Strategies to revive DSM mine pumping projects under the new ESCo model

M van der Merwe

22692487

Dissertation submitted in fulfilment of the requirements for the degree *Master of Engineering* in Mechanical Engineering at the Potchefstroom Campus of the North-West University

Supervisor: Dr JH Marais

May 2017

NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT

Abstract

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Author: M van der Merwe

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Keywords: Energy services company; ESCo; Demand Side Management; load shifting; mine pumping systems; sustainability period; sustainable project strategy; electricity cost saving; Eskom demand TOU period

South Africa has a highly energy intensive economy dependent on a generation fleet of mostly ageing coal-fired power stations struggling to keep up with demand. The mining industry, and specifically mine pumping systems, is one of the major contributors to this energy intensive economy. The mining industry was responsible for approximately 14.3% of Eskom's total electricity sales for the 2015/16 financial year. Pumping systems, meanwhile, are responsible for nearly 14% of the total electricity consumed on a mine.

In an effort to alter the consumer demand profile, Eskom introduced the Demand Side Management (DSM) programme in 2004. One of the initiatives forthcoming from the DSM programme is the energy service company (ESCo) model. The ESCo model entails Eskom contracting ESCos to implement DSM projects with the aim of reducing the electricity consumption or electricity cost of client systems. One such system commonly targeted for DSM projects under the ESCo model is mine pumping systems.

Unfortunately, DSM mine pumping projects tended to deteriorate as a result of inadequate maintenance. A contributing factor was that the initial ESCo model only obligated ESCos to sustain projects for three months. Mine personnel were not equipped to sustain the projects thereafter; resultantly, the performance of a large number of the projects deteriorated. There is therefore an opportunity to revive these projects to achieve electricity cost savings.

In 2015, Eskom introduced fundamental changes to the ESCo model. This included a mandatory three-year sustainability period for all DSM projects that ESCos now have to complete. The funding available to ESCos has also been reduced. The focus of this study was

thus to develop a sustainable project strategy to assist ESCos in reviving DSM mine pumping projects under the new ESCo model.

This study was verified and validated by implementing the sustainable project strategy on two case studies within the same mining company. The implementation of the sustainable project strategy proved to deliver positive results over a three-month period. Case Study A achieved a R785 000 electricity cost saving, and Case Study B achieved a R2.53-million electricity cost saving during this three-month period. If the performance of these two cases studies are extrapolated to a year, this would result in an electricity cost saving of R9.9-million for the mine.

Acknowledgements

I would like to take this opportunity to thank the following people and institutions who contributed to the success of this study:

- Annerike Streicher for her support, understanding and patience during the many late nights completing this dissertation.
- My parents, Klaas and Madelaine van der Merwe, for their support while I was completing this study.
- TEMM International (Pty) Ltd for providing the funding required.
- Prof. Eddie Mathews and Prof. Marius Kleingeld for providing me with the opportunity to complete this study.
- Dr Johan Marais for providing valuable insights in completing this study.
- Dr Handré Groenewald for the many hours proofreading this study.
- Dr Willem Schoeman for the insight provided to successfully complete the case studies used in this study.
- My colleagues – Stephan Taljaard, Brandon Friedenstein and Faiyaaz Khan – for assisting me with implementing the case studies used in this study.
- All of the mine personnel who assisted in gathering data or implementing the case studies of this study.
- Lastly, I would like to thank our Heavenly Father for providing me with the ability and opportunities to be able to complete this study.

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Nomenclature

Units of measure

Symbol	Description
c	Cent
GWh	Gigawatt-hour
h	Hour
km	Kilometre
kPa	Kilopascal
kV	Kilovolt
kW	Kilowatt
kWh	Kilowatt-hour
ℓ	Litre
Mℓ	Megalitre
MW	Megawatt
m	Metre
R	Rand
s	Second
V	Volt
W	Watt
°C	Degree Celsius
$	United States dollar

List of symbols

Symbol	**Description**	**Unit of measure**
ADC	Average daily energy consumption	kW
APC	Average peak hour energy consumption	kW
CS	Contracted savings target	W
ECP	Total energy consumption of post-implementation day	kWh
ECB	Total energy consumption of baseline	kWh
MPA	Maximum payment amount available for PA period	R
N	Number of values in data set	–
PTA	Peak-to-average ratio	–
r	Pearson’s correlation coefficient	–
RPA	Reduced payment amount for PA period	R
SA	Savings achieved in PA period	W
SLAF	Service level adjustment factor	–
x	Data Set 1 value	kW
y	Data Set 2 value	kW
$\sum$	The sum of the values in the data set	kW

Abbreviations

Symbol	**Description**
3-CPFS	3-Chamber Pipe Feeder System
BAC	Bulk Air Cooler
DE	Drive End
DSM	Demand Side Management
ESCo	Energy Service Company
IDM	Integrated Demand Management
M&V	Measurement and Verification
NDE	Non-drive End
OCGT	Open Cycle Gas Turbine
OECD	Organisation for Economic Co-operation and Development
PA	Performance Assessment
PEC	Project Evaluation Committee
PLC	Programmable Logic Controller
PT	Performance Tracking
SCADA	Supervisory Control and Data Acquisition
SD&L	Supplier Development and Localisation
TEC	Technical Evaluation Committee
TOU	Time-of-use
VAT	Value Added Tax

CHAPTER 1: INTRODUCTION

[1, 2]

"*If we want to reduce poverty and misery, if we want to give to every deserving individual what is needed for a safe existence of an intelligent being, we want to provide more machinery, more power. Power is our mainstay, the primary source of our many-sided energies*." – Nikola Tesla

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[1] Images from electronic sources and personal photographs will be referenced as footnotes.

[2] Union of Concerned Scientists, "How the electricity grid works," 2015. [Online]. Available: http://www.ucsusa.org/clean-energy/how-electricity-grid-works#.V_OUcslvBDE. [Accessed: 04-Oct-2016].

1.1. Electricity in South Africa

1.1.1. Introduction

South Africa, the largest economy [1], and electricity exporter in Africa [2], is confronted with major electricity obstacles. Unplanned outages of the electricity generation fleet, electricity supply shortages and inadequate electricity access for low-income households have placed the economy under strain [3]. Expanding the generation fleet is costly and time-consuming [4].

It is projected that Africa's population will reach 1.9-billion by 2050; an increase of 42% from 2015 [3]. This means that stable and secure electricity access will continue to be of critical importance. Figure 1 depicts the results of a study by Lemma *et al.* [5] that investigated the constraints faced by African businesses. Electricity is the number one constraint.

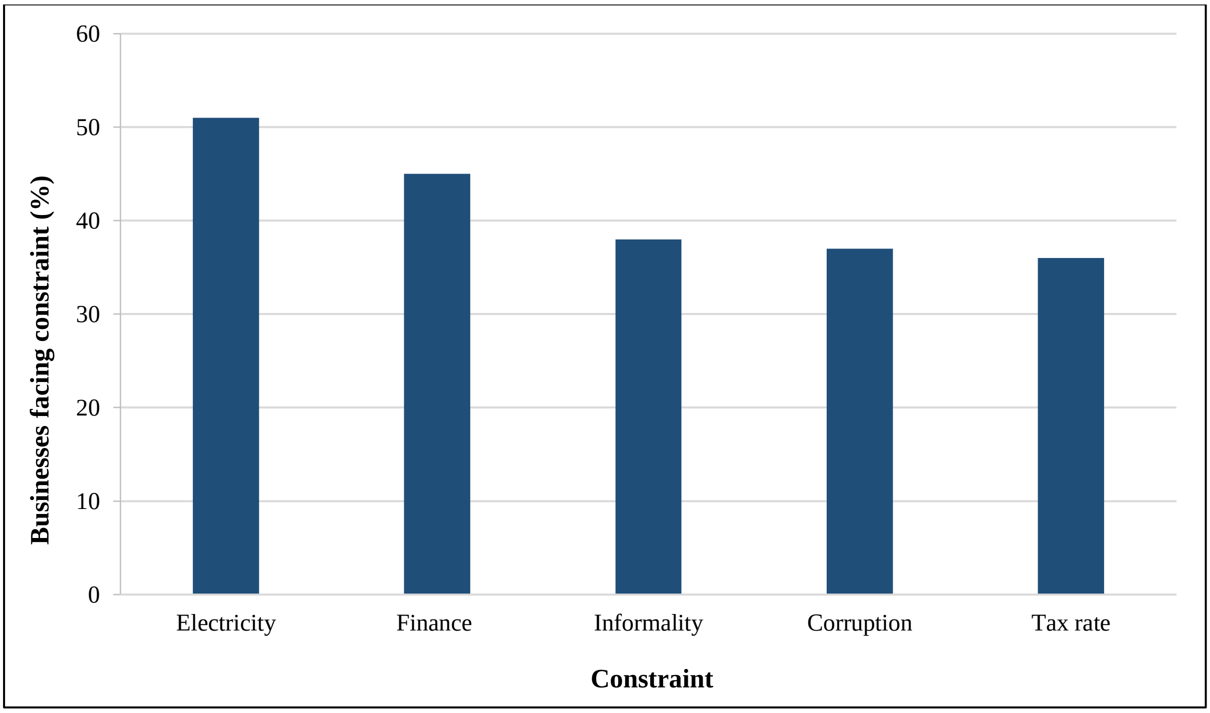

Figure 1: Constraints faced by African businesses (adapted from [5])

Historically, South Africa benefitted from low electricity tariffs that increased at a stable rate. This led to a lack of public awareness regarding the hazards of excessive electricity consumption and lack of appropriate energy management policies. The result is that South Africa developed a highly energy intensive economy [6]. A study performed by Inglesi-Lotz and Blignaut [7] found that South Africa's energy intensity is nearly double the average of member countries of the Organisation for Economic Co-operation and Development (OECD).

Energy intensity is defined as energy consumption measured against an output [7]. In the case of Inglesi-Lotz and Blignaut [7], this output measure is defined as United States dollar of gross domestic product. In 2007, South Africa's energy intensity was 0.713 GWh/$ million, while the average for OECD member countries was 0.329 GWh/$ million [7]. South Africa's economy is therefore easily affected by high electricity price increases [8].

Internationally, energy efficiency has become a major focus point in the quest for sustainable economic development. Energy efficiency is seen as a cost effective method for simultaneously reducing energy consumption and greenhouse gas emissions [6]. Improving energy efficiency will reduce the risk of electricity supply shortages. This in turn will discourage businesses from reducing production or shutting down expansion, thus preventing the negative impact this would have on the economy and employment opportunities [9].

1.1.2. Electricity supply in South Africa

The South African electricity generation network is monopolised by Eskom, a state-owned enterprise. Eskom accounts for 95% of the total electricity generated. This 95% is mostly obtained from traditional coal-fired power stations [10]. Figure 2 depicts the different electricity generation methods used by Eskom for the 2015/16 financial year [11].

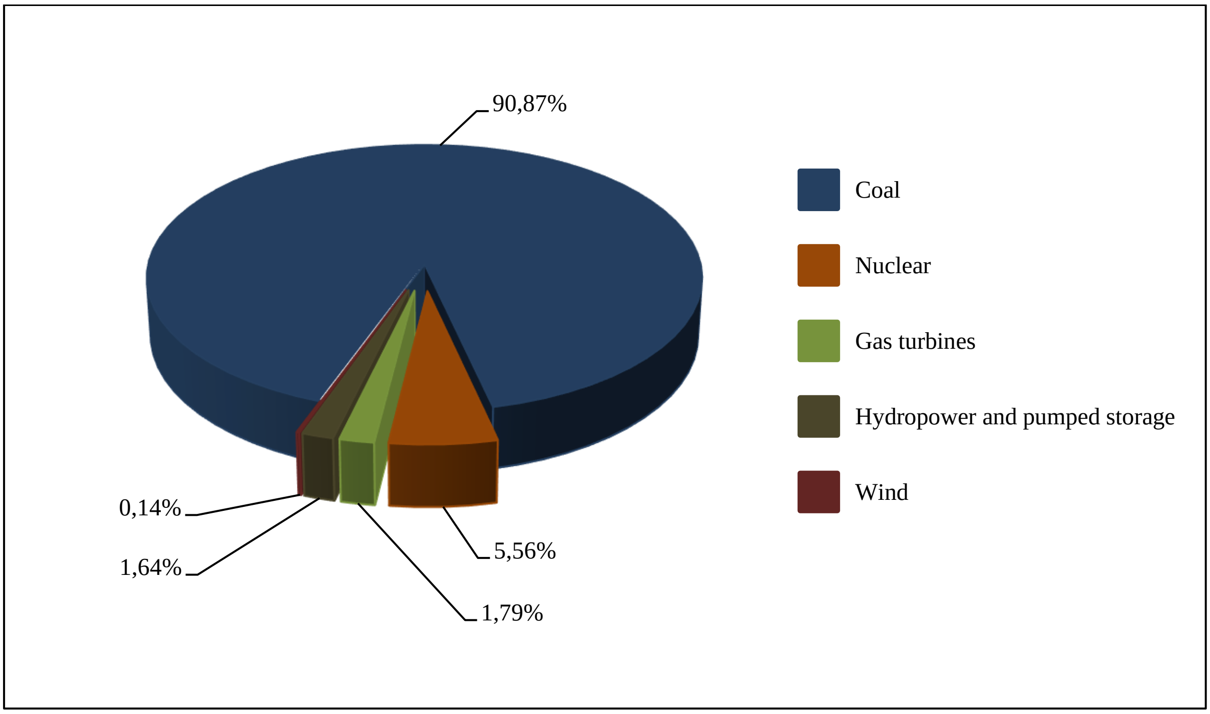

Figure 2: Eskom electricity generation methods (adapted from [11])

Eskom's generation fleet is under pressure to produce enough electricity to satisfy demand. Unplanned maintenance increased from 12.61% for the 2013/14 financial year to 15.22% for the 2014/15 financial year [10]. The generation fleet availability decreased from 85% in 2010 to 73% in 2015 [12]. This indicates the deteriorating condition of the ageing generation fleet.

The international standard for an adequate reserve margin, which is the difference between total electricity supply and demand, is 15% [13]. Between 1979 and 1992, South Africa's generation network increased faster than the demand, resulting in the reserve margin increasing [14]. In 1994, South Africa had a healthy reserve margin of 31% [13]. By 2007, this had decreased to 7% [13]. This reduction in the reserve margin was caused by two factors. Firstly, the electricity demand increased by approximately 50% between 1994 and 2005 [13]. Secondly, no new generation expansion projects were announced between 1983 and 2003 [13].

South Africa experienced systematic load-shedding, otherwise known as blackouts, in 2008 [13]. These blackouts lasted approximately four months, from January until April 2008, and were caused by an electricity supply shortage [2]. The National Energy Regulator of South Africa estimated that this resulted in a R50-billion loss to the economy [15]. Industries directly supplied by Eskom were most affected – specifically mines and smelters [9].

After the last blackout in April 2008, South Africa benefitted from approximately six load-shedding free years. Eskom re-implemented load-shedding on 6 March 2014 [13]. In an effort to prevent load-shedding, Eskom regularly runs open cycle gas turbines (OCGTs) at an estimated cost of R2-billion per month [2]. This expense is defended by Eskom, who in turns estimates that if the OCGTs did not run and load shedding had to be implemented, the cost to the economy would be up to R80-billion a month [16].

In December 2014, the South African government formed the Energy War Room in an effort to curtail the energy crisis. The Energy War Room received the task of implementing cabinet's 5-Point Energy Plan. This 5-Point Energy Plan can be summarised as follows [3]:

1. Ensure the financial and operational stability of Eskom in the short term.
2. Introduce coal independent power producers.
3. Establish co-generation contracts with the private sector.
4. Introduce gas-fired electricity generation technology.
5. Fast-track DSM.

1.1.3. Electricity demand in the South African mining industry

The study by Inglesi-Lotz and Blignaut [7], mentioned in Section 1.1.1, compares the energy intensity per sector in South Africa. Table 1 shows the results of this comparison. The study found that the South African mining industry has an energy intensity of 0.634 GWh/$ million. This is significantly higher than the OECD average of 0.026 GWh/$ million [7].

Table 1: Energy intensity per sector (adapted from [7])

Sector	Energy intensity GWh/$ million	Ranking
Basic metals	1.095	1
Mining and quarrying	0.634	2
Non-metallic minerals	0.524	3
Agriculture and forestry	0.316	4
Paper, pulp and printing	0.207	5
Chemical and petrochemical	0.203	6
Transport	0.089	7
Wood and wood products	0.069	8
Textile and leather	0.067	9
Food and tobacco	0.021	10
Machinery and equipment	0.005	11
Transport equipment	0.003	12
Construction	0.002	13

Figure 3 outlines Eskom’s electricity sales as published in Eskom’s Annual Integrated Report for the 2015/16 financial year. As can be seen from the graph, mining is the third-largest electricity user in South Africa, accounting for 14.3% of all electricity sales [10].

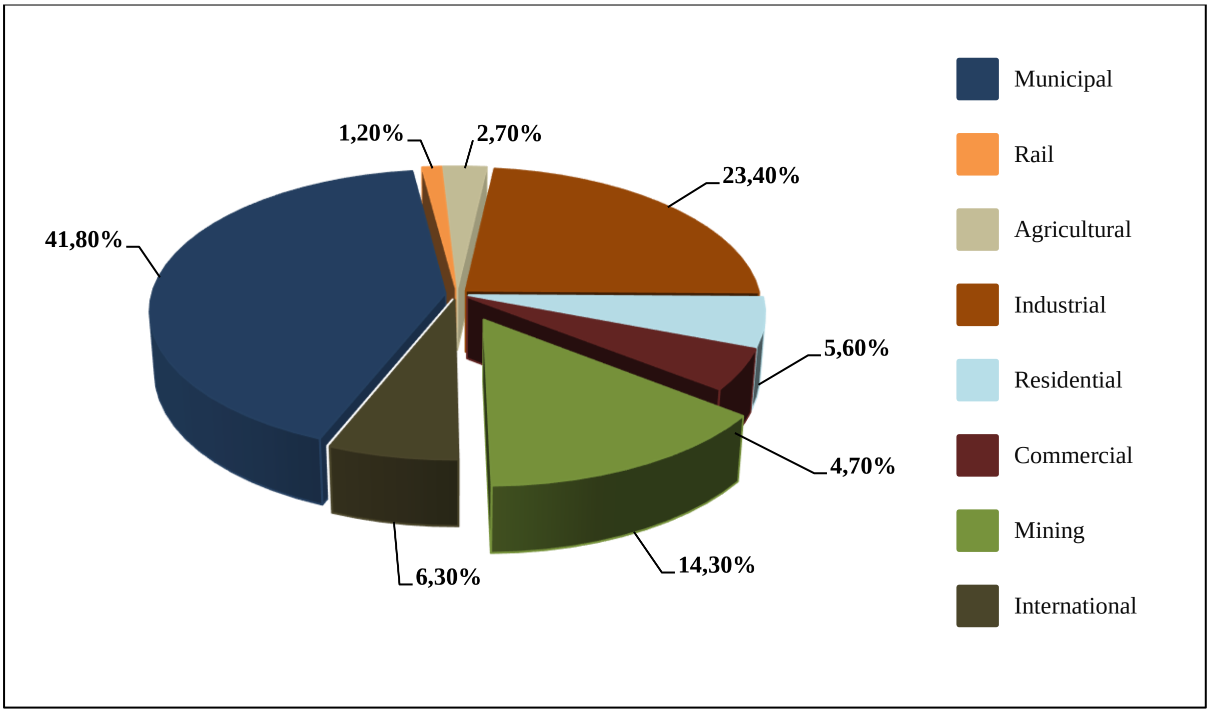

Figure 3: Eskom electricity sales distribution (adapted from [11])

Figure 4 outlines the electricity usage distribution in South African mines for the 2014/15 financial year. As can be seen from Figure 4, pumping contributes almost 14% to the total electricity consumption in mines.

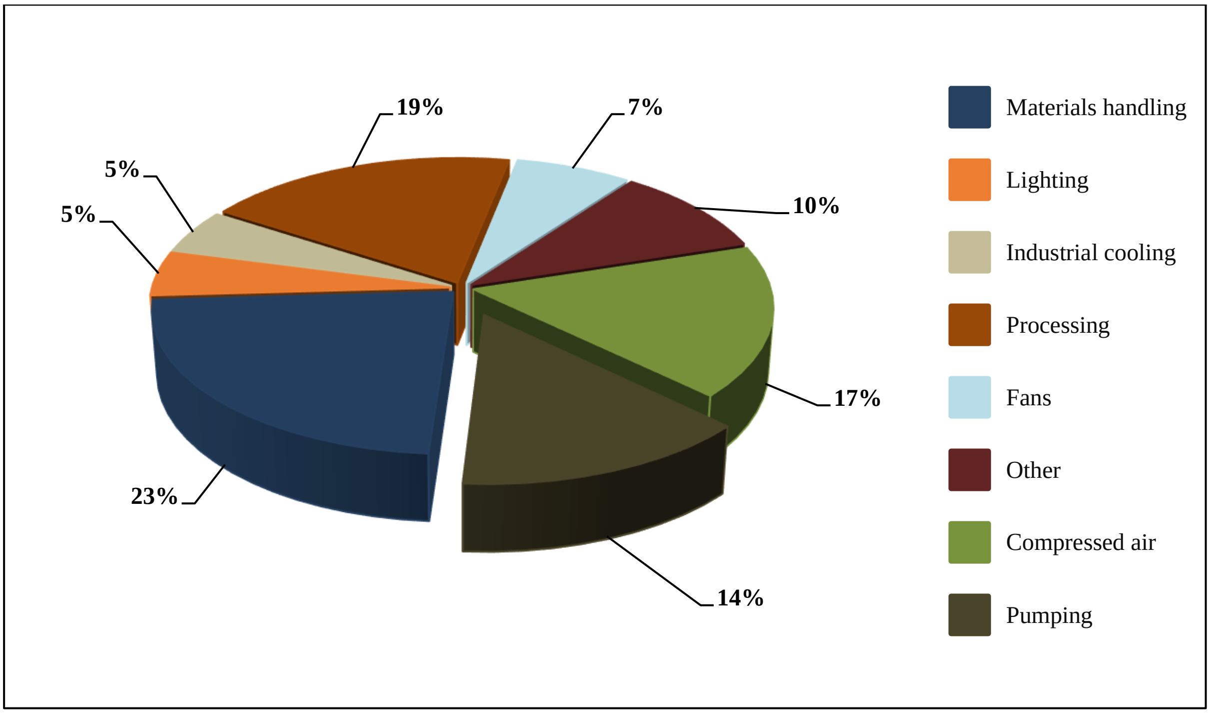

Figure 4: Electricity consumption distribution in mines (adapted from [2])

1.2. Eskom Integrated Demand Management (IDM)

1.2.1. Time-of-use electricity tariff structure

Figure 5 illustrates the South African electricity demand profiles for an average summer and winter day respectively. The demand during evening peak periods is significantly higher than during the rest of the day. The same demand trend is seen seasonally, with winter demand being higher than summer demand. Winter (June until August) is defined as the high demand season, while summer (September until May) is defined as the low demand season [17].

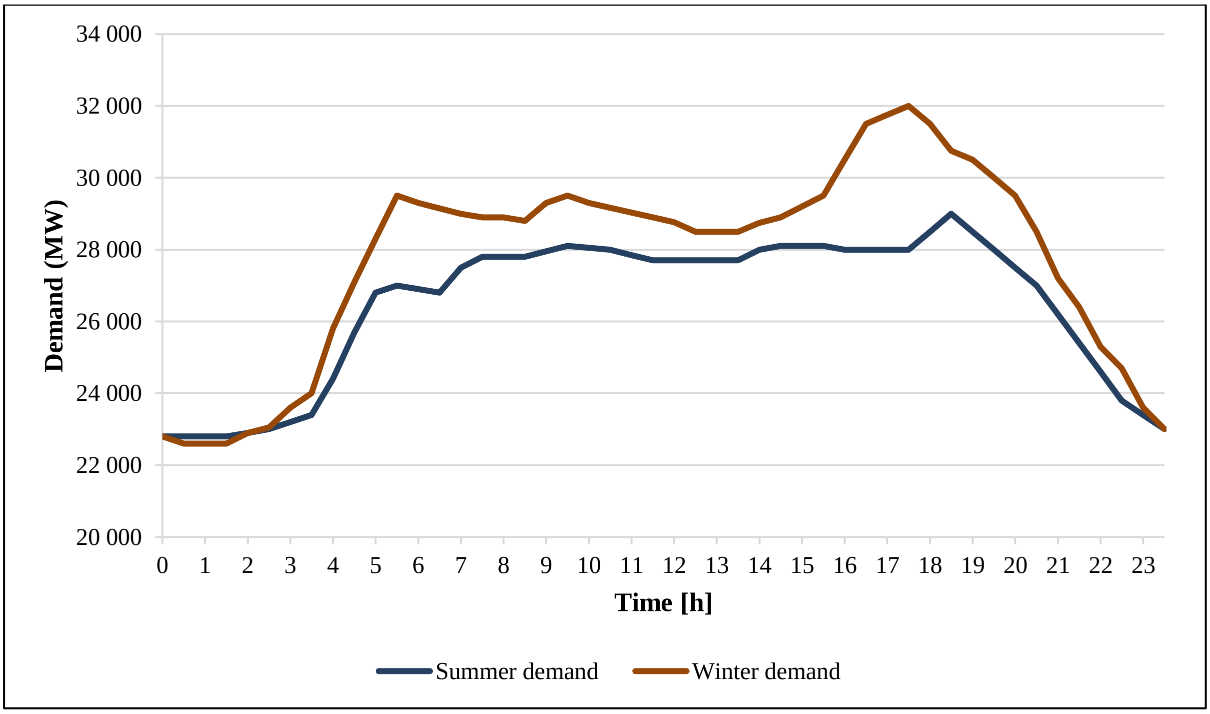

Figure 5: Average consumer demand profiles (adapted from [18])

In an effort to curtail peak demand, thereby reducing the risk of load-shedding or running OCGTs, Eskom introduced time-of-use (TOU) tariffs in 1991 [2]. TOU electricity tariffs vary depending on the time of day. Peak demand periods are the most expensive, while off-peak periods are priced considerably lower [13]. From Figure 5 it can be seen that the winter and summer peak demand periods are not aligned. The winter peak demand periods are roughly an hour earlier than the summer peak demand periods. In 2015, the peak TOU periods were adjusted accordingly to reflect the different winter and summer peak demand periods [17].

South African gold mine electricity tariffs are priced according to the Megaflex TOU tariff structure [2]. The Megaflex TOU structure varies the electricity tariff according to three different periods; namely, peak, standard and off-peak periods. A mine's distance from Johannesburg and the supply voltage also influence the final electricity tariff. Figure 6 displays the Megaflex peak, standard and off-peak TOU periods.

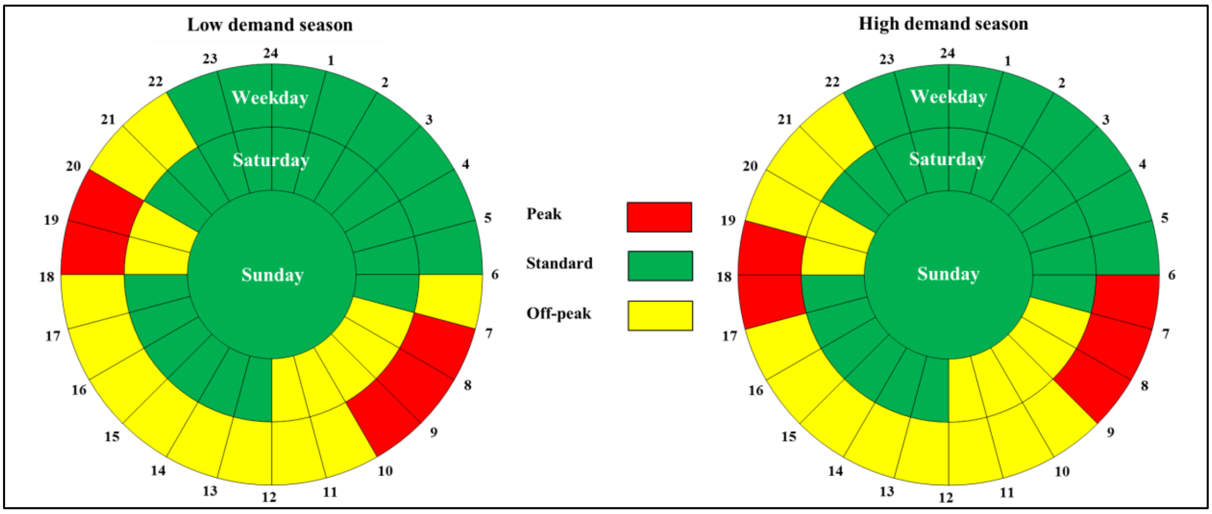

Figure 6: Eskom Megaflex TOU tariff structure (adapted from [19])

Eskom Megaflex 2016/17 TOU tariffs for consumers within 300 km of Johannesburg with a supply voltage of between 500 V and 66 000 V are used for all electricity cost calculations in this study. The applicable tariffs can be found in Table 2.

Table 2: Megaflex 2016/17 TOU tariffs (adapted from [13])

	Megaflex tariffs c/kWh (VAT included)		
	Peak	Standard	Off-peak
Low demand season	99.68	68.62	43.53
High demand season	305.59	92.58	50.27

1.2.2. Demand Side management

In addition to the TOU tariffs discussed in Section 1.2.1, Eskom implemented the Demand Side Management (DSM) programme in 2004 [13]. The aim of the DSM programme is to alter or reduce the consumer demand profile by implementing DSM projects [13]. The most frequently implemented industrial DSM project types are energy efficiency, peak-clipping and load-shifting projects [2]. Energy service companies (ESCos) usually implement these projects on client sites.

In this section, the three DSM project types will be evaluated according to their aim and impact. The impact will be evaluated according to the energy consumption and electricity cost reduction the project type achieves. Eskom low demand season TOU periods, as outlined in Section 1.2.1, will be used for this evaluation. Figure 7 outlines this methodology.

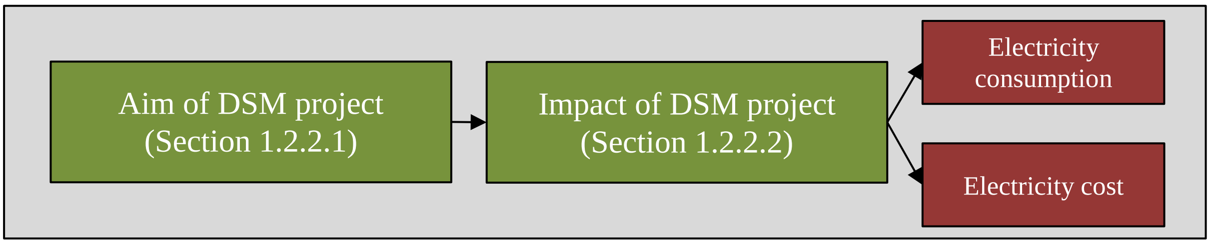

Figure 7: Methodology for evaluating industrial DSM project types

1.2.2.1. Aim of DSM project

Energy efficiency projects

The aim of an energy efficiency DSM project is to reduce the overall electricity consumption of a client [20]. Figure 8 illustrates the impact of a 2 MW energy efficiency project over a 24-hour time period on the client's average power profile, which is referred to as the baseline. Applicable peak TOU periods are indicated with red shading throughout this study. Similarly, power plotted at, for example, 18, indicates the average power between 18:00 and 19:00.

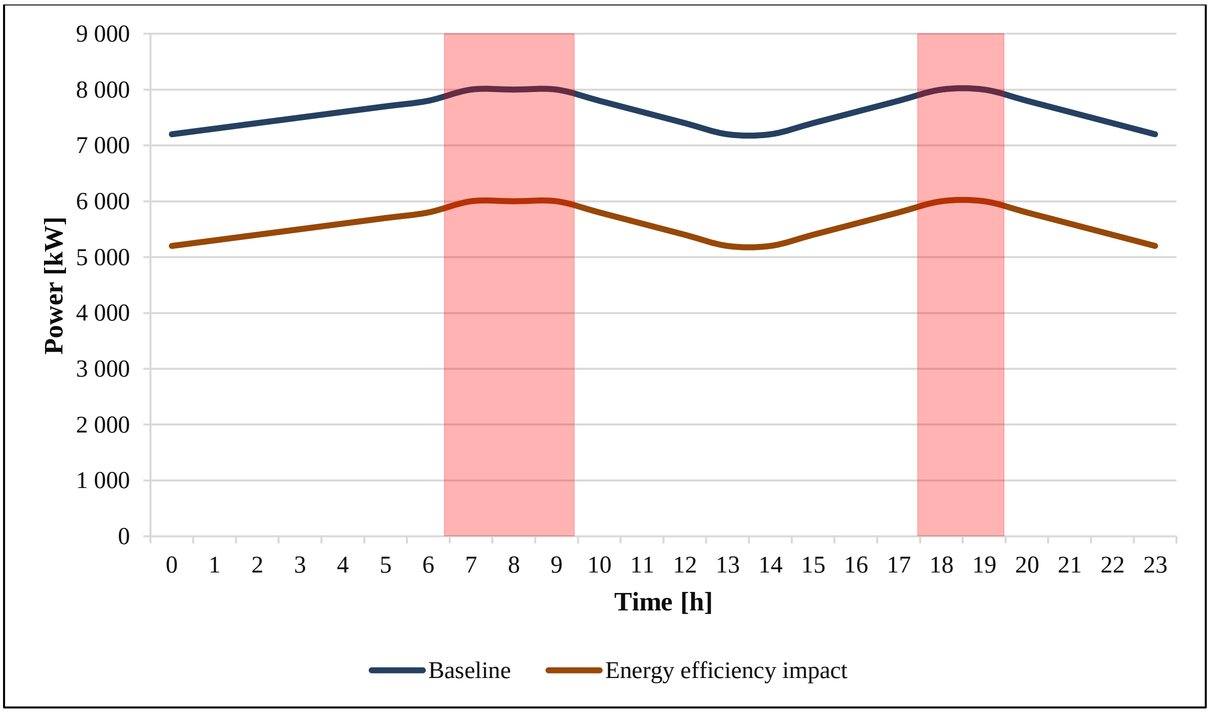

Figure 8: DSM project – energy efficiency (adapted from [2])

Peak-clipping projects

The aim of a peak-clipping DSM project is to reduce the electricity consumption of a client during Eskom peak TOU periods [20]. Peak clipping can also be used to prevent a mine exceeding their notified maximum demand. Figure 9 illustrates the impact of a 2 MW peak-clipping project on the client's average power profile over 24 hours.

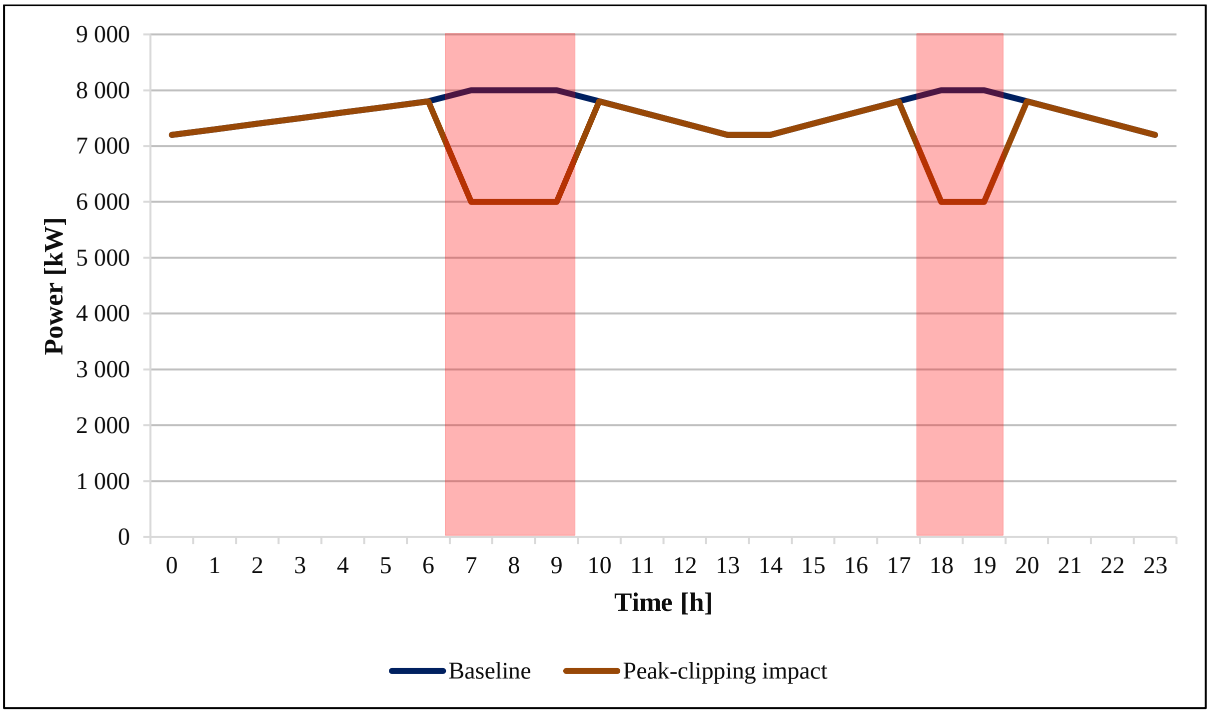

Figure 9: DSM project – peak clipping (adapted from [2])

Load-shifting projects

The aim of a load-shifting DSM project is to move, or shift, the electricity consumption of a client from the Eskom peak TOU periods to standard and off-peak TOU periods [20]. The total electricity consumption that is removed from the peak TOU periods is then used during standard and off-peak periods. This DSM initiative is energy-neutral as the total amount of electricity consumed is not reduced [20].

Although load-shifting projects do not reduce the energy consumed it does provide the advantage of a reduction in electricity cost. This is because the total electricity consumed during expensive peak TOU periods is reduced. DSM load-shifting projects are often implemented on mine pumping systems. Figure 10 illustrates the impact of a 2 MW load-shifting project on the client's average power profile over 24 hours.

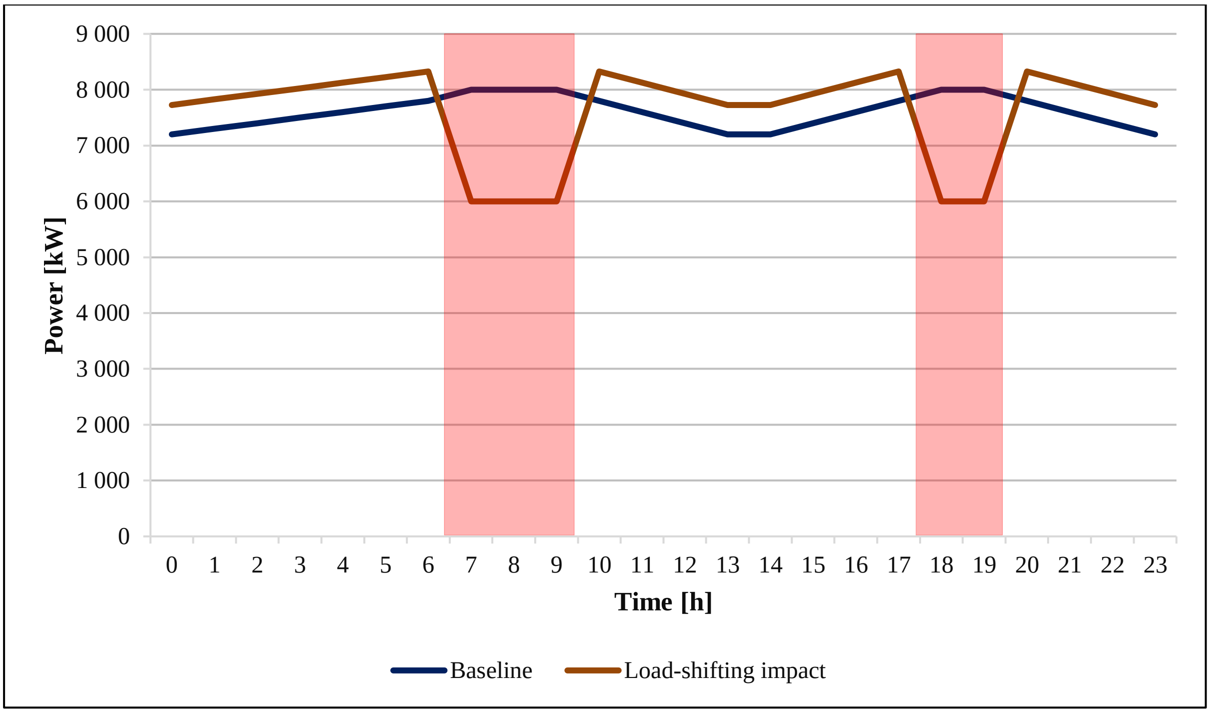

Figure 10: DSM project – load shifting (adapted from [2])

1.2.2.2. Impact of DSM project

Table 3 illustrates the comparative impact of each DSM project type for the current example.

Table 3: DSM project impact comparison

DSM project	Electricity consumption reduction	Electricity cost reduction
Energy efficiency	26.30%	26.00%
Peak clipping	5.48%	9.51%
Load shifting	0%	5.18%

1.2.3. ESCo model

Eskom IDM’s standard offer, standard product, performance contracts, residential mass rollouts or ESCo model programmes can fund DSM projects. For a project to be funded by the ESCo model, ESCos must submit a project with a savings target during evening peak periods of either 500 kW at a single site, or between 250 - 1250 kW spread across a maximum of five sites [21]. Eskom IDM introduced fundamental changes to the ESCo model in 2015 with the aim of improving the impact and cost effectiveness of DSM projects [22]. In this study, “old ESCo model” refers to the ESCo model from 2004 until 2014 while “new ESCo model” refers to the ESCo model from 2015 onwards.

Under the old ESCo model, Eskom IDM contracted ESCos to implement projects with agreed electricity savings targets. Eskom IDM provided funding at the onset of projects based on the size of the project targets. Once implemented, ESCos had to complete three-month performance assessment (PA) periods. If the achieved savings were lower than 90% of the contracted target, ESCos were liable to pay penalties. Clients had to sustain the achieved PA savings for five years thereafter – called the performance tracking (PT) period [2], [13].

The new ESCo model contracts ESCos to sustain project savings for a three-year period that is divided into 12 three-month PA periods. The funding structure has been altered and the total funding provided to ESCos has been reduced. ESCos no longer receive funding upfront, instead payments are received at the end of each PA period based on the project performance during that PA period [22]. Figure 11 provides a flow chart of the new funding model. The reduced funding amount is calculated with Equation 1 [23].

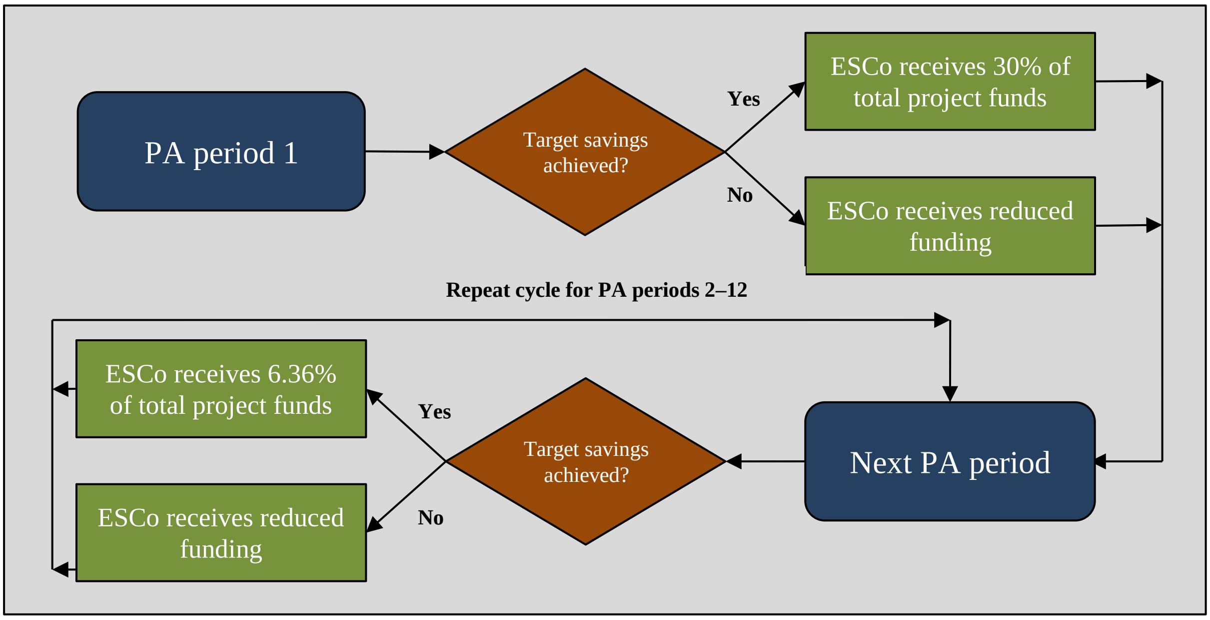

Figure 11: New ESCo funding model

$$\mathbf{RPA} = \mathbf{MPA} \times \frac{\mathbf{SA}}{\mathbf{CS}} \qquad \textbf{Equation 1}$$

Where:

RPA	–	Reduced payment amount for PA period	[R]
MPA	–	Maximum payment amount available for PA period	[R]
SA	–	Savings achieved in PA period	[W]
CS	–	Contracted savings target	[W]

1.3. Sustainability of DSM mine pumping projects

ESCos achieved an average performance of 98% during the PA periods for 261 industrial DSM projects, with a combined target of 676 MW, between 2004 and 2014 [13]. This proves that with ESCo involvement, substantial electricity savings are achievable. Unfortunately, under the old ESCo model, project performance tended to deteriorate when entering the PT period.

The main reason for this deteriorating performance is that when entering the PT period, ESCos were no longer responsible for sustaining project savings. In some cases, clients lacked the needed expertise and resources to properly sustain the projects. Although ESCos entered into maintenance agreements with clients in some cases, the old ESCo model did not necessitate it. The result is that many previously implemented DSM mine pumping projects completing their PT periods are achieving poor to no savings [2], [13].

Figure 12 provides a comparison of the performance of five DSM load-shifting mine pumping projects during the PA and PT periods respectively. Peak impact refers to the average Eskom evening peak period load shift achieved. ESCos were not involved during the PT periods. In each case, the project savings deteriorated drastically.

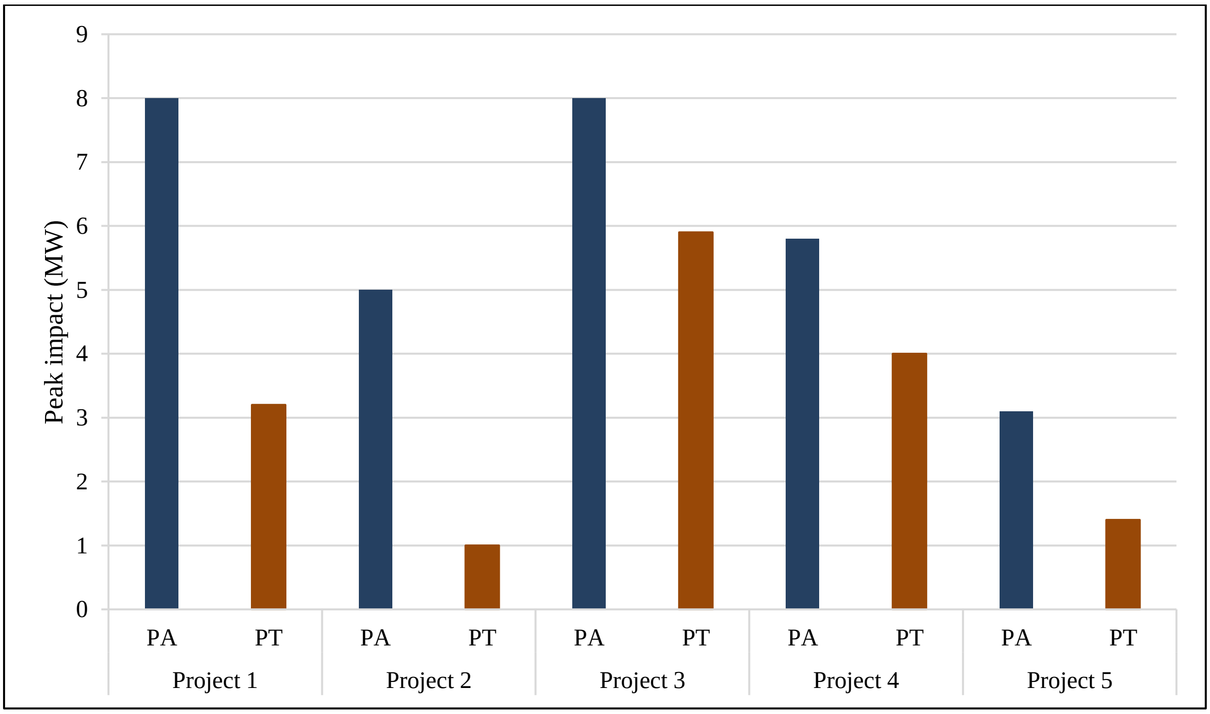

Figure 12: Sustainability of DSM mine pumping projects (adapted from [13])

The performance of the projects during their PA periods prove that the projects can add value to the DSM programme. Most of the infrastructure from the original projects should also still be available and functional [23]. Reviving these projects is therefore supposed to be more cost effective than implementing new projects.

1.4. Problem statement and objectives

South Africa requires an adequate electricity supply to sustain its energy intensive economy. The government identified the DSM programme as a key role player in the quest for energy efficient, sustainable economic development. The mining environment is one of the largest energy consumers in South Africa. Pumping systems as a group is the fourth-largest energy consumer in the mining sector. There is therefore a need to implement DSM initiatives on mine pumping systems.

The ESCo model underwent significant changes in 2015. Eskom IDM funding was restructured and the funding provided to ESCos was reduced. The new payment structure increases the risk associated with DSM projects to ESCos as performance has to be proved over a three-month period before any funding is provided. ESCos are also now required to sustain project savings for three years after project implementation.

Previous studies, which will be analysed critically in Section 2.3, focused on the implementation and maintenance of DSM mine pumping projects under the old ESCo model. No studies have focused on the sustainable implementation of DSM mine pumping projects under the new ESCo model. There is therefore a need to develop a sustainable project strategy to assist ESCos with implementing DSM mine pumping projects under the new ESCo model.

The performance of DSM mine pumping projects often deteriorated during the PT period as ESCos were no longer responsible for sustaining these projects. This can, however, be used as an opportunity. It is more cost effective for Eskom IDM to revive these projects than it is to implement new projects as these projects may still have most of the infrastructure available from the original projects. Eskom also benefits from reviving these projects as they were no longer achieving savings.

Reviving DSM projects that have completed their PT periods can, therefore, be beneficial to both clients and Eskom. This study will focus on developing a project strategy to sustainably revive DSM mine pumping projects, specifically load-shifting projects, that have completed their PT periods under the old ESCo model. Emphasis will be placed on incorporating guidelines of the new ESCo model. The objectives of this study are:

1. Evaluate and critically analyse previous studies related to DSM on mine pumping systems.
2. Identify obstacles and risks associated with reviving DSM mine pumping projects under the new ESCo model.
3. Develop a sustainable project strategy for reviving DSM mine pumping projects under the new ESCo model.
4. Implement the sustainable project strategy on DSM mine pumping projects that have completed their PT periods under the old ESCo model.

1.5. Overview of dissertation

Chapter 1 provided an overview of the need and the objectives of this study. The remaining chapters of this dissertation is structured as follows:

Chapter 2: Literature study

Chapter 2 focuses on the necessary literature review for this study. Mine water reticulation systems, of which the pumping systems form part, are described. Emphasis is placed on evaluating previous studies related to DSM on mine pumping systems. The new and old ESCo model is analysed and compared.

Chapter 3: Development of a sustainable project strategy

Chapter 3 focuses on developing a sustainable project strategy. Lessons and inputs gathered from Chapter 2 are used. The risks associated with the new ESCo model are mitigated.

Chapter 4: Implementation of sustainable project strategy

Chapter 4 focuses on implementing the sustainable project strategy developed in Chapter 3. The sustainable project strategy is implemented on two case studies. The results of the implementation are discussed and analysed.

Chapter 5: Conclusion and recommendations

This chapter provides a summary of the study. The results of the study are discussed. The limitations of the study are outlined and recommendations are made for future work.

CHAPTER 2: LITERATURE STUDY

[3]

“*The more extensive a man's knowledge of what has been done, the greater will be his power of knowing what to do*.” – Benjamin Disraeli

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[3] M. van der Merwe, Personal photograph, “Mine pumping station”, South Africa, 2016.

2.1. Introduction

In this chapter, an overview of mine pumping systems and the associated DSM load-shifting mine pumping projects are provided. This overview commences with a description of a mineshaft's water reticulation system, of which the pumping system forms part. A review of previous studies related to DSM on mine pumping systems is performed. This chapter concludes with an overview of the new and old ESCo model.

2.2. Mine water reticulation systems

Water reticulation systems of deep-level mines are intended to operate with a set amount of water in the system. This amount hinges on factors such as the mine's production rate, size and clear water storage capacity [24], [25]. Water is gravity-fed to underground operations by large vertical pipes, called service water columns. The main uses of water in the mining environment are [26]:

- Cooling
- Drilling and dust suppression
- Cleaning and sweeping

The water used for mining purposes is recycled in the water reticulation system. If needed, additional water is bought from local suppliers to sustain the water volume at the required level [27]. The mining, industrial and power generation sectors combined account for approximately 8% of the total water consumed in South Africa [28].

South African mines have a geothermal gradient of between 10°C/km and 20°C/km and can be as deep as 4 km [4]. This leads to virgin rock face temperatures of up to 60°C [29]. In the interest of miners' safety, cooling is an essential part of the mining process. Cooling water is typically provided by surface refrigeration systems. The cooling water is gravity-fed through the service water columns to underground bulk air coolers (BACs) or cooling cars.

Mines use hydropowered or pneumatic drills to drill the holes required for explosives and support structures. Hydropowered drills use the pressure created by the head of the water in the service water columns [27]. The drilling process creates dust that is harmful to operators and heats up drilling bits. To counteract this, water is used to suppress the dust while simultaneously cooling the drilling bits [30].

Blasting normally occurs at approximately 17:00 and results in a temperature increase in the surrounding areas [31]. Water is used to cool the area by spraying it onto the rock face [20]. Blasted ore and dust are moved to underground loading stations using high pressure water jets. This is known as cleaning and sweeping [32].

The water accumulated underground needs to be removed from the shaft to prevent flooding. This can be service or fissure water. Fissure water refers to naturally occurring underground water [33]. The used and, therefore, hot water is fed via trenches to the bottom level of a mineshaft to be pumped out [27].

A typical mine's water reticulation system can therefore be divided into two systems; namely, the chilled water system and the pumping system. The chilled water system refers to the chilled water sent underground by the surface refrigeration systems. The pumping system refers to the used hot water pumped from underground back to surface. Figure 13 illustrates a typical mine water reticulation system. This layout will be explained in more detail in the following sections.

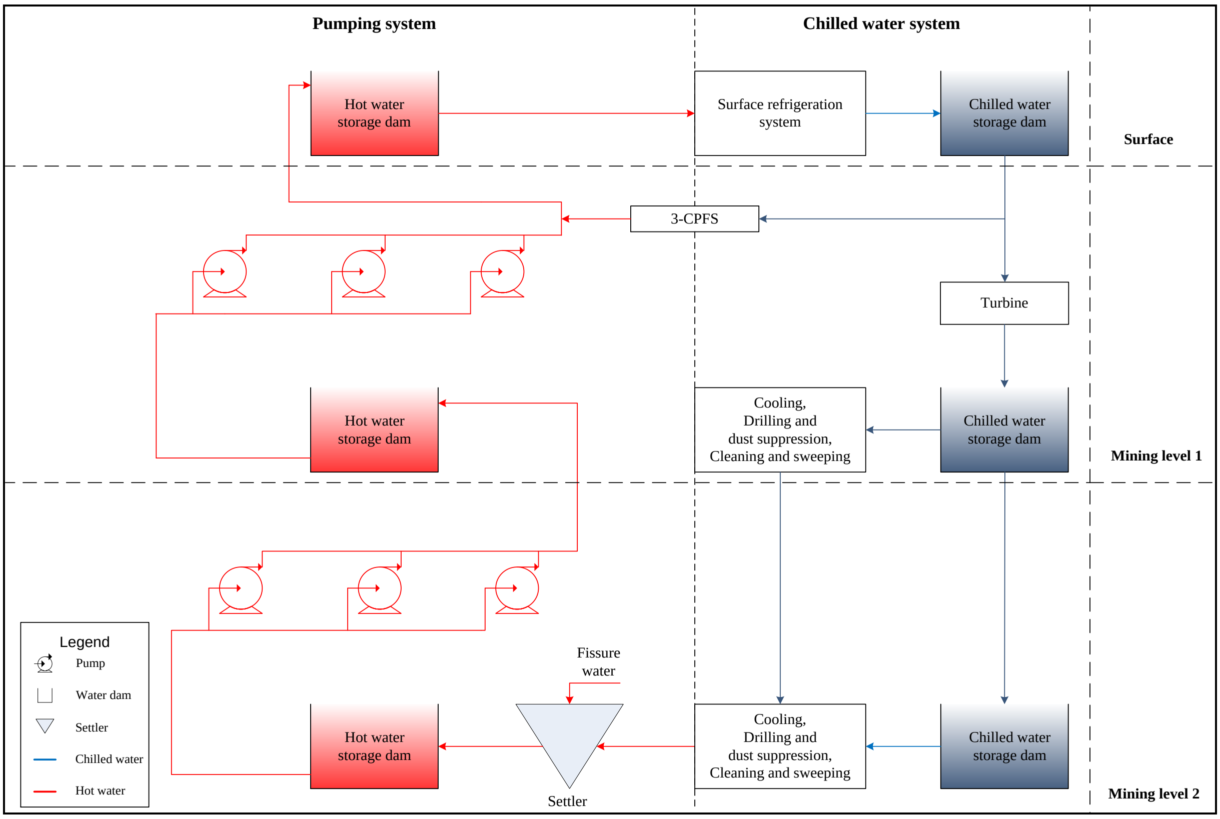

Figure 13: Typical mine water reticulation system (adapted from [30])

2.2.1. Chilled water system

2.2.1.1. Overview

In this section, more detail will be provided about a typical chilled water system as outlined in Figure 13. The first step in the chilled water system is to cool the water pumped from the underground operations. This cooling operation is performed by the surface refrigeration systems. Surface refrigeration systems typically consist of a series of precooling towers, fridge plants, condenser cooling towers and BACs [34]. A simplified layout of a typical surface refrigeration system is shown in Figure 14.

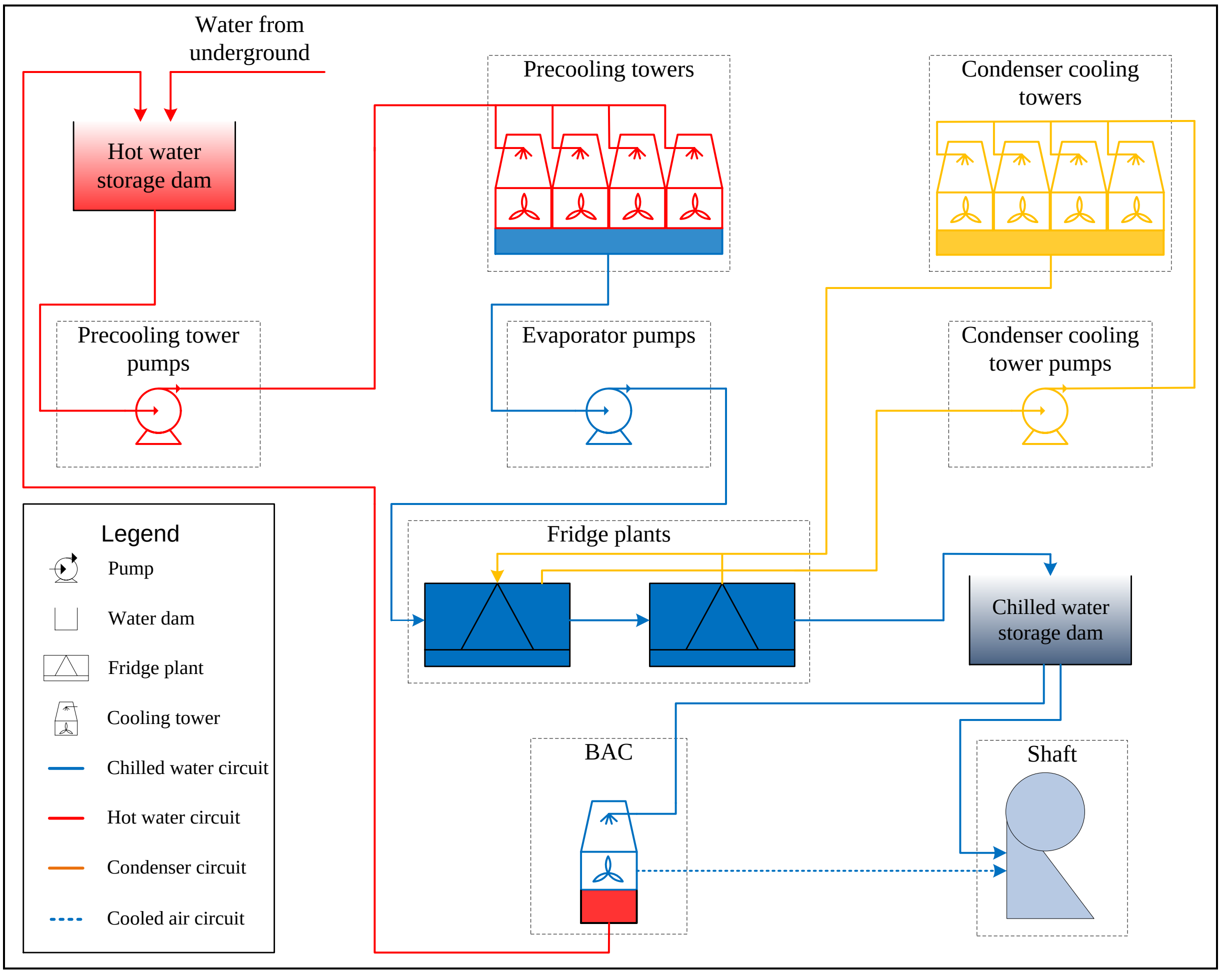

Figure 14: Typical refrigeration system

Water from the underground operations is pumped to a surface hot water storage dam. The temperature of the water in the hot water storage dam is typically between 25˚C and 30˚C [35]. The cooling process starts when this warm water is pumped through the precooling towers. The precooling towers use spray nozzles or splash bars to distribute the warm water through the tower [36]. Ambient air is drawn into the precooling towers by fans. The ambient air cools the water to within 3–6˚C of the wet-bulb temperature [36]. Water exiting the precooling towers is typically at a temperature of between 15˚C and 20˚C [37].

From the precooling towers, the water is pumped to the surface fridge plants with evaporator pumps. The fridge plants use the vapour compression cycle to cool water to approximately 3˚C [38]. A gas refrigerant, such as ammonia, is compressed to form a superheated vapour. The superheated vapour is cooled in a condenser, forming a liquid. An expansion valve flashes the cooled liquid refrigerant, resulting in a drastic reduction in pressure. This causes the temperature of the liquid refrigerant to lower significantly, forming a liquid-gas mixture.

The cooled liquid-gas refrigerant is circulated through a shell and tube heat exchanger in an evaporator along with the precooling tower water. This cools the water while simultaneously boiling the refrigerant at a low pressure, causing the refrigerant to form a gas again. The cycle is repeated as the refrigerant gas is compressed [39].

Water is used to cool the superheated vapour refrigerant in the condenser. This water forms part of a separate condenser water cycle and is not part of the chilled water circuit of the fridge plants. The condenser cooling water is cooled using condenser cooling towers, which operate under the same principle as the precooling towers [39].

The cooled water from the fridge plants is pumped to a chilled water storage dam. From here, the water is either gravity-fed to underground operations to be used as service water, or pumped through BACs [39]. South African mines require average underground working temperatures to not exceed a wet-bulb temperature of 28˚C [32]. BACs are therefore used to cool the ambient air before it enters the mineshaft. Air enters the BAC and is cooled through direct contact with the water from the chilled water storage dam. The air is cooled to between 6˚C and 9˚C [31]. The used water is recirculated to the hot water storage dam to be recooled.

In cases where the mine depth exceeds 2 km, underground BACs are sometimes installed as a secondary cooling measure [40]. Cooling cars are used in working areas where cooled air from the surface and underground BACs does not reach. Service water is fed through a radiator within the cooling car thereby cooling the air. This is known as tertiary cooling and is commonly found near drilling or blasting areas [20].

Water is gravity-fed by service water columns to the underground operations. The water pressure increases by approximately 1 000 kPa for every 100 m that the depth of the mine increases [20]. It is therefore necessary to break the pressure of the water in the service water columns to ensure safe operation. Pelton wheels, cascading dams or pressure-reducing valves are used for this purpose [41]. South African gold mines most commonly use the cascading dam system.

The cascading dam system entails a series of chilled water storage dams to break the pressure of the water. Water is fed from surface to the first chilled water storage dam underground. From here, water is fed to the lower level chilled water storage dams as shown in Figure 13. Service water is fed from the chilled water storage dams to the required mining areas on each mining level. Trenches are used to gravity-feed the used service and fissure water to settlers located near the bottom of the shaft from where it will be pumped to surface [42].

The water in the service water columns has potential energy that can be used. This energy is commonly used by turbines and three-chamber pipe feeder systems (3-CPFSs). Turbines use the potential energy of service water to act as a secondary source of power [35]. 3-CPFSs use the potential energy of water flowing down the service water columns to pump used service water to surface [43].

2.2.1.2. Turbines

The most common type of turbine is the Pelton wheel [31], which can deliver between 1 MW and 5 MW of power [41]. Turbines can be either coupled to a pump or to a generator. A Pelton wheel's efficiency is typically between 55% and 60% and they are ideally suited to high head applications. A Pelton wheel consists of a central circular wheel surrounded by spoon-shaped buckets. The service water is sprayed into the buckets by nozzles, forming high pressure water jets, thereby rotating the turbine [44]. Figure 15 illustrates a simple Pelton wheel.

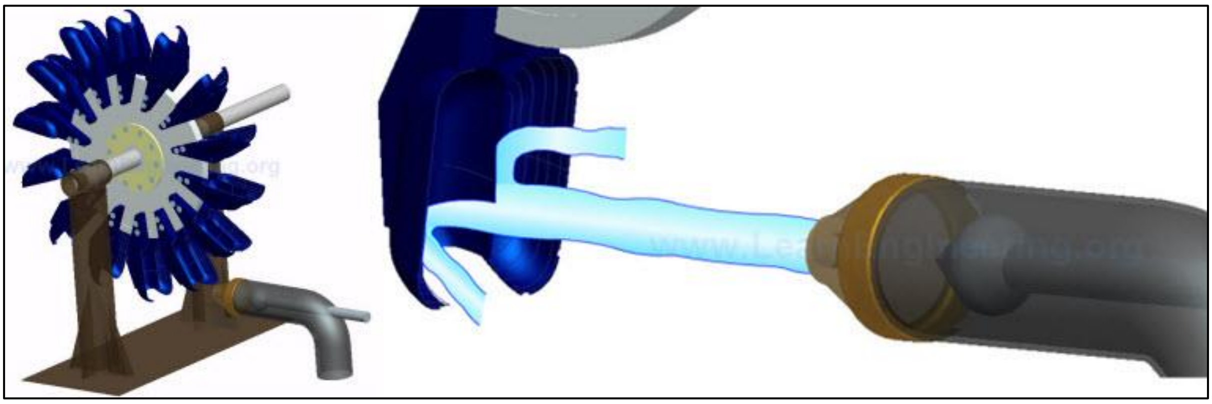

Figure 15: Pelton wheel ([45])

2.2.1.3. 3-CPFSs

As mentioned earlier, a 3-CPFS uses the potential energy generated by the head of the water in service water columns to pump used service water to surface using the U-tube principle. Booster pumps are used to overcome pipe friction in the 3-CPFS. Installing a 3-CPFS system can therefore result in using 80% less energy than a conventional pumping system [31].

A 3-CPFS system is however dependent on water being sent down the shaft to pump used hot water out of the shaft. Additionally, a 3-CPFS system will not be able to pump all of the water out of the shaft due to fissure water being added into the water reticulation system on various pumping levels. A traditional pumping system is therefore still required even if 3-CPFS is installed [27].

2.2.2. Pumping system

As mentioned in Section 2.2.1.1, used service and fissure water is gravity-fed to settlers at the shaft bottom before being pumped to surface. The used service and fissure water accumulates dust and rock particles as a result of the underground mining conditions. The purpose of the settlers are to separate these particles from the water before the water enters the hot water storage dams [46]. This reduces the risk of damage to the dewatering pumps.

To achieve this separation, flocculants are mixed with water entering the settler [47]. The flocculants bind to the solid particles thus forming larger particles. These large particles descend to the settler bottom due to gravity [47]. This allows the clear hot water and the large particles, known as sediment or sludge, to separate. The clear water is transferred to the hot water storage dams, while the sludge is transferred to the sludge dams. The clear water and sludge are pumped to surface by separate pumping systems. The clear water dewatering pumps are typically larger than the sludge pumps and form the focus of this study [27].

The settlers are not able to remove all of the sludge from the water entering the hot water storage dams. This sludge settles on the bottom of the hot water storage dams. This creates the need for a minimum dam level that cannot be exceeded during the dewatering process. If the minimum dam level is exceeded, sludge will enter and damage the dewatering pumps. Commonly, more than one hot water storage dam can be found on a pumping level [20].

Hot water is pumped to surface through a series of hot water storage dams. The water is pumped in an upwards cascading manner from the lowest level to the surface hot water storage dam. This is similar to the chilled water storage dam cascading system. Chilled water cascading storage dams break the service water columns' pressure, while hot water cascading storage dams break the required head of the dewatering pumps. The distance between two pumping levels can be up to 1.3 km [27]. Multistage centrifugal pumps are the most common type of dewatering pump used in South African gold mines [27], [48].

2.2.2.1. Centrifugal pumps

Centrifugal pumps impart energy to the liquid being pumped by increasing the velocity of the liquid with a rotating impeller [49]. A multistage centrifugal pump contains a series of consecutive impellers. The outlet of each impeller is directed to the inlet of the next. Each impeller imparts energy to the liquid being pumped, thereby increasing the discharge pressure from one impeller to the next [49]. The high pressure liquid exits the pump at the discharge end of the final impeller. Figure 16 displays a multistage centrifugal pump.

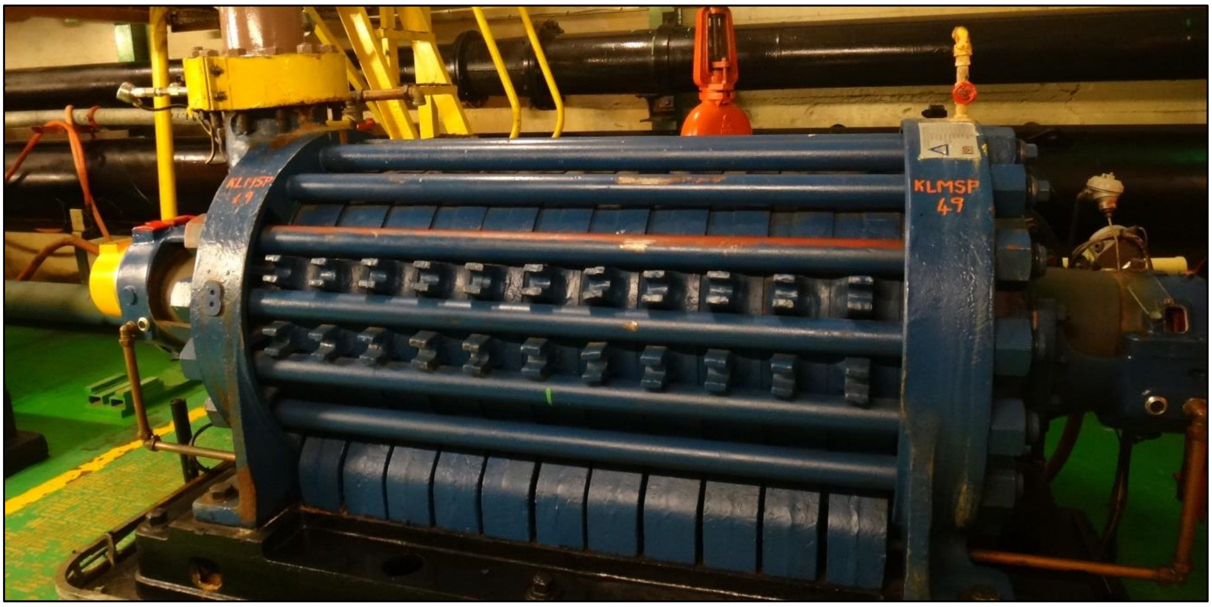

Figure 16: Multistage centrifugal pump[4]

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[4] M. van der Merwe, Personal photograph, "Multistage centrifugal pump", South Africa, 2016.

2.2.2.2. Pump monitoring

Pump monitoring is critical for operating a mine pumping system safely and efficiently. Effective monitoring enables pump operators to pre-emptively identify conditions that can lead to pump failure. This reduces the risk of unplanned pump maintenance, thus reducing the maintenance cost of pumps and the risk of flooding [50].

Centrifugal pumps are driven by three-phase electric motors. Motor winding temperatures are measured for each of the three windings [56]. For this study, the term DE refers to drive end and NDE refers to non-drive end [51]. Typical parameters that can be monitored on centrifugal pumps include the following [52], [53]:

- Pump and motor DE bearing vibration
- Pump and motor DE and NDE bearing temperatures
- Pump and motor shaft displacement
- Motor winding temperatures
- Motor air temperature
- Motor cooling water flow
- Pump balance disc flow
- Pump suction and discharge pressures
- Actuated suction and discharge valves position

The parameters are measured by suitable instruments. The placement of these instruments are illustrated in Figure 17 [27]. The description of each measurement is provided in Table 4. Appendix I contains a set of photos that were taken of some of these instruments during the investigation phase of this study.

Safety limits for the measured parameters are programmed into the programmable logic controller (PLC) of each pump, which continuously monitors these parameters. This prevents a pump from starting under unsafe conditions and trips a running pump if any limits are breached [20], [54]. The reason for a pump tripping is displayed on a human-machine interface.

Information from the pump PLCs are relayed to a supervisory control and data acquisition (SCADA) system. The SCADA system can be accessed remotely from surface. Any information that is measured on a pump can therefore be accessed easily.

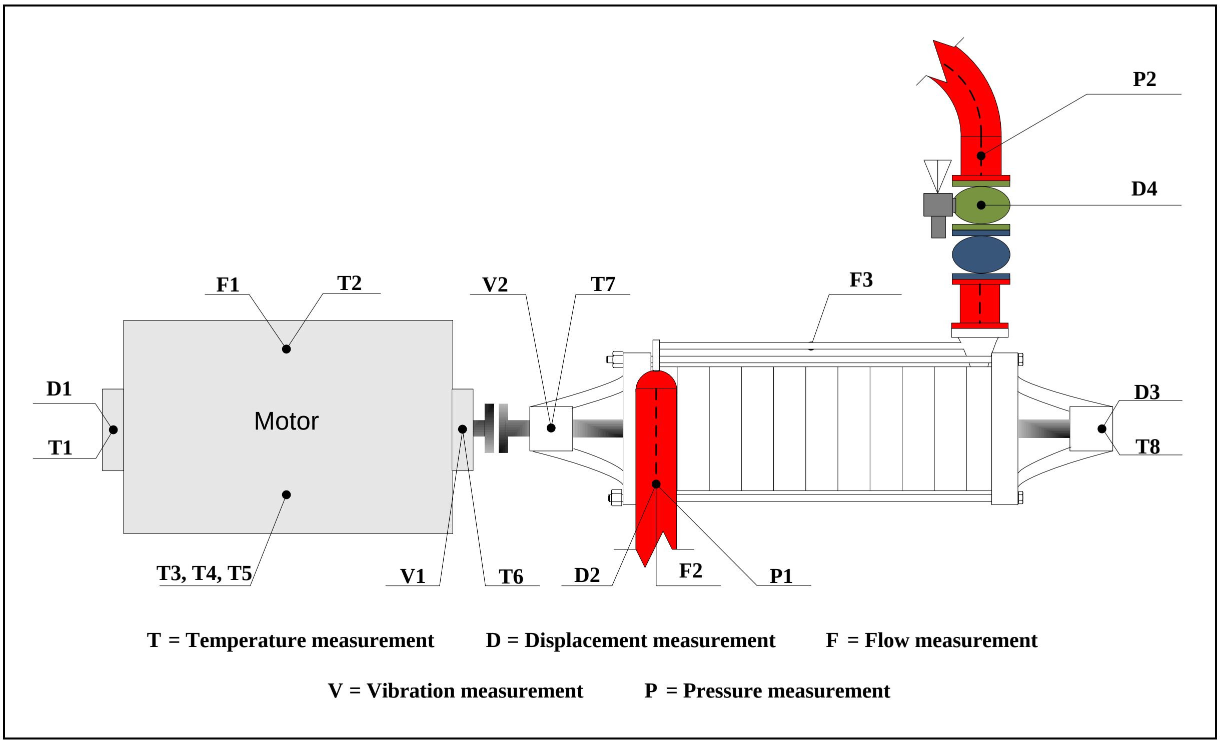

Figure 17: Centrifugal pump instrumentation (adapted from [20], [27])

Table 4: Centrifugal pump instrumentation (adapted from [20], [27])

Temperature measurements		Displacement measurements	
T1	Motor NDE bearing	**D1**	Motor shaft displacement
T2	Motor air temperature	**D2**	Suction valve opening position
T3	Motor winding temperature U	**D3**	Pump impeller displacement
T4	Motor winding temperature V	**D4**	Discharge valve position
T5	Motor winding temperature W	Flow measurements	
T6	Motor DE bearing	**F1**	Motor cooling water
T7	Pump DE bearing	**F2**	Pump suction flow
T8	Pump NDE bearing	**F3**	Balance disc flow
Vibration measurements		Pressure measurements	
V1	Motor DE bearing	**P1**	Pump suction pressure
V2	Pump DE bearing	**P2**	Pump discharge pressure

2.3. Previous studies related to DSM on mine pumping systems

In this section, a critical analysis of previous applicable DSM studies is performed. The purpose of this analysis is to determine the limitations of previous studies, as well as lessons that can be learned. Figure 18 outlines the methodology that is used.

To select a study to analyse, the content of the study will be measured against a predetermined set of criteria. The study must satisfy at least one main and one secondary criteria to be analysed further. If selected, the study will be evaluated to determine its objective, methodology and results. Lastly, the limitations of the study and the lessons learned from the study will be discussed.

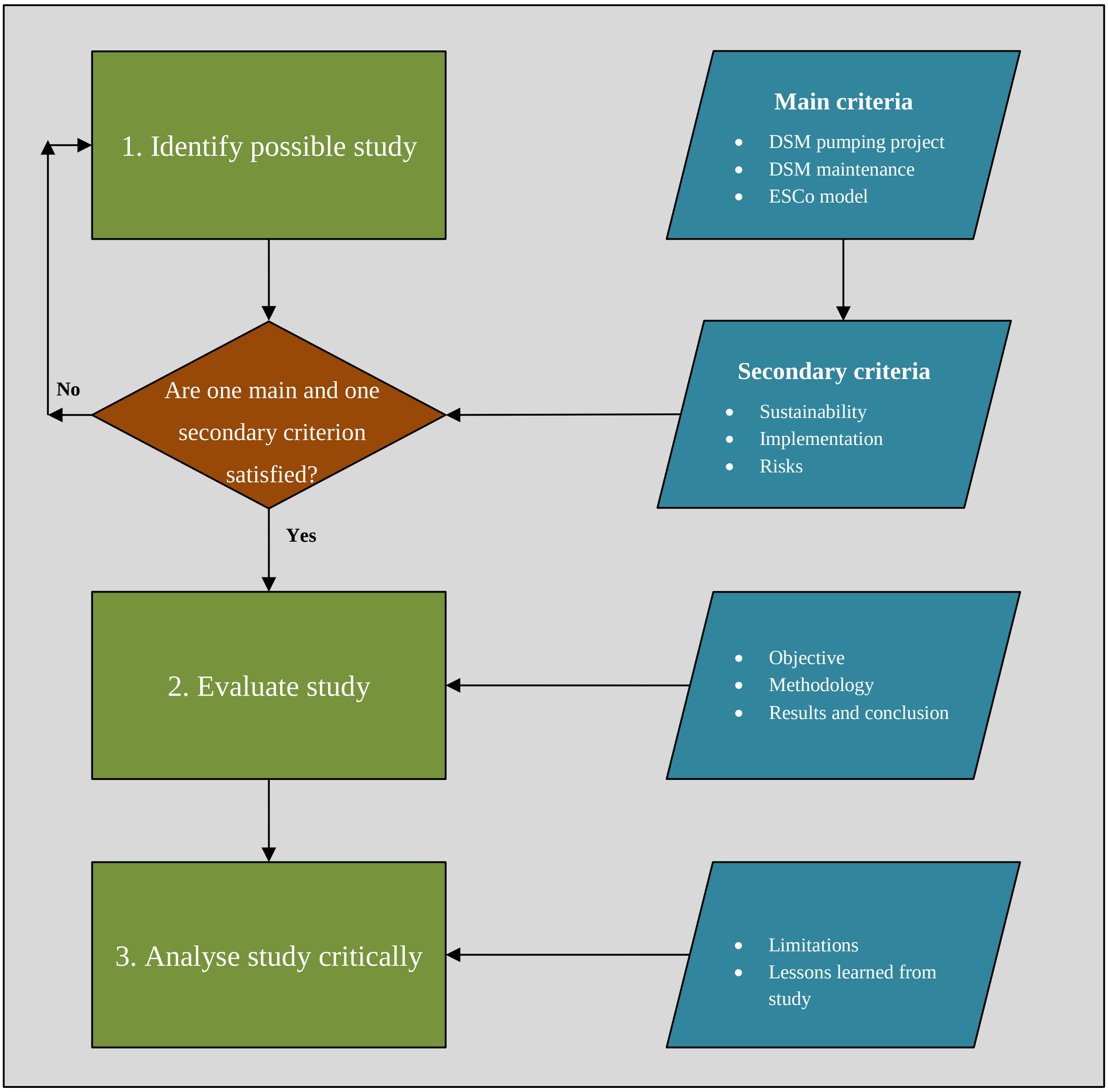

Figure 18: Methodology for identifying, evaluating and critically analysing previous applicable studies

2.3.1. Study A – Improved risk management processes

Title:	Improved risk management processes for South African industrial ESCos
Type:	Ph.D thesis
Author:	R Joubert [23]

2.3.1.1. Identify possible study

This study was chosen as it satisfied the following criteria:

- Main criteria: ESCo model
- Secondary criteria: Risks, implementation

2.3.1.2. Evaluate study

Objective

Joubert's [23] objective was to develop a business model to improve risk management during the implementation of DSM projects under the new ESCo model.

Methodology

Joubert [23] used South Africa's largest ESCo as a case study. This ESCo implemented 129 industrial DSM projects between 2006 and 2015. He interviewed project managers and engineers with experience in implementing DSM projects under the old ESCo model. From these interviews, as well as personal experience, he identified implementation challenges and risks on a business group level.

Joubert [23] proceeded to develop procedures to assist with mitigating these risks and challenges. Lastly, Joubert [23] endeavoured to develop a tool that would score, or quantify, the perceived risk associated with his newly developed processes. He designed the tool and asked the ESCo's senior project managers, each with an average of eight years' experience of implementing DSM projects, to test the tool.

Results and conclusion

Joubert [23] claimed that the implementation of his processes contributed to the ESCo achieving the following accomplishments:

- A 14% DSM project overperformance.
- An 18% reduction in DSM project implementation time.
- A 280% increase in performance when reviving neglected DSM projects.
- A perceived risk decrease of 69% associated with his newly developed processes (as scored by his quantification tool).

2.3.1.3. Critically analyse study

Limitations and analysis

Joubert [23] managed to improve the business model of the ESCo. The overall quality of the ESCo's documentation and processes was enhanced. This newly developed processes, however, only focused on high level risk identification and mitigation. Specific procedures for mitigating risks on a project level were not developed or mentioned.

There can be no doubt that the processes Joubert [23] developed contributed to the ESCo's accomplishments. There is, however, no way of quantifying this contribution. The results he claimed was on a business group level. It is therefore difficult to distinguish between the contribution of his processes, and processes developed by project engineers for a project.

Lessons learned from study

Joubert's [23] study provided insight on high level management of industrial DSM projects. This includes insight on risk mitigation that can be implemented in this study. The following valuable lessons regarding DSM risk management and implementation were also gained:

- Proper risk management contributes to project performance.
- A proper implementation strategy is required to successfully implement and sustain a project.
- Proper documentation is essential to sustain DSM projects over the long term as it allows ESCos to efficiently review any aspect of a project when needed.

2.3.2. Study B – Maintenance procedures on DSM pumping projects

Title:	Maintenance procedures on DSM pumping projects to improve sustainability
Type:	M.Eng dissertation
Author:	HL Grobbelaar [55]

2.3.2.1. Identify possible study

This study was chosen as it fulfilled the following criteria:

- Main criteria: DSM pumping project
- Secondary criteria: Sustainability

2.3.2.2. Evaluate study

Objective

Grobbelaar's [55] objective was to develop a maintenance strategy to sustain the electricity cost savings of DSM pumping projects.

Methodology

Grobbelaar [55] identified four key areas responsible for DSM pumping projects underperforming. These are data loss, mechanical failures, pump instrumentation and control parameters. Grobbelaar [55] proceeded to develop concise maintenance strategies to counteract any problems that could arise within each key area.

To test this developed maintenance strategy, three case studies were used. In each case, Grobbelaar [55] identified whether or not the case study project was achieving its intended savings target. If it was, no action was taken. If the case study was not achieving its intended savings target, the key area responsible for this underperformance was identified. The corrective maintenance procedure within that key area was then implemented.

Results and conclusion

Grobbelaar [55] claimed that implementing his maintenance strategy resulted in his case studies achieving a combined average Eskom evening peak period load shift of 10.16 MW. This resulted in an annual estimated cost saving of R8.05-million. He concluded that his maintenance strategy improved sustainability and resulted in electricity cost savings.

2.3.2.3. Critically analyse study

Limitations and analysis

Grobbelaar’s [55] maintenance strategy did indeed manage to successfully sustain the electricity cost savings of his three case studies. The developed maintenance strategy is generic and can be implemented on various DSM pumping projects in operation. There are, however, limitations to his approach.

Grobbelaar’s [55] maintenance strategy can be classified as a reactive-based maintenance strategy. It was only used when a case study failed to achieve its intended target. It did not endeavour to continuously improve the performance of each case study. This could result in lost electricity cost savings because of the lack of continuous project improvement.

Grobbelaar [55] did not take the importance of proper communication between the client and the ESCo into account. In his maintenance strategy, communication was only required when a case study did not reach its intended target. This lack of regular communication can lead to the relations between the client and the ESCo disintegrating. In turn, this could lead to the project performance deteriorating.

Grobbelaar [55] did not focus on the implementation of DSM pumping projects. His strategy was dependent on a project already being in operation. Additionally, his maintenance strategy was implemented under the old ESCo model. This means that the unique challenges associated with maintaining DSM projects under the new ESCo model were not considered.

Lessons learned from study

From Grobbelaar’s [55] study valuable lessons regarding the maintenance of DSM pumping projects were gained. They are summarised as follows:

- Reactive maintenance is necessary to sustain project savings.
- Reactive maintenance is inadequate to maximise project savings.
- Communication will be required between clients and ESCos to ensure positive relations between both parties.

2.3.3. Study C – Automated control of mine dewatering pumps

Title:	Automated control of mine dewatering pumps
Type:	M.Eng dissertation
Author:	T Smith [56]

2.3.3.1. Identify possible study

This study was chosen as it fulfilled the following criteria:

- Main criteria: DSM pumping project
- Secondary criteria: Implementation

2.3.3.2. Evaluate study

Objective

Smith's [56] objective was to implement a DSM pumping project with the aim of maximising the electricity cost savings.

Methodology

Smith [56] focused on a single case study. He endeavoured to fully automate the pumping system to realise maximum electricity cost savings. To safely implement full automatic control, he followed a five-step methodology, which is described below:

1. Perform simulations to determine the optimum pump schedules.
2. Implement manual control.
3. Implement manual scheduled control.
4. Implement manual scheduled surface control.
5. Implement automatic control.

During manual control, underground pump operators were responsible for controlling the pumps. The underground operators decided when to stop or start pumps based on the simulation schedule and personal experience. Manual scheduled control entailed underground pump operators being instructed by surface control room operators to stop or start pumps. Manual scheduled surface control entailed the surface control room operators controlling the pumps through the mine’s SCADA system. Automatic control entailed the full automatic control of the pumps with little intervention from operators.

Results and conclusion

Smith [28] claimed the following annual electricity cost savings for each control method:

- Manual control – R8 250 035
- Manual scheduled control – R5 960 746
- Manual scheduled surface control – R5 709 462
- Automatic control – R5 571 709

Smith [28] stated that the decrease in electricity cost savings between manual control and automatic control was due to underground pump operators overriding safety parameters such as maximum dam levels. He further stated that the mine suffered significant infrastructure damage – a dewatering column burst due to safety parameters being ignored. He concluded that full automatic control should be the preferred operational method as it safely achieves significant electricity cost savings.

2.3.3.3. Critically analyse study

Limitations

Smith [28] only focused on one case study. His simulation and implementation methods, although valid, were not developed generically or tested on other case studies. He made no mention of any strategies for sustaining the electricity cost savings of his case study. Furthermore, he did not develop any contingency methods to counteract project underperformance or any unexpected setbacks.

Lessons learned from study

Valuable lessons regarding the implementation of DSM pumping projects were gained from Smith’s [56] study. They are summarised as follows:

- Proper pump operator training is essential.
- Various pumping control methods can achieve electricity cost savings.

- Proper contingency methods need to be develop to ensure project performance is achieved safely.

2.3.4. Study D – DSM interventions on water reticulation systems

Title:	Implementing DSM interventions on water reticulation systems of marginal deep level mines
Type:	M.Eng dissertation
Author:	A van Niekerk [42]

2.3.4.1. Identify possible study

This study was chosen as it fulfilled the following criteria:

- Main criteria: DSM pumping project
- Secondary criteria: Implementation

2.3.4.2. Evaluate study

Objective

Van Niekerk’s [42] objective was to identify and implement cost effective DSM projects on the water reticulation system of marginal deep-level mines.

Methodology

Van Niekerk [42] used a five-step methodology in his study, which is described below. For each step, he identified parameters and constraints that had to be adhered to.

1. Select a mineshaft to investigate possible projects.
2. Analyse the selected shaft’s water reticulation system.
3. Identify possible projects and their applicable control strategy.
4. Estimate each possible project’s savings potential and implementation cost.
5. Select and implement the most cost effective project.

Results and conclusion

Van Niekerk’s [42] methodology identified two shafts to investigate further. During this investigation, Van Niekerk [42] found that the savings potential at one shaft was insufficient to justify a DSM project due to the high implementation costs required. Van Niekerk [42] estimated a potential average evening load shift of 3.1 MW at the second shaft. This estimated saving was based on performing load shifting on the shaft's dewatering pumps and surface fridge plants.

Upon implementation, a combined load shift of 2.7 MW was achieved over a three-month period. This resulted in an estimated annual cost saving of R631 000 with a payback period of 1.6 years. Van Niekerk [42] attributed the underperformance to unforeseen breakdowns and unscheduled maintenance on the surface fridge plants.

2.3.4.3. Critically analyse study

Limitations

Van Niekerk [42] developed a generic methodology to identify possible DSM projects on a mineshaft's water reticulation system. This method is sufficient to identify projects, but does not take long-term sustainability into account. As was the case with Smith [28], he did not develop any contingency methods to counteract project underperformance or any unexpected setbacks.

Lessons learned from study

Valuable lessons regarding the implementation of DSM pumping projects were gained from Van Niekerk's [41] study. They are summarised as follows:

- A proper strategy is essential when investigating potential project savings.
- Long-term sustainability needs to be taken into account when implementing DSM projects.
- The electricity cost savings of a DSM project must be measured against its implementation cost before being implemented.

2.3.5. Conclusion

This section focused on analysing studies that have been completed previously. The limitations of these studies as well as the lessons learned from them were identified and discussed. This study builds on the foundation laid by these studies while addressing the limitations. The lessons learned and insight gained from these studies are used as inputs during the development of a sustainable project strategy under the new ESCo model in Chapter 3.

2.4. Overview of the ESCo model

This section provides an overview of the ESCo model. The main differences between the old and the new model are discussed. This section concludes with an overview of the measurement and verification (M&V) process involved with all DSM projects.

The success and longevity of Eskom IDM's ESCo model is reliant on five main contributors. The roles and responsibilities of each are outlined in Table 5 [22], [23], [57].

Table 5: Eskom DSM main contributors' responsibilities

Contributor	Responsibilities
Eskom IDM	Eskom IDM is responsible for funding DSM projects. They review and approve possible DSM project proposals as submitted by ESCos.
ESCos	ESCos are responsible for investigating possible DSM projects and submitting proposals to Eskom IDM. ESCos are then responsible for implementing projects approved by Eskom IDM and for sustaining the project savings over the course of the project lifecycle.
Clients	The DSM projects are implemented on the clients' systems or sites.
M&V teams	The project performance claimed by ESCos are verified by M&V teams. M&V teams are responsible for reporting these verified savings to Eskom IDM and Eskom Energy Audit.
Eskom Energy Audit	Eskom Energy Audit is responsible for managing the M&V process of all DSM projects.

2.4.1. ESCo model phases

The ESCo model can be divided into three distinct phases, namely [23]:

- Phase 1: Project submission and approval (Including baseline development and data gathering)
- Phase 2: Project implementation
- Phase 3: Project PA

2.4.1.1. Phase 1: Project submission and approval

ESCos investigate possible DSM projects on client sites and systems. These can be in residential, commercial, industrial, municipal or agricultural sectors. The municipal sector accounts for approximately 35% and the industrial sector 25% of all DSM projects implemented in South Africa [58]. ESCos identify projects with an electricity cost or energy savings potential during Eskom evening peak periods and submit project proposals to Eskom IDM [59].

The proposals contain the expected DSM impact and implementation cost. The Eskom Technical Evaluation Committee (TEC) and the Eskom Project Evaluation Committee (PEC) evaluate initial proposals. If both committees deem a project as acceptable, Eskom Energy Audit assigns an M&V team to the project. The M&V team submits the applicable M&V reports, described in Section 2.4.2, to assist Eskom IDM in the final decision whether or not to approve a project. If Eskom IDM deems the project feasible from a technical and financial point of view, the relevant ESCo is contracted to implement the project [60].

During this stage Eskom IDM determines the funding that will be made available for each project. The maximum amount, known as the capped value, is based on the expected project savings and project type [23]. The expected DSM impact that ESCos submitted to Eskom IDM becomes contractually binding once a project has been approved. This process also includes the gathering data to develop a pre-implementation baseline. This allows ESCos to predict the expected project performance as outlined in the International Performance Measurement and Verification Protocol (IPMVP) [61]. This is covered in detail in Sections 2.4.2.3 and 3.5.1. The IPMVP was used to provide an overview of the M&V process for this study, but previous research and studies were referenced as they involved practical implementation of projects using the M&V process and highlighted the risks involved.

The first difference between the old and new ESCo model can be identified at this stage. Under the old ESCo model, Eskom IDM recognised savings achieved by energy efficiency projects throughout all 24 hours of the day and paid ESCos accordingly. This was factored into the project proposals by ESCos for energy efficiency projects. The new ESCo model, however, stipulates that ESCos are only allowed to claim savings achieved during Eskom evening peak periods [22].

2.4.1.2. Phase 2: Project implementation

During this phase, ESCos are responsible for implementing projects that were approved by Eskom IDM. The second difference between the old and new ESCo model can be identified at this stage. Under the old ESCo model, ESCos were paid during the implementation of a project [60]. The new ESCo model, however, stipulates that ESCos will only be paid based on verified project performance. This means ESCos no longer receive funding upfront to implement projects. This funding model was outlined in Section 1.2.3.

The new ESCo model stipulates that ESCos must implement projects within six months once a project has been approved by Eskom IDM [22]. Once a project has been implemented fully, Eskom IDM issues a completion certificate, which indicates the start of Phase 3 of the new ESCo model.

2.4.1.3. Phase 3: Project PA

The last phase is the PA period. During this phase, ESCos are responsible for achieving the contracted savings target that was determined during Phase 1. The third difference between the old and new ESCo model can be identified at this point. As explained in Section 1.2.3 under the old ESCo model, ESCos were only required to sustain project savings for three months.

The new ESCo model stipulates that ESCos are responsible for sustaining projects savings for three years. This three-year period is divided into 12 three-month PA periods. At the end of each period, ESCos are paid according to their performance during that PA period. The following stipulations regarding payments were also added to the new ESCo model [22]:

- If a project overperforms against its contracted savings target, Eskom IDM makes no additional payments to ESCos.
- If a project underperforms against its contracted savings target, Eskom IDM reduces payments to ESCos.
- If a project does not reach its contracted savings target during a three-month PA period, the savings cannot be made up in subsequent PA periods. This means ESCos cannot overperform in a PA period in the hope of retrieving financial losses as a result of underperformance in a previous PA period.
- Each payment is subject to a 10% supplier development and localisation (SD&L) requirements retention.

SD&L is a concept that was introduced in 2012 with the aim of developing and promoting skills and businesses of previously disadvantaged South Africans [23], [62]. All DSM projects are subject to SD&L requirements that ESCos need to comply with. These requirements differ from project to project and are negotiated between ESCos and Eskom IDM. ESCos need to comply with all SD&L requirements to receive the 10% retention on each payment [22].

2.4.2. M&V deliverables

The M&V process is critical to all DSM projects. M&V teams are responsible for reporting project performance to Eskom IDM. ESCos are paid based on this reported performance. Independent M&V teams are assigned to each project by Eskom Energy Audit if Eskom TEC and PEC deem an ESCo project submission as acceptable. Once an M&V team has been assigned to a project, they have six deliverables required by Eskom, namely [22], [63]:

- M&V scope report
- M&V plan
- M&V baseline report
- M&V post-implementation report
- PA reports
- PT reports

2.4.2.1. M&V scope report

The scope report kick-starts the M&V process and outlines all the relevant information pertaining to a DSM project. During this step, the M&V team conducts a site visit to the client's system targeted for a DSM intervention by an ESCo. The scope report should outline the expected DSM impact of a project and how the DSM impact will be achieved [22]. This report is completed while Eskom IDM evaluates possible projects with the aim of assisting Eskom IDM in the decision-making process [23].

2.4.2.2. M&V plan

The second deliverable required from the responsible M&V team is the M&V plan. This is a detailed document outlining the entire M&V process that will be followed during the execution of a project. This includes how the performance of a project will be calculated, what data will be used to measure the performance and in what interval the data will be required by M&V.

ESCos are required to sign off on the M&V plan to ensure that all relevant parties are satisfied with how the M&V process will proceed [22]. This report is also completed during the project submission and approval phase.

2.4.2.3. M&V baseline report

The baseline report is the last deliverable required during the project submission and approval phase prior to a project's implementation. The M&V scoping report, plan and baseline report should be completed within 10 days after the M&V team has been assigned to a project [22]. The baseline gives an indication of the pre-implementation power usage of the system being targeted for a DSM intervention. The baseline will be compared with the post-implementation power usage on a daily basis to determine the impact of the project [63]. The baseline should fulfil the following minimum requirements as determined by Eskom Energy Audit, namely [22]:

- The data used to develop the baseline should be in a half-hourly format.
- A minimum of one month's data is required for projects with no seasonal influence.
- A minimum of three months' data is required for projects with a seasonal influence.
- The data should be divided into weekdays, Saturdays and Sundays.

As mentioned in Section 1.2.2, DSM mine pumping projects are often load-shifting projects. Load-shifting projects are energy-neutral and do not increase or decrease the overall power usage of a mine's pumping system. The power usage of the pumps is merely shifted to less expensive TOU periods.

The total power usage is dependent on the amount of water that needs to be pumped per day. This amount may differ from day to day depending on factors such as production and fissure water flow. Comparing the power consumption of a post-implementation day to the baseline can therefore result in an inaccurate depiction of the impact of a load-shifting project.

To overcome this inaccuracy, a service level adjustment factor (SLAF) is used [22]. The SLAF scales the baseline to be energy-neutral to the post-implementation day. The SLAF is determined by using Equation 2 [22]. Equation 2 divides the total energy consumption of the post-implementation day by the total energy consumption of the baseline. The scaled baseline is determined by multiplying each half-hourly value of the baseline by the SLAF. The performance of the project is determined by comparing the scaled baseline and the post-implementation day's power profiles. This process is explained in detail in Appendix II.

$$\boldsymbol{SLAF} = \frac{\boldsymbol{ECP}}{\mathbf{ECB}} \quad \textbf{Equation 2}$$

Where:

SLAF	–	Service level adjustment factor	[–]
ECP	–	Total energy consumption of post-implementation day	[kWh]
ECB	–	Total energy consumption of baseline	[kWh]

2.4.2.4. M&V post-implementation report

The first deliverable M&V teams are required to complete after a project has been implemented is the post-implementation report. This report should be completed within ten days after Eskom IDM issues the completion certificate. The purpose of the post-implementation report is to verify whether a project has been implemented according to plan and what, if any, deviations took place [22].

2.4.2.5. PA reports

PA reports must be completed by the applicable M&V team at the end of each PA period. These reports contain a summary of the project's performance over the previous three months and must be submitted to Eskom IDM and Eskom Energy Audit. Eskom IDM uses these reports to determine the payment ESCos will receive at the end of each PA period [22].

2.4.2.6. PT reports

PT reports are similar to PA reports and should contain the same information. The difference is that PT reports are completed on special request for periods that may differ from the set three-month periods of the PA reports. The PT reports are not used to determine any payments issued to ESCos [22].

Figure 19 outlines when each M&V deliverable must be completed in the DSM project life cycle. For this example, the assumption is made that the initial project proposal has been deemed acceptable and that the project has been approved by Eskom IDM. As can be seen in Figure 19, Eskom IDM may still reject a project even if it has been approved initially by Eskom

TEC and PEC. If this should happen, the M&V scope, plan and baseline reports would still have been completed as they assist Eskom IDM in the approval process.

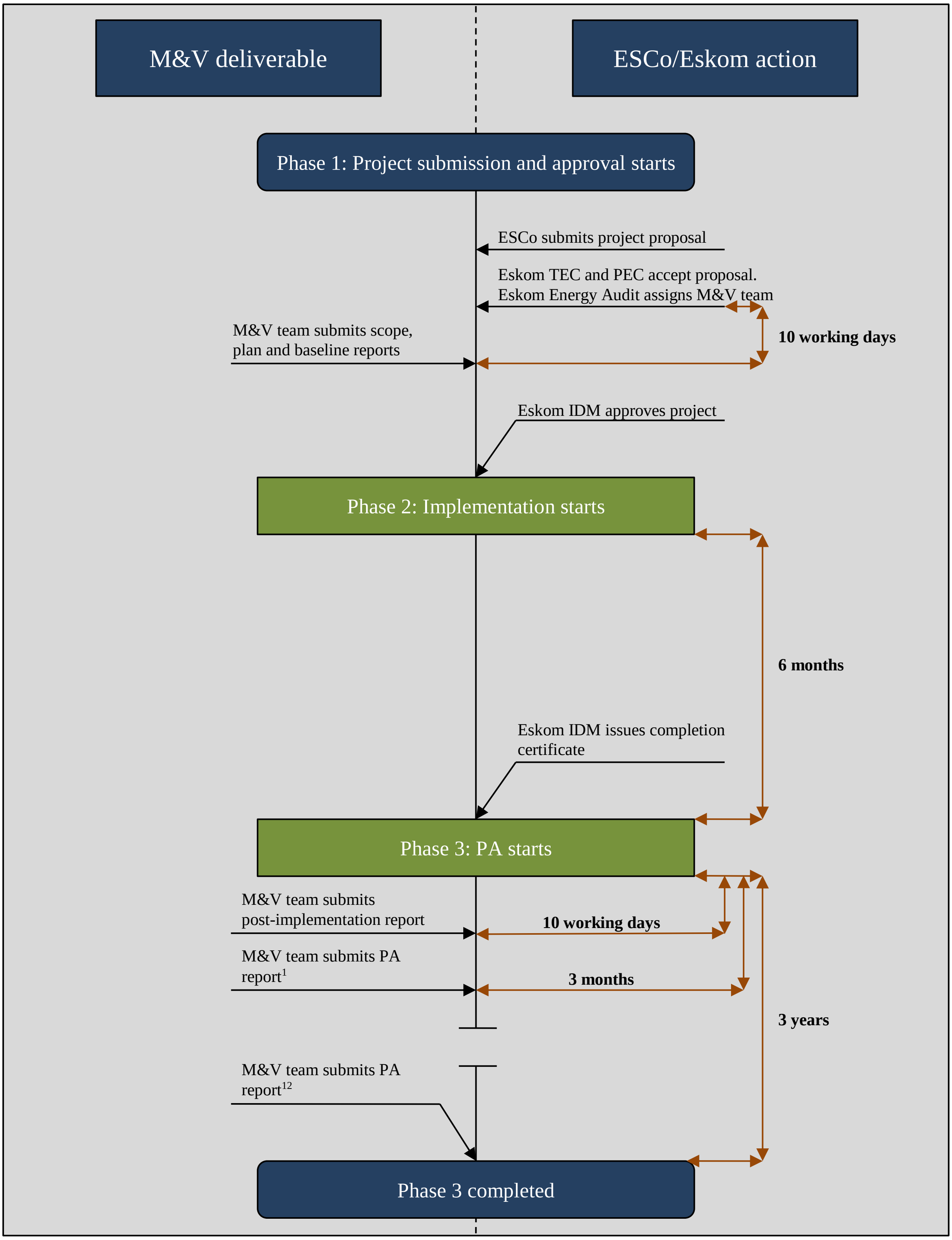

Figure 19: M&V deliverables

2.4.3. DSM mine pumping projects

As mentioned in Section 2.4.2, a load-shifting project is the most common type of DSM project implemented on mine dewatering pumps. Therefore, most DSM mine pumping projects do not endeavour to decrease the overall electricity consumption of the dewatering pumps the project is being implemented on. The aim of these projects is rather to decrease the overall electricity cost. Load shifting DSM mine umping projects therefore form the focus of this study.

Electricity cost savings are achieved by shifting the load of the dewatering pumps from Eskom peak periods to standard and off-peak periods. As the electricity cost is lower during standard and off-peak periods, this will decrease the overall electricity cost of the dewatering pumps. To be able to shift the load of the dewatering pumps, optimised scheduling and control of the dewatering pumps are required.

Optimised scheduling and control of the dewatering pumps entail scheduling the operation of the dewatering pumps to have the fewest number of pumps running during Eskom peak periods. To achieve this, hot water storage dams are used. During Eskom standard and off-peak periods, dewatering pumps are scheduled to drain the hot water storage dams to as near as possible to their minimum allowable levels before Eskom peak periods.

At the start of Eskom peak periods, the dewatering pumps are switched off. The hot water storage dams are allowed to fill until they reach their maximum allowable level. If a hot water storage dam reaches its maximum level before the end of the Eskom peak period, a dewatering pump is started to ensure that it does not overflow. If the hot water storage dams do not reach their maximum allowable levels during the Eskom peak period, the dewatering pumps remain off until the Eskom peak period is completed.

The electricity cost savings DSM mine pumping projects can achieve is illustrated in Figure 20. Profile A illustrates a typical power profile of a mine pumping system where no DSM project has been implemented. Profile B illustrates a typical power profile of a mine pumping system where a DSM project has been implemented. The overall electricity consumption of the two profiles is the same. Profile A and Profile B are plotted on the primary axis. The varying Megaflex TOU electricity tariffs are indicated on the secondary axis. Eskom high demand season TOU periods and tariffs are used for this illustration.

As can be seen from Figure 20, the electricity consumption of Profile B is lower than Profile A during Eskom peak periods, but higher during standard and off-peak periods. However, as electricity tariffs during standard and off-peak periods are lower, the overall electricity cost of Profile B is 5.18% lower than Profile A.

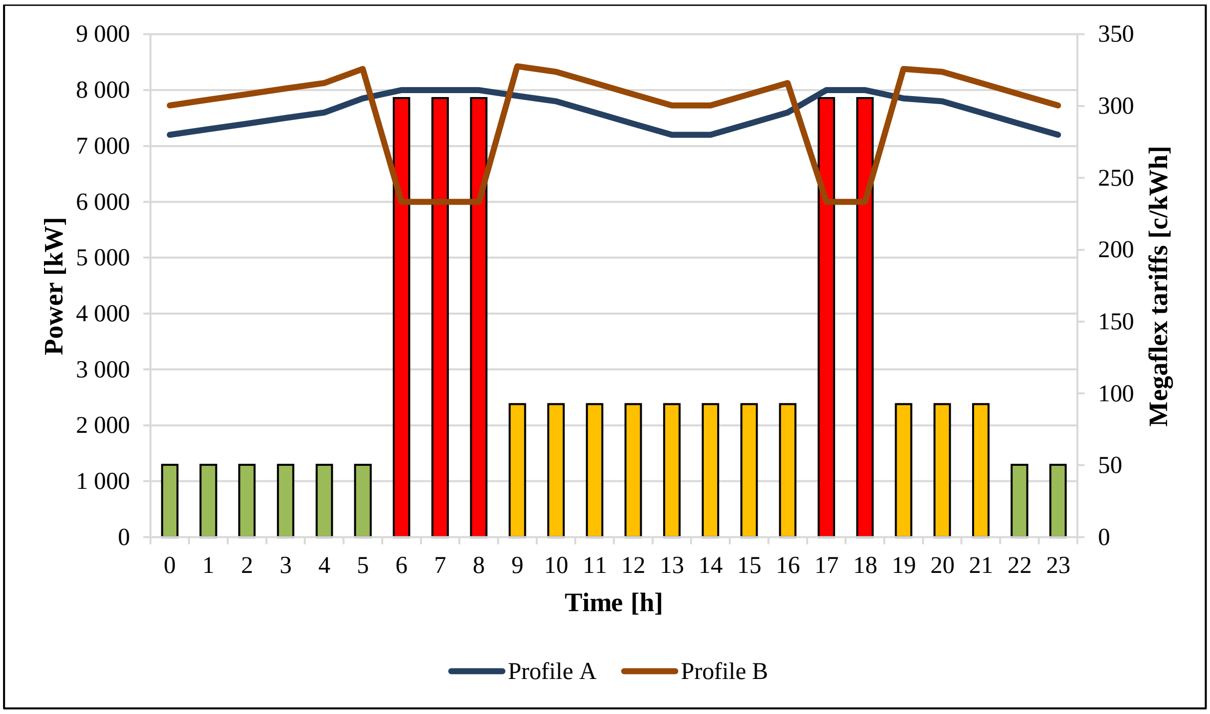

Figure 20: DSM mine pumping projects power profile cost comparison

2.5. Chapter conclusion

In this chapter, an overview of mine water reticulation systems was provided. A critical analysis of previous studies related to DSM on mine pumping systems was performed. This analysis provided the lessons and inputs that are needed for developing a sustainable project strategy. This chapter concluded with an overview of Eskom IDM's ESCo model, the associated M&V processes and DSM mine pumping projects.

CHAPTER 3: DEVELOPMENT OF A SUSTAINABLE PROJECT STRATEGY

[5]

“*A goal without a plan is just a wish.*” – Antoine de Saint-Exupéry

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[5] L. V. Hay, “5 career strategies for writers,” 2013. [Online]. Available: http://www.bang2write.com/2013/06/5-career-strategies-for-writers.html. [Accessed: 24-Jul-2016].

3.1. Introduction

In Chapter 1 the need and objectives for this study were provided. In Chapter 2 an in-depth analysis of mine pumping systems, previous studies related to DSM on mine pumping systems and the new ESCo model were provided. This chapter focuses on developing a sustainable project strategy for reviving DSM mine pumping projects based on the information presented in Chapter 1 and Chapter 2.

3.1.1. Identification of requirements

As mentioned in Section 1.5, this study is focused on reviving DSM mine pumping projects that completed their five-year PT period under the old ESCo model. These are specifically load-shifting projects that have not been maintained and are achieving poor to no electricity cost savings. Five years is a considerable period in the mining environment. During this period, a significant number of changes can occur in a mineshaft’s water reticulation system. A distinction is therefore made between the project as it was implemented originally and the revival of that project. The term “original project” refers to the project implemented originally with the system specifications at the time of implementation. The term “revival project” refers to the revival of the original project under current system specifications.

To verify the suitability of this sustainable project strategy, it has to be measured against clearly defined requirements. The requirements, listed below and described in Table 6, are based on analysing previous studies related to DSM on mine pumping systems (see Section 2.3).

1. Feasibility analysis
2. Reactive maintenance
3. Continuous optimisation of load-shifting performance
4. Regular communication between ESCos and clients
5. Risk management strategies
6. Training of client or ESCo personnel
7. Sustainability of load-shifting performance

The sustainable project strategy is evaluated against the requirements and reiterated until every requirement is met. This chapter concludes with a final verification to showcase where each requirement was met. Figure 21 outlines the legend used to standardise all flow diagrams and organisational charts used in the development of this project strategy.

Table 6: Requirements for sustainable project strategy

Requirement	Description
1	A feasibility analysis needs to be performed by ESCos prior to implementing a project to determine the project risks and savings potential.
2	Reactive maintenance is required to ensure that the cause can be rectified if a project is not achieving its load-shifting target.
3	The strategy should endeavour to continuously optimise and maximise the project's performance.
4	Regular communication is required to ensure good client-ESCo relations.
5	Risk management strategies need to be developed to counteract possible scenarios that may influence the project's performance.
6	Training is required to ensure the project is completed as efficiently as possible.
7	Project savings need to be sustainable over three years.

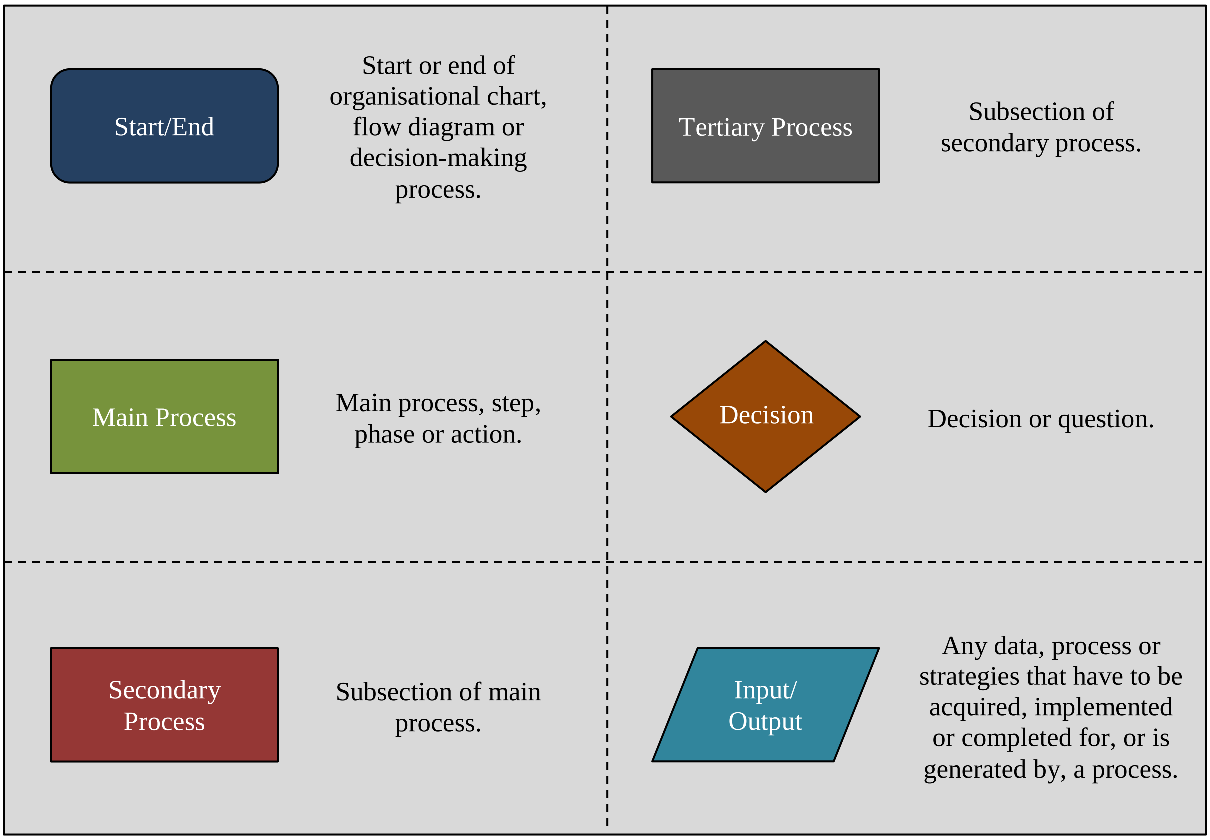

Figure 21: Flow chart legend

As discussed in Section 2.4.1, the new ESCo model can be divided into three phases:

- Phase 1: Project submission and approval
- Phase 2: Project implementation
- Phase 3: Project PA

The sustainable project strategy is divided into three phases to mirror those of the new ESCo model. Phase 1 focuses on investigating the feasibility of reviving possible DSM mine pumping projects. Phase 2 focuses on implementing revival projects that were deemed feasible by ESCos and approved by Eskom IDM in Phase 1. Phase 3 focuses on sustaining the performance of revival projects implemented during Phase 2. A comparison between the project strategy phases and the new ESCo model phases is illustrated in Figure 22.

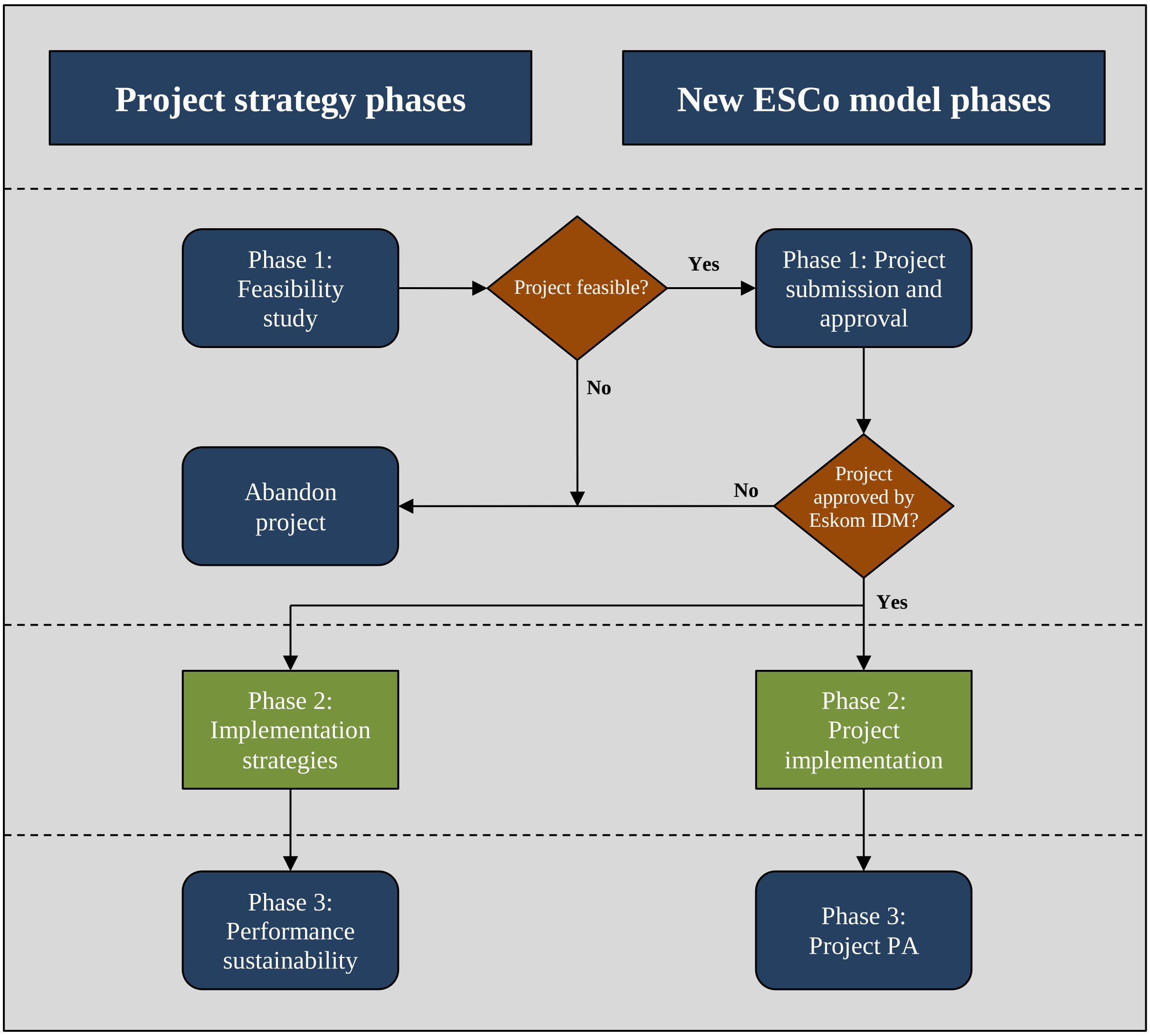

Figure 22: Sustainable project strategy versus new ESCo model

3.2. Project Strategy Phase 1: Feasibility study

This phase entails investigating possible revival projects to determine their electricity cost savings potential and feasibility to revive. Phase 1 is divided into three main steps, namely:

1. [F: I] Investigate
2. [F: S] Simulate
3. [F: A] Analyse

Figure 23 outlines the steps that need to be completed during Phase 1. Please note that abbreviated notations, which are enclosed in square brackets, are allocated to every step of the sustainable project strategy. To serve as an example; the notation [F: I-3] refers to the third section of the [F: I] Investigate step of [F] Phase 1: Feasibility study. The purpose of these notations is to aid with referencing the sustainable project strategy throughout this study. Each main step of Phase 1 is briefly explained here and then elaborated later in this chapter.

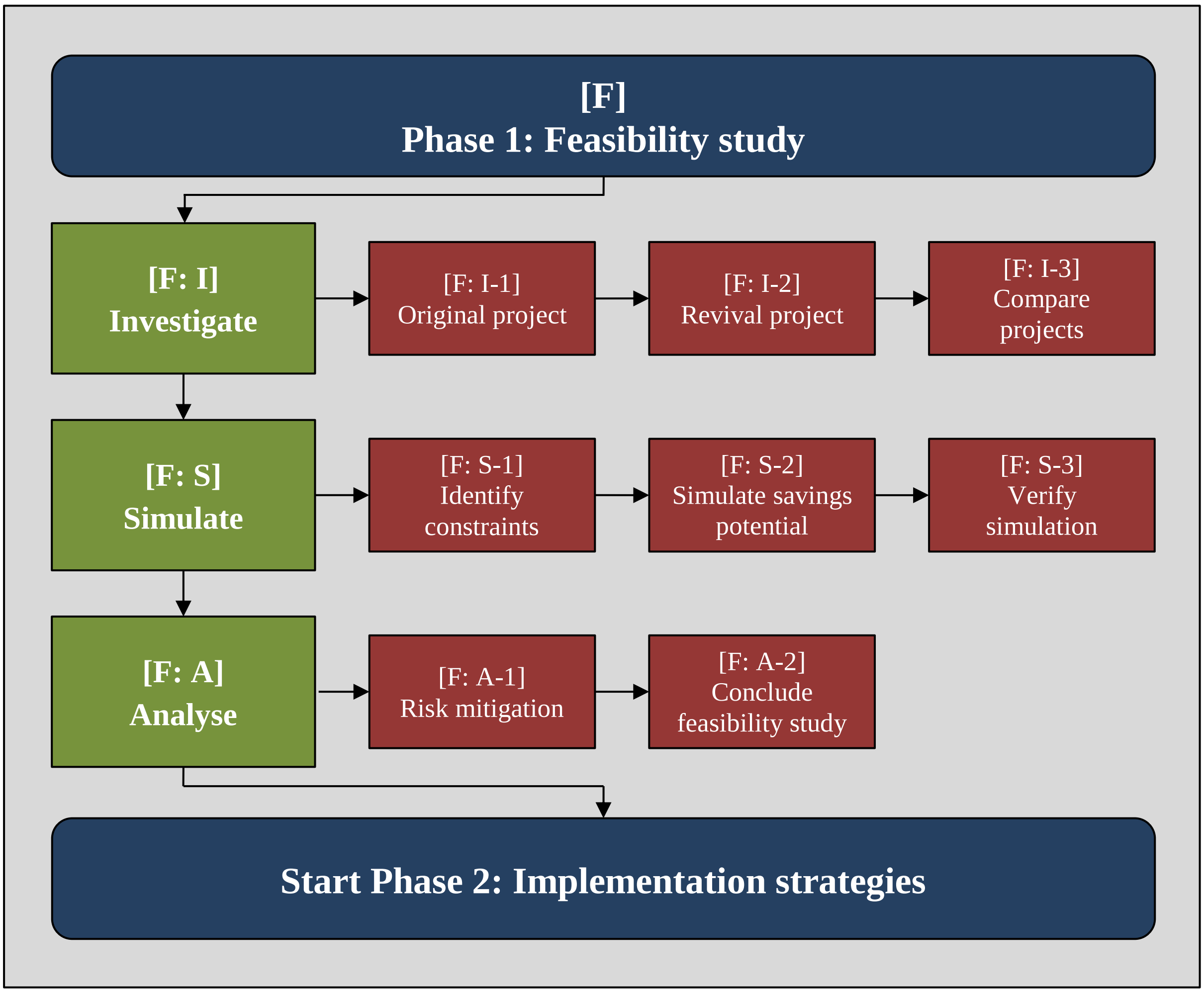

Figure 23: Phase 1: Feasibility study

Step 1: [F: I] Investigate

The purpose of this step is to determine the lessons and inputs that can be acquired from the original projects to sustainably revive them for maximum electricity cost savings. To achieve this, the original project needs to be investigated and compared with the revival project. The following can then be determined:

- Changes that have occurred in the water reticulation system.
- Challenges the original project experienced that may influence the sustainability and performance of the revival project.
- Successful lessons or control strategies that can be carried over to the revival project.

Step 2: [F: S] Simulate

The purpose of this step is to determine the load-shifting potential; therefore, the electricity cost savings potential of the revival project. This aids in determining the feasibility of a revival project. During this step, information regarding the pumping system of the revival project needs to be gathered to perform an accurate simulation.

Step 3: [F: A] Analyse

The purpose of this step is to determine the overall feasibility of the revival project investigated during Step 1 and Step 2. The risks associated with a revival project, its electricity cost savings potential and implementation cost need to be taken into account. This step determines whether a possible project will be revived or not.

3.2.1. [F: I] Investigate

Step [F: I] is divided into three subsections that need to completed sequentially, namely:

- [F: I-1] Investigate the original project.
- [F: I-2] Investigate the revival project.
- [F: I-3] Compare the revival project with the original project.

[F: I-1] Original project

This section of Step [F: I] focuses on investigating the original project's system specifications. This section can be broken down into three subsections, namely:

- [F: I-1a] Determine the layout of the original project's pumping system.
- [F: I-1b] Determine the control methodology of the original project.
- [F: I-1c] Determine the performance of the original project.

This information can be gathered from mine personnel, M&V project reports or the mine's SCADA system. If the revival project is completed by the same ESCo that was responsible for the original project, the original project documentation can be used. Figure 24 outlines this section of Step [F: I].

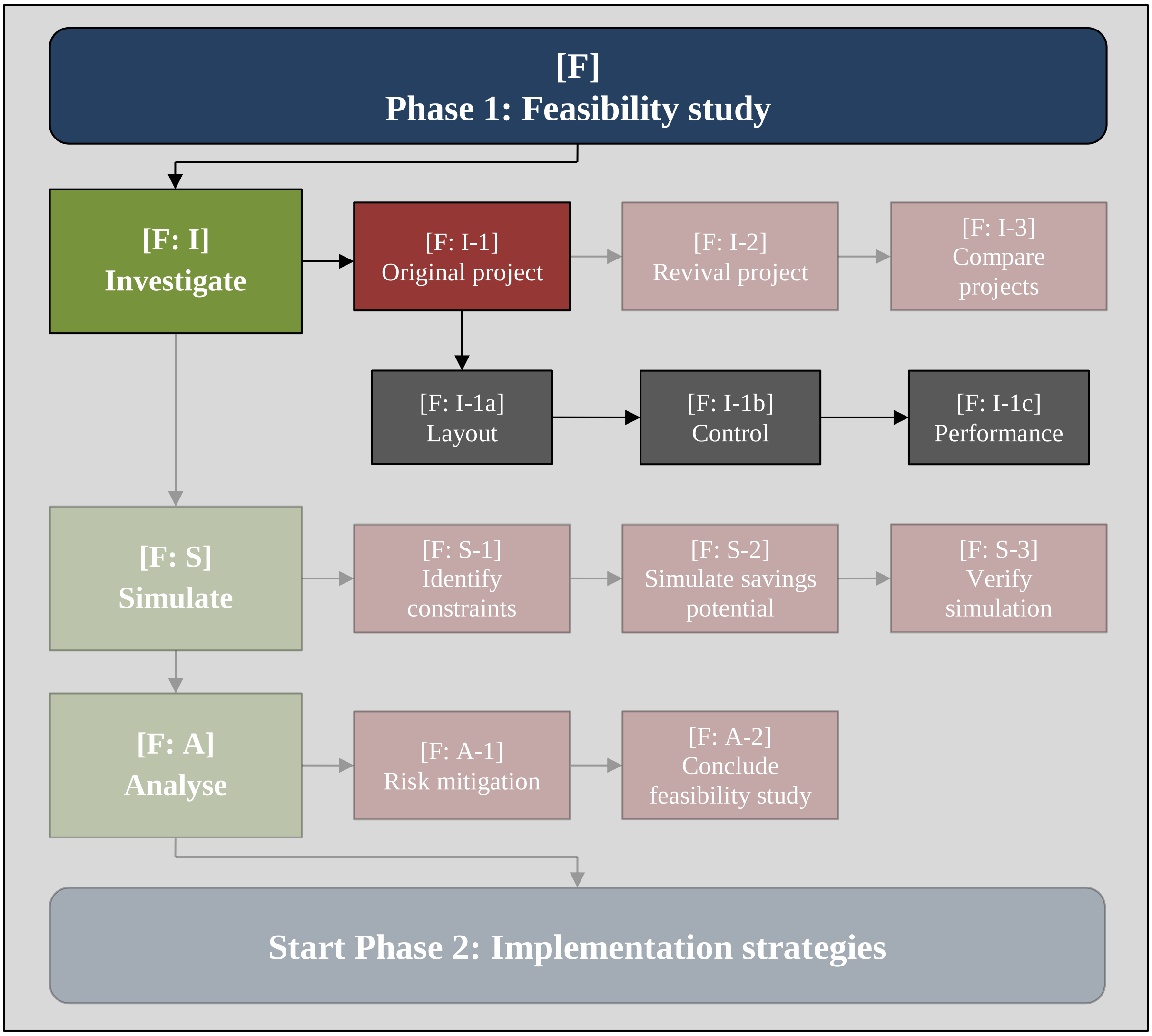

Figure 24: [F: I-1] Investigate original project

[F: I-1a] Layout

To compile an accurate layout of the original project's pumping system, information about the following needs to be gathered for each pumping level:

- Hot water storage dams
- Dewatering pumps
- Water flow rates

For the hot water storage dams, the number of dams and the capacity of each dam have to be determined. For the dewatering pumps, the number of pumps, the average running power of each pump and its delivery flow rate have to be determined. Additionally, the flow rate for the service water, fissure water and transfer water for each pumping level have to be determined. Figure 25 outlines the information that needs to be determined during Step [F: I-1a] of the sustainable project strategy.

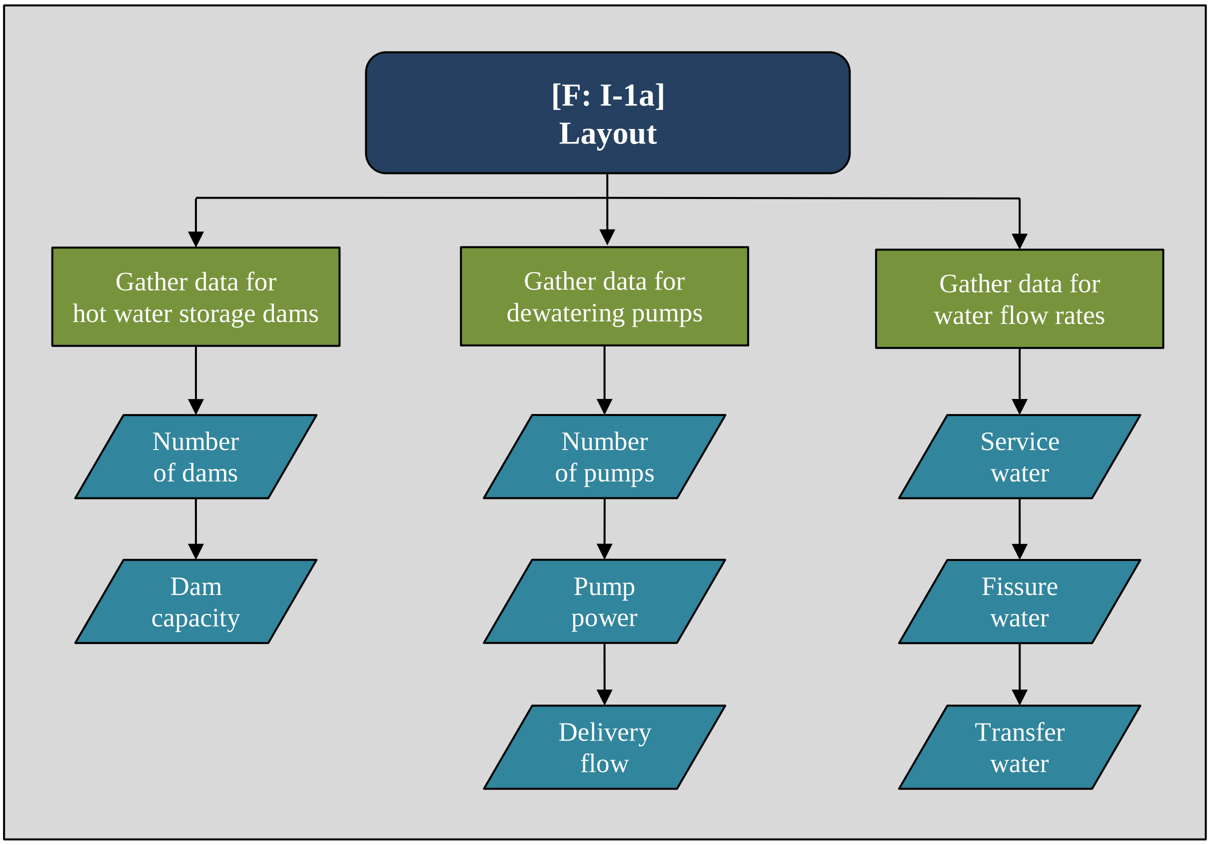

Figure 25: [F: I-1a] Original project's pumping system layout

[F: I-1b] Control

To perform a proper analysis of the original project, the control methodology of the original project needs to be determined. This step can be broken down into two parts:

- Determine the control method of the original project
- Determine the control limits of the original project.

Control method refers to the method of control that was used; for example, the pumps were controlled by the mine's SCADA system in full automatic control mode. The different control methods were outlined while analysing Smith's [56] study in Section 2.3.3. Control limits refer to the maximum and minimum number of pumps allowed to run, as well as the maximum and minimum allowable dam levels. Figure 26 outlines the information that needs to gathered while investigating the control methodology of the original project.

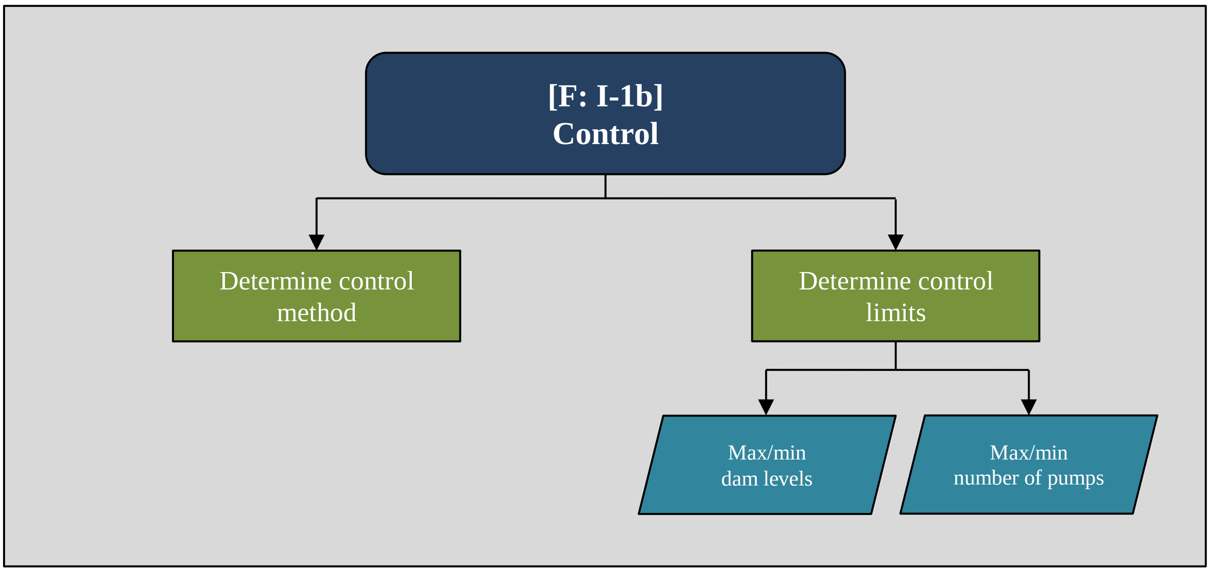

Figure 26: [F: I-1b] Original project's control methodology

[F: I-1c] Performance

The performance of the original projects needs to be analysed. This step can be broken down into two parts:

- Determine the performance of the original project.
- Analyse the performance of the original project.

To determine the performance of the original project, it is advisable that only official M&V PA and PT reports be used. These reports can be obtained from the National Monitoring and Evaluation Centre's website [64] and eliminates the risk associated with untrustworthy data. The performance needs to be determined for both the PA and PT periods. This allows for objective analysis of the original project's sustainability.

The performance analysis needs to be completed to determine possible pitfalls for the revival project. This entails identifying the challenges or risks experienced by the original project that may have influenced its performance. Figure 27 outlines this section of Step [F: I-1].

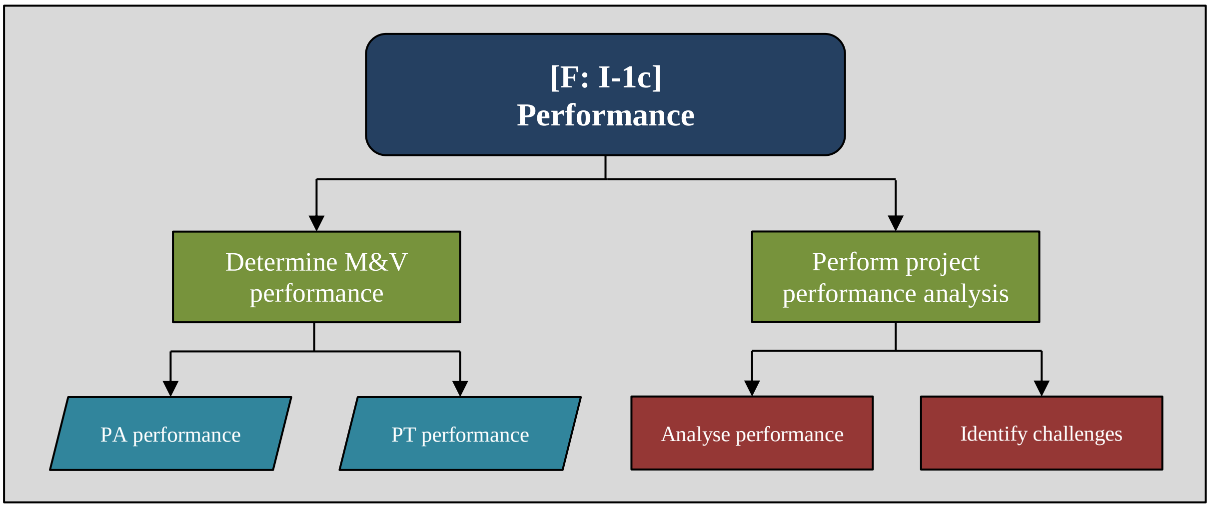

Figure 27: [F: I-1c] Original project's performance analysis

[F: I-2] Revival project

This section of Step [F: I] focuses on investigating the revival project's system specifications. This section can be broken down into two parts:

- [F: I-2a] Determine the layout of the revival project's pumping system.
- [F: I-2b] Calculate a power baseline of the current operation of the dewatering pumps.

As mentioned in Section 3.1.1, a significant number of changes can occur in a mineshaft's water reticulation system over the five-year PT period. This creates the need for ESCos to reinvestigate the revival project's pumping system layout rather than assuming that it is the same as the original project. As the same information is required, the same methodology that was used to investigate the original project can be followed to investigate the revival project. The difference is that M&V reports can no longer be used as a source of information as they focused on the original project. The required information can be gathered by the following methods:

- Investigate the mine’s SCADA system.
- Communicate with mine personnel.
- Conduct site visits to investigate the layout of the pumping system.

A baseline has to be calculated to determine the current operation of the dewatering pumps. This will enable ESCos to determine whether there is scope to achieve additional load shifting to generate additional electricity cost savings. The baseline has to meet the minimum requirements as set out in Section 2.4.2. This step is crucial as the baseline will be compared with the simulated optimised profile in Step [F: S-2] to determine the potential electricity cost savings. Figure 28 outlines this section of Step [F: I].

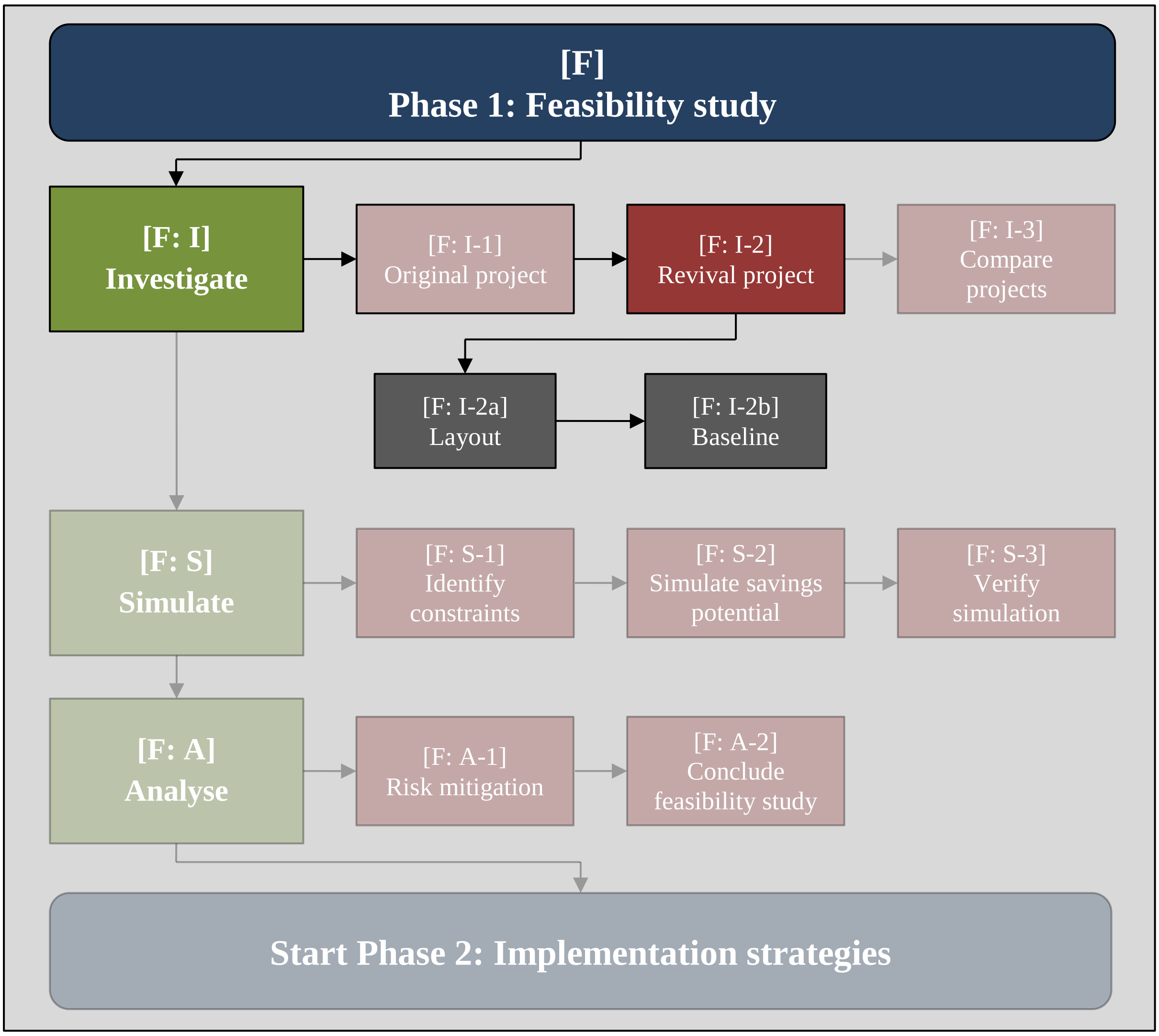

Figure 28: [F: I-2] Investigate revival project

[F: I-2a] Layout

To accurately compare the revival project with the original project, the same information needs to be acquired for both projects – information regarding hot water storage dams; dewatering pumps and water flow rates. This information was described in Step [F: I-1a] of this project strategy and illustrated in Figure 25.

[F: I-2b] Baseline

Various different methods can be used to calculate the power baseline of the dewatering pumps. Each methods relies on a different source of data to determine the average running power of each pump. It is advised that at least two different calculation methods are used to ensure the integrity of the baseline. This is, however, dependent on the available data that may vary from mine to mine. Regardless of which data source is used, it still has to meet the minimum requirements as set out in Section 2.4.2.3. Three of the most common methods used to develop baselines are log sheets, pump status data and power loggers. These methods are described in the subsections that follow.

1. Log sheets

Log sheets refer to physical daily logs that are completed by surface control room operators. When a pump is started or stopped, the operator marks the time of the occurrence. From these log sheets it can be determined when each pump was running. To determine the baseline, the running power of each pump is multiplied with its running status (on or off) for every day.

The running power of each pump can either be determined by installing temporary calibrated power loggers or by using the rated motor power of the pump as an estimation. As pumping baselines are scaled energy-neutral, the degree of uncertainty with using the pump motor rating is acceptable.

2. Pump status data

This method is similar to using log sheets, except in this case, the running status of each pump is obtained directly from the mine’s SCADA system. This method is more accurate than the log sheet method as it eliminates the possibility of human error with logging the running status of each pump manually. The average running power of each pump is multiplied with its running status to determine the baseline.

3. Power loggers

In some cases, the mine already has power loggers installed on each pump from which the baseline can be calculated directly. These are, however, the minority of cases as it is expensive to install power loggers, especially in underground conditions. It also happens that mines may install a single power meter on a pump feeder electrical cable. This data can also be used providing that there is no additional equipment fed from that feeder.

In the rare case that no information is available, temporary calibrated power loggers are installed. These power loggers have to be installed for a period of at least one month to meet the minimum M&V requirements. This should be avoided as it delays the baseline development process and the power loggers should be calibrated beforehand to ensure accurate readings.

Baseline comparison

The main criterion for comparing baselines obtained through different calculation methods should not be their half-hourly average power values. This may seem contradictory, but stems from the fact that there are inherent value differences depending on the data source used. The main criteria should therefore be the following:

- Peak-to-average (PTA) ratio
- Correlation

The PTA ratio of a baseline refers to the ratio between the average power during Eskom peak periods compared with the average power over 24 hours. A PTA ratio of 0 means there is no energy consumption during peak periods, which is indicative of perfect load shifting. A PTA ratio of 1 means that the average power during peak periods is the same as during the rest of the day, which is indicative of no load shifting. A PTA ratio of higher than 1 means that the average power during peak periods is higher than during the rest of the day.

The PTA ratio therefore provides a quick assessment of the additional load-shifting potential of a mine’s pumping system. The higher the PTA ratio, the higher the potential is to achieve additional load shifting compared with the baseline. The final load-shifting potential needs to be determined by a simulation taking all of the system constraints into account. The PTA ratio of baselines developed from different data sources should be similar to verify that the baselines have similar load-shifting potential. Equation 3 illustrates how the PTA ratio of a baseline is calculated.

$$\mathbf{PTA} = \frac{\mathbf{APC}}{\mathbf{ADC}} \qquad \textbf{Equation 3}$$

Where:

PTA – Peak-to-average ratio [–]
APC – Average peak hour energy consumption [kW]
ADC – Average daily energy consumption [kW]

Correlation refers to the statistical analysis of how closely two data sets are related. Correlation can vary between –1, the lowest possible correlation, and 1, the highest possible correlation. In other words, if the correlation between two data sets is 1, it means that when the value of one data set increases, the other increases as well. The same is true for when the value of one data set decreases. The correlation of baselines calculated from different data sources should therefore be close to 1 to verify that they have similar profiles. Equation 4 illustrates how the correlation between two baselines can be calculated by using Pearson’s correlation coefficient [65].

$$\mathbf{r} = \frac{\mathrm{N}\sum xy - (\sum x)(\sum y)}{\sqrt{\left[\mathrm{N}\sum x^2 - (\sum x)^2\right]\left[\mathrm{N}\sum y^2 - (\sum y)^2\right]}} \qquad \textbf{Equation 4}$$

Where:

r – Pearson’s correlation coefficient [–]
N – Number of values in data set [–]
$\sum$ – The sum of the values in the data set [–]
x – Data Set 1 value [kW]
y – Data Set 2 value [kW]

Figure 29 shows a comparison between two baselines that have the same PTA ratio of 0.52, with a correlation of 1. Eskom high demand season TOU periods are used for this illustration. The total energy consumption of Baseline 1 is 75% more than Baseline 2. Figure 30 illustrates that when the baselines are scaled to be energy-neutral to the test profile, they are exactly the same. The test profile symbolises a power profile for a typical mine’s pumping system where a DSM load-shifting project has been implemented.

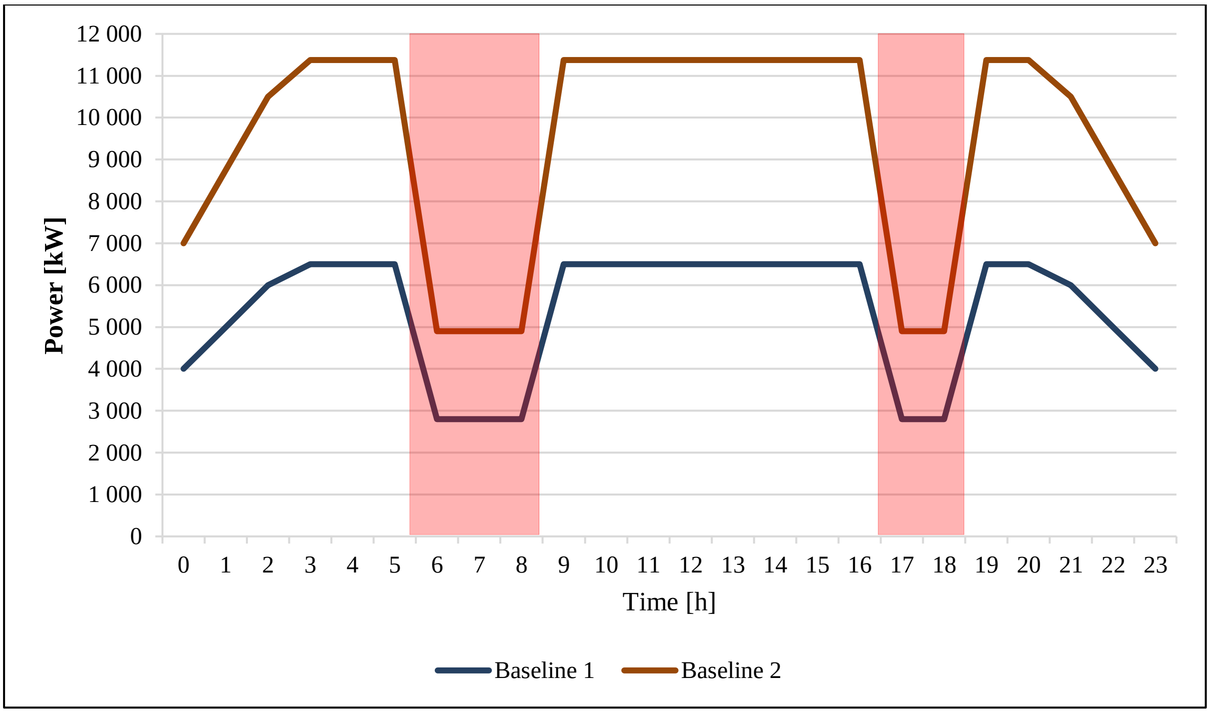

Figure 29: Baseline comparison

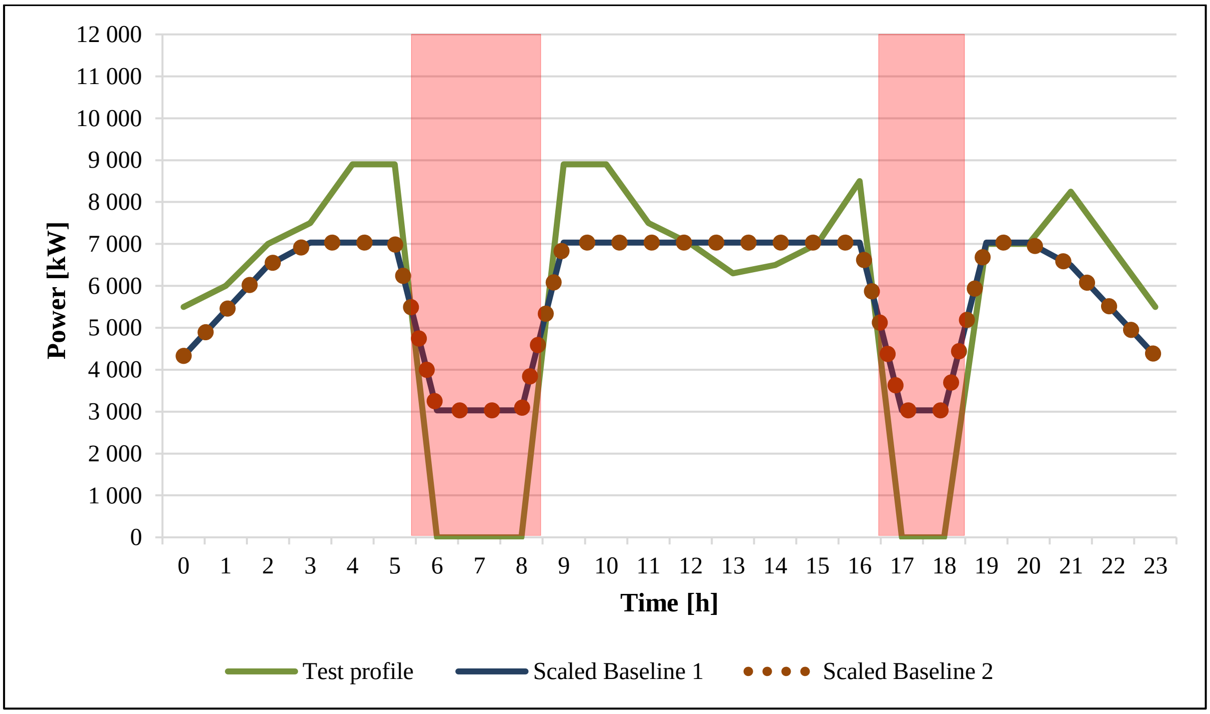

Figure 30: Scaled baseline comparison

Based on personal experience, it is advised that the PTA ratios of comparative baselines must be within 10% of each other and the correlation between the two baselines must be higher than 0.9. If baselines developed from different data sources are within these criteria limits, they can be accepted as an accurate description of the pumping system. If the baselines are not within these limits, the cause of the difference needs to be identified and rectified first. If only one data source is available, mine personnel along with the M&V team and ESCo have to approve the baseline before it can be accepted. Figure 31 outlines this baseline development methodology. The data used to develop the baseline should still, however, meet the minimum M&V requirements as explained in Section 2.4.2.

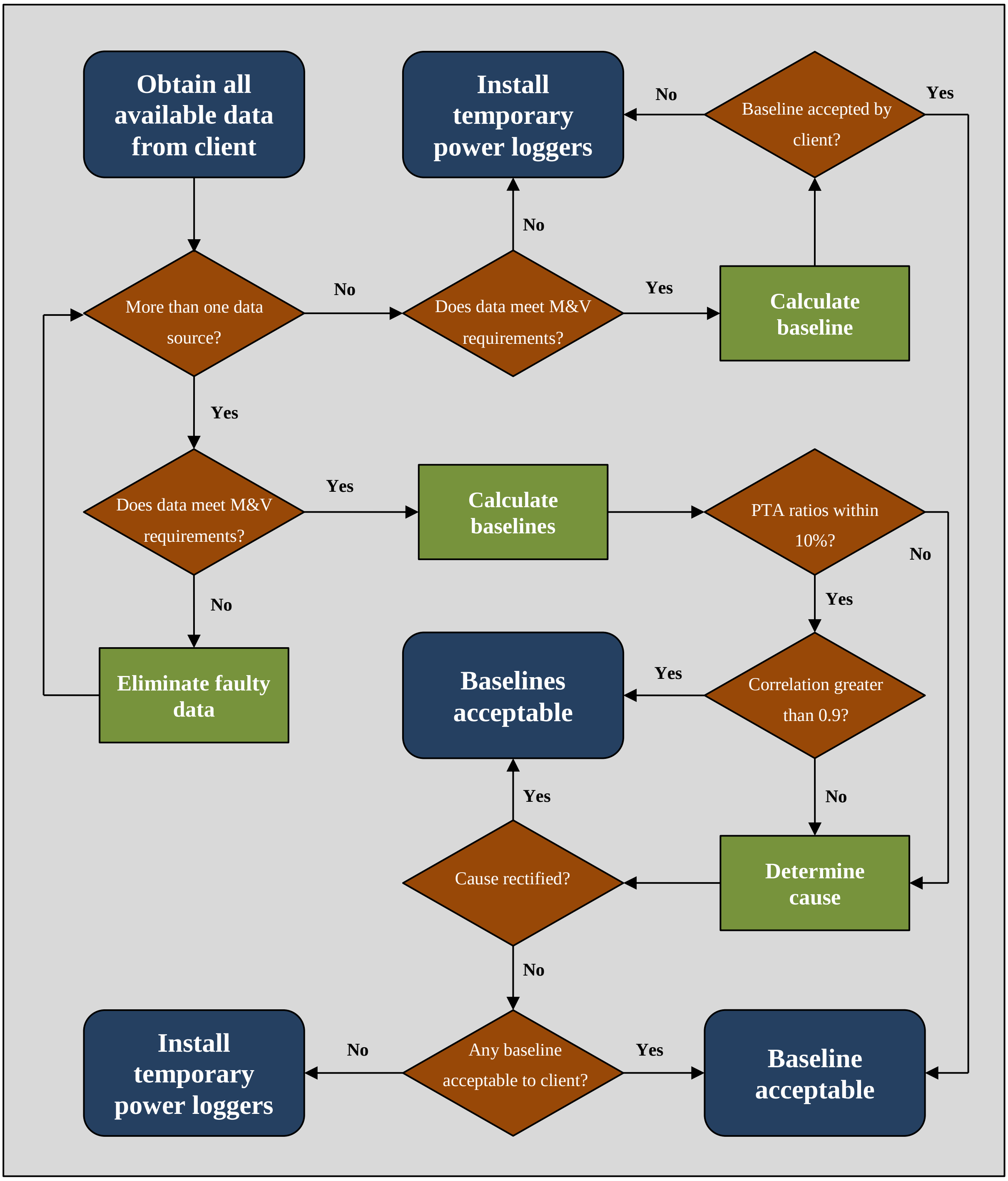

Figure 31: Baseline development methodology

[F: I-3] Compare projects

In the final section of Step [F: I], the original project needs to be compared with the revival project. The pumping system layout of the original project first needs to be compared with the revival project. This allows ESCos to determine any hardware changes that may have an influence on the revival project. Secondly, the pumping system operation needs to be compared. This allows ESCos to determine whether the project constraints are still the same or if there are any additional constraints that have to be adhered to. Figure 32 outlines this section of Step [F: I].

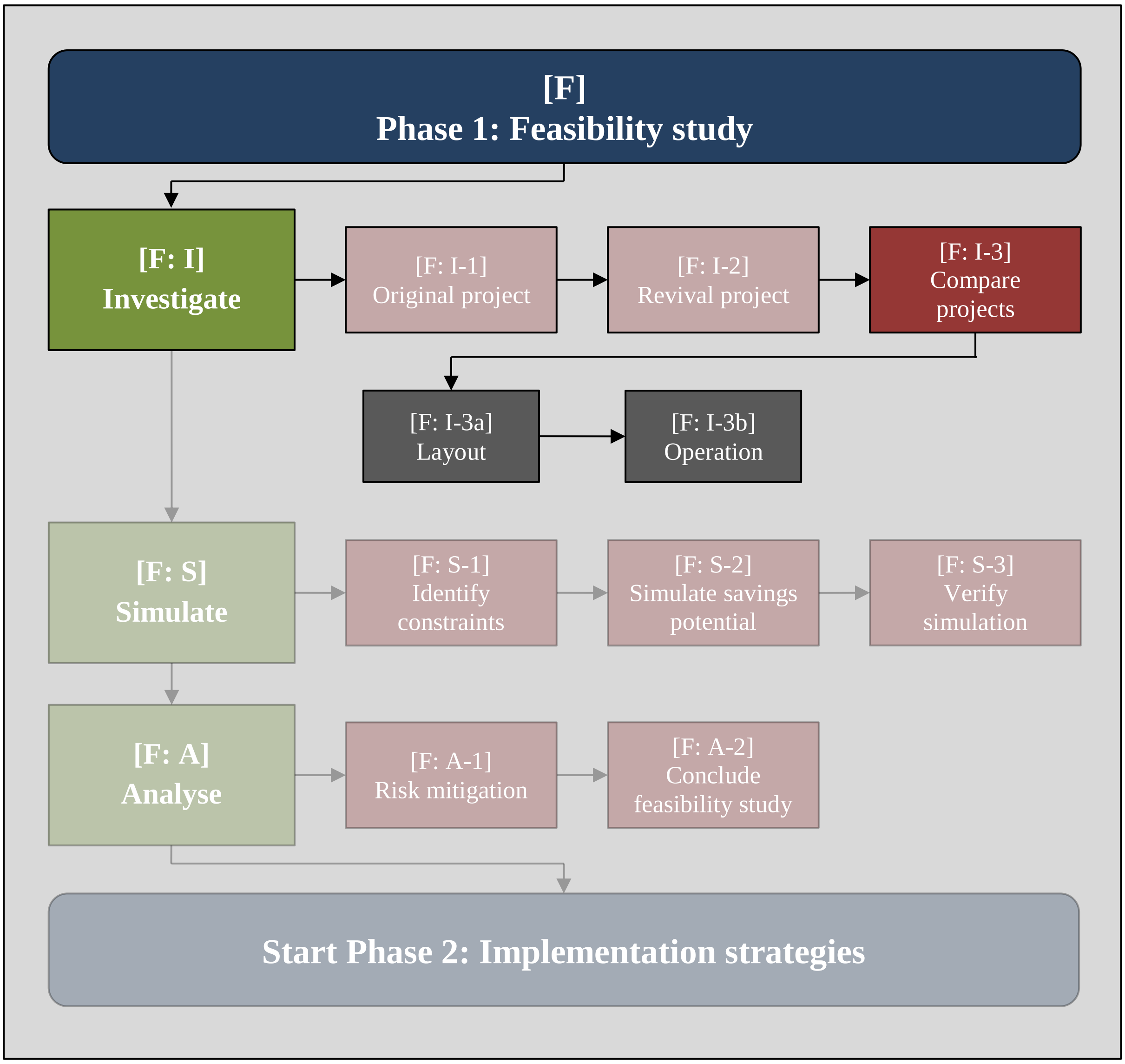

Figure 32: [F: I-3] Compare projects

3.2.2. [F: S] Simulate

Step [F: S] is divided into three sections that need to completed sequentially, namely:

- [F: S-1] Identify the system constraints.
- [F: S-2] Simulate the potential load shifting.
- [F: S-3] Verify the simulation.

[F: S-1] Identify constraints

In this section of Step [F: S], the constraints that the simulation have to adhere to need to be determined. The constraints that have to be determined are:

- Maximum and minimum allowable hot water storage dam levels.
- Maximum and minimum number of pumps allowed to run on each pumping level.
- Shaft-specific constraints.

Maximum dam level refers to the maximum dam limit mine personnel are willing to have while still maintaining a small safety margin in case of emergencies. Minimum dam level refers to the minimum limit before the dewatering pumps start to pump sludge. These values will differ from mine to mine, and even from pumping level to pumping level.

In most cases, mines have more than one hot water storage dam per pumping level. In some cases, not all of the hot water storage dams are used simultaneously. This can either be because the mine is busy cleaning a hot water storage dam, or because the mine prefers to keep one hot water storage dam empty to use in emergency situations only.

The maximum and minimum number of pumps may vary according to the time of day or the hot water storage dam levels. In some cases, mines may prefer to limit the number of pumps. This can be because the mine does not want to breach its notified maximum demand or because the mine prefers not to allow multiple pumps to pump into the same column. These constraints have to be considered for the simulation.

Shaft-specific constraints are constraints unique to each shaft. An example of such a constraint can be that certain pumps on a pumping level are not allowed to run at the same time as they may overload an electricity panel. These are constraints that will influence the simulation and must be determined for each shaft.

Figure 33 outlines the constraints that need to be determined to complete the simulation.

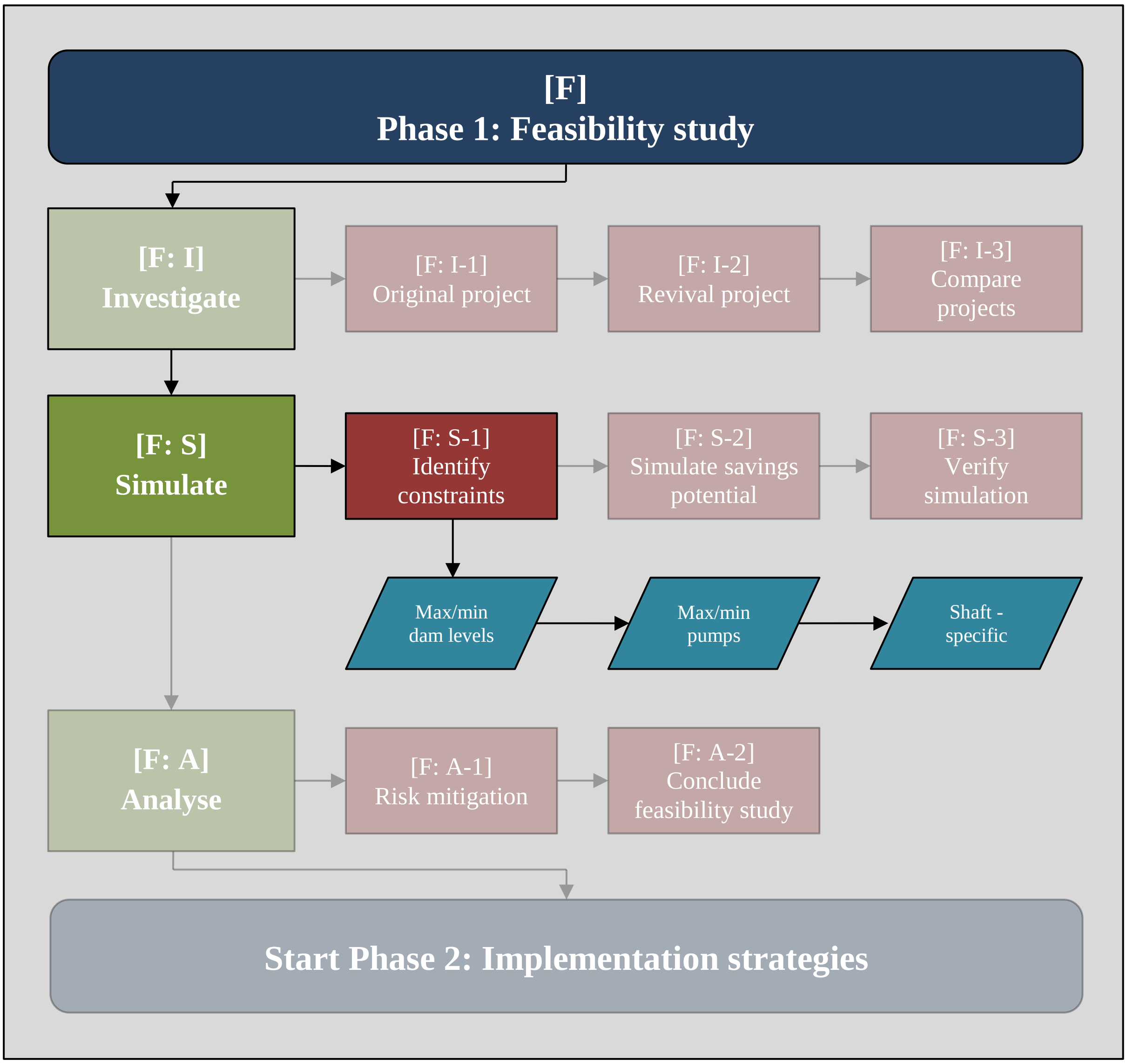

Figure 33: [F: S-1] Identify constraints

[F: S-2] Simulate savings potential

In this section of Step [F: S], a simulation needs to be performed to determine the simulated power profile. The simulated power needs to be compared with the revival project's baseline developed in Step [F: I-2b]. This determines the load-shifting potential, thus the electricity cost savings potential, of a revival project. This section can be broken into:

- [F: S-2a] Decide on the simulation program.
- [F: S-2b] Perform the simulation adhering to the constraints of [F: S-1].
- [F: S-2c] Determine potential load shifting.

To perform the simulation, ESCos need to decide on a simulation program. A variety of programs may be used. Some examples are:

- Microsoft Excel™
- Pumpsim™
- PumpLinx®
- ESCo in-house simulation software

It is advised that ESCos use a standardised program and train their personnel properly in the use thereof. This will ensure consistent and accurate results. Figure 34 outlines this section of Step [F: S].

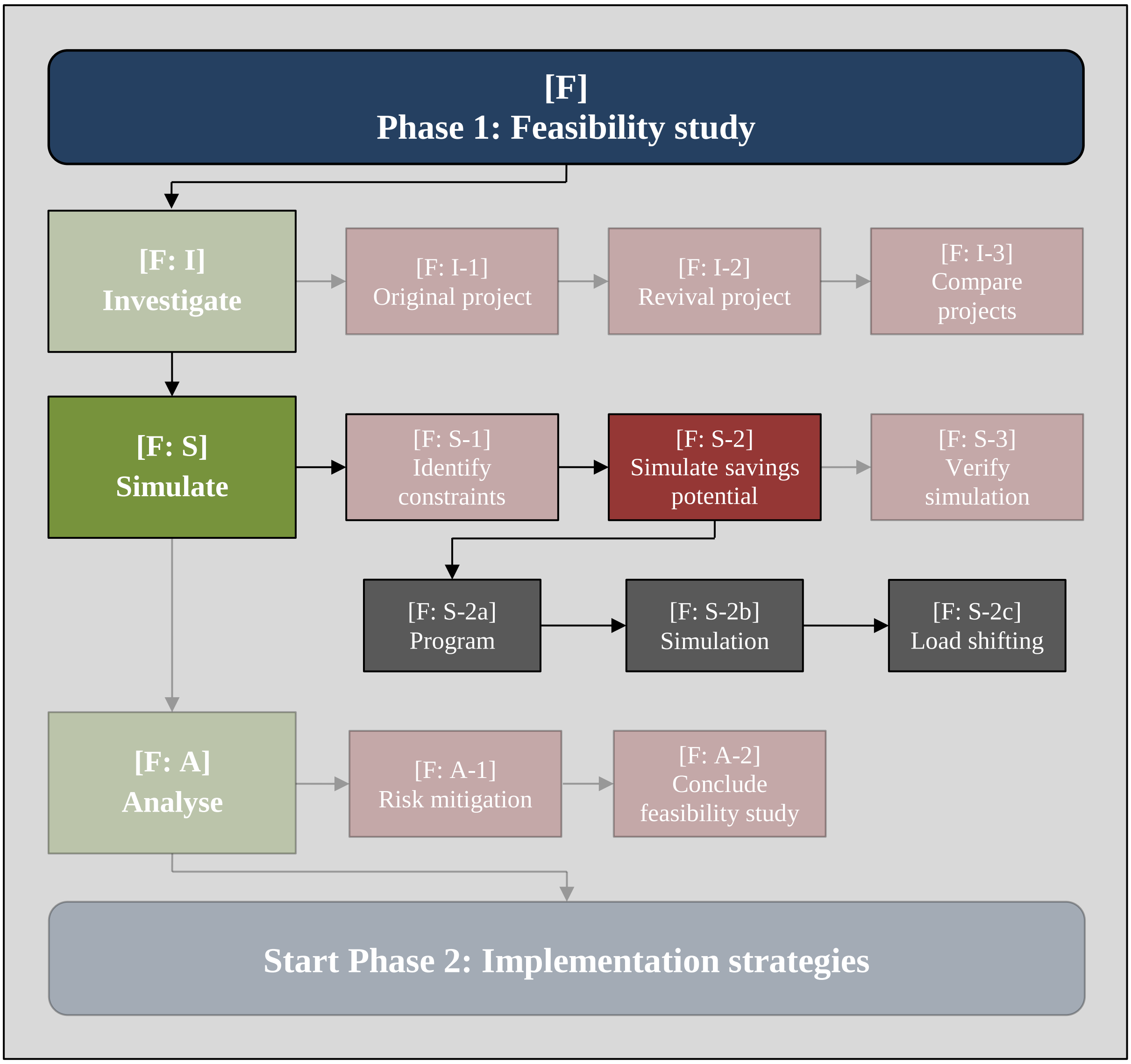

Figure 34: [F: S-2] Simulate savings potential

[F: S-3] Verify simulation

In the final section of Step [F: S], the simulation performed in [F: S-2] needs to be verified to ensure its validity. To verify the simulation, an actual load-shifting test must be performed on-site. A load-shifting test entails ESCo personnel using the simulation constraints of [F: S-1] to manually control the pumps from surface. This will also give ESCos insight into constraints not taken into consideration for the simulation. Figure 35 outlines this section of Step [F: S].

The results of the load-shifting test must be compared with the simulated power profile. The power profiles may not match precisely due to uncontrollable variables during the load-shifting test. It is however advised that the achieved average evening peak period load shift is either higher or within 10% of the simulated load shift to confirm the accuracy of the simulation.

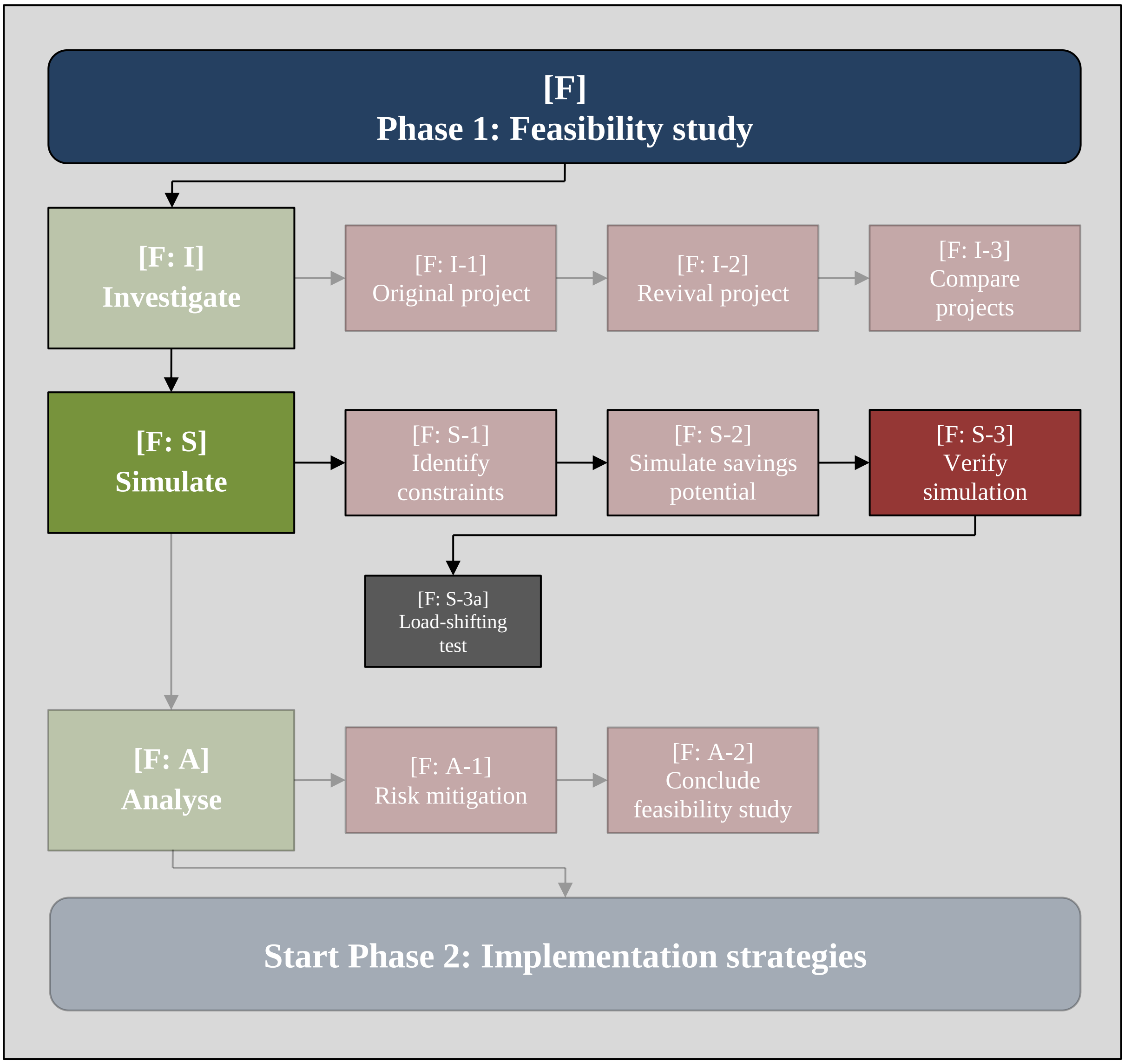

Figure 35: [F: S-3] Verify simulation

3.2.3. [F: A] Analyse

Step [F: A] is divided into two sections that need to completed sequentially, namely:

- [F: A-1] Identify and mitigate the revival project risks.
- [F: A-2] Conclude the feasibility study.

[F: A-1] Risk mitigation

In this section of Step [F: A], the risks associated with a revival project need to be identified. Risks that will influence the performance or sustainability of the revival project need to be mitigated. Communication with mine personnel is crucial as they provide valuable insight into determining the possible risks. Figure 36 outlines this section of Step [F: A].

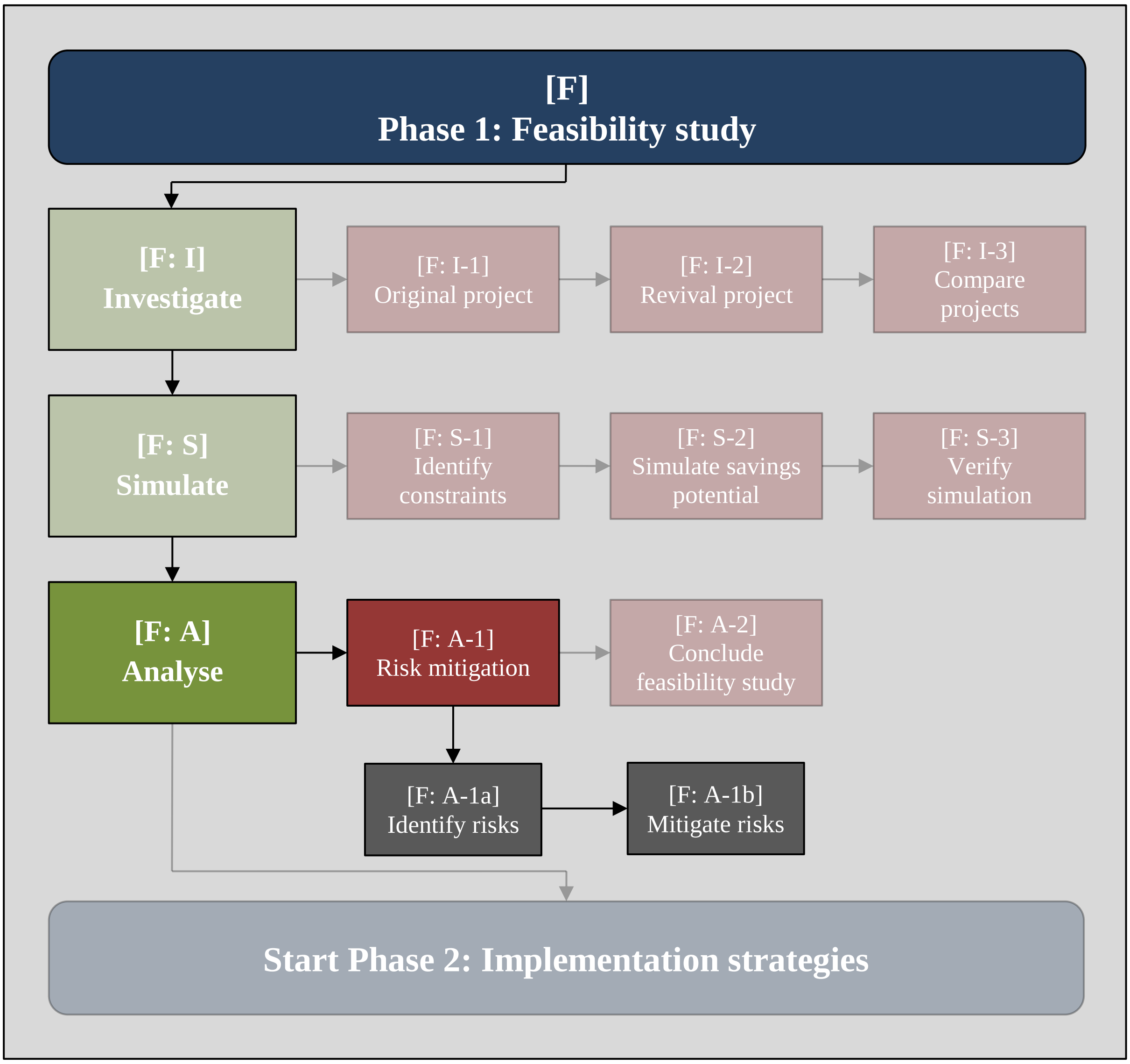

Figure 36: [F: A-1] Risk mitigation

[F: A-2] Conclude feasibility study

In the final section of Phase 1, ESCos need to complete the feasibility study on the possible revival project. This section can be broken down into two steps, as outlined in Figure 37:

- [F: A-2a] Conduct feasibility analysis with pertinent considerations taking into account.
- [F: A-2b] Make a final decision whether to submit a project to Eskom IDM for funding.

The project implementation cost is an important consideration as ESCos no longer receive funding upfront. The potential electricity cost saving has to be considered against the implementation cost, the remaining life of the mine and risks associated with a revival project. It is critical that ESCos perform this analysis to decide whether to implement a revival project.

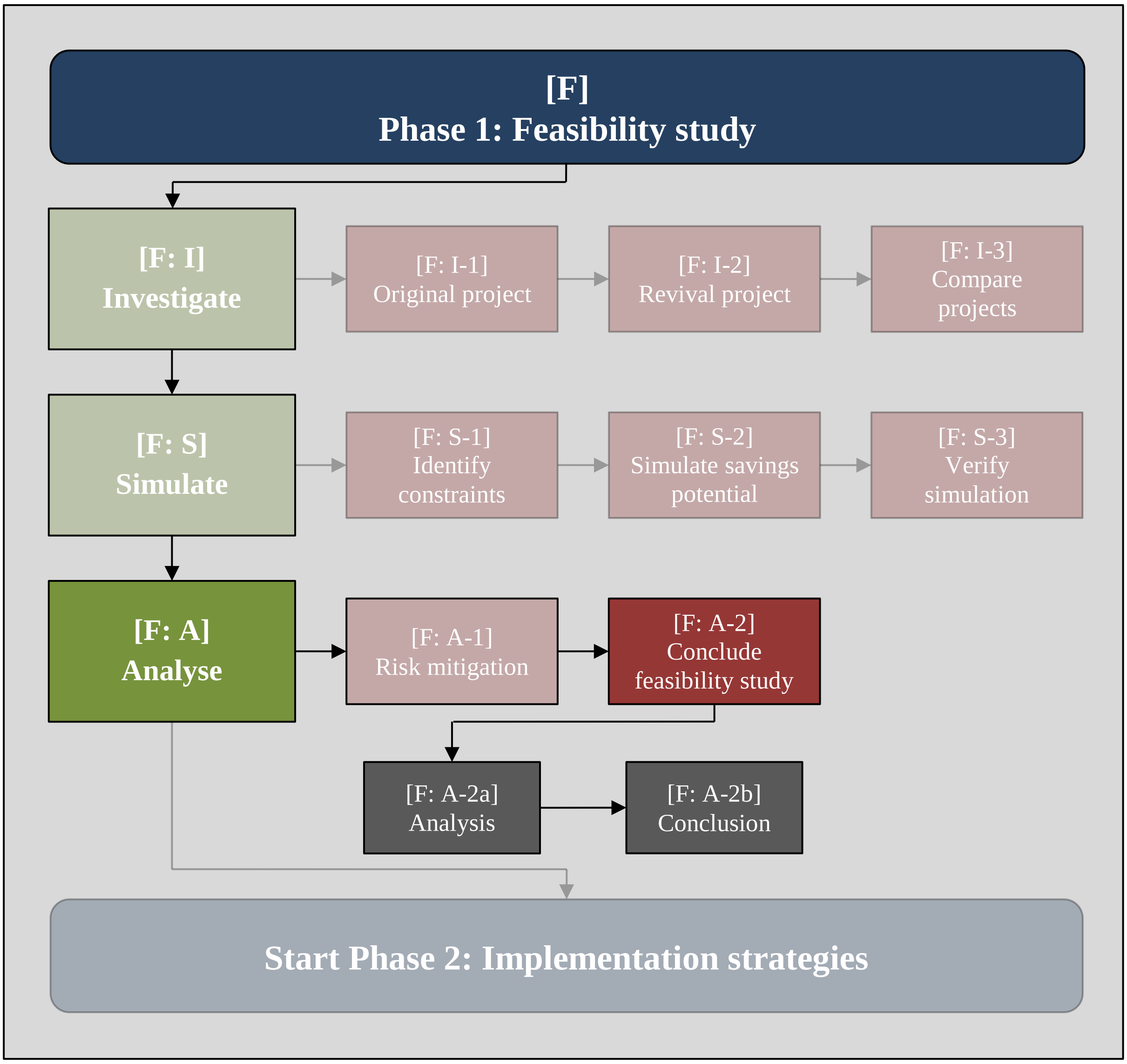

Figure 37: [F: A-2] Conclude feasibility

3.3. Project Strategy Phase 2: Implementation strategies

ESCos are familiar with the required processes for implementing DSM projects under the old ESCo model. The main focus of Phase 2 is therefore to develop strategies to mitigate the risks associated with the new ESCo model. Figure 38 provides an overview of Phase 2. Each section of Phase 2 is explained in the following sections.

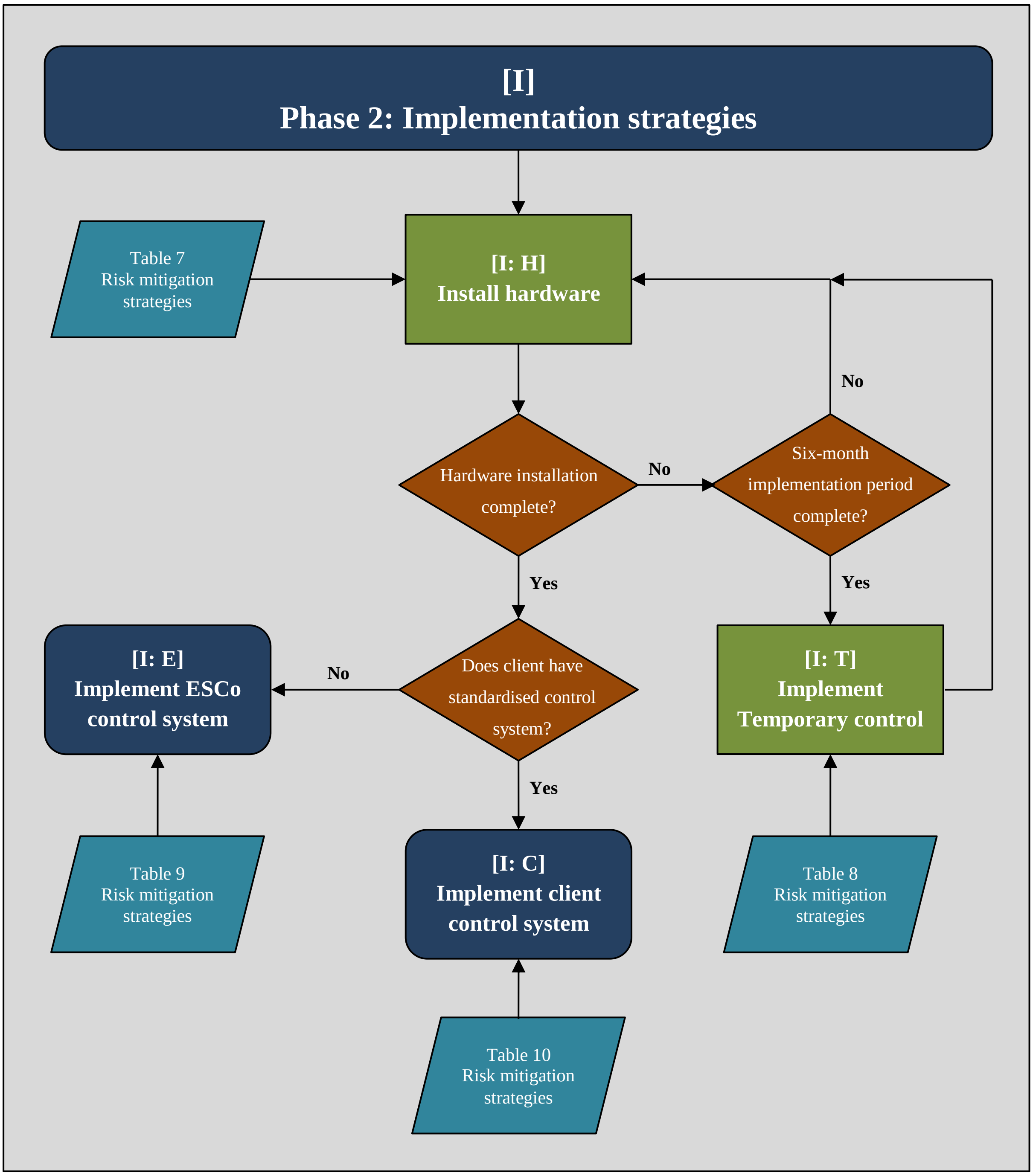

Figure 38: Phase 2: Implementation strategies

3.3.1. [I: H] Install hardware

Revival projects can be seen as the low-hanging fruit of DSM projects because of their expected low implementation costs. The hardware installations required, however, differ from project to project. ESCos need to be prepared if any installations are required. Section 1.2.2 and Section 2.4.2 respectively highlighted the new ESCo model challenges influencing hardware installations. Table 7 lists the risks associated with these challenges and their respective mitigation strategies.

Table 7: [I: H] Risk mitigation strategies for installing hardware

[I: H] Install hardware	
Risk	**Mitigation strategy**
Long lead times on required hardware.	Identify the necessary hardware required during Phase 1. Order long-lead time items as soon as a project has been approved by Eskom IDM.
Costly installations are required that are beyond the ESCo's budget.	Prove the added benefits of the installations to the client in order for them to assist with the installation budget.
	Use a percentage of the electricity cost savings achieved to pay for the required hardware.
Client requests hardware that is beyond the ESCo's budget and is not essential to the project's performance.	Use a percentage of the electricity cost savings achieved over time to pay for non-essential hardware.

3.3.2. [I: T] Temporary control

The risk mitigation strategies of Step [I: H] are not foolproof. It may still happen that the first PA period starts without the hardware installations being completed. This is because of the short six-month implementation period provided by Eskom IDM and the effect of long lead-time hardware. This creates the risk that the project may not be able to achieve its load-shifting target. To mitigate this risk, temporary control methods need to be implemented. Temporary control methods vary depending on the specific project, but can include the following two methods:

- ESCo personnel must train underground pump operators to monitor the pumping system. The operators then monitor key system parameters, such as dam levels and pumps running. The underground operators perform load shifting based on their training by minimising pump operation in Eskom peak periods.
- ESCo personnel must train surface control room operators to monitor the pumping system. The operators either monitor key system parameters on the mine's SCADA system (if available) or phone the underground operators for the information. The surface control room operators perform load shifting based on their training or with the assistance of ESCo personnel monitoring the system remotely.

Temporary control also creates risks that need to be properly mitigated. Table 8 lists these risks and their respective mitigation strategies.

Table 8: [I: T] Risk mitigation strategies for implementing temporary control

[I: T] Implement temporary control	
Risk	**Mitigation strategy**
Specified safety control limits are ignored by underground pump operators.	ESCo personnel need to train pump operators properly.
The project's load-shifting target is not achieved.	ESCo personnel need to identify the cause of the underperformance and improve the temporary control method.
Operators are distracted by other duties and do not monitor the system diligently enough.	ESCo personnel need to monitor the system remotely and notify operators when action is needed.

3.3.3. Control system

Once the required hardware installations have been completed, ESCos can proceed with the planned implementation of a project. This entails implementing the preferred, sustainable control system of the project. Usually ESCos have a preferred control system, developed in-house by each ESCo through their experience of previous DSM projects.

Mining companies have multiple shafts with various large electricity consumers on each. This can lead to multiple different control systems being implemented by different ESCos within a mining company. This complicates the management of DSM projects for mine personnel, as they have to become accustomed to each control system. Also, as ESCos were previously only required to sustain projects for three months, it was the responsibility of mine personnel to maintain the control systems.

Unfortunately, this often led to control systems deteriorating as mine personnel were not fully equipped or motivated to maintain them. This created the perception that automated pump control systems are not sustainable. To combat these perceived challenges, some mining companies have started to develop their own standardised control systems.

This creates risks to the ESCo and the mine itself. The ESCo is unfamiliar with the mine's control systems, which may influence the sustainability and performance of the project. Likewise, if the mine does not have a standardised control system, the number of control systems may keep on increasing as projects are implemented by ESCos. Risk mitigation strategies therefore need to be develop for both scenarios, which are outlined in Table 9 and Table 10 respectively.

Table 9: [I: C] Risk mitigation strategies when implementing client control systems

[I: C] Implement client control system	
Risk	**Mitigation strategy**
ESCo personnel are unfamiliar with the client control system.	ESCo personnel need to arrange with the client to be trained properly in the client control system.
Critical oversights in the control system due to the client being inexperienced with DSM control system development.	ESCo personnel need to assist the client in addressing the critical oversights.
Client personnel are too distracted by other duties to rectify problems experienced with the control system.	ESCo personnel must prove that the problems result in lost electricity cost savings to motivate the client personnel to rectify the problems.
ESCo personnel are unable to modify key parameters on the control system to ensure the optimised control of the project.	Daily communication between the client and ESCo is required to ensure all key parameters are optimised.
The control system is not able to achieve the project's load-shifting target.	ESCo and client personnel need to investigate and mitigate the cause of underperformance and implement improvements.

Table 10: [I: E] Risk mitigation strategies when implementing ESCo control systems

[I: E] Implement ESCo control system	
Risk	**Mitigation strategy**
Client personnel are unfamiliar with the ESCo control system.	ESCos must provide client personnel with the required training for their system.
Client personnel develop their own control system after a project has been implemented using an ESCo control system.	The client control system needs to operate concurrently with the ESCo control system. During this period, the client control system is compared with the ESCo control system with the ESCo control system still controlling. If the client and ESCo is satisfied that the client control system is working as intended, the ESCo control system can be removed.

3.4. Project Strategy Phase 3: Performance sustainability

The final phase of this sustainable project strategy focuses on assisting ESCos to achieve the project target savings for the duration of the three-year sustainability period. This project strategy phase corresponds with the 12 PA periods that ESCos need to complete. As mentioned in Section 2.4.1, ESCos only receive funding for a project based on its performance. This means that performance monitoring and evaluation is a critical part of the project management process under the new ESCo model. Phase 3 is divided into three steps, namely:

- [P: M] Monitor performance
- [P: R] Restore performance
- [P: E] Evaluate performance

Step [P: M] focuses on the monitoring, communication and continuous improvement required for sustaining DSM projects over three years. During this step, the daily performance of a project is monitored and reported. This also entails updating the control philosophy of a project continuously to ensure the maximum load-shifting possible is being achieved.

Step [P: R] focuses on identifying and resolving the cause of an underperforming project. At the end of each PA period, Step [P: E] evaluates the project performance and optimises control for the next PA period. Phase 3 of the sustainable project strategy is shown in Figure 39. This cycle is repeated for the 12 PA periods. PA^n symbolises the start of the first PA period.

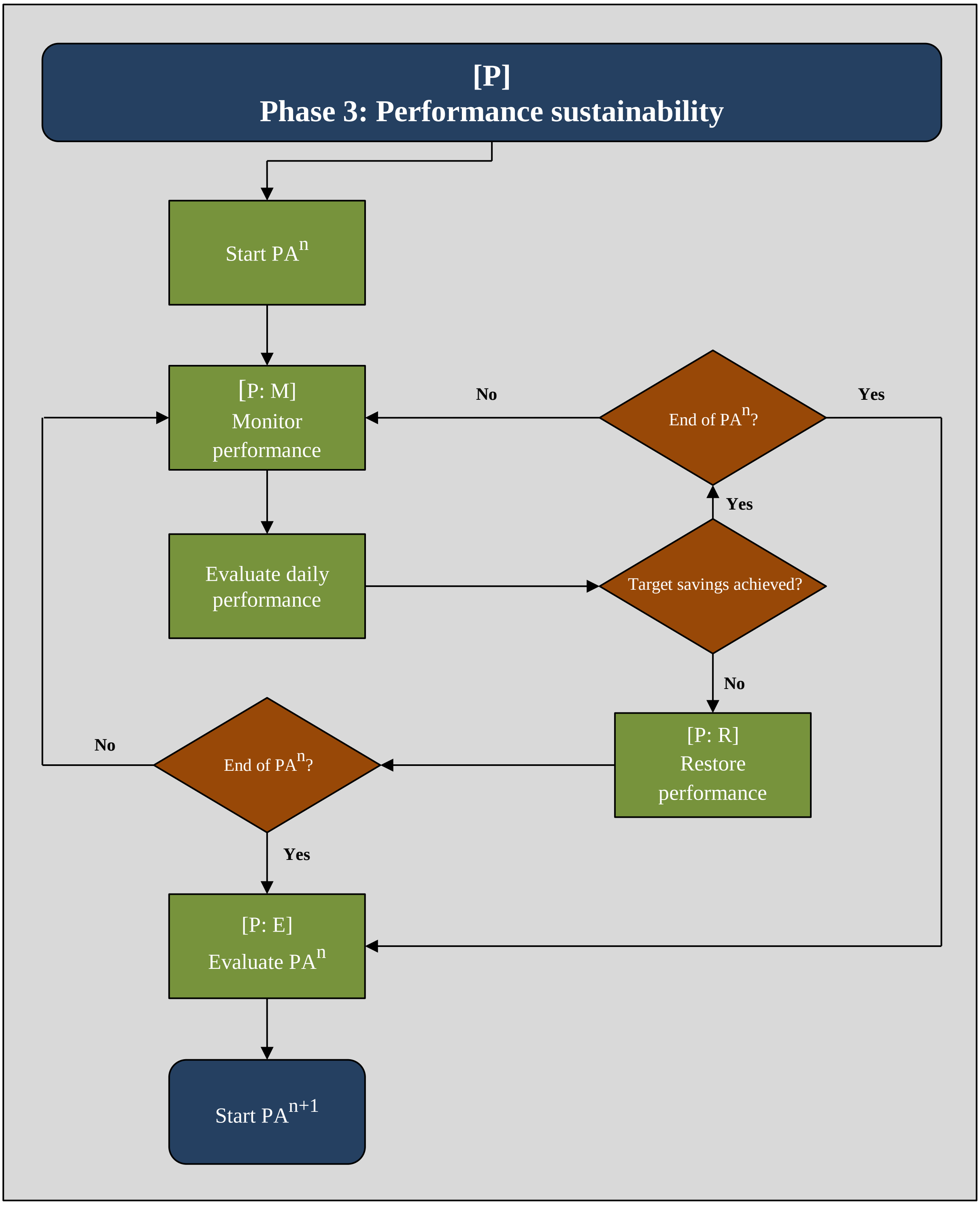

Figure 39: Phase 3: Performance sustainability

3.4.1. [P: M] Monitor performance

As mentioned earlier, this step of Phase 3 focuses on the monitoring, improvement and communication of a project's performance. This step is completed on a daily basis throughout the three-year sustainability period. This step is divided into three sections, outlined in Figure 40, namely:

- [P: M-1] Notify
- [P: M-2] Report
- [P: M-3] Communicate

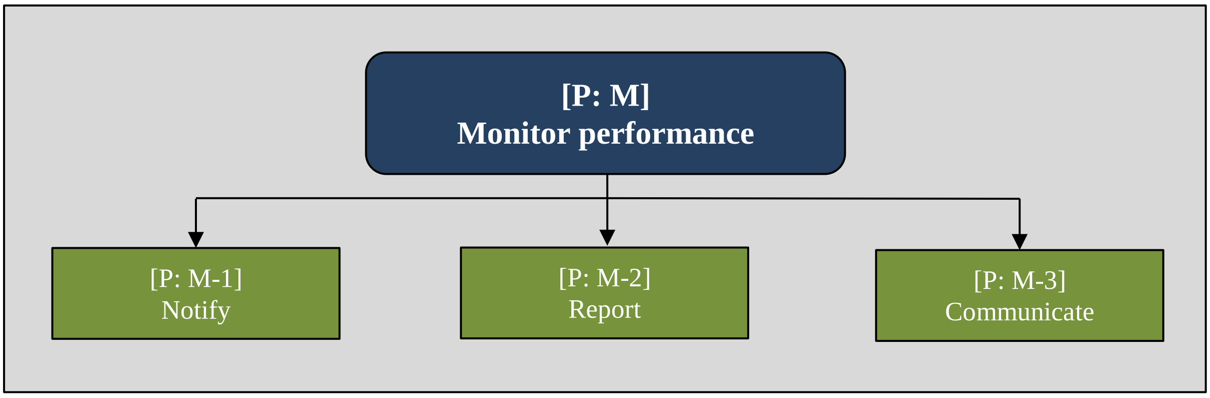

Figure 40: [P: M] Monitor performance

[P: M-1] Notify

The purpose of notifications is to notify or warn ESCo and client personnel that safety control limits are being breached or that the control system pumping schedule is not being followed. This allows for a quick response to rectify any potential problems. It is advised that both ESCo and relevant client personnel receive these notifications, which should be sent via SMS and email. It is advised that ESCos endeavour to incorporate this capability into the control system that is used (be it client or ESCo in-house software). Notifications could be sent for the following:

- Maximum/minimum dam level limits breached.
- Maximum/minimum number of pumps breached.
- Pumping schedule, which is determined by the control system, not being followed.
- Communication failure between the control system and underground SCADA system.
- Pumps running during Eskom peak periods.

The control limits of these notifications differ from project to project. It is advised that ESCo and client personnel decide together what notifications are needed for each project. It should also be decided which ESCo and client personnel should receive these notifications to ensure the most efficient and effective response.

[P: M-2] Report

The purpose of reporting is to track and optimise the performance of a project. Reports should be generated on a daily, weekly and monthly basis. Although the format of these reports differ from ESCo to ESCo, it is advised that they contain the following minimum information:

- The project detail (such as name, load-shifting target).
- The project's average weekday power profile for the reporting period of the report.
- The achieved load shifting of the project for the reporting period of the report.
- The electricity cost savings of the project for the reporting period of the report.

These reports should be generated by ESCos and modified according to each client's needs. ESCo personnel should email the reports to all relevant parties. An example of such a report can be found in Appendix III. These reports allow ESCos and client personnel to quickly identify if a project is achieving its intended load-shifting target. From the power profiles generated by these reports, ESCo personnel can identify where the control of the project can be improved. This contributes to the continuous improvement of projects, even if a project is achieving its load-shifting target.

[P: M-3] Communicate

Regular communication between ESCos and clients is essential for the sustainability of a project. Step [P: M-1] and Step [P: M-2] advised using SMS notifications, emails and reports as communication. This is, however, insufficient to sustain the project properly. It is therefore advised that ESCos and clients hold monthly feedback meetings. The discussion points of these meetings should be clearly defined, and should include the following:

- The performance of the project during the previous month.
- Any potential risks, such as maintenance being performed on dams or pumps, that will influence the performance of the project for the following month.
- Areas where the project performance can be improved.

These meetings contribute to good ESCo-client relations, even if there are personnel changes at either company. Minutes should be taken of these meetings as this allows ESCos and clients to reference decisions that were made to ensure sustained performance of projects.

3.4.2. [P: R] Restore performance

The financial liability attributed to the underperformance of projects lies solely with ESCos under the new ESCo model. This means the responsibility is with ESCos to ensure that projects perform as intended. Underperforming projects are identified during Step [P: M]. The experience and maintenance procedures ESCos developed under the old ESCo model can be transferred to the new ESCo model.

It is advised that ESCos and clients clearly define each other's responsibilities when it comes to resolving the cause of a project's underperformance. The relevant personnel on each side has to be identified to take responsibility for project performance during this step. This is especially important for the new ESCo model as it mandates ESCos to sustain projects for three years. It is advised that clients take responsibility for any of the following:

- Mechanical problems such as pump breakdowns or valve failures.
- System availability problems such as dams being taken offline for cleaning.
- Network-related problems such as communication loss between the SCADA and control system.

ESCos should take responsibility for any of the following:

- Operational changes to the control system that have to be implemented.
- Training of client personnel in the use of the ESCo control system (if used).
- Control system updates such as adjusting maximum/minimum allowable dam levels.

Figure 41 outlines Step [P: R]. If Step [P: M] identifies that a project underperformed for a day, ESCos should identify the cause of underperformance and notify the relevant personnel to rectify the problem. Previous maintenance procedures such as those stipulated by Grobbelaar [55] can be used as inputs during this process. If the problem has been resolved, Phase 3 of this project strategy can continue as normal. If the problem has not been resolved, the temporary control of Step [I: T] needs to be re-implemented while the problem is being attended to. This will ensure that the project still achieves load shifting during this time, reducing the risk of project underperformance.

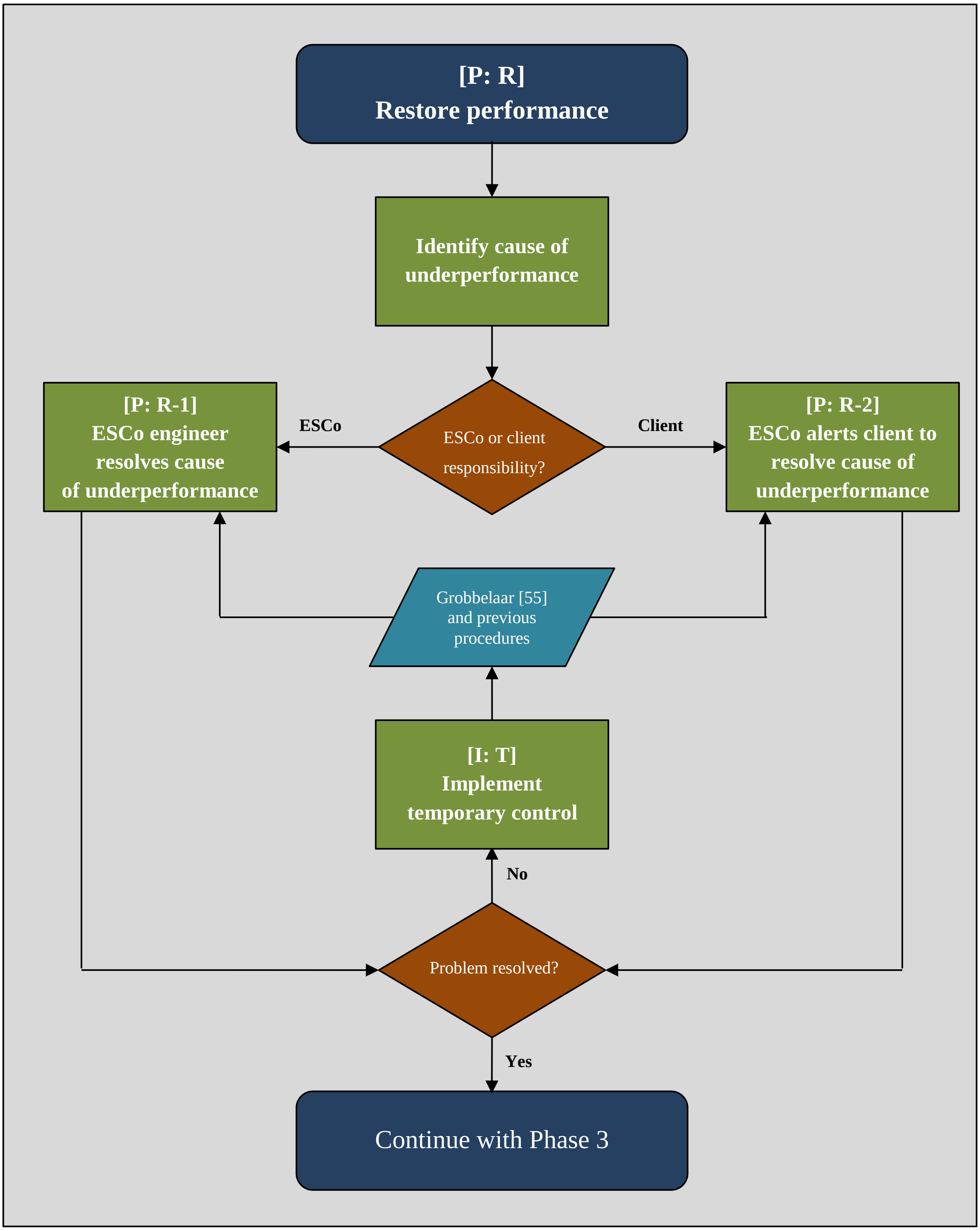

Figure 41: [P: R] Restore performance

3.4.3. [P: E] Evaluate PA^n

This step of Phase 3 focuses on evaluating each PA period to identify any possible performance improvements that might not have been identified during Step [P: M]. The optimal project performance will be resimulated based on the parameters of the PA period completed. This step is divided into four sections, namely:

- [P: E-1] Evaluate PA performance.
- [P: E-2] Evaluate key PA parameters.
- [P: E-3] Resimulate performance.
- [P: E-4] Implement changes.

[P: E-1] Evaluate PA performance

The performance during the PA period needs to be determined in order to perform a thorough performance analysis of the PA period. This can be done in two ways. Firstly, ESCos generated project performance reports on a daily, weekly and monthly basis during Step [P: M-2]. This data should thus be readily available. Secondly, the M&V verified PA report can be used. This also serves a dual purpose by ensuring that the project's performance as reported by the M&V team to Eskom IDM, therefore the performance by which ESCos are being paid, is correct. All parties are required to sing off on the PA performance.

[P: E-2] Determine key PA parameters

These PA parameters are the same as those investigated during Step [F: I] and which were outlined in Figure 25; namely, hot water storage dam, dewatering pump and water flow rate parameters. The parameters have to be determined for the PA period completed.

[P: E-3] Resimulate performance

The simulation developed in Step [F: S] needs to be repeated using the key system parameters of Step [P: E-2]. This allows ESCos to identify if any improvements can be made for the next PA period.

[P: E-4] Implement changes

If any changes are deemed necessary, they should be implemented as quickly as possible by ESCos at the beginning of the next PA period. Figure 42 outlines this step of Phase 3.

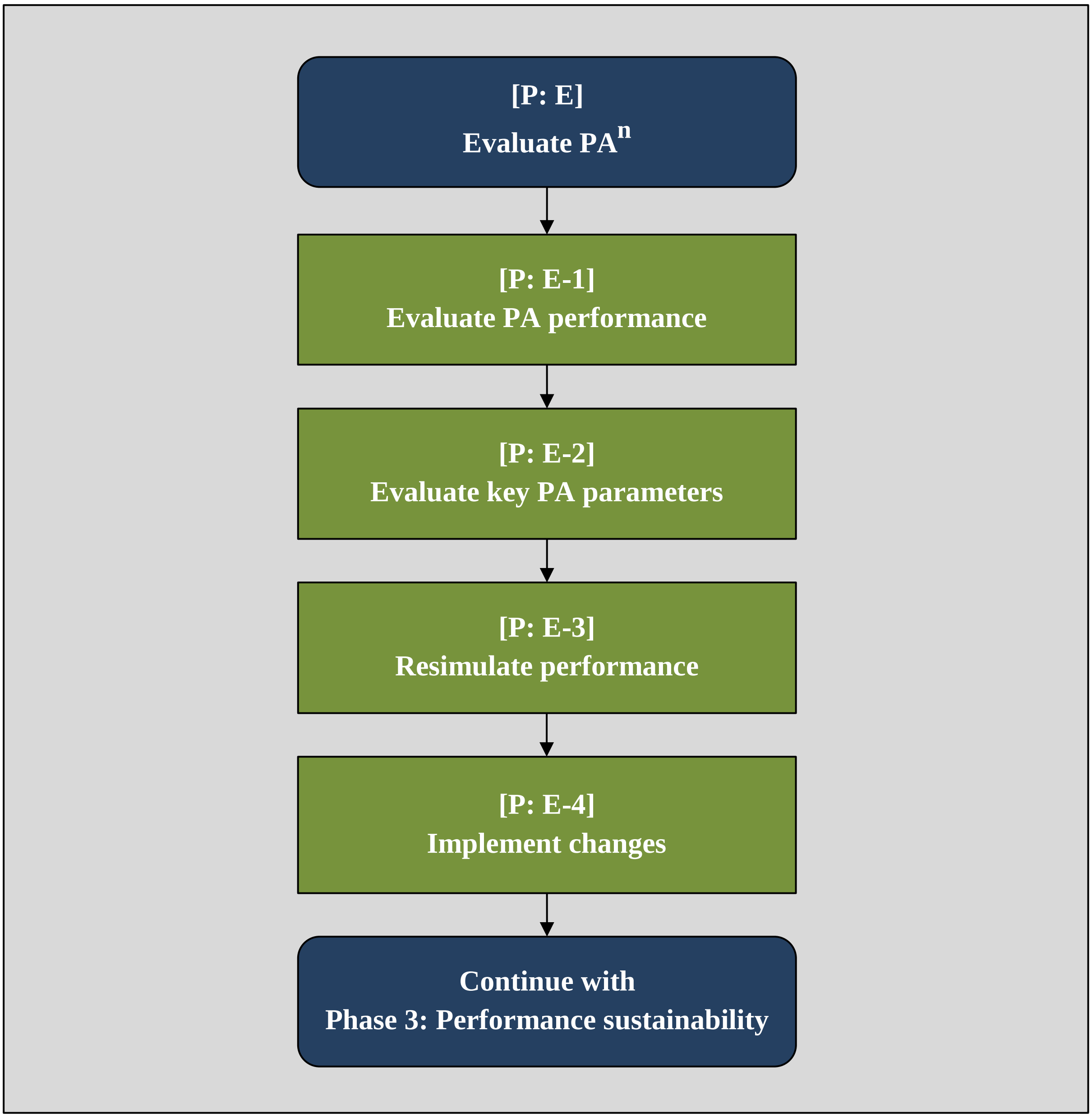

Figure 42: [P: E] Evaluate PA^n

3.5. Chapter conclusion

This chapter focused on developing a sustainable project strategy to assist ESCos in reviving DSM mine pumping projects under the new ESCo model. The strategy built upon the foundation laid by previous DSM studies while addressing the shortcomings of these studies. Risks associated with the new ESCo model were identified and mitigated.

As mentioned in the introduction of this chapter, the sustainable project strategy was developed based on predetermined requirements listed in Table 6. This chapter will now conclude by showcasing where each requirement was satisfied followed by a short description of how the requirements were satisfied. This is illustrated in Table 11.

Table 11: Sustainable project strategy requirements verification

Requirement	Project strategy step	Description
Feasibility analysis.	**[F: I], [F: S] [F: A]**	During these steps, the implementation costs, potential electricity cost savings and risks associated with a revival project need to be identified. The electricity cost savings must be simulated and verified. This project step concludes with a final feasibility decision.
Reactive maintenance.	**[P: R]**	This step focuses on restoring the performance of underperforming projects.
Continuous optimisation of load-shifting performance.	**[P: M], [P: E]**	These steps endeavour to continuously improve the load-shifting performance of a project. This was done by monitoring, reporting and evaluating load-shifting performance.
Regular communication between ESCos and clients.	**[P: M], [P: R]**	These steps advise the regular communication between clients and ESCos through meetings, reports and notifications via SMS's and emails.
Risk management strategies.	**[I: H], [I: T], [I: C], [I: E], [P: R]**	These steps identified and mitigated risks associated with the new ESCo model.
Training of relevant client or ESCo personnel.	**[I: T], [I: C], [I: E],**	These steps advise the training of client or ESCo personnel to mitigate risks associated with reviving projects under the new ESCo model.
Sustainability of load-shifting performance.	**[P: M], [P: R], [P: E]**	These steps focus on increasing the sustainability of a project through continuous monitoring, performance restoration and PA periods evaluation.

CHAPTER 4: IMPLEMENTATION OF SUSTAINABLE PROJECT STRATEGY

[6]

“*Success is the results of perfection, hard work, learning from failure, loyalty, and persistence*.” – Colin Powell

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[6] R. Speculand, “Middle managers’ role in strategy implementation: The lynchpin of success,” Singapore Management University, 2016. [Online]. Available: http://cps.smu.edu.sg/strategy-implementation. [Accessed: 15-Oct-2016].

4.1. Introduction

In Chapter 3, a sustainable project strategy was developed to revive DSM mine pumping projects that completed their PT period under the old ESCo model. In this chapter, this sustainable project strategy is implemented on two case studies. The results achieved by implementing the sustainable project strategy on the two case studies are presented.

The sustainable project strategy was implemented on two case studies in order to test its suitability and effectiveness on the unique constraints of different mine pumping systems. The results of implementing the sustainable project strategy on two cases studies provides an improved dataset from which to draw meaningful conclusions. The two case studies used were chosen as they are situated close to each other and belong to the same mining group, simplifying the process to gather data and arrange load-shift tests.

4.2. Case Study A

Case Study A is a medium- to deep-level gold mine situated in the Gauteng province between Johannesburg and Potchefstroom. The aim of the original project was to shift the power usage of the dewatering pumps from Eskom evening peak periods to standard and off-peak periods. Each phase of the sustainable project strategy is implemented sequentially on Case Study A.

4.2.1. Phase 1: Feasibility study

[F: I] Investigate

[F: I-1] Original project

The original project was completed in August 2008 but the PA period was suspended until March 2009 on recommendation from the mine. The mine was in the process of completing infrastructure upgrades, outside the ESCo project scope, which would influence the performance of the project. The PA period was completed from March to May 2009. The five-year PT period started in June 2009. The client had to sustain the project during the PT period.

[F: I-1a] Layout

The original project's pumping system layout was obtained from the M&V scope report and the database of the ESCo responsible for implementing the project and is shown in Figure 43.

The pumping system consisted of two pumping levels, namely, 3165 Level and 23–60 Level. Water was pumped sequentially from 23–60 Level to a surface hot water storage dam.

The pumping station on 23–60 Level consisted of two 5 Mℓ hot water storage dams with four dewatering pumps. The inflow into the hot water storage dams consisted of service and fissure water. The average service water inflow was approximately 204.1 ℓ/s, or 17.6 Mℓ per day. The average fissure water inflow was approximately 39 ℓ/s, or 3.36 Mℓ per day.

The pumping station on 3165 Level consisted of one 5 Mℓ hot water storage dam with four dewatering pumps. The inflow into the hot water storage dam consisted of the water pumped from 23–60 Level and fissure water. The fissure water inflow was approximately 11.57 ℓ/s, or 1 Mℓ per day. The total inflow into the 3165 Level hot water storage dam was therefore approximately 21.96 Mℓ per day.

The surface hot water storage dam was approximately 2.5 Mℓ in capacity. From the surface hot water storage dam water was pumped to the surface refrigeration system to be cooled. The cooled water was gravity-fed underground for mining operations.

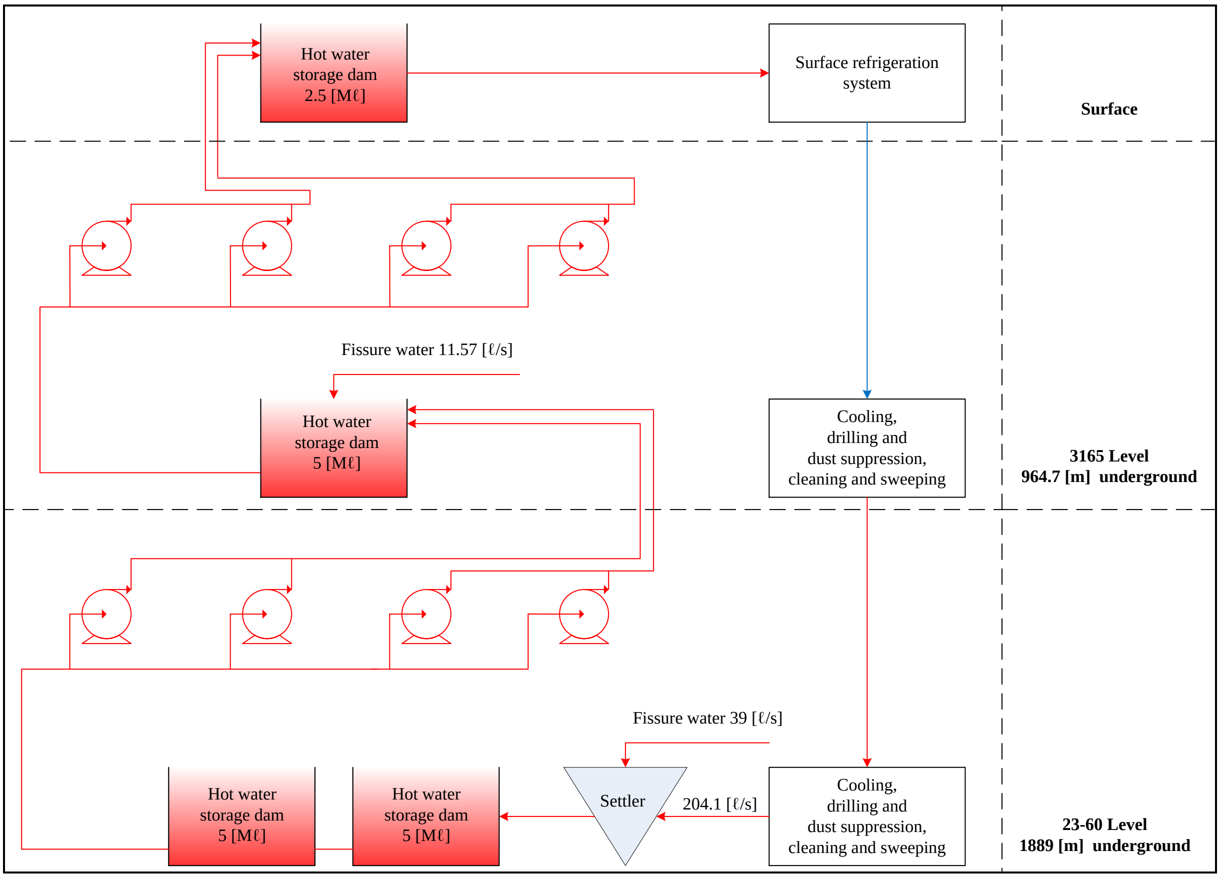

Figure 43: Case Study A – original project's pumping system layout

Table 12 provides a breakdown of the original project’s dewatering pump specifications.

Table 12: Case Study A – original project’s dewatering pump specifications

Pump	Rated power [MW]	Delivery flow [ℓ/s]
3165 Level		
Pump 1	1.567	140
Pump 2	1.567	140
Pump 3	1.567	140
Pump 4	1.567	140
23–60 Level		
Pump 1	1.567	135
Pump 2	1.567	135
Pump 3	1.567	135
Pump 4	1.567	135

[F: I-1b] Control

The control system used for the original project was the ESCo’s Real Time Energy Management System for Pumps (REMS-P). REMS-P used real-time system parameters to calculate a suggested number of running of pumps on each pumping level. Surface control room operators were responsible for phoning underground pump operators to stop or start pumps based on the number of pumps suggested by REMS-P.

The system parameters taken into consideration were the hot water storage dam levels, the number of running pumps on each pumping level and the surface hot water storage dam level. In the case of 23–60 Level, the average level of the two hot water storage dams combined was used. For each system parameter, a minimum and maximum value was assigned for each Eskom TOU period. The control limits of the system parameters used by REMS-P are shown in Table 13.

Table 13: Case Study A – original project's control limits

System parameter	Peak		Standard		Off-peak	
	Min	Max	Min	Max	Min	Max
Surface						
Surface hot water storage dam level	30%	80%	30%	80%	30%	80%
3165 Level						
Number of pumps	0	3	0	3	0	3
Hot water storage dam level	25%	60%	25%	45%	25%	45%
23–60 Level						
Number of pumps	0	3	0	3	0	3
Average hot water storage dam level	30%	80%	30%	45%	30%	45%

[F: I-1c] Performance

The performance of the original project was determined from the available M&V PA and PT reports. The contracted target of the original project was an average Eskom evening peak period load shift of 5 MW. The average Eskom evening peak period load shift achieved and the percentage of the contracted target achieved for the PA and PT periods are shown in Table 14.

Table 14: Case Study A – original project's performance

Period	Average Eskom evening peak period load shift [MW]	Percentage of contracted target achieved [%]
PA	3.6	72%
PT	1.0	20%

As can be seen from Table 14, the original project underperformed during both the PA period with ESCo involvement and the PT period without ESCo involvement. However, the performance reduced significantly with 52% from the PA period to the PT period. This reduction in performance can be attributed to the fact that the ESCo was not contracted by the mine to sustain the project savings during the PT period.

The challenge faced by the ESCo during the PA period was the incorrect installation of dewatering pump excitation panels for 3165 Level. This was due to the incorrect specification of the panels by the main contractor responsible for the installation. The pump excitation panels limited the functionality of the 3165 Level dewatering pumps. The project control method therefore had to be changed. Originally REMS-P would have controlled the pumps automatically, but this changed to a situation where REMS-P calculated a pumping schedule for the surface control room operator to follow.

This challenge is, however, not a risk for the revival project. The limited functionality of the pumps resulted in the mine contracting a different contractor to repair the associated problems when the five-year PT period ended. The dewatering pumps are fully operational and available for the revival project.

[F: I-2] Revival project

[F: I-2a] Layout

The revival project's pumping system layout for Case Study A was obtained via audits conducted during site visits and interaction with mine personnel. The pumping system consists of three pumping levels, 3165 Level, 15 Level and 23–60 Level. Water pumped from the 23–60 Level hot water storage dams bypasses 15 Level and is pumped directly to 3165 Level. Water pumped from the 15 Level hot water storage dam is also pumped to 3165 Level. From the 3165 Level hot water storage dam, water is pumped to the surface hot water storage dam.

From the surface hot water storage dam, water is pumped to a gold plant to be used as part of the gold extraction process. The mine found that underground shaft temperatures were below the allowed safety limit without the surface refrigeration system. The surface refrigeration system is therefore no longer used. Water for mining purposes is purchased from Rand Water.

The 15 Level hot water storage dam is not used to store service water; it is only used to store fissure water flowing down the shaft between 23–60 Level and 3165 Level. This is approximately 3.36 Mℓ fissure water per day, with an average flow of 39 ℓ/s. The 15 Level hot water storage dam capacity is approximately 3.2 Mℓ.

The pumping station on 23–60 Level consists of two 5 Mℓ hot water storage dams with four dewatering pumps. The average inflow into the hot water storage dams is approximately

168.4 ℓ/s, or 14.55 Mℓ per day. The pumping station on 3165 Level consists of one 5 Mℓ hot water storage with four dewatering pumps. The inflow into the 3165 Level hot water storage dam consists of the water being pumped from 23–60 Level and 15 Level.

The static head between 15 Level and 3165 Level is approximately 408 m. This is approximately 50% of the static head that the 23–60 Level and 3165 Level dewatering pumps have to overcome. The 15 Level dewatering pumps are thus smaller, with smaller electric motors, but have similar flows to the 23–60 Level and 3165 Level dewatering pumps. The revival project's layout is shown in Figure 44, and the dewatering pump specifications in Table 15.

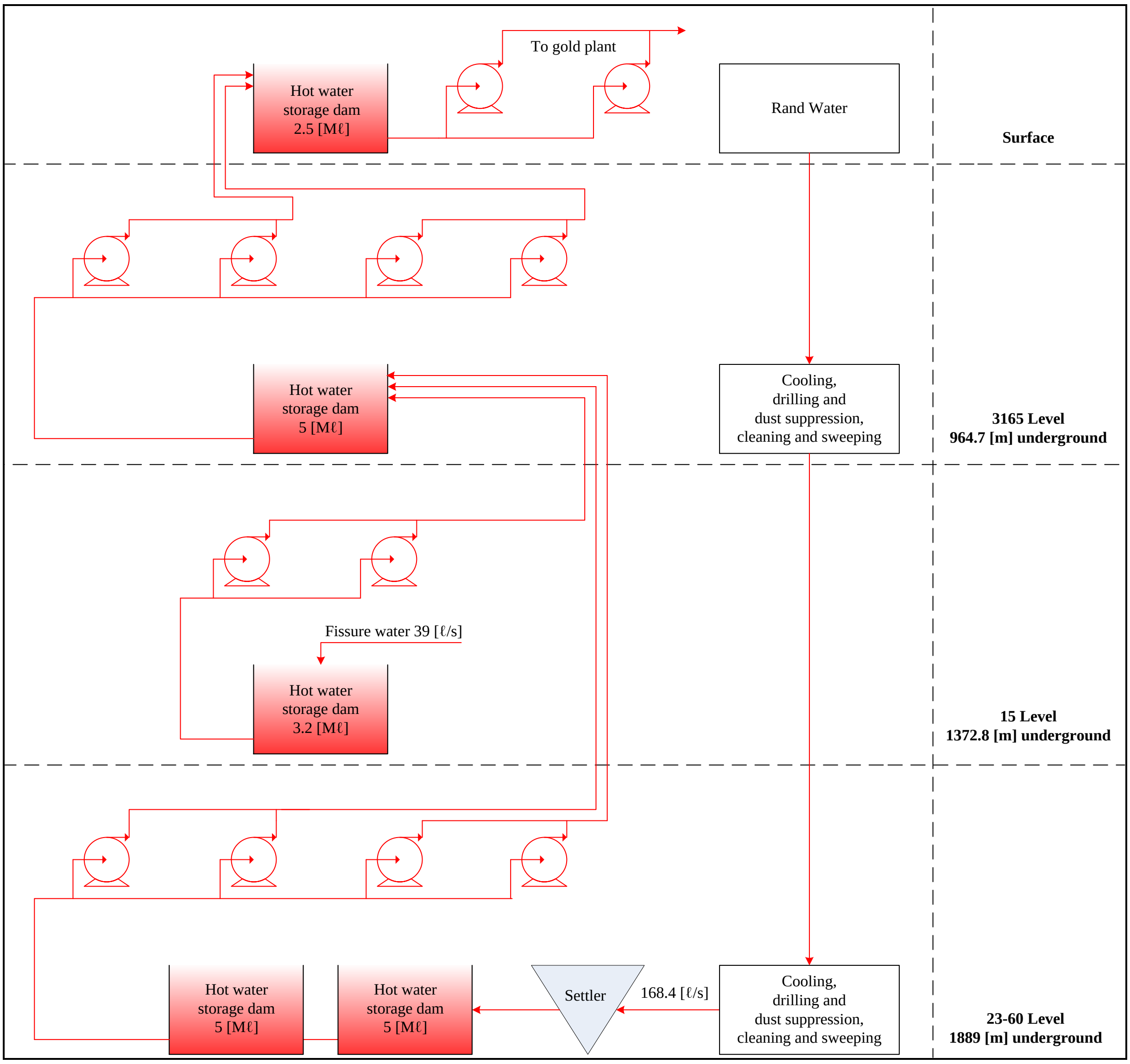

Figure 44: Case Study A – revival project's pumping system layout

Table 15: Case Study A – revival project's dewatering pump specifications

Pump	Rated power [MW]	Delivery flow [ℓ/s]
Surface		
Pump 1	0.25	130
Pump 2	0.25	130
3165 Level		
Pump 1	1.567	134.7
Pump 2	1.567	134.7
Pump 3	1.567	134.7
Pump 4	1.567	134.7
15 Level		
Pump 1	0.9	132
Pump 2	0.9	132
23–60 Level		
Pump 1	1.567	138.9
Pump 2	1.567	138.9
Pump 3	1.567	138.9
Pump 4	1.567	138.9

[F: I-2b] Baseline

The baseline for the revival project was developed using the status data method. There was no other data source available at the time the baseline was developed. The baseline was therefore not compared with a baseline developed from a different data source but was accepted by the client. The baseline was developed before Eskom shifted the high demand season TOU periods an hour earlier, and Eskom low demand season TOU period data was therefore used.

The baseline power profile for weekdays, Saturdays and Sundays is shown in Figure 45. The baseline PTA ratio for Eskom weekday peak periods, using Eskom low demand season TOU periods, is 0.69. This ratio indicates that there is scope for additional load shifting in Eskom peak periods through the optimised control of the dewatering pumps.

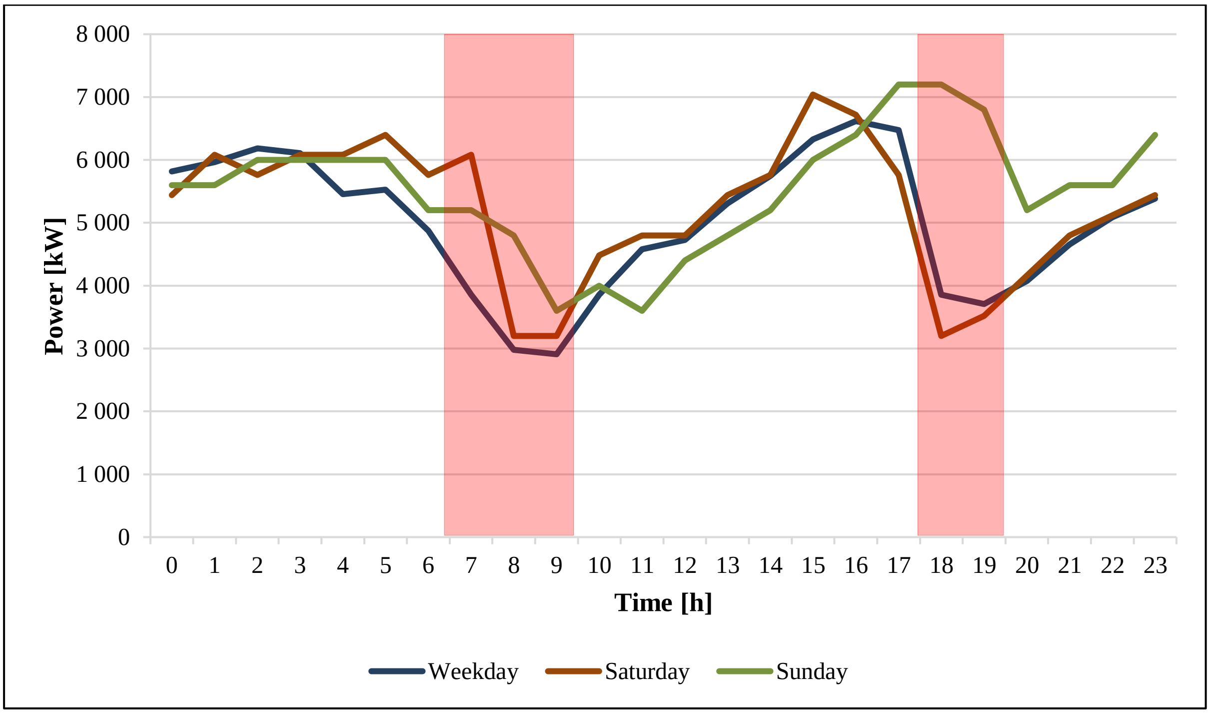

Figure 45: Case Study A – revival project's baseline power profile

[F: I-3] Compare projects

[F: I-3a] Layout

There have been significant changes in the pumping system layout from the original project to the revival project. The revival project has seen the addition of the 15 Level dewatering pumps and hot water storage dam, as well as the surface pumps transferring water to the gold plant. The dewatering pumps and hot water storage dams on 23–60 Level and 3165 Level have stayed the same. The dewatering pumps on 23–60 Level and 3165 Level have been maintained properly and refurbished when necessary.

[F: I-3b] Operation

The addition of the 15 Level dewatering pumps and hot water storage dam should have a positive effect on the revival project's performance. The fissure water now stored in 15 Level hot water storage dam used to be gravity-fed to the 23–60 Level hot water storage dams in the original project. This meant that the water had to be pumped back past 15 Level, resulting in energy wastage.

The additional storage capacity of the 15 Level hot water storage dam also helps to increase the load-shifting potential. This is because the 15 Level hot water storage dam decreases the flow into the 23–60 Level hot water storage dams. There should therefore be a load-shifting improvement for the revival project compared with the original project.

The addition of the surface pumps to pump water to the gold plant may, however, have a negative effect on the load-shifting performance during Eskom morning peak periods. The gold plant requires 5 Mℓ, or 57.87 ℓ/s, of water per day – mostly between 06:00 and 14:00. The gold plant may request additional water during emergencies outside of these times.

The water pumped to the surface hot water storage dam is contaminated and may not be released into the environment. The surface hot water storage dam is therefore not allowed to overflow. Resultantly, the surface hot water storage dam has a low maximum level of 20%. To ensure that there is enough water to supply to the gold plant, water will have to be pumped continuously from underground between 06:00 and 14:00.

[F: S] Simulate

The goal of the simulation is to determine the potential to shift the power usage of the dewatering pumps from Eskom peak periods to standard and off-peak periods. This is achieved by preparing the dams in standard and off-peak periods to ensure that they are at their minimum allowable level at the start of peak periods. During Eskom peak periods, all dewatering pumps are switched off until the dam has reached its maximum allowable level.

The strategy that will be used to simulate the potential load shift for Case Study A is summarised as follows:

1. Obtain the pumping system layout (completed in Step [F: I-2a]).
2. Identify the relevant system constraints (completed in Step [F: S-1]).
3. Construct the simulation model (completed in Step [F: S-2a]).
4. Perform the simulation (completed in Step [F: S-2b]).
5. Determine the load-shifting potential (completed in Step [F: S-2c]).
6. Verify the simulation results (completed in Step [F: S-3]).

[F: S-1] Identify constraints

The supply of water to the gold plant needs to be taken into account for the simulation. For the mine, the gold plant extraction process takes preference over electricity cost savings achievable through load shifting. The supply of water to the gold plant should therefore not be interrupted during Eskom morning peak periods. The gold plant only requests water during emergencies in Eskom evening peak periods. The simulation will therefore be completed under the assumption that full load shifting may be implemented during Eskom evening peak periods.

During Eskom morning peak periods, the goal is to reduce the power usage without influencing the supply of water to the gold plant. To achieve this, there will be a minimum and maximum dam level constraint on the surface hot water storage dam during Eskom morning peak periods. To ensure the simulation provides realistic results, the simulation constraints were determined in conjunction with mine personnel. The simulation constraints are listed in Table 16.

Table 16: Case Study A – simulation constraints

System parameter	Peak		Standard		Off-peak	
	Min	Max	Min	Max	Min	Max
Surface						
Surface hot water storage dam level	5%	20%	5%	20%	5%	20%
3165 Level						
Number of pumps	0	3	0	3	0	3
Average hot water storage dam level	55%	80%	25%	70%	55%	70%
15 Level						
Number of pumps	0	1	0	1	0	1
Average hot water storage dam level	30%	75%	30%	75%	30%	75%
23–60 Level						
Number of pumps	0	3	0	3	0	3
Average hot water storage dam level	35%	80%	35%	50%	35%	50%

[F: S-2] Simulate savings potential

[F: S-2a] Program

The ESCo's in-house simulation software, REMS-P, was used to simulate the potential Eskom peak period load shifting for Case Study A. REMS-P was also used as the control system of the original project, which made it ideally suited for simulating the revival project. The simulation platform was constructed based on the revival project's pumping system layout in Step [F: I-2a]. This simulation platform is shown in Figure 46.

Abbreviated notations are used in the simulation platform. Level is abbreviated to L, pump to P and hot water storage dam to D. For example, 15 Level hot water storage dam is abbreviated to 15L_D, and 15 Level pump 1 to 15L_P1.

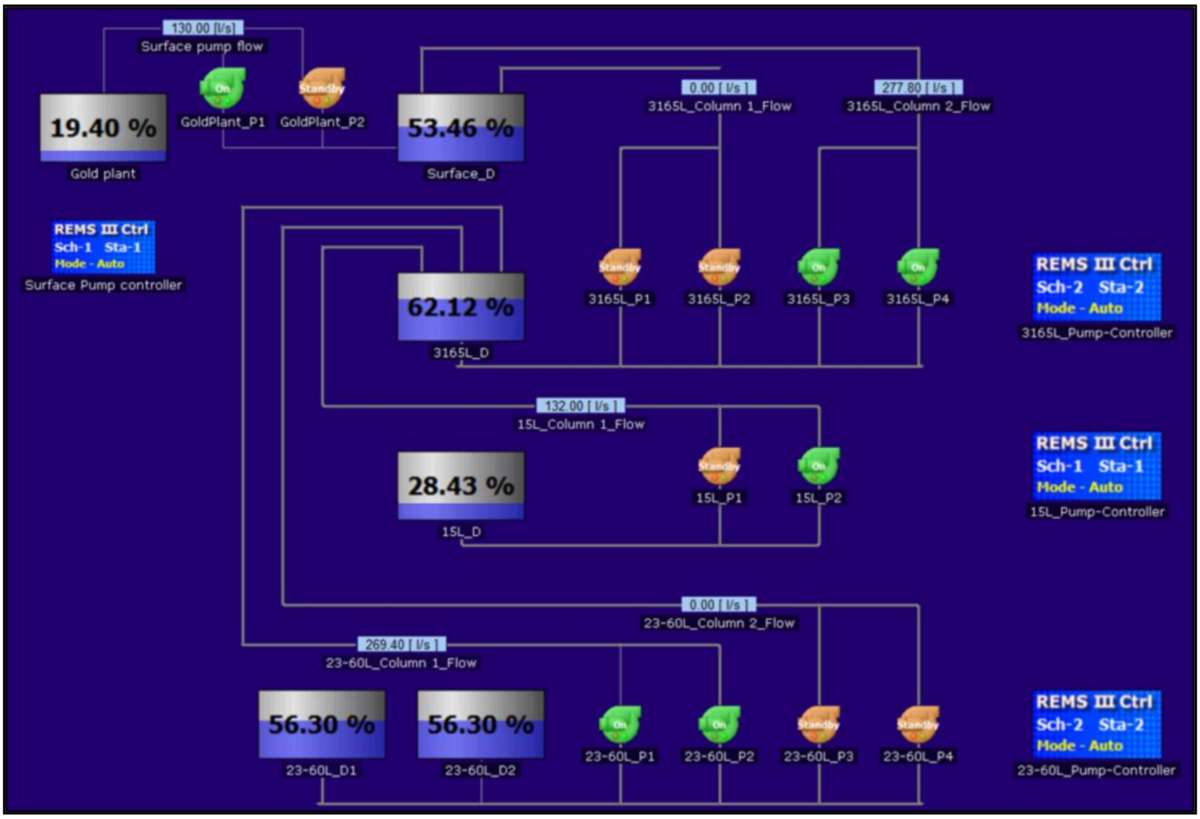

Figure 46: Case Study A – simulation platform

REMS-P uses the real-time dam levels to determine the number of pumps to schedule. The simulation platform is primarily programmed to control each pumping level according to the upstream dam level. As a safety measure, the maximum number of pumps is limited according to the downstream dam level. This will prevent REMS-P from flooding the downstream dam level. The minimum number of pumps is also scheduled according to the downstream dam level. This will prevent the downstream dam level from falling below the minimum level.

[F: S-2b] Simulation

Eskom low demand season TOU periods were used for the simulation as the baseline was developed using Eskom low demand season TOU period data. The simulation result is, however, also applicable to Eskom high demand season TOU periods. This is because the peak demand periods are only shifted an hour earlier during the Eskom high demand season TOU periods.

[F: S-2c] Load shifting

The simulated power profile for the dewatering pumps is compared with the scaled weekday baseline, developed in Step [F: I-2b], in Figure 47. Based on the simulation results, Case Study A should be able to achieve an average Eskom evening peak period load shift of 2.58 MW. The average Eskom morning peak period load shift, without influencing the supply of water to the gold plant, should be 0.94 MW.

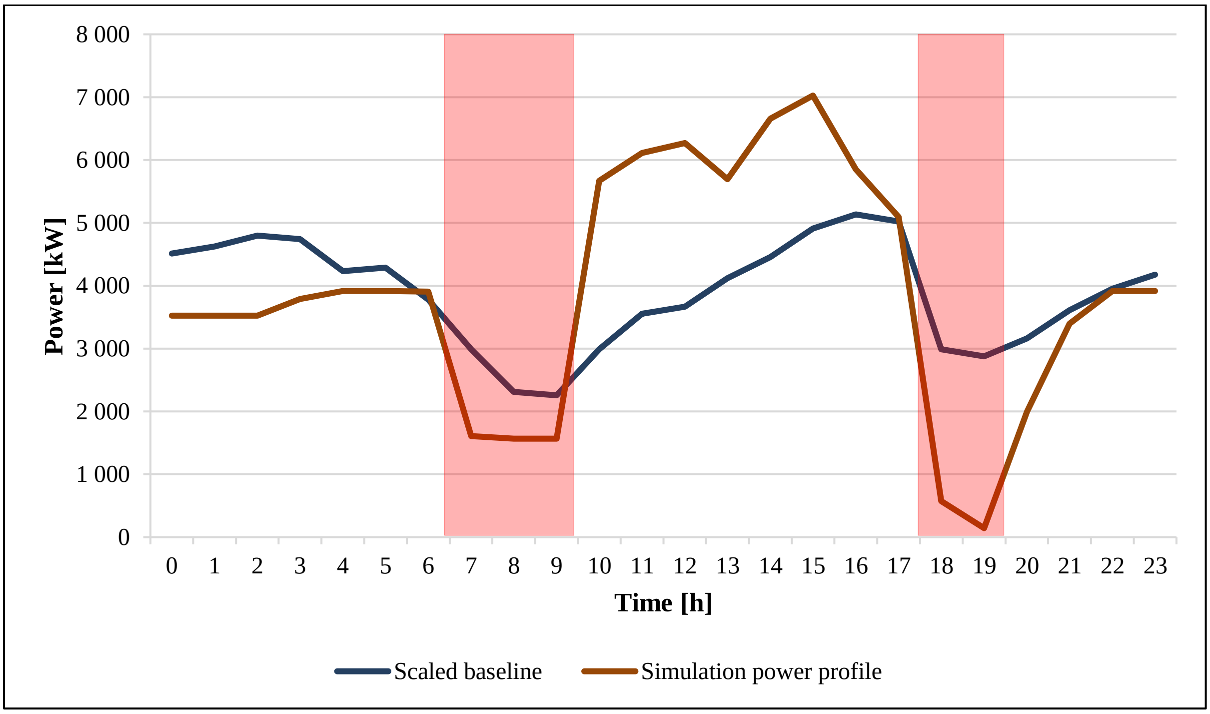

Figure 47: Case Study A – simulation load-shifting results

[F: S-3] Verify simulation

[F: S-3a] Load-shifting test

To verify the simulation, a manual load-shifting test was conducted over a period of one day. The power profile of this test is compared with the simulation power profile in Figure 48. The baseline shown in Figure 48 is scaled energy-neutral to the load-shifting test power profile.

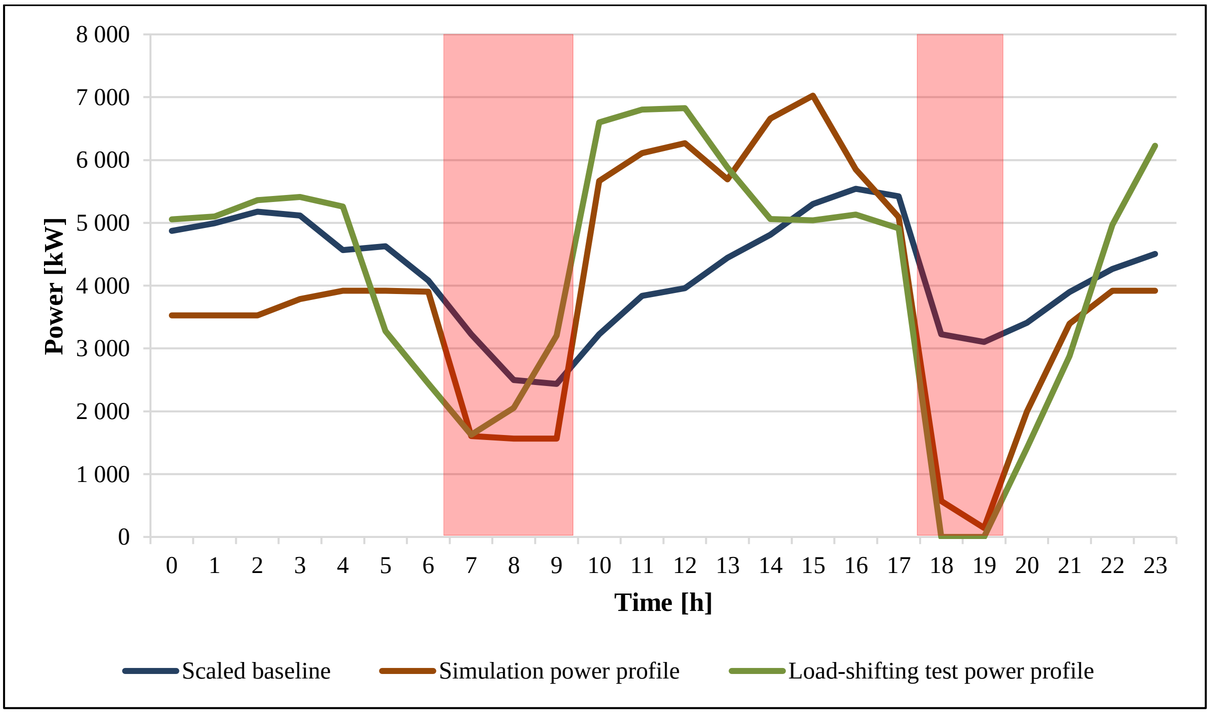

Figure 48: Case Study A – simulation verification

The simulation results are compared with the load-shifting test results in Table 17. The load-shifting test achieved a higher average Eskom evening peak period and a lower Eskom morning peak period load shift. The improvement in the Eskom evening peak period load shift, which is the emphasis under the new ESCo model, therefore proves that the simulation load shift is achievable. The simulation can therefore be accepted as accurate. Based on the load-shifting test results, the expected annual electricity cost savings is approximately R1.7-million.

Table 17: Case Study A – simulation verification results

Result	Simulation	Load-shifting test
Average Eskom evening peak period load shift	2.58 MW	3.18 MW
Average Eskom morning peak period load shift	0.94 MW	0.40 MW

[F: A] Analyse

[F: A-1] Risk mitigation

[F: A-1a] Identify risks

The risk associated with Case Study A is that the gold plant may request water during Eskom evening peak periods. The gold plant processes take preference over DSM projects for the mine, thus these processes may not be altered. As mentioned in Step [F: S-1], the gold plant mainly requires water during Eskom morning peak periods. As the new ESCo model only takes savings achieved in Eskom evening peak periods into consideration, poor morning load shifting will not be a risk to the ESCo involved. It is still, however, important to endeavour to maximise the load shifting during Eskom morning peak periods as this will increase the electricity cost savings for the mine.

If the gold plant requests water during Eskom evening peak periods, water has to be pumped to the surface hot water storage dam from 3165 Level. This has a cascading effect as water now has to be pumped from 23–60 Level or 15 Level to ensure that 3165 Level does not breech its minimum level limit. This cascading effect decreases the load shifting achieved during Eskom evening peak periods.

[F: A-1b] Mitigate risks

To mitigate the risk associated with the gold plant requesting water during Eskom peak periods, the following mitigation strategy is applied:

- 23–60 Level hot water storage dam is drained to its minimum level before Eskom peak periods.
- 15 Level hot water storage dam is drained to its minimum level before Eskom peak periods.
- 3165 Level hot water storage dam is not drained to its minimum level before Eskom peak periods, but will be kept at approximately 70%.
- The surface hot water storage dam is at its maximum level before Eskom peak periods.

This preparation of the hot water storage dam levels ensures that if the gold plant requests water during Eskom peak periods, water is first pumped from the surface hot water storage dam. If the surface hot water storage dam drains to its minimum level, 3165 Level has enough stored capacity to pump water to the surface hot water storage dam for the remainder of the Eskom peak period. This reduces the risk of having to run pumps on 15 Level and 23–60 Level during Eskom peak periods and the negative impact on the load shifting is minimised.

[F: A-2] Conclude feasibility study

[F: A-2a] Analysis

Case Study A has the potential for a 3.18 MW load shift during Eskom evening peak periods and a 0.4 MW load shift during Eskom morning peak periods. This amounts to an annual electricity cost saving of approximately R1.7-million. The pumping system is in good condition and requires no additional hardware installations. Mine personnel are dedicated to achieving electricity cost savings and should not hinder the implementation of the project. The mine should remain in operation for at least the next ten years.

The risk to the ESCo associated with the project has been identified and mitigated. The potential Eskom evening peak period load shift identified during Step [F: S] has been verified by a manual load-shifting test. The Eskom evening peak period load shift should therefore be sustainable.

[F: A-2b] Conclusion

Based on the analysis of Step [F: A-2a], Case Study A was deemed feasible by the ESCo and submitted to Eskom IDM for approval. Eskom Energy Audit assigned an M&V team to the project who completed the M&V scope, plan, and baseline report. The baseline developed during Step [F: I-2b] was verified and approved by the M&V team in the baseline report.

Eskom IDM approved the revival project of Case Study A based on the ESCo project submission and pre-implementation M&V deliverables. The project’s contractual implementation end date is 31 October 2016. Case Study A has an Eskom evening peak period load-shifting target of 2.5 MW, which is significantly lower than the verified load shift achieved during Step [F: S-3]. This reduced target is to allow for any unexpected breakdowns or maintenance on the pumping system that will negatively influence the load shift achieved.

4.2.2. Phase 2: Implementation strategies

The implementation of Case Study A was completed before the final implementation end date set by Eskom IDM. The first PA period could therefore start earlier than required in July 2016. As no hardware installations were required for Case Study A, the control system was the main focus of the implementation phase.

The mine developed their own DSM project control system using their Archestra SCADA system and requested that Case Study A be implemented using this control system. The control system was, however, still in its infancy during the implementation phase of this project. The risk mitigation strategies of Table 9 were therefore used for Case Study A.

The mine's control system uses a similar control philosophy to that of REMS-P. The initial control limits were set according to the simulation constraints of Step [F: S-1]. These control limits will continuously be improved as the project progresses.

Real-time dam levels are used to determine the number of pumps to schedule. The control system is primarily programmed to control each pumping level according to the upstream dam level. As an additional safety measure, the maximum number of pumps is limited according to the downstream dam level. This prevents the control system from flooding the downstream dam level. The minimum number of pumps is also scheduled according to the downstream dam level. This prevent the downstream dam level from falling below the minimum level.

4.2.3. Phase 3: Performance sustainability

The strategies developed in Phase 3 of the sustainable project strategy were used to maximise the load shift achieved during Eskom morning and evening peak periods. At the time of this study, Case Study A had completed its first three-month PA period. The first two months of this PA period was completed during the Eskom high demand season. The last month of the first PA period was completed during the Eskom low demand season.

The results of Case Study A is therefore presented for the Eskom high demand and low demand season TOU periods. This provides an indication of whether the differing TOU periods influenced the project's performance. The results are analysed at the end of this chapter.

Case Study A – Eskom high demand season results

Figure 49 displays the average weekday power profile of Case Study A for the first two months of its first PA period, completed during the Eskom high demand season. The power profile is compared with the M&V verified weekday baseline developed in Step [F: I-2b].

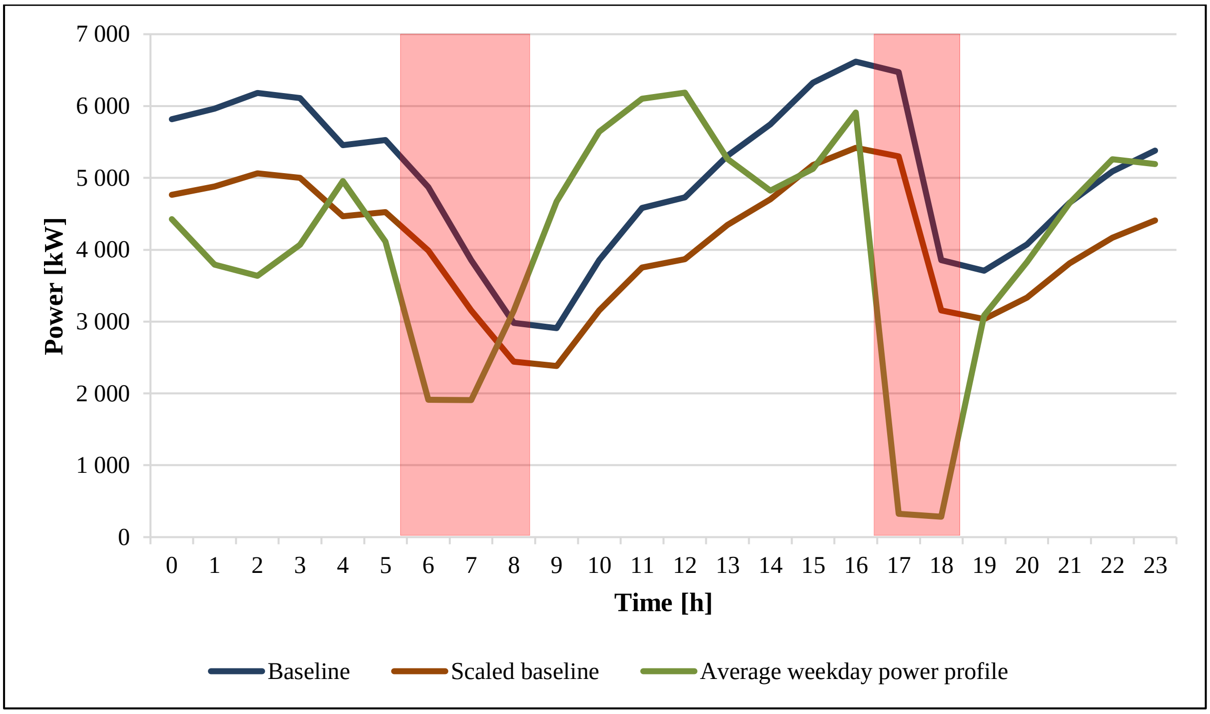

Figure 49: Case Study A – Eskom high demand season average weekday power profile

Table 18 displays the performance of Case Study A during these two months. As can be seen, Case Study A managed to achieve an average Eskom evening peak period load shift of 3.92 MW. This is a performance of approximately 157% against its contracted target of 2.5 MW. The average Eskom morning peak period load shift achieved during this period was 0.87 MW. The electricity cost savings during this period was approximately R745 000.

Table 18: Case Study A – Eskom high demand season performance

Savings type	Result
Average Eskom evening peak period load shift	3.92 MW
Average Eskom morning peak period load shift	0.87 MW
Electricity cost savings	R745 000

Case Study A – Eskom low demand season results

Figure 50 displays the average weekday power profile of Case Study A for the last month of its first PA period, completed during the Eskom low demand season. The power profile is compared with the M&V verified weekday baseline developed in Step [F: I-2b].

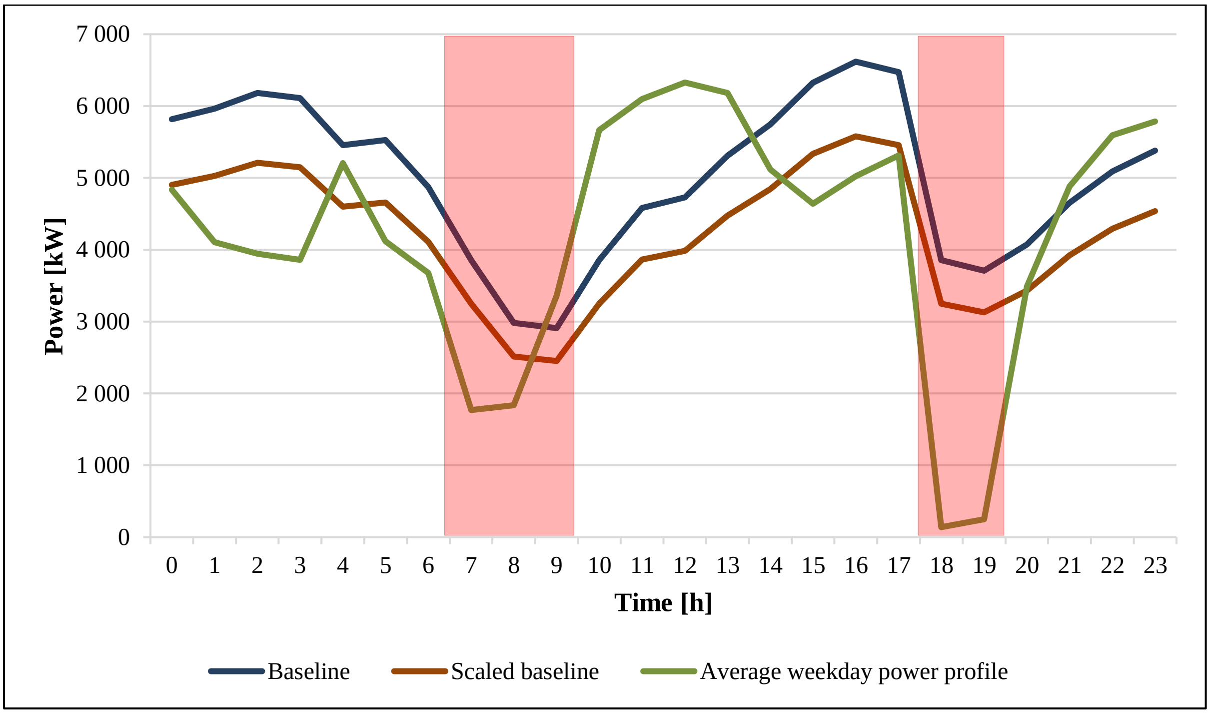

Figure 50: Case Study A – Eskom low demand season average weekday power profile

Table 19 displays the performance of Case Study A during this month. As can be seen, Case Study A managed to achieve an average Eskom evening peak period load shift of 2.99 MW. This is a performance of approximately 120% against its contracted target of 2.5 MW. The average Eskom morning peak period load shift achieved during this period was 0.42 MW. The electricity cost savings during this period was approximately R40 000.

Table 19: Case Study A – Eskom low demand season performance

Savings type	Result
Average Eskom evening peak period load shift	2.99 MW
Average Eskom morning peak period load shift	0.42 MW
Electricity cost savings	R40 000

4.3. Case Study B

Case Study B, the same as Case Study A, is a medium- to deep-level gold mine situated in the Gauteng province between Johannesburg and Potchefstroom. The aim of the original project was to shift the power usage of the dewatering pumps from Eskom evening peak periods to standard and off-peak periods. Each phase of the sustainable project strategy is implemented sequentially on Case Study B. The shafts where Case Study A and Case Study B are located belong to the same mining company.

4.3.1. Phase 1: Feasibility study

[F: I] Investigate

[F: I-1] Original project

The original project, as was the case with Case Study A, was completed in August 2008. The M&V team issued the post-implementation report in October 2008 and the first PA started in November 2008. The five-year PT period started in February 2009 and ended in February 2014. The ESCo responsible for implementing the project was not contracted by the mine to maintain the project during the PT period.

[F: I-1a] Layout

The original project's pumping system layout was obtained from the M&V scope report and the database of the ESCo responsible for implementing the project. The pumping system consisted of two pumping levels; 12 Level and 27 Level. Water was pumped sequentially from 27 Level to a surface hot water storage dam.

The pumping station on 27 Level consisted of two 3 Mℓ hot water storage dams with five dewatering pumps. The inflow into the hot water storage dams consisted of fissure water and water from a plug dam. The average inflow into the hot water storage dams was approximately 293.29 ℓ/s, or 25.34 Mℓ per day.

The plug dam was a large underground reservoir containing naturally occurring fissure water and water transferred from adjacent shafts belonging to the same mining company. The size of the plug dam could not be determined. The plug dam contained contaminated mine water that settled at the bottom of the plug dam. Cleaner water settled at the top of the plug dam.

The pumping station on 12 Level consisted of two 3 Mℓ hot water storage dams with seven dewatering pumps. The inflow into the dam consisted of the water being pumped from 27 Level, fissure water and water transferred from other mineshafts. The average fissure and transfer water inflow was approximately 74.77 ℓ/s, or 6.46 Mℓ per day. The total inflow into the 12 Level hot water storage dam was therefore approximately 31.8 Mℓ per day.

The surface hot water storage dam storage capacity was approximately 2 Mℓ. From the surface hot water storage dam, water was pumped to neighbouring farms. No surface refrigeration system was needed as no mining took place at Case Study B’s shaft.

The plug dam level was controlled with two valves which, if opened, allowed the water to flow into the 27 Level hot water storage dams. The plug dam level therefore needed to be controlled to ensure that it neither overflowed nor transferred contaminated water. If the plug dam overflowed, it would have flooded the interconnected mine network. If contaminated water was transferred, it would have ended in farmland. The layout of Case Study B’s original project is shown in Figure 51.

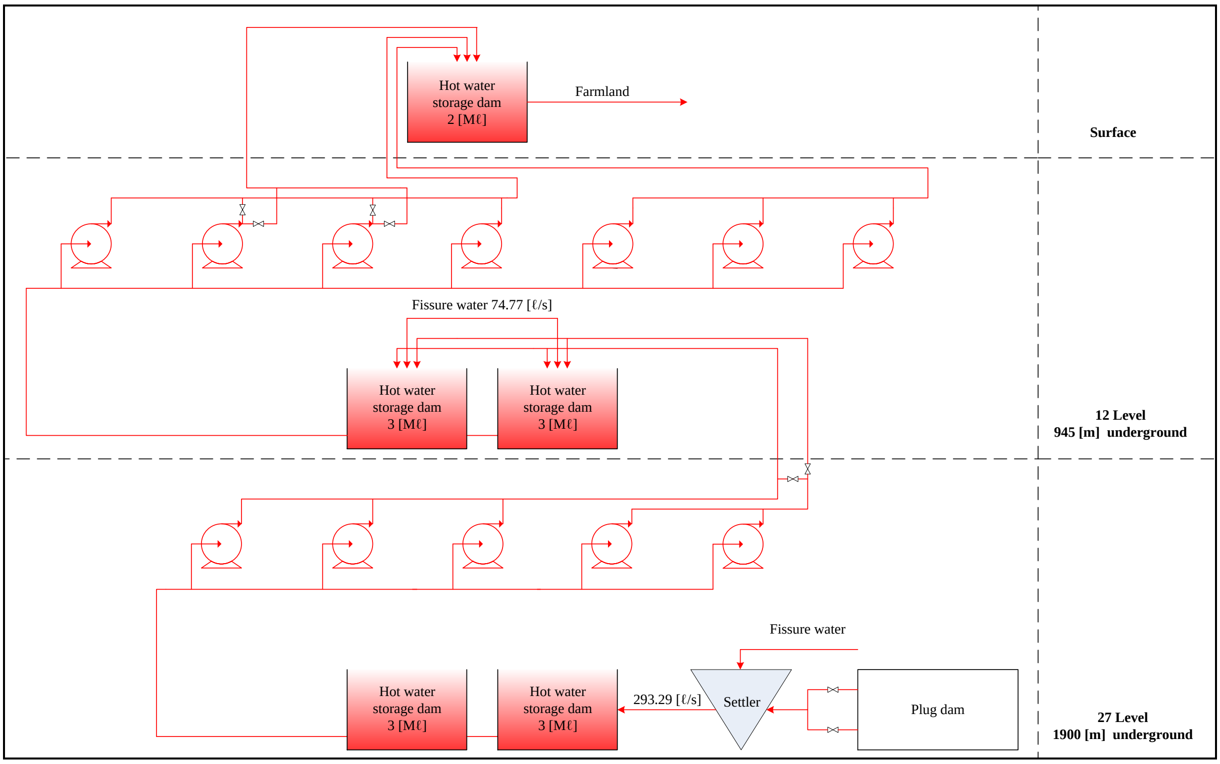

Figure 51: Case Study B – original project’s pumping system layout

The originals project’s dewatering pump specifications are listed in Table 20.

Table 20: Case Study B – original project’s dewatering pump specifications

Pump	Rated power [MW]	Delivery flow [ℓ/s]
12 Level		
Pump 1	3.3	190
Pump 2	3.3	190
Pump 3	3.3	190
Pump 4	3.3	190
Pump 5	3.3	190
Pump 6	3.3	190
Pump 7	3.3	190
27 Level		
Pump 1	2.75	190
Pump 2	2.75	190
Pump 3	2.75	190
Pump 4	2.75	190
Pump 5	2.75	190

[F: I-1b] Control

REMS-P was the control system used by the ESCo for the original project, as with Case Study A. REMS-P used real-time system parameters to calculate the number of pumps to run on each pumping level. REMS-P stopped and started the pumps automatically.

The system parameters taken into consideration were the hot water storage dam levels, the running number of pumps on each pumping level and the surface hot water storage dam level. The size of the plug dam reservoir was unknown and the level could not be accurately measured. Instead, the plug dam level was approximated by using the vertical height of the water from the reservoir bottom. The plug dam level was controlled between 18 m and 19 m of vertical water.

For each system parameter, a minimum and maximum value was assigned for each Eskom TOU period. REMS-P controlled the pumps automatically based on these control limits. The control limits of the system parameters used by REMS-P are shown in Table 21.

Table 21: Case Study B – original project's control limits

System parameter	Peak		Standard		Off-peak	
	Min	Max	Min	Max	Min	Max
Surface						
Surface hot water storage dam level	37%	90%	37%	90%	37%	90%
12 Level						
Number of pumps	0	3	0	3	0	3
Average hot water storage dam level	15%	88%	15%	40%	15%	65%
27 Level						
Number of pumps	0	2	0	2	0	2
Average hot water storage dam level	22%	88%	19%	36%	22%	67%

[F: I-1c] Performance

The performance of the original project was determined from the available M&V PA and PT reports. The contracted target of the original project was an average Eskom evening peak period load shift of 8 MW. The average Eskom evening peak period load shift achieved and the percentage of the contracted target achieved for the PA and PT periods are shown in Table 22.

Table 22: Case Study B – original project's performance

Period	Average Eskom evening peak period load shift [MW]	Percentage of contracted target achieved [%]
PA	7.80	97.50%
PT	5.94	74.25%

As can be seen from Table 22, the original project achieved 97.5% of its contracted target of 8 MW in the PA period with ESCo involvement. Although the project's performance decreased with approximately 23% in the PT period, it still achieved 74.25% of its contracted target. This can be attributed to the ESCo assisting the mine as a goodwill measure when contacted, even though not being contracted to maintain the project during the PT period.

The original project performed well during the both the PA and PT periods. The ESCo did not experience any major challenges regarding achieving the project's load-shifting target. However, the mine infrastructure was old. This resulted in the mine carrying out costly preventative repairs on infrastructure during the PT period. This included replacing the service water columns, pump discharge valves and refurbishing or replacing dewatering pumps.

[F: I-2] Revival project

[F: I-2a] Layout

The revival project's layout for Case Study B was obtained via audits conducted during site visits and interaction with mine personnel. The pumping system consists of two pumping levels; 12 Level and 27 Level. Water is pumped sequentially from 27 Level to a surface biological dam.

27 Level consists of two 3 Mℓ hot water storage dams with five dewatering pumps. The inflow into the hot water storage dams consists of fissure water and water from the plug dam. The inflow into the hot water storage dams is approximately 276.62 ℓ/s, or 23.9 Mℓ per day.

The plug dam, the same as with the original project, is a large underground reservoir containing naturally occurring fissure water and water transferred from adjacent shafts belonging to the same mining company. The plug dam contains contaminated mine water that settles at the bottom of the plug dam. Cleaner water settles at the top of the plug dam.

12 Level consists of two 3 Mℓ hot water storage dams with seven dewatering pumps. The inflow into the dam consists of the water being pumped from 27 Level, fissure water and water transferred from adjacent shafts belonging to the same mining company. The total inflow into the 12 Level hot water storage dam is approximately 515.63 ℓ/s, or 44.55 Mℓ per day.

The surface biological dam is a reservoir filled with reeds to purify the water being pumped from underground. From the surface biological dam, water is fed to neighbouring farms. No surface refrigeration system is needed as no mining takes place.

The plug dam level is controlled, as was the case with the original project, with two valves which, if opened, allows the water to flow into the 27 Level hot water storage dams. The plug dam level therefore needs to be controlled to ensure that it neither overflows nor transfers contaminated water. If the plug dam overflows, it will flood the interconnected mine network. If contaminated water is transferred, it will end up in farmland. The layout of Case Study B's revival project is shown in Figure 52.

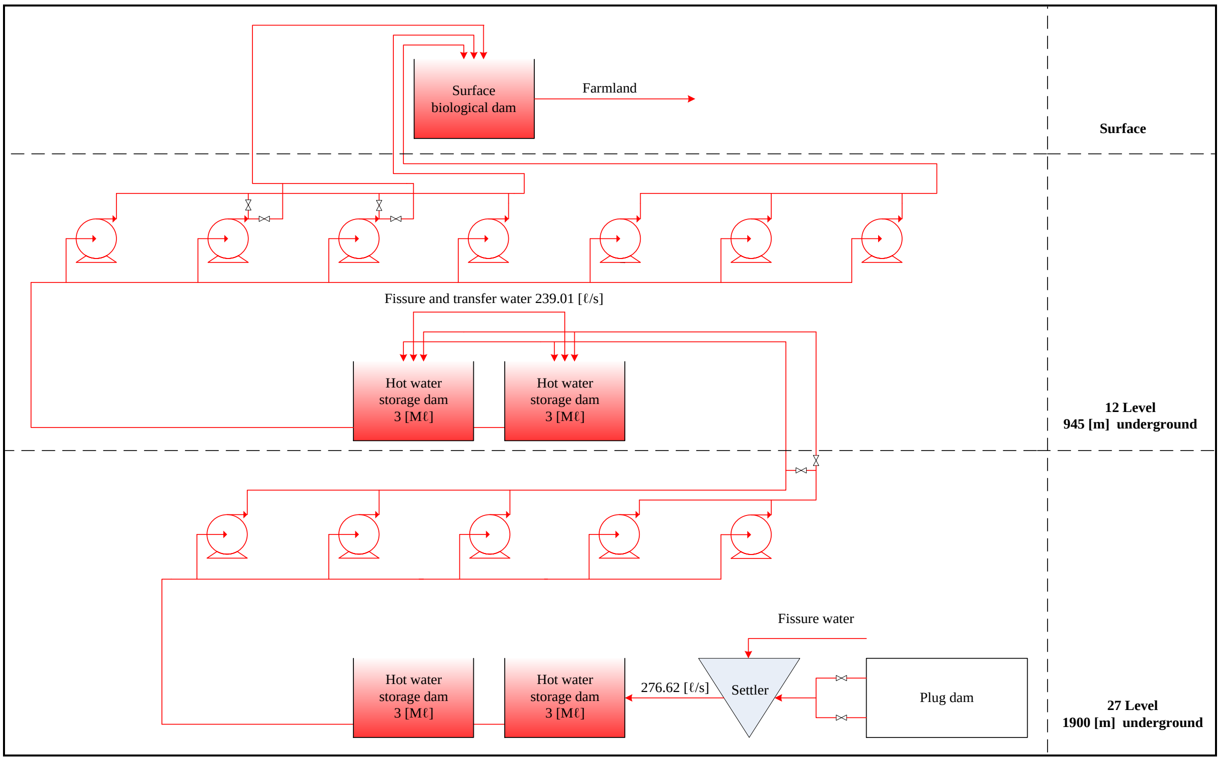

Figure 52: Case Study B – revival project's pumping system layout

The revival project’s dewatering pump specifications are listed in Table 23.

Table 23: Case Study B – revival project’s dewatering pump specifications

Pump	Rated power [MW]	Delivery flow [ℓ/s]
12 Level		
Pump 1	3.3	236
Pump 2	3.3	236
Pump 3	3.3	236
Pump 4	3.3	236
Pump 5	3.3	236
Pump 6	3.3	236
Pump 7	3.3	236
27 Level		
Pump 1	2.75	167
Pump 2	2.75	167
Pump 3	2.75	167
Pump 4	2.75	236
Pump 5	2.75	209

[F: I-2b] Baseline

The status data and the power logger methods were used to develop a baseline for the revival project of Case Study B. The status data was obtained from the mine’s SCADA system. The power logger data was obtained from permanently installed power loggers on each pump. These loggers were installed by the mine when the PT period of the original project ended. The same month’s data, using Eskom low demand season TOU period data, was used to develop both baselines. The average weekday power profiles of the two baselines are shown in Figure 53.

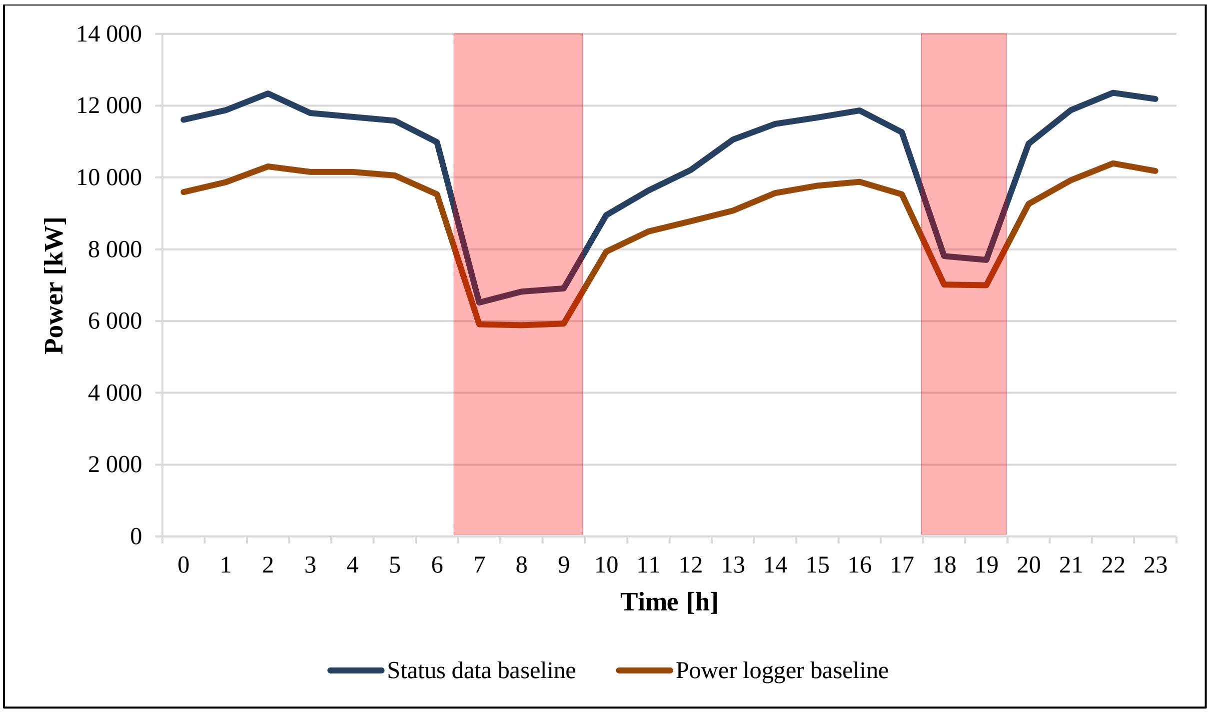

Figure 53: Case Study B – baseline comparison

The status data baseline gives consistently higher power values than the power logger baseline. This difference, as explained in Section 3.2, is attributed to how the data source calculates its power values. The status data method multiplies the running status of a pump with its rated motor power, while the power logger method uses a direct reading from the power logger. The power logger reading is less than the pump's rated motor power. The power logger baseline will therefore give power values that are less than those of the status data baseline.

As mentioned in Section 3.2, power values should not be the main factor to be considered when comparing two baselines. This should be the baselines' PTA ratios and correlation. The status data baseline and power logger baseline have similar PTA ratios of 0.68 and 0.71 respectively. This is a difference of only 3.9%. The two baseline power profiles have an almost perfect correlation of 0.99.

The status data baseline has the lowest PTA ratio; meaning it has the lowest load-shifting potential between the two baselines. Due to the project being a load shifting project, and the baseline therefore being scaled energy neutral, this conservative value is preferred by mine personnel. The status data baseline was therefore chosen and accepted by the mine as the baseline to use for all load-shifting and electricity cost calculations. Figure 54 displays the baseline power profile for weekdays, Saturdays and Sundays.

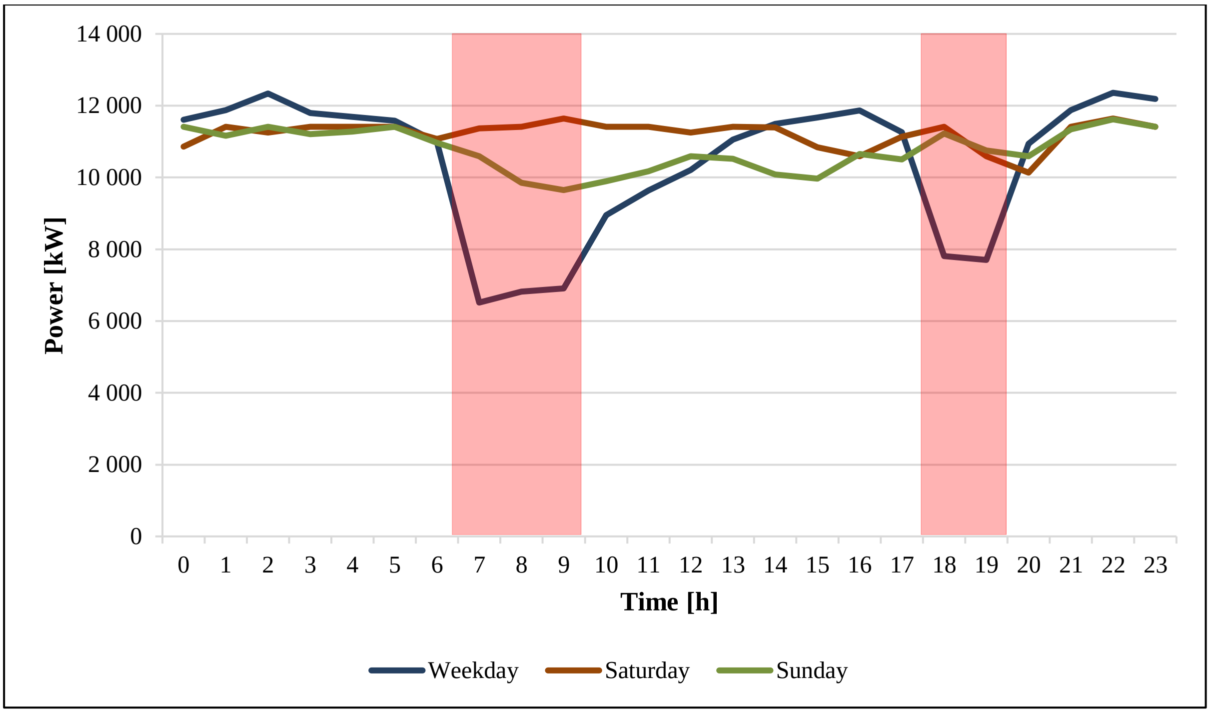

Figure 54: Case Study B – revival project's baseline power profile

[F: I-3] Compare projects

[F: I-3a] Layout

There have been no significant changes in the pumping system layout from the original project to the revival project. The only change in the layout of the two projects is a configuration change from a surface hot water storage dam to a surface biological dam. The original project's infrastructure has, however, been upgraded. No infrastructure is therefore required for the revival project.

[F: I-3b] Operation

The only difference in operation between the original project and the revival project is that inflow of water to the 12 Level hot water storage dams has increased. This is primarily due to more water being transferred from adjacent shafts, which amounts to an increase of approximately 13 Mℓ per day. The increased inflow of water to the 12 Level hot water storage dams is expected to have a negative impact on the revival project's performance.

The overall power usage of the pumping system is expected to increase as a result, as more water needs to be pumped out of the shaft. The load shift achieved during Eskom peak periods is also expected to decrease. This is because the 12 Level hot water storage dams will fill faster, thereby possibly resulting in dewatering pumps to start in Eskom peak periods.

[F: S] Simulate

The simulation procedure for Case Study B is similar to the simulation that was completed for Case Study A. The goal of the simulation is to shift the power usage of the dewatering pumps from the Eskom morning and evening peak periods to the standard and off-peak periods. This is achieved by preparing the dams during standard and off-peak periods to ensure that they are at their minimum allowable levels at the start of peak periods. During Eskom peak periods, all dewatering pumps are switched off until the dam has reached its maximum allowable level.

The strategy that is used for simulating the potential load shift for Case Study B is identical to Case Study A. This strategy is again summarised as follows:

1. Obtain the pumping system layout (completed in Step [F: I-2a]).
2. Identify the relevant system constraints (completed in Step [F: S-1]).
3. Construct the simulation model (completed in Step [F: S-2a]).
4. Perform the simulation (completed in Step [F: S-2b]).
5. Determine the load-shifting potential (completed in Step [F: S-2c]).
6. Verify the simulation results (competed in Step [F: S-3]).

[F: S-1] Identify constraints

To ensure the simulation provides realistic results, the simulation constraints were determined in conjunction with mine personnel. The simulation constraints are listed in Table 24. Note that for Case Study B, there are no requirements regarding the surface biological dam level.

The surface biological dam gravity-feeds water to neighbouring farms. As no water is pumped out of the dam or required for mining purposes, the surface biological dam level is irrelevant. It is acceptable if it overflows or drains completely. There are therefore no constraints attributed to it for the simulation.

Table 24: Case Study B – simulation constraints

System parameter	Peak		Standard		Off-peak	
	Min	Max	Min	Max	Min	Max
Surface						
Surface biological dam level	N/A	N/A	N/A	N/A	N/A	N/A
12 Level						
Number of pumps	0	3	0	3	0	3
Average hot water storage dam level	15%	88%	15%	32%	15%	32%
27 Level						
Number of pumps	0	2	0	2	0	2
Average hot water storage dam level	15%	88%	15%	30%	15%	30%

[F: S-2] Simulate savings potential

[F: S-2a] Program

As with Case Study A, the ESCo in-house simulation software, REMS-P, was used to simulate the potential Eskom peak period load shift for Case Study B. REMS-P was also used as the control system of the original project. The simulation platform was constructed based on the revival project's pumping system layout of Step [F: I-2a]. The simulation platform is shown in Figure 55.

Abbreviated notations are used for the simulation program. Level is abbreviated to L, pump to P and hot water storage dam to D. For example, 12 Level hot water storage dam is abbreviated to 12L_D, and 12 Level pump 1 to 12L_P1.

REMS-P, as was explained in Case Study A, uses real-time dam levels to determine the number of pumps to schedule on each pumping level. Each pumping level is programmed to primarily control according to the upstream dam level. To prevent REMS-P from flooding the downstream dam level, the maximum number of pumps is limited according to the downstream dam level. To prevent the downstream dam level from falling below the minimum level, the minimum number of pumps is also scheduled according to the downstream dam level.

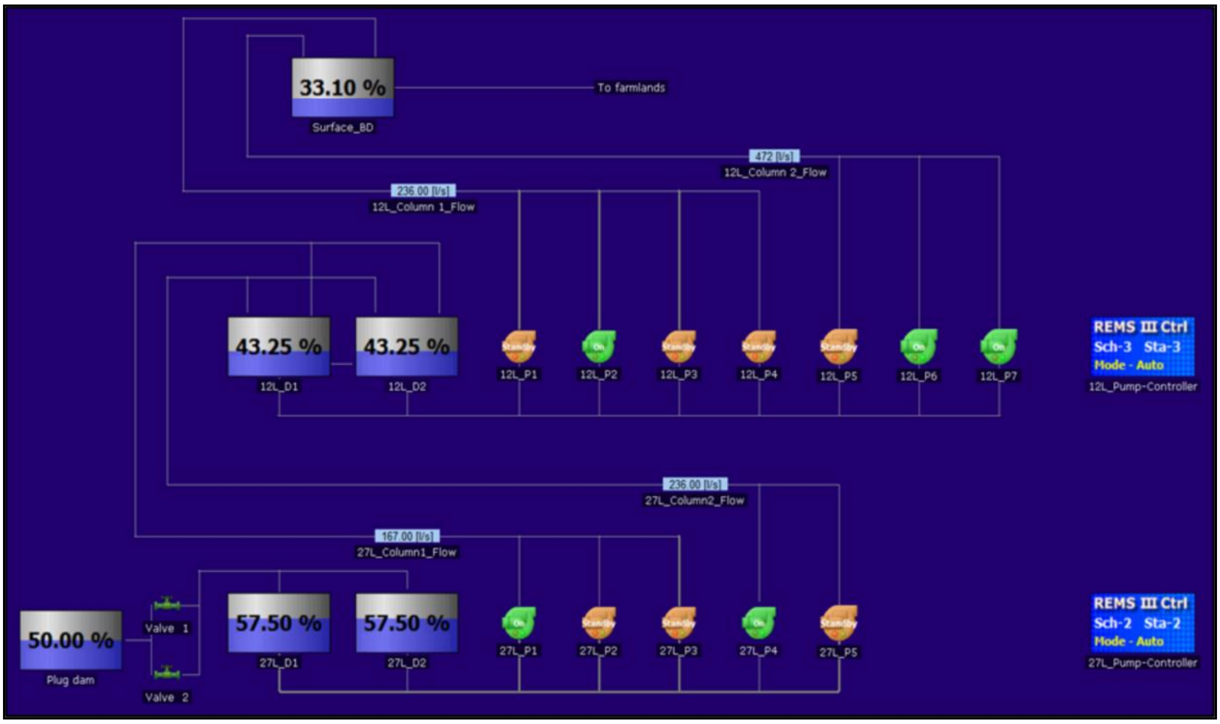

Figure 55: Case Study B – simulation platform

[F: S-2b] Simulation

As with Case Study A, Eskom low demand season TOU periods were used for the simulation as the baseline was developed using Eskom low demand season TOU period data. The simulation result is, however, applicable to Eskom high demand season TOU periods as well. This is because the peak demand periods are only shifted an hour earlier during Eskom high demand season TOU periods.

[F: S-2c] Load shifting

Figure 56 compares the simulated power profile for the dewatering pumps with the weekday baseline, developed in Step [F: I-2b]. Based on the simulation results, Case Study B should be able to achieve an Eskom evening peak period load shift of 8.3 MW and an Eskom morning peak period load shift of 7.2 MW. This translates into a significant possible annual electricity cost saving of approximately R8.6-million.

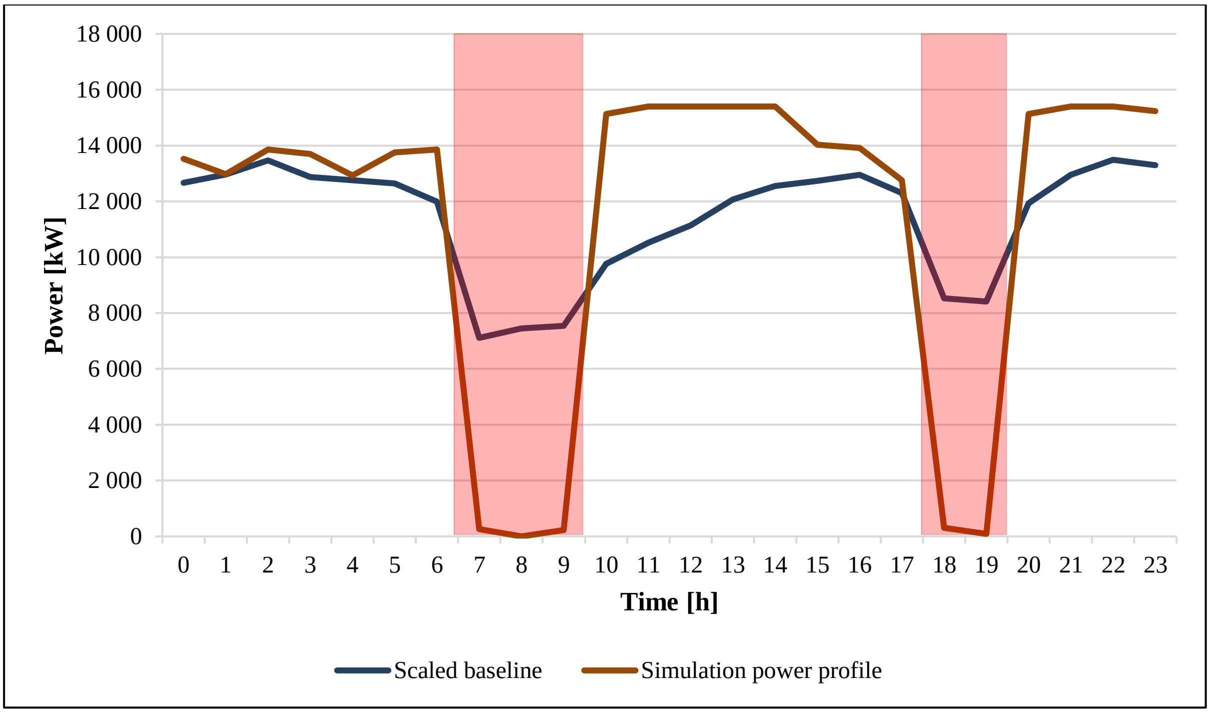

Figure 56: Case Study B – simulation load-shifting results

[F: S-3] Verify simulation

[F: S-3a] Load-shifting test

To verify the simulation, manual load-shifting tests were conducted over a period of three days. The average power profile of these tests is compared with the simulation power profile in Figure 57. The baseline shown in Figure 57 is scaled to be energy-neutral to the load-shifting test power profile.

The simulation results are compared with the load-shifting tests results in Table 25. The load-shifting tests achieved slightly lower average Eskom evening and morning peak period load shifts. The reason for this underperformance can be attributed to maintenance being performed on the service water columns and dewatering pumps during the tests, thus reducing their availability. However, the difference is small, with the load-shifting tests only underperforming with 0.4 MW, or 4.82% and 5.56%, in Eskom evening and morning peak periods respectively. The simulation can therefore be accepted as accurate.

Based on the load-shifting tests results, the expected annual electricity cost savings is approximately R9.4-million. This is slightly higher than the simulation's expected annual electricity cost savings of R8.6-million even though the achieved load shift was less during the load-shifting tests. This is because the electricity consumption of the load-shifting tests was lower during Eskom standard TOU periods compared to the simulation, as can be seen in Figure 57, thereby influencing the total electricity cost savings. This also lowers the baseline, as the baseline is scaled to be energy-neutral to the load-shifting test, thereby causing the reduction in load-shifting performance.

Figure 57: Case Study B – simulation verification

Table 25: Case Study B – simulation verification results

Result	Simulation	Load-shifting test
Average Eskom evening peak period load shift	8.3 MW	7.9 MW
Average Eskom morning peak period load shift	7.2 MW	6.8 MW

[F: A] Analyse

[F: A-1] Risk mitigation

[F: A-1a] Identify risks

The only risk associated with Case Study B is controlling the plug dam level. The plug dam level should not be pumped to below the minimum allowable level to prevent contaminated water being pumped to the surface biological dam. The plug dam should also not be allowed to breach its maximum level to avoid flooding the interconnected mine network.

Further risks associated with Case Study B are few. The mine infrastructure is in good condition and load shifting is easily achievable in Eskom morning and evening peak periods. The mine is keen on achieving electricity cost savings on the dewatering pumps and should therefore not hinder the implementation of the project.

[F: A-1b] Mitigate risks

Underground pump operators are currently responsible for controlling the plug dam level by opening or closing the plug dam valves. The plug dam valves are closed when the plug dam levels fall beneath 18 m in vertical height. The plug dam valves are opened when the plug dam level rises to above 19 m in vertical height.

Currently the surface control room operators only monitor the 12 Level and 27 Level hot water storage dams even though the plug dam level can be monitored from the surface control room. To mitigate the plug dam level risk, the surface control room operators should monitor the plug dam level. This will be a backup measure if the underground pump operators fail to notice the plug dam level breaching its minimum or maximum limit. Surface control room operators can then instruct the underground pump operators to close or open the plug dam valves.

[F: A-2] Conclude feasibility study

[F: A-2a] Analysis

Case Study B has the potential for a 7.9 MW load shift during Eskom evening peak periods and a 6.8 MW load shift during Eskom morning peak periods. This amounts to an annual electricity cost saving of approximately R9.4-million. The pumping system is in good condition and requires no additional hardware installations. Mine personnel are dedicated to achieving electricity cost savings and should not hinder the implementation of the project. The mine should remain in operation for at least the next 15 years.

The risks to the ESCo associated with Case Study B have been identified and mitigated. The potential Eskom peak period load shift simulated during Step [F: S] has been verified by manual load-shifting tests. The Eskom peak period load shift should therefore be sustainable.

[F: A-2b] Conclusion

Based on the analysis of Step [F: A-2a], Case Study B was deemed feasible by the ESCo and submitted to Eskom IDM for approval. Case Study B’s project proposal was submitted at the same time as Case Study A. Eskom Energy Audit assigned the same M&V team who was used for Case Study A to Case Study B. The M&V team completed the M&V scope, plan and baseline report. The baseline developed during Step [F: I-2b] was verified and approved by the M&V team in the baseline report.

Eskom IDM approved the revival of Case Study B based on the ESCo project submission and pre-implementation M&V deliverables. The project’s contractual implementation end date is 31 October 2016, the same as for Case Study A. Case Study B has an Eskom evening peak period load-shifting target of 3.7 MW, which is lower than the verified load shift achieved during Step [F: S-3]. This reduced target is to allow for any unexpected breakdowns or maintenance on the pumping system that will negatively influence the load shift achieved.

4.3.2. Phase 2: Implementation strategies

As with Case Study A, Case Study B was completed before the final implementation end date set by Eskom IDM. The first PA period started at the same time as Case Study A – July 2016. As no hardware installations were required for Case Study B, the control system was again the main focus of the implementation phase.

The mine also requested that Case Study B be controlled using their Archestra SCADA system. As the control system was, however, still in its infancy during the implementation phase of this project, the risk mitigation strategies of Table 9 were used again. The development of the Archestra SCADA control system for Case Study A and Case Study B was completed simultaneously.

The Archestra SCADA system uses a similar control philosophy than that of REMS-P. The initial control limits were set according to the simulation constraints of [F: S-1]. These control limits will continuously be improved upon as the project progresses.

4.3.3. Phase 3: Performance sustainability

The strategies developed in Phase 3 of the sustainable project strategy were used to maximise the load shift achieved during Eskom morning and evening peak periods. At the time of this study, Case Study B had completed its first three-month PA period. As with Case Study A, the first two months of this PA period was completed during the Eskom high demand season. The last month of the first PA period was completed during the Eskom low demand season.

The results of Case Study B are also presented for the Eskom high demand and low demand season TOU periods. This provides an indication of whether the demand TOU period influenced the project's performance. The results are analysed at the end of this chapter.

Case Study B – Eskom high demand season results

Figure 58 displays the average weekday power profile of Case Study B for the first two months of its first PA period, which was completed during the Eskom high demand season TOU periods. The power profile is compared with the M&V verified weekday baseline developed in Step [F: I-2b].

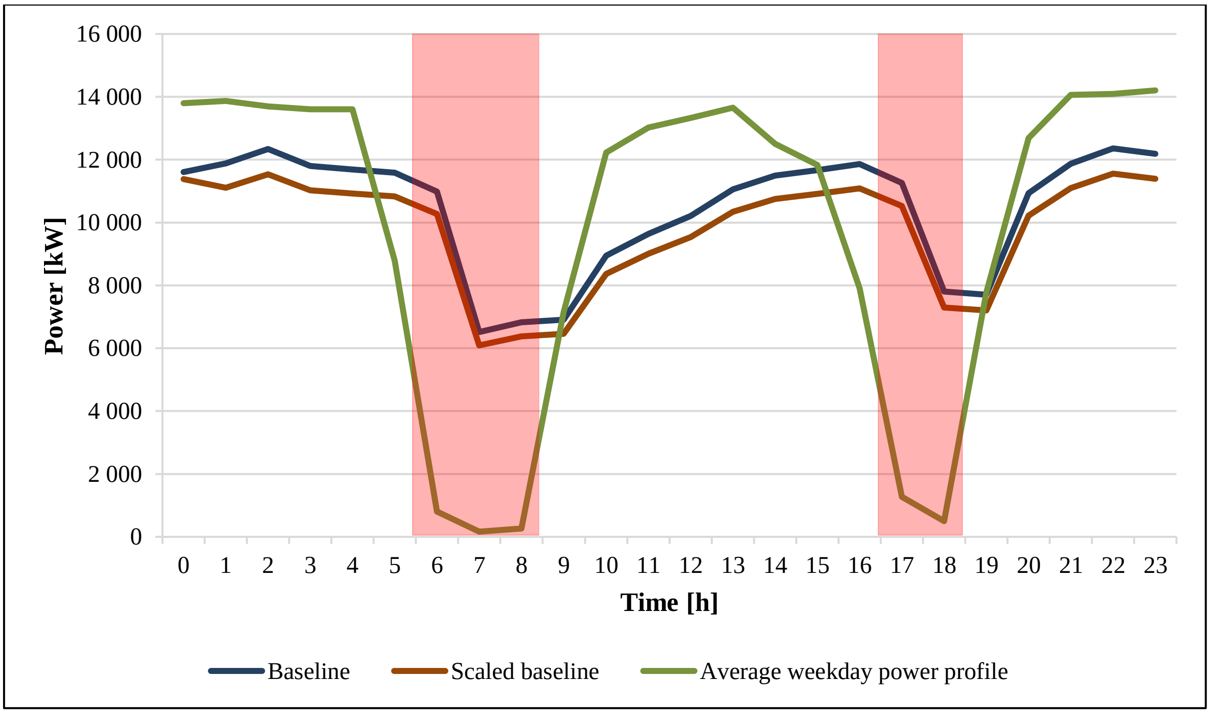

Figure 58: Case Study B – Eskom high demand season average weekday power profile

Table 26 displays the performance of Case Study B during these two months. As can be seen, Case Study B managed to achieve an average Eskom evening peak period load shift of

8.03 MW. This is a performance of approximately 216% against its contracted target of a 3.7 MW. The Eskom morning peak period load shift achieved during this period was 7.17 MW. The electricity cost savings during this period was approximately R2.4-million.

Table 26: Case Study B – Eskom high demand season performance

Savings type	Result
Average Eskom evening peak period load shift	8.03 MW
Average Eskom morning peak period load shift	7.17 MW
Electricity cost savings	R2.4-million

Case Study B – Eskom low demand season results

Figure 59 displays the average weekday power profile of Case Study B for the last month of its first PA period, completed during Eskom low demand season TOU periods. The power profile is compared with the M&V verified weekday baseline developed in Step [F: I-2b].

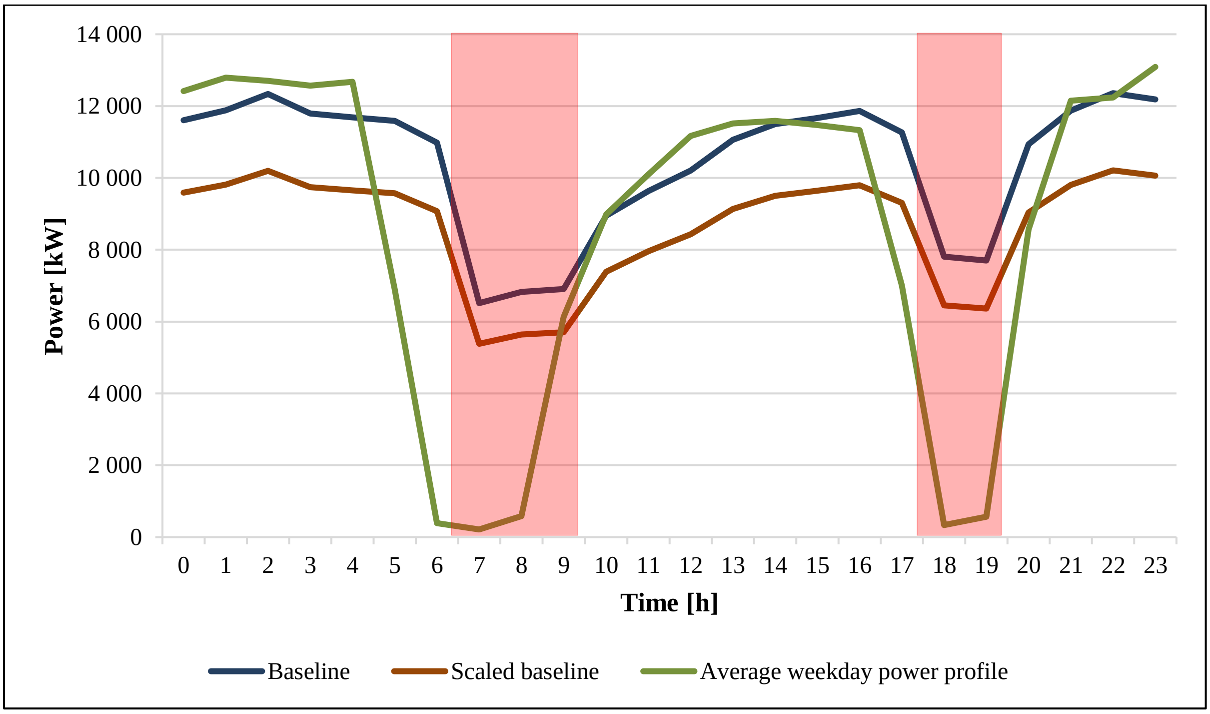

Figure 59: Case Study B – Eskom low demand season average weekday power profile

Table 27 displays the performance of Case Study B during this month. As can be seen, Case Study B managed to achieve an Eskom evening peak period load shift of 5.94 MW. This is a performance of approximately 160% against its contracted target of 3.7 MW. The Eskom morning peak period load shifting achieved during this period was 3.27 MW. The electricity cost savings during this period was approximately R153 000.

Table 27: Case Study B – Eskom low demand season performance

Savings type	Result
Average Eskom evening peak period load shift	5.94 MW
Average Eskom morning peak period load shift	3.27 MW
Electricity cost savings	R153 000

4.4. Results analysis

4.4.1. Case Study A

The implementation of the sustainable project strategy on Case Study A proved to be successful. Case Study A overperformed against its contracted target during both the Eskom high and low demand seasons. During its first PA period, the total electricity cost savings for the mine was approximately R785 000. If the performance of Case Study A is extrapolated to a year, the expected annual electricity cost savings for the mine would be approximately R1.8-million. Case Study A achieved an average performance of 138% during its first PA period.

There is, however, a clear discrepancy that can be made when comparing the performance of Case Study A during Eskom high and low demand season TOU periods. During Eskom high demand season TOU periods, Case Study A achieved an average Eskom evening and morning peak period load shift of 3.92 MW and 0.87 MW respectively. During Eskom low demand season TOU periods, the evening peak period load shift reduced to 2.99 MW and the morning peak load shift to 0.42 MW.

The reduction in performance can be attributed to Eskom changing the high demand season TOU periods in 2015. Load-shifting DSM projects on mine dewatering pumps are non-seasonal, and one month's Eskom low demand season TOU period data was used to develop Case Study A's baseline in Step [F: I-2b]. Eskom does not require a project's baseline to be dependent on the Eskom demand TOU period. The same baseline is therefore used to determine the project's performance during both Eskom high and low demand season TOU periods.

If the PTA ratio of the baseline is calculated using Eskom high demand season TOU periods, it is 0.88. If Eskom low demand season TOU periods are used, the baseline PTA ratio reduces to 0.69. As can be seen from these ratios, the baseline has a higher scope for load shifting using Eskom high demand season TOU periods even though it is the same baseline.

During Eskom high demand season TOU periods, the performance of Case Study A is therefore skewed positively. A true reflection of Case Study A's performance can be determined from the last month of its first PA period, completed during Eskom low demand season TOU periods. This will be the case for any project implemented under the new ESCo model. The true performance of the project will only be reflected in the TOU periods that correspond to the TOU period data used to develop its baseline.

In an effort to provide a true reflection of Case Study A's performance during Eskom high demand season TOU periods, a redeveloped baseline is shown in Figure 60. This baseline is based on the average power values of each TOU period, namely off-peak, standard and peak, of the original, low demand season TOU periods, baseline. These averaged values have been redistributed according to Eskom high demand season TOU periods. This redeveloped baseline is compared to the average weekday power profile of Case Study A during the first two months of its first PA period.

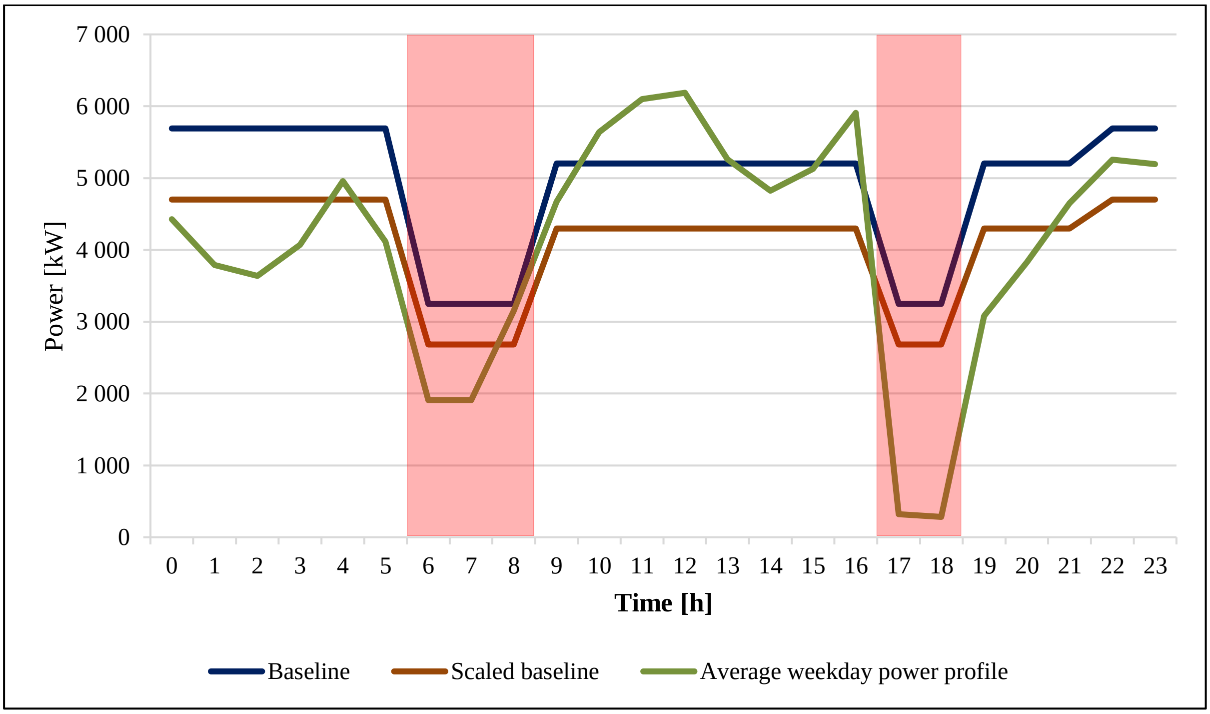

Figure 60: Case Study A – redeveloped baseline comparison

Based on this comparison strategy, Case Study A's performance during Eskom high demand season TOU periods reduces to 2.38 MW and 0.36 MW during Eskom evening and morning peak periods respectively. This is a reduction of 39% and 58% respectively compared to Case Study A's performance measured against the M&V baseline during the Eskom high demand season. This is also a reduction of 20% and 14% compared to Case Study A's performance during Eskom low demand season TOU periods. Using this redeveloped baseline, and the original M&V baseline for Eskom low demand seasons, the expected annual cost saving for Case Study A reduces by 34% to R1.17-million.

4.4.2. Case Study B

The implementation of the sustainable project strategy on Case Study B also proved to be successful. Case Study B overperformed against its contracted target during both the Eskom high and low demand seasons. During its first PA period, the total electricity cost savings for the mine was approximately R2.53-million. If the performance of Case Study B is extrapolated to a year, the expected annual electricity cost savings for the mine would be approximately R8.1-million. Case Study B achieved an average performance of 188% during its first PA period.

The same discrepancy that was noticed for Case Study A can be made when comparing the performance of Case Study B during Eskom high and low demand season TOU periods. During Eskom high demand season TOU periods, Case Study B managed to achieve an average Eskom evening and morning peak period load shift of 8.03 MW and 7.17 MW respectively. During Eskom low demand season TOU periods, this reduced to 5.94 MW and 3.27 MW respectively.

As seen in Figure 59, the Eskom morning peak period load shift during the Eskom low demand season was still being performed according to Eskom high demands season TOU periods. This can be attributed to the morning shift surface control room operators being unwilling to change to Eskom low demand season TOU periods without confirmation from the shaft foreman. The shaft foreman was unavailable at that time. The load shifting was therefore performed an hour earlier than what it was supposed to.

This resulted in missed electricity cost savings for the mine, as the Eskom morning peak period load shifting was not optimal. The Eskom evening peak period load-shifting during the Eskom low demand season was being performed according to the correct Eskom TOU periods. There was therefore no risk to the ESCo involved.

A further analysis that can be made for Case Study B is that the DSM project target of 3.7 MW Eskom evening peak period load shifting was too conservative. Even in Eskom low demand season TOU periods, Case Study B overperforms with 160%. As ESCos are paid based on the size of the project target, this means the responsible ESCo is receiving less funding than what it could have.

In an effort to provide a true reflection of Case Study B's performance during Eskom high demand season TOU periods, a redeveloped baseline is shown in Figure 61. This baseline was developed following the same philosophy that was used for Case Study A. That is, the baseline is based on the average power values of each TOU period, namely off-peak, standard and peak TOU, of the original baseline redistributed to Eskom high demand season TOU periods. This redeveloped baseline is compared to the average weekday power profile of Case Study B during the first two months of its first PA period.

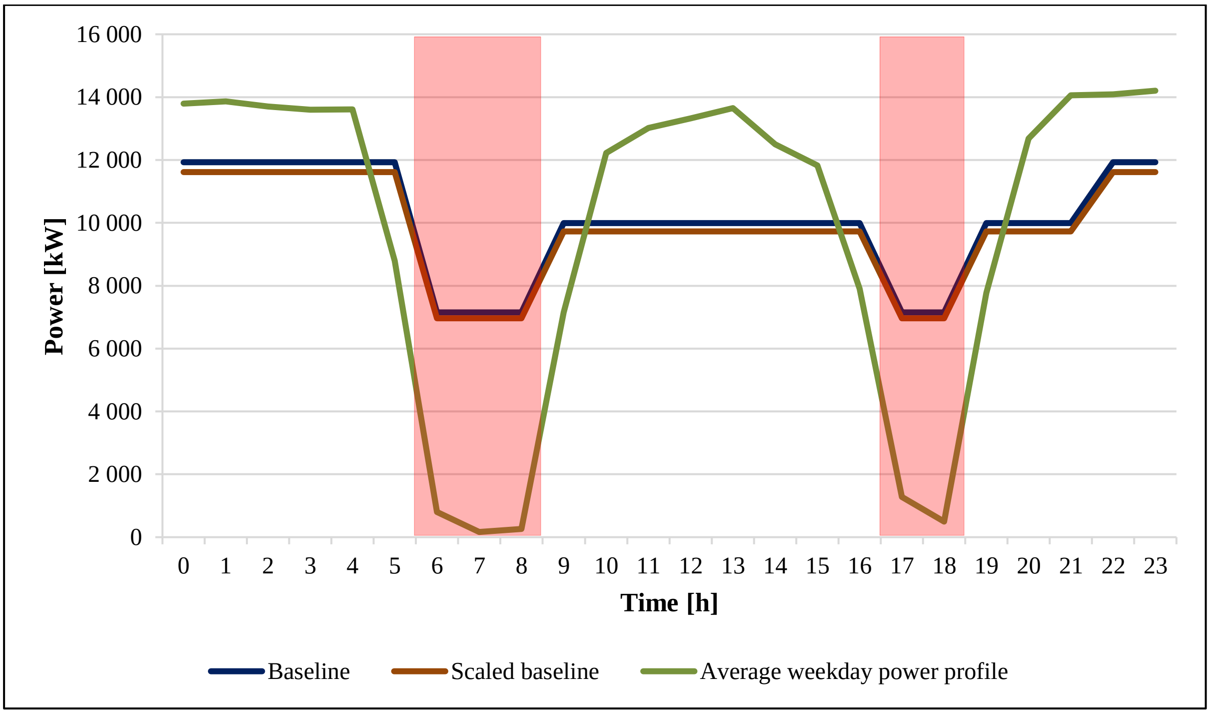

Figure 61: Case Study B – redeveloped baseline comparison

Based on this comparison strategy, Case Study B's performance during Eskom high demand season TOU periods reduces to 6.01 MW and 6.56 MW during Eskom evening and morning peak periods respectively. This is a reduction of 24% and 9.3% respectively compared to Case

Study B’s performance measured against the M&V baseline during the Eskom high demand season. This is however an improvement of 2.7% and 98% compared to Case Study B’s performance during Eskom low demand season TOU periods. Using this redeveloped baseline, and the original M&V baseline for Eskom low demand seasons, the expected annual cost saving for Case Study B reduces by 11.5% to R7.17-million.

4.5. Chapter conclusion

In this chapter, the sustainable project strategy was implemented on two case studies. Both of the case studies were medium- to deep-level gold mines that have completed their PT periods under the old ESCo model. The two case studies were part of the same mining company.

The pumping system specifications and baselines of the two case studies were verified by an official M&V team who audited the pumping systems during site visits. The power data used to calculate the results, excluding the baselines which were calculated from pump run statuses, was obtained from an independent third-party company. The third-party company is contracted to the mining company to which the shafts of the two case studies belong. They ensured the power loggers were calibrated and working. All data used was approved by the mine.

The implementation of the sustainable project strategy proved to deliver positive results. Case Study A achieved a R785 000 electricity cost saving for the mine during its first PA period. Case Study B achieved a R2.53-million electricity cost saving during its first PA period. This amounted to a R3.32-million electricity cost saving for the mine during this three-month period alone. If the proved performance of the case studies during their first PA periods is extrapolated to a year, the total electricity cost saving for the mine would be R9.9-million.

It was, however, found that projects implemented under the new ESCo model will deliver skewed positive results based on the Eskom demand TOU period. This is because of an oversight by Eskom IDM regarding the baseline requirements of projects. These skewed positive results are expected to remain true for any project implemented under the new ESCo model. Using the redeveloped baseline outlined in Section 4.4 for both Case Study A and B, the total annual electricity cost saving for the mine reduces to R8.34-million.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

[7]

"*The ultimate purpose of collecting the data is to provide a basis for action or a recommendation*." – W. Edwards Deming

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[7] A. Hallur, "How to write strong conclusion that rocks your readers' mind," gobloggingtips, 2016. [Online]. Available: http://www.gobloggingtips.com/how-to-write-strong-conclusion/. [Accessed: 17-Sep-2016].

5.1. Summary

Chapter 1 provided an overview of South Africa's electricity generation network, the Eskom IDM DSM programme, the ESCo model and DSM mine pumping projects. The problem statement for this study was outlined. To summarise the problem statement – ESCos need to adapt to the challenges created by the introduction of the new ESCo model when reviving DSM mine pumping projects implemented under the old ESCo model.

Due to the expected low implementation costs, reviving previously implemented DSM mine pumping projects is beneficial to ESCos, clients and Eskom IDM. These are projects that have completed their PT periods under the old ESCo model and are currently achieving poor to no electricity cost savings. The objectives for this study were therefore outlined as follows:

1. Evaluate and critically analyse previous studies related to DSM on mine pumping systems.
2. Identify obstacles and risks associated with reviving DSM mine pumping projects under the new ESCo model.
3. Develop a sustainable project strategy for reviving DSM mine pumping projects under the new ESCo model.
4. Implement the sustainable project strategy on DSM mine pumping projects that have completed their PT periods under the old ESCo model.

Objective 1 was achieved by analysing previous studies related to DSM on mine pumping systems in Section 2.3. During this analysis, it became clear that the scope of previous studies was not sufficient for implementing and sustaining DSM mine pumping projects under the new ESCo model. There were, however, valuable lessons that could be gained from analysing these studies that were used as inputs for this study.

Objective 2 was achieved by identifying and mitigating the obstacles and risks associated with the new ESCo model during Chapter 2 and Chapter 3. The main risk associated with the new ESCo model is the mandatory three-year sustainability period that ESCos were not required to complete under the old ESCo model. This three-year sustainability period is divided into 12 three-month PA periods. Going hand in hand with the three-year sustainability period is that ESCos now only receive funding from Eskom IDM at the end of each PA period. Under the old ESCo model, ESCos received funding upfront when implementing a DSM project.

Objective 3 was achieved by developing a sustainable project strategy in Chapter 3 of this study. The sustainable project strategy was developed with the aim of assisting ESCos to revive DSM mine pumping projects under the new ESCo model. This sustainable project strategy took the lessons learned from analysing previous studies related to DSM on mine pumping systems and the risks associated with the new ESCo model into consideration. The sustainable project strategy was verified against the requirements set out in the beginning of Chapter 3.

The last objective was achieved by implementing the sustainable project strategy on two case studies within the same mining company in Chapter 4. For Case Study A, the implementation of the sustainable project strategy led to an average performance of 138% during its first PA period. This translated into an expected annual electricity cost saving for the mine of R1.8-million. For Case Study B, the implementation of the sustainable project strategy led to an average performance of 188% in its first PA period. This translated into an expected annual electricity cost saving for the mine of R 8.1-million.

The results of the two case studies were analysed at the end of Chapter 4. Although the implementation of the sustainable project strategy proved successful, the results were positively skewed during the Eskom high demand season. This was because the baselines were developed using Eskom low demand season TOU period data. This means that the baselines have more scope for load shifting in Eskom high demand season TOU periods than in Eskom low demand season TOU periods. Using the redeveloped baseline of Section 4.4, the expected total annual electricity cost saving, for both Case Studies, reduces from R9.9-million to R8.34-million.

5.2. Limitations of study and recommendations for future work

This study only focused on reviving DSM mine pumping projects. Other major energy consumers on mines, for example compressors and refrigeration systems, were not included in the scope of this study. There is therefore room to develop the sustainable project strategy further to include these systems.

If the sustainable project strategy is expanded to include other major energy consumers on a mine it will have a twofold benefit. Firstly, the possible electricity cost saving a mine can achieve will increase. Secondly, the demand during Eskom peak periods will be reduced further.

A further limitation of this study is that it only focused on reviving previously implemented DSM mine pumping projects. The implementation of new DSM mine pumping projects was not included in the scope of this study. There is therefore also room to expand the sustainable project strategy to include new DSM mine pumping projects.

Based on the limitation of this study, the following recommendations are made for future work:

- Expand the sustainable project strategy to include other large energy consumers on mines, such as compressors and refrigeration systems.
- Expand the sustainable project strategy to include implementing new DSM mine pumping projects.

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APPENDIX I: PUMP INSTRUMENTATION

Figure 62: Motor shaft displacement switch

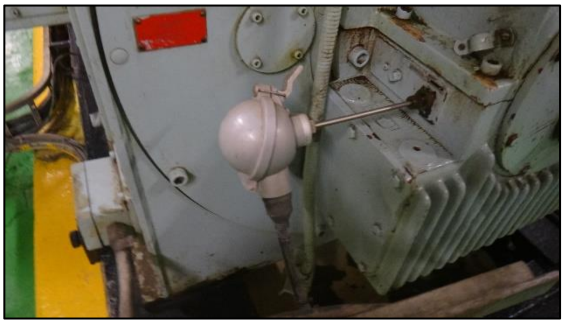


Figure 63: Motor NDE bearing temperature

Figure 64: Motor air temperature sensor

Figure 65: Motor cooling water flow switch

Figure 66: Motor winding temperature junction box

Figure 67: Motor DE bearing vibration sensor (black) and temperature sensor (grey)

Figure 68: Pump DE bearing vibration sensor (black) and temperature sensor (grey)

Figure 69: Pump suction flow switch

Figure 70: Pump balance disc flow sensor

Figure 71: Pump NDE bearing temperature sensor and pump impeller displacement switch

APPENDIX II: SAVINGS CALCULATION METHODOLOGY

The 2016/17 Megaflex TOU tariffs, for industrial users with a supply voltage of between 500 V and 66 000 V, located within 300 km of Johannesburg, are shown in Table 28. The tariffs were used since both case studies fall into this pricing bracket.

Table 28: Megaflex TOU tariffs used in this study

Hour of day	Megaflex tariffs c/kWh (VAT included)					
	High demand season			Low demand season		
	Weekday	Saturday	Sunday	Weekday	Saturday	Sunday
0	50.27	50.27	50.27	43.53	43.53	43.53
1	50.27	50.27	50.27	43.53	43.53	43.53
2	50.27	50.27	50.27	43.53	43.53	43.53
3	50.27	50.27	50.27	43.53	43.53	43.53
4	50.27	50.27	50.27	43.53	43.53	43.53
5	50.27	50.27	50.27	43.53	43.53	43.53
6	**305.59**	50.27	50.27	68.62	43.53	43.53
7	**305.59**	92.58	50.27	**99.68**	68.62	43.53
8	**305.59**	92.58	50.27	**99.68**	68.62	43.53
9	92.58	92.58	50.27	**99.68**	68.62	43.53
10	92.58	92.58	50.27	68.62	68.62	43.53
11	92.58	92.58	50.27	68.62	68.62	43.53
12	92.58	50.27	50.27	68.62	43.53	43.53
13	92.58	50.27	50.27	68.62	43.53	43.53
14	92.58	50.27	50.27	68.62	43.53	43.53
15	92.58	50.27	50.27	68.62	43.53	43.53
16	92.58	50.27	50.27	68.62	43.53	43.53
17	**305.59**	50.27	50.27	68.62	43.53	43.53
18	**305.59**	92.58	50.27	**99.68**	68.62	43.53
19	92.58	92.58	50.27	**99.68**	68.62	43.53
20	92.58	50.27	50.27	68.62	43.53	43.53
21	92.58	50.27	50.27	68.62	43.53	43.53
22	50.27	50.27	50.27	43.53	43.53	43.53
23	50.27	50.27	50.27	43.53	43.53	43.53

The energy neutral savings calculation methodology used for pump load-shifting projects will be explained with an example. Table 29 illustrates the hourly power values of an example baseline and load-shifting power profile for a typical weekday. Eskom low demand season TOU periods are used for this example.

Table 29: Savings calculation example power profiles

Hour of day	Baseline [kW]	Load-shifting power profile [kW]
0	7 200	8 700
1	7 300	8 700
2	7 400	8 700
3	7 500	9 000
4	7 600	9 500
5	7 700	9 500
6	7 800	9 500
7	**8 000**	**5 000**
8	**8 000**	**5 000**
9	**8 000**	**5 000**
10	7 800	9 500
11	7 600	9 500
12	7 400	8 700
13	7 200	8 700
14	7 200	8 700
15	7 400	8 700
16	7 600	9 500
17	7 800	9 500
18	**8 000**	**5 000**
19	**8 000**	**5 000**
20	7 800	9 000
21	7 600	9 000
22	7 400	8 900
23	7 200	8 700
Energy consumption	**182 500 kWh**	**197 000 kWh**

As can be seen in Table 29, the total energy consumption of the baseline and load-shifting power profile differs. The baseline therefore has to be scaled to be energy-neutral to the load-shifting power profile. To achieve this, Equation 2 is used to determine the SLAF. Thus:

$$\boldsymbol{SLAF} = \frac{\boldsymbol{ECP}}{\mathbf{ECB}} \qquad \textbf{Equation 2}$$

$$\boldsymbol{SLAF} = \frac{\mathbf{197\,000}}{\mathbf{182\,500}}$$

$$\boldsymbol{SLAF} = \mathbf{1.079452}$$

To scale the baseline, the baseline power values are multiplied with the SLAF. The total energy consumption of the scaled baseline is then the same as the load-shifting power profile. This is illustrated in Table 30. The daily average electricity cost saving and Eskom peak period load shifting can now be determined by comparing the scaled baseline with the load-shifting power profile. This process is repeated on a daily basis.

The following steps are followed to calculate the electricity cost savings:

1. Determine the total electricity cost of the scaled baseline by multiplying the average hourly power values of the scaled baseline with the corresponding electricity tariff.
2. Determine the total electricity cost of the load-shifting power profile by multiplying the average hourly power values of the load-shifting power profile with the corresponding electricity tariff.
3. Subtract the total electricity cost of the load-shifting power profile from the total electricity cost of the scaled baseline to determine the electricity cost savings. Table 31 shows the result of this electricity cost saving calculation for the current example.

To determine the daily average Eskom peak period load shift the following steps need to be followed:

1. Subtract the hourly load-shifting power profile Eskom morning peak period power from the corresponding scaled baseline Eskom morning peak period power.
2. Subtract the hourly load-shifting power profile Eskom evening peak period power from the corresponding scaled baseline Eskom evening peak period power.
3. Average the Eskom morning and evening peak period power differences to determine the Eskom morning and evening peak period load shift respectively. The results of this steps for the current example are shown in Table 32.

Table 30: Scaled baseline example calculation

Hour of day	Baseline [kW]	SLAF [–]	Scaled baseline [kW]	Load-shifting power profile [kW]
0	7 200	1.079452	7 772.055	8 700
1	7 300	1.079452	7 880.000	8 700
2	7 400	1.079452	7 987.945	8 700
3	7 500	1.079452	8 095.890	9 000
4	7 600	1.079452	8 203.836	9 500
5	7 700	1.079452	8 311.781	9 500
6	7 800	1.079452	8 419.726	9 500
7	**8 000**	**1.079452**	**8 635.616**	**5 000**
8	**8 000**	**1.079452**	**8 635.616**	**5 000**
9	**8 000**	**1.079452**	**8 635.616**	**5 000**
10	7 800	1.079452	8 419.726	9 500
11	7 600	1.079452	8 203.836	9 500
12	7 400	1.079452	7 987.945	8 700
13	7 200	1.079452	7 772.055	8 700
14	7 200	1.079452	7 772.055	8 700
15	7 400	1.079452	7 987.945	8 700
16	7 600	1.079452	8 203.836	9 500
17	7 800	1.079452	8 419.726	9 500
18	**8 000**	**1.079452**	**8 635.616**	**5 000**
19	**8 000**	**1.079452**	**8 635.616**	**5 000**
20	7 800	1.079452	8 419.726	9 000
21	7 600	1.079452	8 203.836	9 000
22	7 400	1.079452	7 987.945	8 900
23	7 200	1.079452	7 772.055	8 700
Energy consumption	**182 500 kWh**	**–**	**197 000 kWh**	**197 000 kWh**

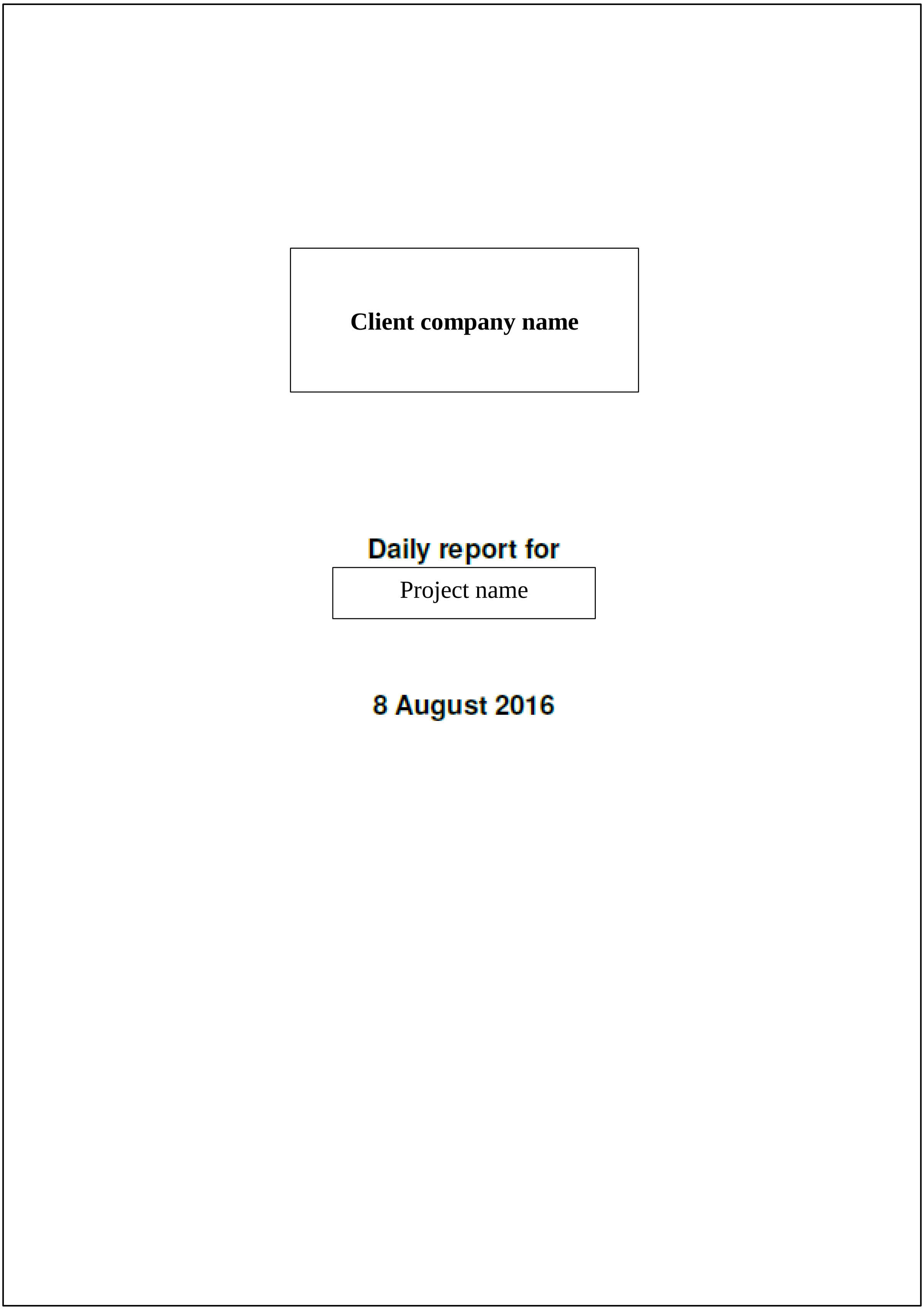
Table 31: Electricity cost saving example calculation

Hour of day	Scaled baseline [kW]	Load-shifting power profile [kW]	Scaled baseline electricity cost [R]	Load-shifting power profile electricity cost [R]	Electricity cost saving [R]
0	7 772.055	8 700	3 383.18	3 787.11	–403.93
1	7 880.000	8 700	3 430.16	3 787.11	–356.95
2	7 987.945	8 700	3 477.15	3 787.11	–309.96
3	8 095.890	9 000	3 524.14	3 917.70	–393.56
4	8 203.836	9 500	3 571.13	4 135.35	–564.22
5	8 311.781	9 500	3 618.12	4 135.35	–517.23
6	8 419.726	9 500	5 777.62	6 518.90	–741.28
7	**8 635.616**	**5 000**	**8 607.98**	**4 984.00**	**3 623.98**
8	**8 635.616**	**5 000**	**8 607.98**	**4 984.00**	**3 623.98**
9	**8 635.616**	**5 000**	**8 607.98**	**4 984.00**	**3 623.98**
10	8 419.726	9 500	5 777.62	6 518.90	–741.28
11	8 203.836	9 500	5 629.47	6 518.90	–889.43
12	7 987.945	8 700	5 481.33	5 969.94	–488.61
13	7 772.055	8 700	5 333.18	5 969.94	–636.76
14	7 772.055	8 700	5 333.18	5 969.94	–636.76
15	7 987.945	8 700	5 481.33	5 969.94	–488.61
16	8 203.836	9 500	5 629.47	6 518.90	–889.43
17	8 419.726	9 500	5 777.62	6 518.90	–741.28
18	**8 635.616**	**5 000**	**8 607.98**	**4 984.00**	**3 623.98**
19	**8 635.616**	**5 000**	**8 607.98**	**4 984.00**	**3 623.98**
20	8 419.726	9 000	5 777.62	6 175.80	–398.18
21	8 203.836	9 000	5 629.47	6 175.80	–546.33
22	7 987.945	8 900	3 477.15	3 874.17	–397.02
23	7 772.055	8 700	3 383.18	3 787.11	–403.93
Total cost	**–**	**–**	**R132 532.02**	**R124 956.87**	**R7 575.15**

Table 32: Load-shifting example calculation

Hour of day	Scaled baseline [kW]	Load-shifting power profile [kW]	Peak period difference [MW]	Average load shifting [MW]
0	7 772.055	8 700	–	–
1	7 880.000	8 700	–	–
2	7 987.945	8 700	–	–
3	8 095.890	9 000	–	–
4	8 203.836	9 500	–	–
5	8 311.781	9 500	–	–
6	8 419.726	9 500	–	–
7	**8 635.616**	**5 000**	**3.636**	**3.636**
8	**8 635.616**	**5 000**	**3.636**	
9	**8 635.616**	**5 000**	**3.636**	
10	8 419.726	9 500	–	–
11	8 203.836	9 500	–	–
12	7 987.945	8 700	–	–
13	7 772.055	8 700	–	–
14	7 772.055	8 700	–	–
15	7 987.945	8 700	–	–
16	8 203.836	9 500	–	–
17	8 419.726	9 500	–	–
18	**8 635.616**	**5 000**	**3.636**	**3.636**
19	**8 635.616**	**5 000**	**3.636**	
20	8 419.726	9 000	–	–
21	8 203.836	9 000	–	–
22	7 987.945	8 900	–	–
23	7 772.055	8 700	–	–

APPENDIX III: DAILY SAVINGS REPORT

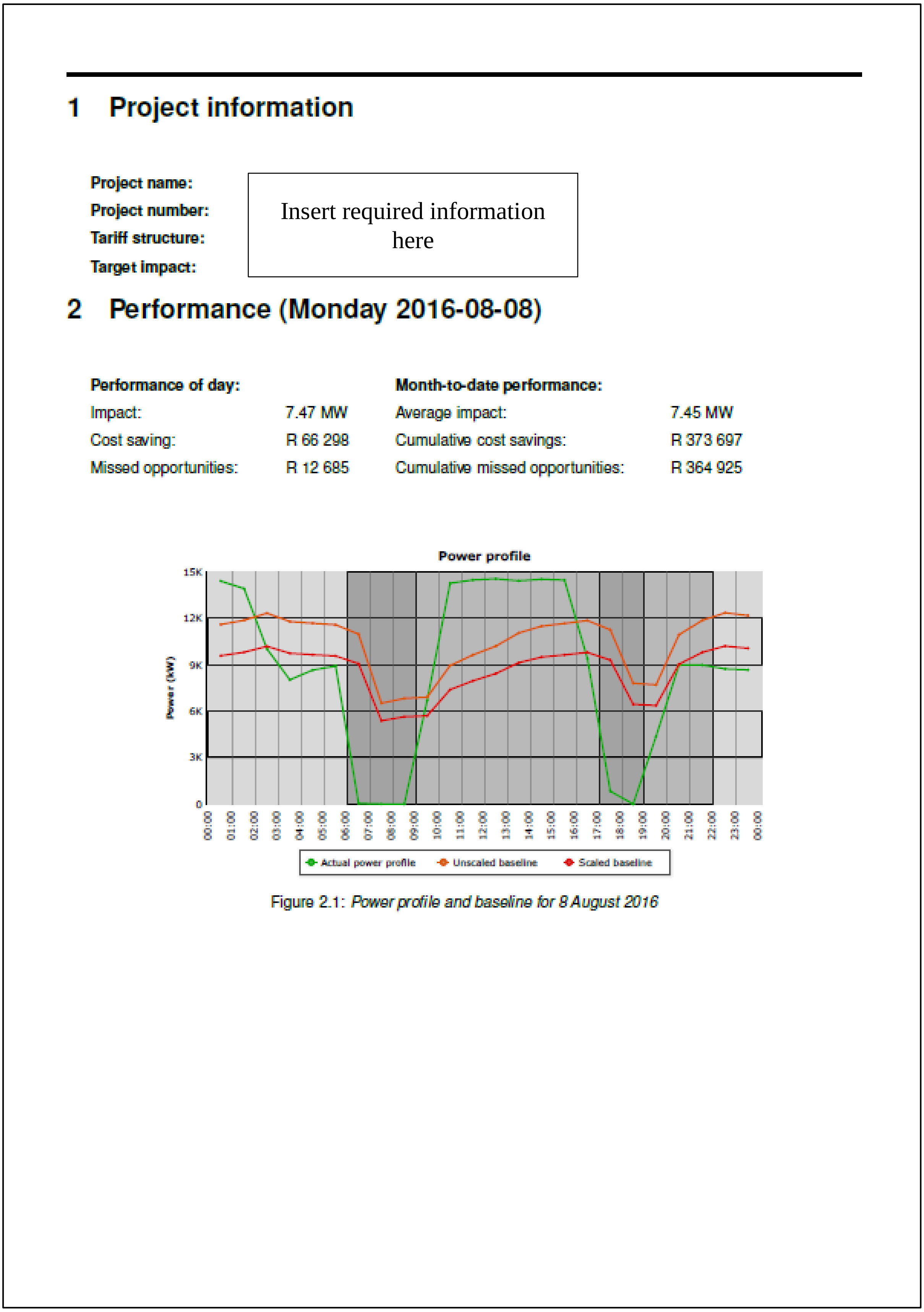


Client company name

Daily report for

Project name

8 August 2016



1 Project information

Project name:
Project number:
Tariff structure:
Target impact:

Insert required information here

2 Performance (Monday 2016-08-08)

Performance of day:		**Month-to-date performance:**	
Impact:	7.47 MW	Average impact:	7.45 MW
Cost saving:	R 66 298	Cumulative cost savings:	R 373 697
Missed opportunities:	R 12 685	Cumulative missed opportunities:	R 364 925

Figure 2.1: *Power profile and baseline for 8 August 2016*

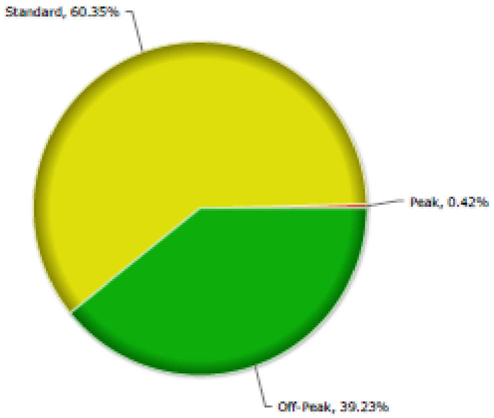


Figure 2.2: *Daily energy usage distribution - 8 August 2016*