessarily realised at the most inefficient shafts, but rather at the shafts with the largest electricity cost-savings potential. The sequencing model can be used by gold mining groups to strategically select a mineshaft where IEMS implementation should commence. The model is also convenient for sequencing the order in which the IEMS should be implemented across all the shafts within the mining group.

CONTRIBUTION 5: UNIQUE SEQUENCING MODEL FOR OPTIMISED IMPLEMENTATION OF DIFFERENT ENERGY SAVINGS INITIATIVES AT MINESHAFTS

Problem statement

During the implementation of energy savings initiatives on gold mines, the challenge arises to implement the initiative with the highest benefits at the lowest risk. For example, it would be impractical to implement a complex initiative with a one-year implementation period at a cost of R5 million if the realised financial cost savings is only R500 000 per annum. The payback period for this example initiative will be at least 10 years with the risk of the mine’s lifespan not allowing this period.

Existing research

The majority of energy savings projects implemented by ESCOs in the gold mining industry was and still is Eskom-funded. The conventional method for ESCOs, therefore, is to implement energy savings projects at a minimum financial input with maximum output [32], [38], [40], [64]. The return on investment risk is on the investor (Eskom) and not the ESCO or the client.

Limitations of existing research

Using the Eskom model for project funding eliminates the need for gold mines to calculate the actual risk of the project in terms of implementation cost, time, difficulty, design complexity and return on investment. The general norm for mines is to accept that the ESCO will deal with these risks and that the mine will benefit from the savings. This seems like a win-win situation, but if the gold mining industry wants to manage electrical energy on its own, a risk analysis for the implementation of these initiatives is required to optimise cost-savings potential.

Contribution of this study

The author developed a sequencing model for EMTs at gold mineshafts to sequence the implementation of energy savings initiatives on the different electricity consuming systems. The basis of the model is to identify the implementation of energy savings initiatives on individual mining systems with the lowest risk and largest cost-savings potential first. The sequencing model is used further to prioritise the remaining initiatives to claim the maximum benefits in a chronological order. Table 4 illustrates an example of the sequencing model and the criteria against which all the initiatives are evaluated.

Table 4: System sequencing model for implementing energy savings initiatives

Energy Savings Initiative Sequence Analysis				
Implementation Criteria	**Old Initiative Maintenance**	**System Inefficiencies**	**New Initiatives**	**Reconfiguring Designs**
Cost	Low	Moderate–High	Moderate–High	High
Time	Low	Low	Moderate–High	High
Complexity	Moderate	Moderate–High	Moderate–High	Moderate–High
Difficulty	Low	Low	Moderate–High	Moderate–High
Benefits	Moderate–High	Moderate–High	Moderate–High	Moderate–High
Sequence (Low Risk–High Risk)	**1**	**2**	**3**	**4**

Key				
Cost	R0–R100 000	R100 000–R1 000 000	R100 000–R5 000 000	R5 000 000 +
Time	1 month	1–3 months	1–6 months	6 months +
Complexity	Low	Moderate	Moderate–High	High
Difficulty	Low	Moderate	Moderate–High	High
Benefits (MW)	0–0.5	0.5–1	0.5–5	5 +
	Low	**Moderate**	**Moderate - High**	**High**

The sequencing model is generic and can be used for all the different systems (compressed air, refrigeration, dewatering etc.) at a gold mine. This creates a high level of convenience for

EMTs to evaluate risks of different initiatives on different mining systems. All of this contributes to an optimised solution in terms of an IEMS for the deep-level gold mining industry.

1.7 Outline of study

Chapter 1 introduced modern day gold mining in South Africa and the factors influencing its production patterns. Electricity, as one of the major operating expenses, and the availability of existing electrical energy management strategies to mitigate the impact are examined. The lack of an IEMS was identified and the need for the study was formulated. Finally, the contributions of the study were stipulated.

Chapter 2 investigates the ISO 50001 standard as an available framework to energy management practices in the industry. The general fundamentals to energy management planning are discussed and the relation to gold mining is stipulated. Extensive literature is provided on the implementation of energy management initiatives and credible procedures to verify the energy savings impact thereof. The chapter concludes with the importance of optimisation techniques to fully benefit from implemented energy management strategies.

Chapter 3 focuses on using the information gathered in Chapter 2 for developing an IEMS for the deep-level gold mining industry. The PDCA cycle of the ISO 50001 energy management standard is used as the framework for the development of the IEMS. The “Plan” step of the cycle entails energy management planning, while the “Do” step executes these plans. The executed plans are verified and reported during the “Check” step. The final step of the cycle focuses on optimising the IEMS implementation for maximised benefits.

In **Chapter 4,** the developed IEMS is implemented on one of South Africa’s largest gold mining groups (Group A). The implementation validates the continual impact of the developed IEMS on the electrical energy performance of practical systems in the gold mining industry.

Chapter 5 concludes the study by highlighting the need for an IEMS for the deep-level gold mining industry and provides an overview of how the need was addressed. The contributions of the study are highlighted. Finally, the limitations of the study and recommendations for future work on energy management in the gold mining industry are provided.

CHAPTER 2

11

“Excellence is in the details. Give attention to the details and excellence will come.” – Perry Paxton

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[11] http://www.mining-technology.com/features/feature-top-ten-deepest-mines-world-south-africa/.

2 ENERGY MANAGEMENT APPLICATIONS IN THE DEEP-LEVEL GOLD MINING INDUSTRY

2.1 Introduction

A need for an IEMS for the deep-level gold mining industry was identified in Chapter 1. The next step is to investigate available research that contributed specifically to the concept of energy management in the gold mining industry. Through the research, one will be able to identify the lack of a holistic approach to integrate these initiatives to form an energy management strategy.

Chapter 2 provides an overview of the key elements an energy management strategy for the gold mining industry should entail. The most important element is to conform to the continual PDCA cycle of the ISO 50001 energy management standard. Further elements include energy management planning fundamentals, executing energy management initiatives, verifying and reporting the results of the executed plans and optimising energy management for continual improvement.

The abovementioned elements are structured and discussed according to their compatibility within the PDCA cycle of ISO 50001. It is important to note that the structure of Chapter 2 does not indicate the existence of a holistic energy management strategy in the gold mining industry, but rather individual studies combined by the author to indicate the possibility. The research solely provides the knowledge and background in a structured manner to be able to develop an IEMS in line with the ISO 50001 energy management standard.

2.2 Standardising energy management

2.2.1 International Organization for Standardization

The International Organization of Standardization (ISO) is a global voluntary organisation originating in the 1940s [19], [55]. Its main purpose is developing standards and fundamental requirements for businesses and organisations around the globe [19], [55], [65]. These standards serve as frameworks and guidelines to effectively manage sustainable economic, social and environmental development of businesses and organisations [19], [55], [56]. Today, ISO has grown to the world’s largest federation specialising in the development of international standards with over 19 600 published standards [19].

ISO standards can be used by any organisation, large or small, in the private or public sectors [62]. There are no limitations to the use of ISO guidelines and businesses may use these standards to best suit the need of their own structures and processes [56]. Regardless of the procedure businesses follow in the implementation of ISO standards, the main goal should be to help the business with [19], [65]:

1. increasing productivity;
2. creating access to new markets;
3. reducing operating costs;
4. increasing profitability;
5. improving quality of delivered services and products;
6. improving customer demands and sales;
7. enhancing global competitiveness; and
8. reducing environmental impact.

As discussed, over 19 600 standards have been published to date. This study focuses on a new member of the ISO family, namely: ISO 50001. The ISO 50001 energy management standard has been developed with the help of elements derived from the ISO 9001 quality management standard and the ISO 14001 environmental management standard [19], [66]. These three standards share a high level of compatibility and ISO 50001 aligns with the requirements of ISO 9001 and ISO 14001 [56], [66]. It is, therefore, important to keep the ISO 9001 and ISO 14001 standards in mind while scrutinising ISO 50001 and the incorporation thereof within this study.

2.2.2 ISO 50001 energy management standard

ISO 50001 is an energy management standard, published in 2011, presenting guidelines and requirements for the implementation of an energy management system (EnMS) [19], [56]. The standard is based on a continual improvement process, which is generally referred to as the PDCA cycle [56], [66]. Each step of the PDCA cycle consists of several processes, which ultimately serve as a framework for organisations to implement effective energy management and continually improve the procedure. Figure 15 illustrates the PDCA cycle, followed by an explanation of each step [19], [56], [66].

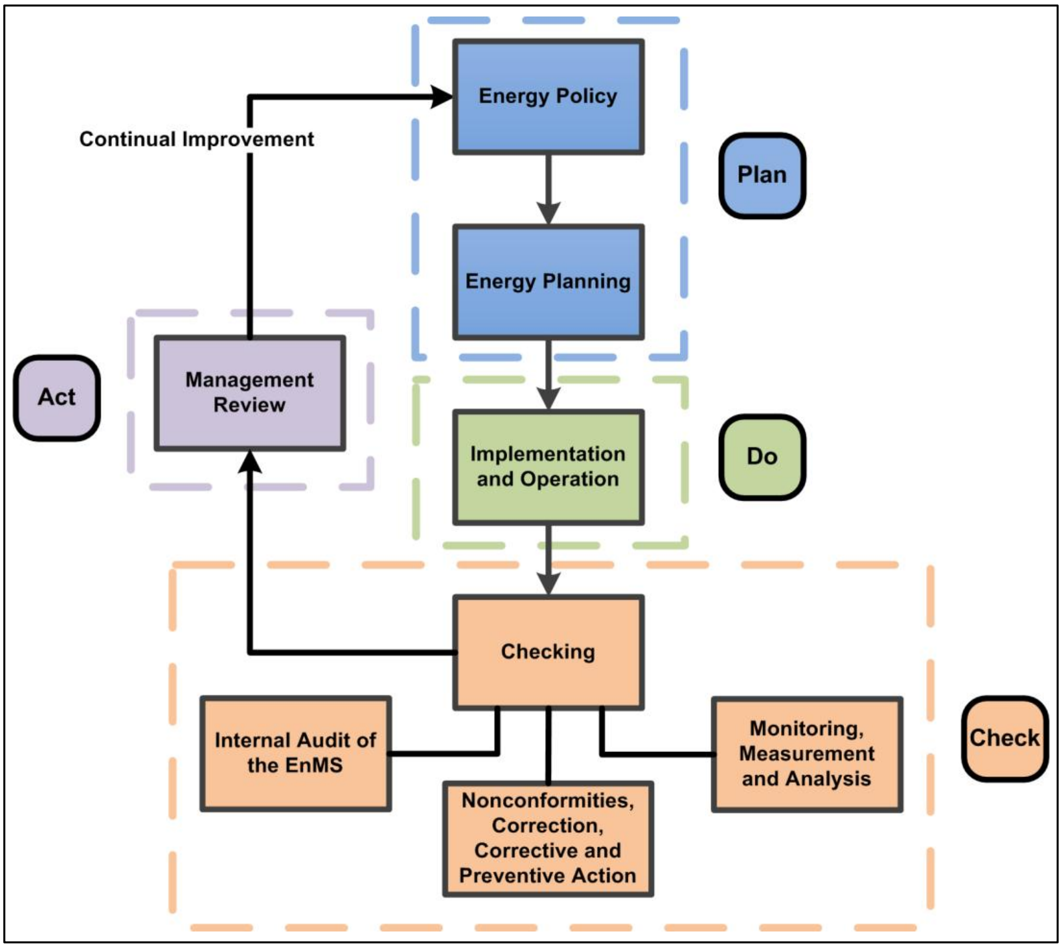


Figure 15: PDCA cycle of the ISO 50001 energy management standard

Plan

The main processes during the planning phase of the cycle, as defined by the standard, are the following [56], [62]:

1. developing an energy policy;
2. conducting energy reviews;
3. benchmarking;
4. developing an energy baseline;
5. identifying the energy performance indicators (EnPIs);
6. stating and defining the objectives and goals; and
7. developing EnMPs.

All of the abovementioned processes should be developed and implemented in accordance with the newly developed or existing energy policy [56].

Do

The second step of the PDCA cycle entails:

1. implementing the developed EnMPs.

During the "Do" phase, the user uses the outputs of the planning phase as action plans to improve the energy performance of the organisation [56], [62], [66].

Check

This phase refers to measuring, verifying and communicating the results to relevant stakeholders. The "Check" phase is divided into the following processes [56], [62]:

1. measuring the performances of implemented plans;
2. monitoring the performances of implemented plans;
3. identifying the characteristics of energy performances against the energy policy and objectives developed during the planning phase;
4. conducting internal audits of the EnMS;
5. identifying nonconformities, correcting them and developing preventive action plans; and
6. reporting the results.

Act

The final phase refers to any actions taken in an attempt to continually improve the performance of the implemented EnMS [56]. This phase includes the following processes [56], [62]:

1. reviewing EnMS (inputs) by members of top management;
2. keeping records of the management inputs; and
3. implementing the outputs of the management reviews.

The PDCA cycle of ISO 50001 provides an energy management framework for organisations to establish, implement, maintain and continually improve energy performance to maximise cost-savings potential [56], [62], [66]. It is important to note that the standard has no predefined objectives and does not specify energy performance criteria for the user [19], [66]. The framework is merely a guideline that can be adopted by users to best meet their requirements and energy performance standards [66].

Regardless of the manner with which the ISO 50001 guideline is incorporated within an organisation's EnMS, it helps the user accomplish the following [19], [66]:

1. reducing energy consumption and carbon emissions;
2. gaining a clear understanding of energy usage patterns and statuses;
3. identifying and understanding the need for objectives and targets to achieve certain goals;
4. creating energy awareness within an organisation's resource hierarchy;
5. realising the impact of energy consumption on the organisation's economic stability;
6. promoting, understanding, evaluating and prioritising the implementation of energy savings technologies;
7. understanding the concepts of benchmarking, monitoring, measuring, documenting and reporting of energy use;
8. managing the use of energy-consuming assets;
9. reducing maintenance costs;
10. demonstrating the organisation's commitments to protect the environment to stakeholders;
11. complying with the associated regulatory requirements;
12. responding positively to green trade barriers in the global market;
13. improving the organisation's energy performance continually; and
14. obtaining certification for compliance with ISO 50001.

Companies and organisations around the globe are increasingly using ISO 50001 to reduce their energy consumption and carbon emissions. Some are of the opinion that ISO 50001 will be the next global highlight, following ISO 9001 and ISO 140001 [67]. According to the Organisation for Economic Co-operation and Development (OECD), more than 7 300 sites worldwide have obtained their ISO 50001 certifications by May 2014 [62]. This was an increase of approximately 232% from March 2013. The increase rate is expected to accelerate further in the near future [62]. Figure 16 depicts the increase in sites that have obtained their ISO 50001 certifications since the establishment of the standard in 2011 [62].

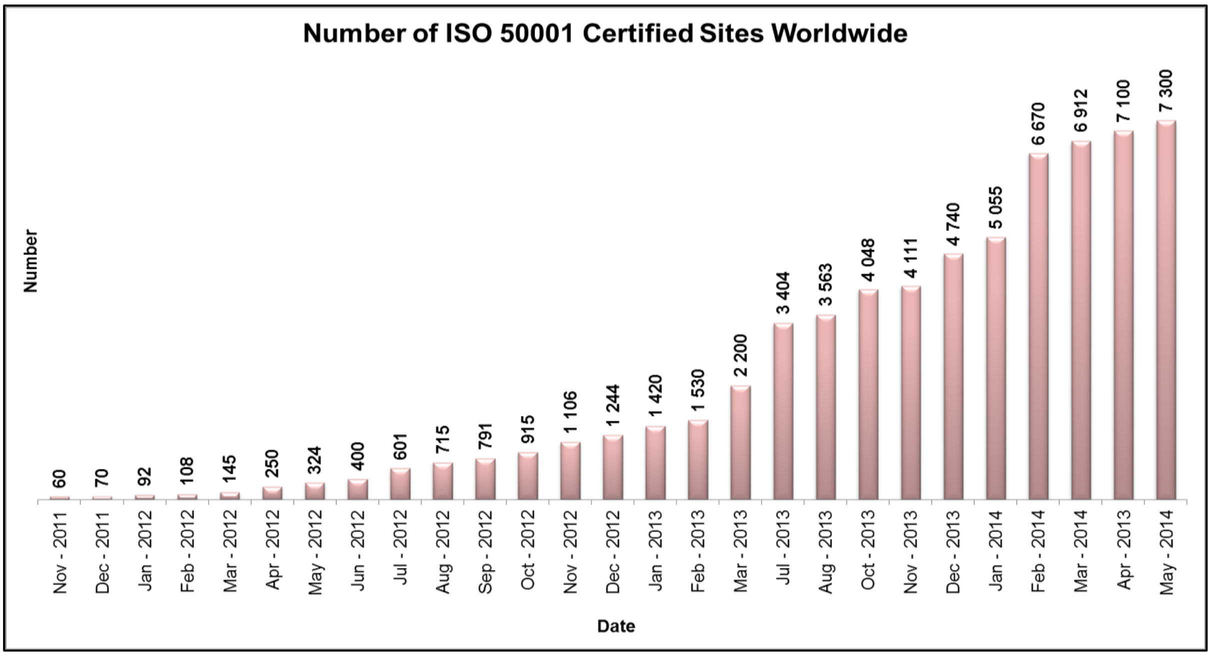


Figure 16: Increasing number of ISO 50001 certifications worldwide

It becomes evident from Figure 16 that complying with ISO 50001 is increasingly becoming a priority for organisations around the globe. For the majority of organisations, the reasons are the following [62]:

1. effectiveness of adopting the ISO 50001 standard within the organisations’ EnMSs;
2. measure to reduce energy consumption and related costs; and
3. pressure from global authorities to reduce greenhouse gas emissions.

This section focused on the particulars of the ISO 50001 standard and its generic compatibility and positive impact on an organisation’s EnMS. The drivers for organisations to implement ISO 50001-compliant EnMSs within their business structures were provided in the preceding paragraph. The following section focuses on ISO 50001 energy management case studies within the industrial sector. The focus is on validating the research compiled during this section and motivating the use of an ISO 50001 framework during the development of an IEMS for the gold mining industry.

2.2.3 ISO 50001 energy management in the industry

2.2.3.1 Preamble

It is stated that ISO 50001 could influence up to 60% of the global energy use across various economic sectors [19], [68]. Some claim that ISO 50001 implementations have helped to reduce energy costs in industrial facilities with approximately 10% after only 18 months [68].

Others claim that implementing a properly maintained EnMS could reduce the energy consumption patterns by 10–30% within several months [62].

A wide range of studies has been conducted on the effectiveness of ISO 50001-compliant EnMSs. Some of these studies were investigated to obtain a general idea of the application of ISO 50001 on EnMSs in the industry. The studies also investigate the likelihood of energy costs savings by implementing an ISO 50001-compliant EnMS.

The case studies are divided into two categories, namely: ISO 50001 energy management implementations worldwide and implementations in South Africa. The aim of the two categories is to particularly identify South Africa's contribution to the use of ISO-compliant EnMSs, as ISO 50001 is a relatively vague topic for organisations in South Africa [63]. This will in turn highlight the uniqueness of developing an IEMS for the deep-level gold mining industry in line with the ISO 50001 energy management framework.

2.2.3.2 ISO 50001 energy management implementations worldwide

Study 1 (Application of ISO 50001)

Schulze et al. developed a conceptual framework for implementing an ISO-compliant energy management strategy in the industrial sector. Figure 17 presents a simplified layout of the energy management framework [44].

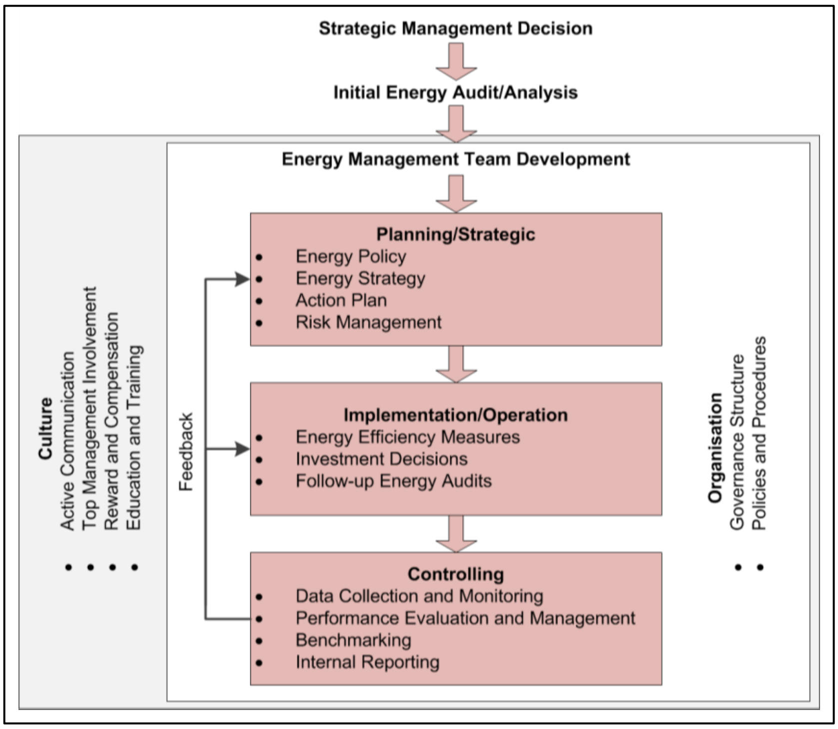


Figure 17: Conceptual framework for an integrative EnMS

The framework is based on the PDCA cycle of ISO 50001 [44]. Schulze et al. mentioned that the comprehensive nature of the framework provides a wide range of industrial organisations with an effective guideline to realise energy efficiency within short periods of time [44]. One important shortcoming of the framework by Schulze et al. is that it does not compensate for contingency factors such as production [44]. Schulze et al. clearly stated in their study that production highly affects the procedure of implementing proper energy management [44].

Schulze et al. further mentioned that the energy consumption patterns of energy-intensive industries are mostly production-related [44]. Gold mining is one of these industries and the developed framework can, therefore, not be adopted without modifications. At the time of the study, the energy management framework had also not yet been implemented on actual case studies. Therefore, no validation data was available to validate the actual impact on an organisation's energy performance.

Study 2 (Application of ISO 50001)

Dzene et al. investigated the sustainability of energy management action plans (EnMAPs) by applying the ISO 50001 standard. A case study was compiled for the Saldus municipality in Latvia, Europe [69]. The basis of the study's methodology was to use existing EnMAPs of the municipality and incorporate the requirements and procedures of the ISO 50001 standard [69].

Implementing the methodology helped the Saldus municipality to develop effective data management procedures and to clearly identify EnPIs [69]. Dzene at al. mentioned that by incorporating ISO 50001 procedures, the municipality was finally able to effectively manage and implement their existing EnMAPs [69]. The results were, however, not provided in the study.

Dzene et al. concluded their study by highlighting the importance of an energy management plan to obtain sustainable energy performance [69]. Existing EnMAPs are a good basis to work from when implementing the ISO 50001 energy management standard [69]. Dzene et al. also mentioned a very important factor that would be useful for facilitating energy management standards in the municipal environment – it is a step-by-step guideline for municipalities to implement certified EnMSs. [69]. Dzene et al., however, did not develop the guideline.

Study 3 (Application of ISO 50001)

Javied et al. investigated the energy efficiency improvements that an effective EnMS offered the German manufacturing industry. According to Javied et al., numerous energy management techniques, guidelines and standards exist in available research, but an approach for implementing them is scarce [70]. The aim of their study was, therefore, to develop a structured and systematic approach for the German manufacturing industry to implement an EnMS [70]. The approach abides with the PDCA cycle of ISO 50001 to ensure continual improvement of energy management (depicted by Figure 18) [70].

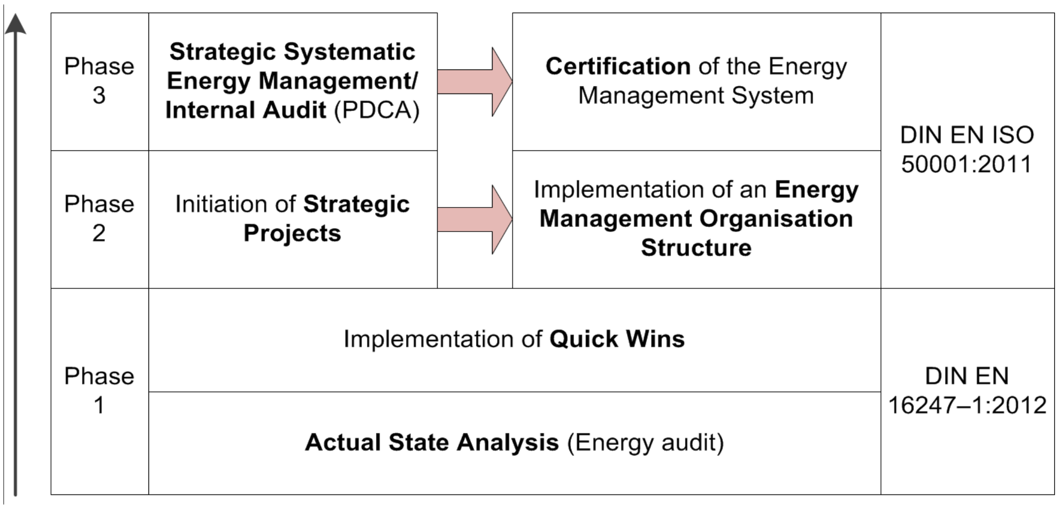


Figure 18: ISO 50001-compliant EnMS for the German manufacturing industry

No clear indication was given whether the approach was implemented on actual case studies. Therefore, no results were documented to determine the effectiveness of the approach. Javied et al., however, concluded the study by reiterating the importance of an EnMS to improve the energy efficiency performance of the German manufacturing industry.

Study 4 (Application and results through ISO 50001)

Gopalakrishnan et al. conducted a study on energy management in the manufacturing sector. The study mainly focused on a structured approach to help incorporate the ISO 50001 standard in this sector [71]. In addition to the study by Javied et al., Gopalakrishnan et al. developed a software tool (ISO 50001 Analyzer) which facilitated the development of a robust ISO 50001-compliant EnMSs for this sector [71]. The tool provides manufacturing plants with the required information and assistance to comply with the ISO 50001 standard and requirements [71].

The ISO 50001 Analyzer software was implemented on numerous sites in the manufacturing industry. With the implementation of the software, manufacturing plants were able to thoroughly understand the scope of work (requirements) in obtaining ISO 50001 certification [71]. The tool provided plant engineers with step-by-step guidance to fulfil these requirements to comply with ISO 50001, which ultimately aided with certification efforts [71].

Gopalakrishnan et al. further mentioned that the facilities where ISO 50001 Analyzer was implemented realised electrical energy savings of 2–5% on an annual basis. The payback periods on these investments were recorded to be less than two years [71]. Gopalakrishnan et al. concluded the study by stating the effectiveness of ISO 50001 and the impact it had on the development of an EnMS [71].

Study 5 (Results through ISO 50001)

The Minntac taconite pellet-manufacturing facility in the United States of America implemented an ISO-compliant EnMS in an attempt to reduce operating costs and carbon emissions. By implementing the EnMS and effectively managing their energy consumption, the facility realised an annual electrical cost saving of $760 000 [62]. A 6% reduction in nitric oxide gas emissions was also realised. Further financial savings of $30 000 per annum were realised by reduced maintenance labour costs [62]. The implementation costs of the initiative were estimated at $1.2 million, which left the facility with an eighteen-month payback period.

2.2.3.3 ISO 50001 implementation in South Africa

Study 1 (Application and results through ISO 50001)

Van Heerden developed an EnMS for implementing DSM projects in the mining environment [19]. The EnMS was developed to provide ESCOs with a step-by-step procedure for implementing DSM projects effectively [19].The procedure aligns with the PDCA cycle of ISO 50001 to ensure maximised energy savings potential during the implementation of the projects [19]. Incorporating the procedure with the PDCA cycle also ensures continual improvement of the implementation procedure [19].

Van Heerden’s ISO 50001-compliant procedure was used during the implementation of eight DSM projects in the mining industry – realising an overall electricity cost saving of approximately R18 million per annum [19]. Van Heerden concluded her study by confirming that an ISO 50001 framework improves the quality and sustainability of DSM project implementation [19].

The inner detail of Van Heerden’s study is discussed in Section 2.4 of this document as it forms an integrative part of the IEMS development.

Study 2 (Application and results through ISO 50001)

Groenewald developed an ISO 50001-compliant strategy to maintain the electricity cost-saving performances of implemented industrial DSM projects, which include the gold mining industry [10]. The PDCA cycle of ISO 50001 forms the basis of the strategy and provides ESCOs with a sequenced strategy to maintain the performances of implemented projects [10]. The PDCA cycle also ensures the continual improvement and sustainability of project performances.

Groenewald's strategy was implemented on ten underperforming industrial DSM projects. It was proven that the performances of the projects increased with approximately 65% on average with the implementation of the strategy [10]. Groenewald also mentioned the continual improvement of project performances as a result of the PDCA framework of the ISO 50001 standard [10].

The inner detail of Groenewald's study is discussed in Section 2.4 of this document as it forms an integrative part of the IEMS development.

Study 3 (Application of ISO 50001)

Van der Zee, Du Plessis and Fockema developed reporting procedures for implementing energy savings initiatives in the mining environment [20], [52], [61]. The reporting procedures were developed in line with the requirements of the ISO 50001 standard [20], [52], [61]. The authors mentioned in all three of the respective studies that the standard simplifies reporting procedures and therefore contributes to effective energy management [20], [52], [61]. Developing reporting procedures in line with the ISO 50001 standard also ensures improved sustainability and performance of implemented initiatives [20].

No results for the reporting procedures were available and the impact of ISO 50001 could not be verified. These studies are, however, further discussed in Section 2.5 as they form an integrative part of the IEMS development.

Study 4 (Application and results through ISO 50001)

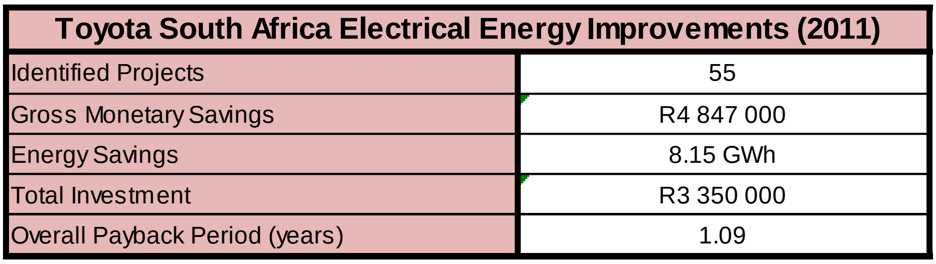
ArcelorMittal, a multinational steel manufacturing corporation in South Africa, implemented an EnMS as part of its Internal World Class Manufacturing Programme [62]. The implemented EnMS was aligned with the standard and requirements of ISO 50001 and focused on implementing system optimisation measures to improve energy efficiency [62].

It is claimed that ArcelorMittal realised a financial cost saving of approximately R98 million in 2011 by adopting an ISO 50001-compliant EnMS [62]. ArcelorMittal invested approximately R500 000 in the implementation of this initiative, which made the payback period just over four production days [62].

Study 5 (Application and results through ISO 50001)

As part of their Industrial Energy Efficiency project, Toyota South Africa (among other automotive manufacturers) welcomed energy management within its organisation. Toyota South Africa developed an EnMS aligned with the PDCA cycle of ISO 50001 [72]. Top management of Toyota South Africa confirmed that the main reason for conforming to the ISO 50001 standard was to develop a structure for effective implementation of its EnMS [72]. Table 5 gives a summary of the results achieved by Toyota South Africa after one year of ISO 50001-aligned energy management.

Table 5: ISO 50001-compliant energy management results



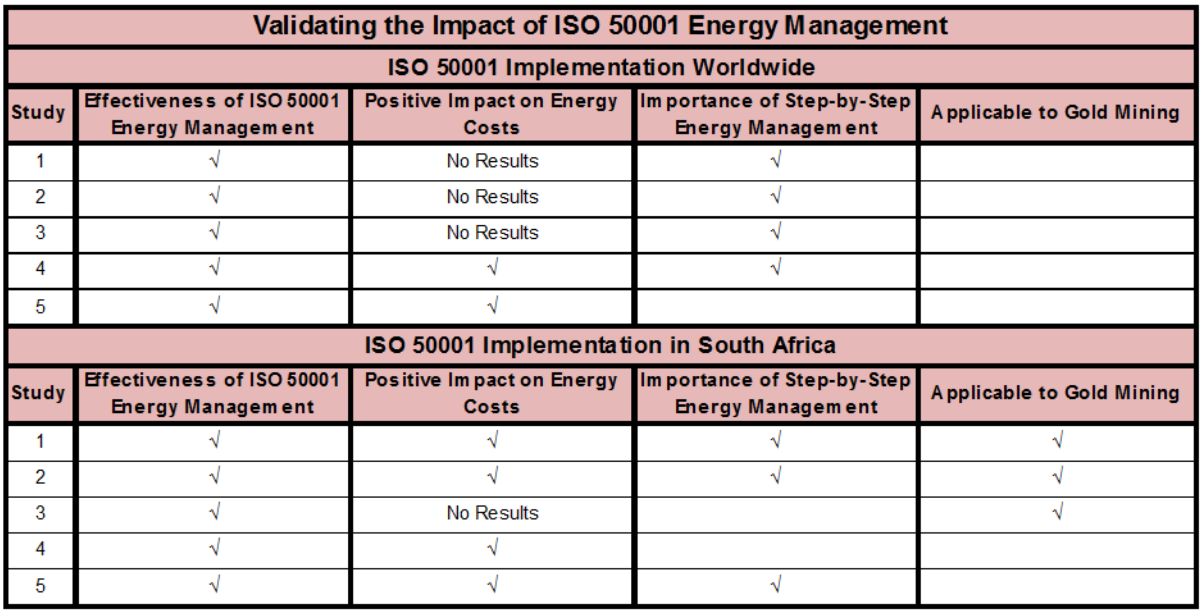
Toyota South Africa Electrical Energy Improvements (2011)	
Identified Projects	55
Gross Monetary Savings	R4 847 000
Energy Savings	8.15 GWh
Total Investment	R3 350 000
Overall Payback Period (years)	1.09

Top management of Toyota South Africa confirmed that the ISO 50001 procedures helped with the continuous improvement of energy performance [72]. From inception of energy management, the energy trend decreased year-on-year with an upwards trend in production [72]. Not only has ISO 50001 helped Toyota South Africa with reducing energy use, but it also contributed to an optimised operation with increased volumes [72].

2.2.3.4 Studies discussion

Table 6 provides a summary of all the investigated studies. The studies are summarised to validate the statements (Section 2.2.2) regarding the impact of ISO 50001 energy management on EnMSs in the industry.

Table 6: ISO 50001 energy management in the industry (case study summary)



Validating the Impact of ISO 50001 Energy Management				
ISO 50001 Implementation Worldwide				
Study	**Effectiveness of ISO 50001 Energy Management**	**Positive Impact on Energy Costs**	**Importance of Step-by-Step Energy Management**	**Applicable to Gold Mining**
1	√	No Results	√	
2	√	No Results	√	
3	√	No Results	√	
4	√	√	√	
5	√	√		
ISO 50001 Implementation in South Africa				
Study	**Effectiveness of ISO 50001 Energy Management**	**Positive Impact on Energy Costs**	**Importance of Step-by-Step Energy Management**	**Applicable to Gold Mining**
1	√	√	√	√
2	√	√	√	√
3	√	No Results		√
4	√	√		
5	√	√	√	

From Table 6 it can be seen that all the studies concluded that ISO 50001-compliant energy management certainly has a positive impact on an organisation’s energy performance. All the studies (with available results) proved a significant reduction in energy costs, of which the majority were realised within short periods after ISO 50001 implementation. Some of the studies confirmed that an ISO 50001-compliant EnMS could also improve the productivity of organisations at reduced energy consumption patterns.

Through the studies, it was also discovered that it could be a difficult process to develop an EnMS without a step-by-step methodology. According to Table 6, numerous authors identified the need for step-by-step procedures to implement effective ISO 50001-compliant EnMSs.

Only three studies identified the use of the ISO 50001 standard in the gold mining industry. A wide variety of literature was studied to identify these studies and proves the scarcity of ISO 50001 applications in this industry. It is also important to note that there is no relation between these studies. For example, referring to Van Heerden and Groenewald’s studies, one would assume that maintenance should be incorporated after project implementation to ensure sustainable performance. This is, however, not the case and indicates the haphazard implementation of energy management initiatives in the mining industry with no form of energy management framework.

The literature compiled in Section 2.2 and the results depicted by Table 6 prove to be sufficient motivation for incorporating the ISO 50001 standard and requirements within the development of the IEMS. The PDCA cycle will not only ensure effective improvements in the gold mining industry’s electrical energy consumption patterns, but also provide a step-by-step procedure to accomplish this. The PDCA cycle will also ensure continual improvement and sustainability of energy performance. Developing the IEMS within the PDCA framework of ISO 50001 will also ensure certification, which in turn has its own benefits [70].

The relevance of the remaining literature compiled in Chapter 2 is structured according to the PDCA cycle of the ISO 50001 energy management standard. Relevant literature is combined to provide a holistic view of a potential energy management strategy for the gold mining industry. The literature will be used in Chapter 3 to develop the novel IEMS.

The following section focuses on the first step of the PDCA cycle, which is energy management planning.

2.3 Plan: Energy management planning

2.3.1 General

The core aspect of any effective energy management strategy is to have a well-documented plan and committed resources to execute these plans [56], [62], [66]. The ISO processes discussed in the previous section provided sufficient literature on the requirements and execution of the “Plan” step from an ISO 50001 perspective. The ISO 50001 standard also adheres to a fully documented process and therefore provides a sufficient guideline to accomplish this task during the implementation of an IEMS in the gold mining industry.

One aspect not addressed by Section 2.2 is creating energy awareness among human resources to establish high commitment towards energy management. Committed resources may be classified as a fundamental factor to effective energy management [62]. Apathetic resources may in many cases be the deciding factor between successful and unsuccessful energy management [62]. Other barriers, besides the influence of energy awareness, may also affect the implementation of energy management. It is, therefore, important to understand and simplify the fundamentals of energy management to lay the foundation for an effective IEMS.

2.3.2 Energy management planning fundamentals

Energy management planning fundamentals can be divided into two main categories, namely barriers and drivers. A barrier is referred to as any mechanism or obstacle hindering the implementation of energy management [73]. Drivers refer to the motivation in tackling these barriers to overcome obstacles that prevent the implementation of an effective EnMS [74]. Overcoming these barriers is the foundation for successful energy management [70].

Trianni, Cagno and Farné investigated over 40 empirical studies on the barriers and drivers of industrial energy efficiency and management [74]. Trianni et al. integrated the studies and developed taxonomy of the barriers and drivers. Literature, not included in the study by Trianni et al., was also investigated and proved similarities in many aspects. Table 7 and Table 8 summarise a combination of the studies compiled by Schulze et al. [44], OECD [62], Bonacina et al. [63], Rohdin [73] and Trianni et al. [74]. Table 7 categorises a summary of general barriers encountered in industrial energy management, while Table 8 summarises the drivers to overcome these barriers.

Table 7: Taxonomy of industrial energy management barriers

	Barrier Classification by Category						
	Technological	Information	Economic	Behavioural	Organisational	Competancy	Awareness
Barriers	Inadequate technologies	Lack of information on costs and benefits	Low capital availability	Other priorities	Lack of time	Implementing interventions	Lack of awareness
	Availability of technologies	Vague information by technology providers	Access to capital	Low leadership values	Lack of support	Identifying inefficiencies	
	Inappropriate technologies	Trustworthiness of information	Investment costs	Lack of sharing objectives (Communication)	Divergent interests	Identifying opportunaties	
	Complexity of industrial systems	Adverse selection	External risks	Lack of interest in energy efficiency	Lack of internal control	Technical skills	
			Interventions not profitable	Resistance to change	Complex decision chain	Gathering external skills	
			Intervention costs	Imperfect evaluation criteria	Split incentives		
			Production disruptions	Irrational decision making	Low status/knowledge of energy efficiency		
			Hidden costs	Perceived complexity of energy management			
				Inertia			

Table 8: Taxonomy of industrial energy management drivers

	Driver Classification by Category							
	Regulatory (Internal)	**Regulatory (External)**	**Economical (Internal)**	**Economical (External)**	**Informative (Internal)**	**Informative (External)**	**Vocational Training (Internal)**	**Vocational Training (External)**
Drivers	Long-term energy strategy	Trustworthiness of information	Reduced costs on energy	Management support	Management with ambitions	External cooperation	Education and training programs	Technical support
	Willingness to compete	Clarity of information	Information about real costs	Public investments subsides	Staff with ambitions	Availability of information		
	Promoting green image	Energy audits		Private financing	Knowledge of energy savings benefits	Awareness		
	Policy obligations	Increasing energy tariffs						
	Voluntary agreements	Technological appeal						
	Regulatory (External)	Interventions cost						
		Public and market demands						
		Legal restrictions						

Cagno et al. developed a structured approach to overcome the barriers of energy management implementation in a sequenced order [75]. The sequenced approach is demonstrated by Figure 19 [75]. The recommended procedures (drivers) to overcome each barrier are explained beneath every step of the sequence, as depicted by Figure 19.

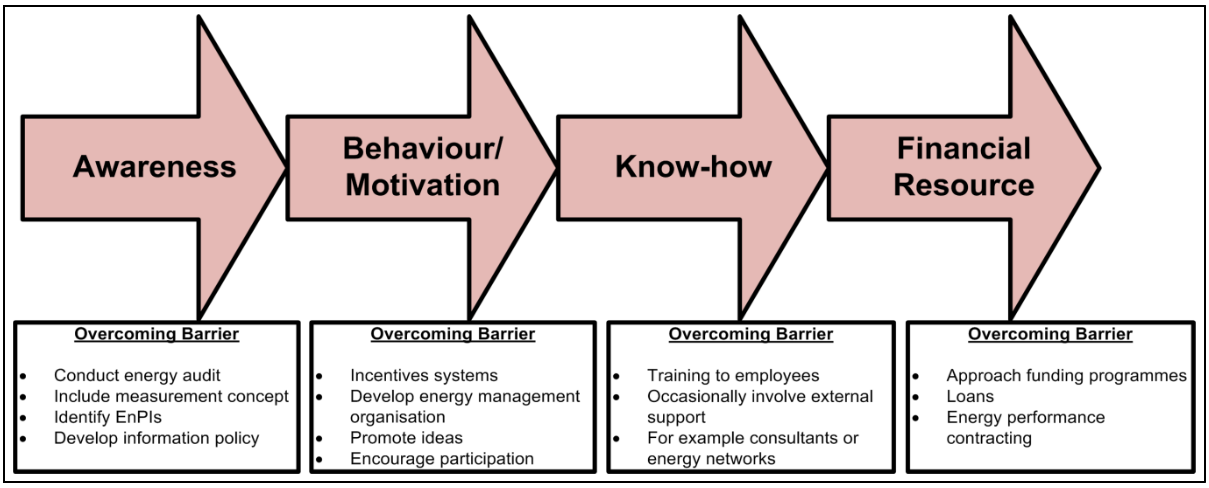


Figure 19: Structured sequenced approach to overcome energy management barriers

According to research, gold mines indicate similar barriers to these discussed in Table 7. The studies compiled by Groenewald [10]; Schutte and Van Rensburg [18]; Van Heerden [19]; Bredenkamp [32]; Schutte [31]; Taljaard [36]; Marais [40] and Schutte, Kleingeld and Vosloo [76]; all identified barriers in the implementation of energy savings initiatives in the gold mining industry. These barriers are highlighted in Table 7.

Table 9: Energy management barriers identified for the gold mining industry

	Gold Mines Barrier Classification by Category						
	Technological	**Information**	**Economic**	**Behavioural**	**Organisational**	**Competency**	**Awareness**
Barriers	Inadequate technologies	Lack of information on costs and benefits	Low capital availability	Other priorities	Lack of time	Implementing interventions	Lack of awareness
	Availability of technologies	Vague information by technology providers	Access to capital	Low leadership values	Lack of support	Identifying inefficiencies	
	Inappropriate technologies	Trustworthiness of information	Investment costs	Lack of sharing objectives (Communication)	Divergent interests	Identifying opportunities	
	Complexity of industrial systems	Adverse selection	External risks	Lack of interest in energy efficiency	Lack of internal control	Technical skills	
			Interventions not profitable	Resistance to change	Complex decision chain	Gathering external skills	
			Intervention costs	Imperfect evaluation criteria	Split incentives		
			Production disruptions	Irrational decision making	Low status/knowledge of energy efficiency		
			Hidden costs	Perceived complexity of energy management			
				Inertia			

The barriers for energy management in the gold mining industry are relatively evenly spread over the categories identified in Table 7. These barriers provide a broad spectrum of the fundamental obstacles that need to be addressed during the development of an IEMS. Overcoming these obstacles from the planning phase of the PDCA cycle will lay the foundation to effective energy management in the gold mining industry.

The next step according to Figure 15 and the literature in Section 2.2 is to implement the developed EnMAPs. The next section gives literature on executing EnMPs to improve the electrical energy performance of gold mines.

2.4 Do: Executing energy management plans

2.4.1 Preamble

The “Do” step for the gold mining industry would entail implementing any initiatives that would reduce electricity consumption or improve electrical EnPIs. The reduction or improved performance would be realised on the electricity-consuming systems of gold mines discussed in Section 1.3 of Chapter 1.

A reduction in electrical energy consumption may be realised in numerous ways in the gold mining industry. Research indicates that electrical energy savings can be realised by implementing new energy savings initiatives, maintaining previously implemented initiatives or improving system efficiencies on the different systems of gold mines [10], [19], [58]. It is, however, inevitable to implement these initiatives without conducting systems analysis to understand the systems and identify the potential for realising energy savings [20], [32].

This section will discuss systems analysis procedures in the gold mining industry to identify potential for electrical energy performance improvements. A background will also be provided on the abovementioned energy savings initiatives and the application to reduce the electricity consumption patterns of gold mines.

2.4.2 Analysing mine systems

To many, the definition of systems analysis is the process of investigating the operations of an existing situation with the intent of developing procedures for an improved output [77]. It is also stated that prior to developing any designs, a proper systems analysis is always required [77]. To develop improved solutions, it is also very important to understand the old system, interpret the facts and diagnose any problems [77]. The same applies during the development of an IEMS for the gold mining industry.

Numerous systems analysis procedures exist in available literature. One is only interested in existing information and procedures applicable to the gold mining industry that can be integrated in the development of the IEMS. Van der Zee and Bredenkamp developed systems analysis during the course of their studies [20], [32]. Van der Zee used systems analysis to identify mining systems with the largest energy savings potential for the implementation of energy savings initiatives [20]. Figure 20 depicts a simplified illustration of Van der Zee's systems analysis [20].

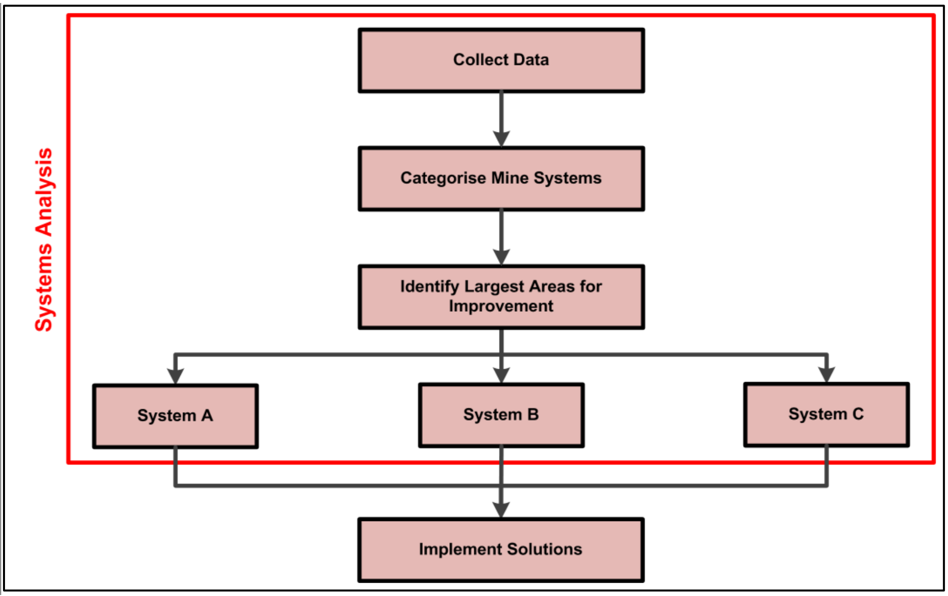


Figure 20: Systems analysis developed by Van der Zee

Bredenkamp developed a systems analysis procedure to identify effective solutions for reconfiguring gold mining compressed air systems [32]. Figure 21 illustrates the methodology, including systems analysis, used by Bredenkamp [32].

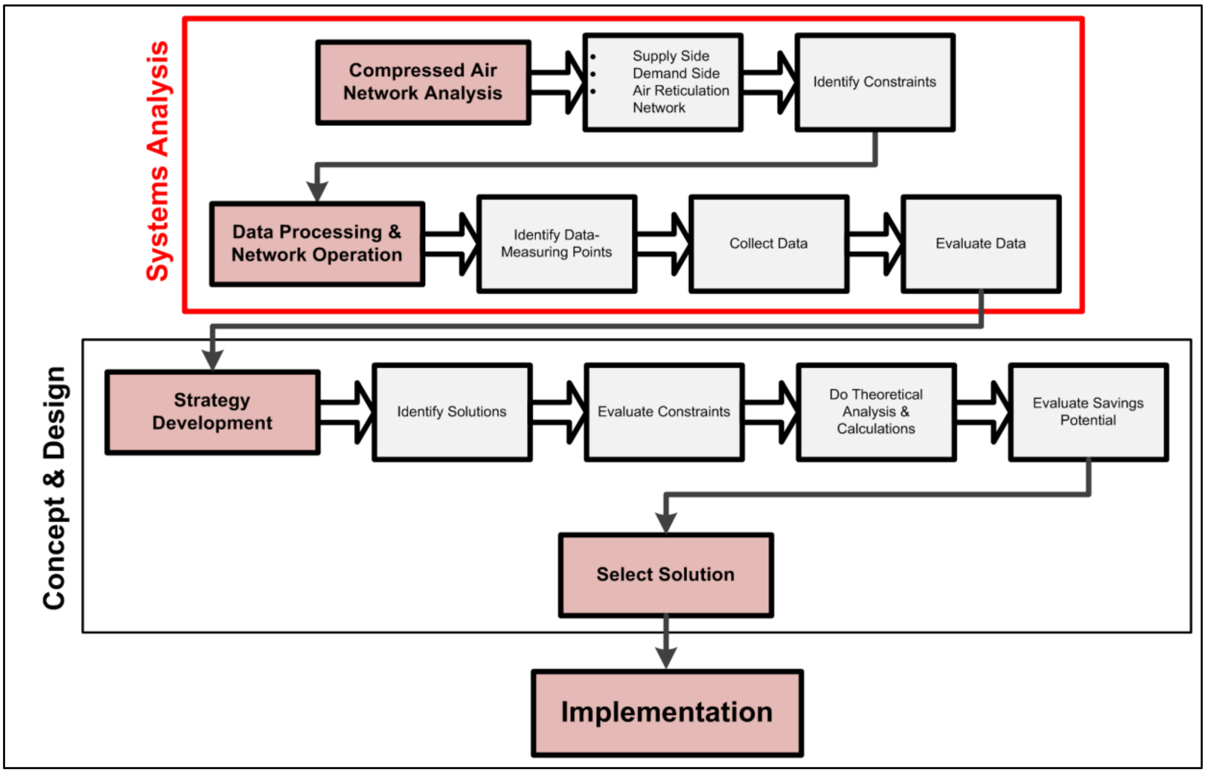


Figure 21: Bredenkamp's methodology including a systems analysis

The author finds the procedures developed by Van der Zee and Bredenkamp very applicable to the development of an IEMS for the gold mining industry. Van der Zee's procedure can be incorporated within the IEMS to identify mining systems where the implementation of energy savings initiatives should commence. Bredenkamp's procedure, on the other hand, can be used to conduct an in-depth analysis of the identified systems through Van der Zee's procedure. Combining these procedures would ensure that the most beneficial energy savings initiatives are identified on the systems with the largest energy savings potential.

The procedure depicted in Figure 21 should also be modified to accommodate all the other systems of a mineshaft and not just be limited to the compressed air system. This is important to consider during the development of a generic systems analysis for the IEMS to accommodate all the systems depicted by Figure 10.

The identified potential through the systems analysis is addressed through the next phase of the “Do” step, which is the implementation of energy savings initiatives. The initiatives, as identified in Section 2.4.1, are discussed in the following sections.

2.4.3 Implementation of new energy savings initiatives

2.4.3.1 Preamble

Due to its positive impact, the implementation of energy savings initiatives is important when it comes to improving the electrical energy performance of gold mines. Mine personnel, therefore, need thorough background on the different energy savings technologies available in literature. It is important for mine personnel to also understand the procedures and technologies in implementing energy savings initiatives and be able to predict the possible impact on electrical energy performance.

A wide variety of energy savings initiatives has been implemented over the years on both the electricity-intensive and non-intensive systems of gold mines (refer to Figure 10). As discussed in Chapter 1, these initiatives mainly formed part of the DSM intervention introduced by Eskom to help stabilise the electricity shortage in South Africa. The initiatives were implemented by ESCOs as part of DSM projects.

Over the years, researchers have also invested time in the development of strategic procedures to assist ESCOs with the implementation of these projects. The procedures are aimed at optimising the impact of implemented projects in terms of maximised cost savings for the clients. The following sections provide the inner details of these procedures and the variety of energy savings initiatives available in literature.

2.4.3.2 Implementation procedures for energy savings initiatives

Implementing energy savings initiatives according to ISO 50001

Van Heerden conducted a study on improving the implementation process of DSM projects through the ISO 50001 standard. The main objective of the study was to improve the existing DSM project implementation process of South Africa’s largest ESCO by incorporating the PDCA cycle of ISO 50001 (refer to Figure 15) [19]. This would ensure continuous improvement of the project implementation process, which would ultimately result in maximised performance of implemented projects [19]. Figure 22 illustrates the ESCO’s project implementation process incorporated within the PDCA cycle [19].

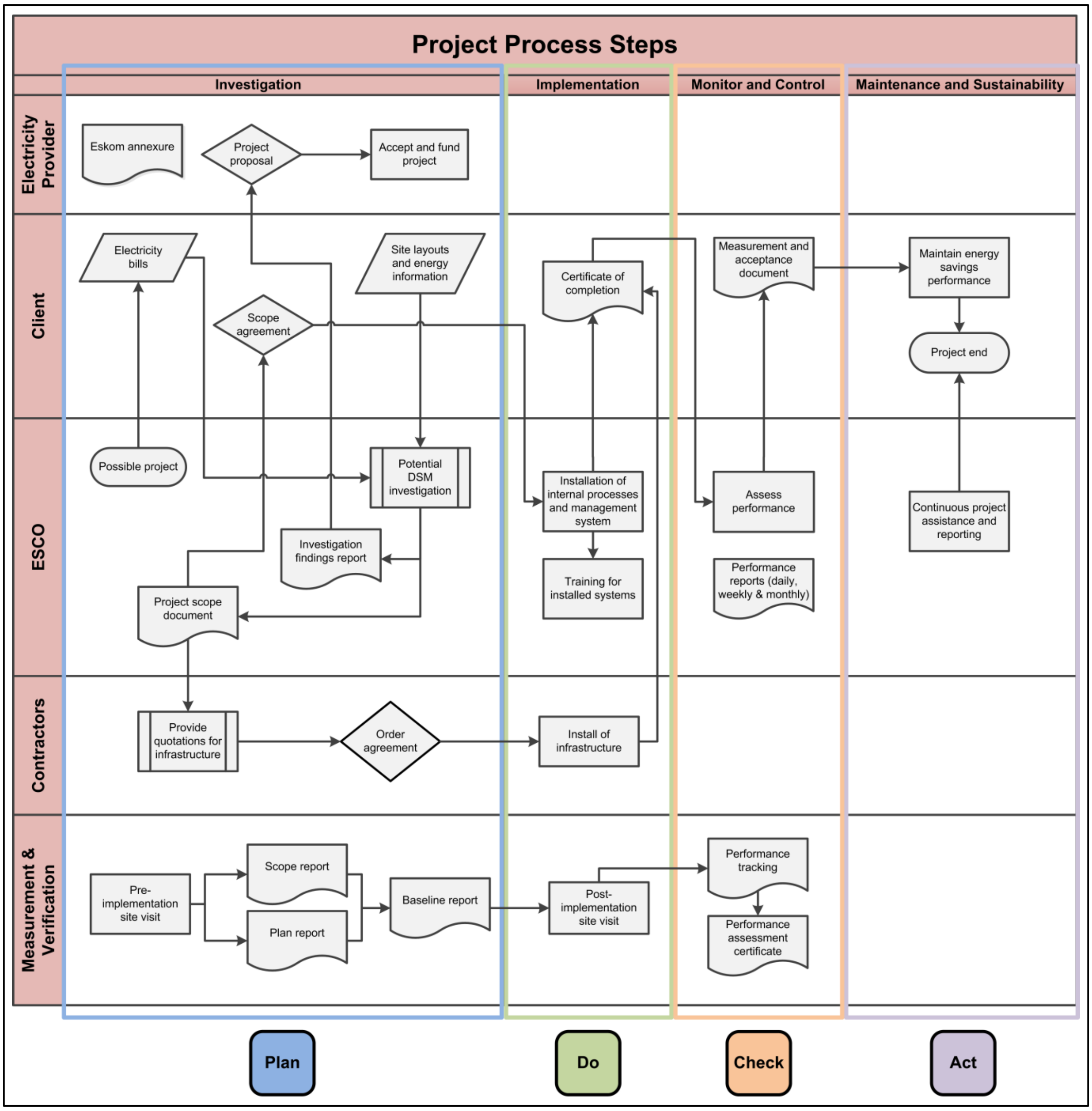


Figure 22: DSM project implementation procedure through ISO 50001 standards

Using the information displayed in Figure 15 and Figure 22, Van Heerden developed a simplified ISO 50001-compliant EnMS for the implementation of DSM projects in the mining environment. Figure 23 depicts a simplified layout of the EnMS developed by Van Heerden [19]. The EnMS was tested on eight case studies and the results proved that projects could be implemented successfully in terms of maximised costs savings for the clients [19]. The continual improvement effect of the EnMS contributed to sustainable energy savings after the implementation of the projects [19].

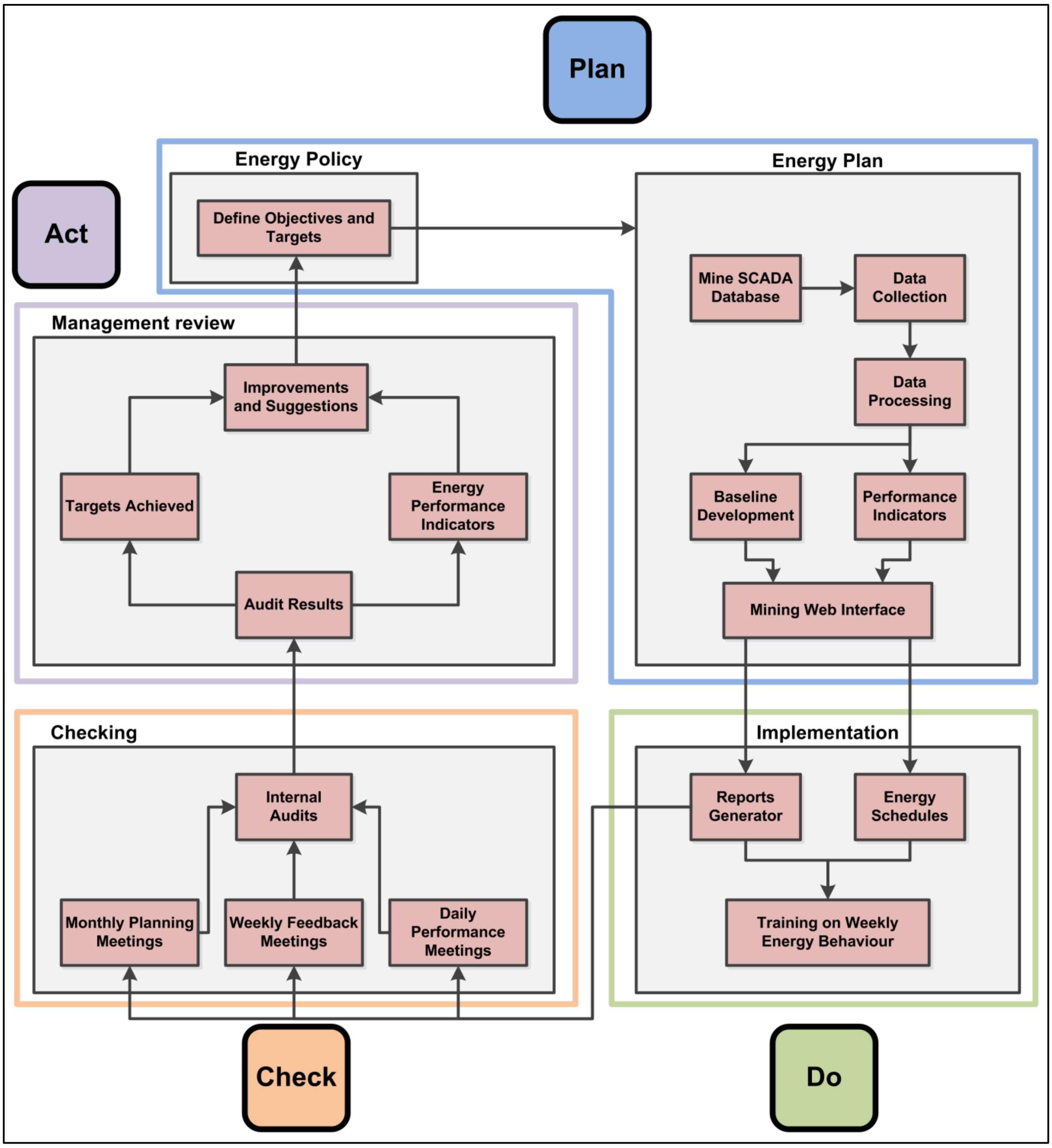


Figure 23: Developed ISO 50001-compliant EnMS for implementing DSM projects

The EnMS developed by Van Heerden can be integrated within the IEMS development as it presents a convenient guideline for the implementation of energy savings initiatives. However, Van Heerden's study had limitations, which will be addressed to improve compliance with the IEMS.

The study focused on improving DSM project implementation processes from an ESCO's perspective. This means that ESCOs have an optimised implementation strategy and will continue to charge the mines maintenance fees for their rendered services (refer to discussions in Chapter 1). There is a need for gold mines to become independent from ESCOs and to implement energy savings initiatives on their own (refer to Table 1 and Table 2).

Energy management in the deep-level gold mining industry also entails much more than just implementing energy savings initiatives. Van Heerden, however, positively contributed to this portion of energy management by developing an effective procedure for gold mines to use. There is, however, scope to incorporate the developed EnMS within an IEMS for the gold mining industry. There is further scope to expand the ISO 50001 standard to the development of the IEMS and not just for the implementation of energy saving initiatives.

Optimised procedures for maximised cost savings on mining systems

Marais and Schutte developed novel integrated strategies to optimise the energy savings potential by implementing initiatives on mine compressed air, dewatering, refrigeration and ventilation systems [31], [40]. Marais focused on compressed air, while Schutte optimised the implementation of the three remaining systems. Figure 24 depicts the strategy developed by Marais and Figure 25 depicts the strategy developed Schutte [31], [40].

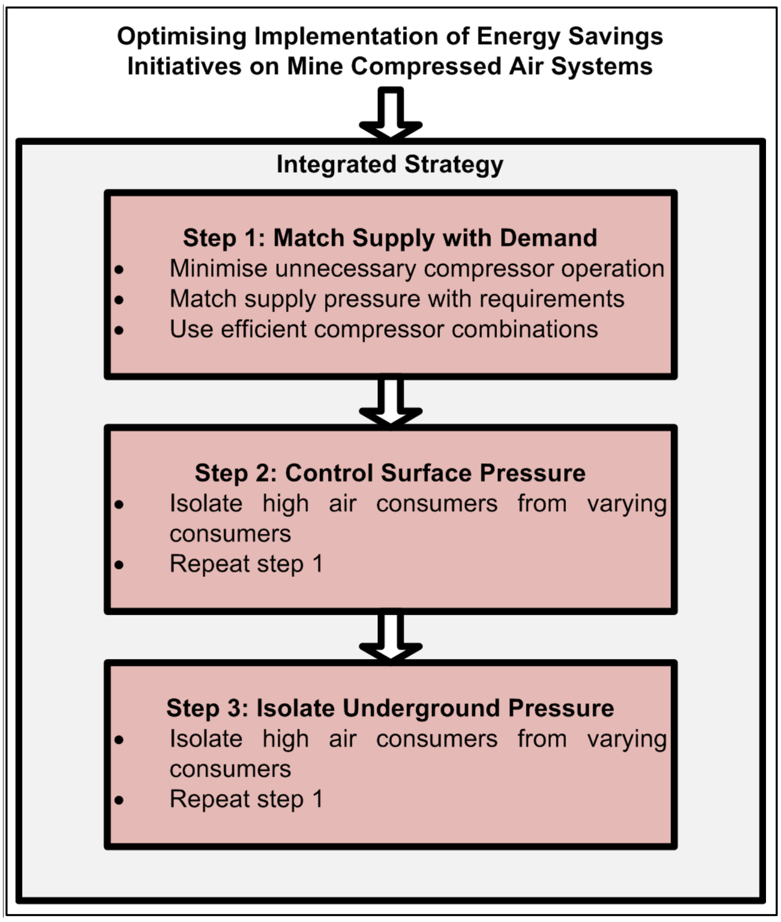
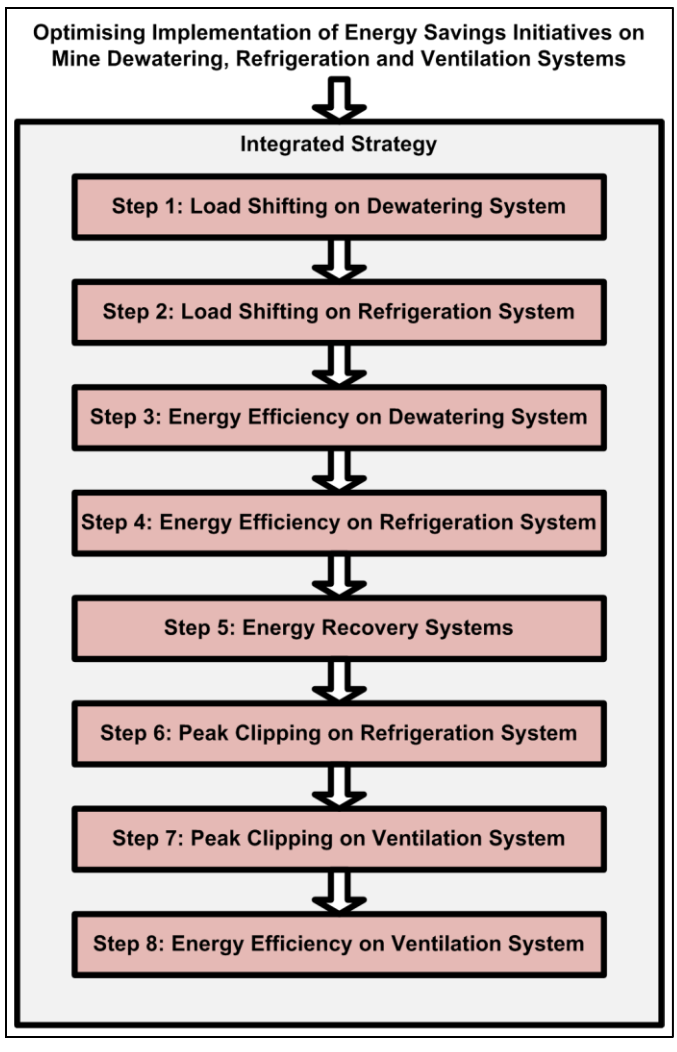


Figure 24: Marais's sequenced approach



[12]

Figure 25: Schutte's integrated sequenced approach

Marais and Schutte stated that implementing energy savings initiatives within sequenced strategies realises the full potential of system energy performance with maximised cost savings [31], [40]. According to Figure 10, Marais and Schutte also focused on the electricity-intensive systems of gold mines. This is because these systems offer the largest potential for optimisation and in turn the largest cost-savings potential for the mines [31], [40]. Research on sequenced approaches for the other systems of gold mines (refer to Figure 10) is scarce in available literature.

The integrated strategies of both Marais and Schutte were implemented on case studies in the deep-level gold mining industry. Marais's strategy was implemented on 22 compressed air systems realising a total average power saving of 109 MW [40]. Schutte proved that a combined power reduction of up to 36% is possible on a mine's dewatering, refrigeration and

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[12] Energy efficiency, peak clipping and load shifting concepts are discussed in the following section.

ventilation systems [31]. These figures accumulated to annual financial cost savings of approximately R315 million[13] and R30 million[13], respectively [31], [40].

The strategies seem to have a significant impact on the electricity consumption patterns of gold mines. Although research is limited for other mining systems, these strategies can be modified to form a generic implementation procedure to maximise the costs savings potential on all the systems of gold mines. Marais and Schutte also mentioned the absence of incorporating system inefficiencies to accurately predict the energy savings impact through their integrated strategies [31], [40].

Van Heerden developed an optimised ISO 50001-compliant procedure for the general implementation of energy savings initiatives. Marais and Schutte focused on optimising the cost-savings potential through sequenced implementation of energy savings initiatives on specific mining systems. Combining these studies and developing a generic implementation procedure for energy savings initiatives on all the systems of gold mines is limited. Incorporating system inefficiencies within the optimised implementation procedures is also limited. These limitations will be addressed and incorporated within the IEMS.

After identifying optimised procedures for the implementation of energy savings initiatives, the author is interested in the variety of existing initiatives that can be implemented on gold mining systems through these procedures.

2.4.3.3 Variety of energy savings initiatives in the gold mining industry

A large variety of publications was found in literature with extensive detail on the different implemented projects and technologies used to obtain electrical energy savings in the gold mining industry. It is, therefore, convenient for gold mines to implement and maintain these initiatives themselves as the technologies to do so already exist. Literature on the different technologies was studied and it was found that energy savings initiatives in the gold mining industry can be divided into three main categories, namely [10], [36], [37], [50]:

1. energy efficiency initiatives;
2. peak clipping initiatives; and
3. load shifting initiatives.

The following sections describe the different initiatives as part of each of the abovementioned categories. This will provide a thorough background for mine personnel on

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[13] Calculated with 2012/2013 Eskom electricity tariffs.

selecting the most effective solutions during the implementation of new energy savings initiatives.

Energy efficiency initiatives

Energy efficiency initiatives are implemented to reduce the average power consumption of electrical components. Energy efficiency can also be defined as a reduction in energy usage, while maintaining the same level of activity or service [21]. The largest financial cost savings are usually realised by implementing energy efficiency initiatives, which are usually preferred by the gold mining industry [31], [40], [48]. The following figure illustrates a typical power profile after implementing an energy efficiency project. The different colours represent Eskom's Megaflex time-of-use (TOU) structure, which is provided in Appendix A.

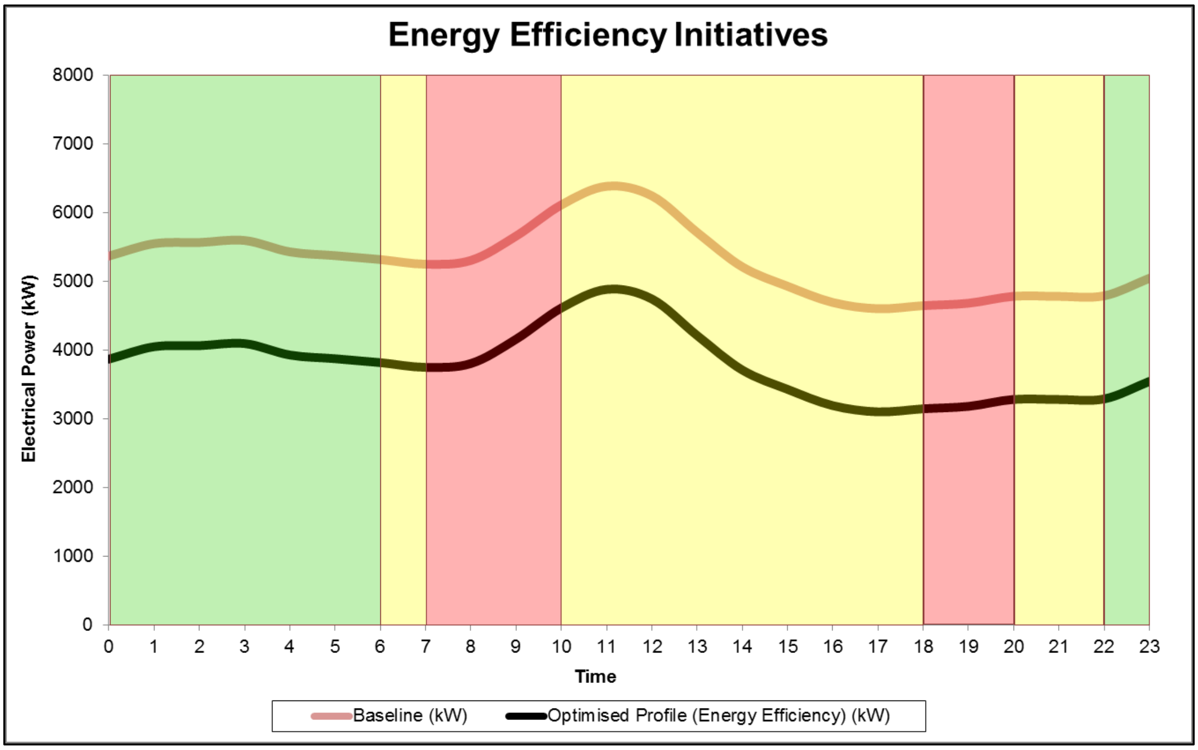

Figure 26: Power profiles for energy efficiency initiatives

Energy efficiency initiatives are widely implemented on numerous electrical components of gold mining systems. These include compressed air, refrigeration, dewatering, ventilation, and water-heating systems in hostels, as well as lightning (refer to Figure 10). The following section gives an overview on the different energy efficiency initiatives implemented in the gold mining industry.

According to literature, automated procedures and systems are more advantageous than manual operations [20], [31], [32], [38], [78], [79]. Automated systems ensure improved control, monitoring and efficient operation [78]. It is also easier when using automated systems to realise electrical energy improvements and to sustain these improvements than when using manual systems [76], [78]. It must be noted that the benefits of automated systems are applicable to all the energy savings initiatives discussed in this section.

Energy efficiency on refrigeration systems

According to several studies, the use of variable speed drives (VSDs) seems to be the most effective method to realise energy efficiency on gold mine refrigeration systems [20], [31], [38], [80]. The use of VSDs in the mining industry was limited in the past due to cost constraints [20]. With the higher-than-inflation electricity costs in the modern day era, investing in VSDs became beneficial in terms of cost-saving benefits and payback periods. According to literature, the incorporation of VSDs in mine refrigeration systems are divided into four categories, namely [20], [31], [38], [80]:

1. variable water flow control of the evaporator pumps;
2. variable water flow control on the condenser pumps;
3. variable water flow control on transfer pumps, and
4. variable airflow control on auxiliary fans.

Using VSDs improves overall refrigeration system efficiency and electrical energy performance, while the refrigeration system still complies with service delivery requirements for underground mining [20], [31], [38], [80].

Other initiatives have also been implemented on the refrigeration systems of gold mines over the years. Schutte investigated the impact of improving the efficiency of pre-cooling towers [31]. During this particular study, the pre-cooling towers were completely replaced due to damage incurred. Through the initiative, a temperature decrease of 4 °C was obtained on the output water [81]. This induced energy efficiency over the entire refrigeration system through colder system operating temperatures [80], [81]. VSDs were also installed on the pre-cooling tower fans, which further reduced electricity consumption [80], [81].

Another, yet more expensive, method to enhance energy efficiency on the refrigeration systems is reconfiguring the physical layout of refrigeration systems. Some case studies investigated replacing chillers with ice machines [20], [31], [38], [59]. Ice absorbs a larger heat load than chilled water [20]. This implies that less chilled water is sent to underground operations, which in turn results in less water to be pumped to surface by the dewatering pumps. Although the energy efficiency is realised as a result of the optimised refrigeration system, the energy savings is measured on the dewatering pumps.

Energy efficiency measures with less impact include regular maintenance on components of the refrigeration system [31]. Although the impact on energy performance is not as noticeable as with other discussed initiatives, regular maintenance is effective in improving the general operational efficiency of the system [31], [80].

Energy efficiency on dewatering systems

Control valve technologies can be used to reduce a mine’s water consumption during mining off-peak periods [31], [36]. Reducing the water demand induces energy efficiency on the dewatering pumps [31], [36]. Controlling the water distribution of gold mines also assists with monitoring the water consumption trends. This aids in identifying excessive water consumption because of leaks, burst pipes and unnecessary wastage [31]. Valve technologies also reduce wastage through leaks due to lower operating pressures [36].

Johnson and Fourie identified the use of VSDs on the dewatering pumps of a gold mine [82]. VSDs were used to vary the dewatering rate of the pumps according to the water consumption of mining operations. However, VSDs do not get used often on gold mine dewatering systems due to cost constraints [82].

Energy efficiency on compressed air systems

Energy savings initiatives on gold mine compressed air systems are divided into three main categories, namely: supply-side, demand-side and reconfiguring initiatives [32], [40], [42], [64], [83]. It is important to note that the actual energy savings by implementing the abovementioned initiatives is realised on the electric motors driving the compressors, which is a supply-side component. Detail on the abovementioned categories is given in the sub-sections that follow.

Supply-side- and demand-side initiatives

Figure 27 is a simplified illustration of the different supply- and demand-side initiatives that can be implemented on the compressed air systems of gold mines.

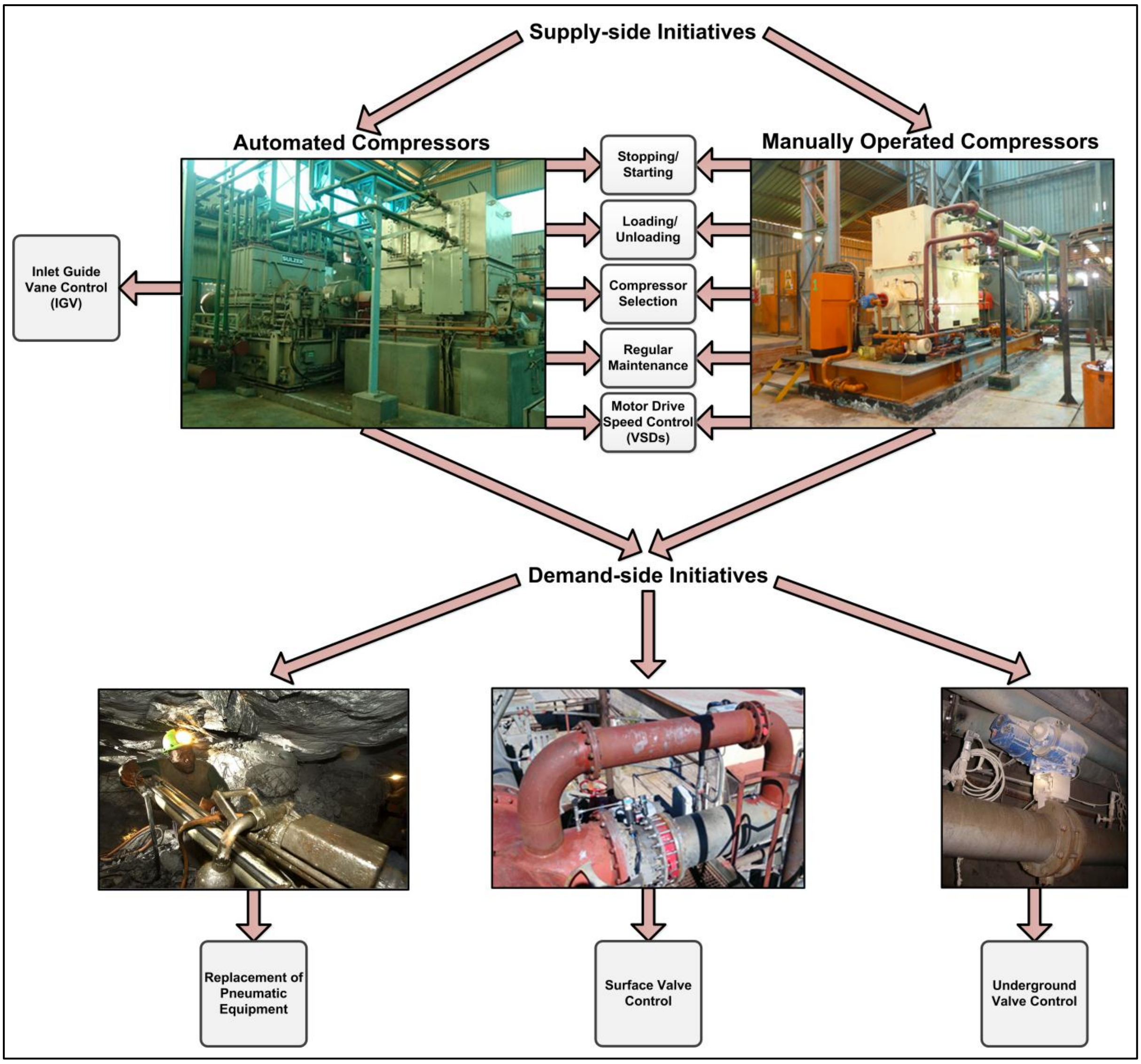

Figure 27: Energy efficiency on gold mine compressed air systems

Table 10 provides a summary of the supply-side initiatives that can be implemented on the compressed air systems of gold mines. The summary entails short descriptions of the initiatives.

Table 10: Summary of supply-side initiatives for gold mining compressed air systems

Supply-side Initiatives on Compressed Air Systems		
Initiative	**Description**	**Citation**
Stop/Start	The most basic output control of a compressor is to start or stop the electric motor driving the compressor. Usually stopped during low compressed air demand periods.	[32], [40], [84]

Supply-side Initiatives on Compressed Air Systems		
Initiative	**Description**	**Citation**
Load/Unload	Unloaded by closing the delivery valve, opening the blow-off valve and allowing the compressor to run freely. Electrical energy savings usually 40–80% less than when switching off the machine.	[40], [64], [83]
Inlet Guide Vane (IGV) Control	Automatically adjusting the IGVs according to compressed air demand, while maintaining relatively good efficiency.	[32], [40], [64]
Compressor Selection	Utilising optimised compressor combinations to match compressed air supply with demand efficiently.	[40], [64]
Regular Maintenance	Replacing air inlet filters regularly. Cooler inlet air temperatures. Periodically inspect air moisture traps. Properly clean and lubricate motors and compressors. Regular inspection of auxiliaries.	[41], [85]
VSDs	Match the compressed air supply with demand by regulating the motor speed. Mostly neglected due to cost constraints.	[32], [40], [41], [86]

Implementing demand-side initiatives on gold mining compressed air systems is usually more cost effective than implementing supply-side initiatives [40]. This is mainly due to significant energy efficiency scope, which results in shorter implementation cost payback periods [40], [87]. A wide variety of demand-side initiatives is implemented on the compressed air systems of gold mines. Table 11 provides a summary of the supply-side initiatives that can be implemented on the compressed air systems of gold mines.

Table 11: Summary of demand-side initiatives for gold mining compressed air systems

Demand-side Initiatives on Compressed Air Systems		
Initiative	**Description**	**Citation**
Surface Valve Control	Used to reduce system air pressures to reduce compressor output.	[32], [83], [88], [89]
Underground Valve Control	Used to reduce the compressed air demand on multiple underground levels while maintaining constant system pressures. Also enables selective compressed air distribution.	[40], [64], [76], [90]
Replacing Pneumatic Equipment	Alternative solutions include electric and hydro powered equipment to eliminate the dependence on compressed air for operations.	[32], [40], [76], [91], [92]

Using valves to improve energy efficiency on the demand side of gold mine compressed air systems is classified as the main technique [42]. These valves can be used in numerous configurations to fulfil several outcomes within gold mining compressed air systems. According to research, surface valves can be used to:

1. create different pressure sections within the same compressed air system (high and low-pressure sections) [83], [88];
2. isolate sections from the compressed air system during certain periods of the day [32], [83], [89]; and
3. isolate sections entirely from the compressed air system [35].

Methods and configurations in which underground valves can be used to improve underground air distribution control include the following [40], [64], [90]:

1. variable pressure control on multiple levels;
2. isolation of certain levels during certain periods of the day;
3. entire isolation of certain non-productive levels;
4. diversion of compressed air from non-productive levels to fully operational levels; and
5. stope[14] isolation control.

It is important to note that replacing pneumatic equipment is an initiative not widely implemented in the gold mining industry [32]. This is mostly due to cost-, time- and production-related constraints [91], [92]. It is, however, important for the gold mining industry to continuously seek initiatives that would improve energy efficiency of their energy-intensive equipment, such as compressed air systems.

Reconfiguring initiatives

Other initiatives resulting in energy efficiency on mine compressed air systems entail the reconfiguration of physical system designs. These initiatives are, however, not widely implemented due to implementation cost and time constraints [31], [32], [79]. Three case studies were found where this initiative was implemented in the gold mining industry [32], [60], [83]. These studies focused mainly on compressor relocations and significant changes to compressed air reticulation networks of gold mines.

The consensus of the case studies is that reconfiguration strategies may have a significant impact on electrical energy savings when implemented [32], [60], [83]. It is, however,

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[14] Escalation in the form of steps made by the mining of ore. Usually where the ore containing the valuable minerals is extracted [32].

important that salvaged equipment and financial incentives are in most cases the deciding factors to the successful implementation of these initiatives [32], [60].

Energy efficiency on ventilation systems

The implementation of energy efficiency initiatives on gold mining ventilation systems generally focuses on two components, namely the main and booster fans [31]. Booster fans have smaller electrical installed capacities than the main fans, which automatically results in more energy efficiency initiatives implemented on the main fans [31].

The initiative with the largest energy savings potential is to reduce the number of operating fans permanently. In most cases, the required ventilation is still provided with one less operating fan [31]. The viability of this initiative, however, varies between different mines and is subjected to testing prior to implementation [31].

Other methods include installing inlet dampers, inlet guide vanes, radial vane controllers, outlet dampers and outlet vane controllers [31], [82]. According to Schutte, the most cost effective of these methods is pre-rotating inlet air using radial vane controllers [31].

A case study was compiled where standard electric motors of the main fans of a gold mine were replaced with high efficiency motors. Through this initiative, an electrical energy saving of 4.5% was realised [82]. Kukard investigated the same initiative on the smaller motors of the booster fans. It was found that an energy savings improvement of 24% is possible by replacing the motors with more efficient ones [93].

VSDs can be used to further reduce the power consumption of fans by regulating the fan speeds according to the ventilation requirements [82]. The motors are also coupled with the fans through gearboxes. It was also found that optimising the gear ratios of these gearboxes induces energy efficiency on the electric motors [82].

Johnson and Fourie stated that by replacing fan impellers with more efficient impellers, the energy efficiency could improve with up to 10% [82]. Other impeller-related initiatives include replacing heavy steel blades with lighter carbon fibre blades. The weight reduction reduces the moment of inertia of the fan, which in turn results in electrical power savings of up to 11% [31], [94].

Energy efficiency through energy recovery systems

The scale and operating pressures of mine dewatering systems allow the effective use of energy recovery systems. These systems include turbines and three-chamber pipe feeders (3-CPFs) [31].

Turbines use the water sent underground to recover electrical energy, which in turn can be used by dewatering pumps to pump mine water back to surface [31]. One of the major disadvantages of turbines is that the generated electrical energy cannot be stored. For this reason, turbines are often bypassed when the demand for chilled mine water and pumping schedules do not align [31].

3-CPFs use the U-tube effect via a series of valves to pump hot water from underground to surface [31], [79]. Electricity savings of up to 80% on mine dewatering systems have been recorded with the use of 3-CPF systems [79]. A disadvantage of using 3-CPF systems is that the mine still requires a fully operational pumping station in cases where the system is unavailable [31]. Incorporating 3-CPF systems is also a very expensive and time-consuming process [31].

Energy efficiency on water-heating systems

The heat generated from a mine’s compressors can be used for water-heating purposes in the mine’s change houses and hostels [40]. It is stated that up to 60% of the generated heat from a compressor can be recovered and used for this purpose [95]. It should, however, be noted that the compressors at most of the South African gold mines are usually too far away from any buildings to benefit from the generated heat [40].

Using heat pumps in mining hostels and change houses is another method to realise energy efficiency on water-heating systems at gold mines [12], [17], [48]. According to one of South Africa’s leading mining groups, an average energy efficiency improvement of approximately 3% was realised over the group by replacing conventional heating systems with heat pumps [48].

Energy efficiency on lighting

According to Figure 10, lighting is one of the smaller electricity consumers of the gold mining industry. Although this figure appears small in comparison with other systems, a substantial amount of energy is still consumed annually due to the quantity of lights used at gold mines [43], [82].

Vosloo states that energy performance will improve substantially when conventional lights at gold mines are replaced with new technology lights [43]. According to Botha, lighting energy savings initiatives entail replacing compact fluorescent lights (CFLs) and high mast lights with light emitting diodes (LEDs) [48]. Replacing CFLs and high mast lights could realise an energy efficiency of approximately 0.1% for a gold mining group [48].

Peak clipping initiatives

Peak clipping initiatives focus on reducing the power consumption of gold mining systems during Eskom's peak demand periods (refer to Appendix A). Implementing these initiatives also reduces the total electrical energy consumption of systems [64], [96]. Figure 28 illustrates a typical power profile after implementing a peak clipping initiative.

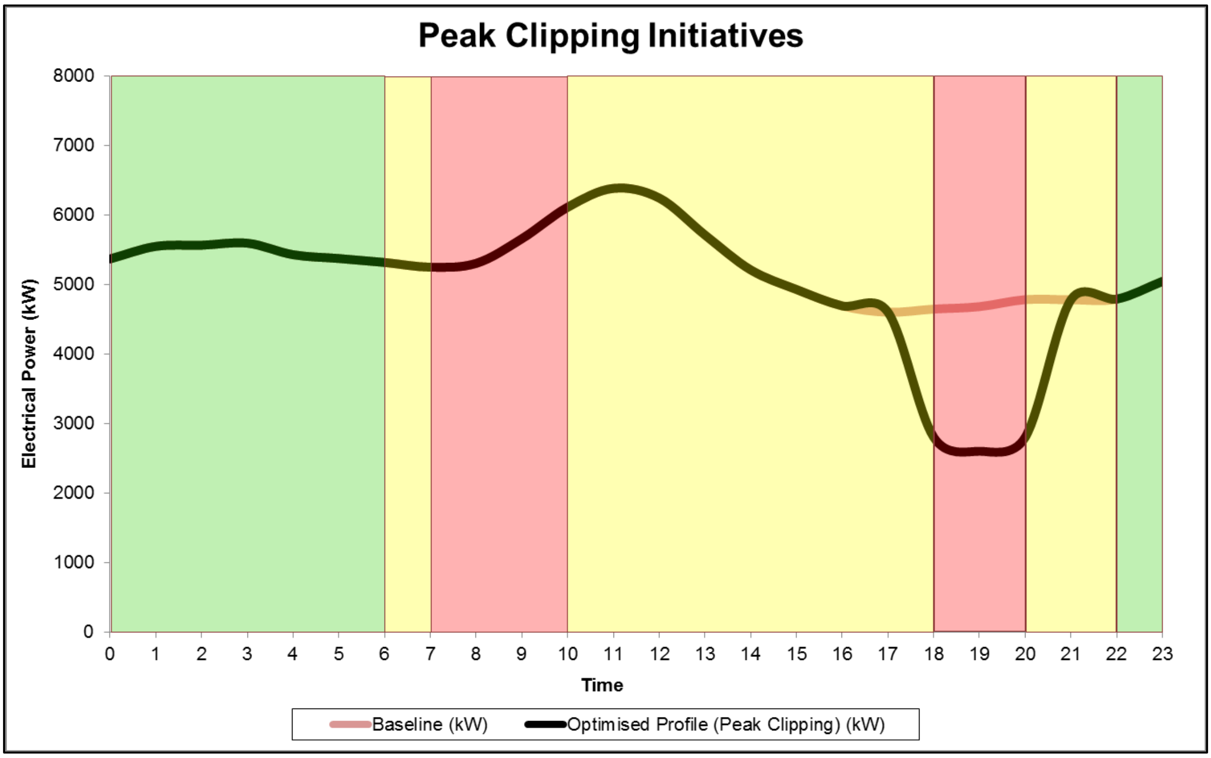

Figure 28: Power profiles for peak clipping initiatives

Most of the strategies and technologies used to realise energy efficiency are also applicable peak clipping initiatives. The main difference, however, is that the strategies and technologies are applied during Eskom's peak periods to assist in power reduction. From literature, peak clipping initiatives are implemented on refrigeration, compressed air and ventilation systems of gold mines [31], [37], [64].

Peak clipping on refrigeration systems

Peak clipping initiatives are mostly implemented on the bulk air coolers (BACs) and cooling tower fans of a gold mine's refrigeration system [31], [97]. Peak clipping on BACs, however, remain a sensitive topic for the gold mining industry. As mentioned in Chapter 1, numerous factors such as high underground temperatures and safety regulations influence mine personnel's perspective on peak clipping.

Booysen and Schutte conducted studies on the implementation of BAC peak clipping initiatives and the impact on underground temperatures. During the studies it was found that underground temperatures increased slightly during peak clipping and stabilised back to normal within hours [31], [97]. It was concluded that peak clipping has no significant impact on underground temperature and is safe to implement.

Peak clipping on ventilation systems

The following initiatives can be used to reduce power consumption of gold mining ventilation systems during the Eskom peak periods [31], [93].

1. stop ventilation or booster fans;
2. reduce airflow through IGV control; and
3. use VSDs to lower motor speeds.

Peak clipping on compressed air systems

Referring to Figure 27, the following initiatives can be used to reduce power consumption on the compressed air system during the Eskom peak periods [18], [32], [40], [42], [64].

1. stop some of the compressors;
2. unload some of the compressors;
3. use VSDs to lower motor speeds;
4. reduce compressor delivery pressures;
5. use IGVs to reduce compressor outputs, and
6. reduce system pressures and flows with surface and underground valves.

It is important to note that the abovementioned initiatives may influence each other and a combination of the initiatives may result in improved cost-savings potential (refer to the implementation sequences in Figure 24 and Figure 25). For example, reducing the system pressures and flows with valves may result in a compressor being unloaded or switched off. It is therefore, important, for mine personnel to understand that the use of the abovementioned initiatives is not limited to a single initiative.

Load shifting initiatives

Load shifting initiatives focus on moving the electrical load out of the Eskom peak periods to other TOU (off-peak and standard) tariffs of the day [97]. With load shifting, gold mines do not benefit from a reduction in electrical load. The aim of implementing these initiatives is not to reduce the total electrical load of systems, but rather to strategically reduce the overall financial expenditure on power consumption as a result of the Eskom Megaflex tariff structure [10], [97]. Figure 29 illustrates a typical power profile after implementing a load shifting initiative.

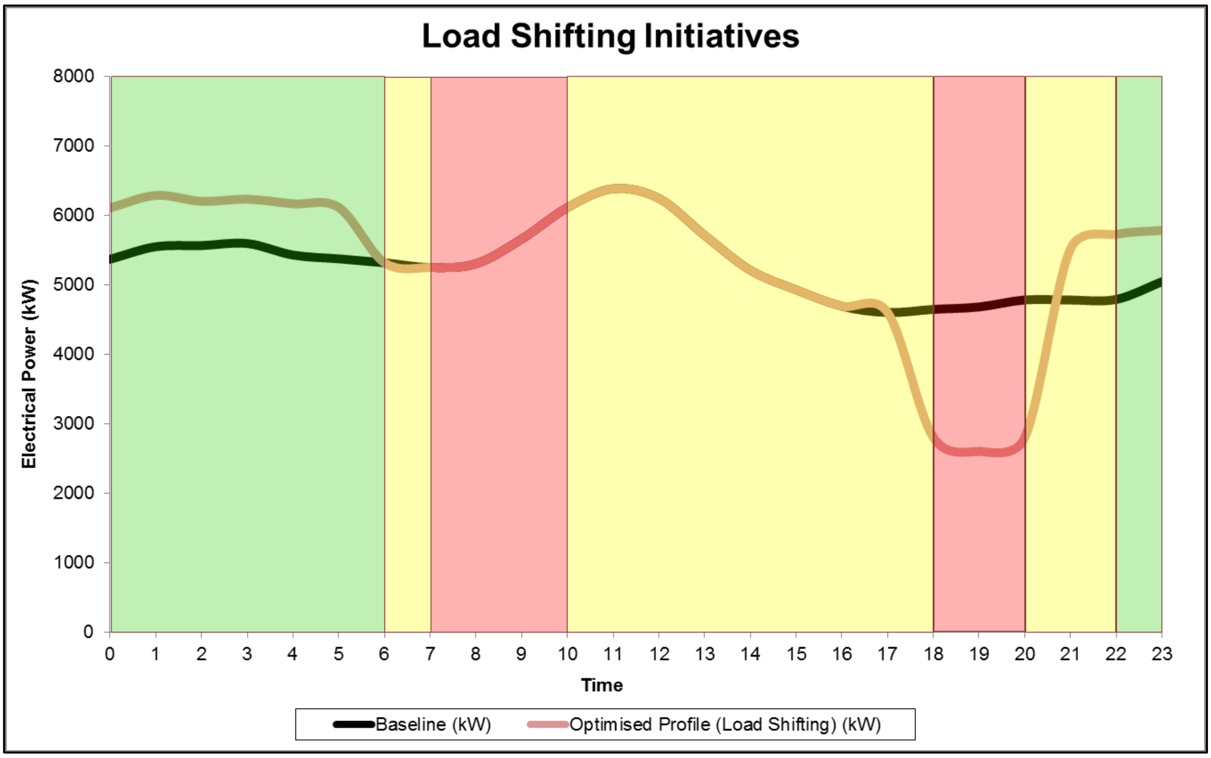

Figure 29: Power profiles for load shifting initiatives

According to literature, load shifting initiatives in the gold mining environment are implemented on refrigeration, dewatering and hoisting systems [31], [37], [43]. The initiatives are made possible by capacitors (such as storage dams and silos) within these systems [38], [43], [79]. The medium stored in the capacitors are removed during other TOU periods of the day, which implies an energy-neutral concept, as the same amount of energy is used with or without load shifting [38].

Load shifting on refrigeration systems

As with peak clipping on mine refrigeration systems, load shifting initiatives are also a sensitive topic. With proper load management techniques, it has, however, been proven that load shifting is possible on mining refrigeration systems without affecting system temperatures or operational parameters [38]. Van der Zee and Van der Bijl both proved the sustainability of load shifting on gold mine refrigeration systems when important system constraints are continuously adhered to [20], [38]. The primary system constraints are the following [20], [38]:

1. chilled and hot water dam capacities;
2. minimum and maximum chilled water dam levels;
3. chilled water dam temperature;
4. chilled water flow rate to surface BACs; and
5. chilled water flow rate to underground operations.

Load shifting on gold mine refrigeration systems is accomplished by switching off the refrigeration machines and auxiliaries during the more expensive Eskom peak periods [31], [80]. The system temperatures and dam levels are then recovered during the cheaper TOU periods of the day [31]. As discussed in the preceding sections, automation procedures ensure improved control and, consequently, sustainable load shifting on the refrigeration systems [31], [38].

Load shifting on dewatering systems

Gold mine dewatering systems offer large potential for implementing load shifting initiatives [31], [43]. This is mainly due to the large installed dewatering pumps and system capacitors [31]. In some instances, load shifting of up to 9 MW has been recorded in the gold mining industry [79]. This accumulates to substantial cost savings for the mines. As with refrigeration systems, constraints need to be adhered to for successful load shifting on dewatering systems. These constraints can be summarised by the following [20]:

1. pumping column (pipe) sizes;
2. number of available pumping columns;
3. size of storage dams;
4. pump installed capacities and ratings;
5. pump availability;
6. minimum and maximum dam levels;
7. mine’s water demand; and
8. water flow into dams.

Load shifting on gold mine dewatering systems is accomplished by switching off the dewatering pumps during the Eskom peak periods [36], [37]. The dam levels are then recovered during the other TOU periods of the day [36], [37]. It is also important to prepare the dam levels during the cheaper TOU periods in order for the capacitors (storage dams) to accommodate load shifting during the Eskom peak periods [79].

Load shifting on hoisting systems

Load shifting on gold mine hoisting systems is a sensitive topic from a completely different perspective. Gold mines have day-to-day production targets and thus they are reluctant to jeopardise production sustainability for cost savings obtained through load shifting [43]. It is inevitable that cost savings through load shifting is not comparable to production figures. It has, however, been proven that sustainable load shifting on gold mine hoisting systems is possible without affecting sustainable production [43]. The constraints that need to be adhered to for successful load shifting on hoisting systems are given as follows [43]:

1. mine production characteristics;
2. surface ore silo capacity;
3. underground ore silo capacity;
4. mine operating schedules;
5. ore skip capacity;
6. cycle time of the winding system; and
7. depth of the shaft.

Load shifting on gold mine hoisting systems entails a reduction in electrical demand of the rock winders[15] during the Eskom peak periods [43]. The ore stored in underground silos are then hoisted during the other TOU periods of the day [43]. Vosloo mentioned that load shifting of 3.5 MW was obtained through implementing a rock winding load shifting initiative successfully on one of South Africa's gold mines [43]. The initiative was expanded to several other gold mines in South Africa [43].

This section provided a detailed overview regarding the different electrical energy savings initiatives that can be implemented on electricity-consuming systems of gold mines. According to Section 2.4.1, maintenance on implemented initiatives is another method in realising energy costs savings for gold mines. Maintenance would also ensure sustainable performance of implemented initiatives, discussed in this section, and ensure continual improvement, which complies with the PDCA cycle of ISO 50001 discussed in Section 2.2. The following section focuses on existing maintenance procedures for the gold mining industry to realise and sustain energy savings.

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[15] Winding system used to transfer mined ore from underground operations to surface.

2.4.4 Maintenance on implemented energy savings initiatives

As this study specifically focuses on developing an IEMS for the deep-level gold mining industry, the author is interested in implemented maintenance initiatives in this particular field. Through studying a large variety of literature, the author was able to identify seven studies applicable to maintenance in the mining environment. Table 12 gives the focus, sector and field of each investigated study.

Table 12: Maintenance practices in the mining environment

Citation	Study Focus	Sector	Study Field
[10]	Development of performance-centered maintenance strategy (PCM) for industrial DSM projects	Mining, cement plants and water schemes	DSM projects
[98]	Value of maintaining a DSM load shifting project on mine dewatering pumps	Deep-level mining	DSM projects
[99]	Business case for industrial DSM maintenance	Mining and cement plants	DSM projects
[100]	Streamlining DSM project maintenance	Mining, cement plants and water schemes	DSM projects
[50], [101]	Sustainable performance of DSM pumping projects through maintenance	Deep-level mining	DSM projects
[102]	New technology to ensure sustainability of DSM projects	Gold and platinum mines	DSM projects

These studies mainly focused on proving the financial benefits and sustainability of industrial DSM projects through maintenance procedures. It was also striking that all of the studies refer to maintenance procedures from an ESCO’s perspective. Most of these studies also follow the same maintenance trend in achieving sustainability and cost savings. It can be summarised by the following discussion points:

1. maintenance on physical infrastructure;
2. communication and software maintenance;
3. rapidly identifying and rectifying problems;
4. use of automated control systems;
5. use of adaptable communication systems;
6. reporting, monitoring and correspondence;
7. awareness and motivation of stakeholders;

8. responsibilities and prioritisation;
9. training and skills development;
10. technologies of ESCOs; and
11. availability of maintenance agreements between clients and ESCOs.

The most relevant to this study is the novel PCM strategy for sustainable performance of industrial DSM projects. The strategy development was based on the experience of one of South Africa's largest ESCOs with electrical energy maintenance on industrial DSM projects [10]. In the study, Groenewald stated three overarching requirements for the development of such a strategy. These requirements included [10]:

1. continual improvement of project performances;
2. ability to dynamically adapt to system conditions; and
3. implementation by specialists (ESCOs) in the energy environment.

The continual improvement part of the strategy adapts the PDCA cycle of the ISO 50001 standard [10]. **Error! Reference source not found.** depicts the methodology of the PCM strategy Groenewald developed in line with the PDCA cycle [10].

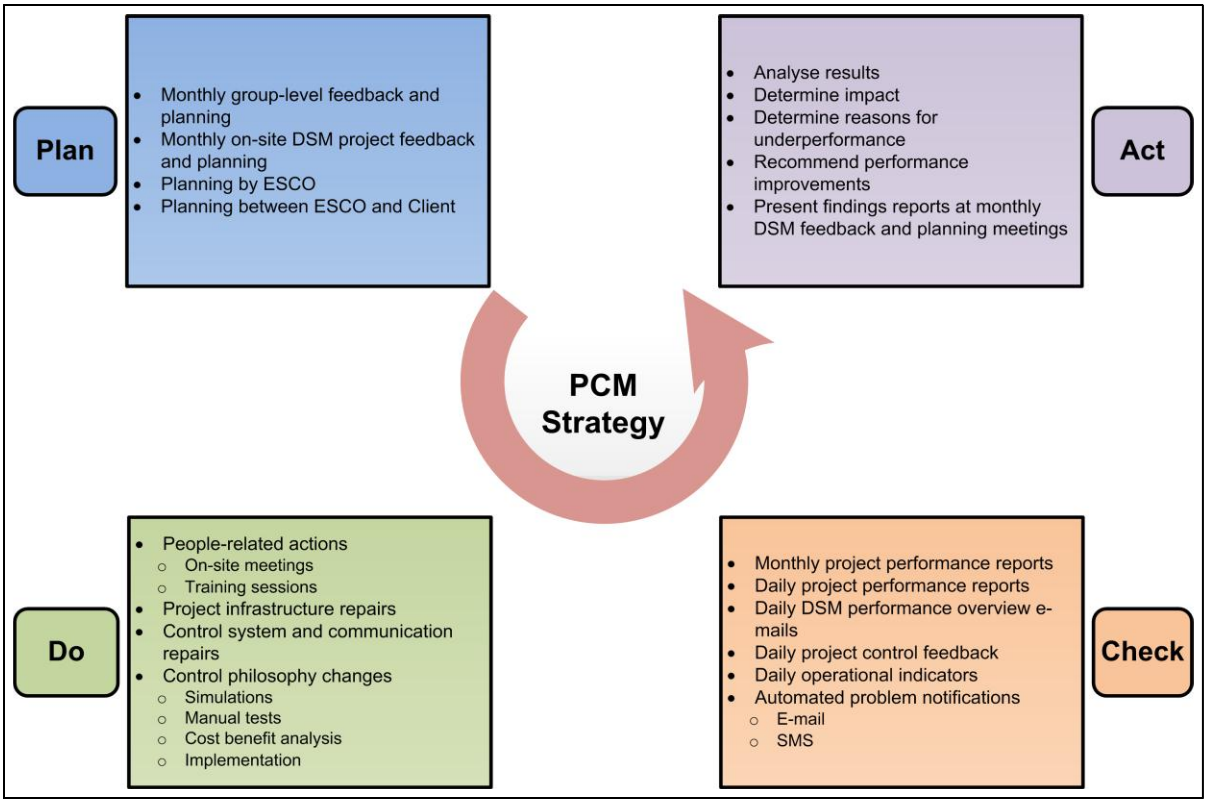

Figure 30: ISO 50001-compliant PCM strategy developed by Groenewald

Groenewald gave three scenarios to prove the credibility of the benefits by implementing the PCM strategy on real-life industrial DSM projects. The PCM was implemented on the dewatering (pumping) and compressed air systems of three South African gold mines. The scenarios included the following [10]:

1. applying the PCM strategy on an existing underperforming project;
2. including the PCM strategy from the implementation phase of a new project; and
3. evaluating the impact on project performance when PCM was cancelled.

Figure 31 illustrates the impact that the PCM strategy had during the first scenario. The results indicated an increase in project performance from the moment that the strategy was implemented. According to Groenewald, the strategy improved the performance on this particular project with 70% [10].

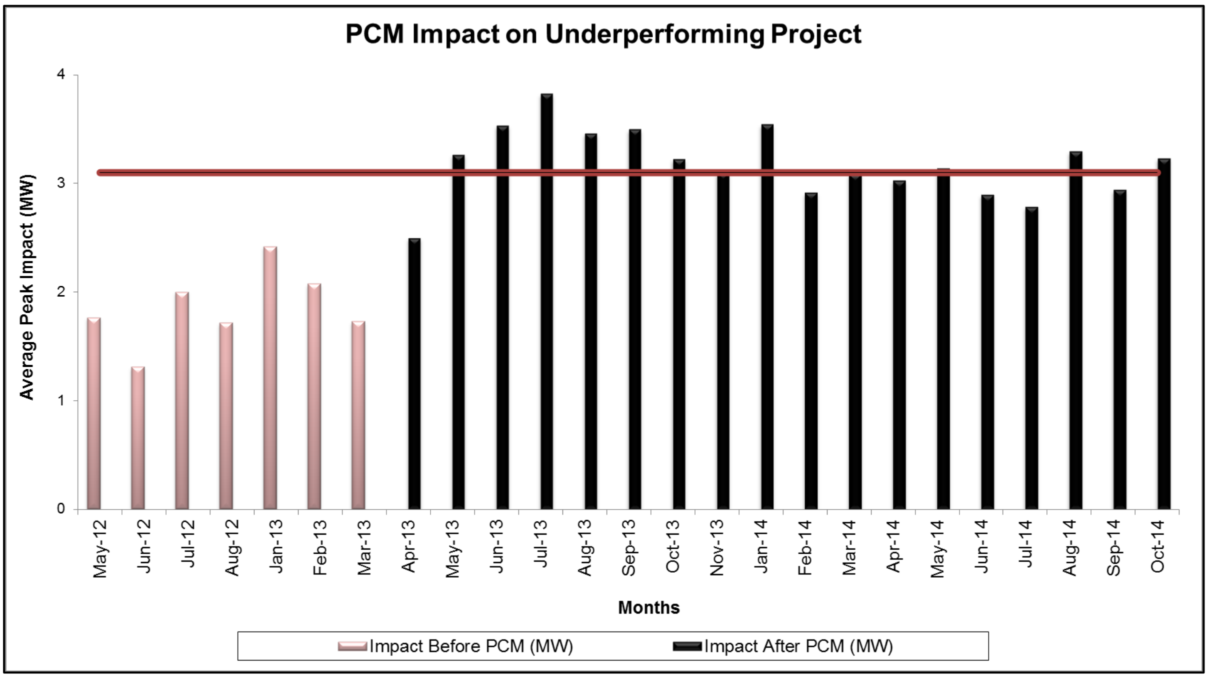

Figure 31: Scenario 1: Impact of PCM on an underperforming project

During the second scenario, the PCM strategy was incorporated during the implementation phase of the project. According to Groenewald, the performance never deteriorated over the lifespan of the project and the PDCA framework of the PCM ensured a constant increase in project cost savings [10]. Figure 32 depicts the results obtained from scenario 2.

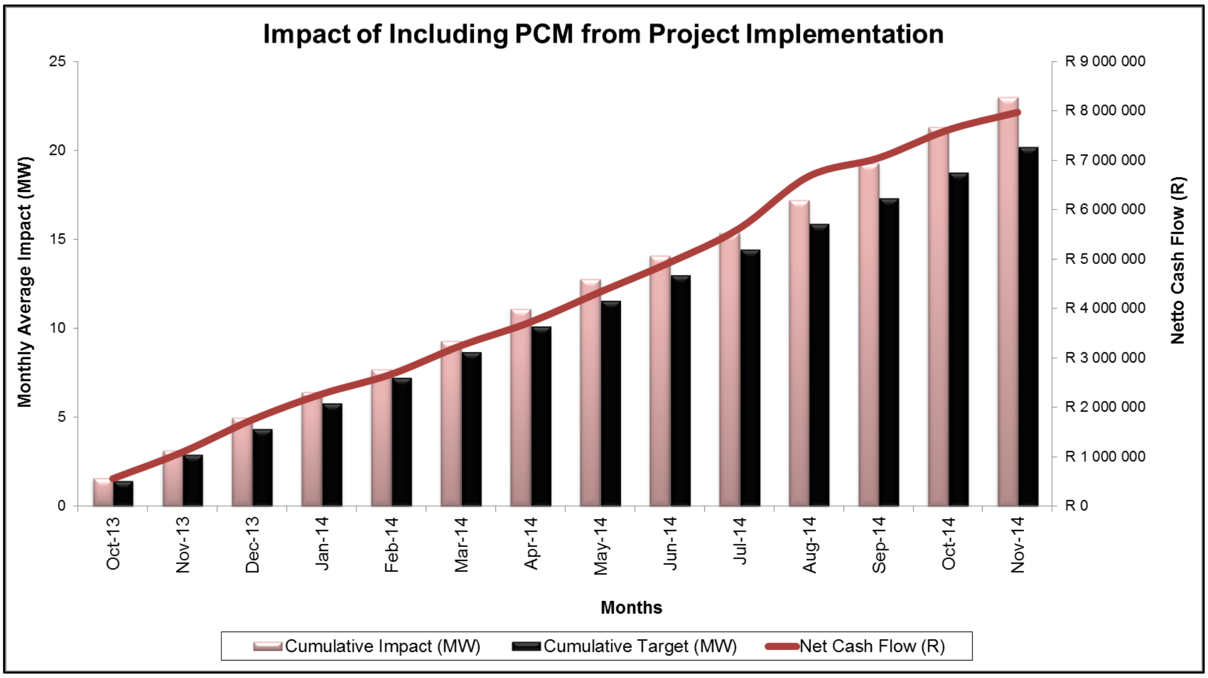

Figure 32: Scenario 2: Impact of including PCM from project implementation

The third scenario represents the project performance when PCM was stopped after a period of 12 months due to a maintenance agreement cancellation between the ESCO and the client. The rapid decline in performance after cancellation is evident from Figure 33.

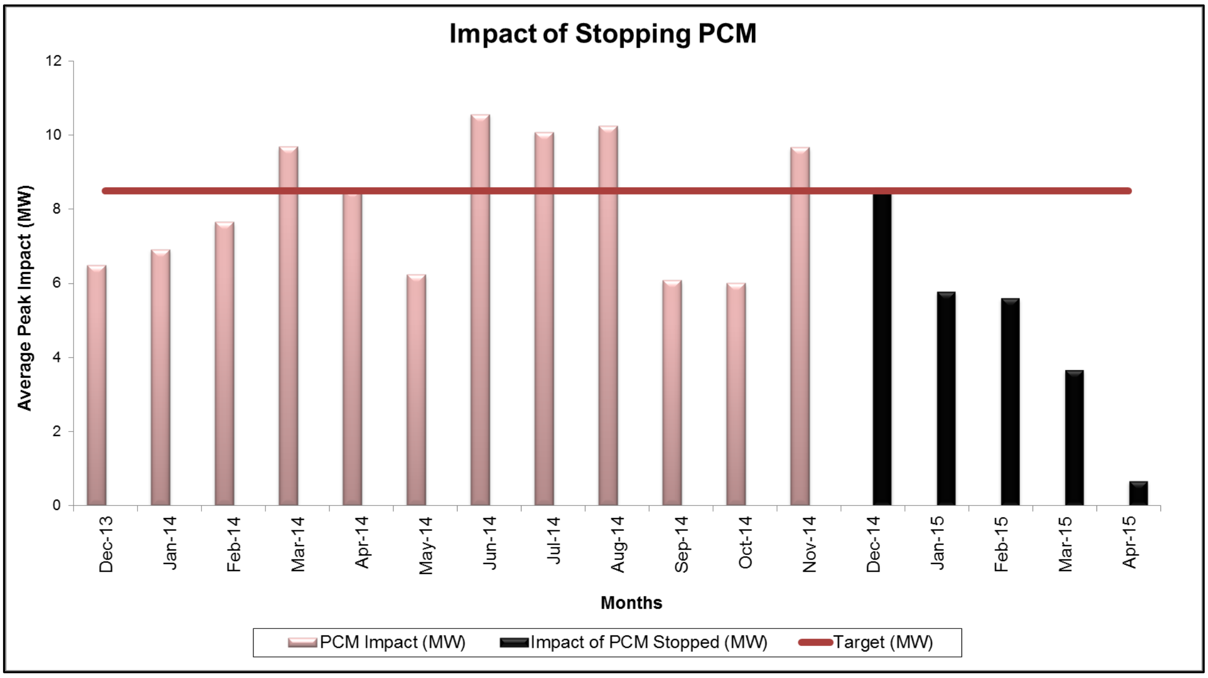

Figure 33: Scenario 3: Impact of stopping PCM on the performance of DSM projects

Groenewald concluded the study by stating the importance of incorporating a PCM strategy to restore and sustain the performance of implemented DSM projects [10]. Groenewald also stated that maintenance should rather be outsourced to ESCOs [10]. The PCM strategy was, therefore, developed to satisfy the needs for effective implementation by ESCOs. However, there is a need for gold mines to become independent from ESCOs and manage their own energy consumption patterns and costs.

Groenewald positively contributed to the concept of energy management in the gold mining industry by developing the PCM strategy. The PCM strategy complies with the requirements of the ISO 50001 standard, which also forms the framework for the development of the IEMS. With minor modifications, the PCM strategy can be incorporated within the development of the IEMS for the gold mining industry. PCM will assist in sustaining the performances of implemented energy savings initiatives discussed in the preceding section and improve performances of deteriorated initiatives.

Integrating the PCM strategy within the IEMS would positively contribute to an optimised energy management solution for the gold mining industry. Gold mines will not only be able to implement energy savings initiatives effectively, but also maintain such initiatives to contribute to continual improvements of electrical energy performance. This would also eliminate the dependence on ESCOs to realise energy savings.

Groenewald recommended condition monitoring on the efficiencies of energy-intensive equipment in the mining industry for further studies. This leaves scope for condition monitoring, and continually maintaining condition-monitoring initiatives, to be included in the IEMS. Section 2.4.1 also identified system inefficiencies as an opportunity to realise energy cost savings on gold mine systems. The following section discusses system inefficiencies in the gold mining environment of which condition monitoring plays a crucial part.

2.4.5 Addressing system inefficiencies

2.4.5.1 Preamble

It is stated in literature that the performance of load management interventions is related to the efficiency of systems and equipment [10]. In other words, the electrical energy performance of a gold mine will increase with improved efficiencies and the electrical energy performance of a gold mine will decrease with reduced efficiencies. Improving system efficiencies could form an important part of the “Do” step (implementation of energy savings initiatives) of the PDCA cycle mentioned in Section 2.2. The following section gives a short background on system inefficiencies such as system losses, metering and inefficient equipment and its impact to the electrical energy performance of gold mines.

2.4.5.2 System losses

System losses may be a comprehensive topic when it comes to the overall operations and configuration of a gold mine. For the purposes of this study, the focus is on the system losses that have an impact on the electrical energy consumption patterns of a gold mine. These losses include leaks and pressure losses through intricate piping networks.

Leaks

System leaks on gold mineshafts can be divided into two main categories, namely compressed air and water leaks. These leaks occur on the respective pipe reticulation networks of mineshafts. Mining pipe networks are very large and in some cases reach total lengths of up to 40 km [32], [37], [40]. For this reason, leak management is a very difficult task at gold mines and is classified as a day-to-day normality [36], [37], [95]. The reality and impact of leaks can, however, be minimised through proper management.

Leaks could account for up to 50% of the total compressed air and water demand, while the acceptable norm is not more than 5% [22], [32], [37], [58], [83], [95]. When these figures are converted into electrical power required by these systems, one understands why significant energy performance improvements are possible by addressing this inefficiency. Figure 34 and Figure 35 provide examples of different compressed air and water leaks on mining reticulation networks.

Figure 34: Examples of air leaks on mining compressed air reticulation networks[16]

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[16] HVACI is acknowledged for the photos taken at South African gold mines.

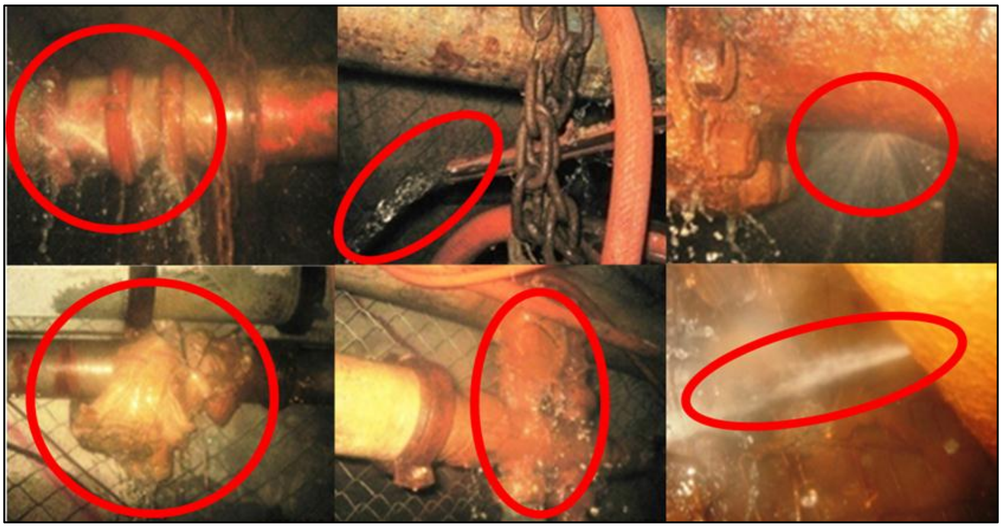

Figure 35: Examples of water leaks on mining water reticulation networks[17]

Repairing compressed air and water leaks is classified as a small modification with large energy savings potential [41]. It has been proven that the capital spent on compressed air generation was reduced with approximately 42% by just repairing leaks [32], [41]. A water leak management case study compiled by Botha proved a reduction of 7 Ml in water usage, which in turn reduced the daily energy consumption with 70 MWh [37].

In order to create a leak repair culture at gold mines, one needs to be able to calculate and understand the potential impact of leak management [32], [36]. According to literature, there are strategies available to determine the potential impact of repairing leaks. These strategies entail the calculation of flow rates through identified leaks. The flow rates are then converted to the electrical power demanded from system equipment to accommodate these leaks. The flow rate and electrical power wastage calculations through compressed air and water leaks are provided in Appendix B.

The financial impact of the leaks can be calculated with the help of the abovementioned equations and serve as motivation for leak repair [58]. Leaks do not only account for energy wastage, but also influence system performances such as pressures, dam levels and chilled water temperatures [31], [37], [40]. Continuously fixing the leaks will not only improve energy performance, but will also improve overall system efficiencies and maximise outputs. It becomes evident that continuous leak detection and repairs are very important for improving system inefficiencies of gold mining systems.

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[17] HVACI is acknowledged for the photos taken at South African gold mines.

Pipe losses

An additional characteristic of gold mine reticulation networks is that they are old and in most instances not maintained adequately [32], [35]. This promotes the occurrence of pressure losses, which in most cases result in decreased energy performance. An example is when compressors are located long distances from the actual compressed air point of use. The users usually have minimum pressure requirements and the compressors are ramped up to overcome the pressure losses over the pipelines to satisfy the required demand [60], [83].

To be able simplify the effect of pressure losses and develop effective solutions, one needs to understand the theory behind the concept of pressure drops. The pressure drop over long pipe networks can be calculated with the use of the Darcy–Weisbach equation[18] for isothermal flow [32], [103]. The equation is provided in Appendix B.

It is also important to consider the factors that amplify pressure losses within compressed air systems. These factors can be derived from Equation 6 (refer to Appendix B) and are summarised by the following:

1. diameter of pipes;
2. different pipe materials;
3. configuration of pipe sections;
4. compressed airflows and corresponding velocities; and
5. system operating pressures.

If the pressure difference between two points and the minimum pressure requirements from the end users are known, one is able to calculate the impact of the pressure loss on the electrical energy performance. Equation 4 in Appendix B is suitable for this purpose. From Equation 4 an increased compressor discharge pressure would induce an increase in power consumption. The impact of pressure losses becomes evident and may immensely influence the electrical energy performance of gold mines.

2.4.5.3 Metering

The accuracy of meters is very important when it comes to decision-making and interpreting the behavioural changes of operating systems [57]. For example, if a power meter on an operating system measures lower than actual, mine personnel may interpret the readings as an improved electrical energy performance, while this may not be the case. This influences mine personnel's behaviour towards energy savings initiatives, as they would assume that

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[18] The assumption is made that gold mines generally make use of round piping networks [32].

the system is already performing. Other cases include the influence of budgeting figures of mineshafts, which may result in the inefficient allocation of funds [104].

Meijsen, Van Rensburg and Booysen studied the impact of inaccurate meter readings on the financial cost savings of implemented energy savings initiatives. According to Meijsen et al., even the slightest variance in power measurement accuracy may have significant repercussions on the reported savings [57]. Meijsen et al. highlighted the factors[19] contributing to inaccurate power readings, which are given as follows [57]:

1. faulty instrumentation transformers;
2. discrepancies in analogue to digital conversions;
3. accuracy of power loggers; and
4. installation and set-up of equipment.

Meijsen et al. compiled numerous case studies to prove the impact of inaccurate power metering on reported energy savings. On one case study, Meijsen et al. found an omitted load of approximately 1 MW, which accumulated to a financial cost impact of approximately R5 million[20] per annum [57]. On other case studies, Meijsen et al. documented the combined impact of current transformer ratio errors. The errors accumulated to a daily impact of 3.4 MW, which related to an annual financial impact of approximately R16 million[20] [57].

To mitigate this inefficiency, Meijsen et al. developed a verification procedure to ensure accurate power readings on a consistent basis. Figure 36 provides the simplified illustration of the procedure.

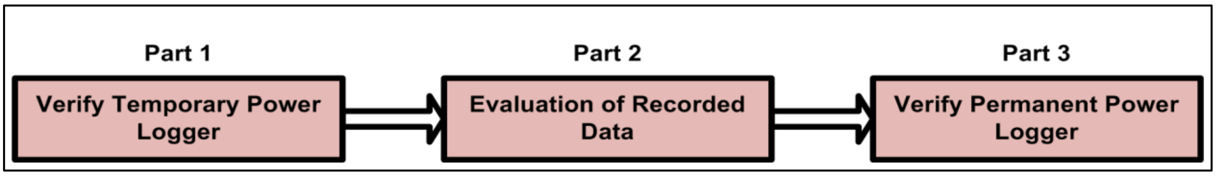

Figure 36: Verification procedure to improve measuring accuracy[19]

The procedure only focused on the influence of inefficient power measuring practices. Meijsen et al. believe that the same may apply when measuring system operational parameters such as flows, pressures and temperatures. This statement is motivated by their recommendation to further investigate the accuracy of pressure transmitters, flow meters, temperature sensors etc. [57].

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[19] Comprehensive detail on the influence of each factor and developed procedure available in [57].

[20] Calculated with 2013/2014 Eskom electricity tariffs.

These parameters may in some cases be the deciding factor to an energy efficient operation or not. For example, if crucial compressed air pressure readings indicate lower than actual values, mine personnel may switch another compressor on to increase system pressures. This in turn increases the power consumption, which decreases the electrical energy performance of the particular mineshaft. The same applies to the parameters of other energy-intensive systems on a gold mine such as pumps, refrigeration machines and fans.

The procedure developed by Meijsen et al. can be used to eliminate the factor of inefficient power metering during the development of an IEMS. In addition to the contribution by Meijsen et al., the developed procedure can be used to improve the accuracy of other measuring devices that influence the electrical energy performance of gold mines. The accuracy of these devices also influences the monitoring of system parameters to eliminate inefficient operation of equipment. This process is referred to as condition monitoring and is discussed during the following section.

2.4.5.4 Condition monitoring

The term condition monitoring may have a comprehensive meaning in literature when it comes to operating industrial appliances and equipment. For the purposes of this study, the term is used for the deterioration of mining equipment efficiencies, which directly influences the electrical energy performance of gold mine systems. The focus is also on the energy-intensive operations of a gold mine, as depicted by Figure 10. Condition monitoring of component inefficiencies on gold mining systems and components is provided in Appendix B.

The impact of system inefficiencies on the electrical energy performance of a mineshaft was highlighted during this section. A variety of procedures available in literature was provided to minimise the impact of these inefficiencies. Procedures include rectifying leaks, reducing pipe losses, rectifying metering inefficiencies and condition monitoring. These procedures are important for the development of an IEMS and contribute to an overall optimised solution for energy management in the gold mining industry.

Section 2.4 provided a thorough background on existing technologies and procedures that forms an important part of the “Do” step of the ISO 50001 standard discussed in Section 2.2. These technologies and procedures are also the drivers for improving a gold mine’s electrical energy performance.

According to Figure 15, the “Check” step would be the next phase of the PDCA cycle. This step entails measuring, verifying and reporting the results of executed plans to relevant stakeholders. For the gold mining industry, it would be to measure, verify and report the results of the initiatives discussed in Section 2.4. The next section provides literature on the procedures available in literature for measurement and verification (M&V) and reporting in the gold mining industry.

2.5 Check: Verifying and reporting on executed plans

2.5.1 M&V procedures

It might be challenging to calculate the impact of implemented energy management initiatives accurately and efficiently [10], [53], [57]. M&V procedures have been developed to mitigate this challenge and ensure the accuracy of reported improvements. M&V procedures also provide all the stakeholders with a credible view on the impact of energy management [53], [57], [105]. The importance of M&V procedures for the development of an IEMS becomes evident.

Several guidelines have been developed to aid with M&V procedures [53], [106]. The most prevalent of these guidelines are the International Performance Measurement and Verification Protocol (IPMVP) and the Federal Energy Management Program (FEMP) [53]. A large variety of South African institutions, specialising in M&V procedures, rely on these international guidelines to comply with the requirements of the South African National Standards (SANS) 50010:2010[21] standard [106], [107]. Booysen stated that adhering to these guidelines and ultimately complying with the SANS 50010 M&V standard provide the competency to measure and verify energy performance with a high level of trust and credibility [53].

Extensive literature is available on the M&V of energy savings in the South African industrial sector, which includes the gold mining industry [53], [57], [105], [106], [107]. These sources provide comprehensive detail on the procedures to be followed for credible M&V. For the purposes of this study, the author is only interested in the most basic concept of M&V procedures. Figure 37 provides a simplified graphical representation of this concept [107].

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[21] South African national standard for the measurement and verification of energy savings.

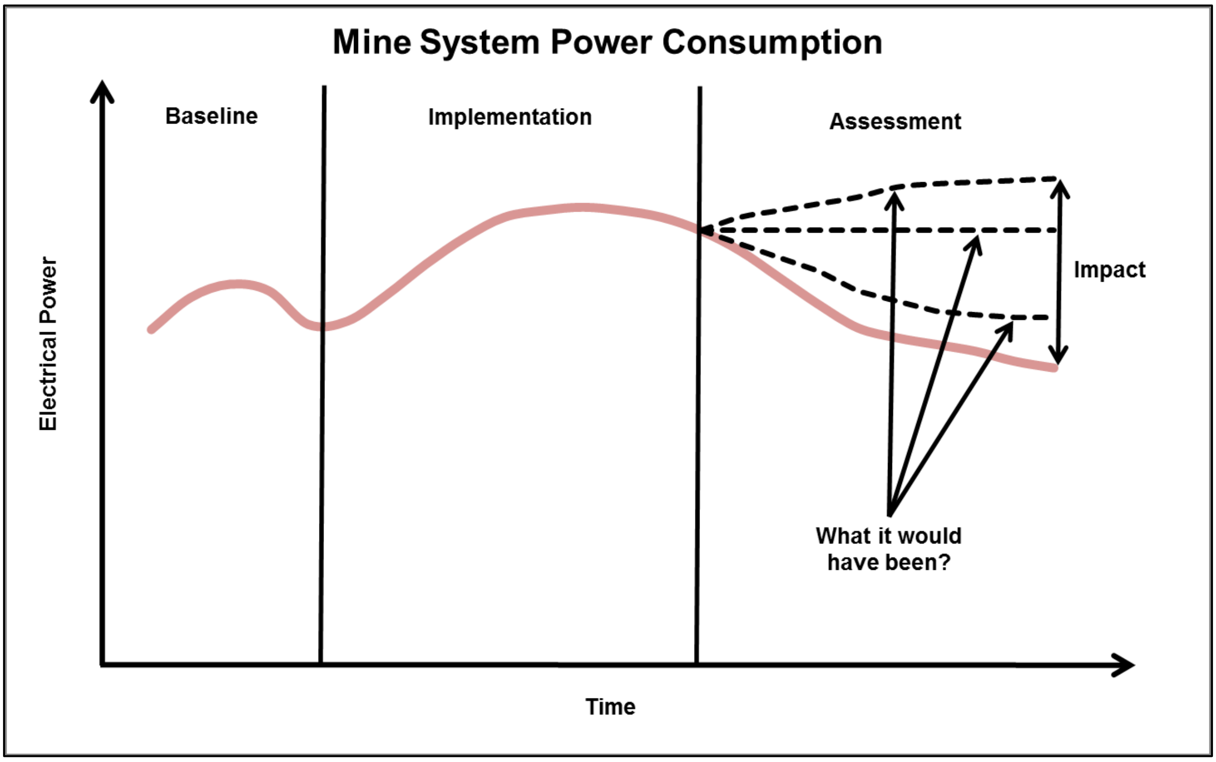

Figure 37: Simplified illustration to verify energy performance improvements

The baseline is developed prior to implementing energy improvement measures. It represents the what-it-would-have-been profile during the reporting period [53], [57], [107]. The baseline-capturing period may vary according to system operational consistency and seasonal influence [53]. Under normal and static system conditions, the original baseline would have been sufficient to calculate the energy improvement after implementation. However, Figure 37 shows that the power profile of systems fluctuates over time [10], [57], [107]. Energy performance improvements are, therefore, calculated with the help of Equation 1 [53], [107].

Equation 1: Energy performance improvement calculation

$$E_{IP} = (B_{Pre-Implementation} - E_{Post-Implementation}) \pm Adjustments$$

Where:

E_{IP}	=	Improved energy performance
$B_{Pre\text{-}implementation}$	=	Original baseline developed during pre-implementation
$E_{Post\text{-}Implementation}$	=	Actual energy profile after implementation
Adjustments	=	Changes affecting energy performance

It is difficult to accurately determine the impact of energy performance improvements with fixed baselines [10], [53], [57]. Baseline adjustments are used to accurately compare post- and pre-implementation periods under the same conditions by continuously compensating for changes to the system [10], [57], [106]. Numerous credible baseline adjustment models and methodologies are provided by literature [53], [57], [105], [106], [107]. Gold mining personnel, therefore, have the convenience of using these techniques to accurately calculate the impact of an IEMS.

After the electrical energy performance improvements have been accurately calculated and verified, it must be communicated to the relevant stakeholders. This should be accomplished through reporting procedures.

2.5.2 Reporting

Reporting is stated by many as being one of the most important aspects in energy management to ensure sustainable and continuous performance of implemented initiatives [20], [38], [52], [31], [61]. Reporting also plays a crucial role in monitoring the day-to-day performance of systems and decision-making during operational planning of mines [20], [31]. Numerous studies focusing on reporting as part of managing energy in the gold mining environment exist in available literature [52], [61], [100]. The study compiled by Van der Zee is, however, relevant to the purposes of this study [20].

The main focus of Van der Zee’s study was to model the electricity risks and opportunities in the gold mining industry. To aid in monitoring the risks and opportunities, Van der Zee developed an electrical energy reporting procedure for gold mines [20]. Figure 38 depicts the reporting procedure developed by Van der Zee [20]. The procedure conforms to the PDCA cycle of ISO 50001. This was to ensure continual improvement in the accuracy and quality of reports [20]. The reporting data was obtained from mining supervisory control and data acquisition (SCADA) systems and electricity bills and the reports were manually generated on a weekly and monthly basis [20].

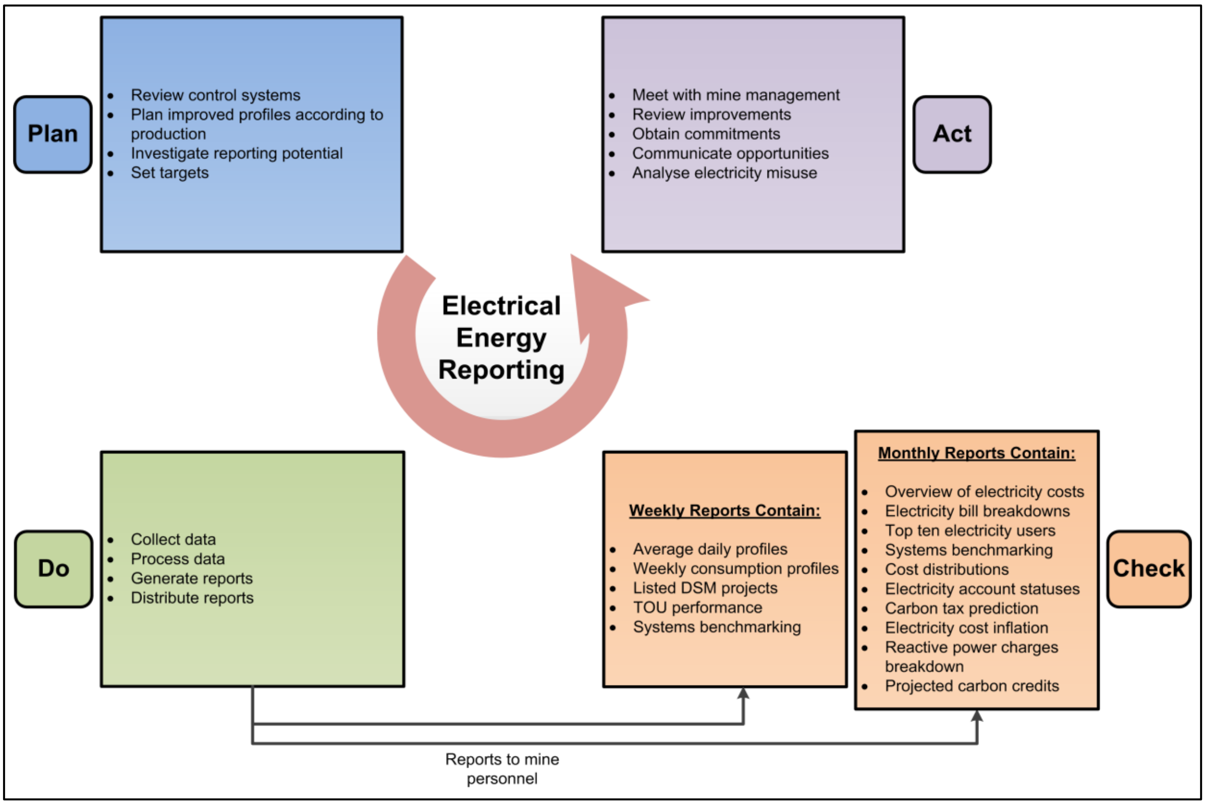

Figure 38: ISO 50001-compliant electrical energy reporting procedure

There are strategies in place for the procedure displayed in Figure 38 to be automated [52]. There are numerous supervisory systems able to capture, verify and process data to automatically generate and distribute reports on energy performance [52], [61], [100]. These systems are mainly used by ESCOs while implementing DSM projects and maintaining performance afterwards [10], [52].

Although Van der Zee regards the reporting procedure as comprehensive, the author is of the opinion that there are other important aspects that need to be incorporated. In particular, both Groenewald and Fockema mention the need for reporting on condition monitoring and system operating parameters [10], [61].

With slight modifications and integration with automated systems, it would be ideal to incorporate the reporting procedure within an IEMS for the gold mining industry. Reporting procedures would enable mine personnel to respond to important aspects of the IEMS and address nonconformities as specified by the ISO 50001 energy management standard (refer to Section 2.2). Through reporting, mine personnel would also have sufficient information to optimise the implementation of energy management. The next section provides procedures for optimising energy management in the gold mining industry, which represents the “Act” step on Figure 15.

2.6 Act: Optimising energy management

Throughout Chapter 1, the influence of electrical energy consumption and related costs to marginal gold mining were discussed. Reducing the electricity consumption of gold mines is, however, in most cases an expensive a technical operation [31], [84]. Gold mines do not always necessarily have the capital and technical skill to invest in energy efficiency measures. It is, therefore, important for the gold mining industry to acquire assistance with the implementation of energy efficiency measures and to implement such measures at the lowest costs to ensure maximum benefits.

Energy efficiency incentives (EEIs) have been developed to help industries with financial and technical support to optimise the use of energy [54], [108]. These incentives can be divided into three main categories, which are depicted by Figure 39 [54], [108].

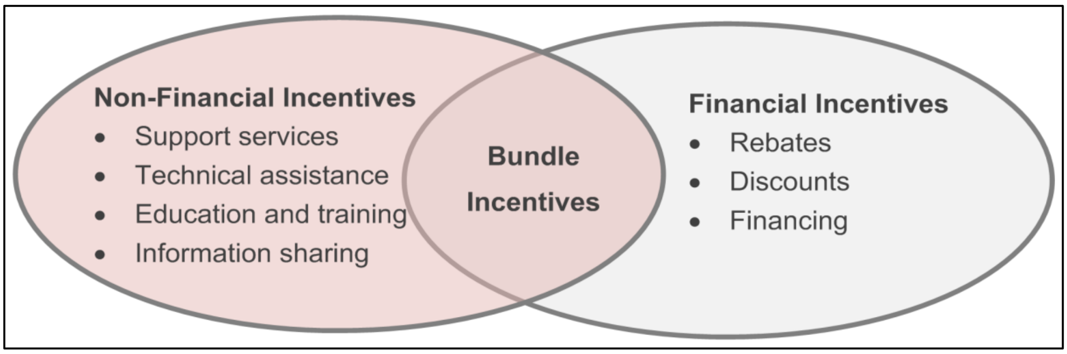

Figure 39: Overarching categories for EEIs

Using EEIs to optimise the use of electrical energy is a scarce topic in South Africa [54]. These incentives are available for organisations to use and gold mines should capitalise on these incentives to further increase profit margins through energy efficiency measures. Table 13 provides a summary on the various EEIs available in South Africa for use by the gold mining industry.

Table 13: EEIs summary for the industrial sector[22]

Incentive	Incentive Driver	Benefits	Disadvantages
12L	Energy efficiency realised through previously implemented initiatives	R0.45/kWh tax deduction for verified energy efficiency savings	Appointment of M&V teams, no concurrent benefits and no renewable energy
12I	Investing in manufacturing assets to improve South Africa's manufacturing sector	Large scale Greenfield and Brownfield investments	Only offered to large scale projects
IDM	Reduce strain on South African electricity grid	R×/MW for verifiable electricity savings	Appointment of M&V teams. Only available for electricity savings projects
NCPC-SA	Promote implementation of resource efficiency and cleaner production	Free energy audits	No funding provided
MCEP-PI	Increase the productivity and competitiveness of businesses	Funding for a percentage of the total investment	Funding only available for new equipment. No concurrent benefits
GEEF	Address the funding gap between actual investments and provided incentives	Loan amount at a preferred interest rate	Industrial Development Corporation (IDC) fees apply
MCEP-LF	Increase the productivity and competitiveness of businesses	Loan amount at a preferred interest rate	Loan period is only four years

Budge, however, mentioned in her study that it is a complex and costly process to select the appropriate incentive for the gold mining industry [54]. Budge addressed this issue by developing a structured approach to select appropriate EEIs for the industrial sector. Figure 40 depicts a simplified illustration of the structured approach [54].

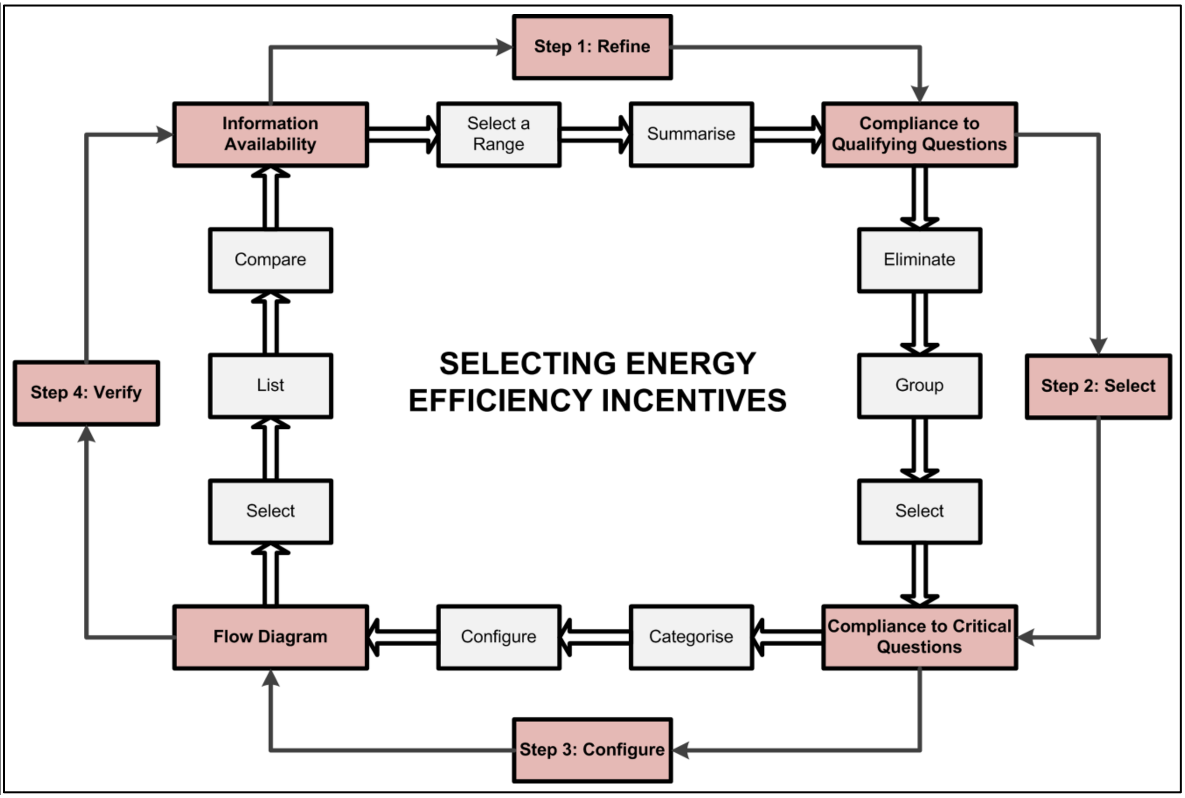

Figure 40: Structured approach for selecting EEIs in the South African industrial sector

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[22] Adopted from a study compiled by Budge [114].

Budge's approach can be integrated in the development of an IEMS to ensure technical and financial optimisation of energy management in the gold mining industry. The PDCA cycle of ISO 50001 in itself provides a framework for organisations to continually optimise the implementation of EnMSs. Combining the "Act" step of the PDCA cycle with the incentives available for the gold mining industry will result in an optimised energy management solution for gold mines, which adheres to continual improvement.

2.7 Conclusion

This chapter investigated available ISO-compliant EnMSs in the industry. The investigation identified the positive impact on an organisation's energy performance by using the ISO 50001 energy management standard. Numerous case studies proved the effectiveness of the standard and the increasing rate of organisations incorporating the standard within their EnMSs. However, it is still scarce to use ISO 50001 in the gold mining industry.

Research in Chapter 2 indicated the absence of a holistic energy management strategy for the gold mining industry. A wide variety of literature was, however, found that contributed to the concept of energy management. The ISO 50001 standard was used throughout Chapter 2 as a discussion framework for available literature in the gold mining industry. Once again, it is important to note that the framework does not indicate the existence of an IEMS, but rather individual studies combined by the author to indicate the possibility for the development of an IEMS. The framework for Chapter 2 is summarised as follows:

"Plan" step

Energy management planning fundamentals were identified, which included barriers that halt the effective implementation of energy management in the gold mining industry. Numerous drivers are available in literature to overcome these obstacles from the planning phase of an IEMS and forms the foundation to effective energy management.

"Do" step

The second phase of the PDCA cycle focused on systems analysis procedures to identify potential for electrical energy improvements on gold mine systems. Further research was compiled on numerous energy savings initiatives and the procedures for the implementation thereof. Maintenance procedures to sustain initiative performances and the impact of system inefficiencies on the electrical energy performance of gold mines were provided.

“Check” step

During this step, credible M&V procedures in available literature were investigated. It was found that there are a wide variety of initiatives for determining the credible impact of implemented energy savings initiatives in the gold mining industry. Electrical energy reporting procedures were also identified for communicating energy management results with relevant stakeholders.

“Act” step

The final step of the PDCA cycle investigated available procedures in literature for optimising energy management for the gold mining industry. It was found that incentives could be used to optimise an IEMS from a financial and technical perspective. The ISO 50001 energy management standard in itself could also provide a framework for continual improvement of electrical energy performance.

The abovementioned elements of energy management in the gold mining industry, discussed in the context of the PDCA cycle of ISO 50001, proved to have no relation to one another. This provides significant scope to use the identified literature in Chapter 2 to holistically approach the development of an IEMS for the deep-level gold mining industry. The development of the IEMS is discussed in the following chapter.

CHAPTER 3

[23]

“Hard work alone will accomplish remarkable results. But hard work with method and system will perform seeming miracles.” – *W.C. Holman*

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[23] http://www.mining-technology.com/features/feature-top-ten-deepest-mines-world-south-africa/.

3 DEVELOPING AN IEMS FOR THE GOLD MINING INDUSTRY

3.1 Introduction

This chapter focuses on using the information gathered in Chapter 2 to develop an IEMS for the deep-level gold mining industry. The framework of the strategy was developed to conform to the continual improvement PDCA cycle of the ISO 50001 energy management standard. The different studies discussed in Chapter 2 are structured to form a holistic approach for electrical energy management in the gold mining industry.

The development of the IEMS is divided into the four steps of the PDCA cycle of ISO 50001, which should be executed in a chronological order from step 1 to 4. The “Plan” step (1) of the cycle entails energy management planning, the “Do” step (2) the execution of these plans, the “Check” step (3) the verification and reporting of the executed plans and the “Act” step (4) the optimisation of the IEMS. The “Act” step reverts to the “Plan” step to improve the implementation and performance of the IEMS continuously. The inner detail and functionality of the strategy are provided in this chapter.

3.2 Overarching energy management strategy

The PDCA framework of the ISO 50001 energy management standard was used during the development of the strategy. The short-term aim in using ISO 50001 guidelines and requirements are to ensure continual improvement of a gold mining group’s electrical energy performance. The long-term aim is to have all the required documents and processes in place to help a mining company obtain ISO 50001 certification by using the IEMS.

Figure 41 depicts the overarching steps of the IEMS. The strategy is divided into four steps where every step represents a segment of the PDCA cycle of ISO 50001. The strategy was designed for the steps to be implemented in a chronological order starting from the “Plan” step and ending with the “Act” step of the cycle. From the “Act” step, the strategy reverts to the “Plan” step from where the cycle repeats itself. This will ensure continual improvement of the strategy’s impact on energy performance. The four main steps of the strategy are the following:

1. **Plan:** Energy management planning
2. **Do:** Execution of energy management plans
3. **Check:** Verification and reporting of executed plans
4. **Act:** Optimisation of energy management

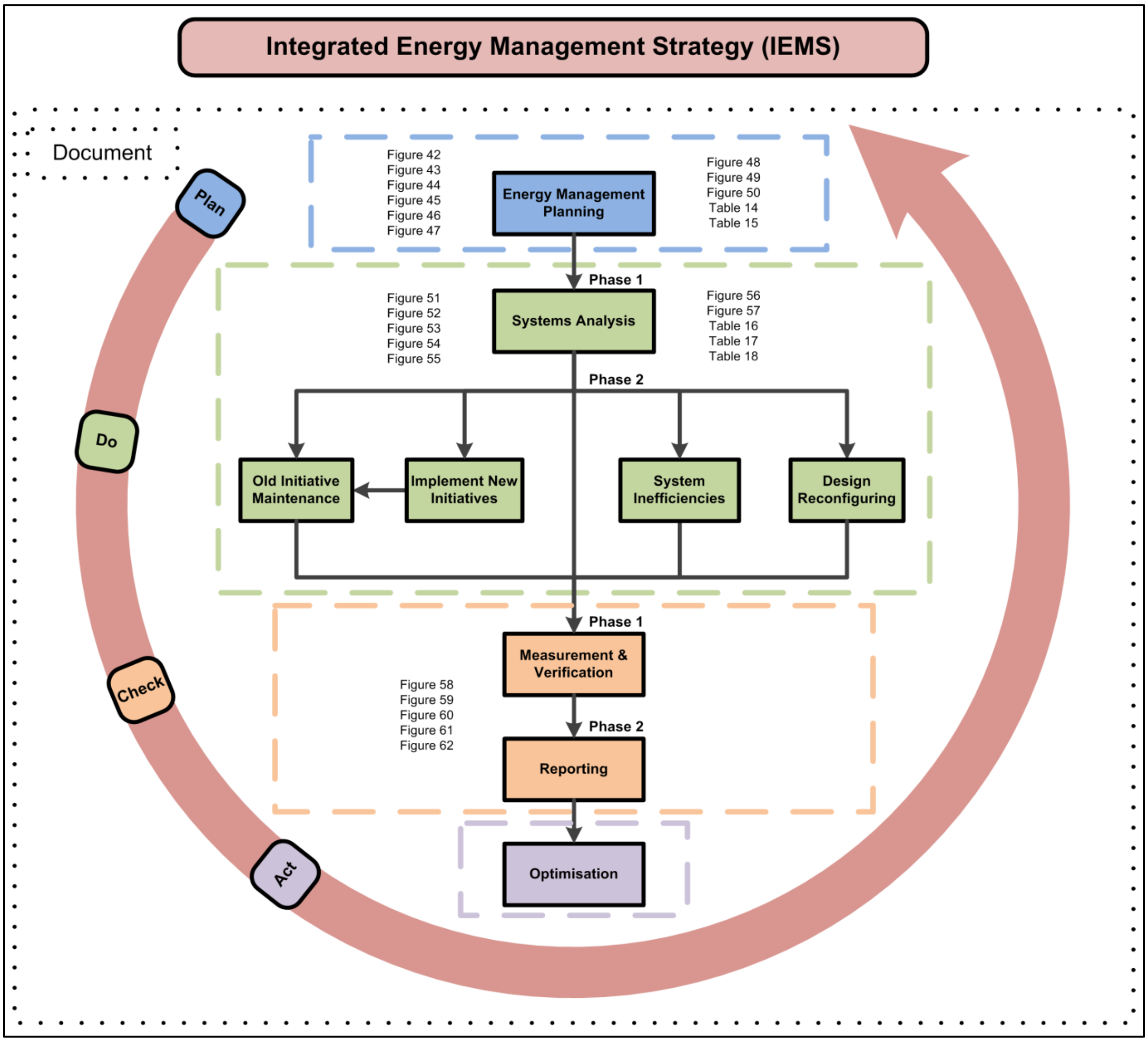

Figure 41: Novel overarching layout of the developed IEMS

The IEMS adheres to a fully documented process – proper documentation ensures effective IEMS implementation and promotes understanding of the procedures to be followed [56], [66]. Documentation should be updated regularly as the IEMS implementation progresses and adapts to a continual improvement cycle. This ensures continual consistency and sustainability in the improvement of electrical energy performance. A documented process also ensures that a manual for mine personnel is developed to implement energy management and assists with the certification process for ISO 50001 compliance of the IEMS.

Figure 41 shows how the “Do” and “Check” steps are sub-divided into two phases each. The first phase of the “Do” step entails a systems analysis to identify potential for energy performance improvements on each electricity-consuming system of gold mines. The second phase focuses on the actual implementation of energy improvement initiatives on the systems to address the potential identified in the previous phase. The implementation of these initiatives is prioritised according to the maximised benefits for the mine. Further details on the prioritisation and the elements of the “Do” step are discussed in Section 3.4.

The first phase of the “Check” step focuses on the M&V of the improvements realised from the “Do” step. The second phase uses the results of the first phase to report on key elements of the implemented IEMS. As with the “Do” step, the inner details of the “Check” step will be discussed in Section 3.5.

The IEMS was strategically developed to be implemented at shaft level of a mining group. The impact of the strategy is, therefore, measured at shaft level and accumulated to determine the overall impact on the mining group’s electrical energy performance. Figure 42 depicts a simplified illustration of this concept.

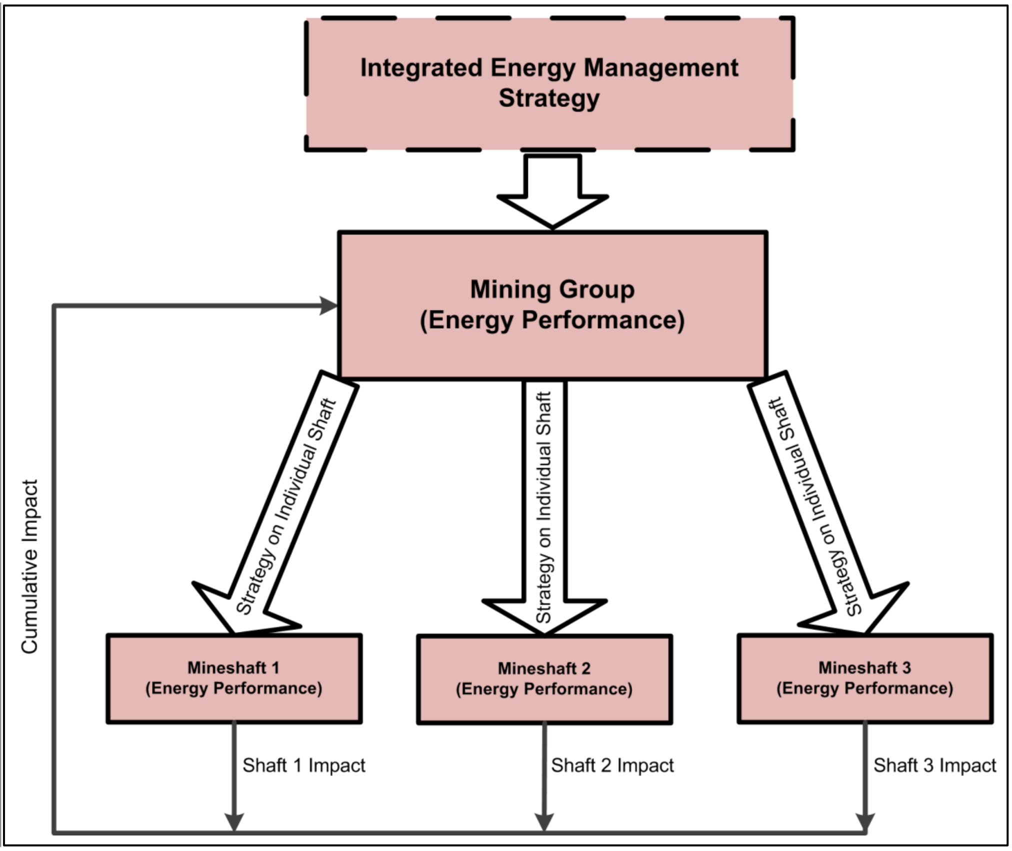

Figure 42: Implementation breakdown of the IEMS

The following section discusses energy management planning as the "Plan" step of the IEMS.

3.3 Plan: Energy management planning

According to literature, the core aspect of implementing any energy management strategy successfully is having a well-documented plan and committed resources to execute the plan. This section focuses on the methodology to conduct proper energy management planning within a gold mining group. Figure 43 is a simplified representation of the chronological steps to be followed during the energy management planning process.

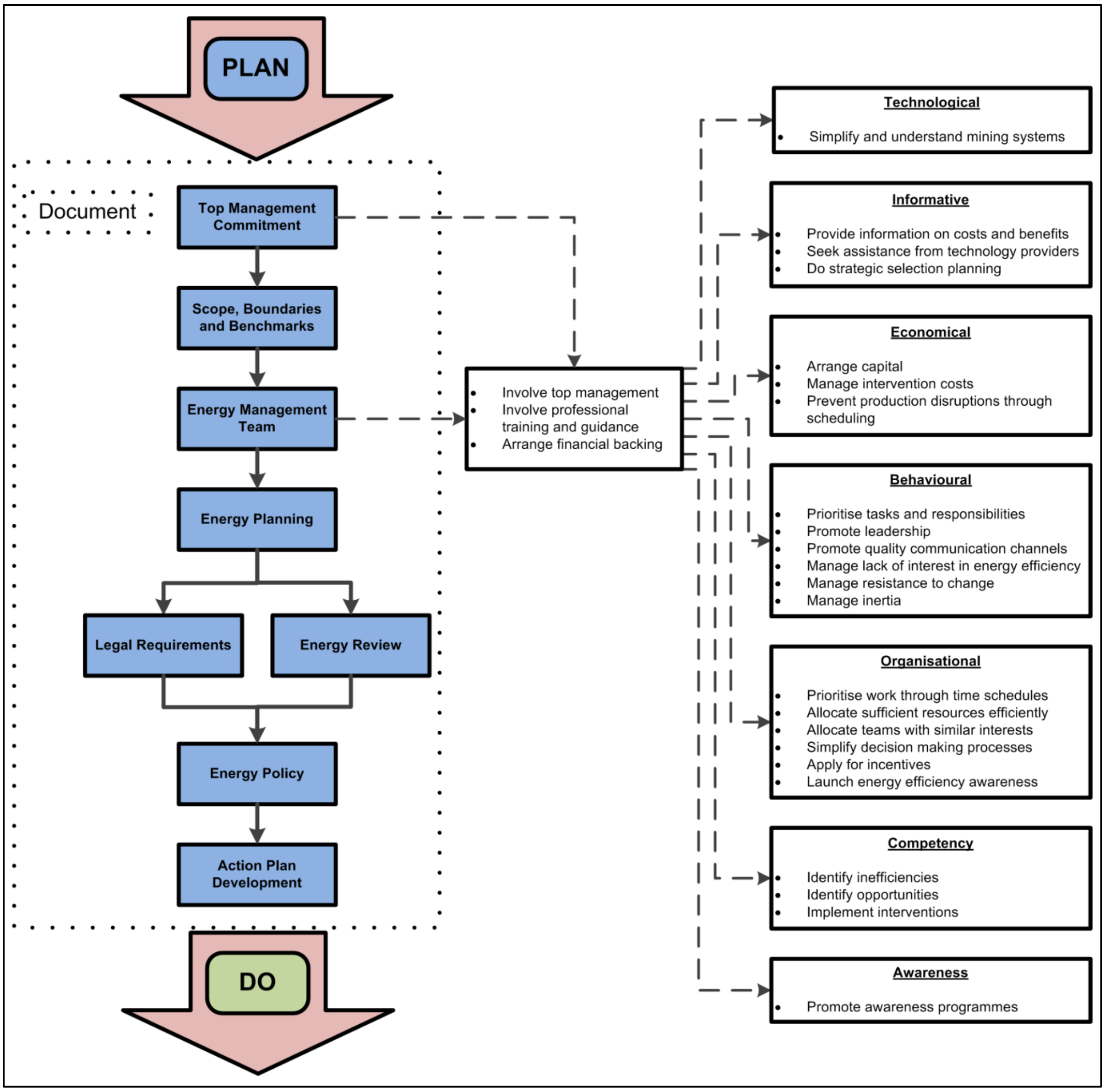

Figure 43: Chronological steps in conducting energy management planning

The planning process was developed to address the energy management barriers identified and stipulated in Table 9, Chapter 2. These barriers are the main culprits for the lack of effective energy management in the gold mining industry. Eliminating these barriers provides the foundation for successful and effective implementation of energy management. It also simplifies the successive steps of the IEMS and its application to systems in the gold mining environment.

As depicted by Figure 43, the EMTs at shaft level collaborate with top management of the mining group. Together they are responsible for eliminating the energy management barriers. Top management should lead by example, advertise their commitment, and drive energy management awareness within the group. Top management should also provide the required financial backing to address these barriers and the physical IEMS implementation. The EMTs are responsible for enforcing drivers to address the barriers at shaft level. The steps of the energy planning process and the roles of top management and EMTs are given as follows:

3.3.1 Top management commitment

Successful energy management starts with commitment from the gold mining group's top management. Energy management initiatives are easier to enforce on the rest of mine employees when top management declares their commitment to energy performance improvements.

3.3.2 Scope, boundaries and benchmarks

Once top management has committed to energy management, the scope must be defined and the boundaries of the IEMS identified. For the purposes of this study, the scope is to continually reduce the energy consumption patterns of the gold mining group to realise financial cost savings for improved profit margins. The IEMS is limited to the electrical energy portion of a gold mine's total energy consumption. The reason being the intensive electricity consumption patterns of South African gold mines, high electricity tariffs and their direct impact on a gold mine's profitability.

After defining the scope and boundaries, the next step for top management is to identify the area for electrical energy improvements that would realise the largest impact in the shortest period for the mining group. According to Van der Zee's study, the ideal method for identifying the most inefficient shafts is by means of kilowatt-hour per processed tonne of rock. This conventional method is not always sufficient, as numerous factors such as mine depth, ore grades and the magnitude of the operations influence the productivity and energy efficiency of gold mines [20]. However, a benchmarking model was developed in this study for top management to easily sequence the IEMS implementation at the different mineshafts of the group. Figure 44 illustrates a graphical representation of the sequencing model.

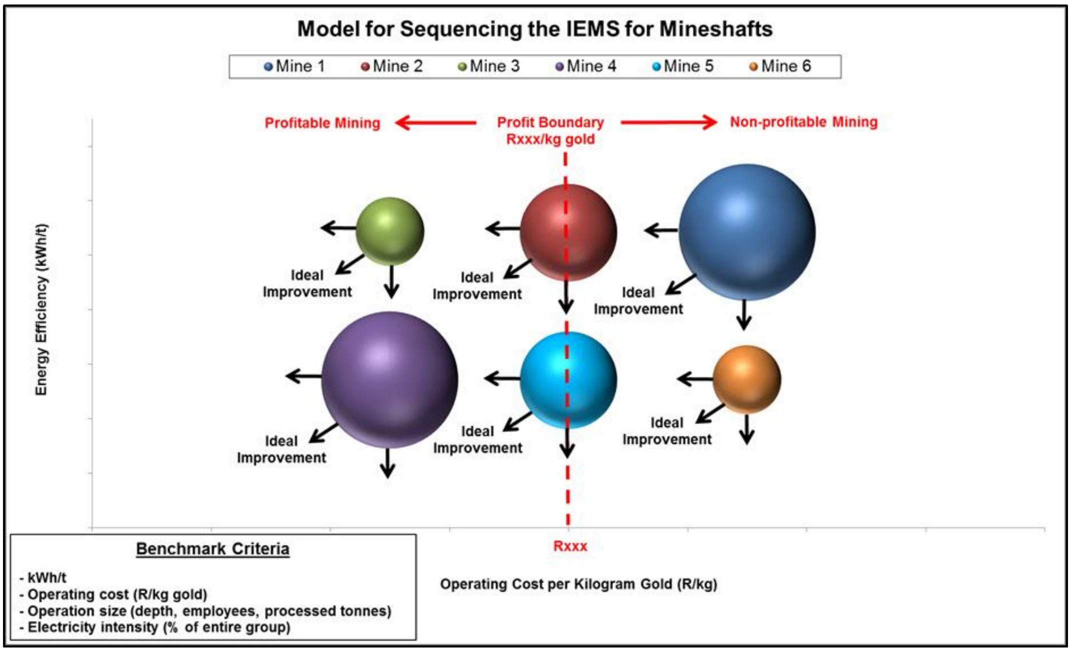

Figure 44: Novel benchmarking model for IEMS implementation at mineshafts

For illustration purposes, six different mines (Figure 44) were considered for the development of the model. The six mines represent scenarios for different shaft operations in a gold mining group. Although there may be many more scenarios than depicted in Figure 44, these six scenarios are sufficient to illustrate the functionality of the sequencing model. Table 14 summarises the operating conditions of the different mineshafts referred to in Figure 44.

Table 14: Criteria for different mineshaft operating conditions in a mining group

Criteria for Mining Shaft Operating Conditions		
Mineshaft 1	**Mineshaft 2**	**Mineshaft 3**
Large operational size High electricity consumer High operating cost Non-profitable mining Average processed tonnes Low ore grade	Medium operational size Medium electricity consumer Average operating cost Marginal mining Low processed tonnes Average–high ore grade	Small operational size Lower electricity consumer Low operating cost Profitable mining Low processed tonnes High ore grade
Mineshaft 4	**Mineshaft 5**	**Mineshaft 6**
Large operational size High electricity consumer High operating cost Profitable mining High processed tonnes High ore grade	Medium operational size Average electricity consumer Average operating cost Marginal mining Average processed tonnes Average ore grade	Small operational size Low electricity consumer Low operating cost Non-profitable mining Low processed tonnes Low ore grade

The ore grade per tonne of processed ore has a major influence on electricity consumption and the profitability of a gold mine [17], [20], [109]. This statement becomes evident from Table 14, as some mineshafts tend to process more ore (consequently more electricity) to produce the same amount of gold than shafts with higher ore grades. Van der Zee regards ore grades and the information depicted in Table 14 as very important when benchmarking the energy use of different shafts within a mining group [20]. This is a valid statement, but the author is interested in Van der Zee's opinion regarding energy performance in terms of kWh/t.

According to Van der Zee, one would typically commence with energy performance improvements at the mineshaft with the highest electricity input per tonne of processed ore [20]. Although kWh/t is an accurate estimation of the shafts' energy performance, it does not necessarily mean the maximum financial benefits will be obtained from these shafts. The sequencing model addresses this issue.

For illustration purposes, the electricity consumption and processed tonnes of the mineshafts illustrated in Figure 44 were used to validate the model. The kWh/t figures were calculated to determine the energy efficiency of all the shafts. An estimated reduction of 10% in electricity consumption was assumed for the shafts and the financial impact was calculated[24]. Table 15 depicts the results of the calculations and sequencing order for maximum benefits.

Table 15: Calculating the IEMS implementation sequence for maximised benefits

IEMS Implementatiion Model Sequence Comparison to Conventional kWh/t Method						
Mineshaft	**Annual Tonnes Treated**	**Annual Electricity Consumption (GWh)**	**Energy Efficiency (kWh/t)**	**10% Electricity Reduction (Financial Savings)**	**Sequence Order (Cost Benefit)**	**Sequence Order (kWh/t)**
Mineshaft 1	700 000	600	857	R33 000 000	**1**	2
Mineshaft 2	350 000	280	800	R15 000 000	**4**	3
Mineshaft 3	170 000	150	882	R8 000 000	**5**	1
Mineshaft 4	1 100 000	550	500	R30 000 000	**2**	5
Mineshaft 5	570 000	300	526	R16 500 000	**3**	4
Mineshaft 6	310 000	150	484	R8 000 000	**6**	6

Table 15 shows that the implementation sequence differs when the conventional kWh/t method is used instead of calculating the potential financial cost-saving benefits. Mineshaft 3 has the highest kWh/t figure and thus energy management should commence with this mine according to the conventional method. Reducing the electricity consumption with 10% at this mine will, however, only realise a financial cost saving of R8 million per annum. When the

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[24] Calculated according to 2015/2016 Eskom tariffs.

developed sequence model is used, Mineshaft 1 would be chosen for IEMS implementation and realise a cost saving of R33 million for a 10% reduction in electricity.

It becomes evident from Table 15 and Figure 44 that the maximum benefits are not necessarily realised at the most inefficient shafts, but rather at the shafts with the largest cost-savings potential. As depicted by Figure 44, where cost savings are equal for two or more shafts, the most inefficient shaft should be chosen for IEMS implementation. In the case of this example, Mineshaft 3 would be chosen instead of Mineshaft 6.

The model can be used by top management to strategically select the mineshaft within the mining group where the IEMS implementation should commence. The model is also used to sequence the order in which the IEMS should be implemented across all the shafts within the mining group. The next step is to establish an EMT at the chosen shaft. The EMT will be responsible for the IEMS implementation at shaft level.

3.3.3 Energy management team

The EMT must be strategically selected in order to fulfil all the needs of the IEMS implementation. Team members must represent all of the energy-intensive sections of a mineshaft as well as top management of the mining group. The role of top management is crucial to the success of the IEMS implementation by the EMT. Top management should not only provide support by authority, but should also be willing to provide resources, finances, materials etc. for the EMT. The EMT for each mineshaft should include the following members:

1. top management representative (usually the shaft general manager);
2. energy management representative (usually the shaft engineering manager);
3. mining services manager;
4. production engineer;
5. chief electrician or electrical foreman;
6. chief technician or technical foreman; and
7. mechanical foreman.

The communication channels of the EMT should be constructed to eliminate the majority of the barriers identified in Table 9 and Figure 43. EMT team members should communicate with mine personnel who share the same interests regarding operations and systems. Figure 45 illustrates the correspondence chain for an EMT at the shaft level of a gold mine.

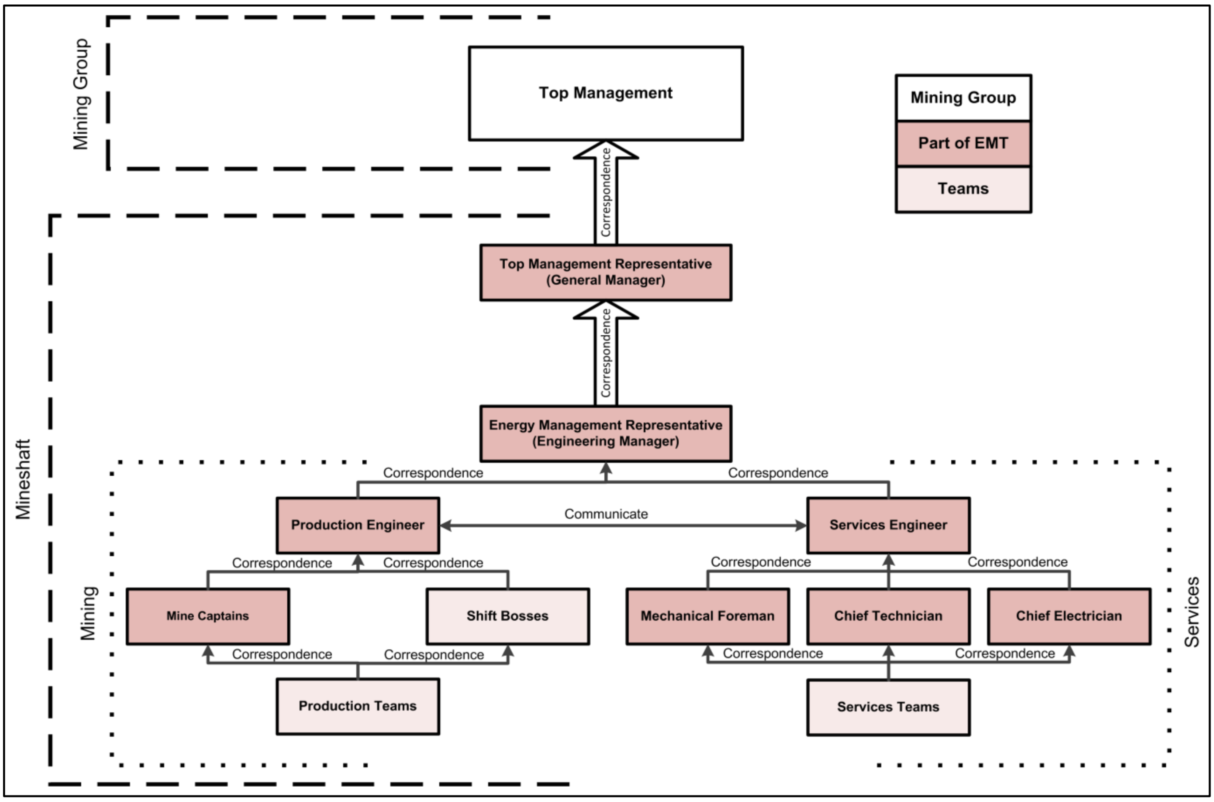

Figure 45: Correspondence chain for the EMT at a mineshaft

Appointed EMT members should receive adequate training on energy management implementation from professionals in the energy management field. Financial support from top management should be provided to appoint certified energy managers or organisations to present certified training. Training should be a continual process to ensure that EMT members are up to date with the latest technologies and techniques.

Appointed team members should be highly committed to energy management and create energy awareness (energy savings culture and positive relationships) among their teams. One major issue in gold mining is the rivalry between mining and services. Employees on the mining side are production-driven as they receive incentives for meeting targets, while services aim to provide energy sources in the most efficient way possible [31], [48], [50]. As indicated in Figure 45, mining and services should communicate regularly to eliminate this barrier. Through regular communication, services would be able to satisfy the requirements of mining operations efficiently.

Another method to counter the rivalry between mining and services is to provide financial incentives for joint efforts between mining and services to improve energy performance. This will ensure that mine personnel are not only committed to receiving incentives for met production targets, but are also accomplishing them in an efficient manner. It is important for the EMT to eliminate all the barriers prior to proceeding with the IEMS implementation. The success in overcoming these barriers determines the response from employees to the commitment of improved energy performance.

The next step for the EMT is to compile an energy review to determine the general operation of electricity-consuming systems at the shaft.

3.3.4 Energy review

The first step of the energy review is to identify data sources from which historical electrical data can be obtained. These data sources may range from utility accounts to third-party metering, with the required verification documents available. Historical data is collected and reviewed to obtain a general overview of total system level electricity consumption patterns at the shaft. The electrical intensity of systems is analysed based on its contribution to the mine's total electricity consumption and production. Production-related systems are classified as the EnPIs. Figure 46 gives an example of identifying the EnPIs.

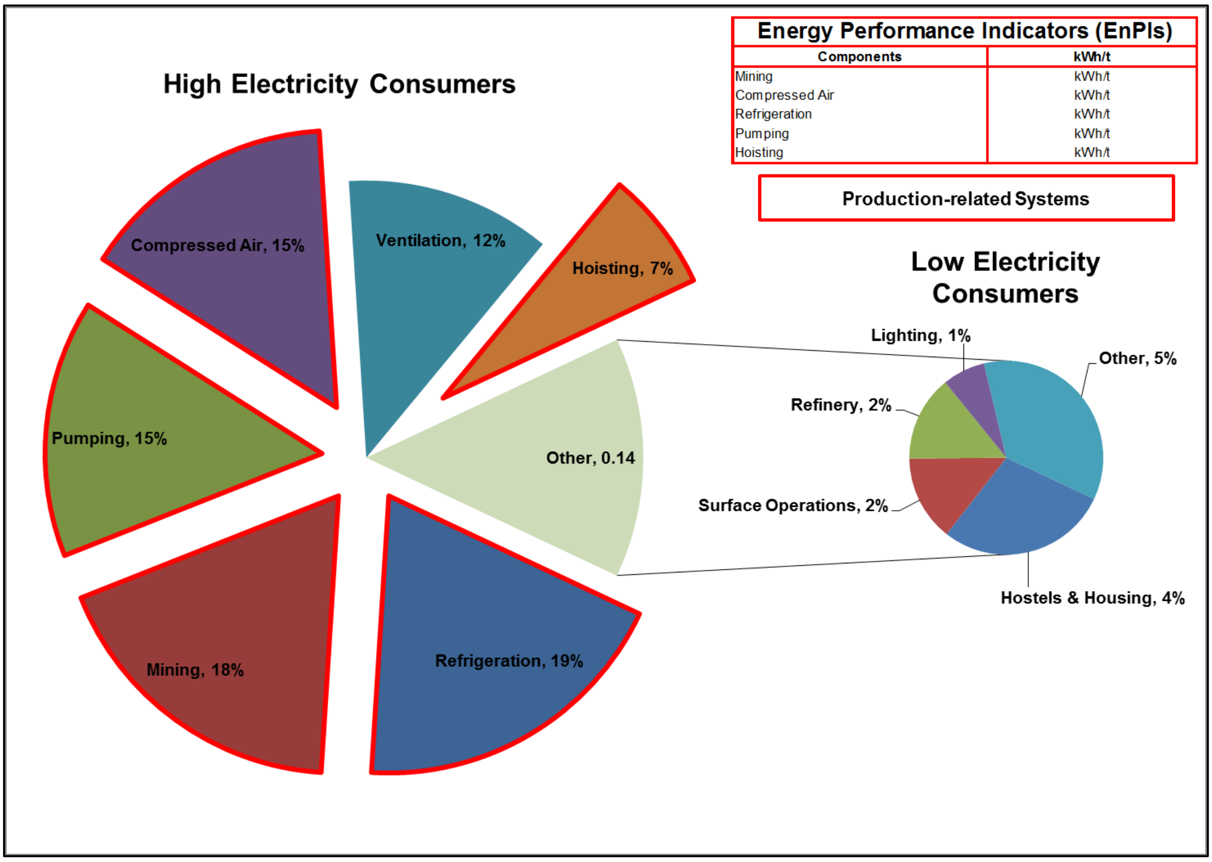

Figure 46: Identifying the EnPIs by analysing systems electricity consumption

The data is used further to develop a baseline for the total electricity consumption of the shaft as well as for individual systems. Baselines are developed for consecutive 12-month[25] periods and serve as the basis against which any energy performance improvements can be measured. The baselines should be updated regularly, as outlined by the shaft energy policy (discussed in the following section), to ensure continual improvement. The baselines need to be verified and signed off by the energy management representative of each shaft. Figure 47 gives an example of a typical total baseline (averaged over 12 months) of a mineshaft.

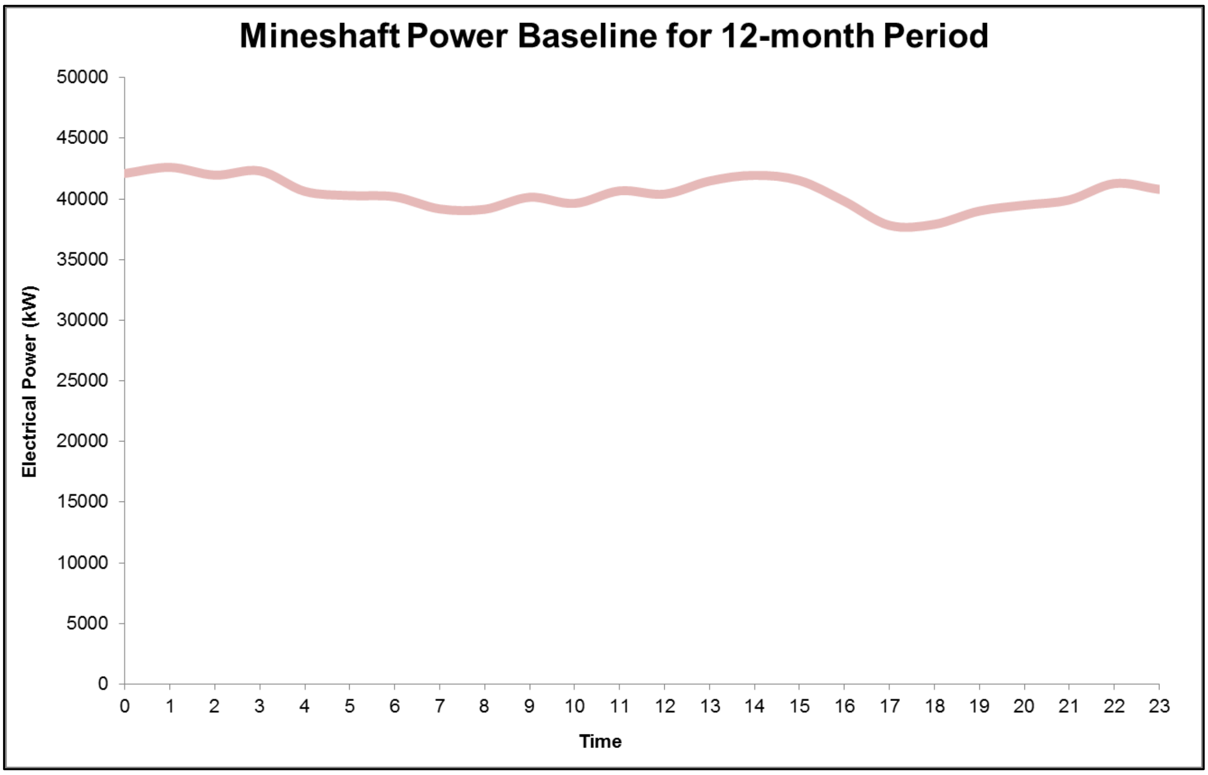

Figure 47: Total electrical power baseline for a typical mineshaft at a gold mine

As part of the energy review, the EMT should also confirm the mineshaft's compliance with the legal requirements pertaining ISO 50001 energy management. According to the ISO 50001 standard, the mining group and mineshafts should identify the applicable legal requirements associated with its energy consumers, consumption and efficiency [56]. The process to be followed by a gold mining group to comply with the applicable legal requirements is given by Figure 48.

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[25] The 12-month data range represents a combined general average for winter and summer months.

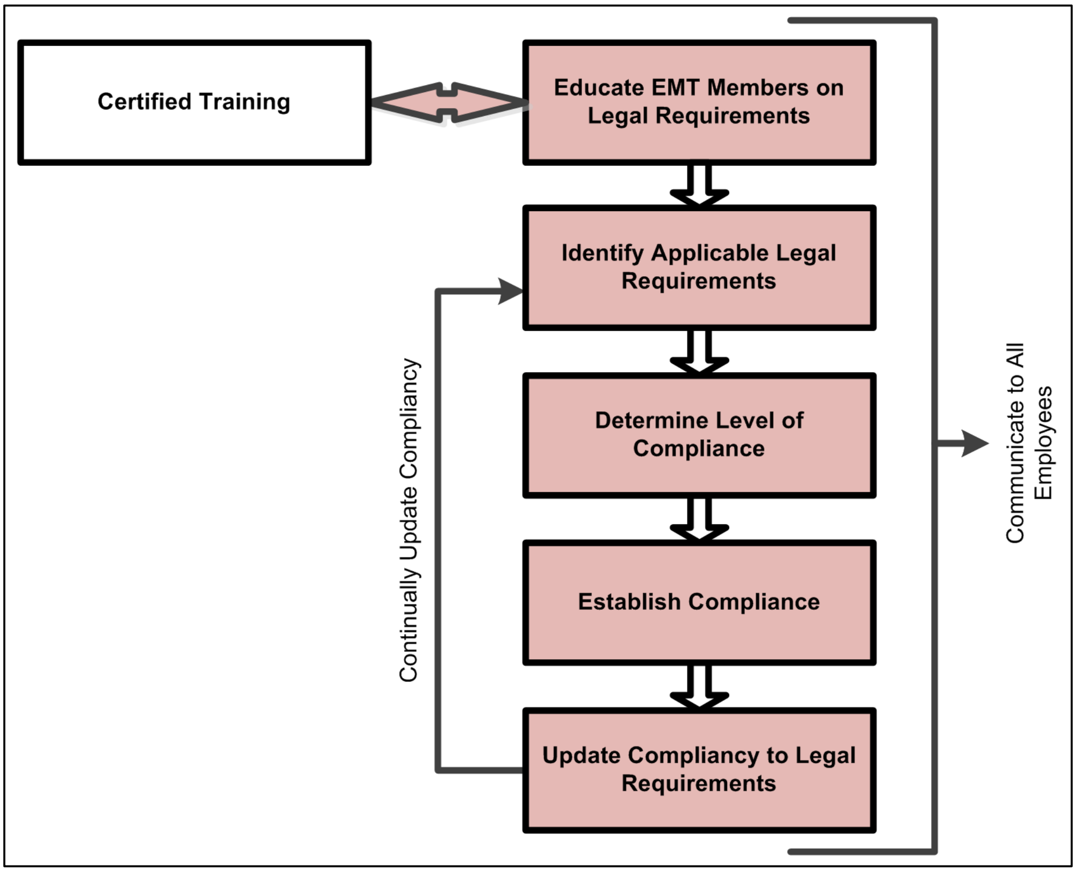

Figure 48: Procedure for a gold mining group to address legal requirement compliance

The energy policy can be developed with the help of the energy review, which is the next step of energy management planning.

3.3.5 Energy policy

The energy policy is set up to give clear vision and direction for the EMT to improve the use and performance of energy. For a gold mineshaft, the main goal is maintaining high production levels while reducing electricity costs on the intensive electricity consumers. Thus, the energy policy includes the objectives and targets for the EMT to achieve this goal and ensure continual improvement.

The objectives and targets for electricity reduction are determined by scrutinising the figures obtained from the energy review. The EMT should use their own discretion in stipulating reachable objectives and targets by identifying the potential on system baselines, EnPIs and electricity consumption patterns. Figure 49 provides the shaft-specific energy policy with the goal, objectives[26] and targets[27].

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[26] What does the gold mine want to achieve?

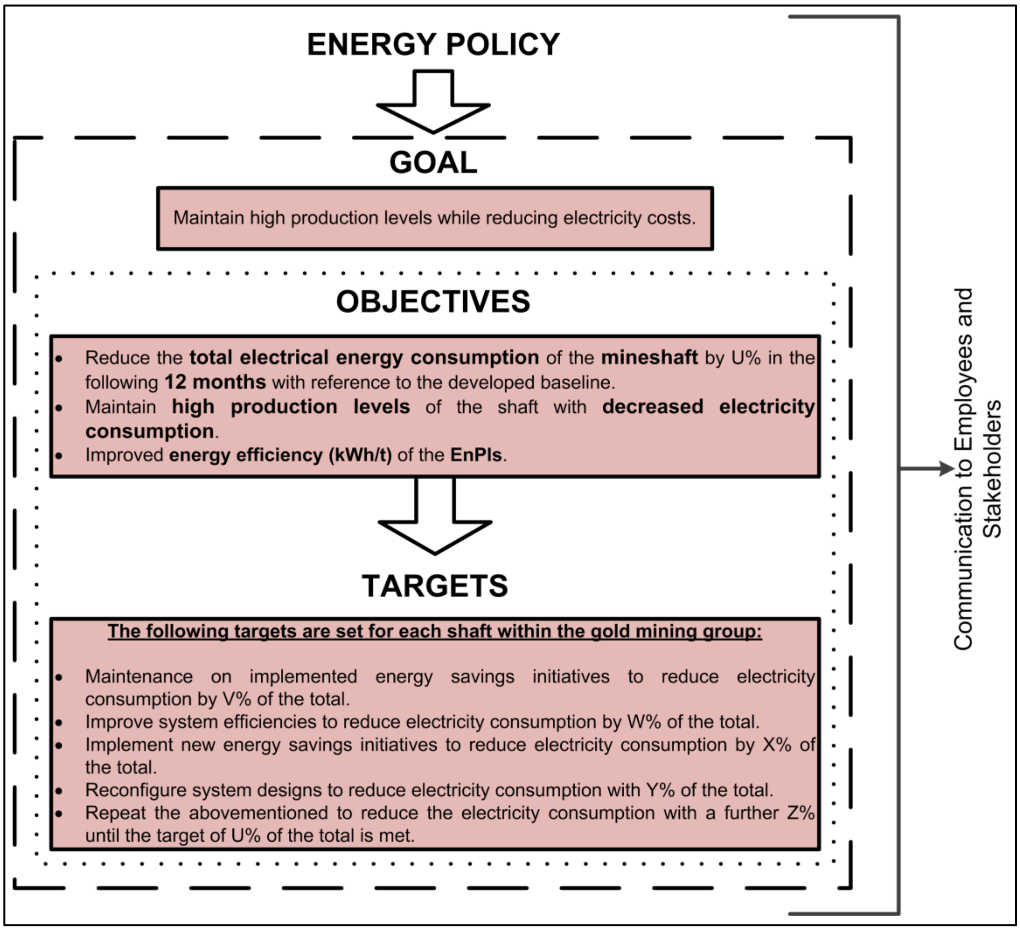

Figure 49: Mineshaft energy policy

The EMT is accountable for this policy, hence realising the objectives and targets. Furthermore, the EMT is responsible for communicating the energy policy to all the employees and relevant stakeholders. All employees are responsible for understanding how this policy applies to their daily activities. This will increase awareness regarding energy management and the mining group's commitments to improving energy performance.

According to the ISO 50001 standard, the energy policy should be reviewed and updated if necessary. The policy, and consequently the energy review for each shaft, will be updated on a yearly basis. This will ensure that the IEMS adapts to a dynamic system. The energy policy will, however, be reviewed on a monthly basis during EMT monthly electrical review meetings. During these meetings, the policy will be compared with the progress of energy improvements to evaluate the viability of reaching the set objectives and targets.

The next step is to develop an action plan on how the objectives and targets set by the EMT in the energy policy will be realised.

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[27] How will the gold mine achieve it?

3.3.6 Action plan development

The action plan is developed in such a manner to be easily interpreted and implemented by the EMT and its resources. Figure 50 depicts a simplified layout of the developed action plan.

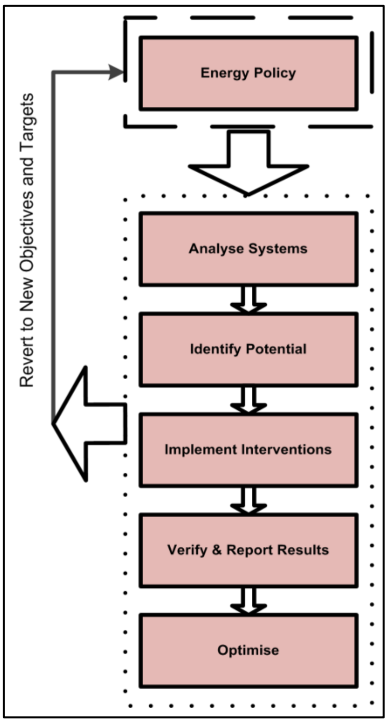

Figure 50: Action plan to realise objectives and targets set by the energy policy

The execution of the action plan is the core aspect of realising the actual electrical energy performance improvements on the mineshafts' electricity-consuming systems. However, the effectiveness of the action plan is determined by the outcomes of energy management planning. If energy management planning is neglected, poor performance will be reflected on the electrical energy performance of the mineshaft and the objectives set by the energy policy will not be reached. The execution of the action plan and the details of every step are discussed in Section 3.4 to Section 3.6.

3.4 Do: Executing energy management plans

3.4.1 Preamble

The next step for the EMT is to execute the developed action plan of the IEMS. The action plan commences with a systems analysis (first phase of the "Do" step) to obtain a general overview of the configurations and day-to-day operations of the different systems of the shaft. The ultimate goal of the systems analysis is to identify the potential of implementing initiatives to improve electrical energy performance of the mineshaft (second phase of the "Do" step).

3.4.2 Phase 1: Systems analysis

As identified by the energy review, there are numerous systems at a gold mine where energy performance improvements can be realised. To reduce the complexity for mine personnel to implement the IEMS, it is required to develop generic procedures that can be used on all the different systems. This also contributes as a driver to address the barriers identified in Table 9 and Figure 43. Figure 51 demonstrates a generic process to be followed by the EMT in conducting the systems analysis on a gold mine.

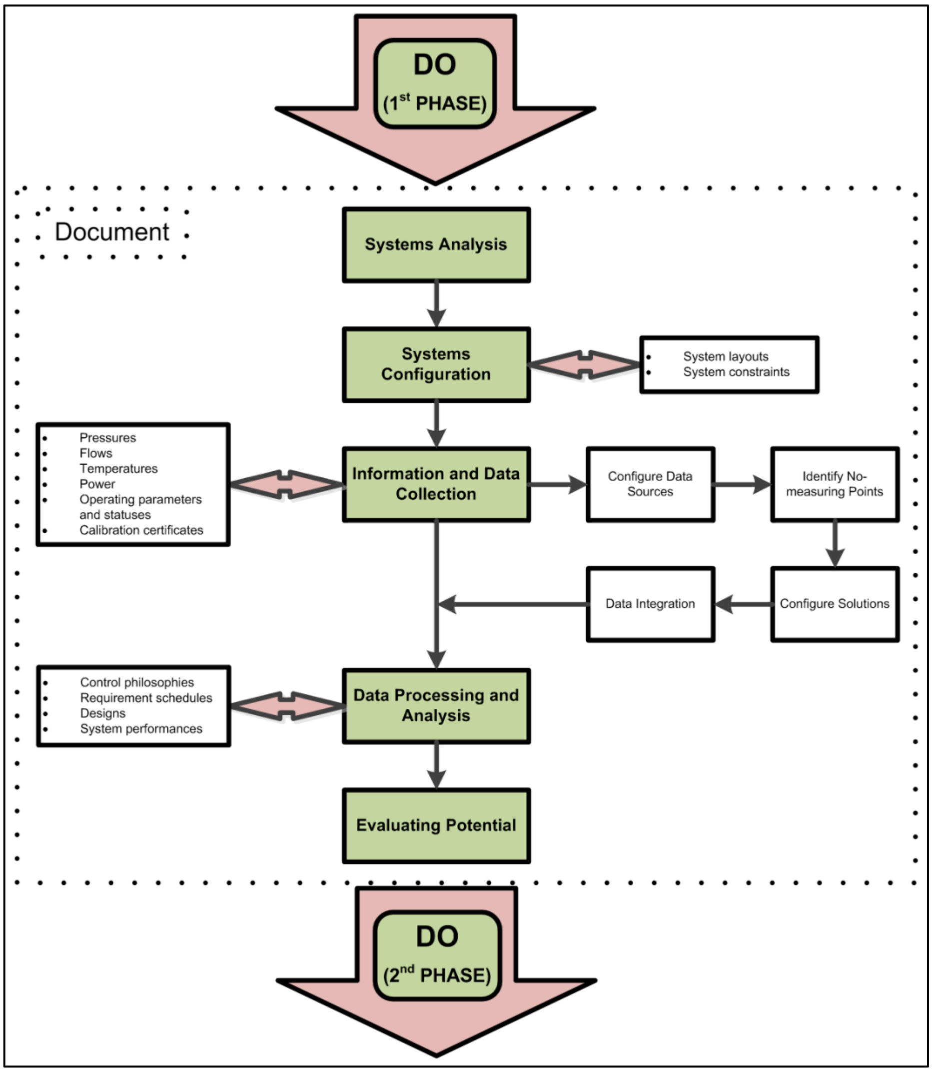

Figure 51: Systems analysis procedure during the IEMS implementation[28]

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[28] The systems analysis was developed with information adapted from literature on Van der Zee [20], Bredenkamp [32], and Vosloo's [106] studies.

A compressed air system of Mineshaft 1, discussed with the benchmarking model in Figure 44 and Table 15, is used as an example to illustrate the concept of systems analysis. It must be noted that the systems analysis is, however, generic and compatible with all the other electricity-consuming systems at the gold mine. Using the compressed air system of Mineshaft 1 as an example should not be confused with the purpose of the study. The concept of the systems analysis is given as follows:

3.4.2.1 Systems configuration

During this step, it is important to obtain information on the following:

1. system layouts; and
2. system constraints.

System layouts

The physical layouts should be obtained for individual systems as well as the entire mineshaft system. Figure 52 gives the simplified illustration of Mineshaft 1's compressed air system.

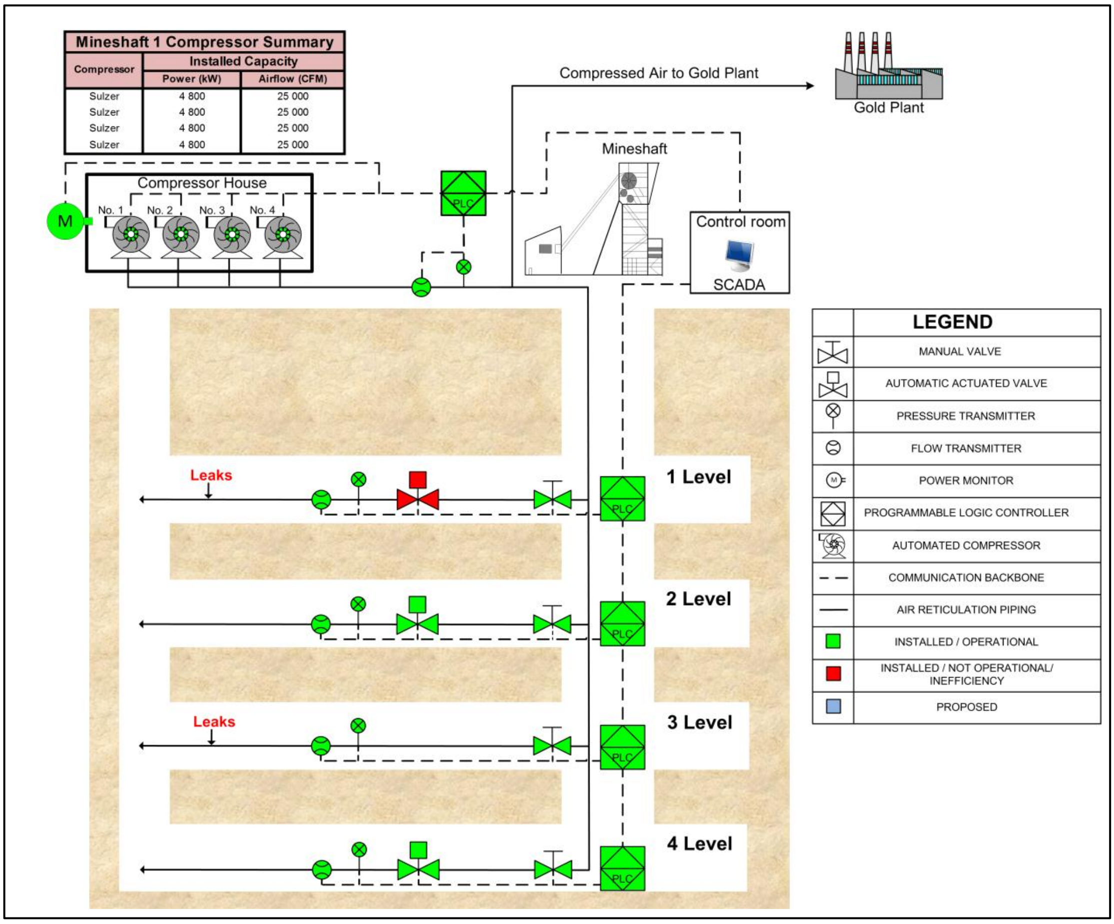

Figure 52: Compressed air system used to demonstrate the systems analysis concept

The system layout step is very important for obtaining an overall idea of the system configuration and interaction with one another (Figure 52). The following information is crucial and mostly illustrated by Figure 52.

1. existing infrastructure;
2. physical state of existing infrastructure;
3. automated capabilities of infrastructure;
4. location of electrical components;
5. number of electrical components per system; and
6. installed capacities of electrical components.

Systems constraints

The system constraints need to be identified as a preventative precaution during the development of energy savings solutions. The constraints also play a crucial role in the sustainability of the IEMS. The following constraints need to be identified.

1. data monitoring and storage capabilities;
2. production patterns;
3. future deviations in production patterns;
4. production targets;
5. systems influence to production;
6. production requirements from services;
7. mining operation schedules; and
8. lifespan of the mine.

For a compressed air system, the demand and schedules from mining is a very important constraint to consider. Table 16 depicts the mining schedule and compressed air requirements for Mineshaft 1's compressed air system.

Table 16: Mineshaft 1 compressed air requirement schedule as an important constraint

Mineshaft 1 Compressed Air Requirement Schedule			
Activity	**Time Period**	**Gold Plant Required Air Pressure (kPa)**	**Shaft Required Air Pressure (kPa)**
Peak drilling	07:00–13:00	400	500
Loading	09:00–16:00 & 22:00–02:00	400	450
Sweeping	09:00–16:00 & 22:00–02:00	400	450
Refuge bays	00:00–24:00	400	150

The compressed air supply continuously needs to satisfy the demand to prevent any influence to production. It is, therefore, very important to consider the requirement schedule when developing and implementing energy savings measures.

3.4.2.2 Information and data collection

Firstly, the data sources need to be specified to determine the extent and format of available data. It is also important to identify the data intervals in which the data is measured as well as the consistency of available data per system component or process.

It may occur that the data of system processes is not monitored or logged on the mine's communication and data acquisition network (SCADA). Some mines still use mechanical measuring equipment and data may just be available from log sheets[29], mobile loggers or manual readings. In some instances, data may also be required from system locations where there is no measuring infrastructure. These locations are referred to as no-measuring points.

The ISO 50001 standard specifically specifies the importance and availability of system data for continual improvement of an EnMS [56], [66]. According to best practices, the data should also be remotely accessible and digitally logged as far as possible [66]. The old technology should, therefore, be replaced with modern equipment and integrated with the mine's SCADA system. The procedure depicted by Figure 53 should be followed in cases where data is required from the no-measuring points.

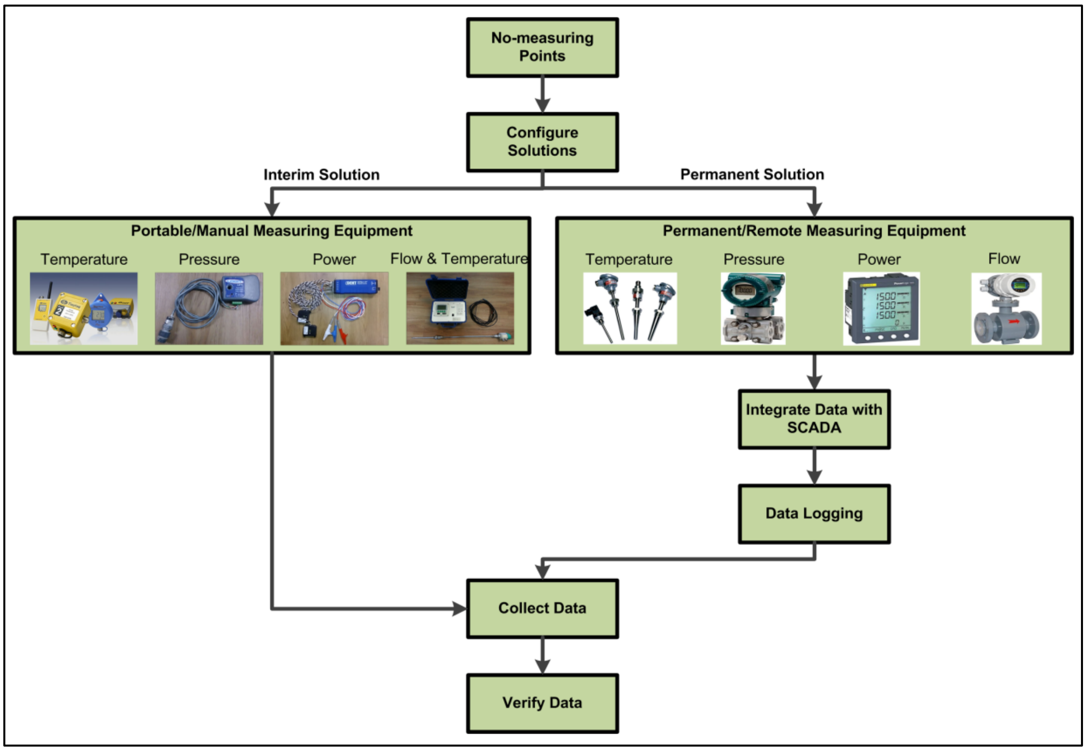

Figure 53: Data collection procedure for the no-measuring points

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[29] Manual handwritten process used by mines to record data.

As with the electrical data obtained during the energy review, data is collected for a period of 12 months to obtain a general operational overview of the systems processes. The data needs to be verified to ensure accuracy. Accuracy of the data is important during the theoretical analysis in the second phase of the "Do" step. Data from installed measuring equipment can be verified by using the method devised by Meijsen et al., which was discussed in Section 2.4.

Data management and documentation

All the captured data from the measuring points on the mine should be integrated with the SCADA system. If there is no backup database for the data, one should be developed in case of any communication failures or shutdowns of the SCADA system. This will ensure access to historical data and trends at all times. Members of the EMT should also have access to the SCADA system and database. This will ensure real-time monitoring of system operations, performances and unlimited access to important data.

3.4.2.3 Data processing, analysis and evaluation

The gathered data is used to develop average 24-hour profiles of the system processes and day-to-day operations. The data reveals the use of existing control philosophies, or the lack thereof. The profiles are then used, in conjunction with the information obtained from the systems configuration, to identify energy savings potential on the different systems. Figure 54 depicts the compressed air pressure profile for Mineshaft 1 and Figure 55 depicts the flow profile.

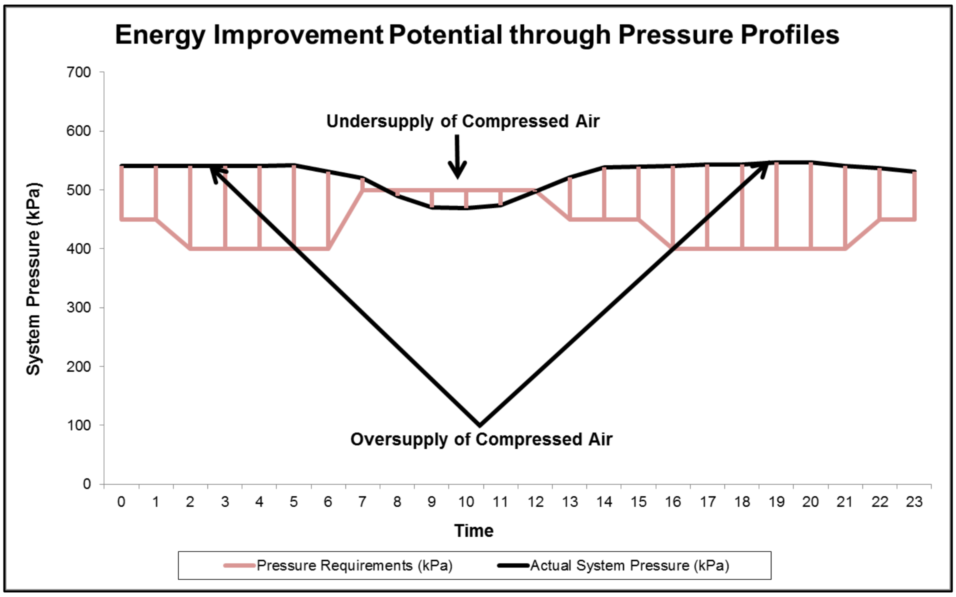

Figure 54: Identifying potential on compressed air systems through pressure profiles

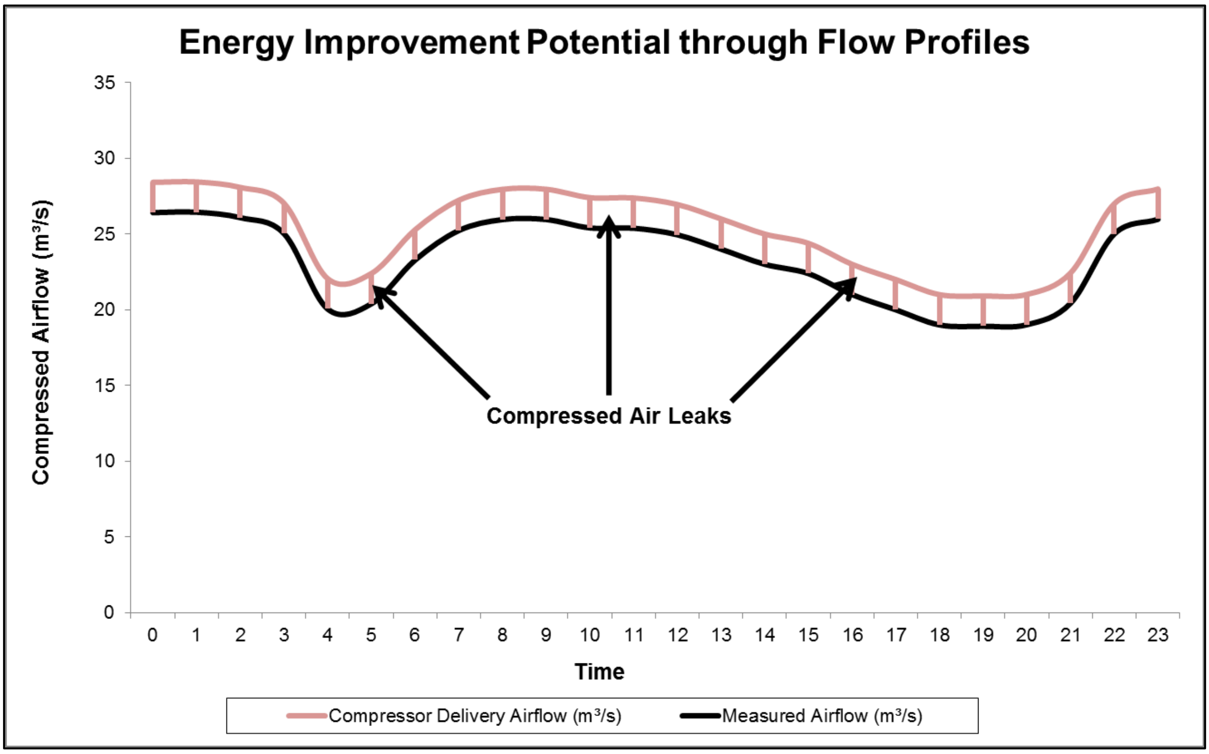

Figure 55: Identifying potential on compressed air systems through flow profiles

It is evident from Figure 54 that an oversupply of compressed air occurs during the majority of the day except for during the peak drilling period where there is an undersupply. This may be the result of compressed air leaks (depicted in Figure 55) causing the system demand to increase above the compressors' supply capacity. These system inefficiencies may offer large energy improvement potential on the compressed air system in the example. The procedures to address this potential are discussed in the following section.

3.4.3 Phase 2: Implementing energy management initiatives

The next step of the action plan (according to Figure 50) is to address the energy savings potential identified through the systems analysis. This step, therefore, entails the implementation of different energy savings initiatives in an attempt to improve the electrical energy performance of a gold mineshaft. Figure 56 illustrates the generic procedure to be followed during the implementation of energy savings initiatives on the systems of gold mines.

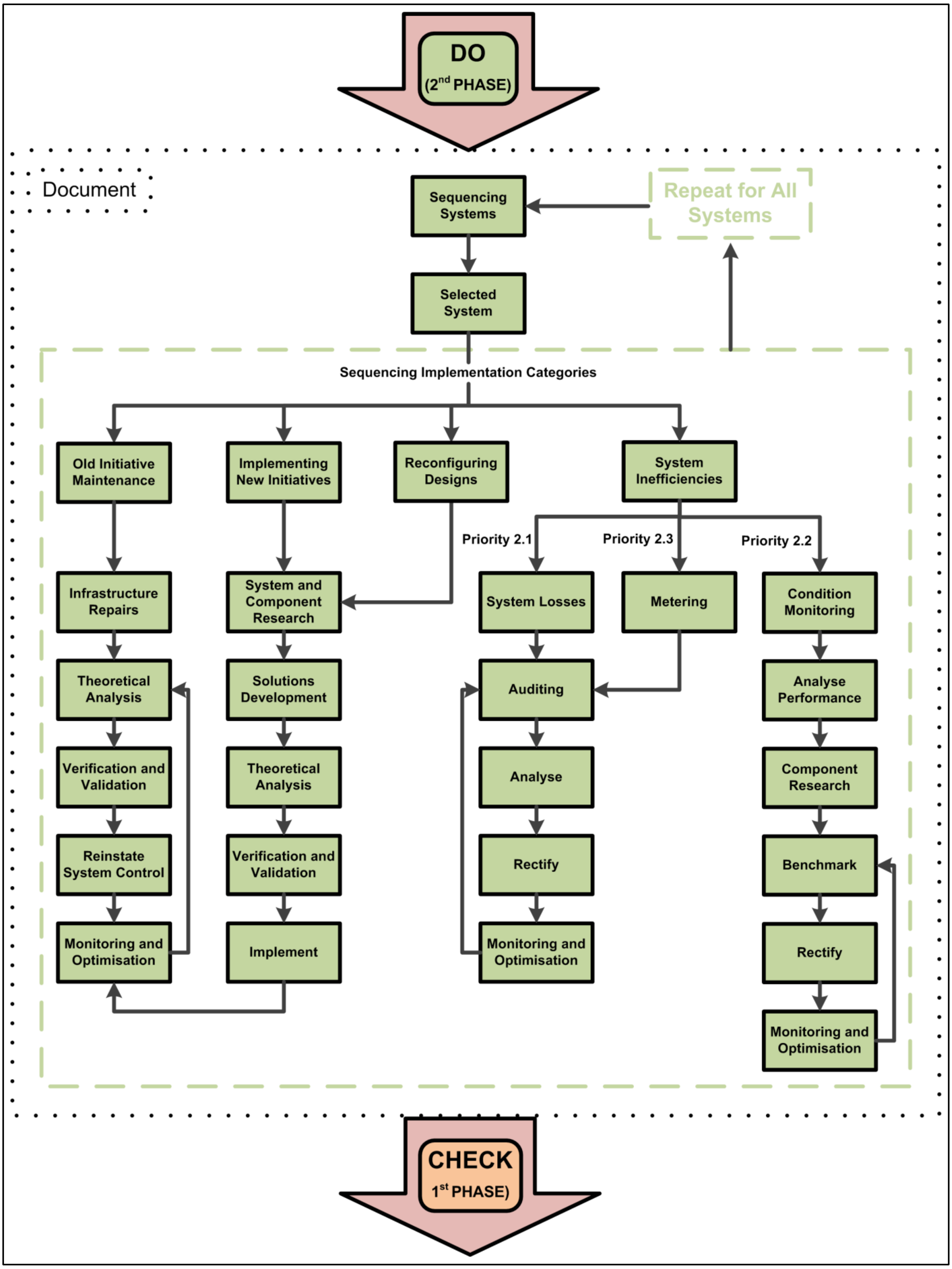

Figure 56: Procedure for addressing identified energy savings potential[30]

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[30] Strategy was developed by integrating studies conducted by Groenewald [10], Van Heerden [19], Van der Zee [20], Schutte [31], Bredenkamp [32], Marais [40], Meijsen [57] and Javied [70].

During this phase, it is important to sequence the implementation of initiatives to claim the maximum benefits from high electricity-consuming systems first and gradually shift to less beneficial systems. The results from the energy review, energy policy and the concept of the benchmarking model developed in Section 3.2.2 are used to accomplish this task. For illustrational purposes, the information of Mineshaft 1 is used to demonstrate the sequencing of systems for the implementation of energy savings initiatives. Table 17 provides a summary of Mineshaft 1's information and the sequencing order of implementing the initiatives by system.

Table 17: Sequencing the implementation of initiatives by system

Energy Savings Initiative Sequence by System				
Mineshaft 1 Systems	**Percentage of Total Consumption (%)**	**Annual Electricity Consumption (GWh)**	**10% Electricity Reduction (Financial Savings)**	**Implementation Sequence (Cost Benefit)**
Compressed Air	19%	114	R 6 200 000	**1**
Mining	18%	108	R 6 000 000	**2**
Pumping	16%	96	R 5 200 000	**3**
Refrigeration	15%	90	R 5 000 000	**4**
Ventilation	12%	72	R 4 000 000	**5**
Hoisting	7%	42	R 2 300 000	**6**
Hostels & Housing	4%	24	R 1 300 000	**7**
Surface Operations	2%	12	R 650 000	**8**
Refinery	2%	12	R 300 000	**9**
Lighting	1%	6	R 50 000	**10**

Table 15 shows that the compressed air system of Mineshaft 1 offers the largest cost-savings potential for the implementation of energy savings initiatives. Implementation will, therefore, commence on this system and be repeated for all the other systems from the largest to the least potential (illustrated by Figure 56).

Figure 56 also indicates that the implementation of energy savings initiatives for the chosen system is categorised. The four different categories are described as follows:

1. maintaining previously implemented initiatives;
2. implementing new initiatives;
3. reconfiguring the designs of existing systems; and
4. addressing system inefficiencies.

The implementation of the initiatives by category is also sequenced to produce the largest benefits for the mine. The implementation sequence by category is demonstrated with the example compressed air system of Mineshaft 1. For illustration purposes, numerous energy savings initiatives that can be implemented to improve the electrical performance of this system are shown (encircled) in Figure 57. The implementation sequence for these initiatives were analysed based on the following criteria:

1. implementation cost;
2. implementation period;
3. complexity of designing solutions;
4. difficulty to implement; and
5. the benefits realised through implementation.

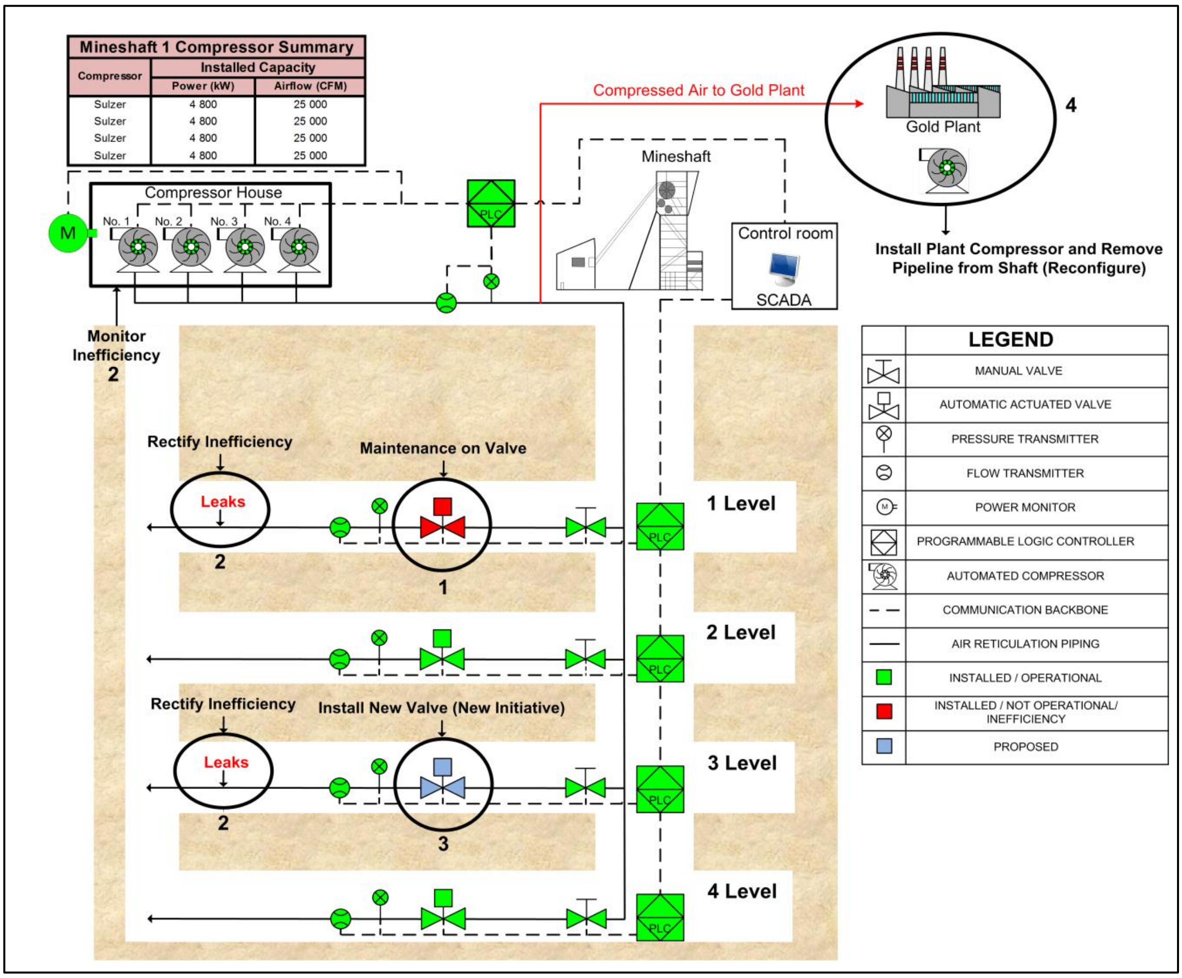


Figure 57: Illustration of energy savings initiatives on Mineshaft 1's compressed air system

South Africa's largest ESCO for implementing industrial energy-savings projects was consulted regarding the technical and financial details of implementing initiatives on gold mining systems [46]. The information and the abovementioned criteria were analysed and the sequencing model for initiative implementation was developed. The initiatives identified on the compressed air system of Mineshaft 1 were analysed with the model. Table 18 illustrates the outcomes of the concept and the implementation sequence for energy savings initiatives at Mineshaft 1.

Table 18: Sequencing model for the implementation of energy savings initiatives

Energy Savings Initiative Sequence Analysis				
Implementation Criteria	**Old Initiative Maintenance**	**System Inefficiencies**	**New Initiatives**	**Reconfiguring Designs**
Cost	Low	Moderate–High	Moderate–High	High
Time	Low	Low	Moderate–High	High
Complexity	Moderate	Moderate–High	Moderate–High	Moderate–High
Difficulty	Low	Low	Moderate–High	Moderate–High
Benefits	Moderate–High	Moderate–High	Moderate–High	Moderate–High
Sequence (Low Risk–High Risk)	**1**	**2**	**3**	**4**

Key				
Cost	R0–R100 000	R100 000–R1 000 000	R100 000–R5 000 000	R5 000 000 +
Time	1 month	1–3 months	1–6 months	6 months +
Complexity	Low	Moderate	Moderate–High	High
Difficulty	Low	Moderate	Moderate–High	High
Benefits (MW)	0–0.5	0.5–1	0.5–5	5 +
	Low	**Moderate**	**Moderate - High**	**High**

The example compressed air system of Mineshaft 1 is only used for demonstrational purposes. The objective of this study is to develop an IEMS for the deep-level fold mining industry. Thus, it should be noted that the procedures given by Figure 56, Table 17 and Table 18 must be used for all the other systems of a gold mine. It should also be noted that the implementation procedures might differ with different mines and systems and, therefore, should be addressed individually. The procedure to be followed with the implementation of each initiative category, as depicted by Figure 56, is discussed in the following sections.

3.4.3.1 Maintenance on old initiatives

For the example system at Mineshaft 1, Table 18 indicated that the first priority of the EMT should be to apply maintenance on previously implemented initiatives. According to literature, most of these initiatives formed part of Eskom's DSM model and large amounts of money have already been invested in infrastructure upgrades. These systems are, therefore, in most cases soft targets for large improvements in energy performance with minimal effort and capital investment [10].

The maintenance procedure commences with identifying any infrastructure faults preventing the system performing to its potential. Infrastructure faults refer to either hardware, software or control system related issues. Top management needs to provide the required funds for the infrastructure upgrades, which have to be executed as soon as possible.

After the upgrades, simulations need to be compiled to determine the system's theoretical response to new control philosophies and scenarios. A cost benefit analysis must also be compiled for the different scenarios. The different scenarios are compared with one another to establish the most practical solution.

Prior to implementation, the simulations need to be verified and validated with manual tests on the system. This will enable the EMT to determine the response of the newly developed control philosophies in a practical system. The results of the tests are compared with the simulations to identify discrepancies in the theoretical analysis. The control is reinstated if all the members of the EMT are satisfied with the results of the updated control philosophy and predicted cost benefits.

After the control has been reinstated, the responsible EMT members need to monitor the performance of the upgraded system continually. The IEMS is a continual improvement process and responsible personnel need to continuously conduct and evaluate simulations, tests and cost benefits to optimise the performance of the systems. The feedback loop of continual improving system performance through maintenance is visible on Figure 56.

3.4.3.2 System inefficiencies

The second priority for Mineshaft 1 is realising improvements in system efficiencies. Improving the efficiencies of system components also offers large return on investment potential. The sequence in implementing the different methods to improve system efficiencies are prioritised from addressing system losses, condition monitoring to improving the accuracy of metering (refer to Figure 56). The sequence was developed to optimise the energy improvement potential and realise maximum benefits in the shortest amount of time (using Table 18).

System losses

The term losses refer to system leaks and pipe losses promoting poor electrical energy performance (refer to Chapter 2). The first step in addressing system losses is conducting system audits to determine the exact location and magnitude of the losses. These losses need to be documented properly, which will ultimately serve as a checklist for the EMT to track progress of rectifying the losses.

The next step is analysing the documented losses. This analysis mainly entails a calculation to determine the financial impact of each loss and listing the benefits of rectifying the losses.

Rectifying the losses is then prioritised (development of a priority list) from the largest financial impact with the highest benefits to the least financial impact. This will ensure that the mine benefits from rapid improvements in electrical performance of the systems.

EMT members should delegate the priority list to appropriate resources to be rectified. It is also the responsibility of the EMT to track and document the progress of rectifying the losses. Identifying, analysing and rectifying the losses are also a continuous process as losses are an inevitable part of the day-to-day operations of a gold mine.

Condition monitoring

According to literature, condition monitoring is a wide term used for detecting machinery faults and deteriorating performance. For the purposes of this study, the focus is on the performance of system components, which affects the electrical energy performance of systems (refer to Chapter 2). The efficiencies of pumps, compressors, refrigeration machines, ventilation fans and the motors driving these machines, are all examples of system components affecting electrical performance.

The first step in addressing the efficiencies of the abovementioned components is to analyse the operating performance. The performance in this context refers to the amount of electrical energy consumed per unit of work output. In order for the EMT to quantify the performance, technical research of component best practices is required. The EMT should focus on the following during the research:

1. technical specification of component;
2. technical operation specifications of component; and
3. component operation best practices.

The results of the research will enable the EMT to compare performances (calculated with equations given in Chapter 2) of system components to the benchmarks set by the system best practices. Discrepancies should be identified, documented and rectified. Figure 56 indicates that the EMT should continuously monitor the performance of system components against the benchmarks. This will ensure optimised operation of components and continual improvement of electrical energy performance.

Metering

During the literature survey, it was found that mines miss cost-savings opportunities through faulty measuring equipment. In some cases, the cost savings are not that much, but when accumulated for all the mineshafts of the mining group, the savings become significant. It is, therefore, very important for the EMT to commence at shaft level and arrange regular audits, maintenance and calibration of important system power meters. The procedure in addressing metering inefficiencies are summarised as follows:

1. Audit physical infrastructure
    a. determine location and condition of meters;
    b. determine availability of communication infrastructure to meters;
    c. determine state of communication infrastructure; and
    d. verify the compliance documentation.
2. Audit data and information system
    a. determine state of communication between data systems and meters; and
    b. determine accuracy of measured and historical data.
3. Analyse
    a. do gap analysis of metering infrastructure;
    b. do gap analysis of metering data communication and storage;
    c. verify metering documentation;
    d. verify meter readings with calibrated portable meters; and
    e. identify the discrepancies.

As indicated by Figure 56, the discrepancies should be rectified and continuously monitored by the EMT for optimised performance. The next section focuses on the procedure of implementing new energy savings initiatives.

3.4.3.3 Implementing new initiatives and reconfiguring designs

In the case of the Mineshaft 1 example, the third and fourth priorities were implementing new initiatives and reconfiguring the designs of the compressed air system (refer to Figure 57). These initiatives usually offer large energy savings potential. However, in most instances these initiatives come with higher input costs than maintenance and efficiency improvements.

From Chapter 2, it was discovered that a large variety of initiatives and technologies can be implemented on the different operating systems of gold mines. The EMT, therefore, selects an initiative or technology that best suits its application in the investigated system. A procedure is, however, still required for the EMT to use as a guideline for implementing appropriate and effective solutions. It must be noted that the implementation guidelines for new initiatives and reconfiguring designs are the same. From Figure 56, the guideline is provided as follows:

System and component research

The EMT must conduct thorough research on the system and its components. This will ensure a complete understanding of the system needs and limitations. The research process should include the following topics:

1. do background research on system and components;
2. establish the functional flow of the system;
3. obtain technical specifications of the system and its components;
4. research system best practices;
5. benchmark system against local and international standards; and
6. review energy saving initiatives from literature.

Solution development

With the information obtained from the research, the EMT will be able to develop several solutions for the system. It is important for the EMT to review and document the risks and constraints of the different solutions. The risk and constraint analysis should address the following topics:

1. revert to constraints identified from the systems configuration (systems analysis);
2. implementation cost of each solution;
3. technical skill required to implement and maintain each solution;
4. duration of implementation; and
5. intended cost-savings benefit versus initiation costs (payback period).

Theoretical analysis

The next step is compiling simulations and calculations to determine the theoretical impact of each solution on the system’s electrical energy performance. The simulations must also be strategically developed to remain within the boundaries of the identified risks and constraints. The financial impact of each solution must be calculated. With the results of the theoretical analysis, the EMT would be able to identify the most feasible solution for application in the system.

Verification and validation

Prior to implementing the chosen solution, the EMT should arrange manual tests to be conducted. The tests would reveal the simulation’s compatibility (theoretical analysis verification) with the actual system and reveal the actual impact on the electrical energy performance (theoretical analysis validation). If no discrepancies are identified and all members of the EMT are satisfied with the results, the solution is implemented on the system.

Implementation

Top management needs to provide financial support for the implementation of new initiatives and reconfiguring the designs. Thus, thorough documentation of the new initiative procedure needs to be in place. The documentation must be used by the EMT to convince top management of the initiative benefits and positive contribution to continual energy performance improvements.

After implementing the new energy savings initiatives, they must be incorporated in the maintenance procedure of the IEMS (illustrated by Figure 56). This will ensure sustainable performance of the newly implemented initiatives and contribute positively to continual improvement of systems electrical performances and the IEMS.

The next step for the IEMS is to verify the improvements realised from executing the EnMPs at Mineshaft 1. The results also need to be reported to relevant stakeholders. This forms part of the “Check” step of the IEMS, which is discussed in the following section.

3.5 Check: Verifying and reporting on executed plans

3.5.1 Phase 1: Verifying system performances

During this phase, the electrical energy performance improvements need to be verified to ensure the credibility of the impact of the IEMS and its reporting to stakeholders. It is also important for the system baselines to be adjusted according to dynamic system conditions and production patterns of the mine. The M&V guidelines discussed in Section 2.5 will be used to perform this task.

The performance of each system at the mineshaft needs to be verified individually as it contributes to the overall energy performance improvement of the entire shaft. The baselines of each system are, therefore, adjusted individually and accumulated to form the total adjusted baseline of the mineshaft. The total improved power profile after implementing the energy savings initiatives is compared with the total adjusted baseline to determine the overall impact of the IEMS. Figure 58 illustrates the baseline adjustment concept to be followed to calculate the total IEMS impact.

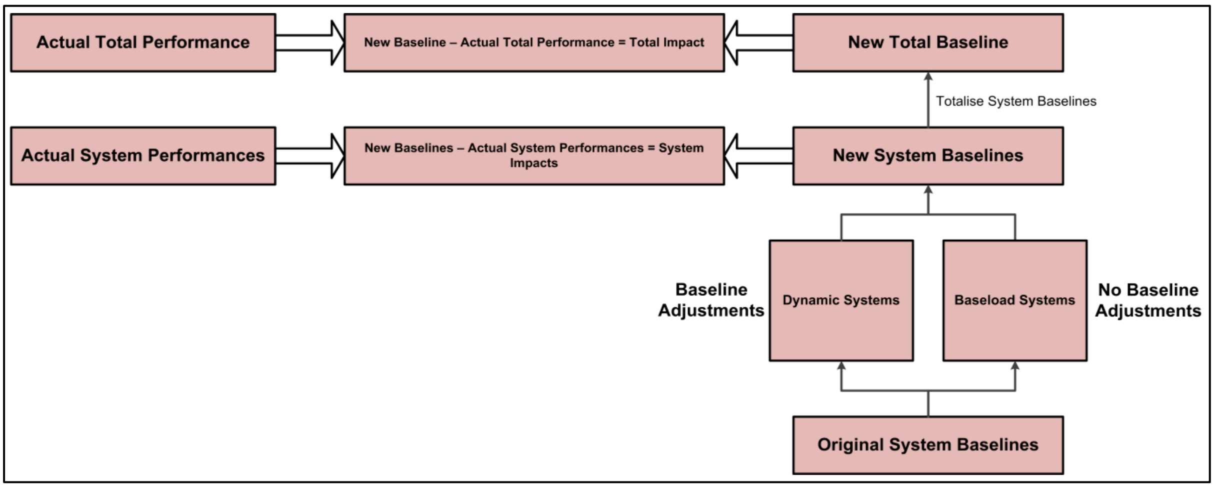


Figure 58: Baseline adjustment approach to calculate the impact of the IEMS

As indicated on Figure 58, some of the system baselines are not adjusted as they are regarded as baseloads. This means that the power consumption of these systems is not related to external factors such as production, ambient temperatures, pressures and flows. These systems usually have relatively constant power consumption profiles during day-to-day mining operations. The baselines of the remainder of the systems are adjusted as these system power profiles are influenced by external factors.

It is also important to quantify each mineshaft’s contribution to the energy performance improvement of the entire mining group. Finally, the energy performance improvement of the mining group needs to be verified.

The compressed air system example of Mineshaft 1 is used to illustrate the verification of the improved electrical energy performance. Figure 59 illustrates the improved power profiles of the compressed air system after executing the EnMPs (refer to Section 3.5). The initiatives implemented included in a sequenced order – maintenance, rectifying inefficiencies, implementing new initiatives and reconfiguring the design (refer to Figure 57 and Table 18).

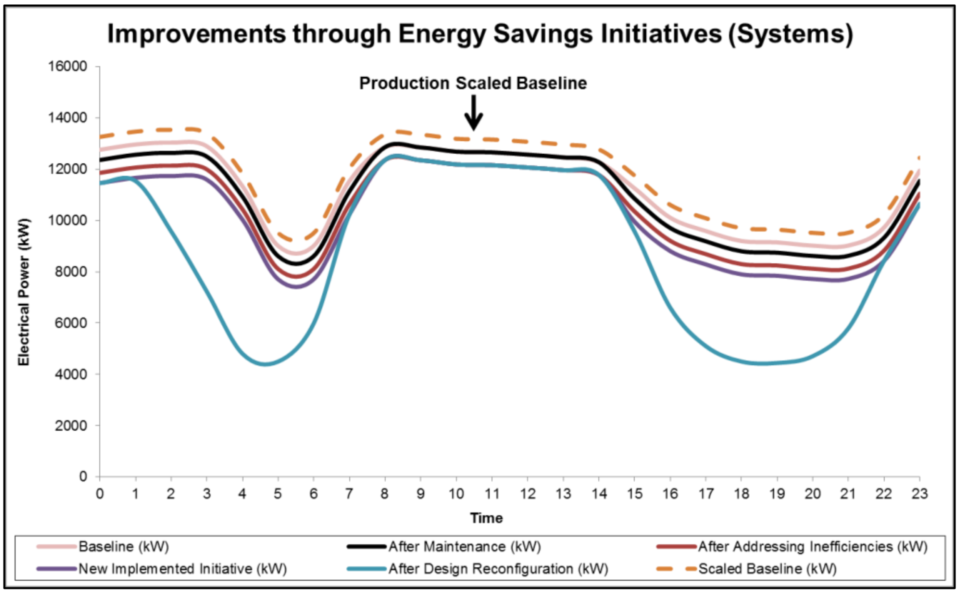


Figure 59: Verifying electrical energy improvements on mine systems

Figure 59 shows the original baseline scaled upwards to compensate for external factors such as increased production. The scaled baseline represents the what-it-would-have-been profile without the implementation of the initiatives. This improves the credibility of the reported improvements after implementation. The electrical energy improvements on the compressed air system are also quantified against the shaft's total baseline (refer to Figure 47). This must also be executed for all the other systems. Figure 60 represents the compressed air system's contribution to the total electricity performance improvement of the mineshaft.

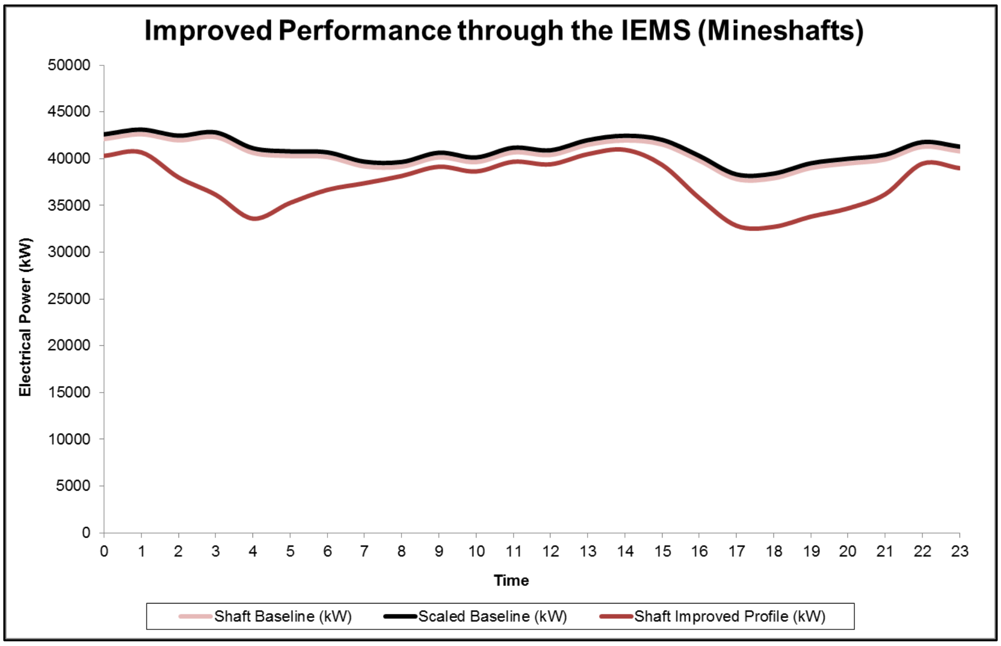
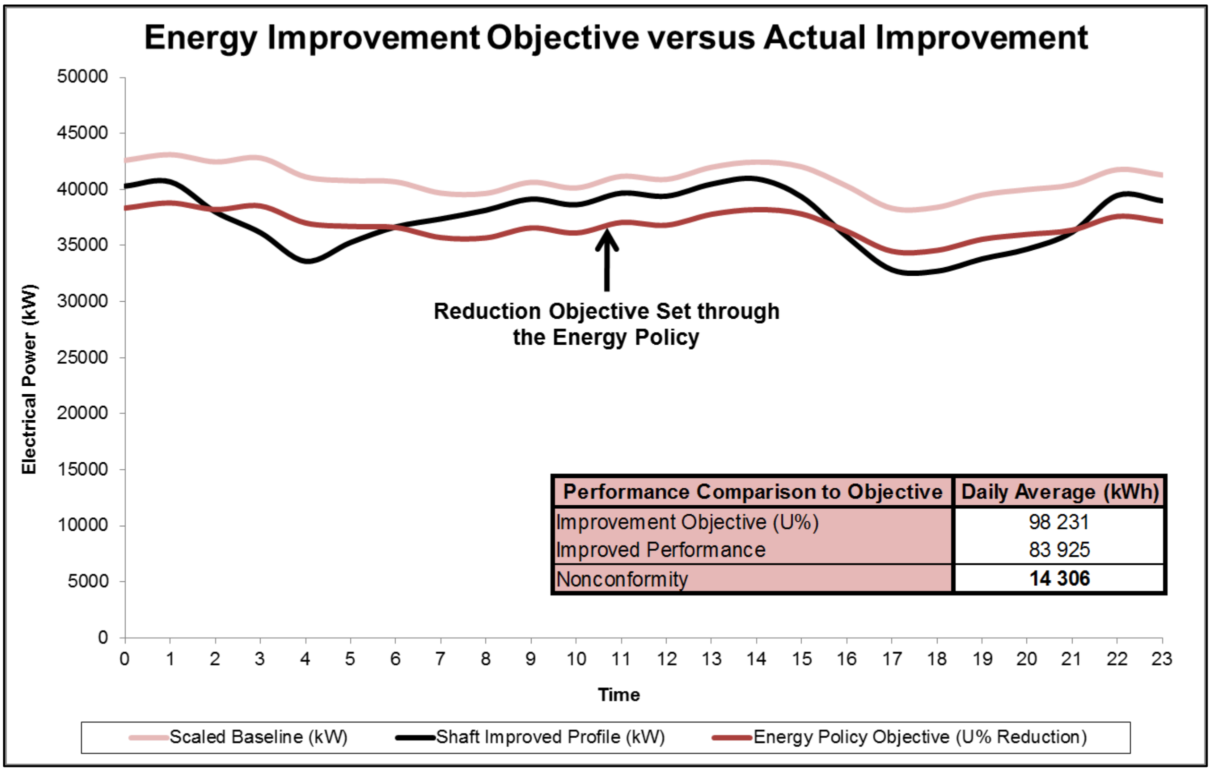


Figure 60: Verifying electrical energy improvements of mineshafts

The next step is identifying the characteristics of energy performances against the energy policy and objectives developed during the planning phase. Figure 61 compares the reduction objective of U% (refer to Figure 49) set through the energy policy and the actual improvement obtained after implementing the IEMS.



Performance Comparison to Objective	Daily Average (kWh)
Improvement Objective (U%)	98 231
Improved Performance	83 925
Nonconformity	**14 306**

Figure 61: Comparing improved energy performance against the energy policy objective

It is evident from Figure 61 that the projected target of U% was not realised by implementing the IEMS. The EMT, therefore, need to revert to the “Do” step of the IEMS in order to address the nonconformity. It is also important for the EMT to develop preventive action plans to address the nonconformities in case of future deviations from objectives.

The next phase of the “Check” step is reporting on the results obtained through the IEMS implementation. It must be noted that the results are only the end product of the IEMS. The IEMS consists of numerous key elements that contribute to the success of this end product. It is, therefore, very important to report on all of these elements to enable the EMT to effectively sustain and continuously improve the performance of the IEMS.

3.5.2 Phase 2: Reporting

A wide range of reports on electrical energy can be distributed within a gold mining group, but the key is to report on relevant aspects, which will enhance the performance of the

IEMS. In order to ensure accurate and timeous feedback, the following steps need to be taken:

1. determine report requirements;
2. identify relevant EMT members to receive reports;
3. prioritise reports among resources;
4. develop the reports;
5. automate reporting procedures;
6. ensure reports are delivered; and
7. ensure correspondence by stakeholders to reports.

Figure 62 provides a guideline for reporting on the key elements of the IEMS and allocating reports to the relevant EMT members. The guideline will aid in simplifying the communication channels within the EMT to address nonconformities within the IEMS. It, therefore, contributes to eliminating the barriers identified in Figure 43.

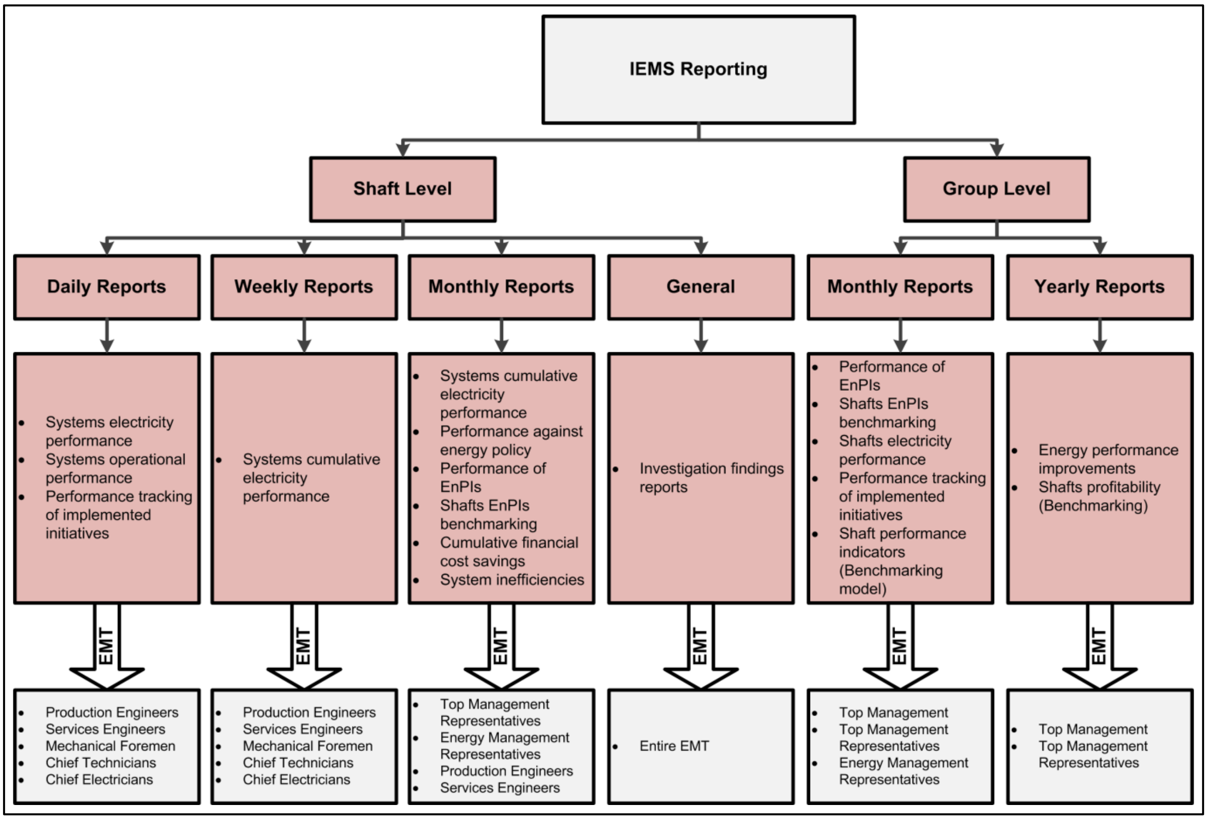


Figure 62: IEMS reporting guideline for EMT members

As depicted by Figure 62, the reporting procedure is divided into two categories, namely: reporting at shaft level and reporting at mining group level. Daily, weekly, monthly and general feedback reports are distributed to relevant EMT members at shaft level, while high-level reports are distributed among top management. This is to ensure that top management is not overwhelmed by a large number of reports, which would lead to them not responding to important aspects of the IEMS.

Through reporting, the EMT has continuous access to the impact and important elements of the IEMS. This presents an opportunity for the EMT to optimise the performance and outputs of the implemented IEMS. The next section presents the final step of the PDCA cycle, which is optimising the output of the IEMS.

3.6 Act: Optimising energy management

3.6.1 General

Optimising the IEMS can be divided into two main categories, namely:

1. technical optimisation; and
2. financial optimisation.

Technical optimisation refers to continually improving the implementation procedure of the IEMS to maximise the output in electrical energy performance. Financial optimisation, on the other hand, refers to incentive application possibilities through improved electrical energy performance realised with the IEMS implementation. The details of the optimisation procedures are provided as follows:

3.6.2 Technical optimisation

Monthly electrical review meetings must be scheduled with all the members of the EMT present. During these meetings, the actual performance is measured against the objectives stipulated by the energy policy. The comparison reveals the progress in reaching the energy reduction targets set by the EMT. Nonconformities are identified and the inputs from top management should be implemented to continually improve the performance of the IEMS.

Each team member should compile a to-do list from the electrical review meeting for tasks that need to be completed within the following month. The performance of team members is evaluated each month based on the outcomes of the given to-do list.

On a yearly basis, the improvements realised as a result of the IEMS implementation are evaluated against the energy policy. This will reveal the effectiveness of the IEMS and scope for improvements for the following year. The energy policy is updated with new objectives and the procedure starts all over again with the “Do” step (energy management planning).

3.6.3 Financial optimisation

As discussed in Chapter 2, there are a number of energy savings incentives available in South Africa. If the gold mining group realised an electrical energy improvement with the same level of production, it may qualify for tax incentives such as 12L. The procedure developed by Budge is useful during this phase of the IEMS and should be used to benefit fully from the incentive opportunities.

Incentives such as Eskom’s Integrated Demand Management (IDM) and the Manufacturing Competitiveness Enhancement Programme (MCEP) can also be used to fund energy savings initiatives implemented. This will increase the gold mine’s profit margins as a result of higher return on investments. The National Cleaner Production Centre’s (NCPC) incentive can be incorporated to assist gold mines with energy audits, which in turn addresses some of the barriers stipulated in Figure 43.

Optimising the IEMS implementation not only entails maximised improvements in electrical energy performance, but also accomplishing this at the lowest financial input. All of this contributes to reduced operating costs and increased profit margins. It is, however, important to note that the purpose of the study is not to help gold mines claim incentives through optimised performance. The aim is to improve the electrical energy performance of gold mines to reduce expenditure on electricity. The incentives are just used to optimise the IEMS implementation in terms of minimum input for maximised output.

3.7 Conclusion

This chapter devised an ISO-compliant IEMS for the deep-level gold mining industry. The strategy was developed according to the PDCA cycle framework of ISO 50001 to ensure continual improvement of a gold mine’s electrical energy performance and IEMS implementation. Literature on energy management concepts provided in Chapter 2 was structured to form a holistic approach for the IEMS implementation. The four steps of the IEMS are given as follows:

“Plan” step

The IEMS development commenced with an energy management planning procedure, which assists in developing an energy management action plan to be implemented at a chosen mineshaft.

“Do” step

The strategy proceeds to the execution of the action plan where a systems analysis procedure aids with identifying electrical energy savings potential. The potential identified by the systems analysis is addressed with the implementation of energy management initiatives to improve the electrical energy performance of the mine.

“Check” step

During the third step of the IEMS, the impact of the implemented initiatives is verified with credible M&V procedures. The results are communicated with relevant stakeholders through a developed reporting procedure where nonconformities are identified for continual improvements.

“Act” step

The final step focuses on optimising the performance of the implemented IEMS from a technical and financial perspective. This ensures maximised electrical energy performance of the IEMS at the lowest possible input (technical and financial). The “Act” step reverts to the “Do” step where the implementation procedure of the IEMS repeats itself. This ensures sustainable and continual improvements of the mine’s IEMS and, consequently, electrical energy performance.

The next chapter focuses on implementing the IEMS on a practical system. This reveals the feasibility of the strategy and the actual impact on the electrical energy performance of a South African gold mining group.

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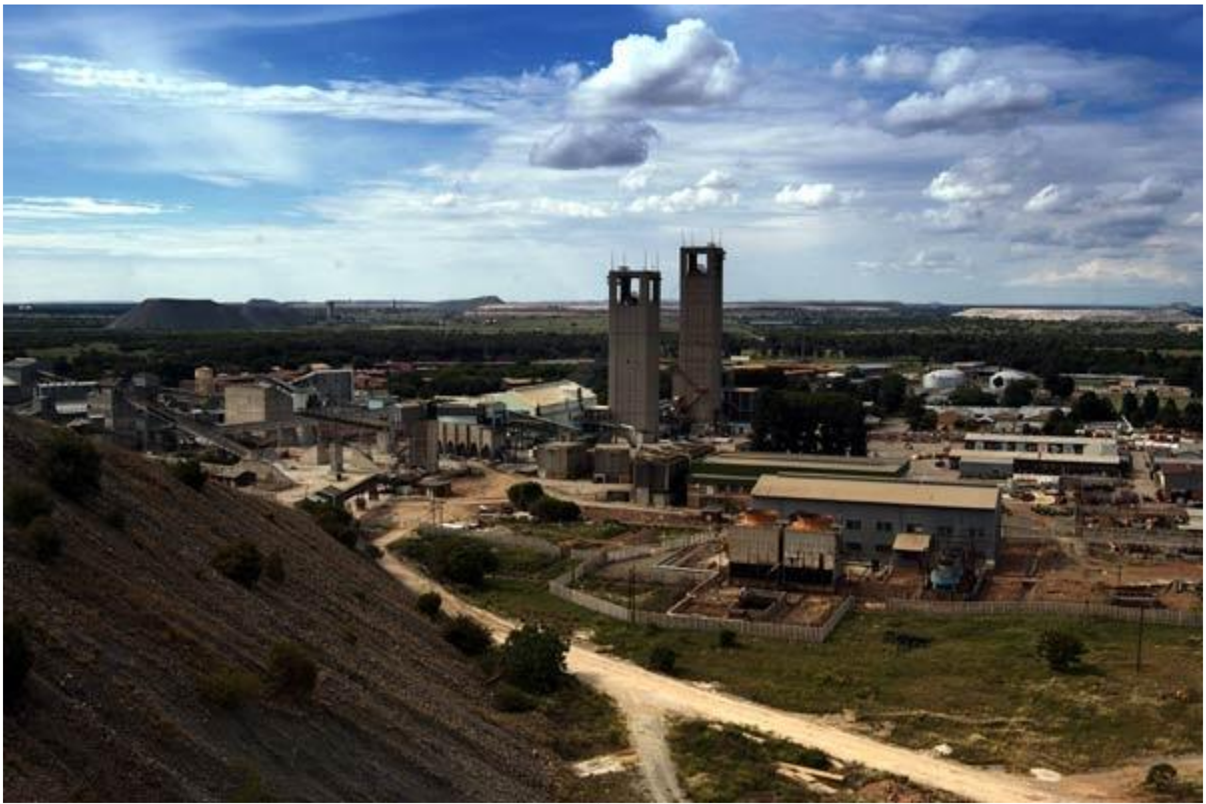
CHAPTER 4



[31]

"There are no traffic jams along the extra mile." – Roger Staubach

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[31] http://www.mining-technology.com/features/feature-top-ten-deepest-mines-world-south-africa/.

4 IMPLEMENTING ENERGY MANAGEMENT STRATEGIES ON THE SOUTH AFRICAN GOLD MINING INDUSTRY

4.1 Introduction

The literature gathered in Chapter 2 aided with developing an ISO-compliant IEMS in Chapter 3. In this chapter, the implementation of the developed IEMS on one of South Africa's largest gold mining groups is analysed. Successful implementation will validate the impact of the IEMS on the electrical energy performance of practical systems.

The PDCA framework of the IEMS provides the mining group with a step-by-step guideline for implementing electrical energy management. The continual improvement framework ensures that the mining group continually improves the IEMS implementation procedure and, consequently, electrical energy performance. Implementing the IEMS will also ensure that the mining group becomes eligible for ISO 50001 certification. The following sections discuss the inner details of the IEMS implementation.

4.2 Case study background

The case study was conducted on one of South Africa's largest gold mining groups (further referred to as Group A[32]). Group A comprises ten operational mineshafts and one opencast mine. Group A processed approximately 19 million tonnes of ore in the 2014 financial year, which contributed to the production of 36 500 kg of gold. The magnitude of Group A's operation is evident.

By the end of the 2014 financial year, Group A had an annual total loss of R1.3 billion. This was mainly due to increased operating costs and a low gold price [12]. Electricity contributed 13% to Group A's total operating costs. Group A stated in its annual report that this portion of the operating costs is becoming a great concern for the future profitability of the company [12]. This is mainly due to the higher-than-inflation electricity tariffs in South Africa [12].

During the 2014 financial year, Group A consumed 2 798 000 MWh of electricity at a total cost of R1.8 billion [12]. During the preceding financial year (2013), Group A consumed

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[32] Mining group and shaft names are kept anonymous to ensure confidentiality.

2 704 000 MWh at a cost of R1.6 billion [109]. In financial terms, the 2014 figure was approximately R200 million more than the previous financial year. Considering the difference in electricity consumption patterns and assuming a constant tariff over the two years, the total electricity cost should have only increased with approximately R35 million. The R165 million difference is ascribed to the increase in electricity tariffs [110].

By the start of the 2015 financial year, top management of Group A decided to invest in measures to drastically reduce expenditure on electricity consumption. The IEMS developed in Chapter 3 was proposed to Group A to accomplish this task. The proposal was accepted and the implementation of the IEMs commenced during January 2015. The particulars and results of the implemented IEMS are discussed in the following sections.

4.3 Plan: Energy management planning

4.3.1 Top management commitment

Referring to the previous section, top management of Group A committed fully to the electrical energy performance improvements. With their commitment, energy performance improvement awareness was created among employees of Group A [110]. Top management also provided financial backing for energy improvement measures and allocated funds to mineshafts' budgets for this purpose [110].

4.3.2 Scope, boundaries and benchmarks

The IEMS was limited to realising improvements on the electrical energy consumption of Group A. It was also decided to neglect the opencast mine and focus mainly on improving the electrical performance of the underground mineshafts [110].

Group A compiled the performance data (operational and electrical) of all the shafts for the 2014 financial year. The sequencing model developed in Chapter 3 was used by top management to benchmark the shafts and highlight the areas to commence with the IEMS implementation. Table 19 summarises Group A's operational and electrical data for the 2014 financial year.

Table 19: Group A operational and electrical data summary for 2014[33]

Group A Mineshaft Operations Summary (2014 Financial Year)							
Mineshaft	**Depth (m)**	**Ore Grade (g/t)**	**Tonnes Treated (t)**	**Gold Produced (kg)**	**Electricity Consumption (GWh)**	**Percentage to Total Group Electricity**	**kWh/t**
Mineshaft B	3 388	4.11	1 143 000	4 694	664	31%	581
Mineshaft C	2 365	12.50	206 000	2 576	143	7%	694
Mineshaft D	2 050	4.06	670 000	2 718	196	9%	293
Mineshaft J	2 945	5.83	771 000	4 493	242	11%	314
Mineshaft L	2 350	4.46	947 000	4 223	301	14%	318
Mineshaft U	2 426	5.16	577 000	2 976	126	6%	218
Mineshaft DD	1 978	3.53	737 000	2 603	187	9%	254
Mineshaft EE	1 452	4.26	548 000	2 335	103	5%	188
Mineshaft FF	2 153	4.50	408 000	1 838	110	5%	270
Mineshaft GG	2 873	4.69	301 000	1 413	94	4%	312

Figure 63 depicts the sequencing model for selecting the most beneficial shaft and Table 20 shows the motivation thereof. It must be noted that the profit boundary as depicted in Figure 63 is determined by the average gold price that Group A received in 2014 per kilogram of gold [12].

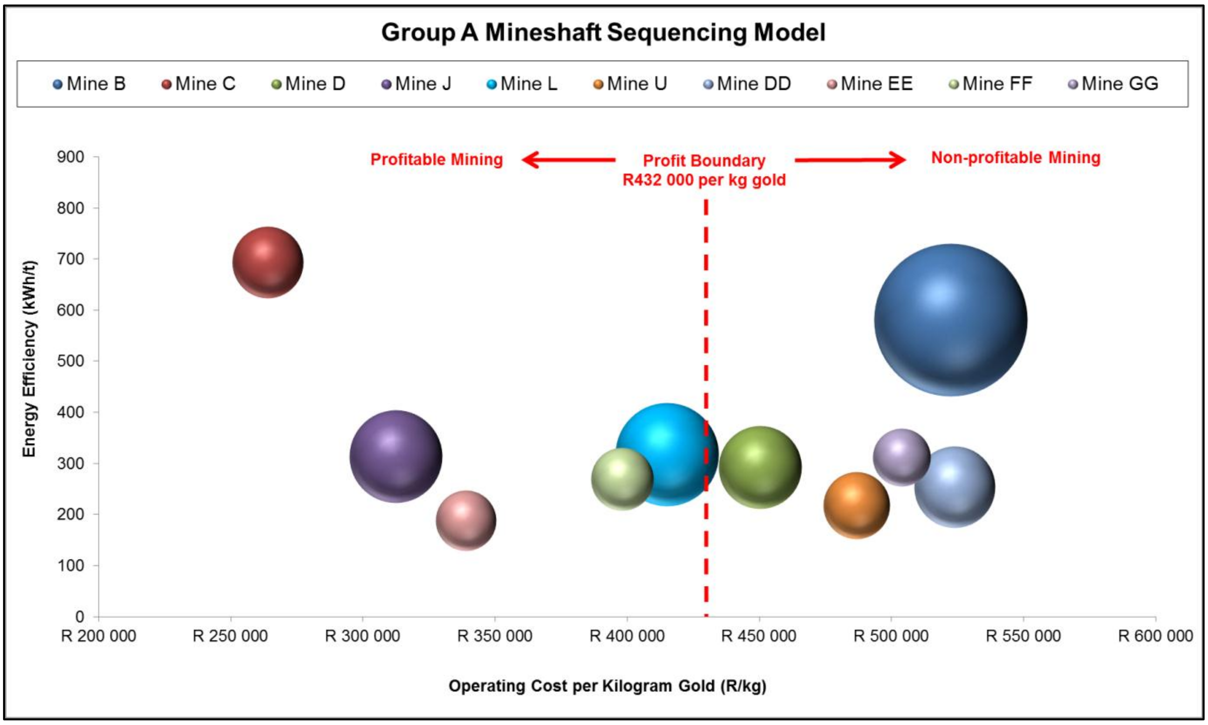

Figure 63: Sequencing model for IEMS implementation at Group A

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[33] Mineshaft names align with the investigated mineshafts in Table 1 (refer to Section 1.4.2).

Table 20: Motivating the IEMS implementation sequence at Group A

IEMS Implementation Sequence for Group A		
Mineshaft	**10% Electricity Reduction (Financial Savings)**	**Sequence Order (Cost Benefit)**
Mineshaft B	R36 500 000	**1**
Mineshaft C	R8 000 000	**6**
Mineshaft D	R11 000 000	**4**
Mineshaft J	R13 000 000	**3**
Mineshaft L	R16 500 000	**2**
Mineshaft U	R7 000 000	**7**
Mineshaft DD	R10 000 000	**5**
Mineshaft EE	R5 500 000	**9**
Mineshaft FF	R6 000 000	**8**
Mineshaft GG	R5 000 000	**10**

From Table 19, Figure 63 and Table 20 Mineshaft B proved to be the most beneficial for implementing the IEMS. Group A selected Mineshaft B and considered the IEMS implementation at Mineshaft B as a trial prior to expanding the implementation to other mineshafts. The reason was for Group A to establish the effectiveness of the IEMS prior to incurring large capital investments with low return on investment. The next step for Group A was establishing an EMT at Mineshaft B.

4.3.3 Energy management team

The EMT[34] of Mineshaft B was selected and structured according to Figure 45 as developed in Chapter 3. The EMT selection was documented and is available in Appendix C. The signatures and names of team members were removed from all documentation to protect the identities of relevant mine personnel. Appendix C also includes a competence, training and awareness register, which was used by the selected EMT to improve their abilities to practise effective energy management and create energy awareness at Mineshaft B.

4.3.4 Energy review

Mineshaft B uses a third-party metering company to measure and report on systems power consumption. The data is stored on Mineshaft B's SCADA database to which all of the EMT members have access to as required. Calibration certificates, to verify the accuracy of the meters used by the third-party metering company, are not available. The accuracy of the meters was, therefore, determined by verifying metering data with corresponding Eskom accounts.

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[34] The author was selected as part of the EMT at Mineshaft B.

One month's worth of metering data was compared with the same month's Eskom account. The comparison revealed an average difference of 0.3% between the two values. The EMT accepted this error margin and the systems data from the third-party metering company was used during the IEMS implementation. Figure 64 depicts the procedure used by Mineshaft B to verify the accuracy of the power meters installed on the different systems. It was, however, proposed that Mineshaft B use the strategy by Meijsen et al. to improve the accuracy of the metering data.

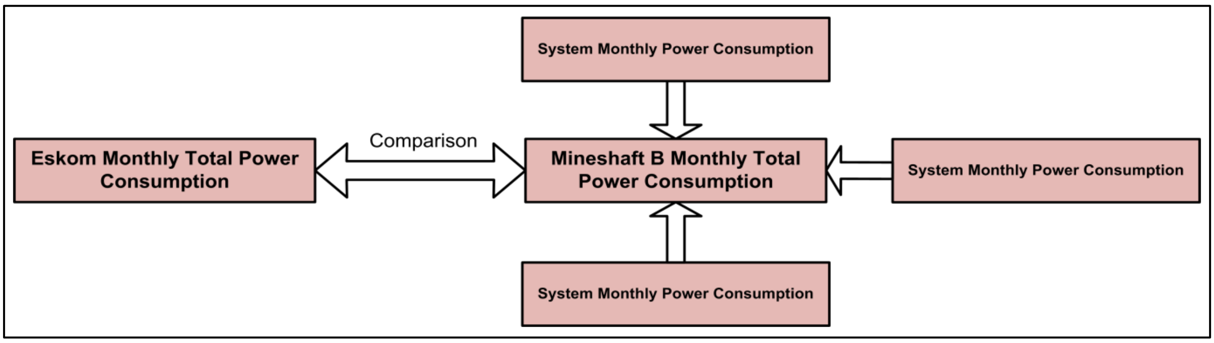
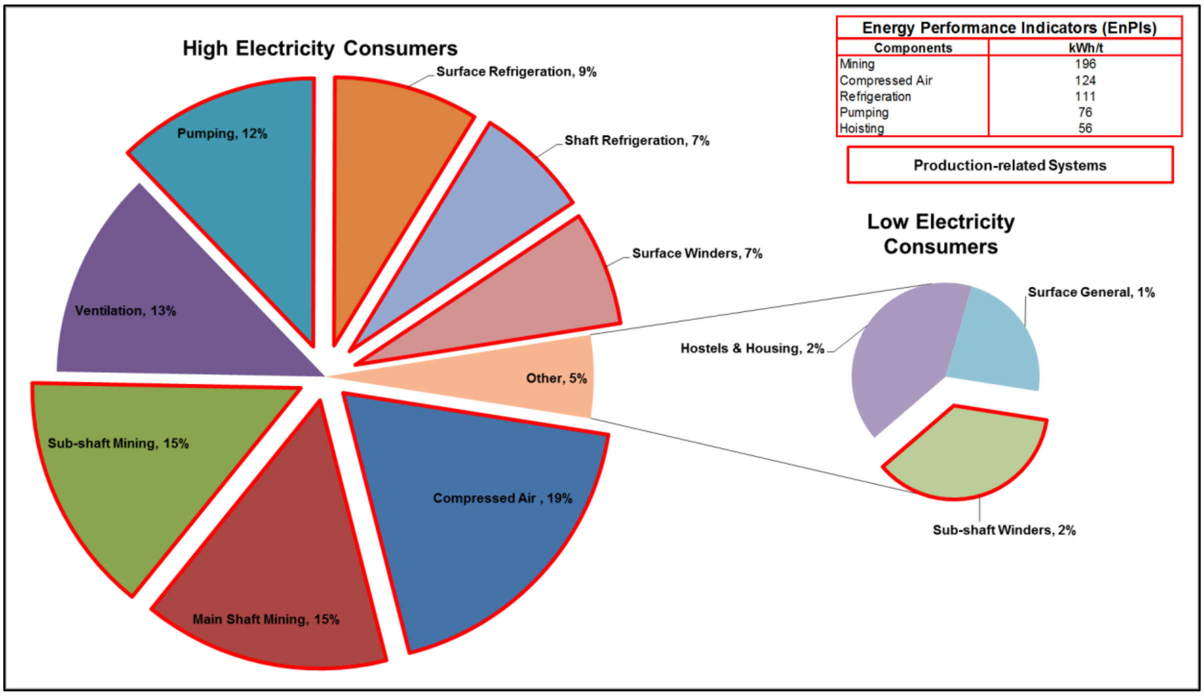


Figure 64: Verifying the accuracy of power data at Mineshaft B

Mineshaft B collected systems data for a period of 12 months (the year of 2014). Figure 65 depicts the electrical intensity of the different systems and the contribution to the mine's total electricity consumption, averaged over the 12 months. The EnPIs are also provided in the form of its contribution to Mineshaft B's production.



Energy Performance Indicators (EnPIs)

Components	kWh/t
Mining	196
Compressed Air	124
Refrigeration	111
Pumping	76
Hoisting	56

Figure 65: Mineshaft B system electricity intensity and EnPIs prior to IEMS

Figure 66 depicts the total power baseline developed for 2014. Baselines were also developed for the individual systems, which are available in Appendix D of this document. A baseline document was compiled for Mineshaft B and signed by the energy management representative. The baseline document is available in Appendix C.

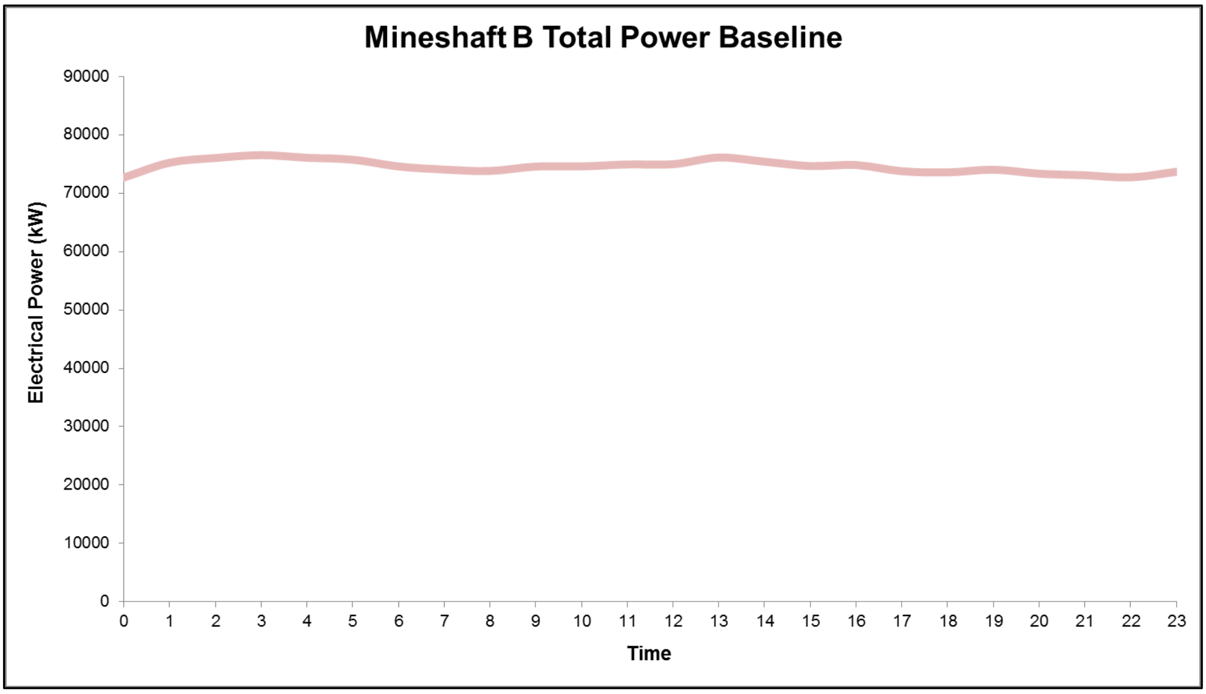


Figure 66: Mineshaft B total power baseline

The next step for Mineshaft B was developing the energy policy as commitment to electrical energy performance improvements for the year of 2015.

4.3.5 Energy policy

The EMT of Mineshaft B used the information depicted in Figure 65 and all the system baselines to identify potential for possible electricity consumption improvements on the systems. The EMT used their own discretion in identifying electrical energy improvement potential to develop achievable objectives and targets for Mineshaft B's energy policy. Table 21 illustrates the identified electricity reduction potential on the systems of Mineshaft B.

Table 21: Electrical energy improvement potential for developing the energy policy

Electricty Consumption Improvement Scope (2015)			
Mineshaft B Systems	**Energy Efficiency Potential (MW)**	**Peak Clipping Potential (MW)**	**Load Shifting Potential (MW)**
Compressed Air	2	3	
Main Shaft Mining	3		
Sub-shaft Mining	3		
Ventilation	3	1	
Pumping	5		7
Surface Refrigeration	1		3
Shaft Refrigeration			4
Surface Winders			1
Sub-shaft Winders			0.5
Hostels & Housing	0.1		
Surface General	0.1		
	17.2	**4**	**15.5**

According to Table 21, Mineshaft B's EMT identified a possible average daily load reduction (highlighted in red) of approximately 17.5 MW (17.2 + 4/24 × 2)[35]. This is a potential improvement of approximately 30% in comparison with the total baseline illustrated by Figure 66. Additional financial cost savings are also viable for Mineshaft B through a load shifting potential (highlighted in grey) of 15.5 MW. The EMT used these figures to develop the energy policy, which is illustrated by Figure 67. The actual energy policy for Mineshaft B is available in Appendix C.

The EMT committed to reduce the electrical energy consumption of Mineshaft B with 20% by the end of 2015. Although Table 21 indicates a possible reduction of 30%, the EMT of Mineshaft B decided on 20% to enable realistic and achievable objectives and targets for a 12-month period (2015). The energy policy was used during monthly electrical review meetings at Mineshaft B to establish the progress of IEMS implementation.

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[35] The load reduction of 4 MW during the two hours of the Eskom evening peak periods is also incorporated in the average daily load reduction.

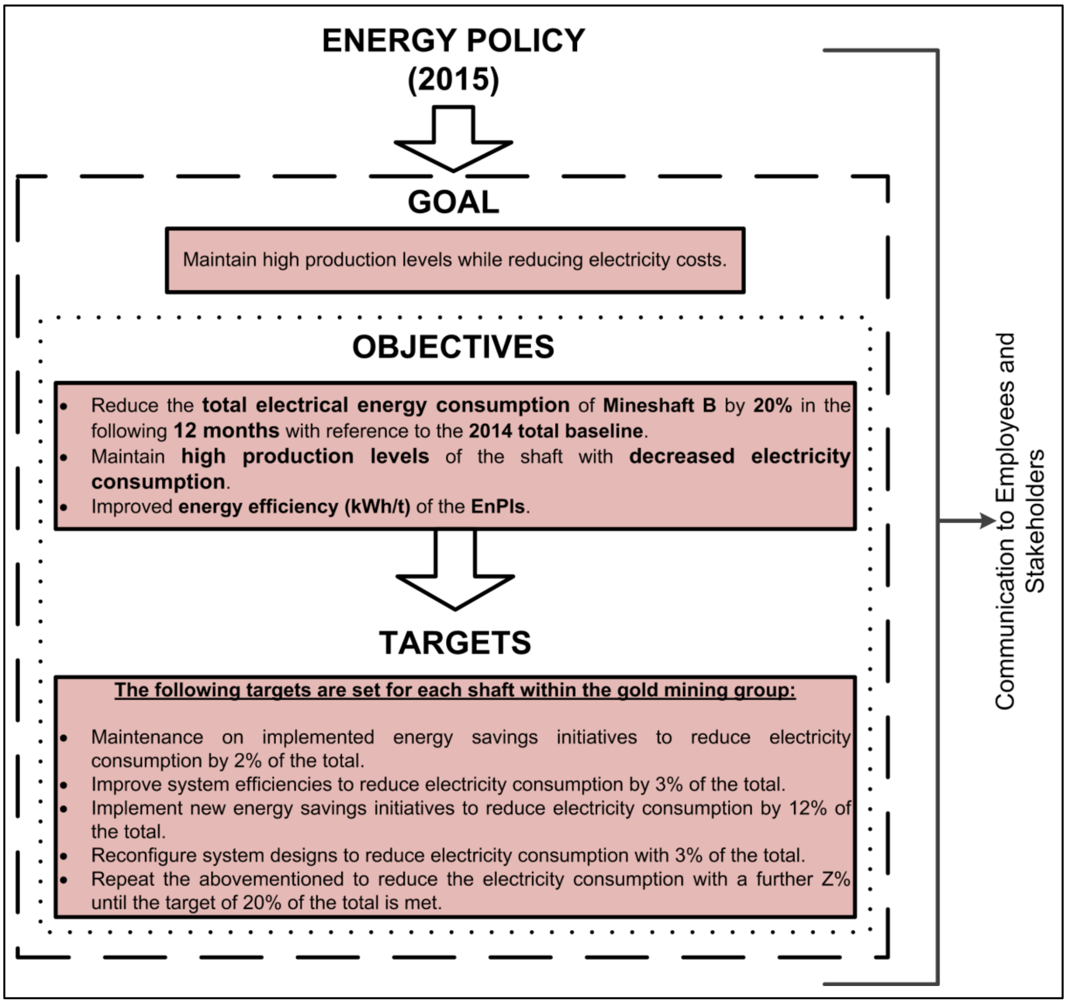

Figure 67: Energy policy developed for the 2015 IEMS implementation

The next step for the EMT was to use the action plan (refer to Figure 50 in Chapter 3) to achieve the objectives and targets stipulated by the energy policy. The following section discusses the execution of the action plan at Mineshaft B.

4.4 Do: Executing energy management plans

4.4.1 Phase 1: Systems analysis

A systems analysis was compiled for all the systems at Mineshaft B according to the procedure depicted in Figure 51. The systems configuration phase (layouts and constraints) of the procedure assisted the EMT with simplifying the system operations at Mineshaft B and their interaction with one another. Figure 68 illustrates a combined layout of the electricity-intensive systems at Mineshaft B. Detailed layouts were also developed for individual systems and the constraints identified. An example of a detailed individual system layout for Mineshaft B is available in Appendix E.

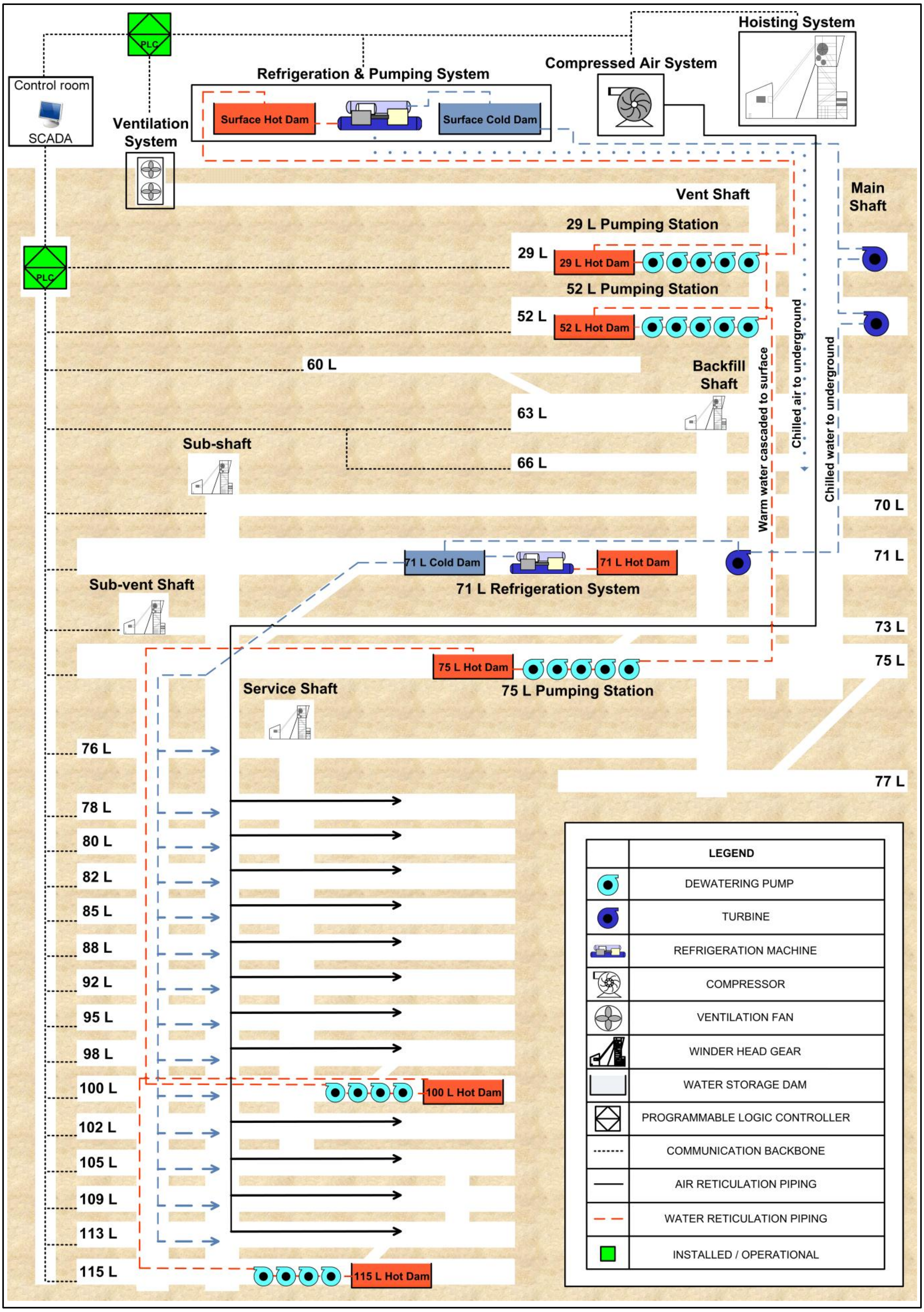

Figure 68: Simplified layout of electricity-intensive operating systems at Mineshaft B

A checklist was compiled to assist the EMT members with configuring the systems and operations at Mineshaft B. The basis of the checklist was to audit systems infrastructure and identify constraints, which may influence the IEMS implementation. The developed checklist is used by the EMT for developing energy savings solutions without affecting mine operations and production negatively. Table 22 depicts the checklist compiled for Mineshaft B.

Table 22: Systems information and constraints checklist at Mineshaft B

Information and Constraint Checklist for Mineshaft B		
Infromation and Constraints	**Source of Information**	**Status**
Existing Infrastructure	System Layouts and Audits	Sufficient
Infrastructure Condition	System Audits	Moderate to Poor due to Age of Mine
Automated Capabilities	Layouts and Audits	Fully Automated
Electrical Component Location	Electrical Drawings and System Layouts	Sufficient
Electrical Components per System	Electrical Drawings and System Layouts	Sufficient
Installed Electrical Capacities of System Components	Electrical drawings, System Layouts and Audits	Sufficient
Data Monitoring and Storage Capabilities	Database and Communication Audits	SCADA with Large Historical Database
Production and Operation Schedules	Mining and Production Engineer	Sufficient
Future Developments	Mineshaft Top Management	Sufficient
Production Targets	Mineshaft Top Management	Sufficient
Mining Requirements from Services	Operational Specifications of System Equipment, System Audits	Sufficient
Mine Lifespan	Mineshaft Top Management	Sufficient

With the systems configured and constraints identified, the next step for the EMT was processing, analysing and evaluating systems data to establish potential for electrical energy improvements on Mineshaft B's systems. Mineshaft B's systems are fully automated with remote data-capturing capabilities. A wide range of historical data was, therefore, available for processing on the SCADA system. Mineshaft B did, however, not have calibration certificates for all system measuring equipment and the strategy of Meijsen et al. was proposed to verify the accuracy of measuring equipment.

Table 23 depicts a summary of the procedure followed to analyse the systems data and evaluate electrical energy improvement potential. System parameters for each system were used to determine the scope for initiatives, while the criteria provided the constraints to which energy savings solutions had to adhere to. The procedure helped the EMT to identify electrical energy improvement potential on Mineshaft B's systems (refer to Figure 54 and Figure 55).

Table 23: Electrical energy improvement potential through systems analysis

Electrical Energy Improvement Potential for Mineshaft B Systems			
Mineshaft B Systems	**Analysed Parameters**	**Criteria**	**Electricity Savings Potential**
Compressed Air	Compressed Air Pressures; Flows; Compressors Inlet Guide Vanes	Shaft Pressure Requirement Schedule	Reduce System Pressures over 24-hour Profile; Reduce Pressures in Eskom Evening Peak Periods; Match Compressed Air Supply with Demand; Rectify Compressed Air Leaks
Main Shaft Mining	Underground Ambient Temperatures	Environmental Regulations and Constraints	Switch Off Booster Fans Having No Impact
	Hot Air Circulation Rates		
Sub-shaft Mining	Underground Ambient Temperatures	Environmental Regulations and Constraints	Switch Off Booster Fans Having No Impact
	Hot Air Circulation Rates		
Ventilation	Underground Ambient Temperatures	Environmental Regulations and Constraints	Switch Off a Ventilation Fan; Peak Clipping on Remaining Fans
	Hot Air Extraction Rates		
	Mine Air Quality		
Pumping	Dam Levels; Flows	Minimum and Maximum Dam Levels, Dam Configurations	Switch Off Pumps during Eskom Peak Periods; Rectify Water Leaks
Surface Refrigeration	Dam Levels; Flows; Water and Air Temperatures	Water Demand Schedules; Environmental Regulations	Water Flow Control; Switch Off Machines during Eskom Peak Periods
Shaft Refrigeration	Dam Levels; Flows; Water and Air Temperatures	Water Demand Schedules; Environmental Regulations	Switch Off Machines during Eskom Peak Periods
Surface and Sub-shaft Rock Winders	Silo Levels	Minimum Silo Levels; Mining Schedules; Production Targets	Switch Off Winders during Eskom Peak Periods
Hostels & Housing	Water Consumption; Geyser Output Temperatures	Water Requirement Schedules; Water Temperature Requirements	Reduce Power Consumption of Lights and Conventional Heating Systems
Surface General	Water Consumption; Geyser Output Temperatures	Water Requirement Schedules; Water Temperature Requirements	Reduce Power Consumption of Lights and Conventional Heating Systems

The next step for the EMT was implementing initiatives to address the potential identified through the systems analysis.

4.4.2 Phase 2: Implementing energy management initiatives

The procedure for implementing energy management initiatives (Figure 56) was used to address the potential identified in Table 23. The first step during the second phase of the "Do" step was for the EMT to sequence the implementation of the initiatives by system, as indicated by Table 17. This was to ensure that the EMT claimed the largest electricity improvement potential from Mineshaft B's systems first and gradually proceeded to less beneficial systems. Table 24 provides the sequence by system for implementing the electrical energy savings initiatives at Mineshaft B.

Table 24: Sequencing the implementation of initiatives by system

Mineshaft B Energy Savings Initiative Sequence by System	
Mineshaft B Systems	**Implementation Sequence (Cost Benefit)**
Compressed Air	**1**
Main Shaft Mining	**2**
Sub-shaft Mining	**3**
Ventilation	**4**
Pumping	**5**
Surface Refrigeration	**6**
Shaft Refrigeration	**7**
Surface Winders	**8**
Sub-shaft Winders	**9**
Hostels & Housing	**10**
Surface General	**11**

Table 24 shows that the compressed air system of Mineshaft B offered the largest cost-savings potential for implementing energy savings initiatives. Implementation commenced on this system and was repeated for all the other systems from the largest to the least potential.

The implementation of initiatives per system was also categorised according to the method discussed and illustrated by Table 18. Table 25 depicts the implementation sequence of initiatives per system at Mineshaft B.

Table 25: Implementation sequences for energy savings initiatives on Mineshaft B's systems

Energy Savings Initiative Implementation Sequence per System				
Mineshaft B Systems	**Old Initiative Maintenance**	**System Inefficiencies**	**New Initiatives**	**Reconfiguring Designs**
Compressed Air	1	3	2	N/A
Main Shaft Mining	N/A	N/A	1	N/A
Sub-shaft Mining	N/A	N/A	1	N/A
Ventilation	1	N/A	2	N/A
Pumping	1	2	N/A	3
Surface Refrigeration	1 (Load Shifting)	N/A	N/A	N/A
	2 (Water Flow Control)	N/A	N/A	N/A
Shaft Refrigeration	N/A	N/A	1	N/A
Surface Winders	N/A	N/A	1	N/A
Sub-shaft Winders	N/A	N/A	1	N/A
Hostels & Housing	N/A	N/A	1	N/A
Surface General	N/A	N/A	1	N/A
	Implementation Sequence (Low Risk–High Risk)			

From Table 25 it can be seen that two projects were implemented previously on Mineshaft B's surface refrigeration system. The sequence analysis (refer to Table 18) revealed that the water flow control initiative would be more expensive and time-consuming than re-implementing the load shifting initiative. Therefore, for this particular system, Mineshaft B commenced with maintenance on the load shifting initiative. Table 26 to

Table 27 present the details of the initiatives implemented at Mineshaft B, including the particulars for the implementation procedures according to Figure 56.

Table 26: Old initiative maintenance on Mineshaft B's systems[36]

Old Initiative Maintenance					
Mineshaft B Systems	**Infrastructure Repairs**	**Theoretical Analysis**	**Verification and Validation**	**Re-instate System Control**	**Monitoring and Optimisation**
Compressed Air	3 Faulty Positioners on Underground Control Valves	Simulations Revealed a 3.30 MW PC	Manual Test Revealed a 3.05 MW PC	Installations Finalised 16 January 2015	Fully Functional by the End of 2015
	Control System Disabled			System Control Enabled 19 January 2015	
Ventilation	Control System Disabled	Simulations Revealed a 0.85 MW PC	Manual Test Revealed a 0.90 MW PC	System Control Enabled 18 February 2015	Fully Functional by the End of 2015
Pumping	Control System Disabled	Simulations Revealed a 1 MW LS	Manual Test Revealed a 1.20 MW LS	System Control Enabled 06 May 2015	Control Disabled 29 May 2015
Surface Refrigeration (Load Shifting)	Control System Disabled	Simulations Revealed a 4.5 MW LS	Manual Test Revealed a 4.65 MW LS	System Control Enabled 19 January 2015	Fully Functional by the End of 2015
Surface Refrigeration (Water Flow Control)	4 Faulty VSDs on Auxiliary Pumps Control System Disabled	Simulations Revealed a 1.30 MW EE	Manual Test Revealed a 1.15 MW EE	System Control Enabled 23 July 2015	Fully Functional by the End of 2015
KEY: ENERGY EFFICIENCY = EE; LOAD SHIFTING = LS; PEAK CLIPPING = PC					

Old Initiative Maintenance Implementation Particulars					
Initiative	**Cost**	**Time**	**Complexity**	**Difficulty**	**Benefits**
Compressor Peak Clipping	R41 000	Low	Low	Low	3.05 MW PC
Ventilation Fan Peak Clipping	R0	Low	Low	Low	0.90 MW PC
Pump Load Shifting	R0	Moderate	Moderate–High	Low	1.20 MW PC
Surface Refrigeration Water Flow Control	R230 000	Moderate–High	Moderate	Moderate	1.15 MW EE
Surface Refrigeration Load Shifting	R0	Low	Low	Moderate–High	4.65 MW LS

From Table 26 it can be seen that the control over the dewatering pumps at Mineshaft B was disabled again at the end of May 2015. Mineshaft B realised that the storage dams of the dewatering system contained large amounts of mud. This resulted in the dams being maintained at high water levels to prevent damaging the dewatering pumps. This influenced the load shifting potential of the pumps as dams overflow when pumps are switched off at high levels. Table 27 and Table 28 include initiatives that address this issue.

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[36] An example of a simulation model used for a theoretical analysis on one of Mine B's systems is provided in Appendix F. Simulation models were compiled on all the systems of Mine B.

Table 27: Implementing new initiatives on Mineshaft B's systems[37]

Implementing New Initiatives						
Mineshaft B Systems	**System and Component Research**	**Solutions Development**	**Theoretical Analysis**	**Verification and Validation**	**Implement**	**Monitoring and Optimisation**
Compressed Air	Identified through Systems Analysis	24-hour Demand Control with Underground Valves Match Compressor Supply with Demand	Simulations Revealed 1.50 MW EE	Manual Test Revealed 1.45 MW EE	System Control Enabled 18 February 2015	Compressed Air Pressure on Mining Levels Fully Functional by the End of 2015
Main Shaft Mining	Booster Fan Ventilation Capacities Environmental Requirements	Switch off Booster Fans with No Impact on Environment	No Environmental Impact Simulations Revealed 3.30 MW EE	Test Revealed No Environmental Impact Test Revealed 3.55 MW EE	9 Booster Fans Switched Off 02 February 2015	Environmental Condition Monitoring Fully Functional by the End of 2015
Sub-shaft Mining	Booster Fan Ventilation Capacities Environmental Requirements	Switch off Booster Fans with No Impact on Environment	No Environmental Impact Simulations Revealed 2.60 MW EE	Test Revealed No Environmental Impact Test Revealed 2.50 MW EE	6 Booster Fans Switched Off 02 February 2015	Environmental Condition Monitoring Fully Functional by the End of 2015
Ventilation	Identified through Systems Analysis Environmental Requirements & Constraints	Switch off 1 Ventilation Fan and Remain within Environmental Constraints	Simulations Revealed 2.5 MW EE	Minimal Environmental Impact Test Revealed 2.5 MW EE	1 Surface Ventilation Fan Switched Off 18 April 2015	Environmental Condition Monitoring Fully Functional by the End of 2015
Pumping	Identified through Systems Analysis	Mud Removal from Underground Storage Dams	Simulations Revealed 5 MW LS	N/A	In Progress	Implementation in Progress
Shaft Refrigeration	Identified through Systems Analysis Environmental Requirements & Service Water Constraints	Switch off 71 Level Fridge Plants during Eskom Evening Peak Periods	Minimal Impact on Environment and Service Water Simulations Revealed 2.60 MW LS	Minimal Impact on Environment and Service Water Test Revealed 2.65 MW LS	Load Shift Implemented from 01 June 2015	System Constraints Monitoring Fully Functional by the End of 2015
Surface Winders	Identified through Systems Analysis	Revise Hoisting Schedules to Enable Load Shift	Simulations Revealed 1.50 MW LS	Test Revealed 1.35 MW LS	Load Shift Implemented from 01 June 2015	Fully Functional by the End of 2015
Sub-shaft Winders	Identified through Systems Analysis	Revise Hoisting Schedules to Enable Load Shift	Simulations Revealed 1 MW LS	Test Revealed 0.80 MW LS	Load Shift Implemented from 01 June 2016	Fully Functional by the End of 2015
Hostels & Housing	Identified through Systems Analysis	Replace CFL Lights with LED Lights Replace Geysers with Heat Pumps	Calculations Revealed 0.20 MW EE	N/A	Commisioned 12 September 2015	Fully Functional by the End of 2015
Surface General	Identified through Systems Analysis	Replace CFL Lights with LED Lights Replace Change House Geysers with Heat Pumps	Calculations Revealed 0.07 MW EE	N/A	Commisioned 24 October 2015	Fully Functional by the End of 2015
KEY: ENERGY EFFICIENCY = EE; LOAD SHIFTING = LS; PEAK CLIPPING = PC						

New Initiative Implementation Particulars					
Initiative	**Cost**	**Time**	**Complexity**	**Difficulty**	**Benefits**
24-hour Compressed Air Demand Control	R0	Moderate	Moderate–High	Low	1.45 MW EE
Main Shaft Booster Fans	R0	Low	Moderate–High	Low	3.55 MW EE
Sub-shaft Booster Fans	R0	Low	Moderate–High	Low	2.50 MW EE
Main Ventilation Fan	R80 000	Moderate	Moderate–High	Moderate	2.50 MW EE
Refrigeration Machine Load Shifting	R350 000	Moderate	Moderate	Moderate	2.65 MW LS
Surface Winder Scheduling	R0	Low	Moderate–High	Moderate	1.35 MW LS
Sub-shaft Winder Scheduling	R0	Low	Moderate–High	Moderate	0.80 MW LS
Hostels and Housing Equipment Replacement	R970 000	Moderate	Low	Low	0.20 MW EE
Surface General Equipment Replacement	R590 000	Moderate	Low	Low	0.07 MW EE

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[37] An example of a simulation model used for a theoretical analysis on one of Mine B's systems is provided in Appendix F. Simulation models were compiled on all the systems of Mine B.

By the end of 2015, the mud removal initiative on Mineshaft B's dewatering system was still in progress. As the IEMS implementation is a continual process according to the ISO 50001 PDCA cycle, this initiative was simply carried over to the next 12 months of IEMS implementation. Further details on the continuous cycle of energy management improvements at Mineshaft B are discussed in Section 4.6 of this chapter. Table 28 depicts the initiatives to reconfigure the designs of Mineshaft B's systems for optimal operation and improved electrical performance.

Table 28: Reconfiguring designs of Mineshaft B's systems

Reconfiguring Design Initiatives						
Mineshaft B Systems	**System and Component Research**	**Solutions Development**	**Theoretical Analysis**	**Verification & Validation**	**Implement**	**Monitoring and Optimisation**
Pumping	System Analysis	Underground Circulation of Service Water	Simulations Revealed 2 MW EE (Less Water Send Underground from Surface) Simulations Revealed Additional 2 MW LS (Increased Dam Level Capacity)	N/A	In Progress	Implementation in Progress
KEY: ENERGY EFFICIENCY = EE; LOAD SHIFTING = LS; PEAK CLIPPING = PC						

Reconfiguring Design Particulars					
Initiative	**Cost**	**Time**	**Complexity**	**Difficulty**	**Benefits**
Pump Efficiencies	R25 000 000	High	High	Moderate–High	2 MW EE 2 MW LS

As with the mud removal initiative, the reconfiguration of Mineshaft B's underground water reticulation system was still in progress by the end of 2015. This initiative is also further discussed in Section 4.6. Table 29 and Table 30 depict the initiatives implemented to address system efficiencies at Mineshaft B.

Table 29: System inefficiency initiatives on Mineshaft B's systems (system losses)

System Inefficiencies (Reducing System Losses)				
Mineshaft B Systems	**Auditing**	**Analysis**	**Rectify**	**Monitoring and Optimisation**
Compressed Air	20% of Compressed Air Consumed by Leaks	Approximately 3 MW of Average Compressor Power R13.5 million per Annum	30% of Leaks Rectified by End of 2015	Leak Detection and Rectification is a Continuous Process
Pumping	15% of Water Consumed by Leaks	Approximately 1.20 MW of Average Pumps Power R7 million per Annum	20% of Leaks Rectified by End of 2015	Leak Detection and Rectification is a Continuous Process
KEY: ENERGY EFFICIENCY = EE; LOAD SHIFTING = LS; PEAK CLIPPING = PC				

Rectifying Inefficiencies Particulars					
Inefficiency	**Cost**	**Time**	**Complexity**	**Difficulty**	**Benefits**
Compressed Air Leaks	R3 000	Moderate	Low	Low	1 MW EE
Water Leaks	R8 000	Moderate	Low	Low	0.25 MW EE

Table 30: System inefficiency initiatives on Mineshaft B's systems (condition monitoring)

System Inefficiencies (Condition Monitoring)					
Mineshaft B Systems	**Analysing Performance**	**Component Research**	**Benchmark**	**Rectify**	**Monitoring and Optimisation**
Pumping	Identified 7 Pumps with Low Efficiency	Comparison to Best Practices	Comparison to Other Shafts	Replaced 7 Pumps by 30 November 2015	Condition Monitoring and Rectifitication is a Continuous Process
	Average Pump Efficiency of 56%	Proved Pump Efficiences of 80%	Reasonable Pumping Efficiency of 75%	Improved Pumping Efficiency to 77%	
KEY: ENERGY EFFICIENCY = EE; LOAD SHIFTING = LS; PEAK CLIPPING = PC					

Rectifying Inefficiencies Particulars					
Inefficiency	**Cost**	**Time**	**Complexity**	**Difficulty**	**Benefits**
Pump Efficiencies	R5 000 000	Moderate–High	Moderate	Moderate–High	1.5 MW EE

According to Figure 56, metering is one of the system inefficiencies that could be addressed to improve electrical energy performance and management of gold mine systems. Energy review, discussed in Section 4.3.4, already covered the verification of the power metering systems at Mineshaft B. The verification proved that the power meters at Mineshaft B were relatively accurate and no initiatives were required to rectify any inefficiency. Mineshaft B decided not to invest time and money rectifying these small errors (0.3% according to energy review).

The energy management initiatives discussed and presented in this section were implemented over the course of 12 months (2015) as part of the energy policy targets presented in Figure 67. The total impact on the electrical energy performance of Mineshaft B was calculated at the start of 2016 to determine the outcome of the IEMS a year after the implementation in 2015. The verification procedures and results are presented in the following section.

4.5 Check: Verifying and reporting on executed plans

4.5.1 Phase 1: Verifying system performances

M&V procedures discussed in Chapter 2 and the methodology in Chapter 3 were used to calculate the impact of the implemented initiatives, consequently the IEMS, on Mineshaft B's electrical energy performance. Credible baseline adjustment methods were used to calculate adjusted baselines for Mineshaft B's systems. Figure 69 illustrates the baseline adjustment approach (refer to Section 3.5.1) followed to calculate the electrical energy performance impact at Mineshaft B.

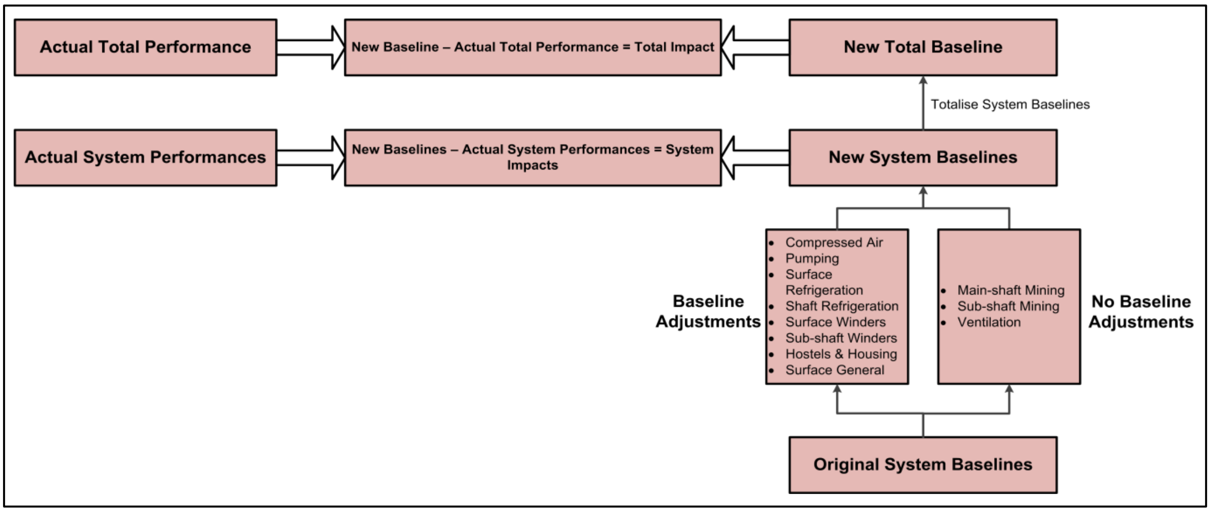

Figure 69: Baseline adjustment approach for Mineshaft B

As indicated by Figure 69, the system baselines of the baseload systems were not adjusted. The power consumption of these systems is not affected by external factors and has relatively constant power consumption profiles during day-to-day mining operations. The baselines of the remaining systems were adjusted as the system power profiles are influenced by production, system and seasonal parameters. Table 31 summarises the adjustment factors used during the baseline adjustments for the different systems.

Table 31: Adjustment factors used for system baseline adjustments at Mineshaft B

Mineshaft B System Baseline Adjustment Factors		
Mineshaft B Systems	**Energy Savings Type**	**Adjustment Factor**
Compressed Air	Energy Efficiency	Production Figures
Pumping	Energy Efficiency	Monthly Quantity of Water Pumped
	Load Shifting	Energy Neutral Adjustment
Surface Refrigeration	Energy Efficiency	Seasonal Parameters
	Load Shifting	Energy Neutral Adjustment
Shaft Refrigeration	Energy Efficiency	Seasonal Parameters
	Load Shifting	Energy Neutral Adjustment
Surface Winders	Load Shifting	Energy Neutral Adjustment
Sub-shaft Winders	Load Shifting	Energy Neutral Adjustment
Hostels & Housing	Energy Efficiency	Seasonal Parameters
Surface General	Energy Efficiency	Seasonal Parameters
Ventilation	Energy Efficiency	Baseload (No Adjustment)
Main Shaft Mining	Energy Efficiency	Baseload (No Adjustment)
Sub-shaft Mining	Energy Efficiency	Baseload (No Adjustment)

The impact of the electricity improvement of the implemented initiatives on all the systems was measured against the adjusted baselines of Mineshaft B's systems. The profiles and results of each system at Mineshaft B are available in Appendix D. For the purposes of this study, the total impact of the IEMS on the electrical energy performance of Mineshaft B is provided. Figure 70 is a graphical representation of the total impact of the IEMS. The original total baseline (Figure 66), adjusted baseline, reduced power profile set by energy policy and the average power consumption profile for January 2016 are compared.

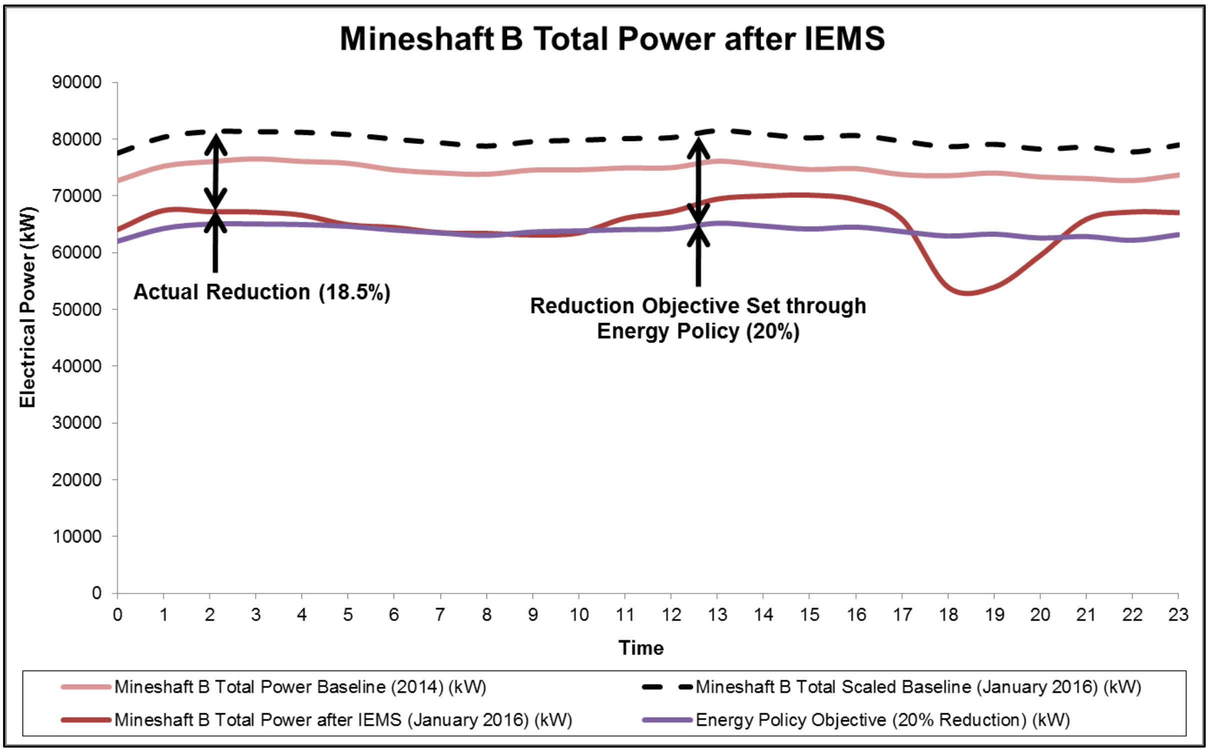

Figure 70: Total impact of the IEMS on Mineshaft B's electrical energy performance

The average performance profiles were developed during the month of January 2016. This was to accommodate the 12-month (January–December 2015) period for implementing the IEMS, as stipulated by Mineshaft B's energy policy. Figure 70 indicates that the electrical energy performance improved by 18.5% from inception (start of 2015) of the IEMS to the end of 2015. This is equivalent to a financial cost saving of approximately R75 million[38] per annum on Mineshaft B's electricity bill.

As indicated by Figure 70, Mineshaft B was not able to reach the objective (20% reduction by the end of 2015) set by the energy policy. The EMT addressed this nonconformity by conducting an energy review after the 12-month period of implementation. The energy review prior to implementation (refer to Figure 65) was compared with the energy review after implementation to identify possible reasons for the nonconformity. Figure 71 and Figure 72 depict the results of the comparison. It is important to note that Figure 71 only indicates

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[38] Calculated with the 2015/2016 Eskom electricity tariffs.

the system electricity consumption to the total shaft consumption and is not a measure of performance.

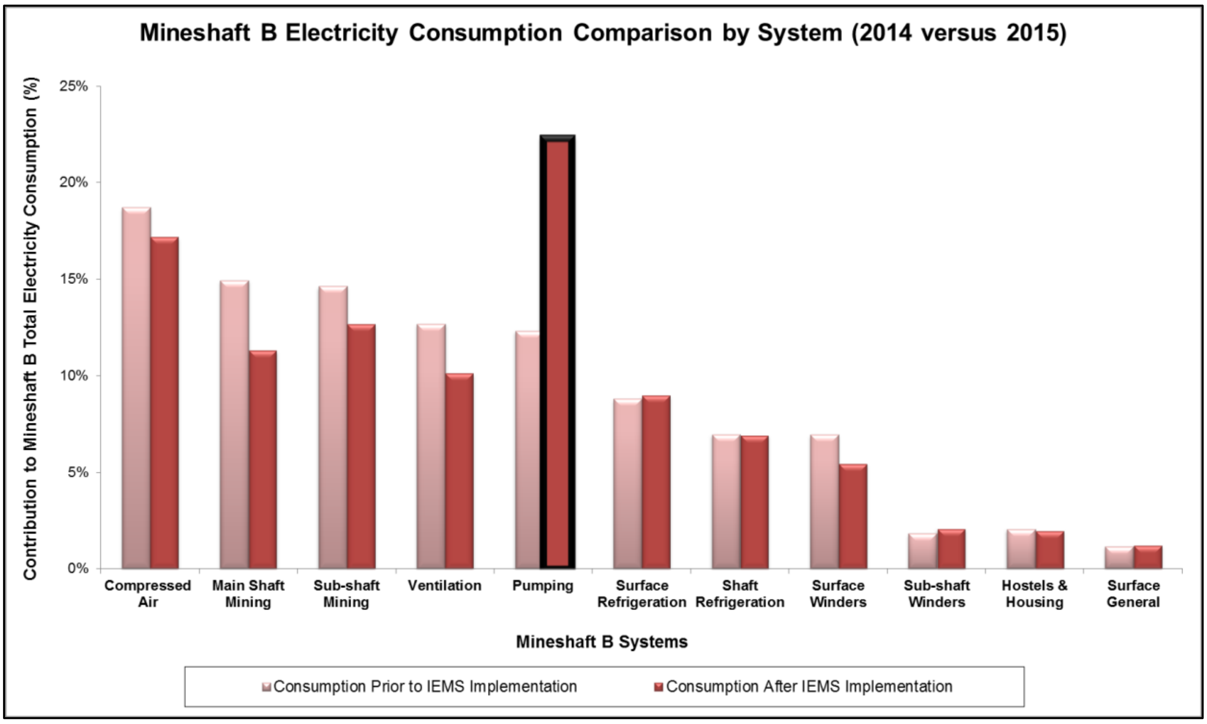

Figure 71: Mineshaft B electricity consumption comparison by system

Other than Figure 71, Figure 72 indicates the improved performance of EnPIs.

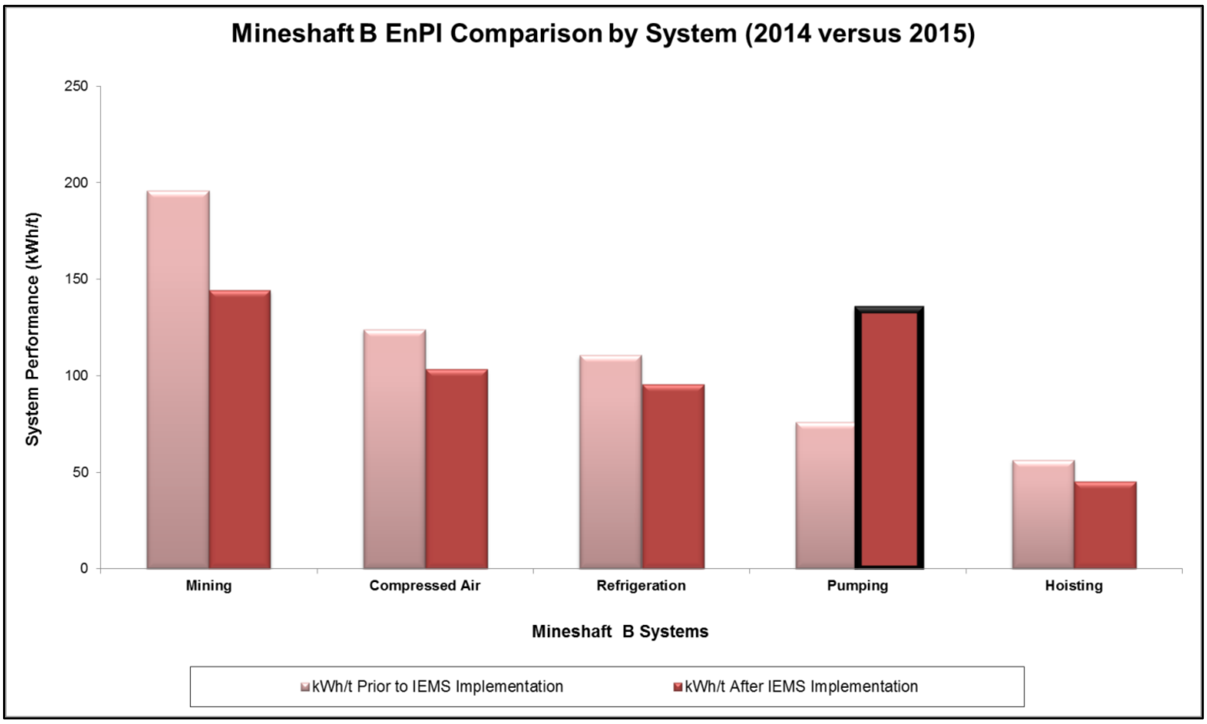

Figure 72: Mineshaft B EnPI comparison by system

The pumping system revealed a significant increase in its electrical energy consumption and deteriorated performance according to its EnPI. This nonconformity is one of the main reasons why Mineshaft B did not reach the reduction target of 20%. Initiatives illustrated by Table 27 and Table 28 were put in place by the EMT to address this nonconformity. This forms part of the "Act" step of the IEMS and is discussed further in Section 4.6.

The impact of the IEMS implemented at Mineshaft B was also verified against Group A's total electrical energy performance. The verification revealed that Group A's total electricity consumption reduced by approximately 4% after the first 12 months of IEMS implementation at Mineshaft B. This had a significant impact on the electricity expenditure of Group A. Table 32 depicts a summary of the financial costs savings on electricity for Group A as a result of the IEMS implementation at Mineshaft B.

Table 32: Group A IEMS implementation results and financials for 2015

Group A 2015 IEMS Implementation Financials				
Group A Mineshafts	**Total Implementation Cost (Rand)**	**Daily Average Power Saving (MW)**	**Bruto Cost Savings per Annum (Rand)**	**Netto Cost Savings (Rand)**
Mineshaft B	R7 300 000	14.5	R75 000 000	**R67 700 000**

After the significant impact that the IEMS had on Mineshaft B's electrical energy performance, Group A decided to expand the IEMS implementation to other mineshafts within the group. Table 20 was used to sequence the IEMS implementation at the other shafts of Group A. The implementation is currently in progress at the other shafts. As the IEMS follows the PDCA cycle of ISO 50001, the implementation is also ongoing at Mineshaft B. Optimising the IEMS implementation at Mineshaft B is discussed in Section 4.6.

The author assumed that a reduction of 18.5% would also be realised at all the other shafts of Group A. Using this figure, a financial cost saving of R220 million[39] per annum is possible. A further increase of 8.4% in the South African electricity tariff is also expected by June 2016. Considering the tariff increase and potential improvement of Group A's electricity consumption, the financial saving increases to approximately R238 million per annum. This figure would reduce the electricity portion of Group A's total operating costs with approximately 14%.

The information presented in Section 4.2 was used to evaluate the impact of the IEMS on the profitability of Group A. If the annual electricity costs of Group A were reduced by

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[39] Calculated with the 2015/2016 Eskom electricity tariffs.

R238 million per annum, the total loss for 2014 would have been approximately R1.06 billion instead of R1.3 billion. Although Group A would have still indicated an operating loss for the 2014 financial year, the profit margin would have been increased significantly. The impact of the IEMS on improved electrical energy performance and consequently increased profit margins becomes evident.

The following section discusses reporting of the IEMS implementation to relevant stakeholders.

4.5.2 Phase 2: Reporting

The reporting procedure developed and illustrated by Figure 62 was used during the IEMS implementation at Mineshaft B. Reporting and distribution of reports is a fully automated procedure at Mineshaft B and engenders great awareness among EMT members regarding the performance and progress of the IEMS implementation. The reports are reviewed by the EMT on a monthly basis during electrical review meetings to ensure that nonconformities are addressed rapidly.

High-level reports are also distributed on a monthly basis to top management of Mineshaft B and Group A. This is to ensure that Mineshaft B remains within range to achieve the objectives and targets set through the energy policy. The yearly (2015) performance of the IEMS was also reported to top management. This is for top management to evaluate the performance and progress of the IEMS and develop action plans to address nonconformities for the following 12 months of implementation.

The main purpose of the reporting procedures at Mineshaft B is to continually track and improve the performance of the IEMS by creating awareness among EMT members and top management. This also aids the IEMS with complying with the PDCA cycle of ISO 50001. The “Act” step of the IEMS implementation at Mineshaft B is discussed in the following section. This step specifically focuses on improving the IEMS implementation and electrical energy performance of Mineshaft B. This step completes the PDCA cycle by reverting to the “Plan” step of the IEMS where the cycle repeats itself.

4.6 Act: Optimising energy management

4.6.1 Technical optimisation

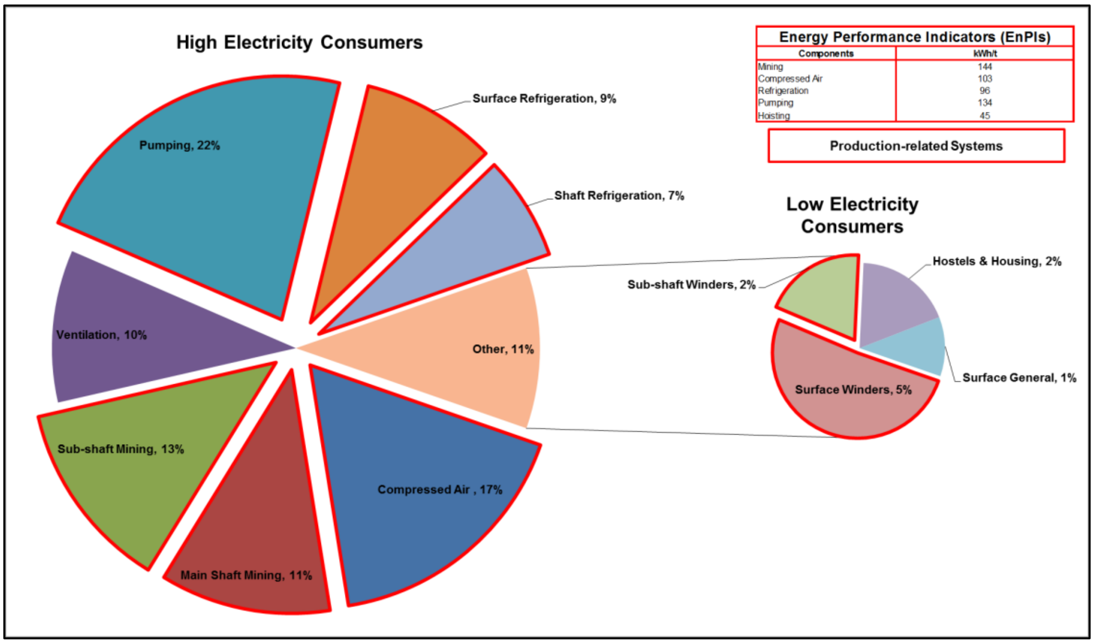
The EMT schedules monthly feedback and progress meetings to evaluate and track the impact and performance of the IEMS. The reporting procedures of the “Check” phase assist in identifying underperforming systems, and action plans are continuously developed during these meetings to address nonconformities. The EMT also uses monthly meetings to evaluate the progress of achieving the objectives set by the energy policy.

The energy management representative of Mineshaft B ensures that EMT members compile a to-do list following every monthly electrical review meeting. The performance of team members is evaluated each month based on the outcomes of the given to-do list. This ensures that the EMT and the IEMS implementation are effective. At the end of every 12 months, the EMT evaluations are used to reconstruct the EMT to ensure sustainable effectiveness and continuous improved performance.

At the start of 2016, the outcomes of the “Check” step were used by the EMT to commence with energy management planning (reverts to the “Plan” step) for the next 12 months (2016). The steps followed were:

1. evaluate top management’s commitments and inputs;
2. evaluate and update the scope, benchmarks and boundaries;
3. evaluate outputs and effectiveness of the EMT;
4. reconstruct the EMT;
5. update the electrical energy review:
    a. power metering verification;
    b. EnPIs;
    c. baselines;
6. update the energy policy; and
7. develop an action plan for 2016.

The outputs of the IEMS implementation during 2015 became the new benchmark for improvements during 2016. Thus, the 2015 improved EnPIs and electrical energy profiles for Mineshaft B became the new baselines for 2016. Figure 73 shows the updated EnPIs and Figure 74 shows the total baseline for 2016 IEMS implementation.



Energy Performance Indicators (EnPIs)	
Components	kWh/t
Mining	144
Compressed Air	103
Refrigeration	96
Pumping	134
Hoisting	45

Figure 73: Updated EnPIs for 2016 IEMS implementation at Mineshaft B

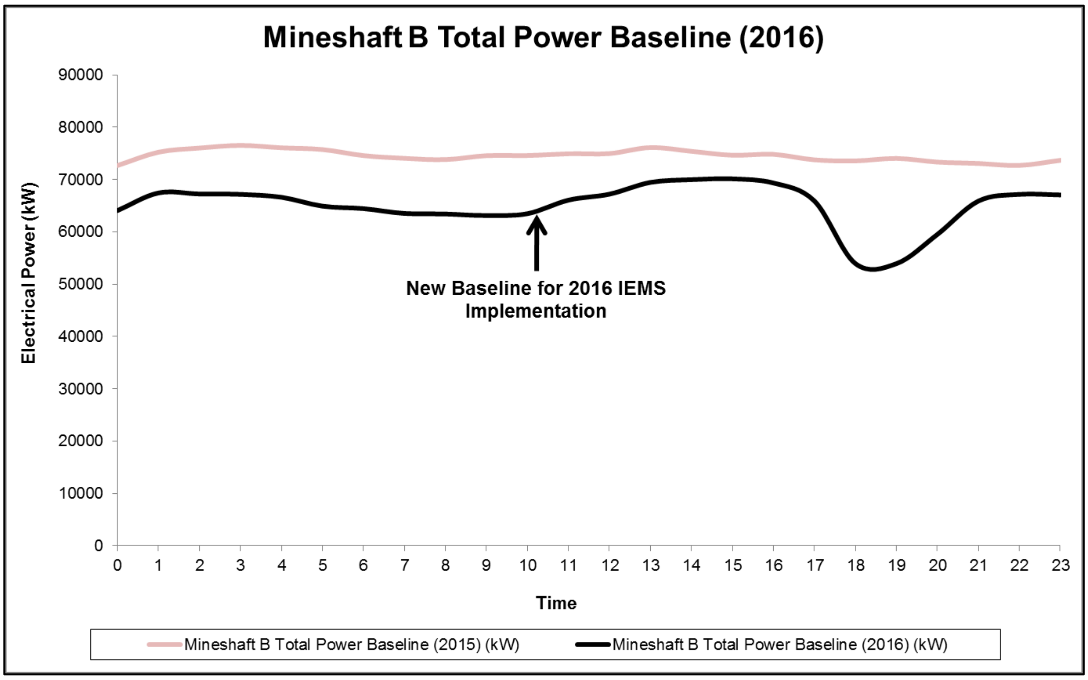


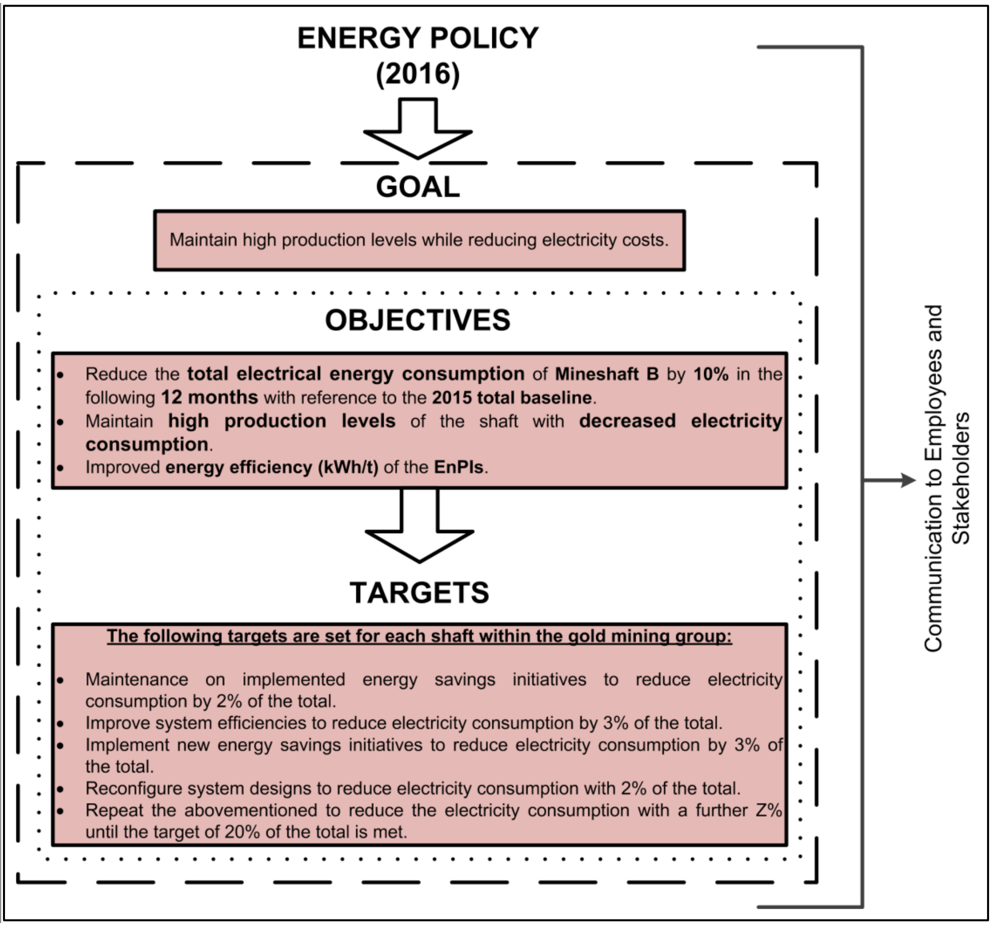
Figure 74: Updated total power baseline for 2016 IEMS implementation at Mineshaft B

The EMT continuously identified new energy savings initiatives during the course of the 2015 IEMS implementation. These initiatives, including initiatives outstanding from 2015, formed part of the scope to reduce the electricity consumption of Mineshaft B further during the 2016 IEMS implementation. The 2016 energy policy was developed with the help of Figure 71, Figure 72, Figure 73, Figure 74 and the potential for new initiatives identified by the EMT. Table 33 summarises the potential identified by the EMT to further improve Mineshaft B's electrical energy performance.

Table 33: Electrical energy improvement scope for the 2016 energy policy

Electricty Consumption Improvement Scope (2016)			
Mineshaft B Systems	**Energy Efficiency Potential (MW)**	**Peak Clipping Potential (MW)**	**Load Shifting Potential (MW)**
Compressed Air	2		
Main Shaft Mining	0.5		
Sub-shaft Mining	0.5		
Pumping	5.2		12
Surface Refrigeration			3
Shaft Refrigeration	0.8		4
	8.5	**0**	**19**

From Table 19, Mineshaft B's EMT further identified a possible average daily load reduction of approximately 8.5 MW and a load shifting potential of approximately 19 MW. This is an additional potential improvement of approximately 13% in comparison with the 2015 total baseline, illustrated by Figure 74. It must be noted that the reconfiguration of Mineshaft B's dewatering system is included in the new potential as this initiative is still in progress from 2015. These figures were used by the EMT to update the energy policy, which is illustrated by Figure 75.



Maintain high production levels while reducing electricity costs.

- Reduce the **total electrical energy consumption** of **Mineshaft B** by **10%** in the following **12 months** with reference to the **2015 total baseline**.
- Maintain **high production levels** of the shaft with **decreased electricity consumption**.
- Improved **energy efficiency (kWh/t)** of the **EnPIs**.

The following targets are set for each shaft within the gold mining group:

- Maintenance on implemented energy savings initiatives to reduce electricity consumption by 2% of the total.
- Improve system efficiencies to reduce electricity consumption by 3% of the total.
- Implement new energy savings initiatives to reduce electricity consumption by 3% of the total.
- Reconfigure system designs to reduce electricity consumption with 2% of the total.
- Repeat the abovementioned to reduce the electricity consumption with a further Z% until the target of 20% of the total is met.

Figure 75: Energy policy developed for the 2016 IEMS implementation

Mineshaft B is currently executing the “Do” step of the IEMS. In conjunction with the second-year IEMS implementation, Mineshaft B is also maintaining the initiatives implemented during 2015. This task is accomplished with the continuous improvement structure of the IEMS and is illustrated by Figure 41 and Figure 56.

4.6.2 Financial optimisation

Group A is in the process of investigating opportunities for 12L tax incentives as a result of improved electrical energy performance at relatively constant production rates. The incentive amounts for Group A would also increase in future with the expansion of the IEMS to other mineshafts within Group A. Applying for 12L tax incentives maximises the outputs of the IEMS at lower input costs and contributes to more profitable mining. The tax incentive investigations and applications were still in progress by the time of this study.

Mineshaft B also applied for funds from Eskom IDM to implement four energy savings initiatives. Funding for the initiatives are currently within the Eskom procurement process and has not been allocated by the time of this study. The funds will assist Mineshaft B with lower investment costs in energy savings initiatives, which in turn reduce payback periods and finally contribute to optimised cost savings.

The NCPC incentive was used by Mineshaft B to assist with an electrical energy audit. The audit was conducted to establish the status of Mineshaft B’s compliance with the ISO 50001 energy management standard for certification. Implementing IEMS assisted Mineshaft B with the required procedures and requirements for ISO 50001 certification. The preliminary audit for ISO certification of Mineshaft B’s IEMS is attached in Appendix G.

4.7 Conclusion

This chapter discussed the results of the actual IEMS implementation on one of South Africa’s largest gold mining groups. The strategy provided the EMT of Group A with a step-by-step guideline for improving the electrical energy performance of its mineshafts. Accumulating the improvement results of all the mineshafts would ultimately contribute to increased profitability of Group A. The results ultimately proved that a holistic approach for energy management in the gold mining industry has a significant impact on electrical energy performance. The four steps of the IEMS implemented at Group A are given as follows:

"Plan" step

Energy management planning assisted Group A with eliminating the energy management barriers during the IEMS implementation. Group A was also able to identify the most beneficial mineshaft (Mineshaft B) at which the IEMS implementation should commence. Furthermore, the "Plan" step assisted Group A with establishing an EMT, developing an energy review and energy policy at Mineshaft B. Finally, an action plan was developed to reduce the electrical energy consumption of Mineshaft B.

"Do" step

The next step for Mineshaft B was executing the action plan developed during the "Plan" step. The systems analysis procedure assisted with identifying energy savings potential on the different systems of Mineshaft B. Various initiatives were identified through the potential which included old initiative maintenance, new initiatives, system inefficiencies and reconfiguring designs. The potential was addressed in a sequenced order to realise maximised benefits for Mineshaft B by using the developed procedures in Chapter 3 for implementing energy savings initiatives.

"Check" step

During the "Check" step, the EMT determined the impact of the IEMS with credible procedures. It was found that by the end of 2015, the electrical energy performance of Mineshaft B had been improved with 18.5%. This accumulated to a cost saving of approximately R75 million per annum on Mineshaft B's electricity bill. Due to the significant impact of the IEMS at Mineshaft B, Group A decided in January 2016 to expand the implementation to all the other mineshafts. Assuming an overall reduction of 18.5% on Group A's electrical energy performance, a financial cost saving of approximately R220 million per annum is expected.

"Act" step

The final step of the PDCA cycle was optimising the IEMS implementation from a technical and financial perspective. From a technical perspective, the IEMS implementation is ongoing at Mineshaft B with the EMT maintaining the improved performance results and continually improving on the benchmarks set by the 2015 implementation. From a financial perspective, Mineshaft B applied for numerous incentives to optimise the financial contribution of electrical energy improvements for maximised outputs. Mineshaft B also used incentives to assist with ISO 50001 certification procedures.

Continually optimising the IEMS implementation will ensure a year-on-year improvement of Group A’s electrical energy performance. This will significantly reduce electricity expenditure as part of Group A’s operating costs and thus ensure increased profitability during the marginal era of gold mining in South Africa.

CHAPTER 5

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"All achievements, all earned riches, have their beginning in an idea." – Napoleon Hill

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[40] http://www.mining-technology.com/features/feature-top-ten-biggest-gold-mines-south-africa/feature-top-ten-biggest-gold-mines-south-africa-9.html.

5 CONCLUSION AND RECOMMENDATIONS

5.1 Overview of the study

REVIEWING THE NEED FOR AN INTEGRATED ENERGY MANAGEMENT STRATEGY (IEMS)

In the modern day era, South African gold mining is struggling to remain profitable and competitive within global markets. Numerous factors influence productive mining and costs have escalated to the point where input costs per unit of gold exceed the market value due to low gold prices (mining below the uneconomical point). Although the gold price changes over time, periods when the gold price is at its lowest (July 2015) is of great concern to the gold mining industry.

One of the few methods to mitigate the impact of low commodity prices is reducing input costs to increase profit margins. Electricity contributes significantly to gold mining operational costs and electricity has been increasing at higher-than-inflation rates in South Africa. Thus, managing the electricity consumption patterns of gold mines has become important for cost reduction in modern day South African gold mining.

A wide variety of energy savings initiatives has been implemented in the gold mining industry in an attempt to mitigate increasing electricity costs. These initiatives contributed positively to the concept of energy management. However, research has proven that the performance of these initiatives is not sustainable due to a lack of an energy management framework. Comprehensive studies on energy management in the global industrial sector prove the scarcity of energy management practices in the gold mining environment.

A need was identified for developing an IEMS for the deep-level gold mining industry. The development was based on structuring previously implemented energy management initiatives within a framework for gold mines to practise effective energy management. Due to proven success, the ISO 50001 PDCA cycle was incorporated while developing the IEMS. This ensures a continuous improvement cycle for the IEMS implementation and consequently electrical energy performance. The developed IEMS is as follows:

INTEGRATED ENERGY MANAGEMENT STRATEGY (IEMS)

Figure 76 depicts a simplified layout of the IEMS developed in this study. The IEMS is divided into four basic steps enclosed within the continuous improvement PDCA cycle of the ISO 50001 energy management standard. The structure of the IEMS was strategically developed to be interpreted and implemented easily in a chronological order by the EMTs of gold mines.

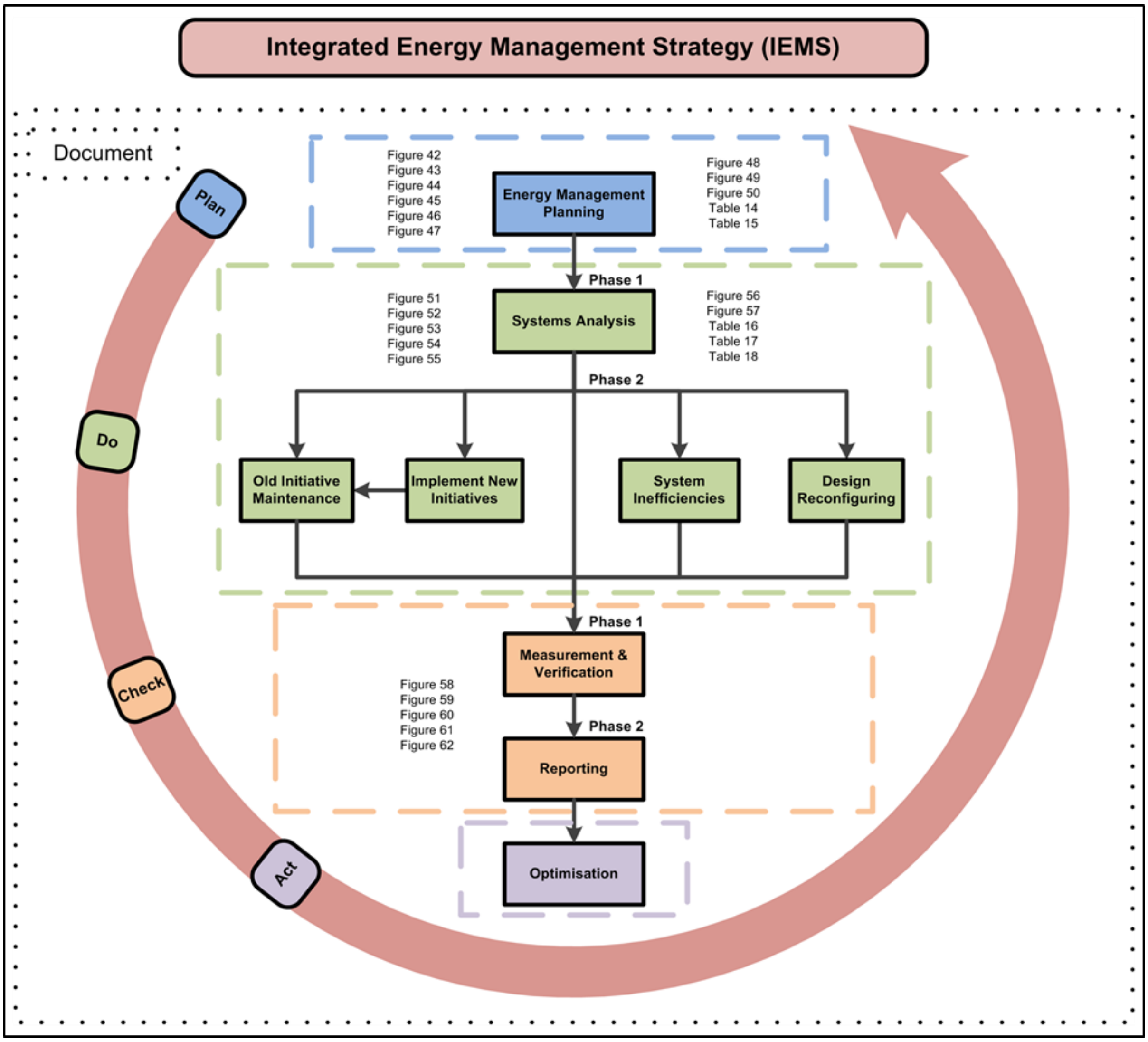

Figure 76: Developed IEMS according to the PDCA cycle of ISO 50001

The developed IEMS was implemented at one of South Africa's largest gold mining groups (Group A). The aim of the IEMS implementation was assisting Group A with reducing electricity costs, while still maintaining high production levels. This would ensure increased profit margins for Group A during the difficult era of gold mining in South Africa. The IEMS implementation at Group A commenced at the start of 2015 and is still ongoing. The particulars of the implemented IEMS at Group A are discussed on the basis of the PDCA cycle.

PLAN: ENERGY MANAGEMENT PLANNING

The first step for Group A was conducting thorough energy management planning. Figure 77, developed in this study, provided Group A with a chronological guideline to perform this task and address existing energy management barriers simultaneously.

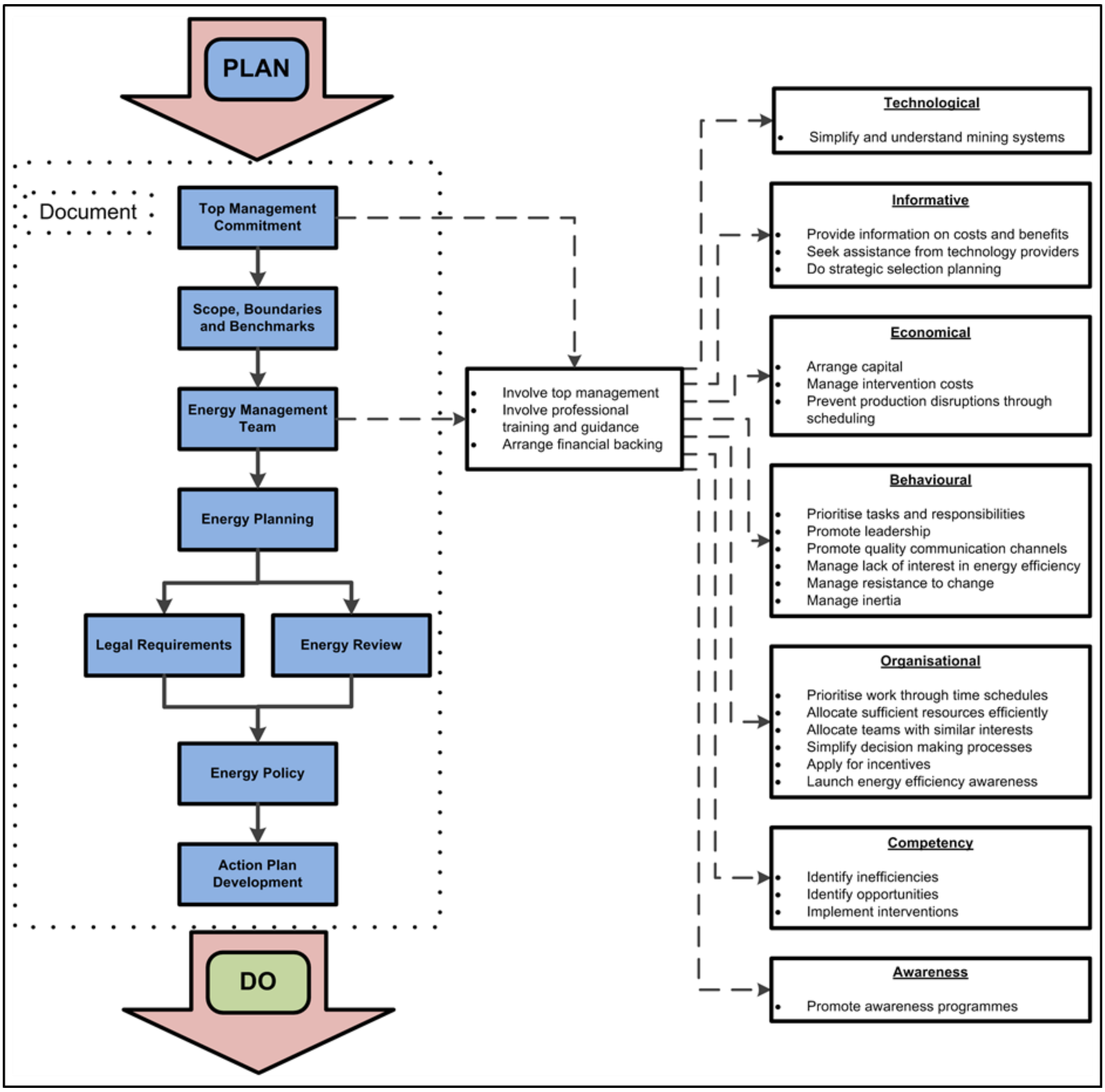

Figure 77: “Plan” step of the IEMS

The procedure depicted by Figure 77 allowed Group A to identify the most beneficial mineshaft for the IEMS implementation. Thus, Mineshaft B was identified and the IEMS implementation commenced at this shaft.

DO: EXECUTING ENERGY MANAGEMENT PLANS

The “Do” step of the IEMS commenced with a systems analysis to obtain a general background on the configuration and operations at Mineshaft B. Figure 78 depicts the systems analysis procedure developed in this study that was followed by the EMT of Mineshaft B.

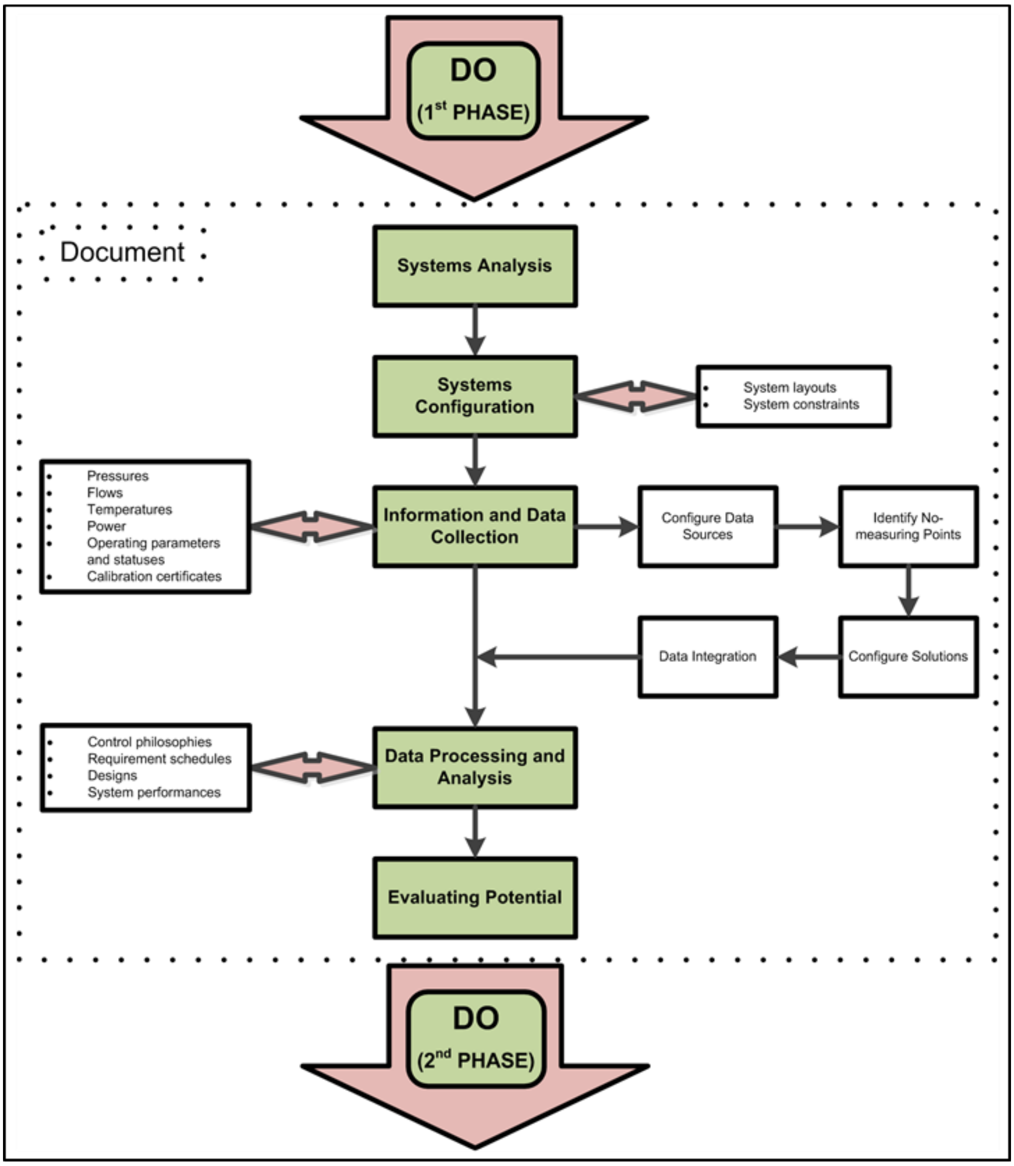

Figure 78: First phase of the “Do” step of the IEMS

The systems analysis assisted the EMT to identify the potential for implementing energy savings initiatives. This allowed the EMT to proceed to the second phase of the “Do” step, which is implementing initiatives to improve the electrical energy performance of Mineshaft B. Figure 79 depicts the procedure for implementing energy savings initiatives at Mineshaft B that was developed in this study.

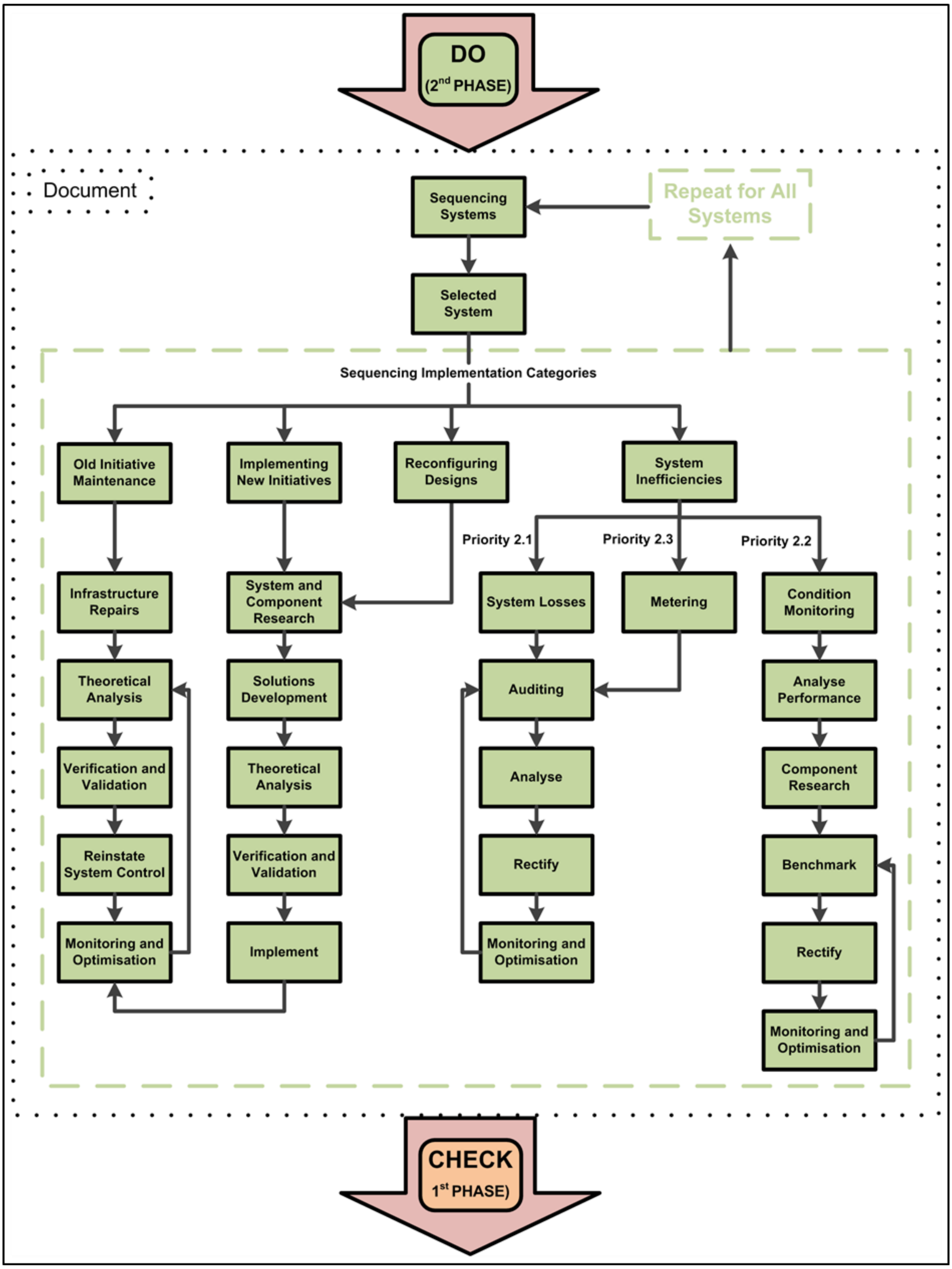

Figure 79: Second phase of the “Do” step of the IEMS

Numerous initiatives were identified for implementation on the electricity-consuming systems of Mineshaft B. The implementation of the initiatives was categorised into four categories for each system as depicted by Figure 79. This study developed a sequencing model that was used on Mineshaft B to identify the implementation sequence for each system. Initiatives were then implemented in chronological order from the largest to lowest benefits for each system. The next step was to verify and report on the electrical energy savings realised through the IEMS implementation on Mineshaft B.

CHECK: VERIFYING AND REPORTING ON EXECUTED PLANS

During the first phase of the "Check" step, the EMT had to verify the impact of the IEMS on the electrical energy performance of Mineshaft B. Credible M&V procedures identified through literature were used to perform this task. Table 34 depicts a summary of the results after the first year (2015) of the IEMS implementation at Group A.

Table 34: Group A financial summary for 2015

Group A 2015 IEMS Implementation Financials				
Group A Mineshafts	**Total Implementation Cost (Rand)**	**Daily Average Power Saving (MW)**	**Bruto Cost Savings per Annum (Rand)**	**Netto Cost Savings (Rand)**
Mineshaft B	R7 300 000	14.5	R75 000 000	**R67 700 000**

During the second phase of the "Check" step, the improvement results were reported to top management of Group A and Mineshaft B. Top management used these results to evaluate the effectiveness of the IEMS and evaluate the improvement scope for nonconformities. Although just reporting of the improvement results is mentioned, it is important to note ongoing reporting of important IEMS implementation aspects do occur.

ACT: OPTIMISING ENERGY MANAGEMENT

During the "Act" step, the verified results were used by the EMT to optimise the IEMS implementation and maximise benefits from improved electrical energy performance. Technical optimisation focused on continually improving the IEMS implementation procedure for optimised performance (developed in this study), which satisfies the PDCA cycle of

ISO 50001. Financial optimisation refers to Mineshaft B’s applications for financial incentives due to improved electrical energy performance realised with the IEMS implementation.

The “Act” step reverts to the “Plan” step of the IEMS and Mineshaft B is currently in the second year of implementation. The “Plan” step of the cycle was finalised during January 2016 and Mineshaft B is currently in the process of executing the “Do” step. Due to the positive impact of the IEMS at Mineshaft B, Group A also decided to expand the implementation to all the other shafts of Group A. It is important to note that the IEMS implementation developed in this study is a continual process and the cumulative impact is calculated on a yearly basis.

5.2 Contributions of the study

INTEGRATING EXISTING ENERGY MANAGEMENT BEST PRACTICES WITHIN A NEW COMPREHENSIVE STRATEGY

A novel IEMS was developed for the deep-level gold mining industry. Previously implemented energy management initiatives in the gold mining industry (refer to Chapter 2) were structured within a comprehensive framework. Gold mines can use the framework to manage electrical energy consumption effectively and ultimately contribute to increased profit margins. The impact of the IEMS was validated through the case study at Mineshaft B.

STRATEGIC DEVELOPMENT OF A NOVEL ENERGY MANAGEMENT STRATEGY IN LINE WITH THE ISO 50001 STANDARD

The development of the IEMS was aligned with the requirements of the ISO 50001 energy management standard. Mineshaft B is currently in progress with the second iteration of the IEMS, which illustrates the concept of incorporating the PDCA cycle of ISO 50001 for continual improvement. An energy audit was also conducted at Mineshaft B to evaluate the status of the IEMS for ISO 50001 certification. The preliminary audit results are available in Appendix G.

NOVEL STEP-BY-STEP PROCEDURE FOR GOLD MINE ENERGY MANAGEMENT TEAMS TO IMPLEMENT THE INTEGRATED ENERGY MANAGEMENT STRATEGY

The IEMS provides the EMT of a deep-level gold mine with a systematic procedure to implement the IEMS. The PDCA structure of the strategy also guides the EMT to continual improvement of the electrical energy performance and sustainability of implemented initiatives. The results of the IEMS guidance for the EMT of Mineshaft B are reflected in Chapter 4 of this document.

UNIQUE BENCHMARKING MODEL FOR SEQUENCING THE IMPLEMENTATION OF THE INTEGRATED ENERGY MANAGEMENT STRATEGY AT MINESHAFTS

A benchmarking model was developed to determine the optimum sequence to commence IEMS implementation in a gold mining group. The benchmarking model was used by Group A to sequence the IEMS implementation at the different mineshafts. The model proved that the maximum benefits for Group A would be realised if the IEMS implementation commenced at Mineshaft B. The model was also used to sequence the order in which the IEMS should be expanded to all the other mineshafts of Group A during 2016.

UNIQUE SEQUENCING MODEL FOR OPTIMISED IMPLEMENTATION OF DIFFERENT ENERGY SAVINGS INITIATIVES AT MINESHAFTS

A sequencing model was developed to determine the optimum sequence for implementing savings initiatives at a mineshaft. The EMT at Mineshaft B used the developed model to sequence the implementation of the identified energy savings initiatives. The model helped the EMT to claim quick wins[41] first and gradually proceed to implementing initiatives with higher risks. This contributed to the optimised IEMS implementation at Mineshaft B as maximised benefits were realised at the lowest input costs.

5.3 Limitations and recommendations

The IEMS has been developed to accommodate the electrical portion of a deep-level gold mine’s total energy consumption. Although it is stated that electricity is the largest portion of a deep-level gold mine’s energy consumption, further studies are recommended to include

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[41] Initiative with high cost-savings potential, low input costs and relatively short implementation period.

other energy sources such as diesel, petrol, gas and oils within the IEMS implementation. This will enable gold mines to effectively manage the entire portion of energy consumption and consequently enhance the reduction in operating costs.

Further work is also required to establish the environmental impact of the IEMS. This study focused on reducing the electricity consumption patterns of gold mines and the impact was quantified through realised financial cost savings. The reduction in CO_2 gas emissions and water consumption as a result of reduced electricity consumption has not been quantified. This is an essential part for future development of the IEMS in order to mitigate future cost risks such as carbon tax and environmental levies [20].

According to Figure 11, the gold mining industry was not the only contributor to the mining industry's shortfall of the reduction target set by the EES and ECS in 2005. Gold mines are, therefore, not the only sector in the mining industry that needs IEMS, especially with higher-than-inflation electricity increases. The author is of the opinion that with some modification to the IEMS, it could also be compatible with energy management in other mining sectors of South Africa.

The developed IEMS is still within early stages of implementation in the South African gold mining industry. At the time of this study, the IEMS was implemented at one of South Africa's gold mining groups. The long-term impact of the IEMS on the electrical energy consumption patterns and profitability of South Africa's entire gold mining industry is yet to be determined. The author is also interested in gold mine personnel's transition towards an energy management environment in the next five years. Creating energy management awareness among mine personnel will further eliminate the barriers identified in Table 9 and enhance the improvements realised from the IEMS.

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"There are no speed limits on the road to excellence." – Unknown

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[42] Photo taken by HVACI personnel at a South African mine.

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APPENDICES

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“The power to move the world is in your sub-conscious mind.” – William James

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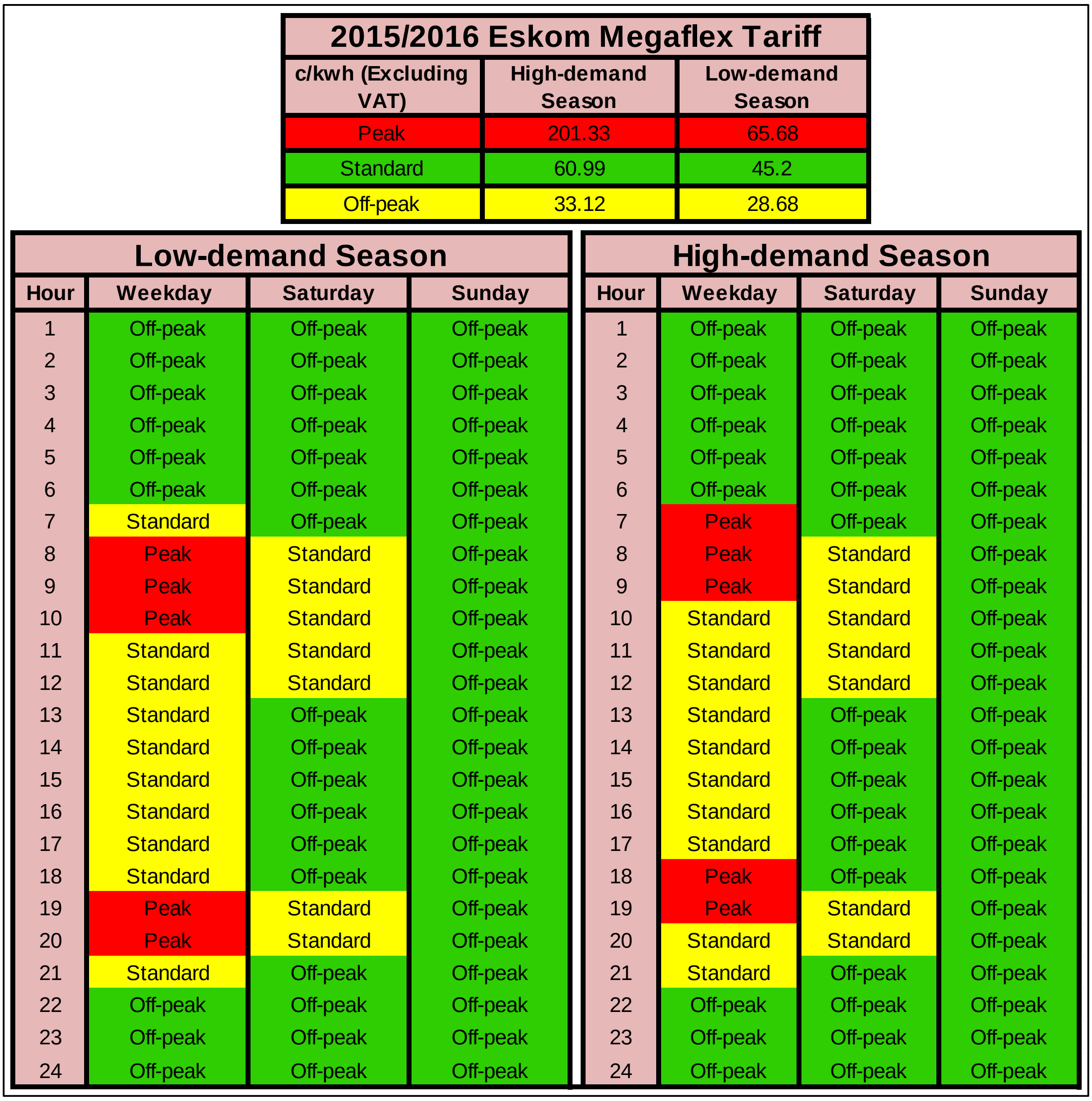
APPENDIX A: ESKOM TOU

Eskom Megaflex structure

The gold mining industry in South Africa makes use of the Eskom Megaflex structure [10]. Figure 80 depicts the 2015/2016 Eskom Megaflex structure and tariff. The structure and tariff was used in this study to calculate the impact of IEMS implementation at Group A.



2015/2016 Eskom Megaflex Tariff

c/kwh (Excluding VAT)	High-demand Season	Low-demand Season
Peak	201.33	65.68
Standard	60.99	45.2
Off-peak	33.12	28.68

Low-demand Season				High-demand Season			
Hour	Weekday	Saturday	Sunday	Hour	Weekday	Saturday	Sunday
1	Off-peak	Off-peak	Off-peak	1	Off-peak	Off-peak	Off-peak
2	Off-peak	Off-peak	Off-peak	2	Off-peak	Off-peak	Off-peak
3	Off-peak	Off-peak	Off-peak	3	Off-peak	Off-peak	Off-peak
4	Off-peak	Off-peak	Off-peak	4	Off-peak	Off-peak	Off-peak
5	Off-peak	Off-peak	Off-peak	5	Off-peak	Off-peak	Off-peak
6	Off-peak	Off-peak	Off-peak	6	Off-peak	Off-peak	Off-peak
7	Standard	Off-peak	Off-peak	7	Peak	Off-peak	Off-peak
8	Peak	Standard	Off-peak	8	Peak	Standard	Off-peak
9	Peak	Standard	Off-peak	9	Peak	Standard	Off-peak
10	Peak	Standard	Off-peak	10	Standard	Standard	Off-peak
11	Standard	Standard	Off-peak	11	Standard	Standard	Off-peak
12	Standard	Standard	Off-peak	12	Standard	Standard	Off-peak
13	Standard	Off-peak	Off-peak	13	Standard	Off-peak	Off-peak
14	Standard	Off-peak	Off-peak	14	Standard	Off-peak	Off-peak
15	Standard	Off-peak	Off-peak	15	Standard	Off-peak	Off-peak
16	Standard	Off-peak	Off-peak	16	Standard	Off-peak	Off-peak
17	Standard	Off-peak	Off-peak	17	Standard	Off-peak	Off-peak
18	Standard	Off-peak	Off-peak	18	Peak	Off-peak	Off-peak
19	Peak	Standard	Off-peak	19	Peak	Standard	Off-peak
20	Peak	Standard	Off-peak	20	Standard	Standard	Off-peak
21	Standard	Off-peak	Off-peak	21	Standard	Off-peak	Off-peak
22	Off-peak	Off-peak	Off-peak	22	Off-peak	Off-peak	Off-peak
23	Off-peak	Off-peak	Off-peak	23	Off-peak	Off-peak	Off-peak
24	Off-peak	Off-peak	Off-peak	24	Off-peak	Off-peak	Off-peak

Figure 80: Eskom Megaflex structure and tariff for 2015/2016

APPENDIX B: SYSTEM EFFICIENCY CALCULATIONS

Leaks

Equation 2: Flow rate calculation through a compressed air leak [58]

$$\dot{m}_{air\_leak} = C_{discharge}\left(\frac{2}{k+1}\right)^{\frac{1}{k-1}}\left(\frac{p_{air\_leak}}{RT_{air\_leak}}\right)A_{air\_leak}\sqrt{kR\left(\frac{2}{k+1}\right)T_{air\_leak}}$$

Where:

$\dot{m}_{air\_leak}$ = Mass flow rate through leak in kg/s

$C_{discharge}$ = Dimensionless leak discharge coefficient

k = Specific heat ratio for compressed air taken as 1.4

p_{air_leak} = Absolute air pressure at the leak in kPa

R = Gas constant for air taken as 0.278 kJ/kg.K

T_{air_leak} = Temperature of the air at the leak in K

A_{air_leak} = Cross-sectional area of the leak in m^2

Equation 3: Flow rate calculation through water leak (based on Bernoulli's theorem) [36], [37], [111]

$$\mathrm{Q}_{\mathrm{water\_leak}} = C_V A_{water\_leak}\sqrt{\frac{2\Delta P_{water\_leak}}{\rho}}$$

Where:

Q_{water_leak} = Water flow through leak in m^3/s

C_V = Dimensionless flow coefficient

A_{water_leak} = Cross-sectional area of the leak in m^2

ΔP_{water_leak} = Pressure difference over leak in Pa

ρ = Fluid density in kg/m^3

Equation 4: Electrical power wasted through a compressed air leak [58][44]

$$P_{lost\_air} = \frac{\frac{\dot{m}_{air\_leak}nRT_{in}}{\eta_{comp}(n-1)}\left[\left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}}-1\right]}{\eta_{motor}}$$

Where:

P_{lost_air} = Compressor power wasted through leak in kW

$\dot{m}_{air\_leak}$ = Mass flow rate through leak in kg/s

---

[44] Calculations are based on the assumption that gold mines generally use centrifugal compressors [32], [39].

n = Polytrophic constant taken as 1.4
R = Gas constant for air taken as 0.278 kJ/kg.K
T_{in} = Compressor inlet (ambient) temperature in K
η_{comp} = Dimensionless compressor efficiency
p_2 = Compressor discharge pressure in kPa
p_1 = Compressor inlet (ambient) pressure in kPa
η_{motor} = Dimensionless compressor motor efficiency

Equation 5: Electrical power wasted through a water leak [36], [37], [111][45]

$$P_{lost\_water} = \frac{\frac{Q_{water\_leak}\rho g h}{3.6 \times 10^{6}}}{\eta_{system}}$$

<u>Where:</u>

P_{lost_water} = Dewatering pumps power wasted through leak in kWh
Q_{water_leak} = Water flow through leak in m^3/h
ρ = Fluid density in kg/m^3
g = Gravitational acceleration taken as 9.81 m/s^2
h = Pump height in m
η_{system} = Dimensionless dewatering system efficiency

Pipe losses

Equation 6: Darcy–Weisbach equation for pressure drops over long piping networks

$$\Delta p = \frac{f \rho L {Q_{volume}}^{2}}{82.76 D^{5}}$$

<u>Where:</u>

Δp = Pressure loss between two points in kPa
f = Dimensionless Darcy–Weisbach friction factor
ρ = Density of air in kg/m^3
L = Length of the pipe in m
Q_{volume} = Volume flow rate in m^3/s
D = Inside diameter of the pipe in m

Condition monitoring

Refrigeration machines

The performance of individual chiller machines (fridge plants) is expressed as the machine's coefficient of performance (COP[46]) [10], [31]. It is also possible for one to express the

---

[45] Calculations are based on the assumption that gold mines generally use centrifugal pumps [30], [37], [77].

performance (COP) of the entire refrigeration system (plant) [31]. The respective COPs can be calculated with the help of Equation 7 and Equation 8.

Equation 7: COP calculation for individual chiller machines

$$COP_{machine} = \frac{Q_{evap}}{P_{machine}} = \frac{\dot{m}_{evap} C_{p_{water}} (T_{out} - T_{in})}{P_{machine}}$$

<u>Where:</u>

$COP_{machine}$ = Dimensionless machine coefficient of performance
Q_{evap} = Thermal energy absorbed by evaporator in kW
$P_{machine}$ = Electrical power input from machine compressor in kW
$\dot{m}_{evap}$ = Evaporator water flow rate in kg/s
Cp_{water} = Specific heat for water in kJ/kg.K
T_{out} = Water outlet temperature in K
T_{in} = Water inlet temperature in K

Equation 8: COP calculation for a refrigeration system (entire plant)

$$COP_{system} = \frac{Q_{evap}}{P_{machine} + P_{aux}}$$

<u>Where:</u>

COP_{system} = Dimensionless system coefficient of performance
Q_{evap} = Thermal energy absorbed by evaporator in kW
$P_{machine}$ = Electrical power input from machine compressor in kW
P_{aux} = Electrical power input from system auxiliaries[47] in kW

The efficiency of the individual chiller machines can be calculated with the following equation [112]:

Equation 9: Efficiency calculation for an individual chiller machine [10], [31], [112]

$$\eta_{machine} = \frac{Q_{evap} + P_{machine}}{Q_{cond}}$$

<u>Where:</u>

$\eta_{machine}$ = Dimensionless chiller machine efficiency
Q_{evap} = Thermal energy absorbed by evaporator in kW
$P_{machine}$ = Electrical power input from machine compressor in kW
Q_{cond}[48] = Thermal energy absorbed by condenser in kW

---

[46] Ratio of the machine's thermal cooling per unit of electricity input [31].
[47] The system auxiliaries include pumps and cooling tower fans.

Equation 7 to Equation 9 can be used to monitor the performance and efficiency of refrigeration systems continuously. It is evident from these equations that when the COP and efficiency of the refrigeration system decrease, the electrical power consumption will follow the opposite trend. It is, therefore, important to monitor the performance of refrigeration machines/systems continuously to identify discrepancies that need to be repaired. This will continuously improve the overall electrical energy performance of the plant.

Dewatering pumps

The most common method when calculating pump efficiency is calculating the ratio between the amount of water pumped and the electrical power consumed (kWh/Ml) [10], [50]. Although this method seems to be effective, the viability thereof is in most cases halted by the availability of flow meters on each pump [10]. These flow meters are expensive and the alternative is to fall back on cost-effective thermodynamic methods. Equation 10 gives the efficiency calculation for a centrifugal pump [113].

Equation 10: Thermodynamic calculation for pump efficiency [113]

$$\eta_{pump} = \frac{1}{\frac{C_{p\_water}}{v}\left[\frac{\Delta T_{pump}}{\Delta P_{pump}} - \mu\right]}$$

Where:

η_{pump}	=	Dimensionless pump efficiency
$Cp_{\_water}$	=	Specific heat for water in J/kg.K
v	=	Specific volume in m^3/kg
ΔP_{pump}	=	Differential pressure over pump in Pa
ΔT_{pump}	=	Differential temperature over pump in K
μ	=	Joule–Thompson coefficient in K/Pa

The instrumentation to measure the required temperatures and pressures used in Equation 10 is less expensive and is, therefore, a more cost-effective solution.

It is also possible to calculate the efficiency of the entire dewatering system. This method compares the theoretical power with the actual power consumption of the dewatering system to move the water (total) from underground to surface. The equation is given as follows:

Equation 11: Calculation for the dewatering system efficiency [36], [37]

---

[48] The calculation for thermal energy absorbed by the condenser is the same as for the evaporator circuit.

$$\eta_{system} = \frac{P_{theoretical}}{P_{actual}} = \frac{\frac{Q_{total\_out}\rho g h}{3.6 \times 10^{6}}}{P_{actual}}$$

Where:

η_{system} = Dimensionless dewatering system efficiency

$P_{theoretical}$ = Total theoretical power required in kWh

P_{actual} = Actual power consumed in kWh

Q_{total_out} = Total water moved to mine surface in m^3/h

ρ = Fluid density in kg/m³

g = Gravitational acceleration taken as 9.81 m/s^2

h = Pump height in m

Again, Equation 10 and Equation 11 above validate the influence of efficiencies on power consumption. Inefficient pumps need to be replaced or reconditioned to ensure acceptable system efficiencies at all times [31].

Compressors

As with pumps, the most common method when calculating compressor efficiencies is to calculate and monitor the kWh/m^3 ratio [10]. Through this ratio, one would be able to identify increased power consumption with a decreased flow output and decreased power consumption with increased flow output.

Winders/Hoisting

It is a difficult task to calculate the efficiency of winders and its effect on the electrical energy performance of a gold mine. The Sigurd Grimestad’s hypothesis, however, states that a rock winder consumes 1 kWh/t for every 367 m of hoisting distance [95]. This theory was developed assuming 100% winding efficiency. The hypothesis can, therefore, be used as a benchmark to measure the existing performance of the winding system. Equation 12 gives the equation to calculate the efficiency of a winder with the help of the Sigurd Grimestad’s hypothesis.

Equation 12: Calculation for the efficiency of a winder derived from the Sigurd Grimestad’s hypothesis

$$\eta_{winder} = \frac{\frac{P_{winder\_hypothesis}}{tonnes\_hypothesis} \times \frac{D_{winding}}{367}}{\frac{P_{winder\_actual}}{tonnes\_actual} \times \frac{D_{winding}}{367}}$$

Where:

η_{winder} = Dimensionless winding efficiency

$P_{winder\_hypothesis}$ = Hypothetical power consumption in kWh

P_{winder_actual} = Actual power consumption in kWh

$Tonnes_{\_hypothesis}$ = Hypothetical weight of hoisted load in tonnes

$Tonnes_{\_actual}$ = Weight of hoisted load in tonnes

$D_{winding}$ = Winding distance in m

There is another method for calculating the operational efficiency of a winding system. This calculation usually helps with load shifting preparation for the Eskom evening peak periods [10]. Gold mines have certain daily production targets that need to be adhered to. It is, therefore, important to use the full potential of the winding system during other parts of the day to ensure load shifting capacity during Eskom evening peak periods. The equation for calculating the operational efficiency is given as follows:

Equation 13: Calculation for the operational efficiency of winding systems [10]

$$\eta_{winding\_system} = \frac{Skips/hour}{Skips_{capacity}/hour}$$

Where:

$\eta_{\ winding\_system}$ = Dimensionless winding operational efficiency

Skips/hour = Skips[49] of ore hoisted per hour

$Skips_{capacity}$/hour = Winding capacity for hoisting skips per hour

---

[49] Container used to carry mined ore from underground operations to the shaft's surface.

APPENDIX C: ENERGY MANAGEMENT PLANNING DOCUMENTATION

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ELECTRICAL ENERGY BASELINE

MINESHAFT B

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Electrical energy baseline

An energy baseline is compiled to determine future energy savings. The graph below shows the baseline electrical energy baseline.

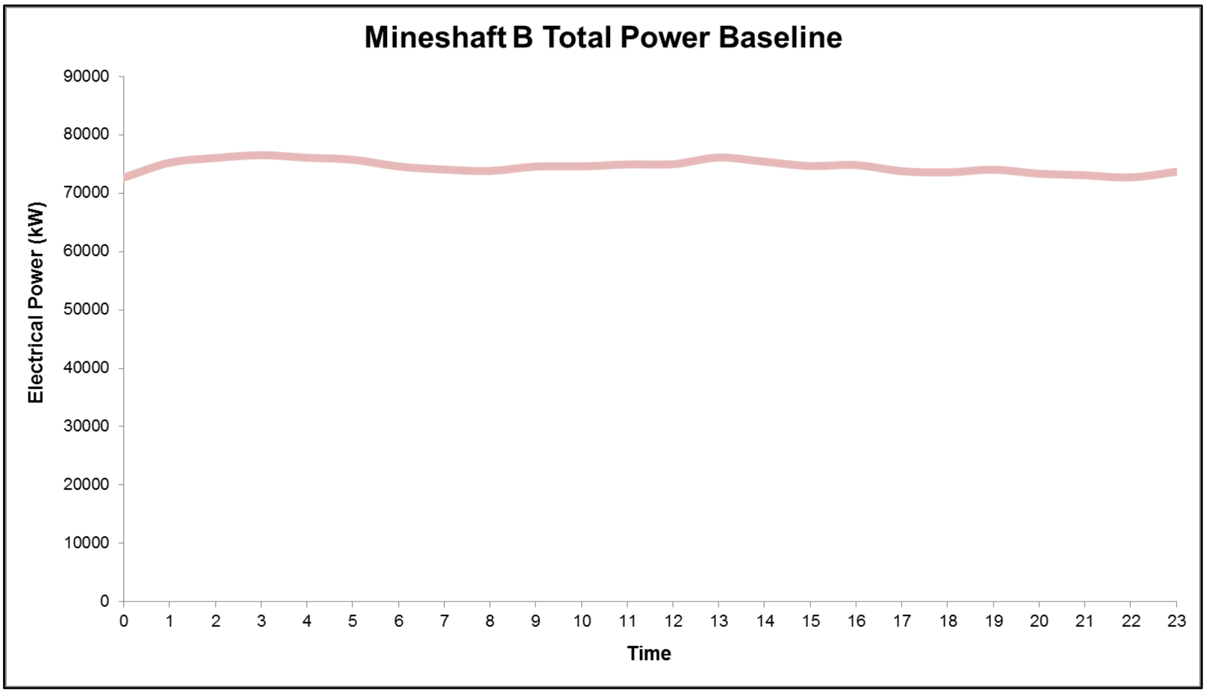

Figure 1: Mineshaft B electrical energy baseline for 2015

The baseline is used to indicate if electrical energy savings are present. Adjustments have been made whenever one or more of the following occurred:

1. The EnPIs no longer reflect the company's energy use and consumption.
2. Major changes to the process, operational patterns or energy systems have been made.

The baseline is kept up to date by ensuring that the relevant data is used for the energy baseline calculations. The last revision of the baseline was checked on [Date] by [Responsible person].

________________________ ________________________

[Responsible person] Date

[Job title]

GROUP A LOGO

APPOINTMENT OF ENERGY MANAGEMENT TEAM
MINESHAFT B

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Appointment as energy management team (EMT) of Mineshaft B

Dear all,

I am pleased to appoint you as our energy management team with effect from [Appointment Date].

This appointment is subject to the following terms and conditions:

1. EMT members act within the scope and boundaries as stipulated in the EnMS.
2. Major decisions involving numerous disciplines of the organisation will be presented for approval by the energy management representative. These include major financial decisions as stipulated in the EnMS under financial planning.
3. EMT members maintain a positive attitude towards continual energy improvements and continues to communicate and promote energy awareness and energy improvements throughout the company.

This document concludes that you have the authorisation to act within the scope and boundaries of the EnMS on behalf of the energy management representative.

Table 1: Energy management team members for Mineshaft B

EMT for Mineshaft B				
Name	**Area of representation**	**Responsibility**	**Signature**	**Date**
Team member 1	Area	Responsibility		
Team member 2	Area	Responsibility		
Team member 3	Area	Responsibility		
Team member 4	Area	Responsibility		
Team member 5	Area	Responsibility		

Yours sincerely

______________________ ______________________

[Responsible person] Date

[Job title]

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APPOINTMENT OF TOP MANAGEMENT REPRESENTATIVE MINESHAFT B

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Appointment as top management representative for Mineshaft B

Dear [Responsible person],

I am pleased to appoint you as our top management representative for Mineshaft B with effect from [Appointment Date].

Your responsibilities include:

1. ensuring an energy management representative is appointed;
2. ensuring the EnMS scope and boundaries are determined and documented;
3. assisting the energy management representative and the EMT with the review of documentation, periodical review meetings and assessment of EnPIs;
4. assisting the energy management representative with major decisions involving numerous disciplines of the organisation; and
5. maintaining a positive attitude towards continual energy improvement, communicate and promote energy awareness and energy improvements throughout the company.

This document concludes that you have the authorisation to act within the scope and boundaries of the EnMS. You are also granted permission to choose an energy management representative who will manage an inter-organisational energy management team. You have access to the necessary financial resources and allowed to outsource the necessary work within the boundaries and scope as documented in the EnMS.

Yours sincerely,

______________________ ______________________

[Responsible person] Date
[Job title]

I, [Responsible person], hereby accept the appointment as top management representative for Mineshaft B.

______________________ ______________________

[Responsible person] Date
[Job title]

GROUP A LOGO

APPOINTMENT OF ENERGY MANAGEMENT REPRESENTATIVE

MINESHAFT B

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Appointment as energy management representative for Mineshaft B

Dear [Responsible person],

Top management is pleased to appoint you as our energy management representative for Mineshaft B with effect from [Appointment Date].

This appointment is subject to the following terms and conditions:

1. The energy management representative acts within the scope and boundaries as stipulated by the EnMS.
2. Major decisions involving numerous disciplines of the organisation will be presented for approval at top management. This includes major financial decisions as stipulated in the EnMS under financial planning.
3. The energy management representative maintains a positive attitude towards continual energy improvements and continues to communicate and promote energy awareness on energy improvements throughout the company.

This document concludes that you have the authorisation to act within the scope and boundaries of the EnMS on behalf of top management. You are also granted permission to choose an energy management representative who will manage an inter-organisational energy management team. You have access to the necessary financial resources and allowed to outsource the necessary work within the boundaries and scope as documented in the EnMS.

The responsibilities of the energy management representative include the following:

1. establish the necessary documents to operate the EnMS;
2. define the necessary management documents and establish them as the author;
3. prepare the necessary records for EnMS performance evaluation;
4. appoint a company energy manager to work under the energy management team;
5. appoint persons as energy management team members, authorised by an appropriate level of management, to assist him/her with the implementation of various EnMS activities;
6. define and communicate responsibilities and authorities in the process of facilitating effective energy management;
7. manage the energy management team actions according to the EnMS action plan.

8. promote communication of the EnMS in order to promote a good working relationship among the people in the organisation;
9. identify the overall training needs associated with the control of significant energy users and the operation of the EnMS; and
10. plan and implement the necessary EnMS related education/training programs on behalf of the organisation.

Yours sincerely,

______________________ ______________________

[Responsible person] Date
[Job title]

I, [Responsible person], hereby accept the appointment as energy management representative for Mineshaft B.

______________________ ______________________

[Responsible person] Date
[Job title]

GROUP A LOGO

ENERGY POLICY
MINESHAFT B

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Energy policy for Mineshaft B

Mineshaft B is committed to sustainable growth based on our principles of:

1. integrity,
2. quality,
3. safety; and
4. social and environmental responsibilities.

This energy policy is set up to give a clear vision and direction to improve our use of energy. Our goal is to maintain high production levels while reducing energy use. In order to achieve our objectives and targets, the management of Mineshaft B operates under the EnMS. The EnMS is in compliance with the ISO 50001 energy management standard.

Our aim is to reduce energy consumption by 20% with reference to the 2014 baseline.

By operating the EnMS effectively, our objectives are:

1. provide adequate information and resources to achieve the targets;
2. provide information and training to employees to make them aware of the energy policy and enhance their skills regarding energy conservation;
3. understand the status of energy use and consumption to review the energy situation and identify new energy conservation opportunities;
4. conduct energy audits to verify the performance of the EnMS and pursue the continual improvement of energy performance, objectives and targets;
5. collaborate with suppliers to produce and deliver energy efficient products;
6. comply with legal requirements relevant to the company's energy use, consumption and efficiency; and
7. review and update the policy regularly.

Top management is ultimately accountable for the energy policy. Responsibilities for the implementation of this policy are delegated by top management to the energy management representative. All employees are responsible for understanding how this policy is applicable to their daily activities.

______________________ ______________________

[Responsible person] Date

[Job title]

GROUP A LOGO

COMPETENCE, TRAINING AND AWARENESS
MINESHAFT B

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Introduction

Areas were identified where the lack of training exist. This document will discuss the actions that will be taken to address these shortcomings.

Areas where training needs were identified

The EMT ensures that all persons working for or on behalf of the organisation regarding significant energy users has the appropriate education, training, skills and experience. It is the responsibility of the EMT to identify training needs associated with their section of responsibility regarding the implementation and operation of the energy management system. The following table shows areas where lack of training was identified:

Table 1: List of areas where lack of training exists

Description	Recommendation	EMT Member Name
Area	Recommendation	Team member name
Area	Recommendation	Team member name
Area	Recommendation	Team member name
Area	Recommendation	Team member name
Area	Recommendation	Team member name

EnMS training action plan

The areas where the lack of training exists have been identified. It is now necessary to evaluate these needs and draft an action plan to address the training situation. Each identified area where a lack of training exists has been discussed. The following action plans have been drafted to ensure that the area where inadequate training exists is addressed.

EnMS training action plan 1

Action plan: [Plan]
Responsible person: [Name]
Training outcome: [Outcome/Status]

EnMS training action plan 2

Action plan: [Plan]
Responsible person: [Name]
Training outcome: [Outcome/Status]

EnMS training action plan 3

Action plan: [Plan]

Responsible person:	[Name]
Training outcome:	[Outcome/Status]

EnMS training action plan 4

Action plan:	[Plan]
Responsible person:	[Name]
Training outcome:	[Outcome/Status]

EnMS training action plan 5

Action plan:	[Plan]
Responsible person:	[Name]
Training outcome:	[Outcome/Status]

Awareness

ISO 50001 requires that the EnMS must be improved continually. This is accomplished through the EMT ensuring that the persons working for or on the behalf of the organisation are aware and remain aware of the following:

Importance of conformity with the energy policy, procedures and requirements of the EnMS

This is done through:

1. Demonstrating the energy policy to all persons within the organisation through posters placed at strategic areas such as entrances to mineshafts and buildings.
2. Training sessions where the EMT and persons working for or on their behalf to understand the requirements of the energy policy.

Roles, responsibilities and authorities in achieving the requirements of the EnMS

The role, responsibilities and authorities have been declared in the authorisation and appointment letters of all of the applicable personnel.

Benefits of improved energy performance

This is done through:

1. The benefits of improved energy performance are demonstrated to all persons in the organisation through the comparison of the actual EnPI and baseline EnPI on a real-time basis on the organisation's intranet.

2. The benefit of improved energy performance is presented to the production and utility organisations of the company on a regular basis.
3. Automated meter reading systems.
4. Energy tariff analysis and cost allocation, management and reduction of energy- and utility costs efficiently.
5. Real-time and forecasted energy and utility data.
6. Monthly review meetings.
7. Daily reporting on energy projects.
8. Weekly consumption progressive reporting against budgets.

Impact and actions of employees

The actual or potential impact of the actions and behaviour of the persons working for or on behalf of the organisation – regarding the energy use and consumption, the achievement of the energy objectives and targets and the potential consequences of the departure from specialised procedures have been addressed. This has been done through the combination of training and good leadership. The energy management representative has announced all deviation, the effect of the deviations on the objectives and targets through the most adequate communication method determined at the time of communication.

APPENDIX D: SYSTEM BASELINES AND IMPROVED PROFILES

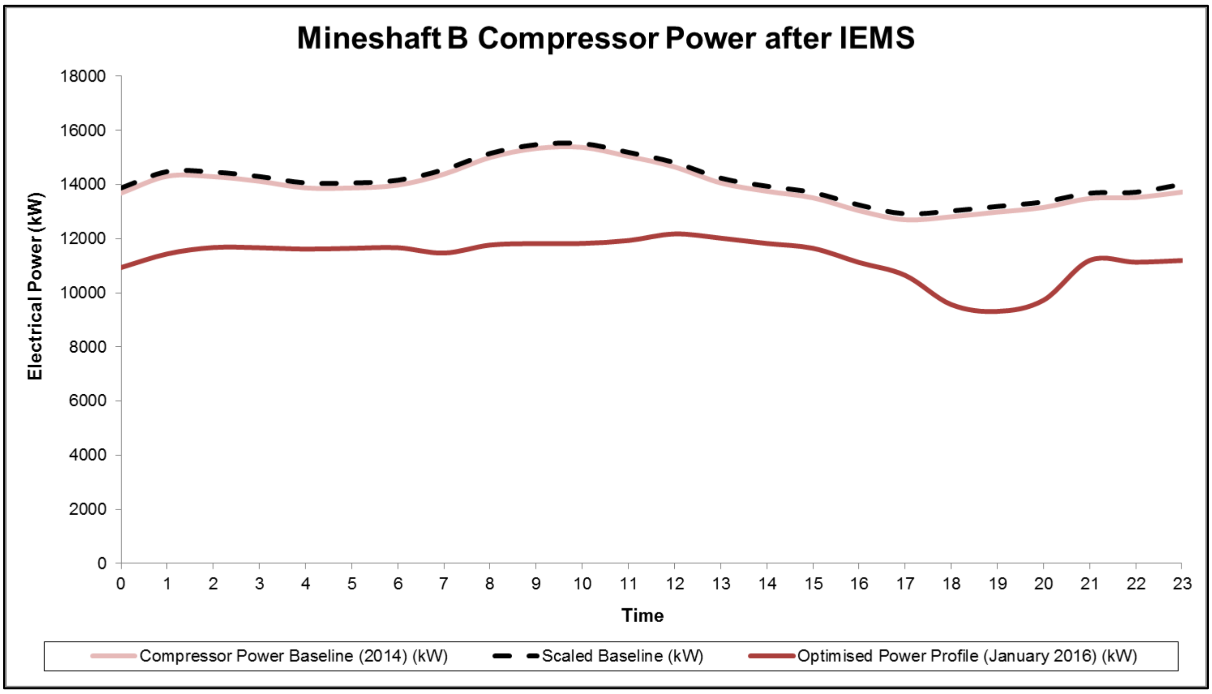


Figure 81: Compressor power baseline and improved profile after IEMS implementation

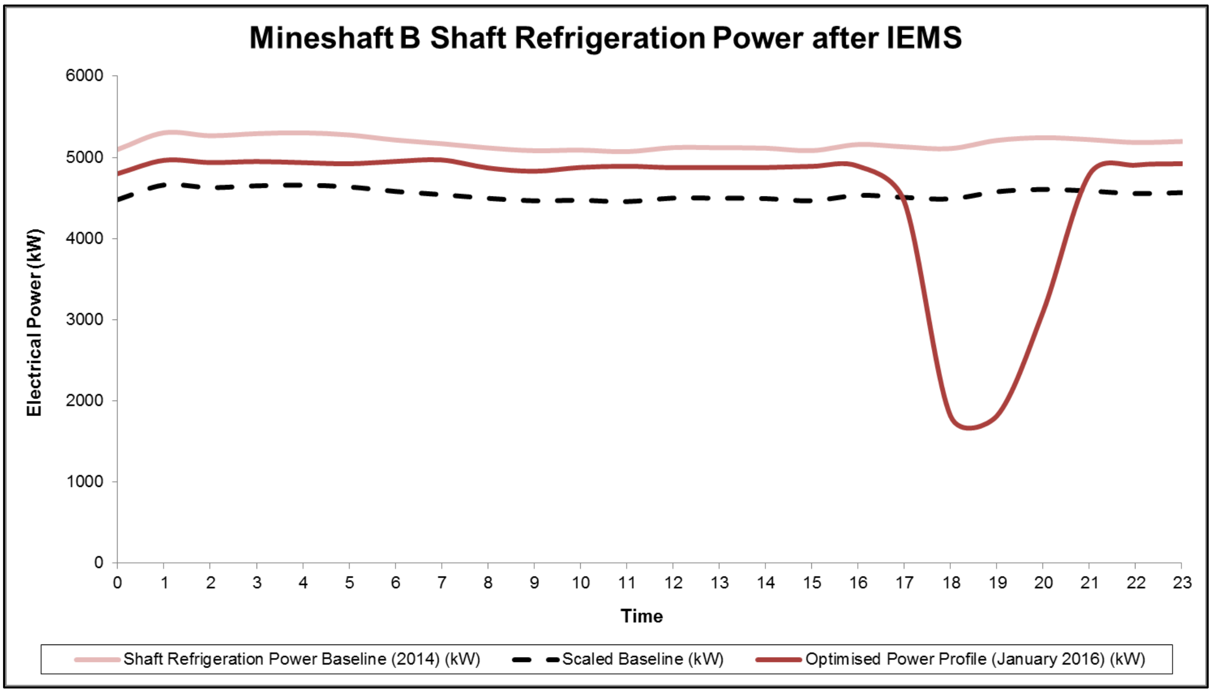


Figure 82: Shaft refrigeration power baseline and improved profile after IEMS implementation

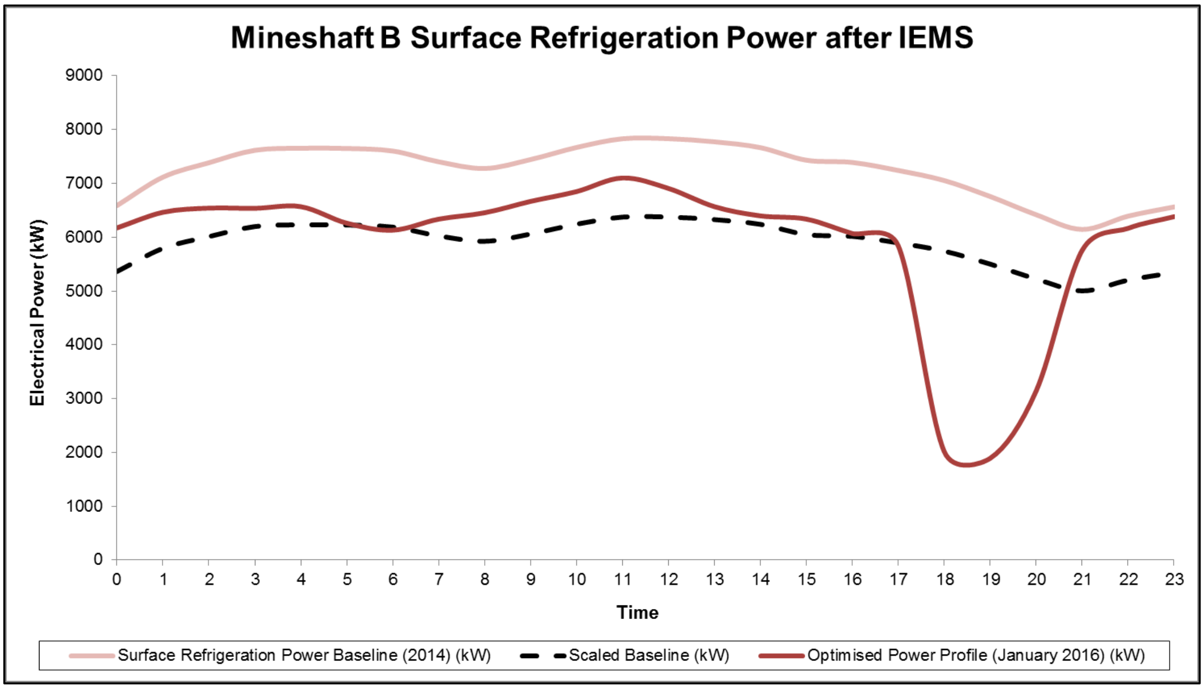


Figure 83: Surface refrigeration power baseline and improved profile after IEMS implementation

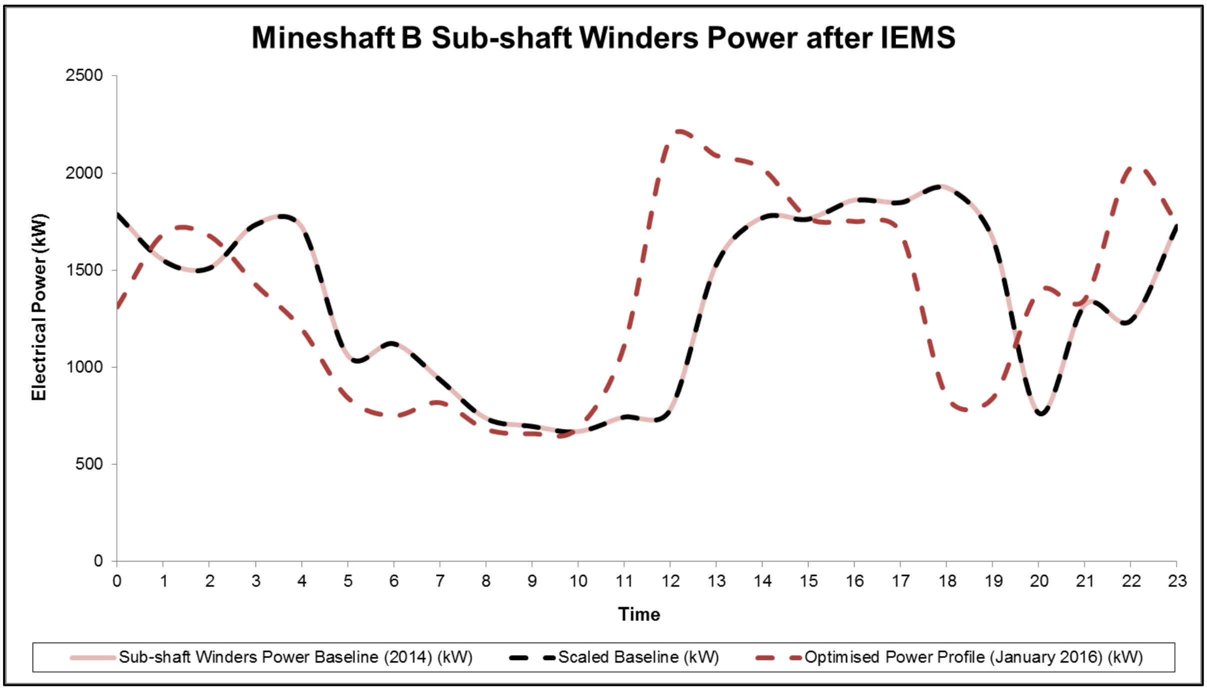


Figure 84: Sub-shaft winders power baseline and improved profile after IEMS implementation

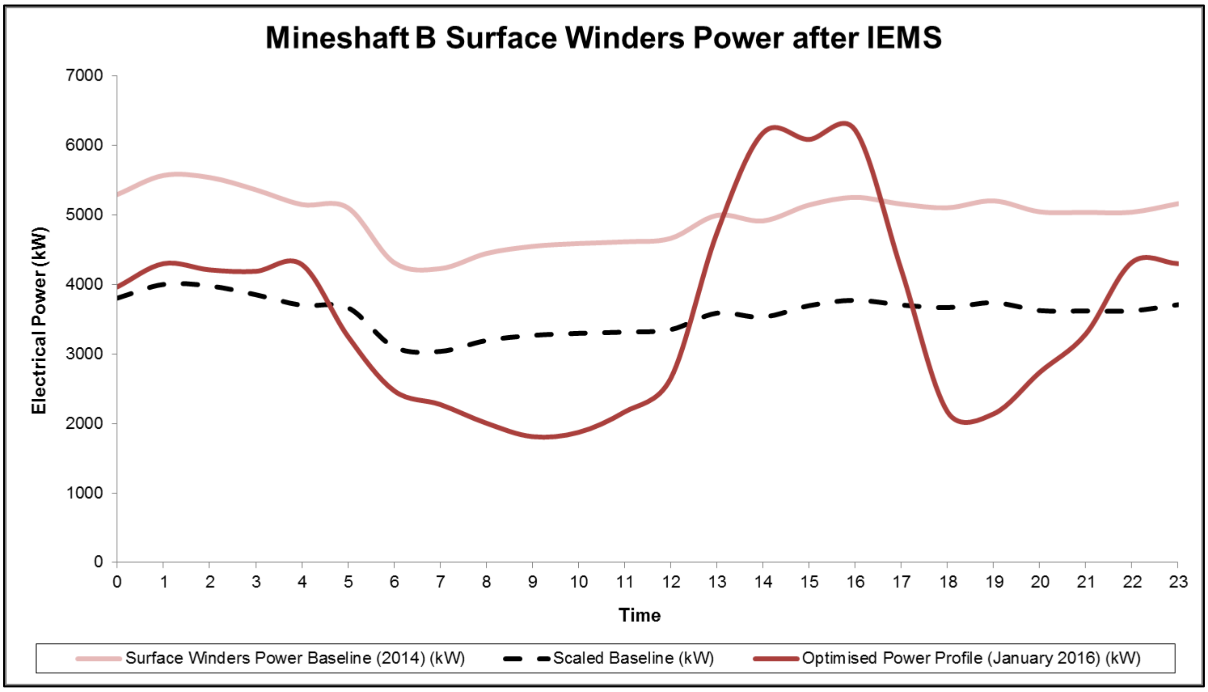


Figure 85: Surface winders power baseline and improved profile after IEMS implementation

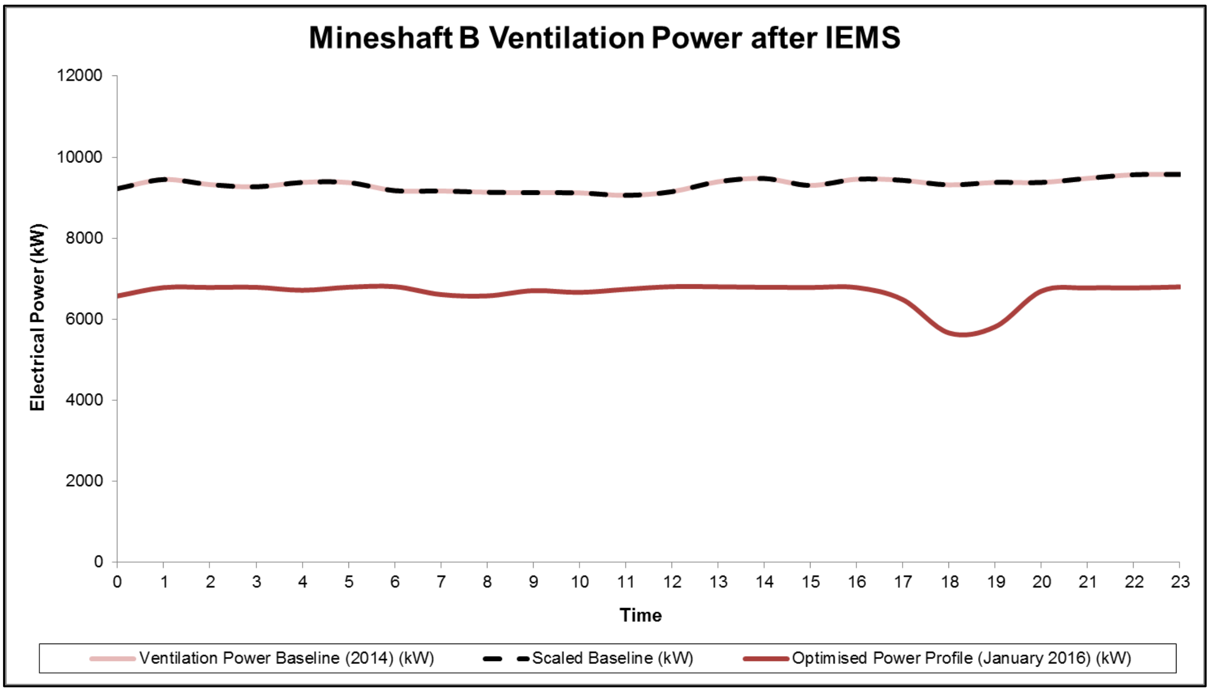


Figure 86: Ventilation power baseline and improved profile after IEMS implementation

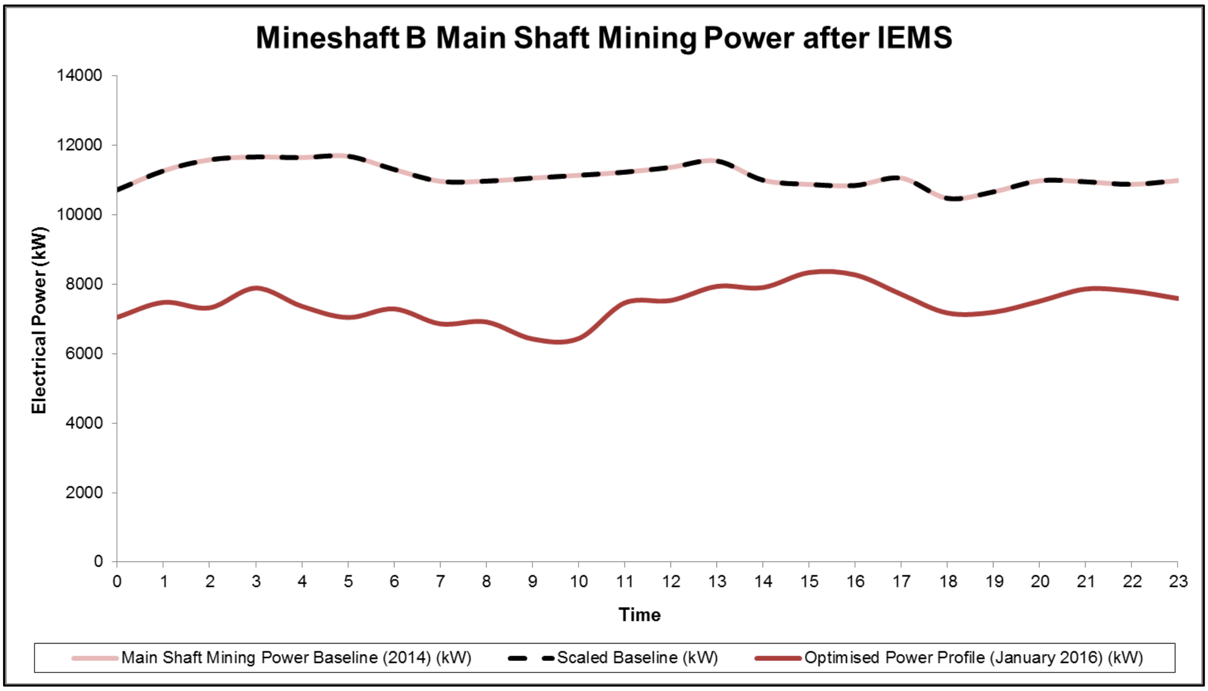


Figure 87: Main shaft mining power baseline and improved profile after IEMS implementation

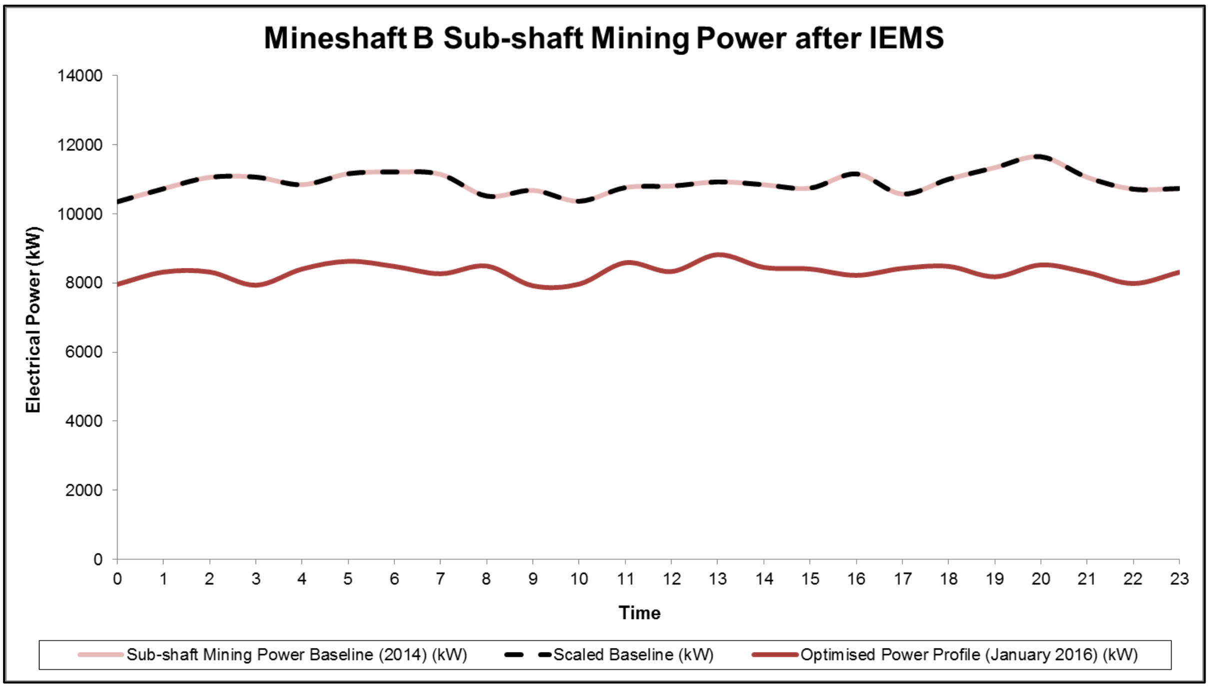


Figure 88: Sub-shaft mining power baseline and improved profile after IEMS implementation

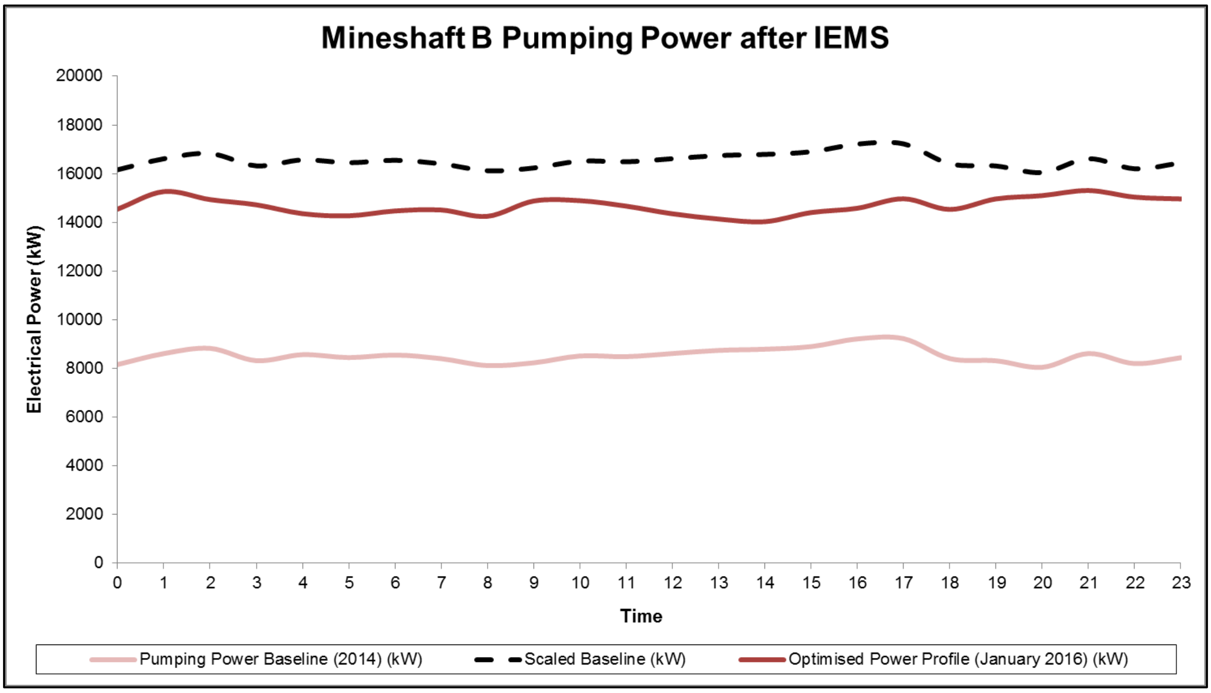


Figure 89: Pumping power baseline and improved profile after IEMS implementation

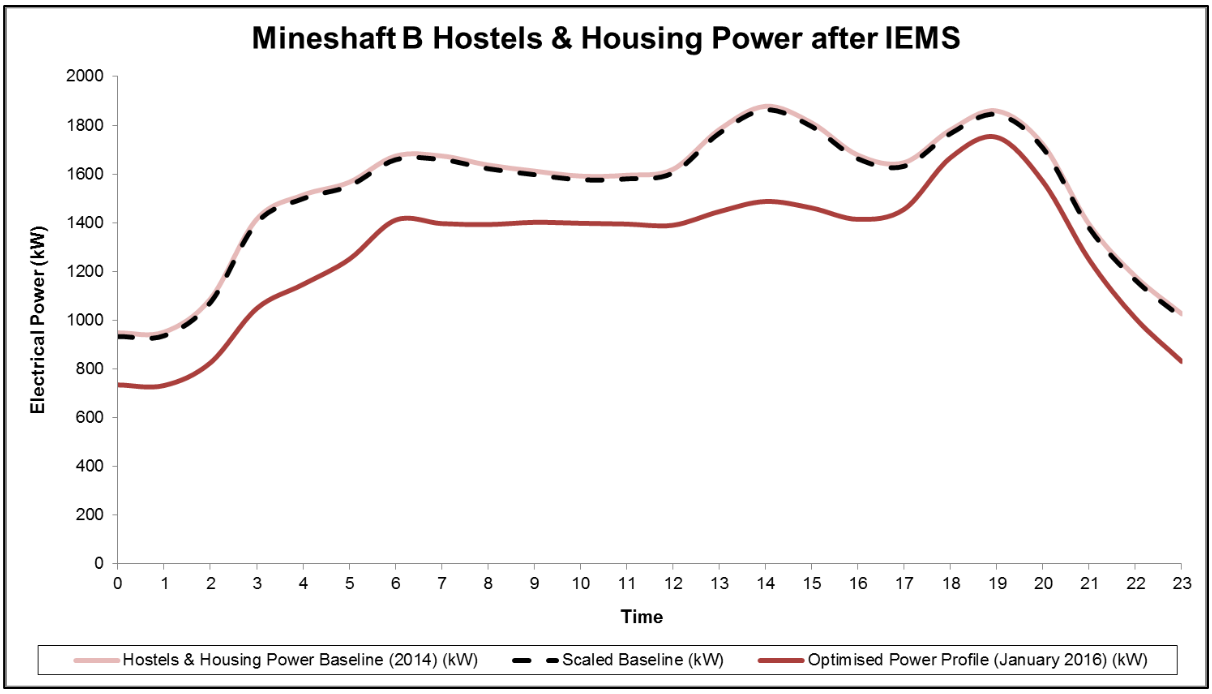


Figure 90: Hostels and housing power baseline and improved profile after IEMS implementation

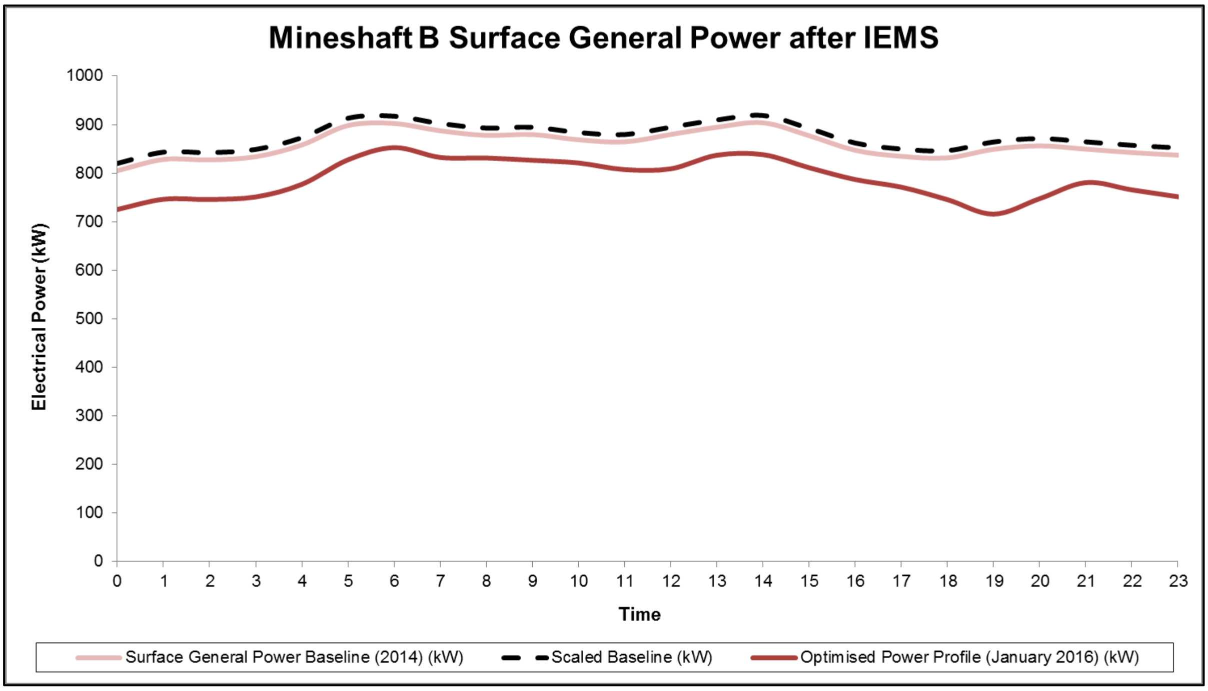


Figure 91: Surface general power baseline and improved profile after IEMS implementation

APPENDIX E: SYSTEM LAYOUT EXAMPLE

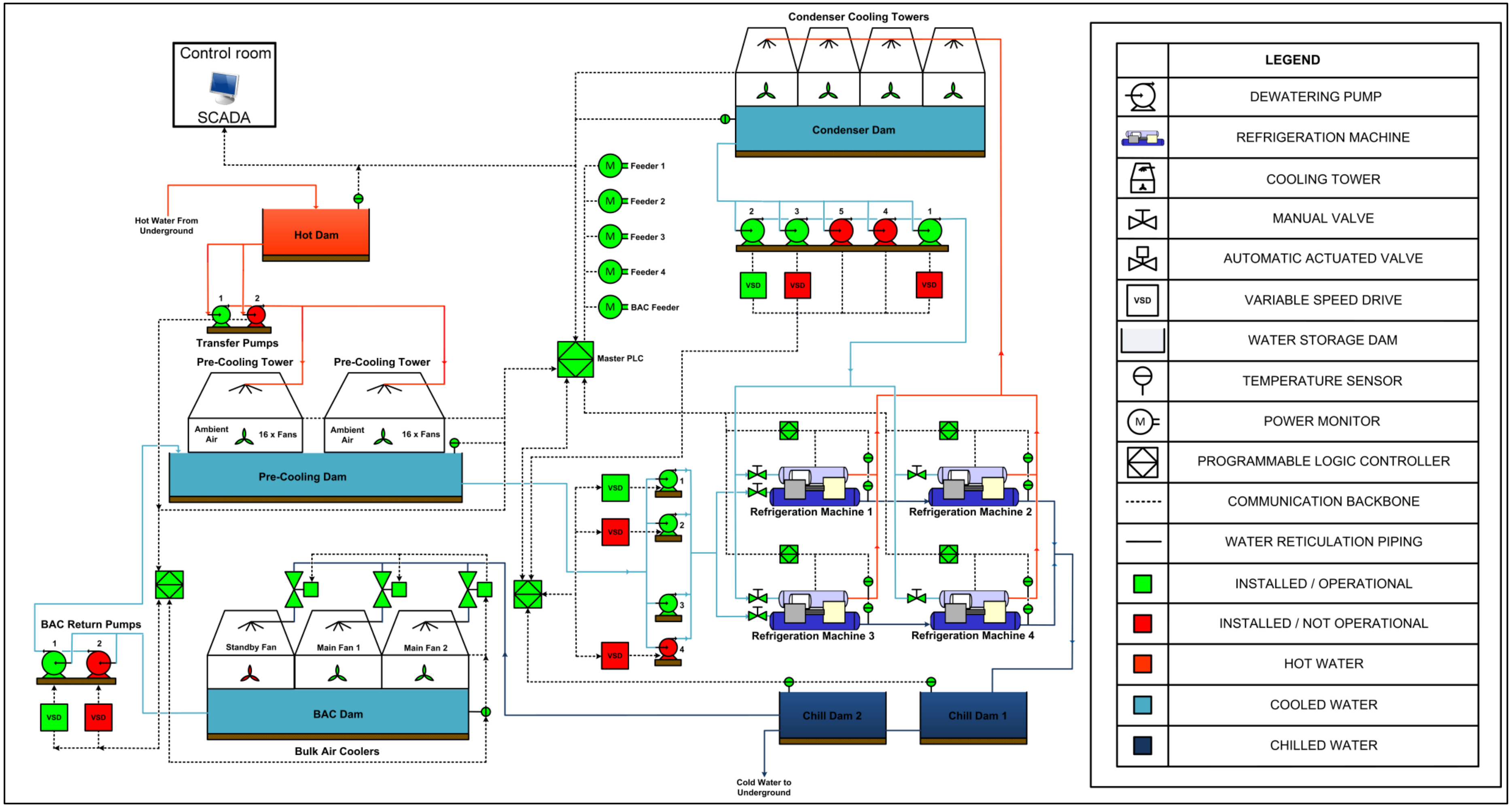


Figure 92: Example of a system layout for the surface refrigeration system of Mineshaft B

APPENDIX F: SYSTEM THEORETICAL MODEL EXAMPLE

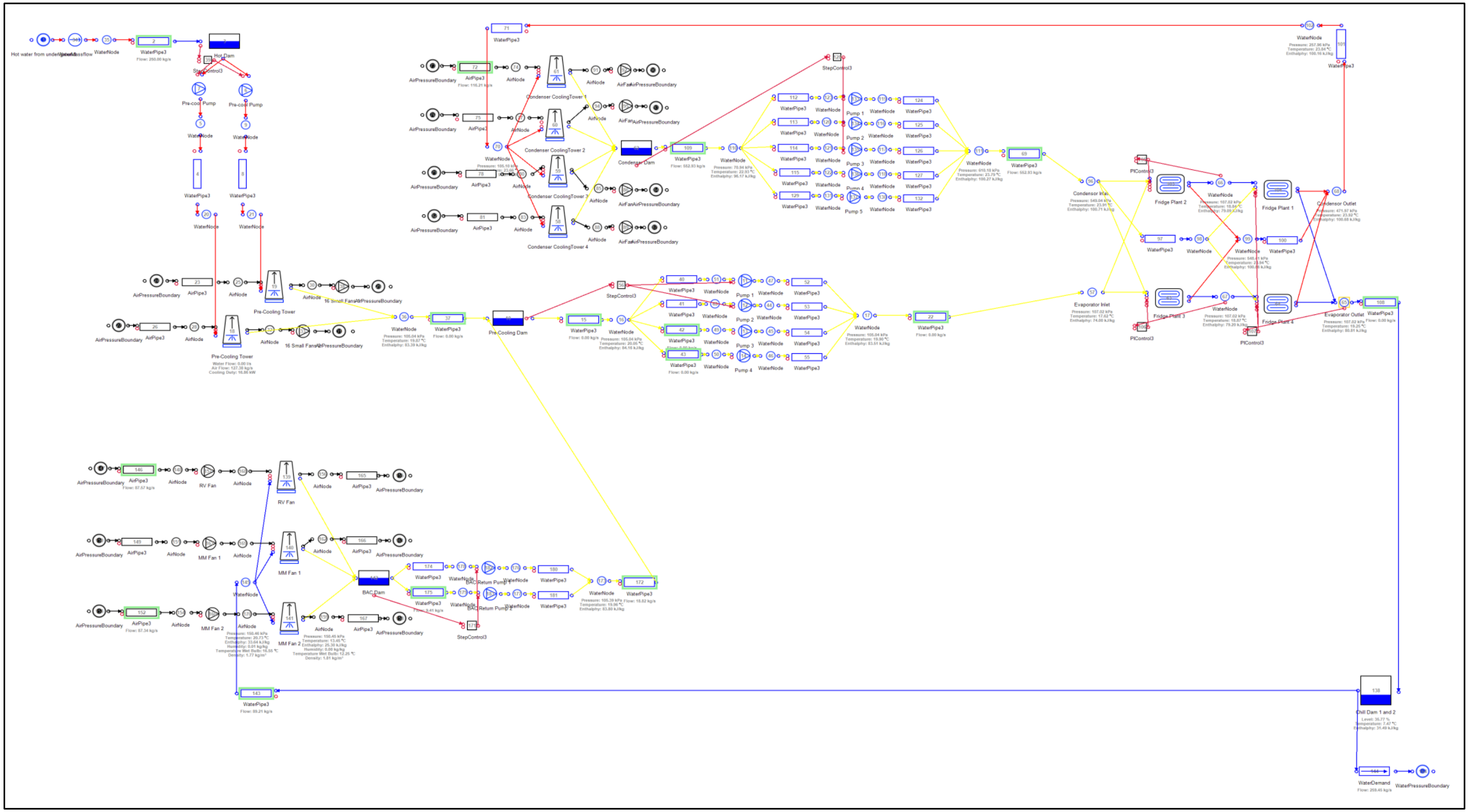
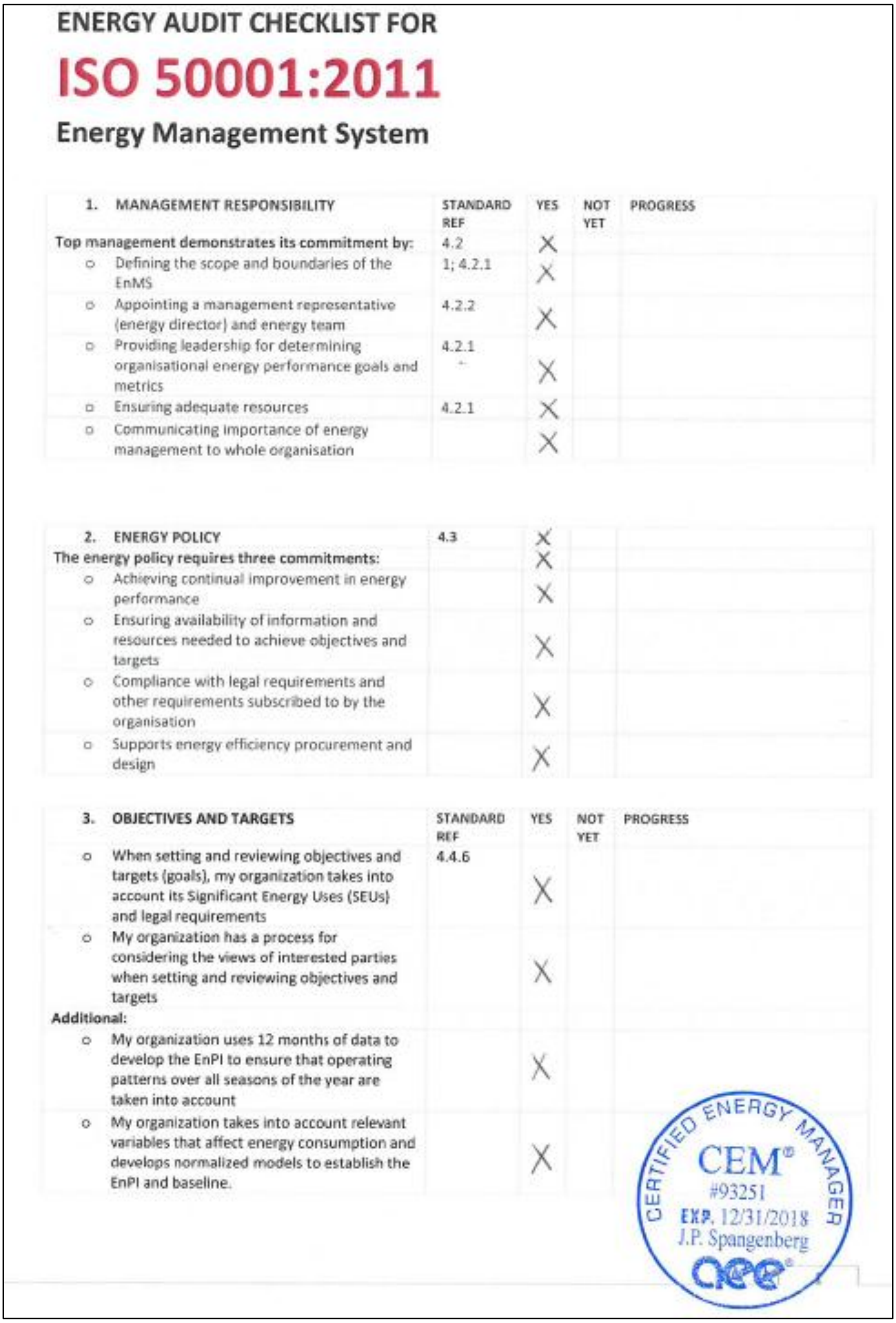


Figure 93: Example of a theoretical analysis for the refrigeration system of Mineshaft B

APPENDIX G: PRELIMINARY AUDIT FOR ISO 50001 CERTIFICATION



ENERGY AUDIT CHECKLIST FOR

ISO 50001:2011

Energy Management System

1. MANAGEMENT RESPONSIBILITY	STANDARD REF	YES	NOT YET	PROGRESS
Top management demonstrates its commitment by:	4.2	X		
○ Defining the scope and boundaries of the EnMS	1; 4.2.1	X		
○ Appointing a management representative (energy director) and energy team	4.2.2	X		
○ Providing leadership for determining organisational energy performance goals and metrics	4.2.1	X		
○ Ensuring adequate resources	4.2.1	X		
○ Communicating importance of energy management to whole organisation		X		

2. ENERGY POLICY	4.3	X		
The energy policy requires three commitments:		X		
○ Achieving continual improvement in energy performance		X		
○ Ensuring availability of information and resources needed to achieve objectives and targets		X		
○ Compliance with legal requirements and other requirements subscribed to by the organisation		X		
○ Supports energy efficiency procurement and design		X		

3. OBJECTIVES AND TARGETS	STANDARD REF	YES	NOT YET	PROGRESS
○ When setting and reviewing objectives and targets (goals), my organization takes into account its Significant Energy Uses (SEUs) and legal requirements	4.4.6	X		
○ My organization has a process for considering the views of interested parties when setting and reviewing objectives and targets		X		
Additional:				
○ My organization uses 12 months of data to develop the EnPI to ensure that operating patterns over all seasons of the year are taken into account		X		
○ My organization takes into account relevant variables that affect energy consumption and develops normalized models to establish the EnPI and baseline.		X		

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EXP. 12/31/2018
J.P. Spangenberg

4. LEGAL AND OTHER REQUIREMENTS	STANDARD REF	YES	NOT YET	PROGRESS
My organisation:	4.4.2	X		
○ Identifies and manages its energy related legal requirements		X		
○ Identifies and manages other energy related requirements to which it subscribes		X		
○ Has processes to evaluate compliance with legal and other energy-related requirements to which it subscribes		X		

5. ENERGY REVIEW: **5.i ANALYSING ENERGY CONSUMPTION**	4.4.3	X		
My organization has a documented process for energy planning including:		X		
○ Analysis of past and current energy consumption		X		
○ Identifying the significant energy uses (SEUs)		X		
○ Prioritizing opportunities for improvement		X		
○ Selecting EnPIs	4.4.5	X		
○ Establishing energy baselines	4.4.4	X		
○ Setting objectives and targets	4.4.6	X		
○ Developing energy action plans	**4.4.6**	X		

	STANDARD REF	YES	NOT YET	PROGRESS
5. ENERGY REVIEW: **5.ii DETERMINING SEU**	4.4.3		X	
My organisation has:				
○ Has a clearly defined and documented process for determining its SEUs based on consumption and/or opportunity for improvement		X		
○ Analyzes current performance of its SEUs;		X		
○ Estimates future energy use and energy consumption for its SEUs			X	Documented process required.

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5 **ENERGY REVIEW:** **5.iii IDENTIFYING OPPORTUNITIES**	**4.4.3**	X		
My organisation:				
○ Prioritizes its energy improvement opportunities		X		
○ Has a process to update its prioritised energy improvement opportunities		X		

6. ENERGY METRIX AND ESTABLISHING BASELINES AND ENPI	4.4.4	X		
My organisation has:				
○ Has determined conditions for adjusting energy baselines		X		
○ Has defined methods for determining and updating energy EnPIs		X		

7. ENERGY ACTION PLANS	4.4.6	X		
○ Are designed to achieve the objectives and targets		X		
○ State how energy performance improvements will be verified		X		
In addition, for each action plan, my organization:				
○ Estimates expected energy savings,		X		
○ Implements action plans that achieve our EnPIs		X		
○ Verifies the actual energy savings achieved, and		X		
○ Tracks the energy performance improvements in our action plans to check the energy performance improvement. This bottom-up sanity check confirms the energy performance improvement could reasonably have resulted from the action plans.		X		

8. OPERATIONAL CONTROLS	4.5.5.	X		
○ Has operation and maintenance controls in place for all identified SEUs	4.5.5	X		
○ Has processes in place to communicate relevant operational and maintenance controls to on-site contractors		X		

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9. DESIGN	4.5.6	X		
○ My organization considers energy performance improvement in its design processes for new, modified and renovated facilities, equipment, systems and processes		X		

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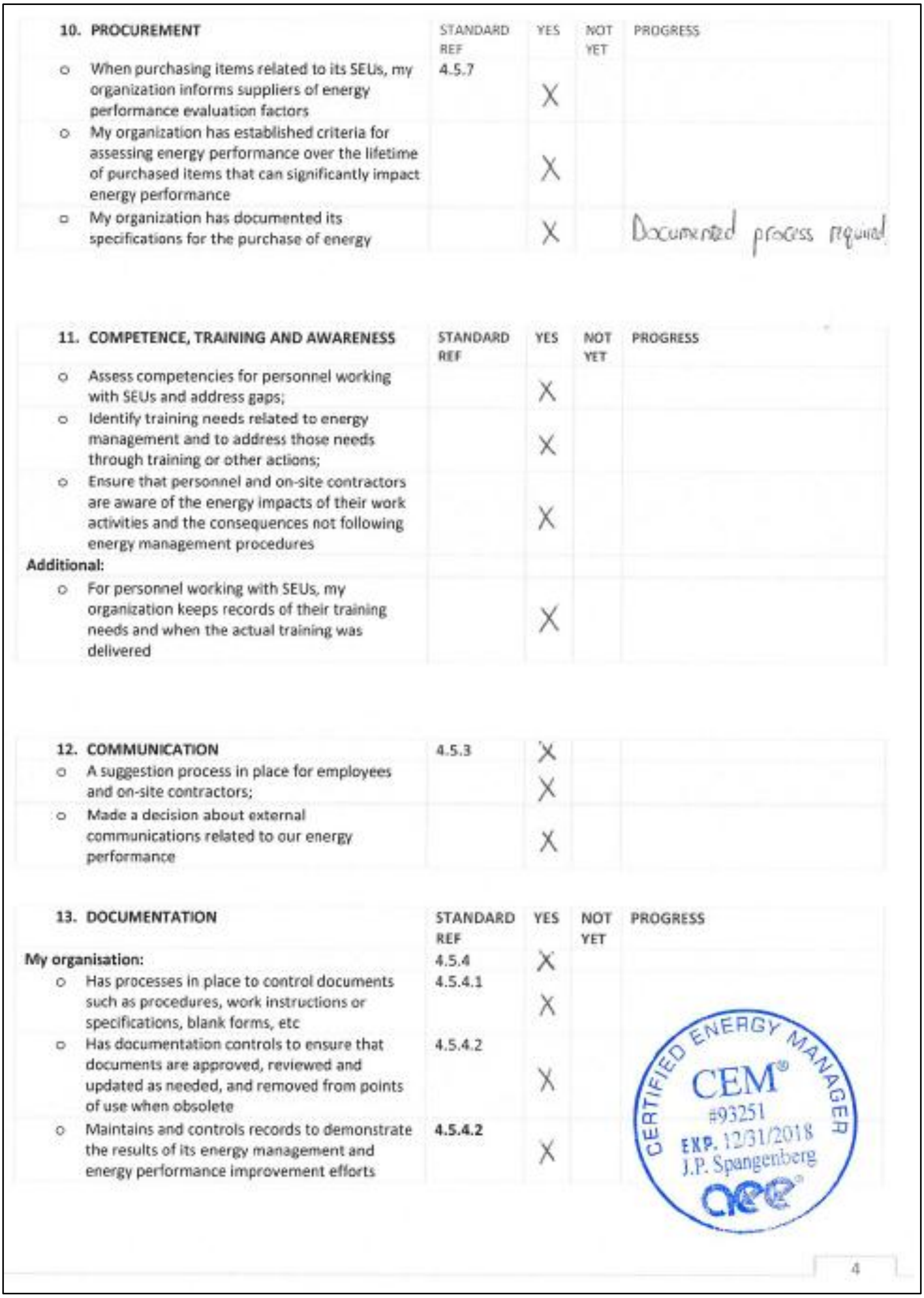

10. PROCUREMENT	STANDARD REF	YES	NOT YET	PROGRESS
○ When purchasing items related to its SEUs, my organization informs suppliers of energy performance evaluation factors	4.5.7	X		
○ My organization has established criteria for assessing energy performance over the lifetime of purchased items that can significantly impact energy performance		X		
○ My organization has documented its specifications for the purchase of energy		X		Documented process required

11. COMPETENCE, TRAINING AND AWARENESS	STANDARD REF	YES	NOT YET	PROGRESS
○ Assess competencies for personnel working with SEUs and address gaps;		X		
○ Identify training needs related to energy management and to address those needs through training or other actions;		X		
○ Ensure that personnel and on-site contractors are aware of the energy impacts of their work activities and the consequences not following energy management procedures		X		
Additional:				
○ For personnel working with SEUs, my organization keeps records of their training needs and when the actual training was delivered		X		

12. COMMUNICATION	4.5.3	X		
○ A suggestion process in place for employees and on-site contractors;		X		
○ Made a decision about external communications related to our energy performance		X		

13. DOCUMENTATION	STANDARD REF	YES	NOT YET	PROGRESS
My organisation:	4.5.4	X		
○ Has processes in place to control documents such as procedures, work instructions or specifications, blank forms, etc	4.5.4.1	X		
○ Has documentation controls to ensure that documents are approved, reviewed and updated as needed, and removed from points of use when obsolete	4.5.4.2	X		
○ Maintains and controls records to demonstrate the results of its energy management and energy performance improvement efforts	**4.5.4.2**	X		

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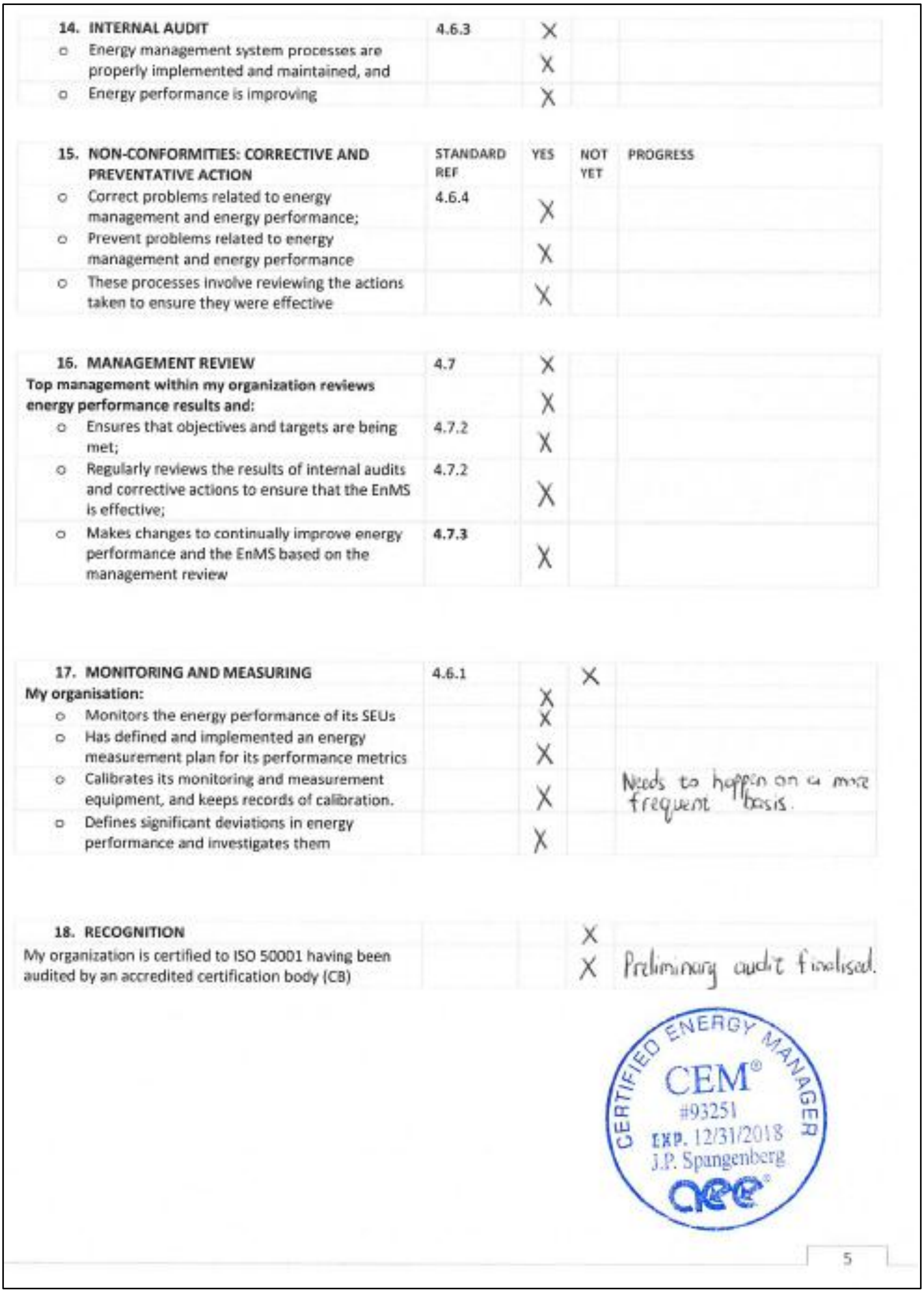

14. INTERNAL AUDIT	4.6.3	X		
○ Energy management system processes are properly implemented and maintained, and		X		
○ Energy performance is improving		X		

15. NON-CONFORMITIES: CORRECTIVE AND PREVENTATIVE ACTION	STANDARD REF	YES	NOT YET	PROGRESS
○ Correct problems related to energy management and energy performance;	4.6.4	X		
○ Prevent problems related to energy management and energy performance		X		
○ These processes involve reviewing the actions taken to ensure they were effective		X		

16. MANAGEMENT REVIEW	4.7	X		
Top management within my organization reviews energy performance results and:		X		
○ Ensures that objectives and targets are being met;	4.7.2	X		
○ Regularly reviews the results of internal audits and corrective actions to ensure that the EnMS is effective;	4.7.2	X		
○ Makes changes to continually improve energy performance and the EnMS based on the management review	**4.7.3**	X		

17. MONITORING AND MEASURING	4.6.1		X	
My organisation:		X		
○ Monitors the energy performance of its SEUs		X		
○ Has defined and implemented an energy measurement plan for its performance metrics		X		
○ Calibrates its monitoring and measurement equipment, and keeps records of calibration.		X		Needs to happen on a more frequent basis.
○ Defines significant deviations in energy performance and investigates them		X		

18. RECOGNITION			X	
My organization is certified to ISO 50001 having been audited by an accredited certification body (CB)			X	Preliminary audit finalised.

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