An integrated sustainability framework for environmental impact reduction in the gold mining industry

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Thesis submitted in fulfilment of the requirements for the degree Doctorate in Mechanical Engineering at the Potchefstroom campus of the North-West University

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April 2014

NORTH-WEST UNIVERSITY
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NOORDWES-UNIVERSITEIT
POTCHEFSTROOM CAMPUS

It all starts here

Abstract

Title:	An integrated sustainability framework for environmental impact reduction in the gold mining industry.
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Degree:	Philosophaie Doctor in Mechanical Engineering
Keywords:	Environmental impact reduction, energy reduction projects, sustainability framework, energy management system, environmental management system.

The gold mining industry pollutes both water and air resources in numerous ways. Of these, air pollution from greenhouse gasses inducing climate change poses the highest threat to human existence, with water scarcity as a result of pollution presenting the third highest risk (Mathews, 2007; Akorede *et al.*, 2012; Jones *et al.,* 1988). Water pollution, indirect air pollution and direct air pollution should be mitigated for sustainable gold mining.

Environmental impact reduction is achieved by the implementation of effective Environmental Management Systems (EMSs). These systems aim to achieve ISO 14001-compliance by setting targets and implementing a systematic approach to achieving these targets. However, ISO 14001-compliant systems do not ensure environmental impact reduction and give the mine no competitive edge (Hilson & Nayee, 2002).

EMSs available are too generic for implementation on gold mines. Reporting on Key Performance Indicators (KPIs) on gold mines should also be improved as it is unclear exactly what values should be reported on. This is due to a general lack of an environmental reporting standard (Jones, 2010).

Manpower and expertise to identify and implement projects is limited and the mines need assistance with the implementation of projects to effect resource pollution. Priority for the mines is an emphasis on production and safety rather than environmental impact reduction, so implementing projects to reduce pollution is often neglected.

A novel sustainability framework is developed in this study. In this framework a database of electricity- and environmental impact reduction projects is created that can be implemented in the gold mining industry. Projects are automatically identified by monitoring key operational indicators.

By involving a third party in the form of an Energy Services Company (ESCO), project funding for these sustainability projects can be attained. This novel approach to environmental impact reduction creates a situation where ESCOs implement these EMSs at a reduced cost to the mines. This reduces the cost of lowering the mine's environmental impact, while aiding the ESCO in identifying sustainability projects.

KPIs from various studies are consolidated to determine exactly what values should be reported on. These values are incorporated into a successful EMS. This allows the availability of all the necessary data for reporting to the Department of Energy (DoE) and the South African National Energy Development Institute (SANEDI) on electricity-savings.

Projects are prioritised based on an integrated electricity- and environmental impact reduction payback approach. This approach allows funding options to be assessed for each project individually, based on both electricity- and environmental impact reduction advantages. This allowed the best funding option for each individual project to be determined.

Automatic identification of these projects reduces the required manpower and resources to implement sustainability projects. Projects proposed by this study showed a combined energy efficiency reduction of 11.8 MW and achieved a load shift of 15.6 MW. In addition to electricity reduction, these projects also reduced the water usage by 1135 Ml per annum and the carbon dioxide equivalent production by 214 205 ton per annum.

The proposed projects were effective at increasing the sustainability of gold mining. It also streamlined the implementation of these projects on gold mines. By applying this framework, sustainability improvements can now be achieved on gold mines worldwide.

Acknowledgements

I would like to thank Prof. Eddie Mathews, TEMM International (Pty) Ltd., HVAC International (Pty) Ltd and CRCED Pretoria, for providing the opportunity and financial support to complete this study.

Thanks go to Dr. Gerhard Bolt, Dr. Marius Kleingeld and the other study leaders for providing guidance and advice throughout the course of this study.

Finally, acknowledgments go to my friends and family for their continued support in everything I do.

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Abbreviations

APN	Access Point Name
AMD	Acid Mine Drainage
ANFO	Ammonium Nitrate/Fuel Oil
AQA	The Air Quality Act
BAC	Bulk Air Cooler
CA	Cooling Auxiliary
CCGT	Combined-Cycle Gas Turbine
CDM	Clean Development Mechanism
CER	Certified Emission Reduction
COP	Coefficient of Performance
DEA	Department of Environmental Affairs
DoE	Department of Energy
DWAF	Department of Water Affairs and Forestry of the Republic of South Africa
DWA	Department of Water Affairs
ECA	Environmental Conservation Act
EMS	Environmental Management System
ESP	Electrostatic Precipitation
FGD	Flue Gas Desulphurisation

GDP	Gross Domestic Product
GRI	Global Reporting Initiative
HMI	Human-Machine Interface
IDM	Integrated Demand Management
IEA	International Energy Agency
ISO	International Organisation for Standardisation
KPI	Key Performance Indicator
LOI	Letter of Intent
M&V	Measurement and Verification
MAR	Mean Annual Runoff
MEA	Monoethanolamine
NEES	National Energy Efficiency Strategy
NERSA	National Energy Regulator of South Africa
NPDES	National Pollutant Discharge Elimination System
NWA	National Water Act
OAN	Optimisation of Air Networks
O/C	Open/Close
OLE	Object Linking and Embedding
OPC	OLE for Process Control
PAT	Pump as Turbine
PI	Proportional-Integral

PLC	Programmable Logic Controller
RAW	Return Airway
REMS-CA™	Real-Time Energy Management System for Cooling Auxiliaries
REMS-Pumps™	Real-Time Energy Management System for Pumps
REMS-WSO™	Real-Time Energy Management System for Water Supply Optimisation
SANAS	South African National Accreditation System
SANEDI	South African National Energy Development Institute
SARS	South African Revenue Services
SCADA	Supervisory Control and Data Acquisition
SRG	Sustainability Reporting Guideline
VSD	Variable Speed Drive
WCA	Water Catchment Area
WSO	Water Supply Optimisation

Nomenclature

Units of measure

%	Percentage	**m**	Metre
°	Degree	**min**	Minute
°C	Degrees Celsius	**Pa**	Pascal
c	Cent	**R**	South African rand
g	Gram	**s**	Second
h	Hour	**t**	ton
J	Joule	**W**	Watt
K	Kelvin	**Wh**	Watt hour
l	Litre	**pH**	Power of Hydrogen

Symbols

Symbol	**Description**	**Unit**
c_p	Specific heat capacity at constant pressure	J/kg.K
d	Diameter	m
f	Darcy friction factor	-
g	Gravitation	m/s^2
H	Height	m

k	Ratio of specific heats	-
Kl	Loss factor	-
l	Length	m
$\dot{m}$	Mass flow	kg/s
ρ	Density	kg/m^3
P	Power	W
Q	Heat	J
T	Temperature	°C
v	Velocity	m/s
W	Electrical Energy	W

Periodic symbols

As	Arsenic	**Mn**	Manganese
B	Boron	**Mo**	Molybdenum
Ba	Barium	**N**	Nitrogen
Be	Beryllium	**Na**	Sodium
Br	Bromine	**Ni**	Nickel
C	Carbon	**O**	Oxygen
Ca	Calsium	**P**	Phosphorus

Cd	Cadmium
Cl	Clorine
Co	Cobalt
Cr	Cromium
Cs	Cesium
Cu	Copper
F	Fluorine
Fe	Iron
Ge	Germanium
H	Hydrogen
Hf	Hafnium
Hg	Mercury
I	Iodine
K	Potassium
Mg	Magnesium

Pb	Lead
Rb	Rubidium
S	Sulfur
Sb	Antimony
Se	Selenium
Si	Silicon
Sn	Tin
Sr	Strontium
Te	Tellurium
Th	Thorium
Ti	Titanium
U	Uranium
V	Vanadium
W	Tungsten
Zn	Zinc

Glossary

Actuator

An actuator is an electrical- or pneumatic-powered piece of equipment that opens or closes valves.

Airless shaft

Mines that do not use compressed air for drilling purposes are referred to as airless shafts. In the same way that compressed air is used in a series of cylinders hammering a drill bit into rock, pressurised water can be used to drill.

Coefficient of Performance (COP)

The COP is the ratio between the cooling capacity of a refrigeration machine and the electrical energy consumed by it. The COP can be calculated using Equation [0.1] (Calitz, 2006).

$$COP = \frac{Q}{W} \qquad [0.1]$$

Where,

COP = The Coefficient of Performance [no unit]

Q = The cooling capacity of the refrigeration machine [kJ]

W = The electrical energy consumption of the refrigeration machine [kW]

Comeback load

When electricity usage is shifted from one timeframe to another, the load used in the new timeframe is called the comeback load.

Electrostatic precipitation (ESP)

Electrostatic precipitation is the process by which solid particles are removed from the air. Air travels through positive- and negatively-charged plates that electrostatically charge the particles. This causes the solid particles to adhere to the oppositely charged plate. Striking the charged plates causes the particulate matter to fall off the plates and be removed.

The efficiency of ESP decreases with a decrease in the sulphur content of the particulate matter. For this reason, sulphur is added to ash from power generation processes. While this increases the efficiency of removing ash from effluent systems, it also increases the sulphur pollution of flue gases (Liqiang & Yongtao, 2013).

Flue gas desulphurisation (FGD)

In this process, a limestone/water mixture is sprayed into the passing flue gas. Limestone removes the sulphur from the flue gas by chemically reacting to form insoluble gypsum, which is used in other industries (Galos *et al.*, 2003).

Framboidal and crystalline pyrite

Framboidal pyrite describes the mineral pyrite with spherical micro morphological formations, while crystalline pyrite is made up of crystal structures. These can be seen in Figure 1.

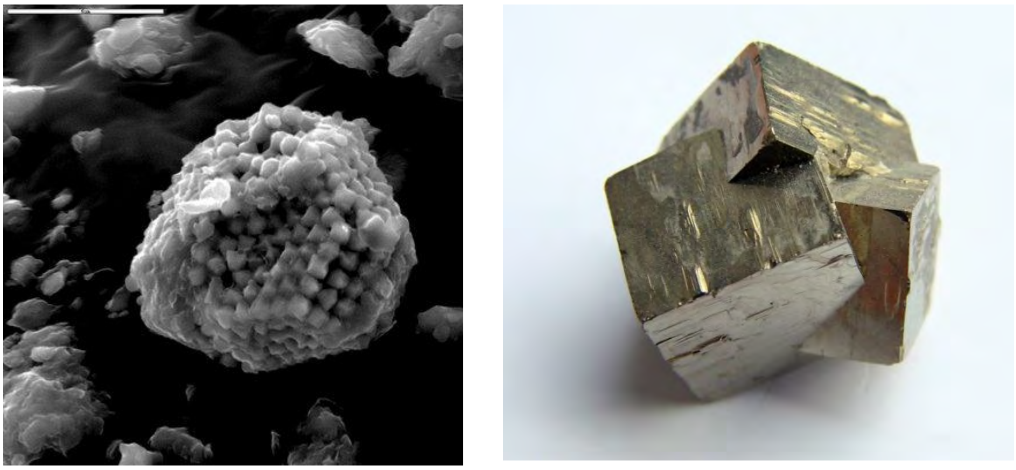


Figure 1: Pyrite formations, showing framboidal pyrite on the left and crystalline pyrite on the right

Gross Domestic Product (GDP)

The market value of a country’s services and goods.

Hydro-mining

Airless shafts rely on hydraulic water pressure build-up to power drills and other underground equipment. This is known as hydro-mining.

International Organisation for Standardisation (ISO) 14001 and ISO 50001

ISO 14001 is a guideline to systematic environmental impact reduction. ISO 50001 is the guideline for reducing energy consumption.

Kyoto Protocol

The Kyoto Protocol is a commitment from industrialised countries to reduce their greenhouse gas emissions. This protocol came into effect in 2005 with a reduction target of 5.2% by 2012. Unfortunately, no further commitment has been made since 2012 (Hu & Monroy, 2012).

Karst aquifers

Karst aquifers are underground water chambers (Winde & Erasmus, 2011), formed in areas where water has reacted with dolomite and air to erode the rock faces (Durand, 2012). Water seeps from the earth’s surface into these chambers.

Measurement and Verification (M&V)

The measurement and verification team comprises students from various universities across South Africa. These students ensure that the reported project savings is correct.

NO_x

This is the chemical formulae referring to all variants of nitrous oxide.

Peat

Peat is a mass of partially decomposed plants, accumulating at the bottom of wetlands. The large quantity of plant matter creates a situation where the wetland plants cannot decompose completely, and banks of organic matter are formed (Winde & Erasmus, 2011).

Photochemical smog

This is a type of air pollution created when nitrogen oxides react with hydrocarbons (excluding methane) under the influence of sunlight (Abdul-Wahab, 2001).

PI control

Proportional Integral (PI) control is an algorithm used in process control to allow smooth transitions between output values by oscillating the system to the next set-point. This is a simplified version of the PID controller (Brand, 2011). The algorithm for a PI controller can be seen below in Equation [0.2] (Brand, 2011):

$$u(t) = K_p E(t) + K_i \int_0^t E(\tau)d\tau \qquad [0.2]$$

Where,

$u(t)$ = The output of the PI function

K_p = The constant for the proportional control

K_i = The constant for the integral control

$E(t)$ = The proportional function

$\int_0^t E(\tau)d\tau$ = The integral function

Here it can be seen that the output is a function of the proportional and integral functions. By adjusting the Kp and Ki values, the oscillation amplitude and frequency can be adjusted respectively (Brand, 2011).

Object Linking and Embedding (OLE) for process control (OPC)

OPC is a software program used for automated process control. OPC converts hardware communication like programmable logic controller (PLC) signals into information that can be interpreted by a Human-Machine Interface (HMI) such as a personal computer running Windows operating system.

Refuge chambers

Refuge chambers are rooms dispersed throughout a mine to accommodate workers during dangerous situations. These are supplied with compressed air from the surface level to ensure that the air pressure inside the chamber is kept at a pressure higher than atmospheric pressure, ensuring that flames and dangerous diffusing gasses do not enter into the refuge chamber.

Saline aquifer

Saline aquifers are natural underground salt water karsts. These can be used to store dissolved carbon dioxide (Raziperchikolaee *et al.*, 2013).

Tailings

Tailings are the residue waste material left after all valuable material has been removed from processed ore. Tailings are also called mine dumps, slimes dams, tails, or leach residue.

Truteq

Truteq is a closed network connection across different networks at different sites. It is also called a private Access Point Name (APN).

1. Mining processes and the pollutants created

This chapter discusses the basic mining methods used in deep-level gold mining and investigates the pollution created during normal operation. The focus then shifts to the environmental management of gold mines and the identification of pollution reduction projects.

1.1.Introduction

Water is a scarce resource in South Africa that should be managed with care. Water shortage is considered the third highest threat to human existence (Jones *et al.,* 1988) with climate change the greatest threat to our existence (Mathews, 2007; Akorede *et al.*, 2012). It is therefore of critical importance that water resources and climate change are carefully managed.

Deep-level gold mining is identified as one of the biggest polluters in South Africa. It is generally accepted that effluent water generation by mines is the most dangerous pollutant created by this industry (Kalin *et al*., 2006). Unfortunately society has become reliant on the mining of precious metals (Van Berkel, 2007; Newbold, 2006), thus making it necessary to improve the sustainability of deep-level gold mining by reducing its environmental impact.

Water and electricity is used by the gold mining industry during normal operation. This chapter starts by looking at the management of these resources by understanding how pollution is created on deep-level gold mines. This understanding will enable improved sustainability of the mining process by minimising pollution of natural resources affected by gold mines.

1.2.Basic gold extraction process

It is essential to have a basic knowledge of deep-level mining practices in South Africa in order to grasp how resources are polluted. The typical mining methods employed in South Africa are the longwall mining and sequential grid mining methods (Wenbing *et al.*, 2012; Handley *et al.*, 2000). To explain these practices, a simplified layout of a deep-level gold mine is shown in Figure 2.

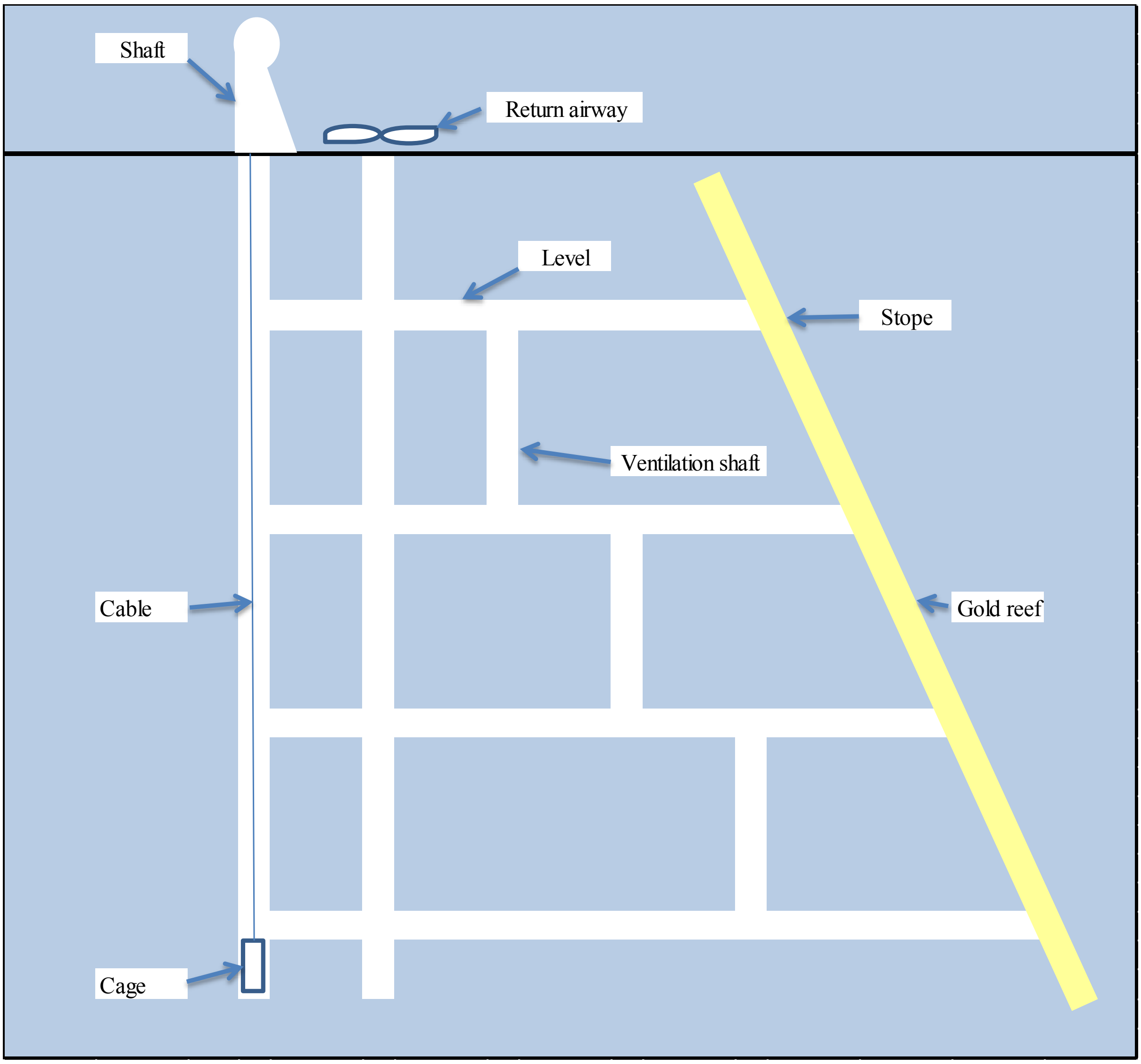


Figure 2: Deep-level gold mine layout

Figure 2 shows the shaft on the ground level. This shaft has a cabling system capable of hoisting a cage up and down the shaft to transport tools, workers and gold-bearing ore up and down the shaft. The ore is usually hoisted in the return airway shaft, although there are exceptions. Levels extend all the way from the shaft to the gold-bearing ore. In some mines these levels can reach up to 8 km in length in various directions.

To ventilate the mine, air is extracted through the return airway to induce a draft. This extraction is done using large fans with electrical motor sizes often in excess of 4 MW. A series of doors blocking the airflow is utilised to ensure that the airflow is optimised throughout the mine. Ventilation shafts connecting the levels are also blasted to ensure every level is ventilated.

Gold-bearing rock is blasted from the earth using Ammonium Nitrate/Fuel Oil (ANFO). To insert the explosives, holes are drilled into the rock in a specific pattern, shown in Figure 3. These holes are drilled using compressed air-powered drills. The explosives are then detonated from the inside outward.

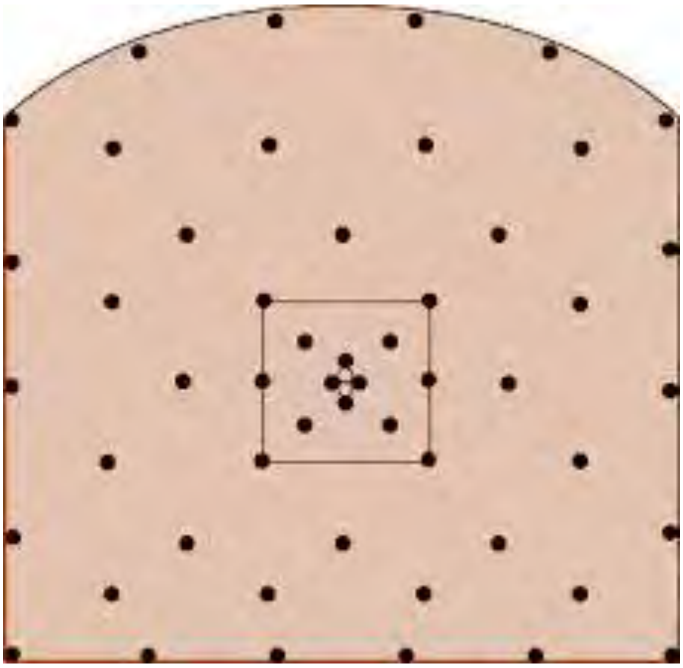


Figure 3: Hole drilling pattern

After blasting the rock face of the gold reef, the ore is first cooled down using water, then loaded onto locomotives using loaders, and transported to the shaft. A typical example of a rock loader can be seen in Figure 4.

Figure 4: Pneumatic underground rock loader

From here it is loaded into the rock hoist using loading boxes, to be hoisted to surface. The ore can then be transported to the gold plant for gold ore extraction.

Water reticulation system

A typical mining day is divided into three shifts, namely the drilling, blasting and sweeping shifts. Water is used by machinery throughout each shift, for different purposes. For this reason water is distributed to each section of the mine. This is known as the water reticulation system.

The drilling shift usually starts at 07:00 and continues until 13:00. During this time, holes are drilled into the gold reef for the placement of explosives. Water is consumed in the drilling process to cool down the drill bit during operation.

The pressure of the water supply for drilling purposes should be at least 400 kPa. This pressure is achieved by ensuring that the dam supplying the level of the mine is sufficiently higher than the level; auto-compression is enough to force water through the drill.

The next shift is the blasting shift which would typically start at 13:00 and end at 21:00. The drilled holes are filled with explosives and wired to detonators. It is then necessary to evacuate the mine for safety reasons before detonating the explosives, blasting the rock from the reef. During this shift, water is only consumed by the cooling cars situated throughout the mine to cool down the air.

The final shift is the sweeping shift, during which the loose rocks are cooled down by spraying water on them. The rocks are then collected and transported to surface using rock winders. This shift usually ends at 07:00. The typical water usage and flow profile across the different mining shifts can be seen in Figure 5.

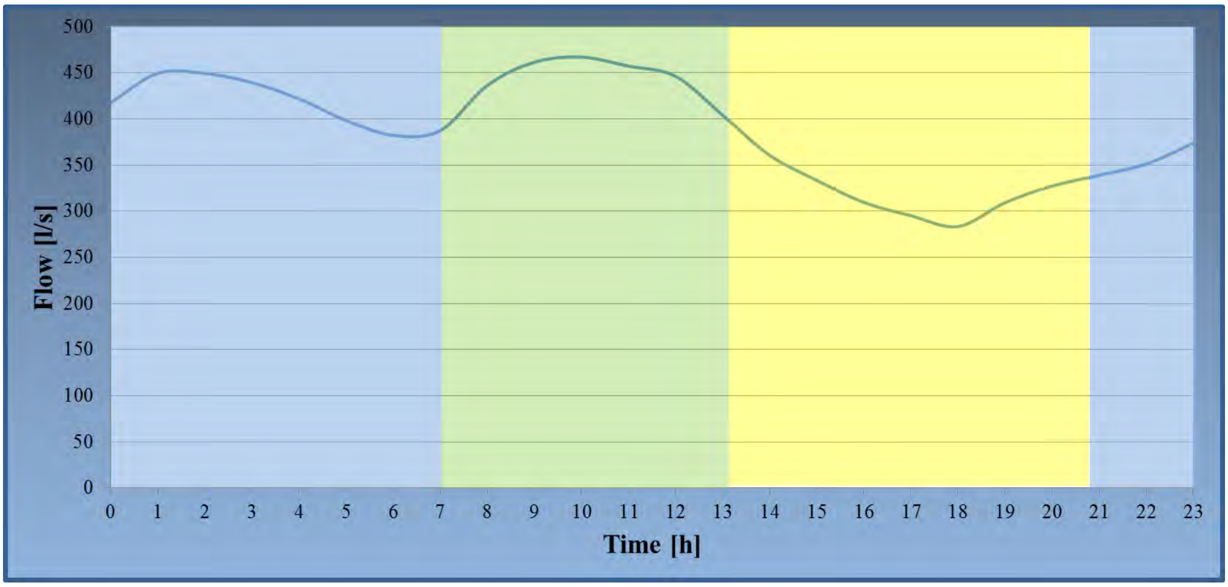


Figure 5: Typical water usage profile

The drilling shift is displayed as the green area, the blasting shift as the yellow area and the sweeping shift as the blue area of Figure 5. The water reticulation system consists of three separate systems that generally work in conjunction, although operations may vary between mines. This operation can be seen in Figure 6.

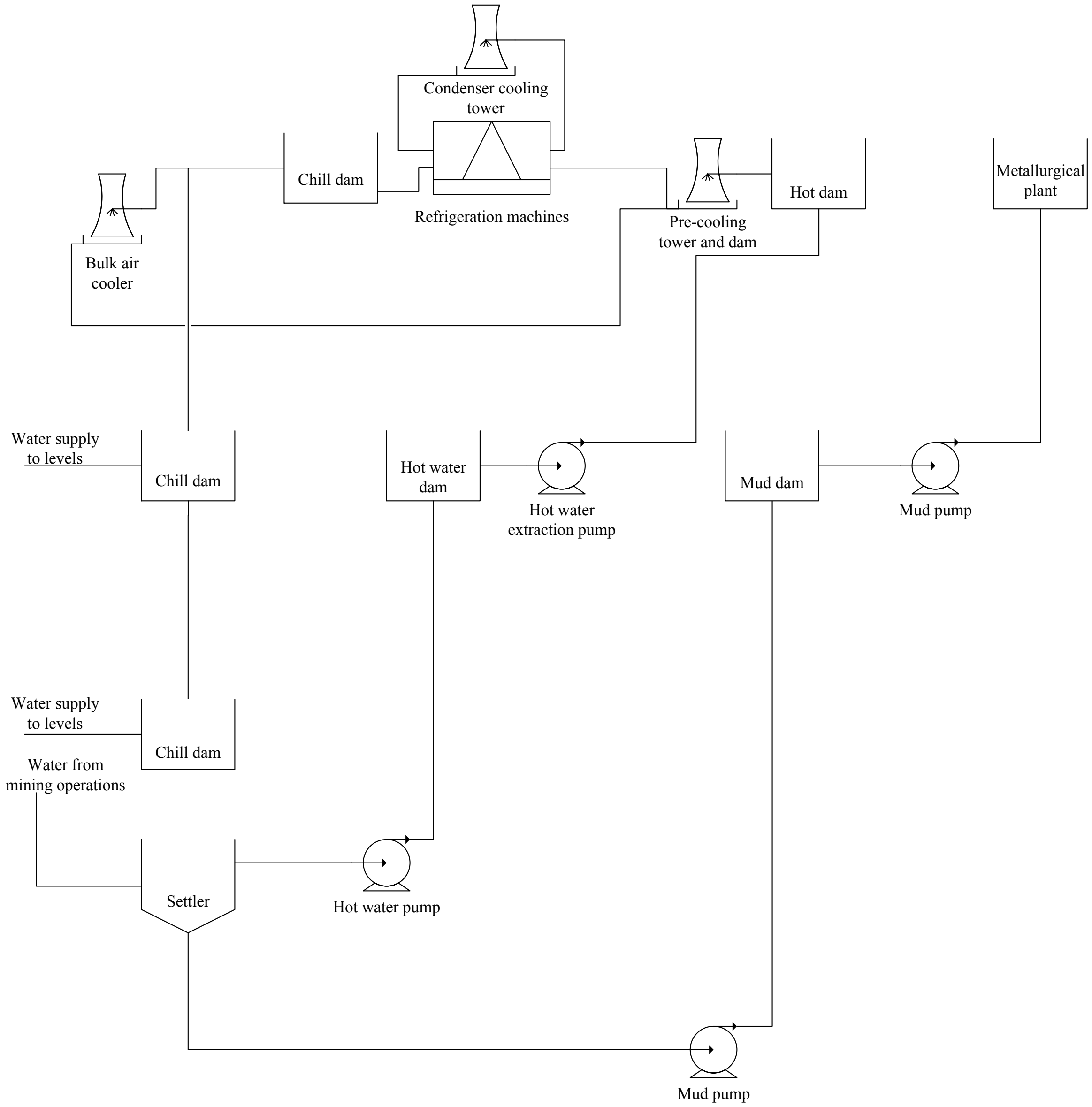


Figure 6: Water reticulation system (adapted from Pulles *et al*., 1995; Botha, 2010)

With rock temperatures reaching 60°C in deep gold mines (Stanton, 2004), cooling is one of the main uses for cold water (Calitz, 2006). The standard atmospheric temperature that mines try to maintain underground is 28°C (wet bulb) (Den Boef, 2003) and work cannot continue if the temperature reaches 32.5°C (wet bulb) (Vosloo, 2008). Water is cooled using refrigeration machines, accounting for approximately 7.9% of the mine's total electricity consumption (Calitz, 2006).

The refrigeration machines compress a gas, usually R-134A, using a centrifugal compressor. The R-134A then goes through a condenser heat exchanger that cools the gas to ensure that it is in the liquid phase. The R-134A is flashed over a valve that expands it to gas form and causes the temperature to drop drastically. It then passes through an evaporator heat exchanger that allows the cycle to cool down water for mining purposes (Calitz, 2006). This process can be seen in Figure 7.

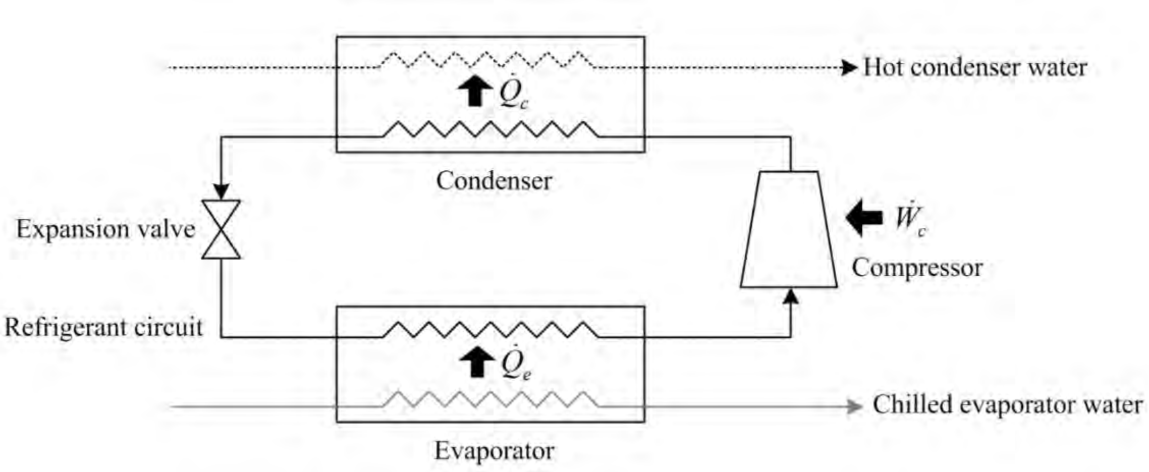


Figure 7: Refrigeration cycle (Du Plessis, 2013)

The water in the condenser cycle is in a closed loop that continually gets heated in the condenser heat exchanger and then cooled in the condenser cooling towers. Water that needs to be cooled flows from the pre-cooling dam, through the refrigeration machine's evaporator cycle, to the cold water storage dam. Storage of the cold water in a chill dam is necessary since the water consumption varies throughout the day.

The water temperature in the cold dam is required to be less than 3°C. This ensures effective cooling of the mine. Some of the water exiting the refrigeration system is tapped off and mixed with the water entering the refrigeration system. This water is known as back pass/ feedback water and ensures the correct inlet temperature to the evaporator heat exchanger.

A portion of the cold water is then pumped though a surface Bulk Air Cooler (BAC) in order to cool down the air entering the mine (Pulles *et al.*, 1995; Botha, 2010). The rest of the cold water is sent down the shaft to a cascading dam system that supplies water to all the operational levels (Botha, 2010; Schoeman *et al.*, 2011). Using cascading water dams reduces the pressure build-up in the pipes.

Cooling cars are added to areas of the mine that are not cooled effectively by the BACs (Stanton, 2004). These cooling cars consume cold water and their operation is similar to that of a radiator. If additional cooling is needed for extraordinarily deep mines, it is usually done using underground BACs that operate in a closed loop with a refrigeration machine. This has the advantage of reduced costs for pumping water to the surface. The efficiency of the refrigeration is however lower due to higher condenser air temperatures (Botha, 2010).

The levels are designed to direct the water to settling dams after usage. Fissure water that seeps into the mine also flows to these settling dams, in which the solids sink to the bottom. The clear water, which has been heated by the underground rocks, is pumped to surface.

Water extraction is achieved using a system of pumps and dams in order to prevent the pressure of the accumulated water building up to extreme levels (Vosloo *et al.*, 2011). This reticulation system accounts for approximately 17.7% of the electricity consumption of the mine (Calitz, 2006).

After reaching the surface, the hot water is pumped into a hot dam. Typically the water reaches the surface at a temperature of 28°C. As this water is sometimes well above the average atmospheric temperatures, initial cooling is done by the pre-cooling towers (Pulles *et al.*, 1995). From the pre-cooling towers' sump, the water enters the refrigeration machines and the cycle is repeated. Fissure water seeps into the mine continually from karsts and the water reticulation system becomes saturated. This excess water is dispersed into streams.

The mud that settles at the bottom of the settling dams, known as settlers, is pumped to the dam surface using mud pumps. This mud is also treated at the gold plant to extract all possible gold (Pulles *et al.*, 1995). It has a high concentration of heavy metals, which include radioactive materials (Duracovic, 1999). The water in the settlers is treated in the following ways to assist the precipitation of these solids (Vosloo, 2008):

1. Soda ash or lime is added for pH correction and heavy metal removal once a week.
2. A polymeric flocculent is added for precipitation of solids.

Compressed air network

The compressor systems on gold mines are responsible for an estimated 20% of the total electricity usage (Howells, 2006). Drills are powered by compressed air from the mine surface as it is rare for deep-level gold mines to use airless mining techniques, due to the safety hazard of using electricity in methane-rich environments (Schroeder, 2009). Typical pneumatic drills can consume 3.3 m^3/min to 5.3 m^3/min when the air supply is at a pressure of 500 kPa.

Surface compressors which are centrifugal fans are situated inside a compressor house. At deep-level gold mines, compressors can range in size from 1 MW to 15 MW, consisting of four to nine compression stages (Marais, 2012). A five stage rotor of a large centrifugal compressor can be seen in Figure 8.

Figure 8: Compressor rotor with multiple stages

Compressors suck in large amounts of air through air filters and compress it to approximately 550 kPa for use in these mines. Typically these compressors operate at an efficiency of between 70% and 80%. The amount of electricity required to produce a certain amount of air can be calculated using Equation [1.1] (Adapted from Schroeder, 2009):

$$P = \dot{m}\, c_p\, T_{in}\, ((\frac{p_{out}}{p_{in}})^{\frac{k-1}{k}} - 1) \;/\; \eta \qquad [1.1]$$

Where,

P = The electrical power consumed by the compressor [kW]

η = The efficiency of the compressor [%]

c_p = The molar specific heat at a constant pressure for air [J/kg.K]

T_{in} = The inlet temperature of the air into the compressor [K]

p_{out} = The outlet pressure of the compressor [kPa]

p_{in} = The inlet pressure of the compressor [kPa]

k = The ratio of specific heats of air [no unit]

$\dot{m}$ = The mass flow generated by the compressor [kg/s]

Piping is then installed down the shaft to each level and between shafts to form large compressor systems. The piping used for this application is mild steel pipes ranging in size from 150 mm to 700 mm. Several shafts are usually connected to the same air network, enabling compressor houses to supply air to any shaft.

Large compressor networks are necessary to ensure that maintenance on compressors does not interrupt production. For this strategy to be successful surplus compressors are available to replace the one that is unable to operate (Marais, 2012).

Compressed air is readily available underground, and is used for several functions, including rock drilling, powering loading boxes, supplying pressure to refuge chambers and pumps etc. Compressed air is so versatile that up to 100 000 m^3/h can be consumed per shaft (Marais, 2012).

1.3.Pollutants produced by deep-level gold mines

Pollutants created during the mining process affect water and air resources both directly and indirectly. Water pollution is discussed first.

Water pollution

To analyse the water pollution caused by the mining industry, the Witwatersrand region was investigated. Witwatersrand is the area situated south and south-east of Johannesburg, South Africa. The gold-rich area investigated has a length of 350 km and a width of 150 km, comprising seven gold fields (Tutu *et al.*, 2008). The Witwatersrand area is supplied by water primarily from the Vaal Dam (Tempelhoff, 2001) which has a capacity of 3364 Gl (Turton, 2004).

Adjacent to the Witwatersrand region is a karstic aquifer that stretches from the North West province, through Gauteng, Mpumalanga and parts of the Limpopo province. This karst holds more water than the Vaal Dam and is a reliable source of water (Cloete *et al.*, 2010; Winde & Erasmus, 2011).

The proximity of a karst aquifer causes huge amounts of water to seep into underground mines as fissure water (Durand, 2012). This water, which can be up to 130 Ml/day, must be pumped to the surface to prevent flooding of the mines (Funke, 1990; Warwick et al., 1987).

Up to 3% of the gold-bearing ore consists of pyrite (Naicker *et al.*, 2003; Tutu *et al.*, 2008) which, when coming into contact with water and air simultaneously, oxidises to form sulphuric acid and iron hydroxide (Scott, 1995; Hasan, 2009; Kalin *et al.*, 2006; Hashim *et al.*, 2011; Coetzee *et al.*, 2010). This reaction can be seen in Equation [1.2] (Hashim *et al.*, 2011):

$$4FeS_2 + 15O_2 + 14H_2O \rightarrow 4Fe(OH)_3 + 8H_2SO_4 \qquad [1.2]$$

Framboidal pyrite oxidises quickly while crystalline pyrite oxidises slowly (Coetsee *et al.*, 2010) and any heavy metals trapped in the pyrite are released into the water. These heavy metals can include the following (Durand, 2012; McCarthy & Venter, 2006; Hasan, 2009; Marsden, 1986): manganese, aluminium, uranium, iron, zinc, nickel, thorium, radium, lead, copper, protactinium, radon, polonium, bismuth and cobalt, all of which can be fatal to organisms.

Some of the heavy metals that are released into the water are radioactive and can cause tissue damage, including 238Uranium, 234Uranium 234Protactinium, 234Thorium, 230Thorium, 226Radium, 222Radon, 218Polonium, 210Polonium, 214Polonium, 214Lead, 210Lead, 214Bismuth, 210Bismuth (Duracovic, 1999).

During the 1990s, rapid dewatering of the mines led to the water levels of four of the karst water compartments dropping considerably (Durand, 2012; Dreybrodt, 1996; Winde & Erasmus, 2011). After 1998, the karst water levels started rising again when mines were closing down and no longer pumping water from the shafts. This caused abandoned mines to flood with water high in sulphuric acid, iron hydroxide and heavy metals (Durand, 2012, McCarthy & Venter, 2006).

Today, managing this effluent water effectively is of critical importance. Although mines only produce 10% of the country's effluent water, it poses the greatest risk to the environment when considering the quantity and type of pollutants produced by gold mining (Cloete *et al.*, 2010). Typical pollutants include (Cloete *et al.*, 2010):

- Increased salinity caused by chloride- and sulphide anions as well as magnesium-, calcium- and sodium cations;
- Increased nutrient levels due to minerals leached from explosives, sewage and agricultural activities in surrounding areas; and
- High concentrations of heavy metals.

The water flowing from these abandoned mines is estimated to be 350 Ml/day (Durand, 2012). This water enters the South African streams and some of it ends up in the Vaal Dam (Scott, 1995). The Department of Water Affairs and Forestry (DWAF) of the Republic of

South Africa estimates that 20% of the mineral salts present in the Vaal Dam come from mine effluent water (Durand, 2012).

<u>Indirect air pollution</u>

It has been established that climate change is a result of greenhouse gas production and that the leading cause of producing these gasses are man-made processes. Greenhouse gasses form an atmospheric barrier, trapping heat radiated from the earth's surface. As a result, the incoming radiation from the sun is greater than the radiation that should be reflected back into the atmosphere and over an extended period of time, the earth heats up (Akorede *et al.*, 2012). This effect can be seen in Figure 9.

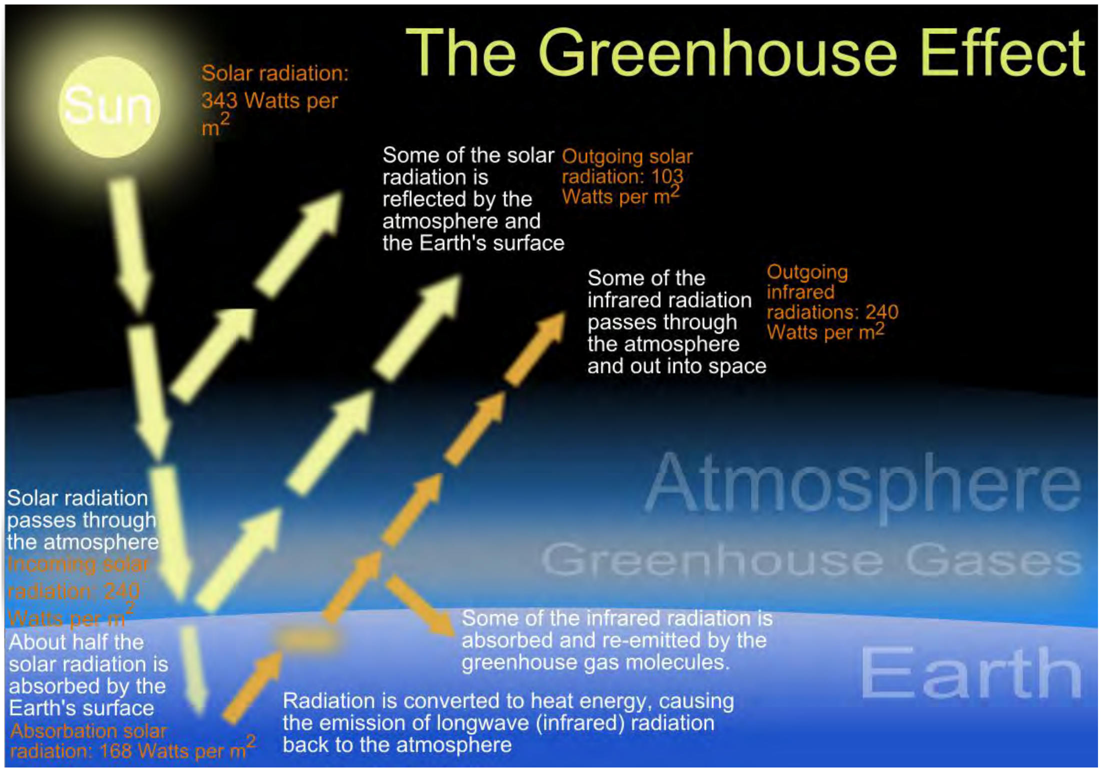


Figure 9: The greenhouse effect

Greenhouse gasses include carbon dioxide (CO_2), water vapour, methane (and other carbon gasses) and nitrous oxide, all of which occur naturally in differing quantities. Some of the synthetic greenhouse gasses produced by industrial processes include halocarbons, perfluorocarbons and sulphur hexafluoride (Akorede *et al.*, 2012; Bolt, 2008). These gasses should allow the earth to maintain its temperature, however, when produced in excess quantities, the environmental balance is disturbed, and the earth's temperature is affected.

Of these gasses, carbon dioxide has the greatest impact. This is not because it has the highest heat retention capacity, but because it is the greenhouse gas that is produced in the highest quantities by man-made processes (Mathews, 2007; Akorede *et al.*, 2012; Bolt, 2008). Climate change caused by these processes is referred to as anthropogenic climate change (Bolt, 2008), and gasses contributing to anthropogenic climate change are shown in Figure 10.

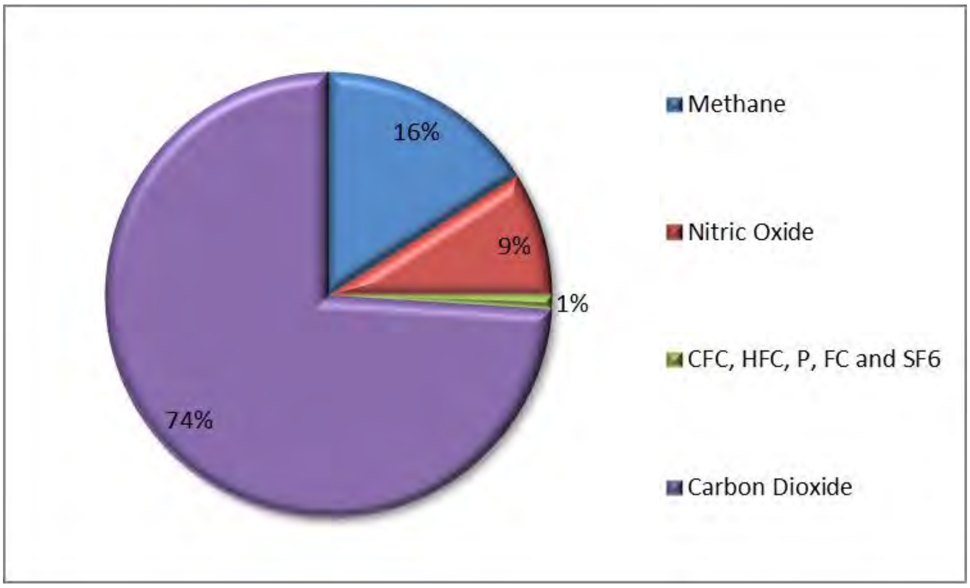


Figure 10: Anthropogenic greenhouse gas emission comparison (Karakurt *et al.*, 2011)

This does however not reflect a particularly true picture, as the gasses have different heat retention capacities. The largest carbon dioxide-producers in the world are coal fired power stations, which are responsible for 41% of the carbon dioxide production, and electricity generation is expected to grow by 2% per year (Akorede *et al.*, 2012). The highest carbon-producing countries per capita can be seen in Figure 11.

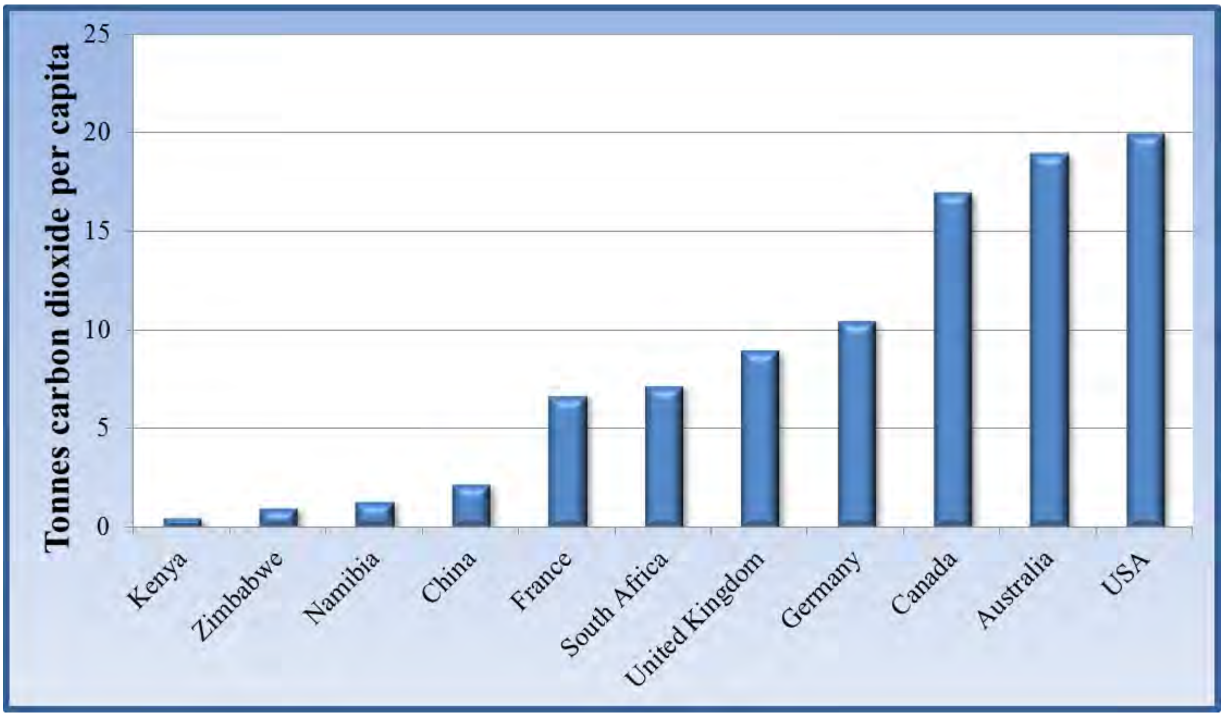


Figure 11: Carbon production per capita of the highest carbon-producing countries

Electricity in South Africa used to be relatively cheap and was a minor concern when originally designing many of the mines in the Witwatersrand region (Vosloo, 2008). Energy efficient strategies were never a priority (Bolt, 2008), until the recent significant increases in electricity prices in South Africa. Energy-efficiency projects to rectify this are becoming increasingly viable.

The large electricity consumption of mines warrants investigation of the pollution created by power stations, specifically coal-fired power stations. With carbon dioxide identified as the largest pollutant created by power generation, other pollutants are often overlooked, of which there are numerous others (Hasan, 2009). Other pollutants created include nitrogen oxide and sulphur dioxide.

Nitrogen oxide is one of the others, causing acid rain and suspected of causing photochemical smog in addition to being a greenhouse gas. Typical reactions that produce nitrogen oxide in the coal-burning electricity generation process can be seen in Equation [1.3] and [1.4] (Stanmore & Visona, 2000):

$$4HCN + 5O_2 \rightarrow 4NO + 4CO + 2H_2O \qquad [1.3]$$

$$4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O \qquad [1.4]$$

The reactions are complex and dependent on the coal, burner, boiler and combustion conditions, so exactly how much NO_x will be produced is difficult to estimate. What is well known however, is that nitrogen oxide is only produced when the flame temperature within the power station's boiler is too hot (Hewitt, 2001; Stanmore & Visona, 2000). The production of nitrogen oxide is between 30% and 40% of the total nitrogen contained in the coal (Stanmore & Visona, 2000).

The production of nitrogen oxide can be reduced significantly by a process called re-burning, which involves injecting methane gas above the flame inside the boiler. This burning of the methane reduces the nitrogen oxide production. The reaction can be seen in Equation [1.5].

$$2CH_4 + 10NO \rightarrow 2CO + 5N_2 + 8OH \qquad [1.5]$$

Additionally, technologies like low NO_x burners are implemented in coal-fired power stations to minimise the nitrogen oxide production. These burners starve the initial part of the coal-burning process and supply the oxygen in phases. This allows the systematic combustion of the coal, which keeps the flame temperature low, but still ensures that all the coal is burnt (Stanmore & Visona, 2000).

The Measurement and Verification (M&V) team that analyses the performance of electricity efficiency projects in South Africa estimates the nitrogen oxides pollution production rate at 4.39 gNOx/kWh. A worldwide total of around 25 million tons of nitrogen oxides is produced yearly (Hewitt, 2001).

One of the other well-known gasses produced by power stations is sulphur dioxide (Hasan, 2009). More than 90% of the sulphur in coal is converted to sulphur dioxide, which, if not removed from the plumes before it is released into the atmosphere, is a leading cause of acid rain. Sulphur dioxide is oxidised by the hydroxyl radical (OH) to form sulphite, which in turn reacts with water to form sulphuric acid (H_2SO_4) (Hewitt, 2001).

The M&V team appointed by Eskom estimates the average sulphur oxides pollution production rate at 8.1 gSO_x/kWh. The worldwide total production of sulphur dioxide is 65 million tons yearly (Hewitt, 2001).

Numerous heavy metals are produced by power stations as well. These heavy metals are present in the coal and after combustion in the flue gas produced. Two technologies are available to reduce pollutants in the flue gas – Electrostatic Precipitation (ESP) and wet Flue Gas Desulphurisation (FGD) (Meij & Te Winkel, 2008).

ESP removes the solid particles from the air. Wet FGD is a process of blowing the flue gas through a spray of limestone mixed with water. This mixture reacts with the sulphur dioxide to produce gypsum, a product that can be sold for application in dry walls and ceilings. These processes do however not remove all the pollutants (Meij & Te Winkel, 2008). Typical removal percentages of the elements present in the flue gas can be seen in Table 1.

Table 1: Pollutant removal by ESP and wet FGD processes (Meij & Te Winkel, 2008)

Element	ESP [%]	FGD [%]	Total removal [%]
Al	99.8	80.0	100.0
As	98.3	75.0	99.6
B	49.8	90.0	95.0
Ba	99.7	80.0	99.9
Be	99.6	80.0	99.9
Br	39.8	90.0	94.0
Ca	99.8	80.0	100.0
Cd	98.5	80.0	99.7
Cl	0.9	95.0	95.0
Co	99.5	80.0	99.9
Cr	99.7	80.0	99.9
Cs	99.8	80.0	100.0
Cu	99.5	80.0	99.9
F	19.7	94.9	95.9
Ge	98.5	80.0	99.7
GHf	99.8	80.0	100.0
HgS	49.6	50.2	74.9
Hg	49.6	80.0	89.9
I	3.0	80.0	80.6
K	99.8	80.0	100.0
Mg	99.8	80.0	100.0
Mn	99.7	80.0	99.9
Mo	99.2	80.0	99.8
Na	99.7	80.0	99.9
Ni	99.4	80.0	99.9
P	99.5	80.0	99.9
Pb	99.1	80.0	99.8
PM	99.8	80.0	100.0
Rb	99.8	80.0	100.0
S	2.0	92.0	92.2
Sb	98.9	82.1	99.8
Se	82.4	65.6	93.9
Si	99.8	80.0	100.0
Sn	99.1	80.0	99.8
Sr	99.8	80.0	100.0
Te	99.1	80.0	99.8
Th	99.8	80.0	100.0
Ti	99.1	80.0	99.8
U	99.5	80.0	99.9
V	99.4	80.0	99.9
W	99.4	80.0	99.9
Zn	98.9	80.0	99.8

Although these processes are very effective, a small percentage of heavy metals still remain in the gas emitted from the power station. This percentage relates to large amounts when considering that electricity is continuously generated and significant amounts of coal are burned during the process. In China the pollutant particle production from their coal-fired power stations has increased to more than 300 million tons/annum (Liqiang & Yongtao, 2013).

It should be noted that although the wet FGD process has become standard operation internationally, none of the power stations presently producing electricity for South Africa uses the FGD process. With the construction of the new power plants, Kusile and Medupi, this technology will be implemented in South Africa for the first time.

When considering that the wet FGD is not standard practice in South Africa, the pollutants produced in Table 1 are more serious. It can then be seen that only 2% of the sulphur in the flue gas is removed. This, combined with the fact that more than 90% of the sulphur present in coal is converted to sulphur dioxide, is a worrying statistic. An estimation of the total production of pollutant material that is produced by power stations in South Africa can be seen in Table 2.

Table 2: Heavy metal production by South African coal-fired power stations (Adapted from Meij & Te Winkel, 2008)

Material	Weight/kWh	Unit	Ton/year
CO_2	835.0	[g]	180309900
SO_2	4.9	[g]	1060805
NOx	636.0	[mg]	137337
Si	20.0	[mg]	4318
Al	11.5	[mg]	2483
Ca	2.0	[mg]	432
K	1.0	[mg]	216
Mg	1.0	[mg]	216
P	1.0	[mg]	216
I	0.9	[mg]	185
Fe	0.7	[mg]	153
Ti	0.7	[mg]	151
Na	0.5	[mg]	108
F	490.2	[μg]	105
Ba	230.0	[μg]	49.7
Cl	200.0	[μg]	43.2
Ge	67.5	[μg]	14.6
B	62.0	[μg]	13.4
V	61.5	[μg]	13.3
Zn	55.0	[μg]	11.9
Mn	46.0	[μg]	9.9
Ni	34.5	[μg]	7.4
Cr	25.5	[μg]	5.5
Pb	18.5	[μg]	4.0
As	18.0	[μg]	3.9
Cu	16.0	[μg]	3.5
Co	9.5	[μg]	2.1
Mo	7.5	[μg]	1.6
Sn	4.5	[μg]	1.0
Te	3.5	[μg]	0.8
Br	3.0	[μg]	0.6
U	2.5	[μg]	0.5
Be	2.0	[μg]	0.4
W	1.6	[μg]	0.3
Cd	0.5	[μg]	0.1
Hg	0.1	[μg]	0.02

It can be seen that numerous heavy metals and other serious pollutants are produced during electricity generation. The effect of combining these pollutants with water is well known, however, not well understood is the effect of these metals and pollutants when airborne. This is a question that should be investigated further, but will be left for a future study.

The Department of Environmental Affairs (DEA) specifies that for solid-fuel power generation, the maximum allowed pollution production is 50 mg/m^3 for particulate matter, 3500 mg/m^3 for sulphur dioxide and 1100 mg/m^3 for oxides of nitrogen. For methane-power generation, these values are 10 mg/m^3, 500 mg/m^3 and 300 mg/m^3, respectively.

Direct air pollution

Air pollution is directly released by mines as well. As mines develop underground, gas trapped in the rock is released into the mining levels. From here the gas mixes with ventilation air and is extracted through the Return Airway (RAW) by extraction fans. Typical gasses that are produced by gold mines include methane, ethane, propane, butane, carbon monoxide, helium, hydrogen and hydrogen sulphide (Cook, 1998).

Most of these gasses are flammable and cause a safety risk in addition to polluting the air. In Table 3 the gasses produced by the gold and platinum mines of South Africa are quantified. The table also specifies the required ignition concentrations.

Table 3: Gas production in gold and platinum mines (adapted from Cook, 1998)

Gas	Lower ignition concentration [%]	Higher ignition concentration [%]	As percentage of total [%]
Methane (CH_4)	5	15	80-100
Ethane (C_2H_6)	3	12.4	0-1
Propane (C_3H_8)	2.1	9.5	0-1
Butane (C_4H_{10})	1.8	8.4	0-5
Carbon monoxide (CO)	12.5	74	-
Helium (He)	Not flammable	Not flammable	0-15
Hydrogen (H_2)	4	75	0-20
Hydrogen sulphide (H_2S)	4	44	Trace amounts

From this table it is evident that methane has the highest production rate in gold mines. Legislation specifies that the maximum concentration of flammable gasses in air is 1.4 %. This legislation assumes that the largest portion of the gas is methane and that 1.4% is well below the flammable concentration of 5% (Cook, 1998). The heat of combustion for each of these gasses can be seen in Table 4.

Table 4: Heat of combustion for typical flammable gasses found in mines

Flammable gas	Heat of combustion [MJ/kg]	Power generation [kW/kg]
Methane	55.5	15.4
Ethane	51.9	14.4
Propane	50.35	14.0
Butane	49.5	13.8
Carbon monoxide	10.1	2.8
Hydrogen	141.8	39.4

It is generally accepted that the gasses trapped in the rock are transported underground dissolved in water. It was also determined that these gasses are produced in the Witwatersrand region by the Karoo Strata, a biomass ridge covering most of South Africa, and up to 12 km thick in areas. Water seeps through the strata, to underground water karsts (Cook, 1998).

Kerogen granules composing of hydrocarbon material are found in most reefs in South Africa. These granules produce organic gasses like methane and are associated with platinum-, gold- and pyrite-bearing reefs. As a result methane gas is produced in large quantities in the gold mining industry (Cook, 1998), with mines like Mine C gold mine producing up to 1600 l/s of methane gas throughout the mine (ESI-Africa, 2013). The underground methane pockets containing flammable gasses can take years to drain into the mine (Cook, 1998).

Because methane is not encountered in dangerous quantities throughout the mining industry, only a few mines are identified as having methane explosion risks. By looking at the reported methane incidents, it can be determined that this is a widespread problem throughout South Africa. The reported incidents per region can be seen in the Figure 12.

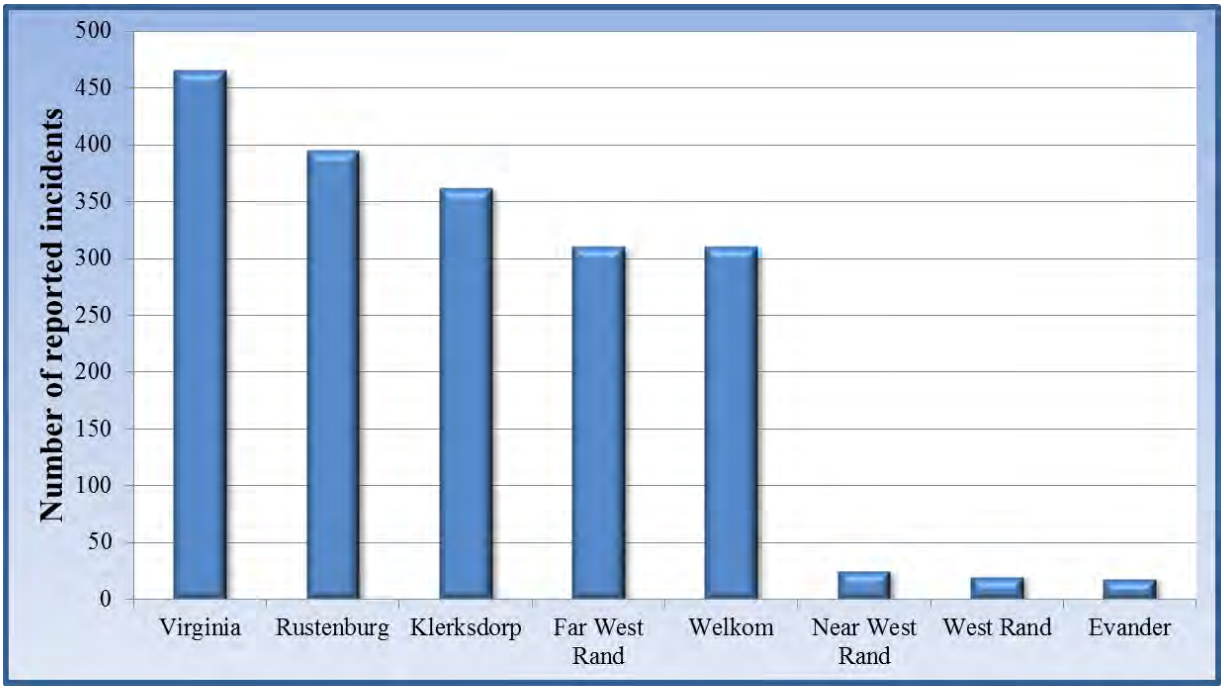


Figure 12: Reported flammable gas incidents (Adapted from Cook *et al.*, 1998)

From Figure 12 it is evident that methane production is not limited to a few mines. This is a problem throughout South Africa and incidents occur at most gold- and platinum-producing deep-level mines. Methane has twenty times the heat retention capacity of carbon dioxide (You & Xu, 2008). As a result methane has a significant effect on climate change, at least as big as the impact of carbon dioxide (Karakurt *et al*., 2011). In addition to being a greenhouse gas, methane is also highly flammable if the concentration in air ranges between 5% and 15% (Karacan *et al.*, 2011).

Typically the concentration of methane gas in mine ventilation air ranges from 0.1% to 1%, ensuring that it is not flammable (Karacan *et al.*, 2011). With modern mines that are well ventilated, the concentration of methane does not generally build up to dangerous levels. In mines that are not ventilated sufficiently however, methane gas can cause serious safety issues.

1.4.Reporting on pollution at deep-level gold mines

The benchmark for environmental reporting is the Sustainability Reporting Guidelines (SRGs) document, compiled by the Global Reporting Initiative (GRI). In this document reporting guidelines for water and air pollution are explicitly outlined. For water pollution, the following are the core reporting values (GRI, 2012):

- Total water used; and
- Water quality and location of discharge.

For air pollution, the core reporting values are more extensive (GRI, 2012):

- Direct and indirect greenhouse gas emission weight;
- Emission of gasses that deplete the ozone; and
- Concentration of SO, NO and other dangerous gasses and particles.

The question arises, which Key Performance Indicators (KPIs) are presently reported on by the largest South African mining companies? By analysing these KPIs it can be determined which of the values reported on can be used for project identification. The compliance with the SRG can also be determined.

Analysing these KPIs will aid in identifying improvements that can be made on environmental reporting on mines. This will clarify which benefits can be gained from additional reporting. Table 5 shows what values the largest mining companies in South Africa are reporting on, based on the mining company’s sustainability report.

Table 5: KPI reporting on gold mines

	Total electricity consumption	Water recycled	Total direct greenhouse gas emissions	Ozone depleting gas emissions	Total indirect greenhouse gas emissions	Other dangerous gas emissions	Total water usage	Total water discharge	Location of water discharge	Water discharge quality monitoring	Amount of environmental incidents
Mining company 1	●				●		●				●
Mining company 2	●	●			●		●				●
Mining company 3	●				●		●	●		●	●
Mining company 4	●	●	●	●	●		●	●		●	●

From Table 5 it can be seen that there is 52% compliance with the SRGs among these companies. It is evident that mines report on the total energy consumption and the associated carbon dioxide production (indirect greenhouse gasses), the total water usage and the number of environmental incidents.

Two of the companies also report on the water discharge amount and quality. This is something that should be included in reporting systems as it allows the monitoring of the total water pollution from gold mines.

Water recycling should also be reported on by all the companies, to assess the capacity of the water treatment plants. There is a significant lack in the monitoring of gasses extracted directly from the gold mines, including methane and equivalent carbon gasses.

1.5.Project identification and implementation

On the mine

The first step to determining how to improve a system is to specify how it is presently operated. The responsibility of implementing pollution and electricity-reduction projects lies with the environmental department of the mine. This is in addition to their regular tasks of ensuring safe operating conditions underground, including monitoring ventilation, air quality, underground temperature, etc.

The employees of the environmental department often have no way of quantifying the pollutants present in either the air or water. A measurement of air temperature is manually taken, at most once a week. Methane levels are measured at critical points to ensure the concentrations do not exceed the lower ignition concentration. If this concentration is exceeded the area is evacuated and the ventilation supply increased to reduce methane build-up.

This measurement does however not allow the quantification of the greenhouse gasses pumped into the air. Also, false representation can be understood if methane concentrations are below the required 1.4% measured from the shaft itself. Water treatment plants dedicated to treating the mine water is also the exception. Limestone treatment is done in the settling dams once a week to remove heavy metals and precipitate the solids (DWAF, 2008).

If environmental projects are identified, they must be motivated to the relevant procurement committee, where the benefits are evaluated to determine project feasibility and potential project funding. However, as emphasis in the mining industry is on production, few environmental projects are approved. Those that are approved take months to motivate and wastes valuable time during which the pollution could have been reduced.

By the Electricity Services Company (ESCO)

The ESCO has an arsenal of electricity reduction projects with which they are familiar and comfortable implementing. An ESCO researches a mine to determine what their large electricity consumers are, and if these are in a similar field as one of their projects, they will approach the mine to organise a meeting.

Here, the ESCO will explain typical projects that they have implemented in the past and would like to investigate on that mine as well. For accepted projects, the mine will grant the ESCO a Letter of Intent (LOI) giving them sole authority to investigate electricity-reduction projects on a specific process in the mine.

This allows the ESCO to get in touch with the relevant person, usually the instrumentation foreman or engineer, who is familiar with this system. That person can supply the necessary background to the system and the required data for analysing the system using a simulation. The first simulation is to establish a baseline for the system operation, creating benchmark levels for comparison and determining the electricity-savings that can be achieved.

If the savings are above the minimum benchmark (usually more than 1 MW electricity efficiency), quotes to do the necessary upgrades are acquired. This allows the cost per MW saving to be calculated, determining whether a project is feasible or not. In cases where the client is optimistic about a certain project, they are often willing to contribute funds for the implementation. Presently Eskom – Integrated Demand Management (IDM) contributes a maximum of R 5.25 million/MW saved.

To make the project feasible for the ESCO, the cost per MW should at least be below the calculated benchmark figures. If this is the case, the necessary documentation is compiled and the project is proposed to Eskom for approval.

After project implementation, a three month evaluation period follows where the ESCO must prove that the improved system delivers the proposed savings. When the performance assessment period is over, the mine is responsible for maintaining the savings. This is called the ESCO funding model.

1.6.Conclusion

It is evident that the gold mining industry pollutes water resources and is directly (carbon gas production) and indirectly (electricity consumption) a large-scale producer of greenhouse gasses. Society is however reliant on metal mining and the process cannot be stopped (Van Berkel, 2007). For this reason it is imperative that gold mining be done as sustainably as possible.

In this chapter the basic mining process was explained. It was seen that numerous water and air pollutants are extensively produced throughout the mining process. It was shown that the reporting on mines is insufficient when compared to the SRGs.

The present pollution project implementation process was also discussed to identify shortcomings. It is now necessary to start investigating what the effect of the different pollution types is and what has been done to improve the sustainability of deep-level gold mining.

2. Environmental management of mines

This chapter discusses the importance of reducing the environmental impact of deep-level gold mines. It also investigates the work done by other authors on water management, environmental impact reduction, climate change and environmental management systems for environmental impact reduction. Shortcomings in present environmental impact reduction efforts and environmental management systems based on literature are assessed, as are different funding models available for project implementation. Finally, novel contributions that can be made towards sustainable gold mine operation are identified and discussed.

2.1.Introduction

As the basic deep-level gold mining process was discussed in the previous chapter, it now becomes necessary to investigate the effect of the pollutants created during the mining process. In this chapter the work done by previous authors is studied to determine what progress has been made in the field of environmental impact reduction and sustainability improvement on deep-level gold mines.

The chapter looks at environmental management systems that can be implemented in the mining industry. It also looks at environmental management software available for environmental impact reduction. By doing the necessary research, deficiencies in the mining Environmental Management Systems (EMSs) are identified.

Since funding these management systems is expensive, alternative funding models are investigated. This leads to guidelines for a novel sustainability framework for monitoring and reducing environmental impact on gold mines. The discussion is started by investigating the importance of reducing water and air pollution.

2.2.Importance of environmental impact reduction

Water pollution

Gold mining started on the borders of the Witwatersrand main reef in 1886 and expanded to the East Rand in the 1890s. The development was mainly focussed in the Klip River basin in the eastern part of the Witwatersrand. As a result, much of the run-off from the Witwatersrand mines ended up in this basin; 85% of the water in the Klip River is estimated to be the result of human influence (McCarthy & Venter, 2006).

The water from the mines is mainly excess water pumped from underground (McCarthy & Venter, 2006). The first reports of the presence of Acid Mine Drainage (AMD) in the Klip River basin was in 1976 (Wittmann & Förstner, 1976), although it could have been polluted long before 1976. Wetlands in the Klip River basin sequestrate the heavy metals from the water and prevent heavy metals from reaching the Vaal Dam (McCarthy & Venter, 2006).

This study also showed that while peat has been building up in the Klip River basin over approximately the past 2500 years, heavy metal deposits have increased dramatically over the past 100 years. Wetlands like the one in the Klip River basin contribute to environmental impact reduction by the removal of heavy metals from effluent water; although unfortunately not all water being pumped from mines enter rivers that flow through a wetland (McCarthy & Venter, 2006; Tutu *et al*., 2008). The Klip River basin can be seen in Figure 13.

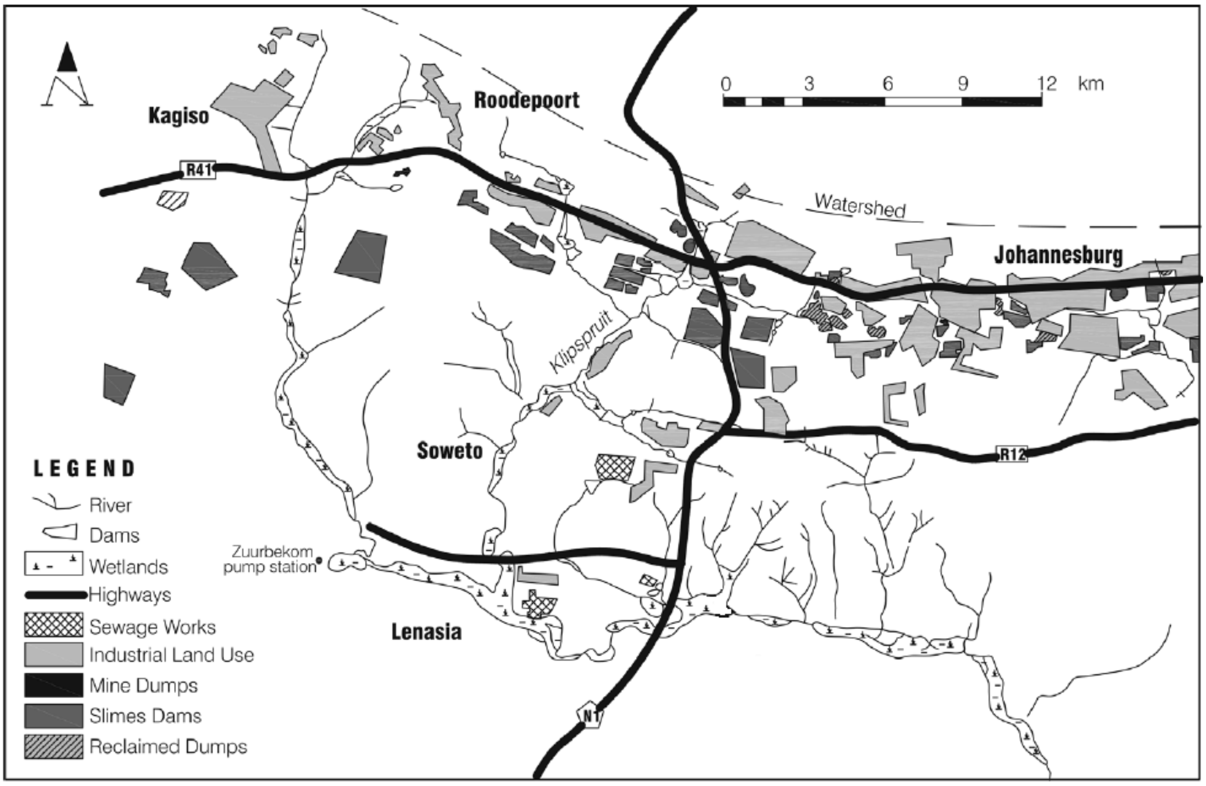


Figure 13: Layout of the Klip River basin in the Witwatersrand region (McCarthy & Venter, 2006)

Unfortunately up to 60% of the peat in the Klip River basin has been extracted for mushroom production. This further reduced the already small amount of peat available in South Africa - only 1% of the worldwide peat deposits are found in the southern hemisphere (Winde & Erasmus, 2011).

The water entering the Vaal Dam naturally is insufficient for regular South African consumption and is therefore supplemented with water from Lesotho (Turton, 2004). This is a result of the fact that South Africa has a relatively low average rainfall of 450 mm/annum compared to a worldwide average of 860 mm/annum (Cloete *et al*., 2010). When considering that the evaporation in South Africa is relatively high, it can be seen why water is such a scarce resource in South Africa.

This is especially true for the Witwatersrand region, which consists of parts of the Crocodile West and Marico, Olifants, Upper- and Lower Vaal Water Catchment Areas (WCAs). In Figure 14 it can be seen that industries found in the WCAs of the Witwatersrand region afford a high Gross Domestic Product (GDP) when correlated to the Mean Annual Runoff (MAR) of the area. This emphasizes the need for the Witwatersrand area to rely on receiving water from other parts of South Africa, and more specifically the Vaal Dam.

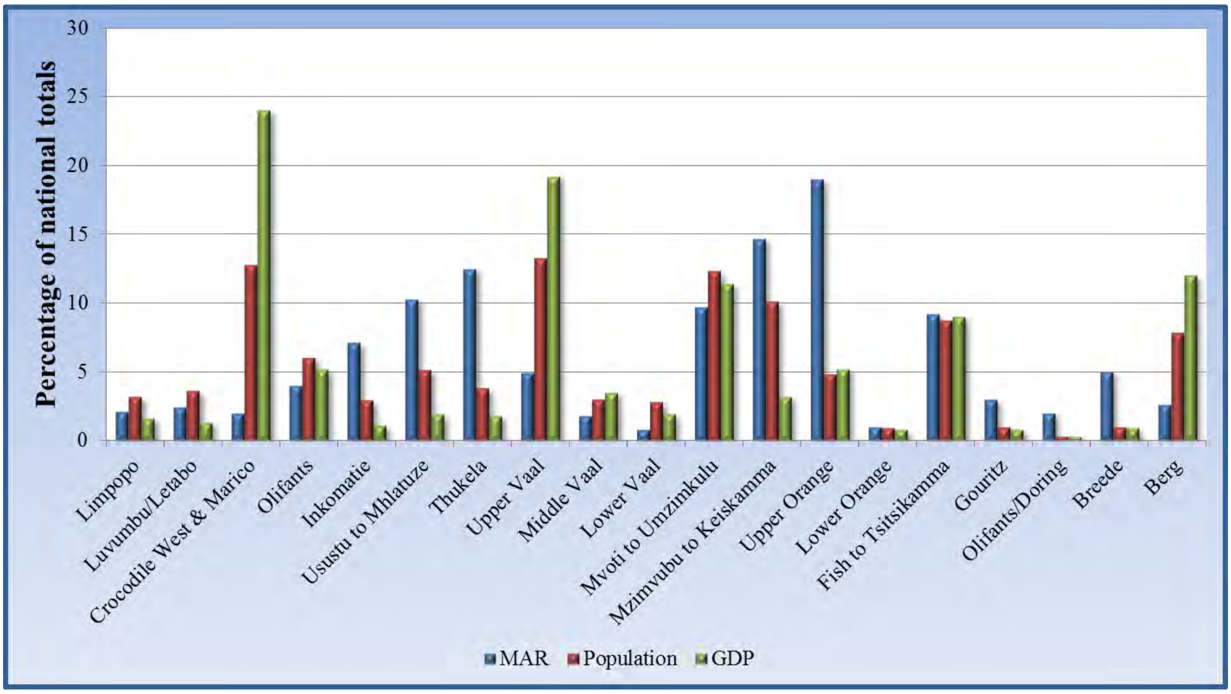


Figure 14: Comparison of the MAR, population and GDP for the different WCAs of South Africa (Adapted from Cloete *et al.*, 2010)

From Figure 14, we see that the gold rich areas of South Africa have a very low rainfall and require high water supply to support industries contributing to the GDP. Polluting the local water resource prohibits mines from re-using the water and affects the local population in the area.

Air pollution

Worldwide it is estimated that surplus carbon dioxide of 10.65 billion tons is produced annually and as a result carbon dioxide constitutes 76.7% of all the greenhouse gasses (Akorede *et al.*, 2012). It is expected that it will be necessary to reduce the global carbon dioxide production by 70% before 2050 and that the next 10 to 20 years will be of critical importance in this reduction drive (Mathews, 2007). This is to prevent further global temperature increase.

Presently the global average temperature has increased by 0.74°C since 1906 (Barker *et al.*, 2007) and if nothing is done to reduce greenhouse gas emissions, this will continue. As climate change is seen as the highest threat to human existence (Mathews, 2007; Akorede *et al.*, 2012), it stands to reason that something must be done, and done quickly.

While the requirements and methodologies to reduce carbon dioxide emissions are clear, and most of the technology necessary is readily available, switching to alternative green energy sources is expensive and will be a timely process (Mathews, 2007). This will become a priority in the near future, as coal reserves are only expected to last approximately 52 more years at current consumption levels (Bolt, 2008).

To this end, one of the preventative measures will be to reduce the amount of electricity consumed by the mines, in order to minimise carbon dioxide production from coal-fired power stations. It is expected that electricity utilisation effectiveness, also known as demand side management, will ensure a reduction in carbon dioxide emissions of 33% (Akorede *et al.*, 2012).

The International Energy Agency (IEA) identifies efficient energy use as the most important factor in reducing carbon dioxide production. This is supported by the prediction made by Eskom that 84% of the carbon dioxide-reduction in 2014 in South Africa will result from increased electricity efficiency (Eskom, 2007).

This is especially true in the Witwatersrand, where 92.7% to 94.2% of the power used in South Africa comes from coal-fired power stations (Trading Economics, 2012). This equates to 215 940 GWh of the 232 812 GWh that was generated in 2010 (Wassung, 2012). Globally, fossil fuel such as coal supplies approximately 78% of the world's energy requirements (Renewables, 2010), and South Africa has the world's seventh highest coal supply, at 5% of the global supply (Bolt, 2008).

Measuring and monitoring the pollution created by power stations is relatively easy as they are stationary and limited in numbers (Sims *et al.*, 2003). From data collected, research has found that the concentration of carbon dioxide in the atmosphere has increased by 31% since the industrial revolution (Akorede *et al.*, 2012).

The other carbon greenhouse gasses expelled by mines might not be produced in such high quantities as carbon dioxide. However, with the global warming effect of methane gas twenty times that of carbon dioxide, it is suggested that the climate change effect of methane is comparable to that of carbon dioxide (You & Xu, 2008).

Methane represents 8% of the total anthropogenic greenhouse gasses produced. It is however responsible for 16% of the climate change (Karacan *et al*., 2011). With methane gas already produced naturally, it is imperative that anthropogenic production be kept to a minimum.

Greenhouse gasses are expected to increase the temperature by another 6.4°C by the end of this century (Barker *et al.*, 2007). This is the result of carbon being produced at a rate of 973 gCO_2/kWh (Akorede *et al.*, 2012). Typical effects of climate change include the following:

- Increased evaporation (This in turn increases the amount of greenhouse gasses, since water vapour also increases the heat retention of the atmosphere);
- Increased health risks caused by diseases;
- Rise in the global sea levels;
- Extinction of certain plant and animal species; and
- Reduction in crop yields.

From this information, one can see why climate change is considered the highest threat to human existence, and emphasizes how necessary projects that reduce electricity usage are.

2.3.Literature analyses

It is clear that reducing the environmental impact of the gold mining industry is of critical importance. To determine exactly how to go about reducing this pollution, it is necessary to analyse the work done by other authors. This will allow the analyses of environmental impact reduction techniques and software.

Work done on environmental reporting

Mudd (2007) identified the correlation between gold ore grades and the pollution produced by mines. This study stated that the ore grade is indirectly related to energy usage and water consumption and therefore, the effluent water produced by the mine. It is added that the South African gold ore grades are declining as gold is a finite resource. This trend can clearly be seen in Figure 15.

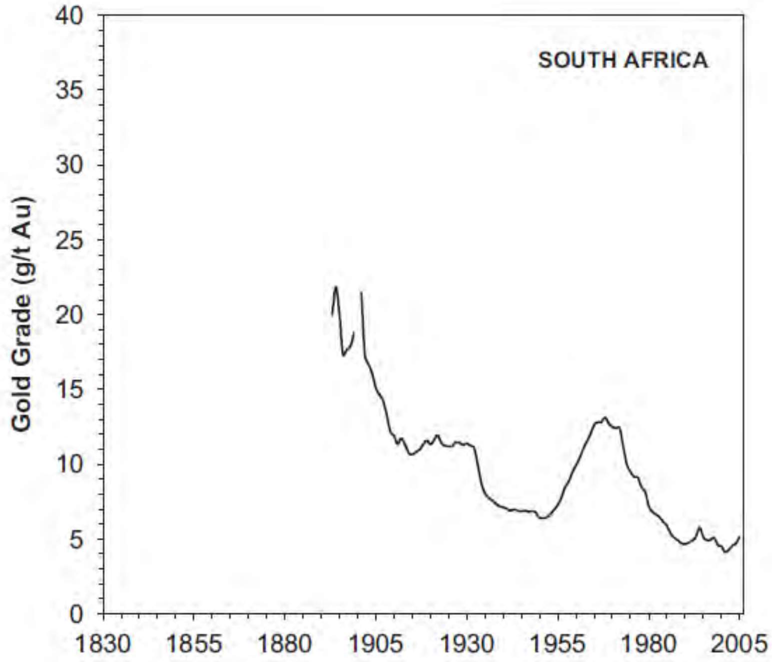


Figure 15: Gold ore grade in South Africa from 1886 to 2005 (Mudd, 2007)

It can therefore be deducted that the environmental impact of mining will only increase. Mudd (2007) also states that the rehabilitation and waste management of mines are not up to standard as the emphasis is on production and not environmental impact reduction. In that study the resource usage per kilogram of gold was analysed and is listed below:

- 691 kl water;
- 143 GJ energy;
- 11.5 tCO_2; and
- Up to 1 ton cyanide.

These values can be seen as the true environmental cost of producing one kilogram of gold. Mudd (2007) did not propose a specific method of reporting the environmental impact of mining, but it is emphasized that the reporting of the following usage data is of critical importance:

- Ton ore milled;
- Ore grade;
- Amount of metal contained by the ore;
- Waste rock;
- Clean water usage;
- Quality and amount of effluent water produced;
- Electricity usage;
- Chemical usage;
- Cyanide consumption; and
- Greenhouse gas emissions.

Mudd (2007) identifies the need for a reporting system on gold mines, but doesn’t specify how the pollution can be reduced or what the impact of environmental management on a mine can be. His study neither identifies projects specifically aimed at environmental impact reduction, nor offers alternative funding models for these projects.

Durand (2012) investigated the extent of the pollution in the rivers of the Witwatersrand region. The effects of these pollutants on the human body and other organisms were reported. Polluted rivers were then identified and measurements were taken from the water to determine the amount of metals present in these rivers. These results can be seen in Table 6.

Table 6: Pollutants in the rivers of the Witwatersrand (Adapted from Durand, 2012)

Metal	pH	Al	Ca	Co	Fe	Mg	Mn	Ni	U	Z
Maximum Levels	-	0.501 (DWAF, 1996)	-	0.00004 (Durand, 2012)	0.3 (Durand , 2012)	-	0.05 (Durand, 2012)	0.00007 (Durand, 2012)	0.00007 (DWAF, 1996)	5 (Durand, 2012)
1	7.6	0.1	61	<0.025	0.51	30	2.8	0.09	<0.001	<0.025
2	7.3	0.1	63	0.06	1.01	33	5.29	0.11	<0.001	<0.025
3	3.6	0.68	124	0.23	51	57	16	0.42	0.007	0.16
4	3	0.61	140	0.28	70	51	17	0.5	0.008	0.15
5	2.6	1.6	367	0.98	233	158	60	1.69	0.024	0.41
6	2.6	2.51	497	1.37	438	237	92	2.47	0.036	0.6
Other study maximums	2.3	629.7	-	53.7	-	-	189.1	71.4	72.8	107.8

It is added that government is not doing enough to reduce the problem. Importantly Durand (2012) then identifies important steps that can be taken to reduce the effect of water pollution. These are summarised below:

1. The three main water basins must be emptied;
2. Water seeping into underground works must be reduced;
3. Underground water must be treated;
4. Monitoring of the water pollution and use should be improved. This monitoring should be done by a committee comprising multiple organisations;
5. Other sources of AMD should be identified and treated; and
6. An environmental levy should be imposed and the money used to remedy the problem.

Durand (2012) identified the need to reduce environmental pollution on deep-level gold mines. This study also proposed projects that can reduce the amount of water pollution and that the funding for these projects should be generated by imposing an environmental levy. Importantly it identified the need for an environmental management system to monitor environmental pollution. However, this study does not propose a method of identifying specific projects.

Jones (2010) quotes sources stating that there is no acceptable accounting and reporting standard. This study emphasizes the importance of environmental reporting and states that conventional reporting is not sufficient for environmental management. It is added that with the possible implementation of a carbon market it becomes necessary to measure the carbon dioxide emissions generated. Jones (2010) states that organisations should be held responsible for their own environmental impact.

Jones (2010) therefore did consider alternative funding models, but did not attempt to propose specific projects that can reduce the environmental impact of mining.

Work done on sustainability reporting guidelines

Nel (2008) investigates requirements of sustainable reporting pertaining to the environmental, economic and social performance of organisations, and states that sustainability reporting is a new concept in Africa. The GRI helps companies to voluntarily report on the triple bottom line stated above.

Nel (2008) investigated the integration of International Organisation for Standardisation (ISO) 14001 and the SRG. This study shows that the data gathered by EMSs to fulfil in the requirements of ISO 14001 is the same as the data required for sustainable reporting. Reporting on the SRGs is not sufficient and should also be managed (Nel, 2008). This emphasizes the need for an EMS on mines. This study also states that ISO 14001 specifies the process of reducing environmental impacts, but not the method of creating these impacts.

This study does not look at the similarities between the ISO 50001 and ISO 14001. It should be noted that similarly it could have been shown that the energy management standard can be used to aid the GRI on energy reporting. Both energy and environmental reporting form part of the GRI.

By combining all the reporting values specified in the section, a sustainable and thorough environmental management system can be produced. In the mining industry however there seems to be additional requirements to environmental management systems. It is necessary to investigate the presently available environmental reporting systems, which is done in the next section. The GRI specifies the energy aspects that should be reported as part of a sustainability framework. These values can be seen below (GRI, 2012):

- Energy consumption;
- Indirect energy consumption;
- Energy saved by initiatives;
- Renewable technologies utilised and energy savings achieved; and
- Description of energy reduction projects.

Work done on pollution-reduction issues

Hilson (2000) investigated obstacles to implementing environmental impact reduction projects. This study states that pollution-reduction is not being achieved in the mining industry, with major obstacles being:

- Funds for pollution-reduction projects are hard to come by. It is believed that it is cheaper to rectify the effect of pollution than to prevent it.
- Workers should identify the pollution-reduction projects, but are afraid that new systems would make them obsolete.
- Manpower is not available to do these project identifications as workers are too busy.
- Although the technology exists, it is not available to the mine.

Hilson (2000) quotes Yakowitz (1997) in stating that pollution-reduction project examples should be given to companies. This study also adds that technical assistance should be supplied to companies aiming to reduce their environmental impact.

Hilson (2000) does not propose methods of funding these projects. This study also does not propose methods of project identification other than relying on stubborn personnel. Lastly it does not propose a method of making the pollution-reduction projects available to mines.

Work done on environmental management (ISO 14001)

According to the ISO 14001 standard a company must commit to continually improving its environmental impact to comply. The standard states that environmental targets must be set and documented. In the same way documentation that describes the entire EMS must be compiled. This includes the management, training, plan, policy, etc. These must take into consideration the legislation governing its operations.

The ISO 14001 standard allows companies to differentiate between the environmental factors it has control over versus those it cannot control. This creates a grey area whereby some environmental pollution can be excluded from the EMS. In the same manner the company decides which values are relevant and which are irrelevant.

In South Africa 91% of deep-level gold mines have attained ISO 14001 accreditation, despite the stated problems with the implementation. This system will be successful if the company is effective at identifying pollution-reduction projects.

The challenge then presents as what if the company cannot identify areas to where it can reduce its environmental footprint? For this reason it is necessary to establish a central database of projects that can be implemented on mines. This needs to be continually updated to ensure that the latest technology advancements are available to each mine. However, implementing an EMS that is ISO 14001-compliant does not mean that the mine will be effective at reducing its environmental impact (Hilson & Nayee, 2002).

Hilson & Nayee (2002) investigated how implementing an EMS can improve environmentally conscious production in the mining industry. In this study an EMS is defined according to Begley (1996) as: “a set of organizational [*sic*] procedures, responsibilities, processes, and necessary means to implement corporate environmental policies”.

It is stated that ISO 14001 is a guideline for what an EMS should cover. ISO 14001 is an effective marketing tool as the consumers are moving toward environmentally friendly products. It does however not hold enough advantages for the mining industry as it does not give them a competitive edge (Hilson & Nayee, 2002). ISO 14001 can be summarised as seen in Figure 16.

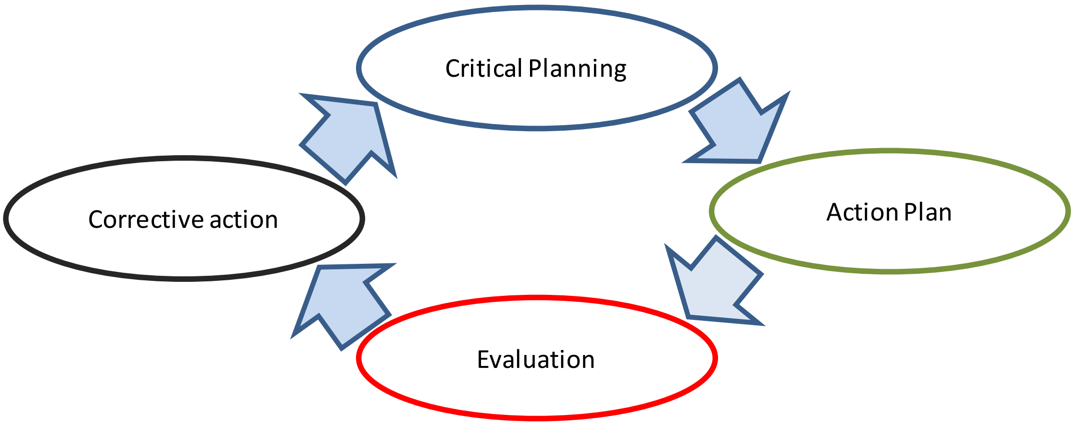


Figure 16: Basic ISO 14001 procedure (Adapted from Hilson & Nayee, 2002)

An ISO 14001 EMS is a continual process whereby environmental risks are identified, a solution to the project is found and implemented and finally the solution is evaluated to determine its effectiveness. Hilson & Nayee (2002) states that implementing an EMS supplies a systematic, proactive approach to environmental impact reduction.

In this study it is emphasised that monitoring should be done continually. Hilson & Nayee (2002) also specifies that the relevant reports should be generated by an effective energy management system. This study does extensive research regarding an EMS and gives general guidelines for implementation in the mining industry. It states that current EMSs are not sufficient for implementation on mines. It also adds that third parties should get involved in the pollution-reduction effort (Hilson & Nayee, 2002).

Newbold (2006) looks into the environmental effort of Chilean mines and their ISO 14001 accreditation. It is stated that cleaner production can only be achieved through a company wide effort to increase environmental friendliness. This study quotes Foster (1998) in saying that imposing strict environmental regulations on mines will have a negative impact on the socio economy.

Newbold (2006) stated that most of the Chilean mines had developed an environmental plan, although many environmental risks are overlooked. It is deducted that this extends to environmental impact reduction projects.

This study states that implementing an EMS shifts the strategy from a reactive to a pre-emptive approach. However, Newbold (2006) states that there are concerns regarding the consistency of ISO 14001 accreditation on different sites. Choi *et al.* (2012) and Newbold (2006), both state that an EMS does not have to be ISO 14001-compliant to be successful.

Newbold (2006) did a lot of work on the implementation and benefits associated with EMSs on mines but does not propose specific projects or quantify the pollution-reduction benefits associated with the implementation of ISO 14001 projects.

Work done on energy and environmental management integration (ISO 50001)

O'Donnell *et al.* (2013) importantly identifies the interdependency of energy and environmental management. They show that it is necessary to approach these concepts in a holistic manner. This research is unfortunately limited to the electricity and environmental management of buildings and does not investigate the effect of a management system integrating electricity and environmental management.

Work done on climate change

Bolt (2008) investigated climate change and how it is affected by power generation. This study went further to investigate the potential of using Certified Emission Reductions (CERs) (also known as carbon credits) under the Clean Development Mechanism (CDM) model of the Kyoto Protocol to fund electricity reduction projects.

Under this protocol, developed Annex I countries have binding emission reduction targets, which can be met by buying carbon credits from other countries. The CDM model allows Annex I countries to invest in energy reduction projects in developing countries, like South Africa and in return, receive carbon credits to meet their reduction targets.

The study stated that the CER price is volatile which makes direct comparison to the Eskom Demand Side Management (DSM) funding model difficult. Bolt (2008) developed an energy-efficiency decision model to determine if the DSM or CDM funding model will be the most profitable for ESCO application.

In this study the conclusion was made that the CDM funding model is the most feasible method of implementing electricity-reduction projects on mines. This funding model has however been delayed. It was additionally added that electricity efficiency technologies also reduce equipment replacement and maintenance costs.

Bolt (2008) investigated the relationship between electricity reduction and carbon dioxide production. That study proposed the utilisation of carbon credits to supplement the implementation of electricity-reduction projects. It was however not proposed to utilise electricity-reduction projects as a means of reducing other environmental pollution types.

Akorede *et al.* (2012) looks at the causes and effects of greenhouse gasses. It is stated that water vapour is the leading greenhouse gas since it also retains heat. Akorede *et al.* (2012) identifies areas where greenhouse gas production can be mitigated.

Power stations are identified as the worst polluters of the earth's atmosphere through the redundant production of carbon dioxide. Electricity efficiency measures are identified as one method of reducing the production of excess carbon dioxide. Akorede *et al.* (2012) expects that electricity efficiency measures should contribute up to 33% of the carbon dioxide-reduction.

2.4.Available environmental management systems

Environmental management systems provide the right tools to implement continuous improvement on the environmental impact of mining practices. The tools used include exceptional software packages that ultimately help the company to comply with ISO 14001 standards, the systematic approach to a reduction in environmental pollution.

Unfortunately these software packages are expensive, reducing their popularity with South African mines which are struggling to remain profitable. Constant threats to mining income like varying gold prices, strikes by workers and high operating costs are difficult to manage and avoid, so spending on pro-active environmental activities is often not a priority. It will firstly be necessary to identify the capabilities of these EMSs.

WebEMS

The first of these systems is called WebEMS developed by RegAction. This system has the following specifications:

- Is web-based;
- Aids the user in identifying, controlling and monitoring system components that do or can produce an environmental impact reduction;
- Allows the company to measure their performance against set objectives;
- Enables reports to be generated for monitoring and auditing;
- Gives the company the ability to become ISO 14001-compliant;
- Increases environmental awareness among employees;
- Monitors parameters to ensure compliance;
- Stores historical data to establish trends;
- Assigns responsibility to specific people; and
- Consolidates data.

Intelex

The second EMS is called the Intelex EMS. This is a comprehensive software package that can be installed on smartphones, tablets and computers for ease of access. The specifications of Intelex EMS include:

- Enables reporting of environmental incidents;
- Guides the user to identify aspects and processes where environmental impact reduction can be achieved;
- Helps to define objectives for the company’s environmental impact reduction program;
- Assists with ISO 14001 compliance, through the implementation of the system (continuous process of plan-do-check-act);
- Generates reports to simplify the auditing process;
- Drives the management process;
- Offers a consolidated, web-based platform to create and access documents;

- Documents are easily retrieved using a search function;
- The competency of the specific user can be tracked and monitored;
- Manages the compliance with legal legislation;
- Creates an efficient communication network to connect different users within the company;
- Allows the import and export of data;
- Sends notifications in case of emergencies and emergency tests; and
- Stores historical data to establish trends.

EHSInsight

EHSInsight is another environmental management system that allows companies to achieved ISO 14001 compliance. The specifications of the system can be seen below:

- Allows the management of documentation for ISO 14001 compliance;
- Enables environmental incident reporting and damages caused;
- Manages environmental spill response in regards to planning, documentation and personnel response;
- Guides a company to set environmental objectives and monitor present performance;
- Manages the setup and review of environmental policies;
- Tracks usage and distribution of hazardous material;
- Helps with violation reporting;
- Captures spill reporting;
- Monitors waste management;
- Assists with National Pollutant Discharge Elimination System (NPDES) reporting; and
- Helps with air pollution calculation and reporting.

Enverity

Enverity is another EMS that can be implemented at companies. The system is capable of the following functions:

- Managing environmental parts;

- Managing the environmental impact;
- Allowing companies to become ISO 14001-compliant;
- Developing environmental plans;
- Setting objectives;
- Managing the companies' adherence to objectives;
- Generating reports;
- Managing environmental compliance and documents; and
- Tracking greenhouse gas emission.

It is evident that these systems are very similar, aimed at adhering to ISO 14001 standards and generating the necessary documentation. These systems help identify areas where environmental impacts can be reduced. Pollution and electricity-reduction targets are set and a systematic approach is followed to attain these targets. Unfortunately the problem with these systems is the availability of specific project identification and the funding for these projects, among other problems stated later in this chapter.

2.5.Pollution project funding models

To fund environmental impact reduction projects, carbon credits have been a logical option. If these projects have electricity-savings potential however, other funding models become available. These include Eskom-IDM, tax incentives and self-funding. To determine the best funding model for each project, it is necessary to review these funding models. The first of these projects is the Eskom-IDM funding.

Eskom-IDM supplies funding for DSM projects, as it is cheaper than building power stations to supply this demand. The projects that will be covered in this study have large electricity-savings potential, but also require significant funds to implement. The Eskom funding model that covers projects of this size is called the ESCO model. This requires a registered ESCO with Eskom to implement these projects.

Projects also fall into different categories depending on when the electricity is saved and if the usage is shifted to other periods of the day. The first project type is energy efficiency projects. These projects result in savings throughout the day, calculated as an hourly average between 06:00 and 22:00. The energy efficiency profile can be seen in Figure 17.

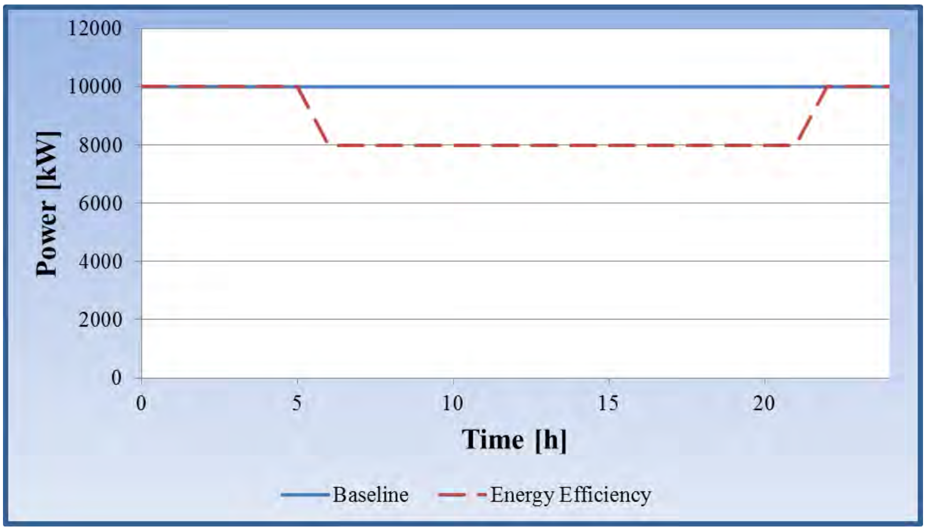


Figure 17: Energy efficiency project profile

From the profile in Figure 17 it is evident that the electricity-savings are realised throughout the day. The next project category is the peak clip projects. These projects only save electricity during the peak electricity demand period (18:00 to 20:00) as this is the period where Eskom has the most difficulty in supplying the demand. This project profile can be seen in Figure 18.

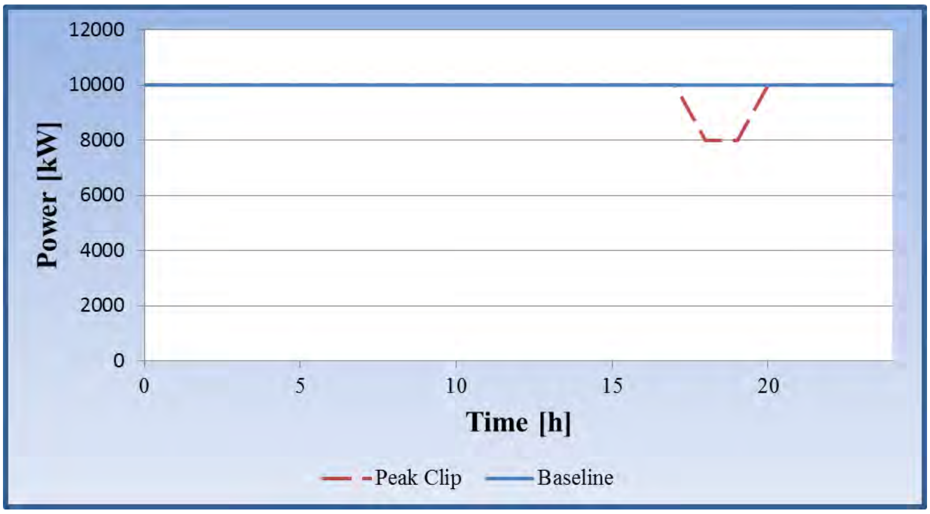


Figure 18: Peak clip project profile

The final project category is for load shift projects. These projects do not save electricity, but rather shift electricity usage into periods that have lower electricity consumption. Eskom also funds projects that create a more manageable load during the peak periods even if it is consumed at a later stage. This ensures that electricity for industry is used at times when the general domestic population does not have a high consumption demand.

A typical load shift project profile can be seen in Figure 19. Load shift projects allow the delay of electricity consumption during the evening Eskom peak periods to other periods when the demand can easily be met.

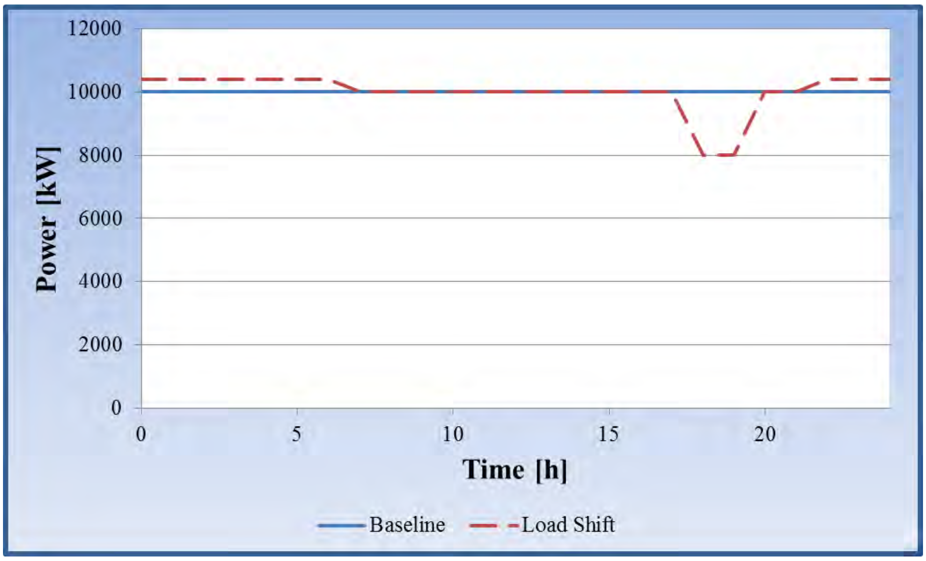


Figure 19: Load shift project profile

Funding these projects has traditionally been done by ESCOs utilising Eskom-IDM funding. This has been lucrative for the ESCO and as a result, the mines as well. During 2014, the benchmark Eskom-IDM funding will be reduced with recent estimates indicating a reduction of 40% to 50%. This is due to the fact that the IDM funding made available to Eskom by National Energy Regulator of South Africa (NERSA) is only R5.18 billion of the required R13.09 billion (Creamer, 2014).

If the reduction of 50% is introduced, the benchmark Eskom-IDM funding becomes R2.625 million/MW for energy efficiency, R1.75 million/MW for peak clip and R1.75 million/MW for load shift projects.

The second funding model utilises tax incentives. On the 9th of December 2013, Minister Pravin Gordhan (Minister of the Department of Energy) announced the introduction of tax incentives for electricity reduction in the government gazette. Section 12L of the Income Tax Law of 1962 makes provision for tax breaks for the implementation of electricity-efficiency projects. This excludes renewable energy implementations.

This is in an effort to reduce the country's greenhouse gas production by 12% before the end of 2015. This target forms part of the National Energy Efficiency Strategy (NEES). Qualifying for this tax break has certain requirements (Van der Zee, 2013):

- A company must register with the South African National Energy Development Institute (SANEDI) which will manage the technical aspect of the tax incentive.
- A M&V member that is part of the South African National Accreditation System (SANAS) must be appointed to verify the savings. This professional must submit the baseline report and M&V plan to SANEDI.
- If the project delivered savings, SANEDI will issue a savings certificate.
- This certificate then allows one to claim a tax break from the South African Revenue Service (SARS).

This incentive will give a registered company a tax break of 45 c/kWh (Government Gazette, 2013). This is an annual tax break of R3.94 million/MW and a tax saving of R1.1 million/MW per annum (at taxation in the 28% tax bracket). Since the previous year's electricity usage becomes the new baseline, the tax break can only be claimed once at the end of the year. This is compared to present Eskom funding of R5.25 million/MW electricity efficiency, which will be reduced during the year to an estimated R2.625 million/MW electricity efficiency. In Table 7 a comparison is done between the two funding models.

Table 7: Eskom-IDM and tax incentive comparison

Eskom-IDM	Tax incentives
Funds can be used to implement project	Project must be funded by the mine
Funds are received once-off at the start of the project	Funds are received annually with the previous year's electricity usage becoming the new baseline
Approval for projects can take years	Project is analysed on the savings and does not need to be approved
Projects are assessed for a three month period	Projects must continually deliver savings to receive tax incentive
An ESCO is required to implement the projects	The company must be registered with SANEDI to receive incentive

Another funding model is carbon credits, also known as CERs. It is assumed that the average spot price for CERs is R3.5/ton of carbon dioxide-reduction. Using this information the financial position of the mine can be assessed for the different funding models on a 1 MW energy efficiency project. This comparison is shown in Figure 20.

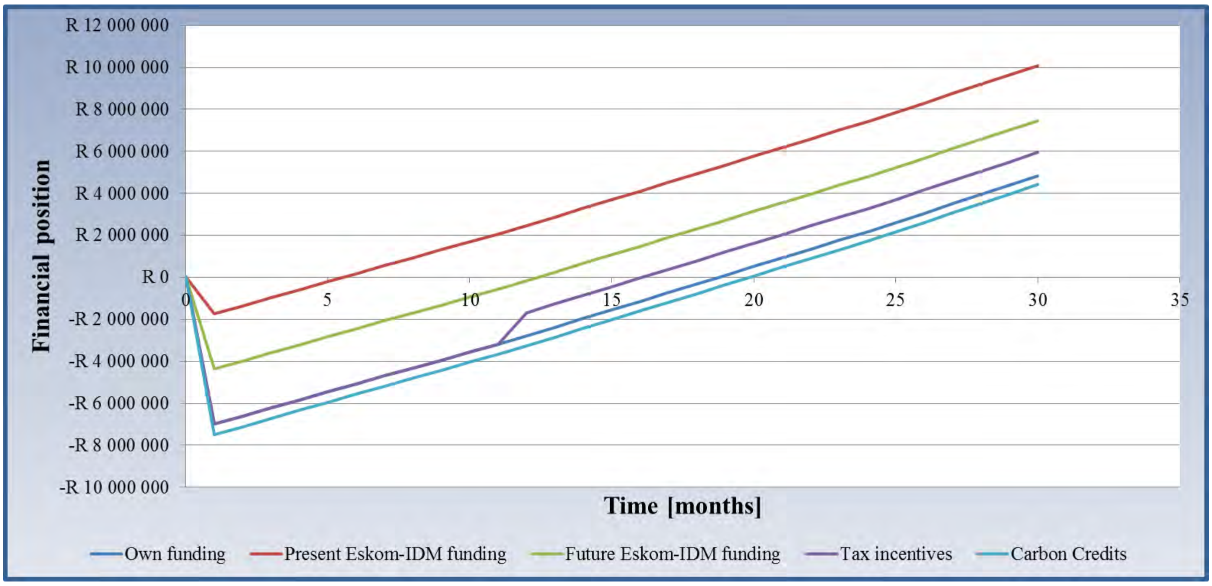


Figure 20: Funding model comparison for a 1 MW project

It can be seen from Figure 20 that the best alternatives are present and future Eskom-IDM funding. Utilising tax incentives is another viable option which may become the preferred option if Eskom-IDM funding continues to be reduced. CERs are not a feasible funding method for these projects. This is because of the R500 000 fee to register a carbon emission reduction project and the low CER spot price. It will take 17 years to recover the registration fee if a 1 MW project is submitted (Van der Zee, 2013).

This simple project funding comparison shows that involving an ESCO in electricity reduction projects will remain the most feasible option.

2.6.Problem statement and need for this study

From the literature analysed, it is evident that there are significant flaws with the present environmental management and reporting systems. These problems are summarised below:

- There is a need for environmental management systems on mines (Mudd, 2007);
- Environmental impact reduction is not a priority for many mines (Mudd, 2007);
- There is no environmental reporting standard (Jones, 2010);
- Too much pollution is created by mines (Durand, 2012);
- Becoming ISO 14001-compliant does not ensure pollution-reduction (Hilson & Nayee, 2002);
- Implementing an ISO 14001 accredited system does not give the mine a competitive edge (Hilson & Nayee, 2002);
- Project examples should be given to mines to reduce the uncertainty associated with selecting a pollution-reduction project (Hilson, 2000);
- The project technologies are not available to the mines as many are prohibitively expensive (Hilson, 2000);
- Pollution monitoring should be improved (Durand, 2012);
- Monitoring of pollution-reduction should be done continually (Hilson & Nayee, 2002);
- Funds for pollution-reduction projects are not readily available (Hilson, 2000);
- Workers do not want to identify projects as they are afraid it might make them redundant (Hilson, 2000);
- The manpower to identify projects are limited (Hilson, 2000);

- Third parties should get involved with the implementation of these projects (Hilson & Nayee, 2002);
- The mine needs assistance with the implementation of projects (Hilson, 2000); and
- Electricity and environmental management should be done on an integrated basis (O'Donnell *et al.*, 2013).

These are significant shortcomings with the present environmental management systems which delay the implementation of environmental impact reduction projects. This study must propose methods of eliminating the shortcomings identified by these authors to improve participation efforts and streamline project implementation.

There are numerous EMSs available to mines. These are used to source the tools needed to manage their environmental impact and identify areas where pollution can be reduced. The EMSs also help companies to manage environmental incidents and generate the necessary documentation. These are particularly useful in allowing companies to become ISO 14001-compliant by supplying the necessary framework for continued environmental impact reduction.

However, mines are hesitant to implement these systems as they do not lead to gaining any competitive edge. Gaining ISO 14001 accreditation also does not ensure the effectiveness of an EMS (Hilson & Nayee, 2002).

There is no law enforcing the implementation of environmental management systems on mines. The regulations prescribing the reporting on specific operational indicators are limited. These generic EMSs are capable of quantifying the resource usage on mines and managing their systematic environmental impact reduction.

Implementing an EMS on a mine gives the framework for continually improving the mine's environmental friendliness. But these mines are old and have been operating in a specific way for many years without any environmental concern. It is not feasible to expect mines to identify environmental impact reduction projects without providing examples of these projects. Ideally, all of the most recent environmental impact reduction projects should be implemented on all mines around the world as soon as the projects are developed.

It is necessary to quantify the benefits that EMSs can have on the mining industry. Specific projects must be identified that are capable of reducing the environmental impact of deep-level gold mining. Finally, a novel funding method for implementing these EMSs must be identified to ensure their implementation.

2.7.Aim and novel contributions of this study

Novel contribution 1 (Sustainability framework for the mining industry)

- **What must be done?** – Develop an implementation framework for environmental impact-reducing projects on mines.
- **How is it done presently?** – Presently ISO 14001-compliant EMSs are being implemented on South African mines.
- **Why is this not sufficient?** – These systems are generic and aim to help a company become ISO 14001-compliant. Mines do not gain a competitive edge by becoming ISO 14001-compliant and these systems are not suited to a gold mine's needs. This hampers the implementation of these systems in the mining industry, which is in need of reducing its environmental footprint.
- **How does this study solve this problem?** – This study develops a new sustainability framework for a novel EMS tailor made to the mining industry's needs.

Novel contribution 2 (Automatic project identification)

- **What must be done?** – Environmental impact reduction projects must be identified continually.
- **How is it done presently?** – Present EMSs are reliant on personnel to identify environmental impact reduction projects as part of the ISO 14001 process.
- **Why is this not sufficient?** – These systems do not enable proactive identification of electricity- and environmental impact reduction projects. By relying on personnel to do project identification, this process is not done continually. Once-off audits identify potential projects but these systems change sooner than the timeframe required to develop a project.
- **How does this study solve this problem?** – This study proposes a new project identification methodology that monitors key operational indicators to immediately

identify projects as the potential arises. This allows ESCOs to respond with project proposals to rectify unnecessary electricity consumption. It also reduces the reliance of the system on personnel and streamlines the process to ensure quick implementation. Automatic project identification is a novel addition to the sustainability framework.

Novel contribution 3 (Alternative funding models)

- **What must be done?** – The implementation of EMSs should be done at a reduced cost to the mine. This will ensure speedy implementation of these systems and projects.
- **How is it done presently?** – Mining companies fund environmental management systems only to avoid paying penalties under the NWA and the AQA.
- **Why is this not sufficient?** – Mines are struggling to remain profitable. This is especially true for locally-owned mines that do not have the capital to implement these systems or environmental impact reduction projects.
- **How does this study solve this problem?** –The projects identified by this study not only reduce pollution, but also electricity consumption. This enables the EMS to be implemented at a reduced cost, because the funding can be done using Eskom-IDM or alternative funding models. This study analysed the electricity-reduction projects based on different funding models to determine the ideal funding for the proposed projects. Analysing individual project funding requirements is a novel addition to the sustainability framework.

Novel contribution 4 (Standardised savings methodologies)

- **What must be done?** – Every possible environmental impact reduction project must be identified.
- **How is it done presently?** – Areas where pollution is created are identified. Projects that can be implemented to reduce the pollutant creation are researched and proposed. The ISO 14001 standard ensures that projects are continually identified, implemented and analysed.
- **Why is this not sufficient?** – There has been little effort to consolidate the environmental impact reduction projects. Mines rely on workers to identify these

environmental impact reduction projects. These workers are not capable of identifying all the environmental impact reduction projects that are found at international mines. This can be a result of under-qualified personnel or a lack of involvement or enthusiasm for the projects from workers. Little technology is available to mines so to facilitate the identification of the projects, project examples should be given to mines.

- **How does this study solve this problem?** – This study identifies standardised saving methodologies that can be implemented continuously by a mine through the use of EMSs. Specifying specific projects for implementation in the deep-level gold mining industry is a novel addition to the sustainability framework.

Novel contribution 5 (Project prioritisation)

- **What must be done?** – Electricity- and environmental impact reduction projects must be implemented for continual sustainability enhancement.
- **How is it done presently?** – To implement environmental impact reduction projects, a cost-to-pollution-reduction ratio is used to determine the implementation priority.
- **Why is this not sufficient?** – Electricity-reduction projects have a environmental impact reduction component. For this reason a holistic view of a projects' electricity- and environmental impact reduction advantages must be used to identify projects.
- **How does this study solve this problem? –** Electricity- and environmental impact reduction is quantified in terms of cost saving. This allows a combined payback period to be developed and the effective prioritisation of projects in terms of electricity- and environmental impact reduction. Prioritising projects based on their combined payback periods is a novel addition to the sustainability framework.

Novel contribution 6 (Consolidated reporting values)

- **What must be done?** – Sustainability reporting must be done in the mining industry.
- **How is it done presently?** – Sustainability reports are created each year to report on all the environmental issues.
- **Why is this not sufficient?** – The values that are reported are not comprehensive and vary significantly between gold mining companies. Jones (2010) clearly states that there are no reporting standards.

- **How does this study solve this problem? –** This study investigates the reporting done by mining companies, guidelines on sustainable reporting and other authors' reporting suggestions and creates a consolidated list of reporting criteria. Additionally all operational indicators used for identifying the proposed projects are included.

Novel contribution 7 (Load shift carbon dioxide-reduction)

- **What must be done?** – Load shift projects must be implemented to reduce the evening peak electricity usage.
- **How is it done presently?** – Load shift projects are implemented for the cost reduction associated with their implementation.
- **Why is this not sufficient?** – These projects do not gain carbon credit funding. This is because they are not credited with carbon dioxide-reduction.
- **How does this study solve this problem? –** This study shows how the implementation of load shift projects has a carbon dioxide-reduction effect. It also quantifies the reduction associated with a load shift project.

Novel contribution 8 (Data availability)

- **What must be done?** – Mandatory reporting on electricity efficiency must be done to the Department of Energy (DoE) as part of DSM. Reports must be sent to SANEDI for 12L tax incentives.
- **How is it done presently?** – These reports must be compiled and taken or sent to the respective organisations.
- **Why is this not sufficient?** – This is time consuming and ineffective.
- **How does this study solve this problem? –** This EMS makes the data available by continuously updating it from the mine's Supervisory Control and Data Acquisition (SCADA) system. Reports are generated automatically and accessible on the web. This dramatically speeds up the reporting process for DSM initiatives and tax incentives.

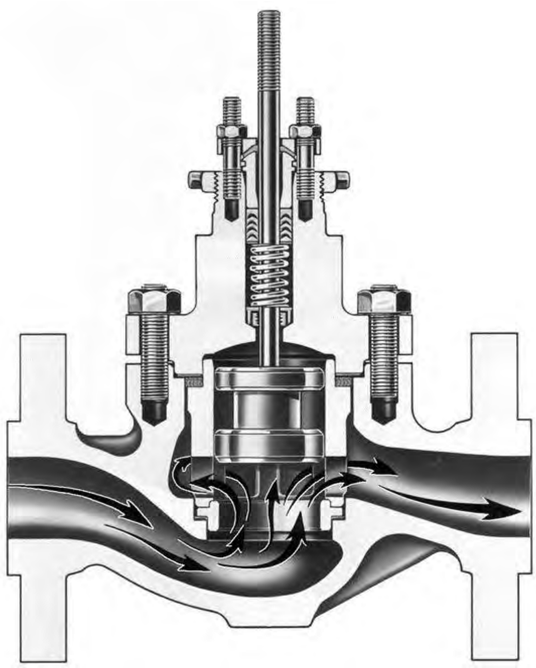
2.8.Conclusion

In this chapter it was shown that South Africa is in need of reducing its water- and air-pollution. Investigation was done into work done by other authors on sustainability management. EMSs available to mines were investigated to identify shortcomings and improve their effectiveness.

This research led to the identification of serious shortcomings of presently available EMSs that was formulated into a problem statement. Eight novel contributions that can be made by a new approach to sustainability management were then identified.

One of these contributions is to identify, describe and create a database of projects that can be implemented to increase the sustainability of deep-level gold mining. This will be covered in the following two chapters. Funding models identified in this chapter can then be applied to these projects to determine suitable funding methods.

3. Water reticulation projects



This chapter discusses the implementation of projects for pumping, water supply optimisation and cooling auxiliaries. These are the first three projects included in the electricity- and environmental impact reduction project database that are suggested to mines to determine the actual savings that can be achieved.

3.1.Introduction

Previous chapters discussed the extensive research on water and air pollution, noting that mines are of the highest polluters of water. Mines are also one of the largest electricity consumers in South Africa, and power generation was identified as a large-scale carbon dioxide-producer, contributing to extensive air pollution. For this reason, gold mines are targeted as an effective means of reducing air and water pollution simultaneously.

One of the problems identified with current mining pollution prevention efforts is that mines are not given specific project examples. In this chapter, projects on the water reticulation system of mines are identified, the first of three projects included in the recommended sustainability project database.

Each project influences the environmental impact reduction caused by the other two projects and as such, is discussed in implementation order. The projects discussed in this chapter will reduce the water usage of a mine. This in turn reduces the power consumption of the mine and the associated carbon dioxide emission reduction. The first of these projects is the pumping project.

3.2.Pumping system project

Savings strategy

As discussed, water is pumped from underground in phases. The water reticulation system usually comprises two to four pumping stations, each with a hot dam to store water before it is pumped to the next level. This means the pumps are stopped and started in order to empty the dams. This process can be automated to ensure that the least amount of electricity is used during the evening peak period (18:00 to 20:00). One way of reducing electricity usage at this time is by automating these pumps to stop and start remotely, avoiding the necessity of manpower from travelling up and down the shaft.

Automating pump projects have been shown to shift up to 12 MW from the peak periods (Kleingeld *et al.*, 2011). The electricity usage in deep-level mines is high and as a result, mines are forced to adopt a Time-of-Use (TOU) electricity tariff. Being able to schedule the pumping times allows the mine to extract the water at times when electricity is the cheapest.

The automated pumping system measures the dam level and maintains a specified level depending on the time of day. To achieve this goal, the hot dams are emptied during the period preceding the evening peak period, from 15:00 to 18:00. This allows the dams to fill during the peak period without overflowing. This strategy relies on two factors: the availability of large storage dams to ensure that dams do not overflow, and being able to predict the water consumption profile (Kleingeld *et al*., 2011). It is also necessary to have redundancy in the pumping system.

Automating pumping can be achieved using Real-Time Energy Management System for Pumps (REMS-Pumps™) to ensure that the cost saving is sustainable. This type of project is an example of a load shift project (Vosloo, 2008), as discussed in Chapter 2.

When implementing this type of project, it is necessary to install measuring equipment to ensure that the pumps are operating safely. Some of the important variables that must be measured include pump temperature and vibration, suction and discharge pressure, pump flow, cooling water flow and discharge valve status (Schoeman *et al*., 2011). The typical installation set up can be seen in Figure 21.

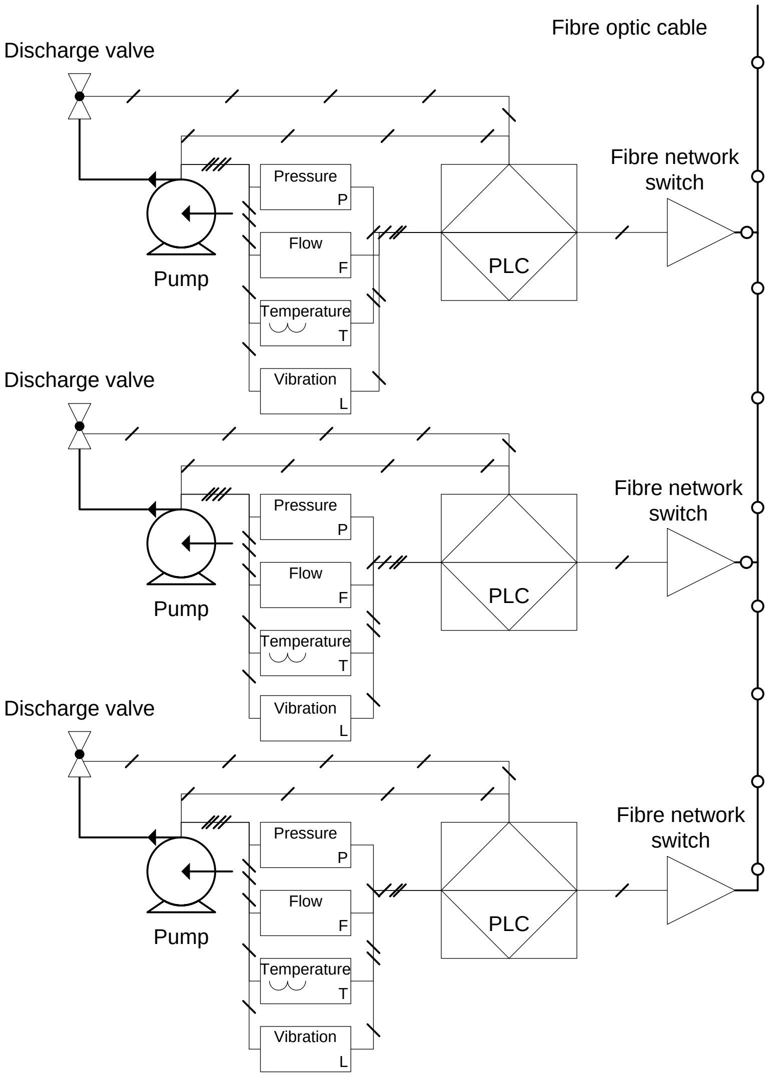


Figure 21: Pumping project installation (adapted from Schoeman *et al.*, 2011)

From Figure 21 it can be seen that the pump and discharge valve are controlled by the programmable logic controller (PLC). The PLC also measures the pressure, flow, temperature and vibration of the pump to ensure the pump is operating correctly and at peak efficiency.

These signals are transmitted using an Ethernet, which is not capable of transmission ranges over 100 m when not enhanced. For this reason a fibre optic network switch is installed to convert the electrical signals to light signals that are transmitted through the fibre optic cables. The fibre optic cables are installed down the shaft to allow communication to the underground PLCs from the surface.

The SCADA system thus monitors the system from the surface. The values are subsequently read by REMS-Pumping™ which is capable of controlling the system by making decisions based on the inputs from the SCADA system. The control signal is then sent down the shaft to stop and start some of the pumps in order to shift the load from peak periods.

It was found that these projects shifted too much of the load to the standard tariff periods leading to an electricity-supply shortage in these periods. This is known as the comeback load. For this reason Eskom is currently only funding load shift projects that shift the load to off-peak periods: from 21:00 to 06:00 (Kleingeld *et al*., 2011).

The pumps on a pumping station usually pump the water into a common manifold. This is because the cost of installing a pipe column from one station to the next is high. As a result, the more pumps are started, the higher the water flow in the pipe column becomes. The problem with this setup is that with an increase in flow, there is a corresponding increase in friction- and pipe-losses (Vosloo, 2008). This emphasises the need to minimise the pumps running simultaneously and the speed of the water flow.

Simulated saving

Firstly it is necessary to look at the system layout before the project implementation. This can be seen in Figure 22.

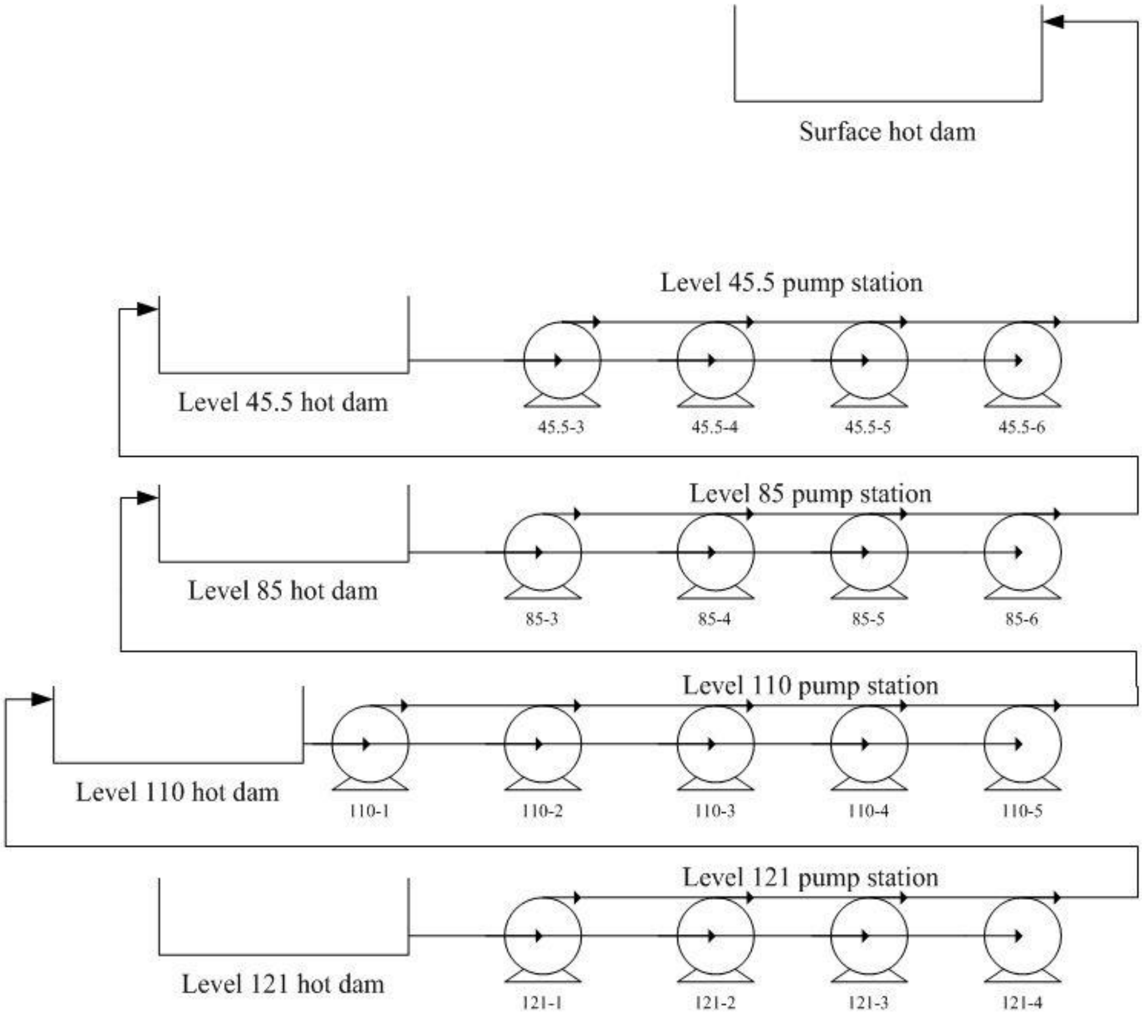


Figure 22: Mine A pumping layout

For determining the savings associated with each project it will first be necessary to develop a simulation to gather baseline data. The simulated pump power usage after the installation of this project is compared to the simulated baseline usage in Figure 23.

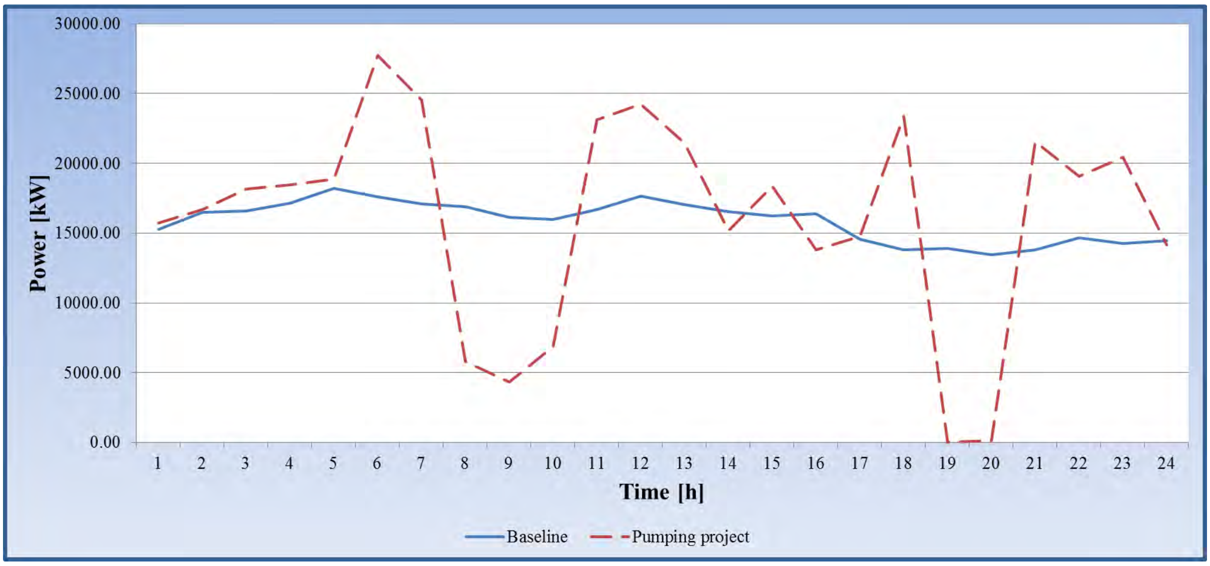


Figure 23: Pump power after pumping project installation

From Figure 23 it is evident that the pumping power is predicted to be significantly reduced during the morning peak period from 07:00 to 10:00 and the evening peak period from 18:00 to 20:00. This pumping load was shifted to other periods of the day when electricity is cheaper.

According to the simulation, the load that can be shifted from the morning peak is 10.67 MW or 65.3% of the total baseline consumption during this period. Similarly the load shift during the evening peak period is predicted to be 13.6 MW or 99.5% of the baseline power consumption. It is predicted that not all the load can be shifted from the morning peak period because the dams do not have sufficient capacity to store all the water settling in the hot dams during the morning peak period of three hours.

3.3.Pumping project results and interpretation

Verification of simulated savings

As stated, pumping projects aim to shift the electrical load from the peak Eskom periods to periods of lower electricity usage. Eskom-IDM funding is only available for load shifted from the evening peak periods; however, the electricity tariff during the morning peak period is the same as the evening peak period. As a result, this morning peak period also holds financial implications for the client. Since the morning peak period load can be shifted with no extra implementation costs, this too is always included in the load shift effort, if not to receive Eskom-IDM funding, then simply to shift the load to cheaper electricity periods.

The implementation of the Mine A pumping project was challenging since the pumps are supplied with electricity by two different feeders. Panel 10 has a power supply limit of 20 MW and panel 11 has a supply limit of 18 MW. The power supply to the different pumps can be seen in Figure 24.

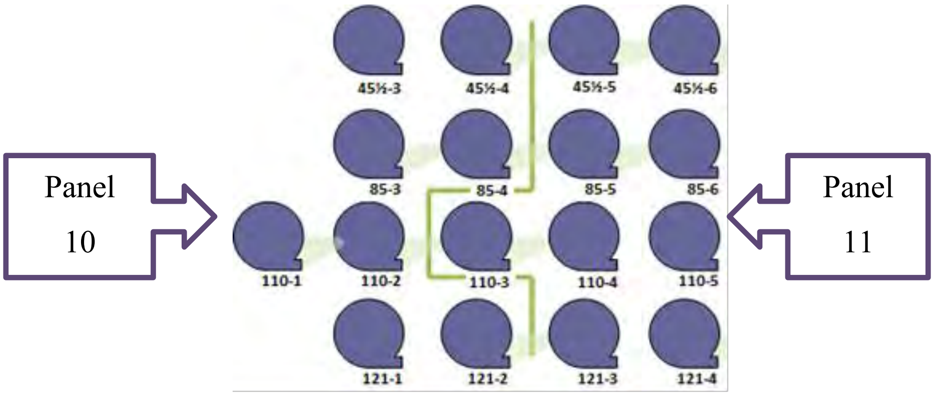


Figure 24: Pump feeders

The pump control strategy had to be optimised, not only to ensure optimum control from one level to the next, but also between the two different feeders. This limits the maximum water that can be pumped and extracted from the mine at any given time. It also makes the system vulnerable to breakdowns. The performance of the pumping project during the performance assessment period is shown in Figure 25.

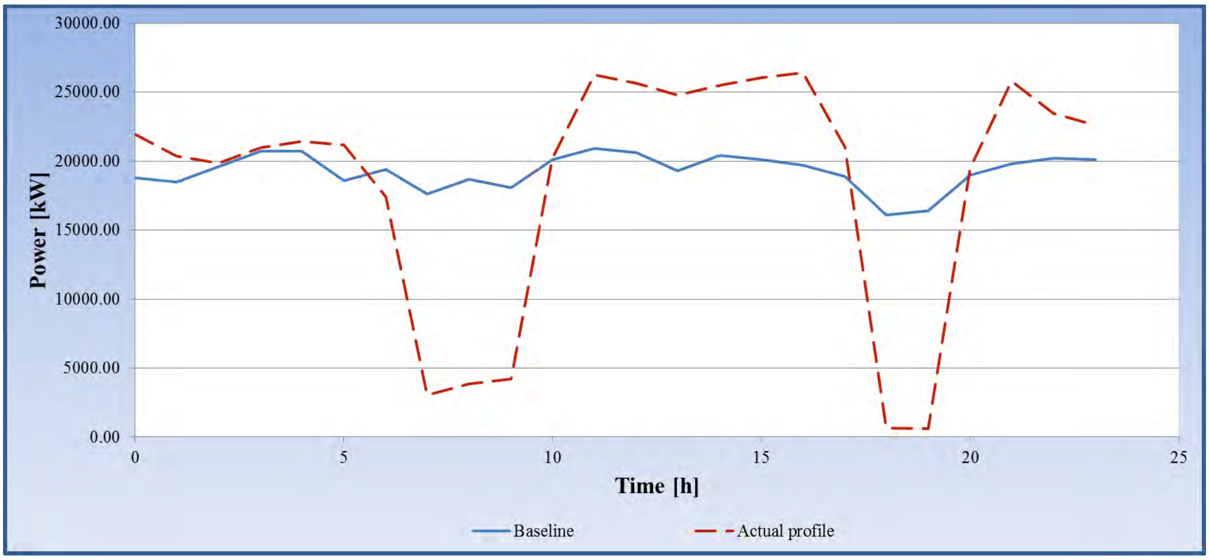


Figure 25: Pumping project performance

In Figure 25 it can be seen how the load is shifted from the morning and evening peak periods to the rest of the day. An average of 14.43 MW load shift was achieved in the morning peak periods when compared to the measured baseline. During the evening peak period, a load shift of 15.61 MW was achieved, which is the majority of power consumed during this period.

Interpretation of savings

The total load shift and power savings during the morning peak period achieved by the pumping project was 14.43 MW or 79.6%. This is higher than the predicted savings of 65.3%. The total load shift and power savings during the evening peak period achieved by the pumping project was 15.61 MW or 96%. This compared favourably with the predicted savings of 99.5%, therefore it can be concluded that the savings prediction was accurate.

It is clear that it was not possible to do a full morning peak load shift, as predicted. This is because of insufficient water storage capacity at the pumping stations. During the shorter evening peak however, most of the load was shifted.

The total installation cost for the project was R6.08 million. This installation was however, done in 2012 and to compare the cost saving to the implementation cost, the electricity tariff of 2012 must be used.

The cost savings associated with this project installation was R15.45 million/annum in 2012. At an implementation cost of R6.08 million the payback period for this project would have been less than 5 months. It should be noted that the ESCO installing this project also makes a profit that will increase the cost of the project and negatively affect the payback period. The benchmark funding from Eskom for load shifting projects is R3.5 million/MW. With a project saving of 15.61 MW the funding that could have been used for the project implementation is R54.64 million.

This project saves the client R15.45 million/annum and cost Eskom R0.39 million/MW (excluding ESCO profit). It is necessary to investigate the environmental benefit that load shift projects has, since the aim of this study is to reduce the environmental impact of mining.

To do this, it is necessary to investigate the carbon dioxide pollution created by power stations. This can be seen in Table 8.

Table 8: Pollution production per power plant (Eskom, 2011)

Technology	Site	CO_2 Production [kg/MW]
Coal-fired power stations	Komatie	1260
	Camden	1240
	Grootvlei	1240
	Hendrina	1180
	Arnot	1090
	Majuba	1060
	Matla	1060
	Tutuka	1050
	Duvha	1040
	Kriel	1040
	Kendal	1030
	Lethabo	1000
	Matimba	890
	Kusile	780
	Medupi	750
Nuclear power stations	Koeberg	
Conventional hydro-power stations	Gariep	
	Vanderkloof	
Pumped storage schemes	Drakensberg	
	Ingula	
	Palmiet	
Gas-fired power stations	Acacia	820
	Port Rex	820
	Ankerlig	820
	Gourikwa	820
Wind power stations	Klipheuwel	
	Sere	

From this table, it can be read that the pollution produced at any given time is dependent on the specific power stations that are generating the power. If the power stations with the lowest pollutant production are utilised, the carbon dioxide production varies to differing extents, as shown in Figure 26.

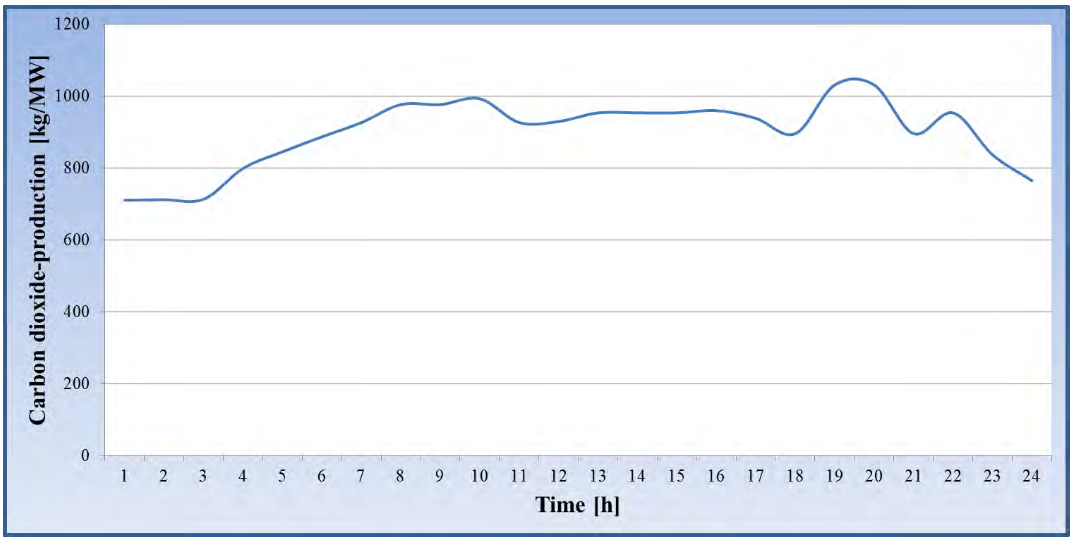


Figure 26: Minimum carbon dioxide-production by Eskom throughout the day

The carbon dioxide production during the evening peak period is 1030 kg/MW and 710 kg/MW during the early morning hours. This shows that by generating the electricity in the early morning hours instead of the evening peak period, 320 kg/MW can be saved. Thus by implementing this project 43 758 kg CO_2/annum emission could be prevented.

One consideration that must be investigated is the negative effects that load shifting can have on the water quality. This is specifically when surface water treatment plants are sensitive to flow variations. Not all mines have surface water treatment plants though. On mines that do have a water treatment plant, it is necessary to ensure that the minimum water should always be supplied to ensure efficient operation (Hasan, 2009). This was however not the case at Mine A and the entire load could be shifted.

3.4.Water Supply Optimisation (WSO) project

Savings strategy

There is vast potential for reducing the amount of water used by a mine's underground operations (Vosloo, 2008). By reducing the water sent underground, electricity used to pump the water out, is reduced. This is done by limiting the pressure supply to each mining level, reducing the flow during non-production shifts.

If the position of the underground cooling systems can be determined, the water to the areas of the mine that does not have cooling equipment can be isolated during the blasting shift.

The pressure to the levels that do have cooling systems can also be reduced as cooling cars require a lower pressure than rock drills.

The high pressure during blasting shifts is not necessary. If the pressure during the blasting shift remains high, the water flows through pipe leaks. Past projects have shown that reducing the pressure supply during the blasting shift allows the flow to be reduced by as much as 40%. This is an average water flow reduction of between 10% and 15%. The valves that reduce the flow on each level can be automated to ensure sustainability. The valve setup for each level can be seen in Figure 27.

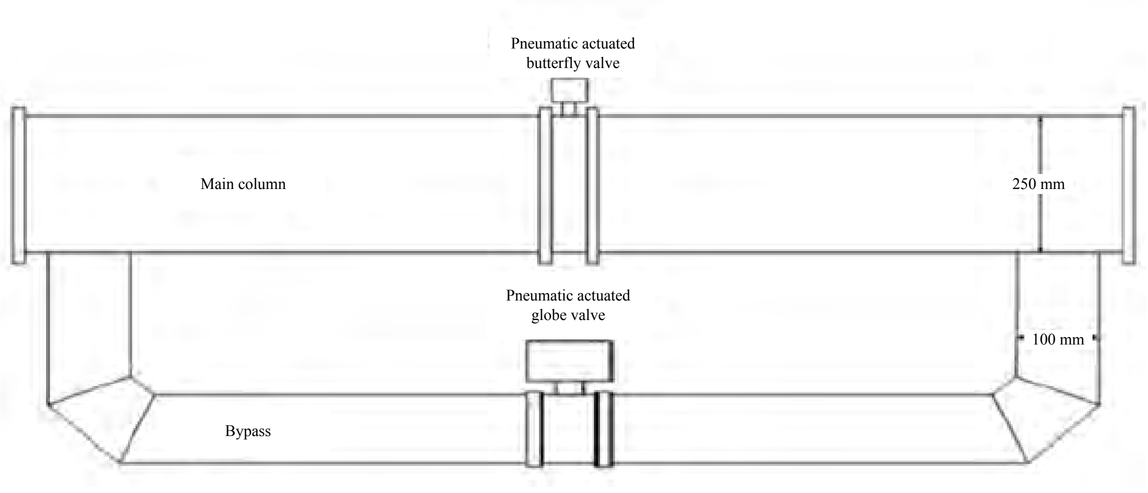


Figure 27: Underground valve setup

A butterfly shut off valve is placed in the main line. During the drilling period the butterfly valve is opened to supply the maximum amount of water. The valve is also left open during the sweeping shift as water needs to be readily available.

During the blasting shift however, the main butterfly valve is closed and the bypass valve is opened. The bypass valve is usually a 150 mm actuated globe valve that reduces the flow. The flow and pressure is monitored and the valve opening can then be controlled to maintain a set output pressure. The control system Real-time Energy Management System for Water Supply Optimisation (REMS-WSO™) has been developed to automate this system.

An additional consideration when undertaking WSO projects is leak management. Fixing the underground leaks can reduce the water usage by up to 7 Ml/day (Van Rensburg *et al.*, 2011). Reducing the water usage reduces the amount of water that needs to be pumped from underground. Since these gold mines extend deep underground, the power saved from the reduced pumping is significant.

This also reduces the amount of water that enters the hot dams, ensuring that pumping projects can consistently deliver load shift savings. The amount of water that needs to be cooled by the refrigeration machine is also reduced. It can therefore be seen that water usage reduction, pumping projects and refrigeration machine optimisation projects complement each other.

Simulated savings

The baseline simulation results will be to determine the power used by the pumps initially, before the implementation of the WSO project. In this simulation the following assumptions are made:

- Mine A will represent the typical South African mine.
- The flow profile of the water flowing down the mine is recorded as the flow down the shaft of Mine A during the period 1 January 2012 to 31 January 2012.
- The efficiency of the pumps is 65%.
- The water used at the stopes takes an hour to reach the hot dam after entering the settling dams.
- One baseline pump is always running and the rest of the pumps switch on alternately with each 10% increase in dam level.
- The initial dam level is set at 60%.

Using these assumptions, it is possible to draw a baseline pumping profile from underground to the surface. During the implementation of the actual WSO project, the water consumers were situated on level 89 to level 109. Although some water was consumed on level 113 to level 126, the flow requirement of these development levels was irregular and could not be reduced.

The water that can be reduced, by installing pressure-reducing bypass valves, settles in the settling dam on level 110. For this reason only the pumping power consumption on level 110 and higher will be influenced. The pumps situated on each individual level can be seen in Table 9.

Table 9: Mine A pump sizes

Pump	Install capacity [kW]	Average flow [l/s]
121-1	1300	245
121-2	1300	245
121-3	1300	245
121-4	1300	245
110-1	3200	280
110-2	3200	280
110-3	3200	280
110-4	3200	280
110-5	3000	270
85-3	4000	230
85-4	4000	230
85-5	4000	230
85-6	4000	230
45½-3	4000	245
45½-4	4000	245
45½-5	4000	245
45½-6	4000	245

The power profile of the three pumping stations (level 45.5, level 84 and level 110) together with the total power profile of the pumps can be seen in Figure 28.

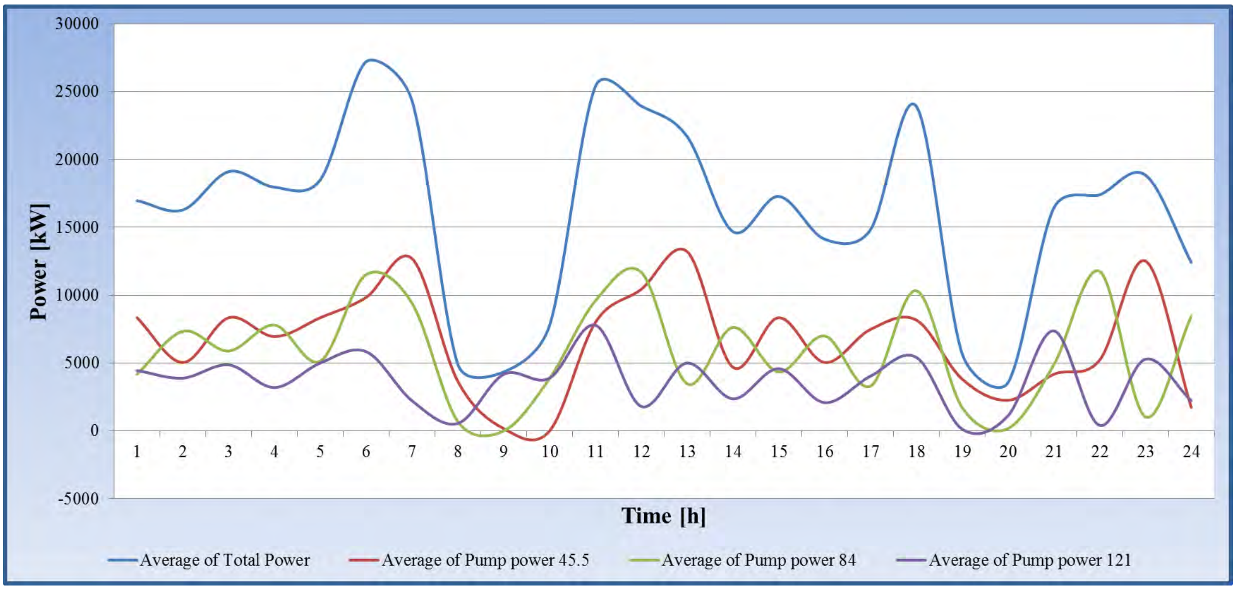


Figure 28: Baseline weekday power usage simulation

From the graph, we can see a drop in the power usage from approximately 08:00 to 10:00. This is because of the pumping project load shift already implemented during the baseline period, as at Mine A. The average power consumed by the pumps is 16.15 MW and the daily average water consumption on the mine is 289 l/s. The predicted reduction in water flow by the WSO project can be seen in Figure 29.

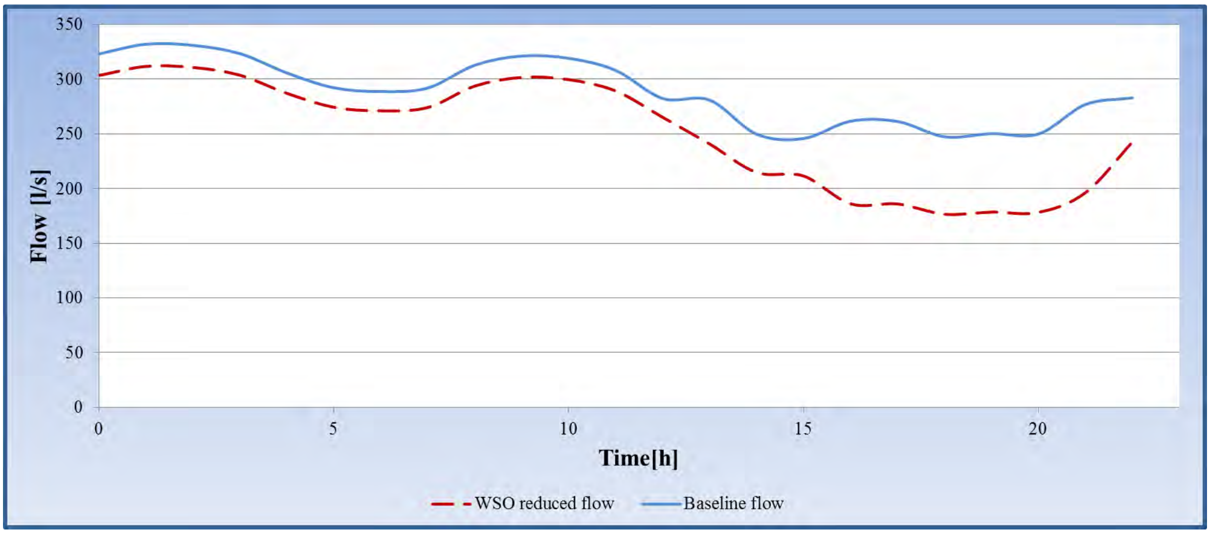


Figure 29: WSO reduced flow

From Figure 29 it can be seen that the flow can be significantly reduced during the blasting shift (13:00 to 21:00). There is however a reduction in flow throughout the day. This will be the result of the leaks that will be fixed during the course of the project and the slight pressure drop caused by the valves even in the fully open position. The power comparison between the baseline and WSO reduced profile can be seen in Figure 30.

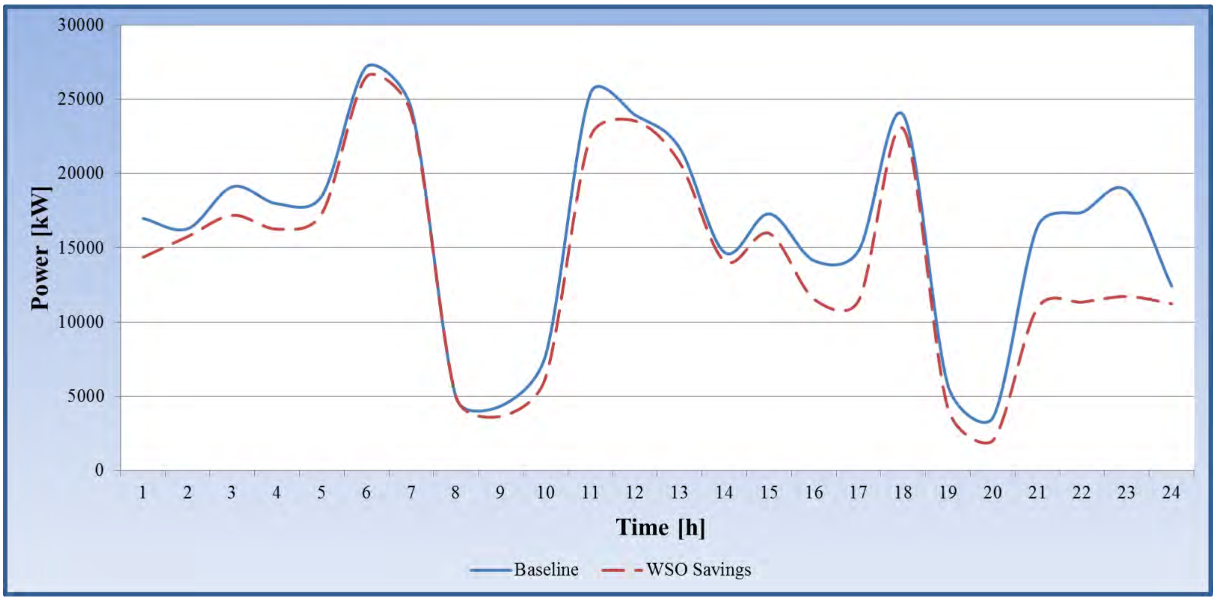


Figure 30: Electricity-saving by the WSO project installation

From Figure 30 it is clear that the pumping power can be significantly reduced by implementing the WSO project. It is predicted that the electricity usage will be reduced from 15:00 to 01:00. This is because of the delayed effect of the water flowing to the settling dams from the stopes. The water present in the hot dam must also be extracted before the pumps start switching off. The simulated average power consumed by the pumps with the WSO project installed is 14.19 MW. This gives an average predicted saving of 1.96 MW or 12.1%.

From this profile it is evident that significant electricity-savings can be realised by implementing the WSO projects. It can be seen that the largest electricity-savings should be realised during the evening and night-time periods. This project also creates a water usage reduction. The daily average water consumption on the mine was reduced to 253 l/s. This is an average reduction of 36 l/s, which is just over 3.11 Ml per day.

3.5. WSO results and interpretation

Verification of simulated savings

The savings in water usage and electricity that can be realised using the WSO project has now been determined. It was determined from the simulations that WSO projects should be able to save 12.1% of the pumping power usage. This is the result of a reduction of 12.5% in the water usage on the mine.

The WSO project at Mine A was implemented to verify the accuracy of these projected savings. Valves were only installed on the 5 levels from level 89 to level 109. These five levels are the high production levels and as a result consume the highest percentage of the water. Limiting the water flow on these levels would ensure that the best savings, with the lowest capital expenditure, were achieved.

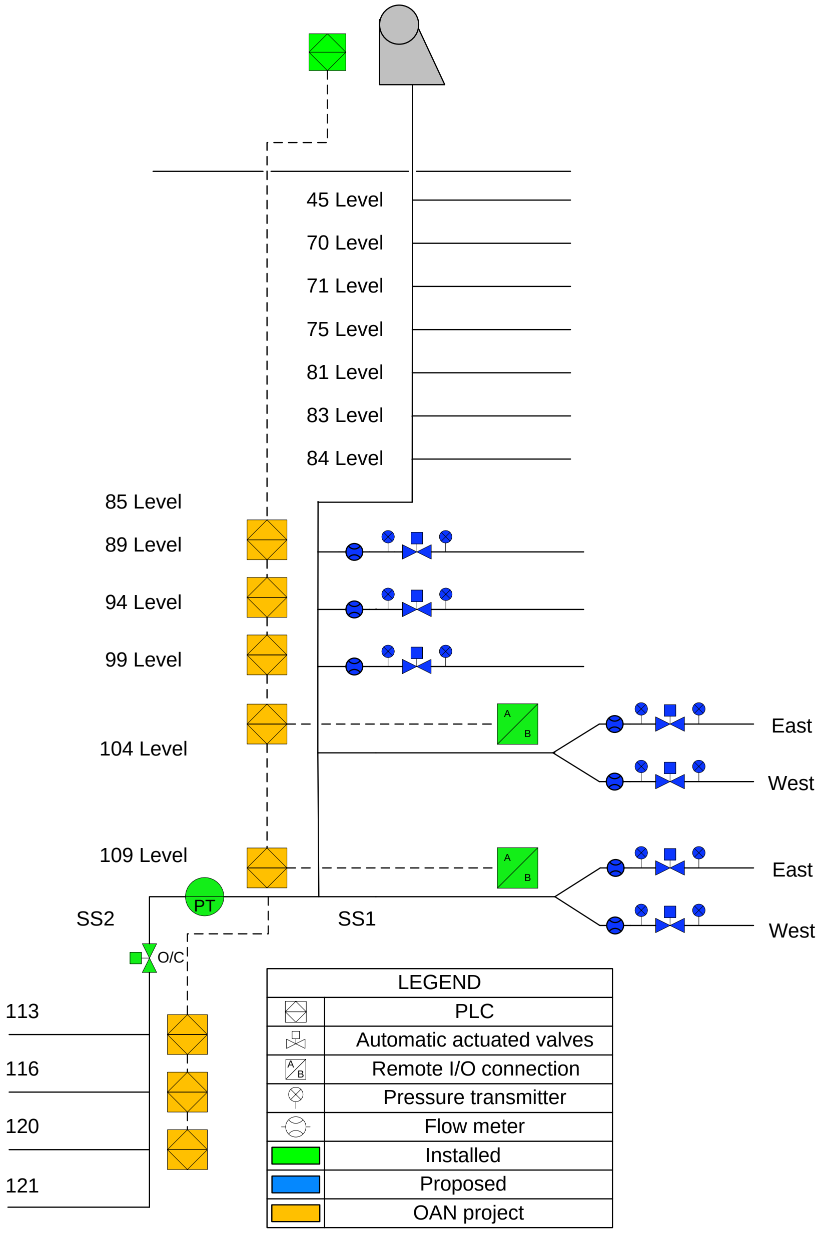


Figure 31: Mine A WSO project installations

Level 104 and 109 split into two mining sections, namely the East and West sections. To manage these sections' flow independently, it was necessary to install two valves on each of these levels. The project cost was significantly reduced by the availability of PLCs already installed on each of the five levels. This was the result of a previous project similar to the WSO project on the air distribution network. This project is called an Optimisation of Air Network (OAN) project and is discussed in chapter 4.

A flow sensor as well as two pressure sensors, one on each side of the valve, was installed at each valve station. Pressure sensors were installed to allow REMS-WSO™ to control the valves based on the outlet water pressure. The pre-set minimum water pressure was determined and this pressure was maintained to ensure the minimum amount of water is used during the blasting shift.

Control of these valves cannot be done based on the water flow, since the mining levels require a minimum pressure to operate the cooling equipment. An additional advantage that is gained from the pressure sensors is the monitoring of the valve. This can ensure that the valve does not cavitate, as is often the danger in high pressure fluid applications.

All these flow and pressure measurements are then transmitted to the surface SCADA system. REMS-WSO™ extracts these values from the SCADA system and analyses it. REMS-WSO™ determines the suitable valve position to ensure water reduction without influencing the cooling equipment. These set-points are then transmitted to the valves. The WSO project was implemented on Mine A during 2010. The power savings for this project can be seen in Figure 32.

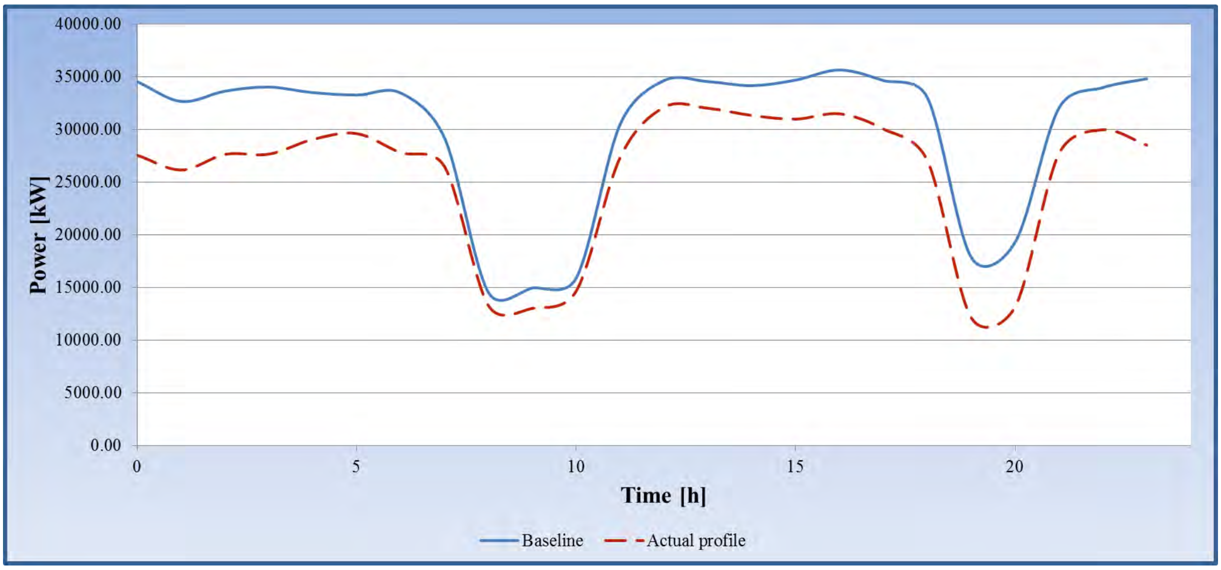


Figure 32: Mine A WSO Project savings

The total savings that was achieved by the WSO project was 4.28 MW or 15%. This is higher than the predicted savings of 1.96 MW or 12.1%.

Interpretation of savings

The higher savings can be attributed to the savings achieved by fixing leaks that was not accurately predicted. The baseline usage for the actual project is higher than the baseline for the simulated project. This can be attributed to the fact that the simulation assumed that only the water going down the mine would have to be pumped out. In reality however there is a lot of fissure water that must be extracted as well. This will however not affect the absolute saving, because of the direct relationship between water flows and pumping power consumption.

It can be seen that the same control strategy was followed before and after the project implementation. Power usage was minimised during the peak periods in order to minimise cost. As a result, the electricity consumption was lowered significantly.

There is a difference between the simulated savings profile and the actual achieved savings profile. Most of the simulated savings were achieved during the afternoon, whereas the actual savings was achieved throughout the day. This is because the delay between water usage and water settling in the hot dams is much longer than the initially expected time of one hour. In reality, this time was closer to five hours.

This means that the power saving for the pumps is achieved in entirely different periods of the day than initially expected – an incorrect assumption made during the project's simulation. It does however not affect the overall savings prediction as the savings is calculated for the entire day and there is a linear relationship between the pumping power used and quantity of water pumped from the mine.

Additional electricity-savings were achieved during the project by decreasing the number of pumps that needs to operate, the water flow was reduced, and thus the inefficiency caused by surface friction in the pipes was decreased. The decreased number of pumps running equates to an increase in electricity-saving.

There is also a small flow reduction as a result of the valves that were installed. The values cause a small pressure drop throughout the day that lowers the water leaking out of the pipes and the water consumed by the drills.

The total cost for the project was R1.95 million. This installation was however, done in 2011 and to compare the cost saving to the implementation cost, the electricity tariffs of 2011 must be used.

The cost savings associated with this project installation are R12.05 million/annum in 2011. At an implementation cost of R1.95 million, the payback period for this project will be less than two months. It should be noted that the ESCO installing this project also makes a profit that will increase the cost and payback period. The Benchmark funding from Eskom is R5.25 million/MW. With a project saving of 4.28 MW the funding that could have been used for the project implementation is R22.47 million.

In conclusion, this project saves the client R12.05 million/annum. The project cost Eskom R0.45 million/MW (excluding the ESCO profit) in comparison to the R20 million it would have cost them to install the increased generation capacity. Finally and most importantly, it saves the environment 1135.15 Ml/annum in water consumption. Further air pollutant reductions can be seen in Table 10.

Table 10: WSO air pollutant reduction

Material	Weight/kWh	Unit	kg/year
CO_2	835.0	[g]	22361777
SO_2	4.9	[g]	131560
NOx	636.0	[mg]	17032
Si	20.0	[mg]	536
Al	11.5	[mg]	308
Ca	2.0	[mg]	54
K	1.0	[mg]	27
Mg	1.0	[mg]	27
P	1.0	[mg]	27
I	0.9	[mg]	23
Fe	0.7	[mg]	19
Ti	0.7	[mg]	19
Na	0.5	[mg]	13
F	490.2	[µg]	13
Ba	230.0	[µg]	6.2
Cl	200.0	[µg]	5.4
Ge	67.5	[µg]	1.8
B	62.0	[µg]	1.7
V	61.5	[µg]	1.6
Zn	55.0	[µg]	1.5
Mn	46.0	[µg]	1.2
Ni	34.5	[µg]	0.9
Cr	25.5	[µg]	0.7
Pb	18.5	[µg]	0.5
As	18.0	[µg]	0.5
Cu	16.0	[µg]	0.4
Co	9.5	[µg]	0.3
Mo	7.5	[µg]	0.2
Sn	4.5	[µg]	0.1
Te	3.5	[µg]	0.09
Br	3.0	[µg]	0.08
U	2.5	[µg]	0.07
Be	2.0	[µg]	0.05
W	1.6	[µg]	0.04
Cd	0.5	[µg]	0.01
Hg	0.1	[µg]	0.003

3.6.Cooling Auxiliary (CA) project

Savings strategy

Water exiting the mine has dissolved particles in it, and water temperatures can exceed 30°C. This is the result of the contact with the underground rock while the water flows from the stopes to the settling dams. Most of the solid particles in the water are removed in the settling dams before the hot water is pumped to surface.

When this water reaches the surface, all or some of it should be treated at a water treatment plant. The water is then pumped to a hot water dam for storage before being cooled. The cooling of this water is necessary to ensure that effective ventilation cooling and drill bit cooling can be done in the mine. The process of cooling the water is electrically intensive and often ineffective. This section will investigate a potential electricity-reduction strategy for refrigeration plants, where water cooling takes place.

Up to 25% of the electrical energy on a mine is consumed by the refrigeration machines. This can however by reduced by approximately 31% if variable flow strategies are implemented on a mine (Du Plessis *et al*., 2013). For implementing this strategy, Variable Speed Drives (VSDs) are installed on the pumps regulating the flow of water through the cooling system. A typical installation of this project on a mine can be seen in Figure 33.

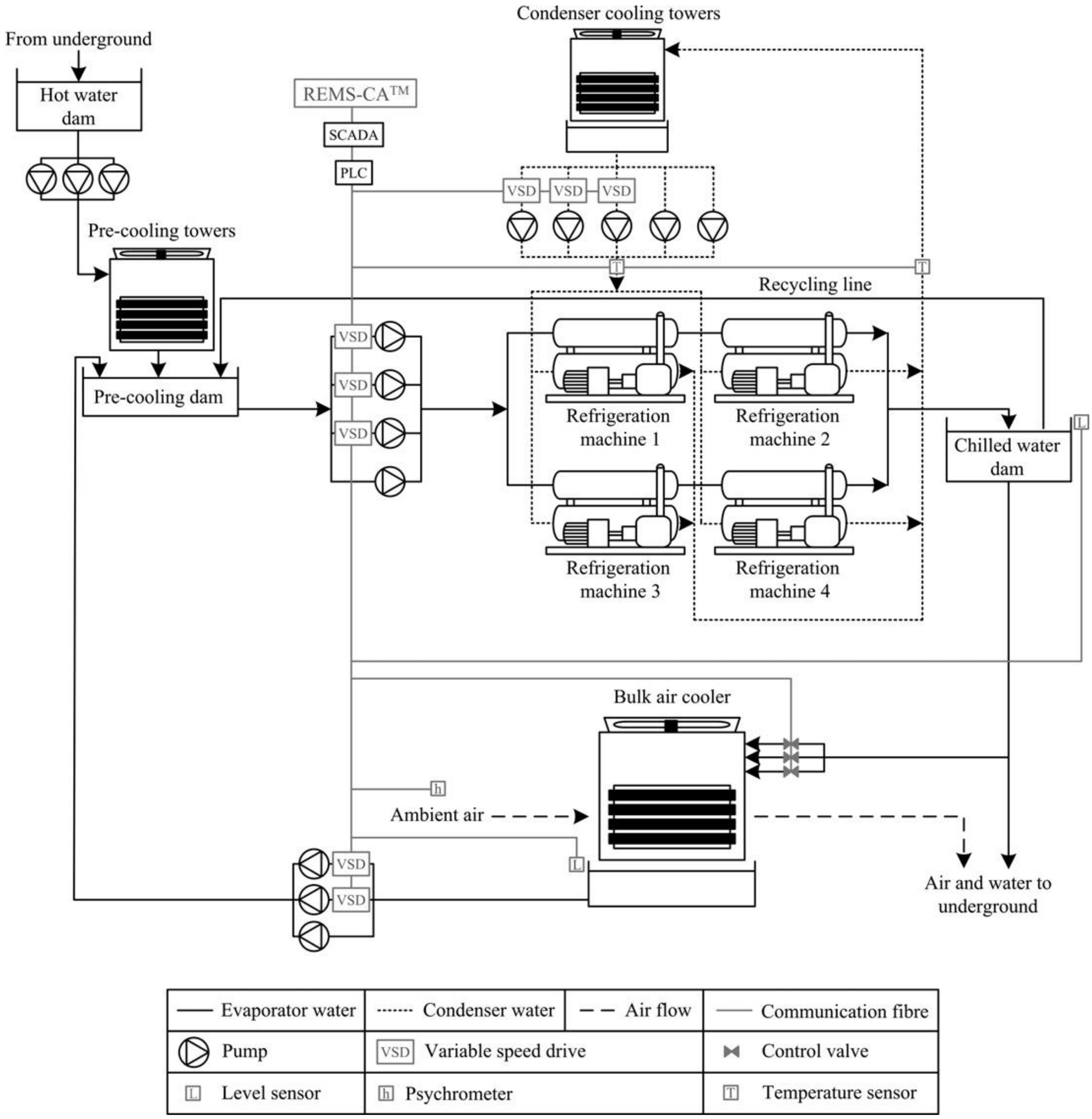


Figure 33: Typical mine cooling system (Du Plessis *et al*., 2013)

Since the flow through the refrigeration machines in regular systems cannot be adjusted, the temperature drop through the evaporator is almost constant. To ensure a set temperature for a cold water storage dam, it is essential for the inlet temperature to be constant. The normal operation of the refrigeration machines relies on a feedback loop between the cold water storage dam and the pre-cooling dam to achieve a set output temperature.

Recirculating through the refrigeration machines numerous times to get the water to the required temperature is electrically intensive and can be prevented if the water only needs to pass through the refrigeration machines once. For this reason, the flow through the refrigeration machines must be adjusted to ensure the correct temperature drop on the first pass.

The temperature of the water exiting the pre-cooling towers typically ranges from 16°C to 20°C and the temperature of the cold dam is required to be between 1°C and 5°C. This temperature drop is achieved by limiting the flow through the refrigeration machines. Limiting the flow through the evaporator circuit also increases the Coefficient of Performance (COP) (Navarro-Esbrí *et al*., 2010; Du Plessis, 2013).

In the condenser circuit, the temperature can vary depending on the environmental conditions. The operation of the refrigeration machines is optimised at a specific condenser temperature drop. The VSDs vary the flow to maintain this temperature drop. This saves electricity as no unnecessary water is pumped through the condenser heat exchanger. The flow should however not be dropped too low as this may decrease the COP (Gordon *et al*., 2010).

The operation of the surface BAC is dependent on the atmospheric conditions, the supplied water flow and the water temperature. If the atmospheric temperature drops below the water temperature, the BAC becomes ineffective. Additionally if the humidity of the air is too high the water will not evaporate into the air and as a result the air will not be cooled down. For this reason the enthalpy of the air is measured. Enthalpy compensates for both the temperature and humidity (Du Plessis *et al*., 2013).

As a result the flow through the BAC can be limited when the enthalpy is too low. This will ensure that the BAC does not operate when it is ineffective. This saves on the amount of water pumped to and from the BACs and the amount of water that must be cooled.

On most mines the air temperature that must enter the mine for sufficient cooling down the shaft is 8°C (wet bulb). To maintain this temperature throughout the day requires large amounts of cold water. During the night and in winter, the temperature often reaches temperatures below this benchmark. This is also referred to as overcooling. When this happens, the water flow can be reduced, saving pumping- and cooling electricity usage.

This system is monitored by installing flow- and temperature sensors on the refrigeration machines. These values are then displayed on the SCADA system (Vosloo, 2008). For controlling the VSDs to minimise the cooling and pumping requirements, Real-Time Energy Management System for Cooling Auxiliaries™ (REMS-CA™) is used (Du Plessis *et al.*, 2013). REMS-CA™ is capable of simulating and controlling the system in real-time, optimising electricity-savings (Vosloo, 2008).

REMS-CA™ connects to the SCADA system to assess the measured variables and make adjustments based on these values. This system is necessary as the SCADA system cannot perform complex calculations (Vosloo, 2008).

In the same way, the condenser flow can be managed. This system is automated to ensure that the savings are sustainable. Automation has been shown to increase the savings by up to 40% and reduce the maintenance cost and labour (Richter, 2008). This also enables decisions to be made, based on analyses of all the constraints (Schoeman *et al.*, 2011).

A weather station, capable of measuring the temperature and humidity of the environment and convert it to enthalpy, is installed. Determining the upper and lower limit of the enthalpy at the mine's location allows the flow through the BACs to be adjusted for ultimate BAC efficiency. This can all be done using the capabilities of REMS-CA™ (Du Plessis *et al.*, 2013).

Implementing this system can increase the COP by as much as 33%, the pumping cost by up to 19% and the refrigeration machine electricity usage by 31.5% (Du Plessis *et al.*, 2013). This implementation does not negatively affect the system operation.

Simulated saving

As discussed, the flow through the refrigeration machines is adjusted in order to ensure that the least power is used to cool the water. The flow profile of Mine A simulated in the previous sections will be used to analyse the CA project performance. Again, it is first necessary to determine the baseline power usage by the refrigeration machines. These simulation results can be seen in Figure 34. For this baseline simulation the following assumptions were made:

- The power usage before any of the VSD installations is determined.
- The flow profile before the WSO installation is used for the baseline simulation.

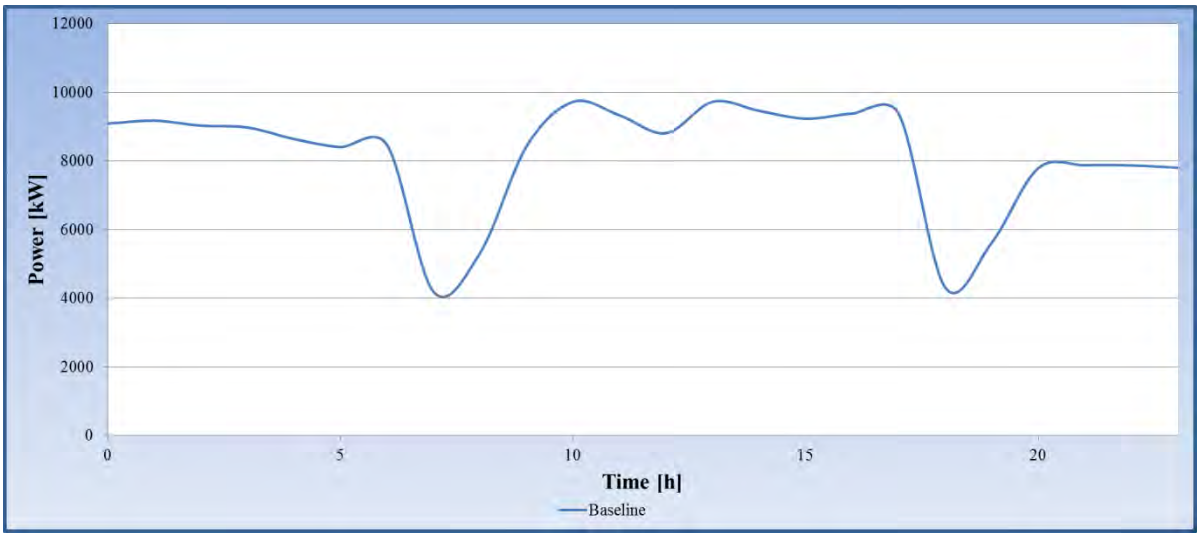


Figure 34: Baseline simulation for the CA projects before WSO project

From the simulation in Figure 34, it is evident that the mine attempts to reduce the refrigeration plant power usage during the peak electricity usage hours. The average electricity usage for the refrigeration machines is 8.17 MW but the WSO project will affect the electricity consumption of these refrigeration machines. For this reason it will be necessary to draw a second baseline for the refrigeration machines.

This will allow quantification of the savings on the refrigeration machines associated with the reduced water flow that was achieved by the WSO project. The profile will then serve as the baseline for the variable flow strategy savings. This simulation can be seen in Figure 35. It is assumed that the WSO project has been installed but not the CA project.

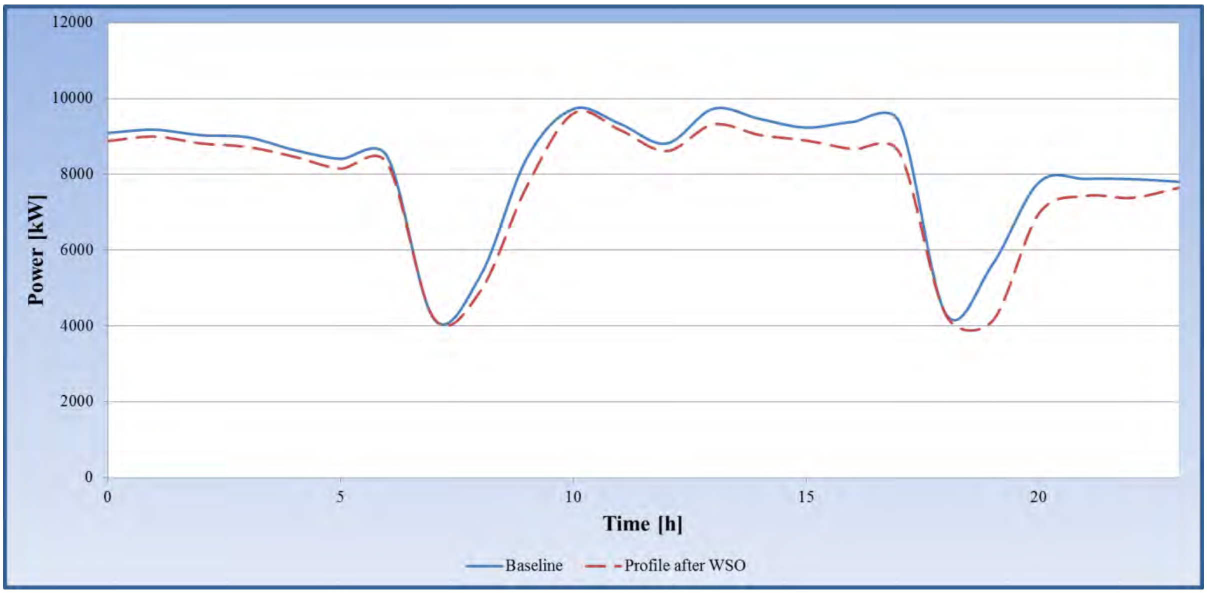


Figure 35: CA baseline project simulation after the WSO project implementation

From Figure 35 it can be seen that the control strategy has not changed. The only difference in power usage can be attributed to the reduced water consumption of the mine as a result of the WSO project. This is evident from the reduced refrigeration machine power usage during the blasting shift, which correlates to the flow reduction achieved by the WSO project. The average power usage for this simulation is 7.79 MW.

This relates to electricity-savings of 380 kW or 4.7% which is the electricity reduction on the cooling system as a result of the WSO project. Finally it is necessary to simulate the savings that can be achieved by installing the VSDs on the refrigeration machine's auxiliaries. The simulation results can be seen in Figure 36 and for this simulation it is assumed that:

- All the VSDs have been installed on the evaporator, condenser and BAC pumps.
- The flow control on the BAC has been installed and is adjusted using the enthalpy input from the weather station.
- The flow profile of the water being pumped from the mine is the flow profile after all the previous projects has been installed.

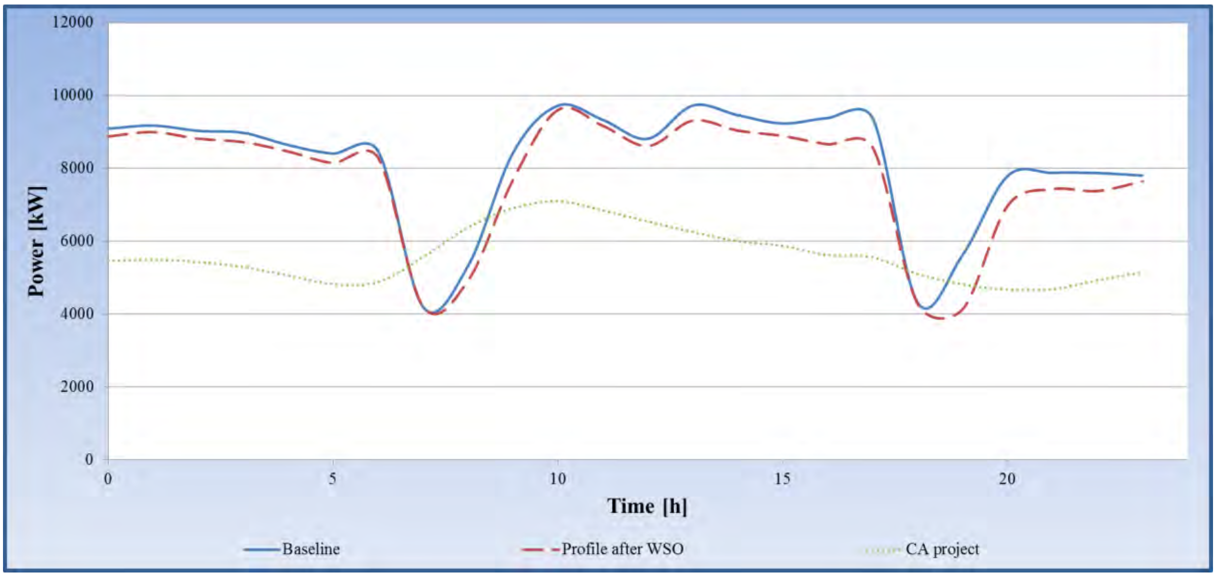


Figure 36: Simulation results for the CA project

From the simulation in Figure 36 it is evident that a different control strategy was used. The profile is closer to the water usage profile as water is made available as it is needed. The electricity consumption of the refrigeration machines after this project implementation is 5.60 MW. This is a saving of 2.19 MW or 28.1%, achieved by the CA project.

A total saving of 2.57 MW or 31.5% can be achieved on the cooling system as a result of the water reduction and the variable flow strategy. By implementing the water and electricity reduction projects discussed in this chapter, the amount of water in the system will also be reduced.

3.7.CA results and interpretation

Verification of simulated savings

As discussed, the saving that can be achieved by the CA project was estimated to be 28.1% of the total cooling system electricity usage. This is the saving associated with only the flow reduction strategy, as calculated in the previous section. The first step at Mine A was to install speed control on the evaporator flow. This can be seen in Figure 37.

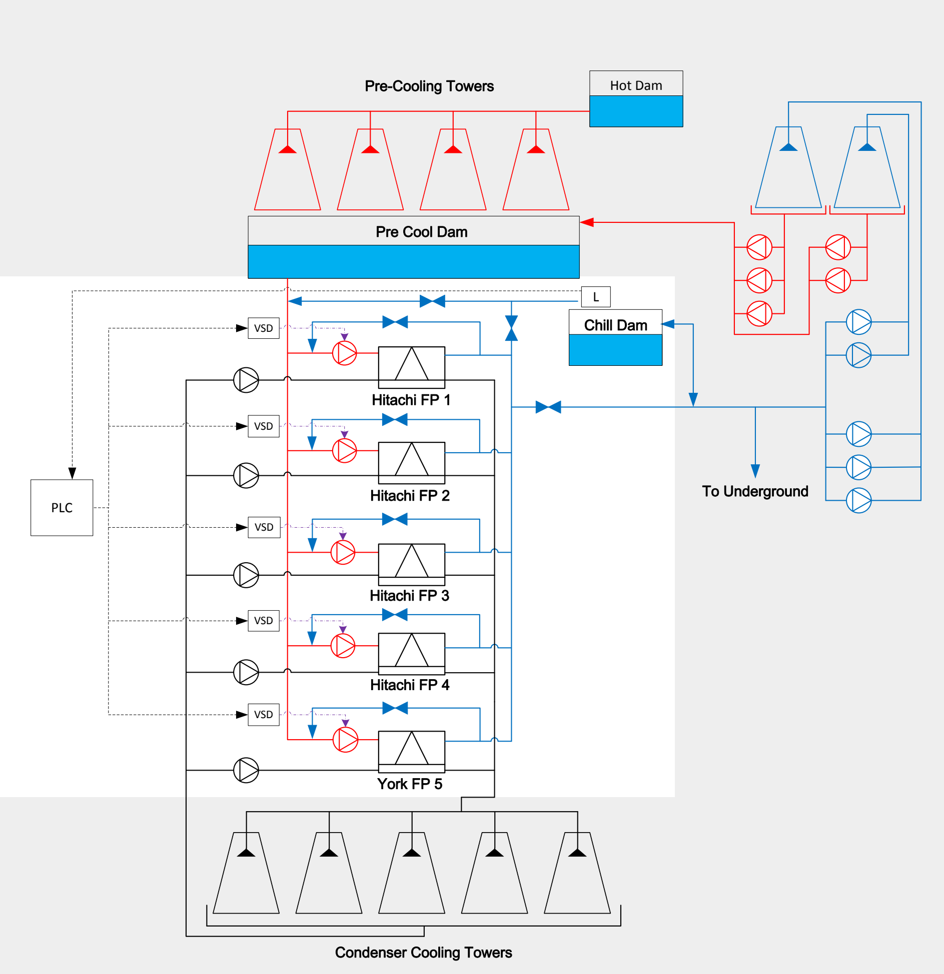


Figure 37: Evaporator flow control

This allowed the flow through the evaporators to be controlled to give a set output temperature. The next step was to install flow control on the condenser towers. This allowed the VSDs to maintain a set temperature drop over the condenser cooling towers. This can be seen in Figure 38.

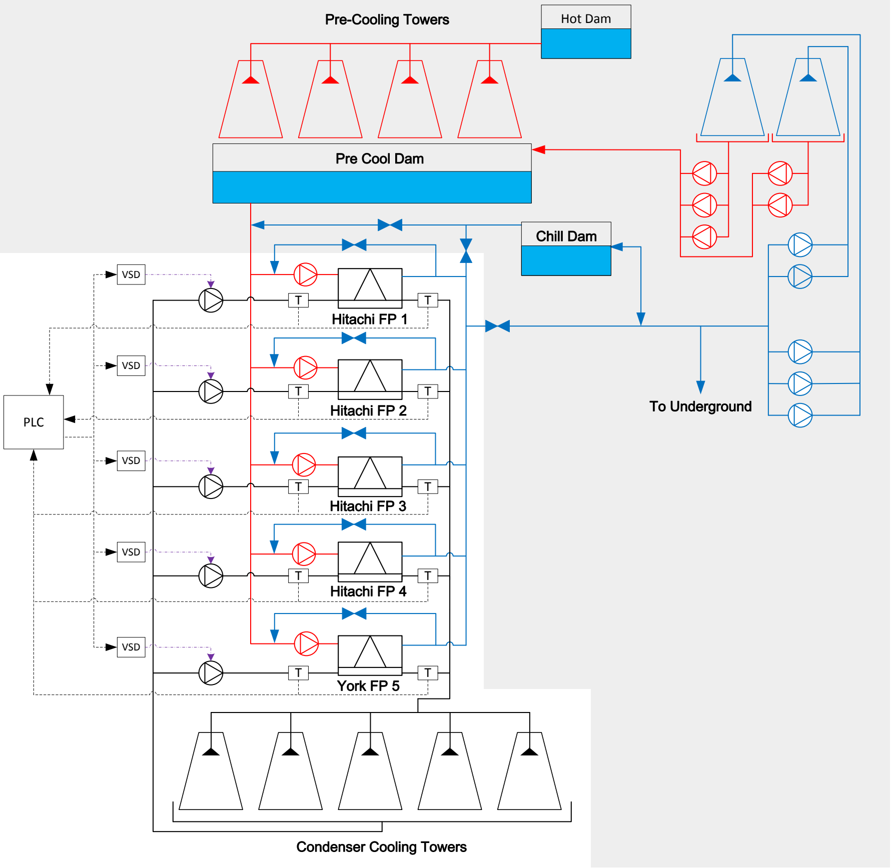


Figure 38: Condenser flow control

If the temperature drop over the condenser towers is too high, the water is overcooled and the flow must be increased. If the temperature drop is too small, the refrigeration machines are not cooled sufficiently. For this reason the PLC maintains a constant temperature drop of 5°C through the towers. This is done using VSD speed control on the five condenser pumps, each with an installed capacity of 185 kW.

The final step is to control the flow though the BAC relative to the atmospheric air temperature. The water is pumped through the BACs from the chill dam and gathers in the sump underneath the BACs. As this sump fills up it is necessary to pump the water to the pre-cooling dam.

The PLC measures the dam level and maintains a desired level. This is done using VSDs on the BAC pumps. This varies the speed of the pumps to ensure the least amount of water is pumped. These pumps are also automated to shift load from the evening peak periods. The BAC VSD installation can be seen Figure 39. The savings on the Mine A CA project can be seen in Figure 40.

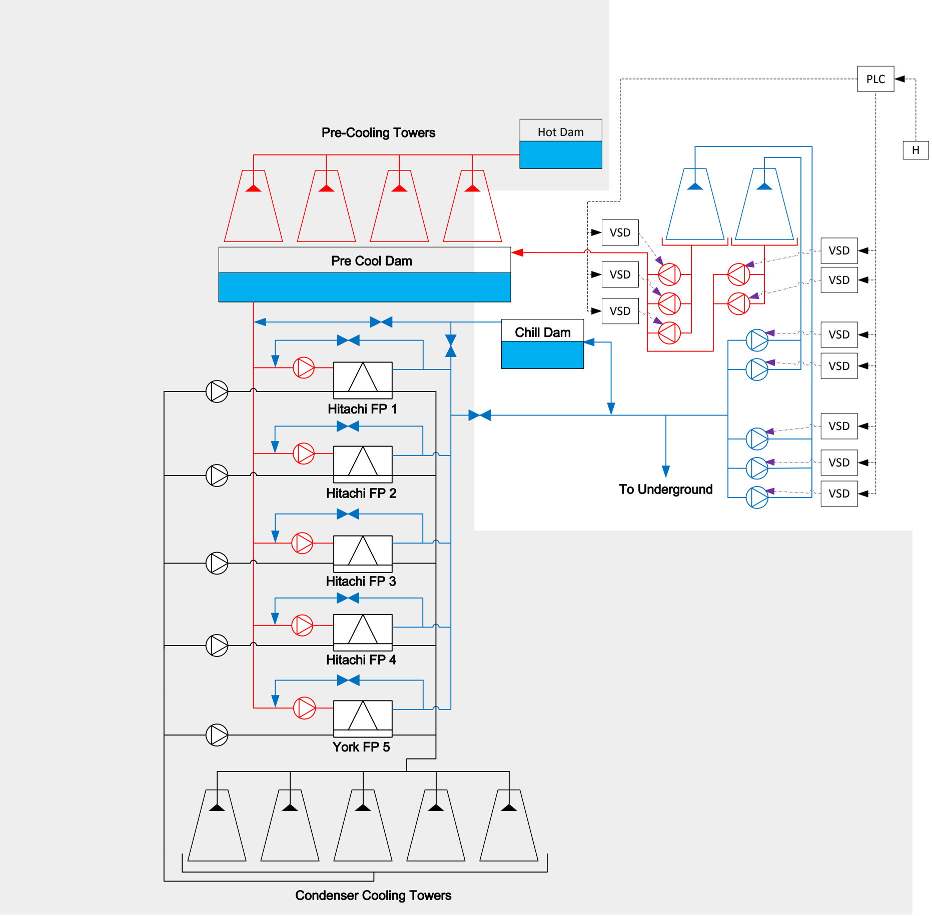


Figure 39: BAC flow control

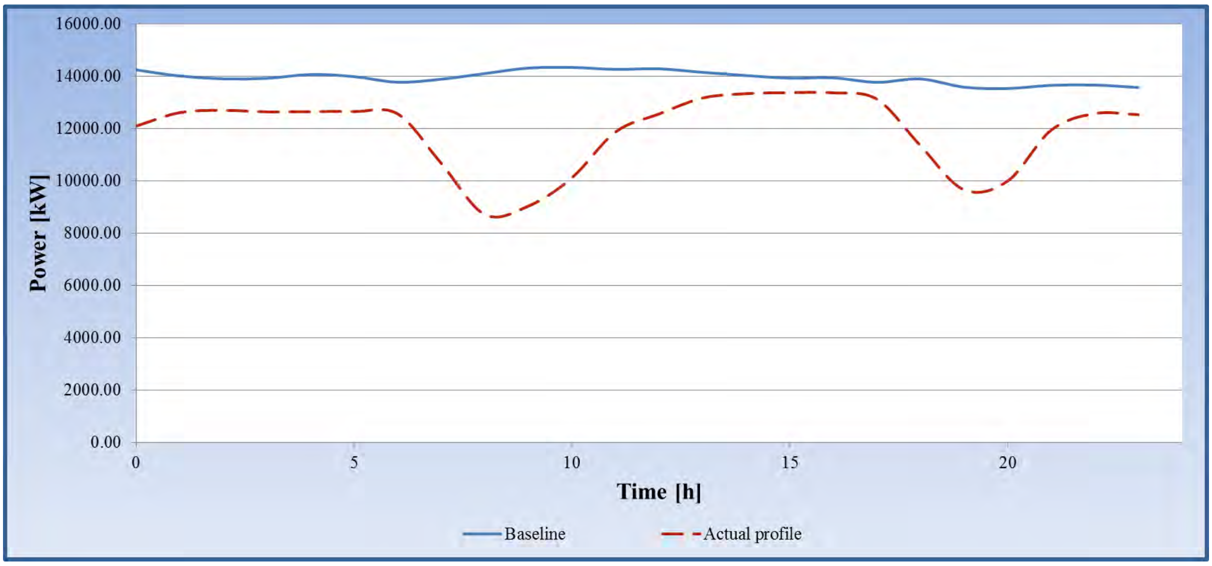


Figure 40: Savings achieved on the Mine A CA project

The savings achieved in this project was 2.06 MW or 14.8% of the baseline power usage. This compares favourably with the simulated saving of 2.19 MW or 28.1%. As a result it is safe to assume that the simulated saving prediction at Mine A was realistic.

Interpretation of savings

The total cost associated with this project was R3.19 million. The installation of the Mine A CA project was done in 2013 and the electricity tariff of that year will be used to analyse the savings.

The savings associated with this project installation are R8.90 million/annum. At an implementation cost of R3.11 million the payback period for this project will be just over four months, at 127 days. It should be noted that the ESCO installing this project also makes a profit that will increase the cost and payback period. The Benchmark funding from Eskom is R5.25 million/MW. With a project saving of R2.06 million/MW, the funding that could have been used for the project implementation is R10.50 million.

It can be seen that the simulated savings was similar to the achieved savings. The electricity consumption profile is reduced throughout the day, and is roughly constant, which resembles the water usage profile. In conclusion, this project saves the client R8.89 million/annum. The project cost Eskom R1.50 million/MW (excluding ESCO profit) in comparison to the R20 million it would have cost them to install the additional generation capacity at power stations. Finally, the pollutant saving can be seen in Table 11.

Table 11: CA project environmental impact reduction

Material	Weight/kWh	Unit	kg/year
CO_2	835.0	[g]	10762911
SO_2	4.9	[g]	63321
NO_x	636.0	[mg]	8198
Si	20.0	[mg]	258
Al	11.5	[mg]	148
Ca	2.0	[mg]	26
K	1.0	[mg]	13
Mg	1.0	[mg]	13
P	1.0	[mg]	13
I	0.9	[mg]	11
Fe	0.7	[mg]	9.2
Ti	0.7	[mg]	9.0
Na	0.5	[mg]	6.4
F	490.2	[µg]	6.3
Ba	230.0	[µg]	3.0
Cl	200.0	[µg]	2.6
Ge	67.5	[µg]	0.9
B	62.0	[µg]	0.8
V	61.5	[µg]	0.8
Zn	55.0	[µg]	0.7
Mn	46.0	[µg]	0.6
Ni	34.5	[µg]	0.4
Cr	25.5	[µg]	0.3
Pb	18.5	[µg]	0.2
As	18.0	[µg]	0.2
Cu	16.0	[µg]	0.2
Co	9.5	[µg]	0.1
Mo	7.5	[µg]	0.1
Sn	4.5	[µg]	0.1
Te	3.5	[µg]	0.05
Br	3.0	[µg]	0.04
U	2.5	[µg]	0.03
Be	2.0	[µg]	0.03
W	1.6	[µg]	0.02
Cd	0.5	[µg]	0.01
Hg	0.1	[µg]	0.001

Consideration must be given to the underground temperatures of the air as a result of the CA project. These temperatures can be affected by the reduced BAC flow. This is discussed in Appendix A.

3.8.Conclusion

It is evident from the water reticulation projects proposed in this chapter that significant potential exists to reduce the water pollution and electricity consumption of the mining industry. The savings simulations were effective at predicting the end performance of the projects. It was shown that it is feasible to implement the electricity-reduction projects as environmental impact reduction projects.

The pumping project reduced the electricity consumption during the peak periods. This is not expected to reduce air pollution. However this study explained how even load shift projects have an air pollution-reduction benefit.

The WSO project reduced electricity consumption by reducing pump requirements. It also greatly reduced the amount of water that needs to be circulated in a gold mine. This reduces air and water pollution by the mine.

The CA project reduced the electricity requirement to cool water significantly. The reduction was done by reducing pumping costs and overall system efficiency. This has air pollution-reduction advantages on the electricity supply side.

It must now be shown how these projects can be effectively implemented on other sites. This will be done by the utilisation of a novel sustainability framework. With these projects identified and understood, operational indicators that can aid in project identification can be specified.

It is now necessary to asses these projects in an integrated manner to assess their financial feasibility. This must include electricity- and environmental impact reduction payback periods as these projects aim to reduce both. This is discussed in chapter 5.

4. Alternative projects

This chapter discusses the implementation of electricity-generation projects and compressed air projects. Together with the water reticulation project (discussed in the previous chapter), these projects make up the six projects included in the project database. The remaining three projects are implemented on mines to determine the environmental and electricity-savings that can be achieved.

4.1.Introduction

In this chapter different electricity-generation projects utilising the available energy in gold mines will be investigated. These relate to the potential energy in the water sent down the shaft and methane gas extracted from the mine. These energy sources can be used to minimise the production of carbon dioxide and other gasses.

A compressed air project for gold mines is also discussed to determine what savings can be achieved on these networks. These projects make up the final three projects that are analysed in the sustainability framework.

4.2.Turbine project

Savings strategy

In deep-level gold mines, a static water head of 1 km is not uncommon. In the chill water supply columns this pressure is redundant and can be utilised. The static head in these pipes can cause pressure build-ups of more than 10 MPa. This is especially true for mines using hydro-mining.

To reduce these pressures to acceptable levels, mines use dissipater valves to create safe working conditions. These are a series of valves that cause large pressure drops while ensuring the pressure drop over the individual valves is not high enough to cause cavitation.

These valves reduce the area the water can flow through and regulate the pressure to half of the original pressure. Alternatively the water is fed into a dam to reduce the pressure to atmospheric pressure. The latter is the better option as water hammer is detrimental to the dissipater valves.

This setup creates potential for installing water turbines to reduce the pressure instead of dissipating it (Vosloo *et al.*, 2011). The turbines that are installed in these applications are Pelton-wheel turbines. Pelton-wheel turbines are chosen because they are more rugged than the alternative Francis and Kaplan turbines. Francis and Kaplan turbines can be damaged easily by any particles in the water and since the water in mines is re-used and potentially contains many particles, this can result in significant maintenance costs.

Pelton-wheel turbines are essentially a series of buckets that rotate around a central axis. The water is directed to spray into the centre of each bucket pair as it passes the nozzle. The water jet is split between the two buckets.

The buckets are designed to reverse the direction of the water by 180°. This allows all of the energy in the water to be transferred to the buckets to make the turbine as effective as possible. The effectiveness of the Pelton-wheel turbine can be adjusted by changing the position it sprays on the bucket. A representation of a Pelton-wheel turbine can be seen in Figure 41.

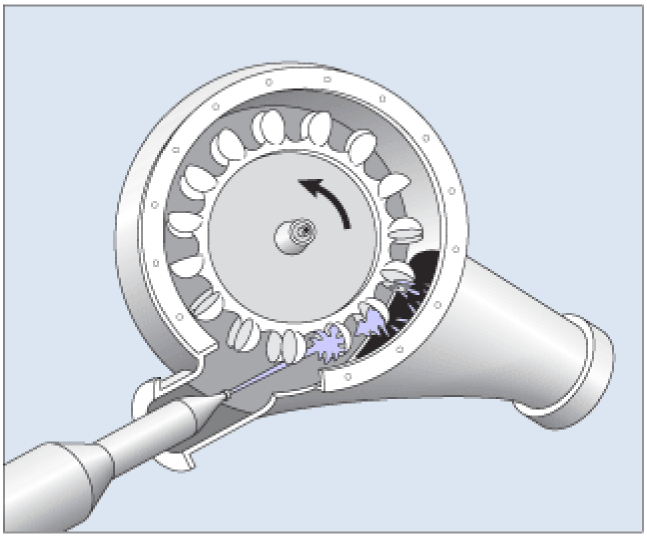


Figure 41: Pelton-wheel turbine

These turbines are connected to a generator or to a pump that is used to pump hot water that has already been used to the surface. This lowers the amount of electricity used and although it is technically co-generation, it produces an electricity-saving.

These turbines are not manufactured in South Africa and have to be imported. Delivery times on them can be up to one year which can prolong the project's schedule significantly. It also makes maintenance on these turbines difficult, and it is advised that a full set of spares is always available.

Recently the Pump as Turbine (PAT) technology was developed. A pump transfers energy to water to increase the pressure and therefore induces flow. A turbine uses pressure build-up and converts it to energy. So in essence a pump and a turbine have the exact opposite effect.

With the PAT technology, a pump is connected in such way as to perform the reverse operation - the function of a turbine (Singh & Nestmann, 2010; Ramos & Borga, 1999).

This saves on equipment costs for implementing turbines in the mining industry. More importantly, because there are no suppliers of Pelton-wheel turbines in South African mining industry, it reduces the lead time on equipment installations. It also ensures that spares are readily available.

A long lead time on spares greatly increases the risk of implementing turbines. A risk the PAT technology mitigates. The average efficiency of PATs tested by Singh & Nestmann (2010) is 75.3%. This is by installing pumps with an average efficiency of 78.4%. Three pipe systems can also be utilised to convert this potential energy to electric energy. This technology is discussed in Appendix E.

Simulated saving

The turbine project should typically follow the WSO project. With the flow reduction of the WSO project, smaller turbines can be used. This will reduce the installation cost. Because of the disadvantages of the three pipe system (discussed in Appendix E) and the similarity between the turbine and three pipe systems, only the turbine project implementation will be discussed here.

To investigate the potential electricity generation by turbines, Mine A was again studied. The water on Mine A is only used on the levels below level 84. This is approximately 2.7 km below the surface of the mine. As a result, the mine can convert this potential energy into electricity using Pelton-wheel turbines.

The chill water supply system consists of three pipe columns in series, each feeding a storage dam. The static head of the three pipes is respectively 1372 m, 915 m and 426 m. These pipes consecutively feed the dams on level 45, level 70 and level 84. A layout of the cascading dams can be seen in Figure 42.

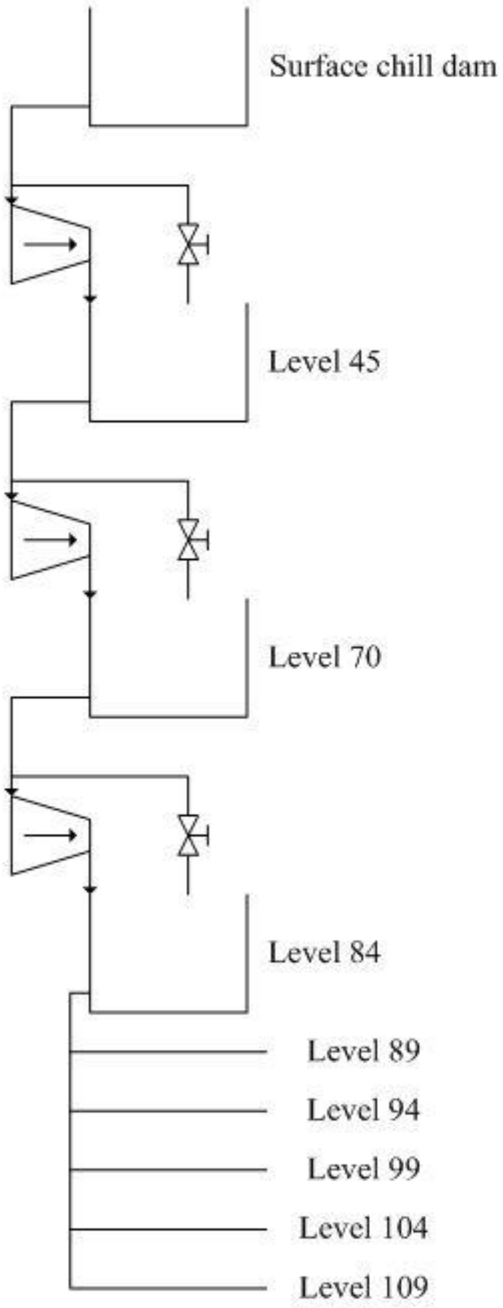


Figure 42: Mine A water supply layout

At the end of each section, a turbine can be installed to enable electricity generation at the point of highest pressure. Each of these turbines is equipped with a dissipater valve that allows it to bypass some of the flow if the maximum rated flow of the turbine is exceeded. The valves used as dissipater valves for the turbines must be able to handle significant pressures. These valves are discussed in Appendix B. The maximum flow of the turbines in this installation is respectively 448 l/s, 475 l/s and 480 l/s. The average flow profile through the turbines can be seen in Table 12.

Table 12: Average water flow sent down Mine A

Time	Average Flow [l/s]
0	413
1	444
2	442
3	433
4	414
5	393
6	378
7	381
8	432
9	458
10	460
11	448
12	435
13	387
14	355
15	328
16	304
17	291
18	280
19	305
20	321
21	333
22	349
23	370

From this profile it is evident that the average flow is below the maximum of the turbines on levels 70 and 84. However during the drilling, the absolute flow becomes higher than the rated maximum for the turbine on level 45 and some of the flow must then be bypassed.

A simulation was done to determine what the possible power generation could be with this strategy. The electricity generated by the turbines would be utilised to reduce the pumping electricity usage. The power generated by the turbines and the power usage profile of the pumps can be seen in Figure 43. For the turbine project simulation the following assumptions were made:

- The turbine efficiency is 82%.
- The pump efficiency is 65%.

- The turbine project was implemented after the WSO project.
- The flow going down the shaft at any given time is the average flow of the previous 24 hours.
- The cascading dams are refilled as soon as they are emptied to maintain the levels at 80%.
- January 2012 is used as a representation of the typical water usage by Mine A. It is necessary to simulate the power generation during January 2012 as this is the period in which the actual project savings were monitored.

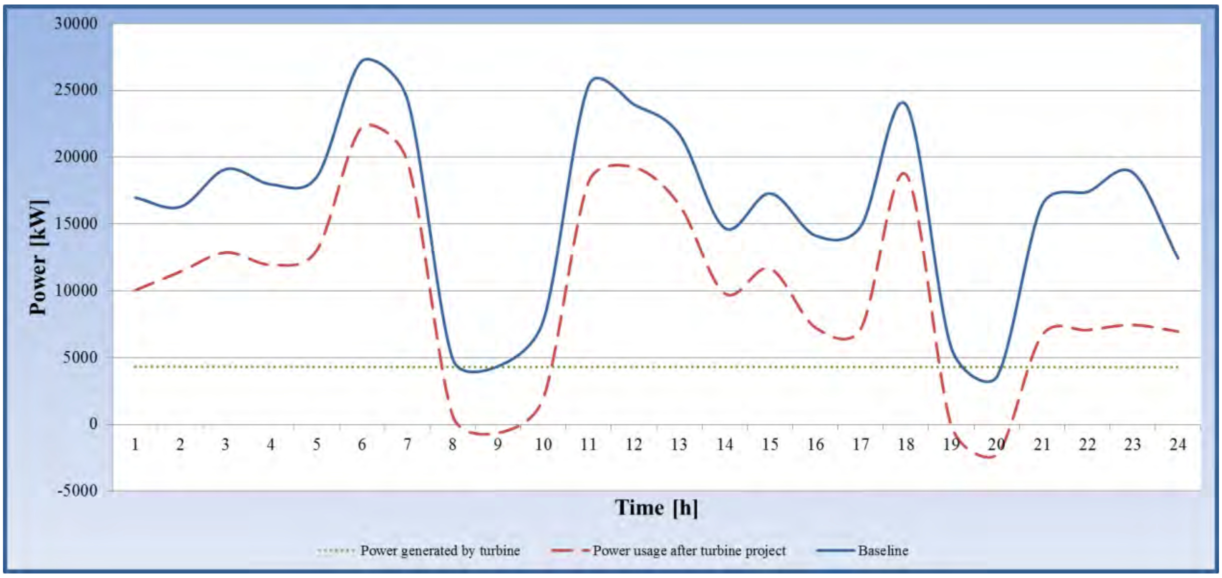


Figure 43: Power profile of the pumping system with turbines installed and the power generated by the turbine

In Figure 43 it can be seen that the average power usage of the pumps is drastically lowered throughout the day. The average electricity usage is 9.89 MW, which is a saving of 4.3 MW. This is 30.3% of the electricity used when compared to the electricity usage after the WSO project installation.

It is evident that significant savings can be realised using water turbine power generation in the main water supply column. This will ensure that the mine can regain the capital spent to implement this expensive project.

4.3. Turbine results and interpretation

Verification of simulated savings

From the simulation, it was evident that the turbine project savings can be substantial. It was predicted that these projects can generate up to 30.3% of the electricity consumed by the pumping system to extract the water from the mine. It should be noted that the fissure water that needs to be extracted additionally was not considered in the simulation.

This does however not affect the savings but only total electricity used to extract the water from underground. The project was implemented on Mine A and can therefore be compared on an absolute electricity-saving basis. With these restrictions in mind the savings can be seen in Figure 44.

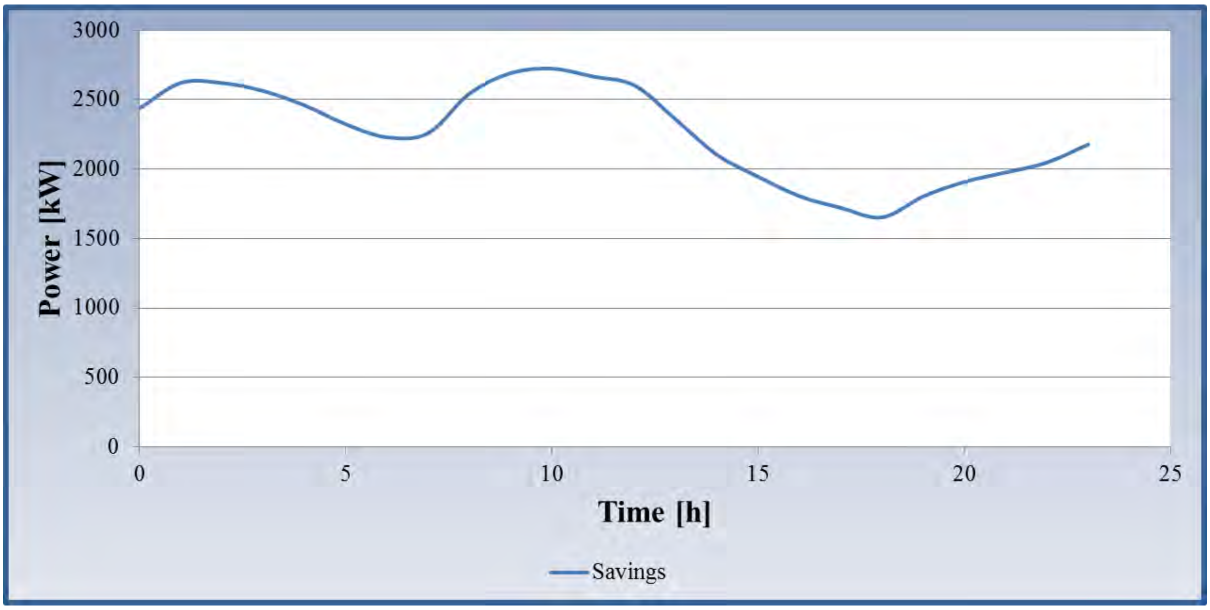


Figure 44: Mine A turbine-generated power

From the profile in Figure 44 it is evident that electricity is generated at the same rate the water is used by the mine. The control strategy is to replenish the water used immediately to maintain the cold water supply dam levels.

The average actual electricity generation by the turbines is 2.26 MW. This is significantly lower than the amount of electricity that can theoretically be generated – originally determined to be 4.30 MW.

Interpretation of savings

The project underperformed, as the achieved saving was only 2.26 MW compared to an estimated saving of 4.30 MW. This can be attributed to the control strategy of the dissipater valves. During the analysis of the turbine project performance, the flow regularly exceeded the maximum ratings of the turbines, thus nullifying the efficiency of the turbines.

To protect the turbines, some of the flow needed to be bypassed through the dissipater valves. These dissipater valves were not automated which further hampered the savings. As a result they were opened manually by mining personnel to allow the permanent bypass of some of the water. An average of 50% of the water was bypassed on the levels, which is evident from the savings achieved.

The control philosophy should be adjusted to utilise the turbines to their full potential. An average flow for the day should be sent down continually to minimise the effect of flow spikes on the system performance. Additionally the dissipater valves should be automated to ensure that the turbines are protected against flow spikes.

This strategy will ensure that most of the water goes through the turbine, as water will only be bypassed if the average flow exceeds the turbine rated flow. This control strategy measures the flow used by the production levels and then sends down a moving average flow of the previous 24 hours. It also increases the flow during low flow periods. Since the Eskom evening peak period is a low water-usage period, this strategy is very effective.

The moving average strategy will ensure higher water flow going down the shaft during the Eskom electricity usage peaks. As a result, the same electricity is generated during the Eskom peak times as the rest of the day. In this way 81.6% of the potential energy in the water can be extracted. This is compared to typical efficiencies of 60% (Vosloo *et al*., 2011).

The main concern with regulating the flow in this manner is the dam levels. It is evident from the flow control strategy that the water in the cold water supply dams is not replenished at the same rate it is used. For this reason it is necessary to simulate the dam levels which can be seen in Figure 45. The cold water dam capacities on level 45, level 70 and level 84 are 2.2 Ml.

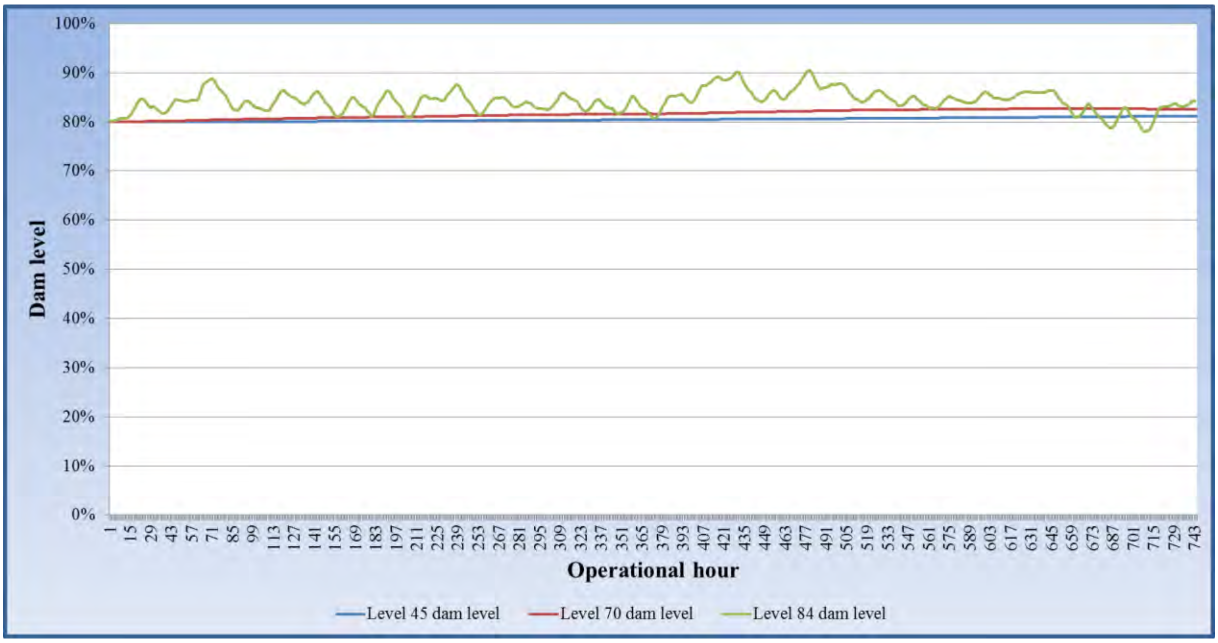


Figure 45: Simulated dam levels with turbine flow control strategy

From the simulation in Figure 45 it can be seen that this flow control strategy is viable and the dam levels remain within a 10% margin of the desired level of 80%, irrespective of the flow requirement.

The turbines at Mine A did not need to be installed, they were only refurbished. The total cost for the project was R6.41 million. The project assessment was done in 2012 and to compare the cost saving to the implementation cost, the electricity tariff of 2012 must be used.

The cost savings associated with this project installation is R7.60 million in 2012. At an implementation cost of R6.41 million, the payback period for this project will be 10 months. It should be noted that the ESCO installing this project also makes a profit that will increase the cost of the project and negatively affect the payback period. The Benchmark funding from Eskom is R5.25 million/MW. With a project saving of 2.26 MW the funding that could have been used for the project implementation is R11.87 million.

In conclusion, this project saves the client R7.60 million/annum. The project cost Eskom R2.80 million/MW (excluding ESCO profit) in comparison to the R20 million it would have cost them to install the generation capacity. The pollutant saving can be seen in Table 13.

Table 13: Turbine project environmental impact reduction

Material	Weight/kWh	Unit	kg/year
CO_2	835.0	[g]	12016843
SO_2	4.9	[g]	70698
NOx	636.0	[mg]	9153
Si	20.0	[mg]	288
Al	11.5	[mg]	166
Ca	2.0	[mg]	28.8
K	1.0	[mg]	14.4
Mg	1.0	[mg]	14.4
P	1.0	[mg]	14.4
I	0.9	[mg]	12.3
Fe	0.7	[mg]	10.2
Ti	0.7	[mg]	10.1
Na	0.5	[mg]	7.2
F	490.2	[µg]	7.1
Ba	230.0	[µg]	3.3
Cl	200.0	[µg]	2.9
Ge	67.5	[µg]	1.0
B	62.0	[µg]	0.9
V	61.5	[µg]	0.9
Zn	55.0	[µg]	0.8
Mn	46.0	[µg]	0.7
Ni	34.5	[µg]	0.5
Cr	25.5	[µg]	0.4
Pb	18.5	[µg]	0.3
As	18.0	[µg]	0.3
Cu	16.0	[µg]	0.2
Co	9.5	[µg]	0.1
Mo	7.5	[µg]	0.11
Sn	4.5	[µg]	0.06
Te	3.5	[µg]	0.05
Br	3.0	[µg]	0.04
U	2.5	[µg]	0.04
Be	2.0	[µg]	0.03
W	1.6	[µg]	0.02
Cd	0.5	[µg]	0.01
Hg	0.1	[µg]	0.001

4.4.Methane power-generation project

Savings strategy

Flammable gasses are a serious concern in deep-level gold mines. The ventilation is not always monitored to ensure that sufficient airflow is present throughout the mine. Sections of the mine that have been closed after all the gold was extracted cause serious safety concerns. When these gasses are present in the right concentrations, huge explosions can occur.

Relying on the fact that compressed air is used underground as an alternative to the more dangerous use of electricity, is not a sufficient preventative measure. This is evident from the two large methane explosions at an alternative mine, Mine C, that killed 19 people, bringing the total methane-related deaths at Mine C to 40 (Creamer, 2013). Alternative methods of dealing with flammable gasses, especially methane gas, are required. This chapter will investigate a feasible method of mitigating this effect.

As stated earlier, the flammable concentration of methane gas is between 5% and 15%. This is the concentration needed to burn methane gas in order to generate heat for power generation – methane is a clean-burning gas that is suitable for power generation (Karacan *et al.*, 2011).

Ideally, methane will be burned in a combustion chamber, heating water to superheated vapour that is capable of powering a turbine. This is a similar process to coal fired power stations, but on a smaller scale. The gasses produced by the burning process can also power a turbine directly.

In the gold mining industry, the concentrations are too low to sustain a flame and specialised technologies are required to be able to utilise methane for power generation. The concentration of methane gas can be improved by the removal of oxygen, carbon dioxide and water vapour. This is an expensive process and only necessary if the power station is off site and the methane needs to be condensed in order to save on transportation costs. (Karacan *et al.,* 2011).

In deep-level gold mines, lean-burn gas turbines are an alternative option but the methane concentration in gold mine ventilation air is still too low. A suitable technology is to use the ventilation air from gold mines as supply air to internal combustion engines or turbines (Karacan *et al*., 2011). In Figure 46 an example of such an engine can be seen.

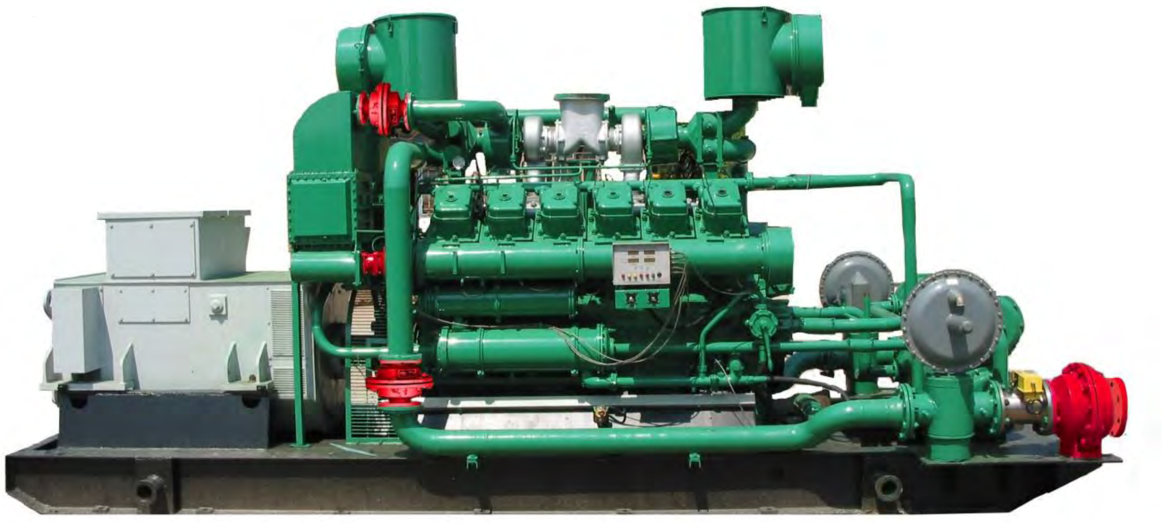


Figure 46: Methane internal combustion engine with generator.

Simulated saving

Using the heat of combustion, the theoretic electricity generation of methane can be determined. From Table 4 it was seen that the heat of combustion for methane is 55.5 MJ/kg. The methane production of mines is measured in l/s and the electricity-generation capacity of methane can then be calculated as 36.38 kW/l.s^{-1}.

The total amount of available methane gas at this mine is 1600 l/s (ESI-Africa, 2013) of which the mine expected to extract 400 l/s (Beatrix West Mine, 2006). This means that the theoretic energy that is released during the combustion of the available methane is 14.55 MW. As internal combustion engines range in efficiency from 25% to 30%, if we assume that the engine has an average efficiency of 27.5%, the kinetic energy that can be extracted from the methane is approximately 4 MW.

4.5.Methane power results and interpretation

Verification of simulated savings

A methane power plant was constructed at Mine C gold mine. Three high methane production pockets were identified and piping was installed to extract the methane from the source. These sources are approximately 860 m underground (Van Greuning, 2011).

The methane recovered is of a concentration between 82% and 90%. Part of the mine where production has seized is used as storage for the methane. These sections are sealed off and the methane is pumped to surface using two methane blowers when it is required for power generation. The pipes are monitored for pressure drops to ensure leakages do not occur. Shut off valves and flame arrestors ensure that the system operates safely (Van Greuning, 2011). The methane is then flared in a burner shown in Figure 47.

Figure 47: Methane burner at Mine C

This methane burner was step one of the project implementation and does not generate electricity using the methane, but rather flares the methane gas. This was used as a means of disposing of excess methane gas. The carbon dioxide produced by the burning process is less damaging than the original methane gas (Methane gas has 20 times the heat retention of carbon dioxide, an important factor in the effect of greenhouse gasses on global warming).

The next phase in this project was to install internal combustion engines that utilise the methane for power generation. Flaring is only used in extreme cases of methane oversupply.

The waste heat generated by the internal combustion engines is used in an absorption cooling plant (Beatrix West Mine, 2006).

The internal combustion engines each have a generation capacity of 1.35 MW (Beatrix West Mine, 2006). The mine can therefore generate 2.7 MW when the internal combustion engines are running at full capacity. The power generated in this way supplies 2.4% of Mine C's electricity. It is suggested that the capacity will be doubled to 4.8% of the mine's electricity needs. Electricity is generated at a cost of 37.44 c/kWh, 33% cheaper than the Eskom tariff which is expected to increase even further (Creamer, 2013).

The power generation during the assessment period was however only 1 MW. The methane production by the mine was decreased by 28% due to the methane flaring. Presently the methane recovery and flaring has required an investment of R42 million, but this will be covered by the expected R 200 million that will be received in carbon credits (Creamer, 2013).

The generators stationed on the mine were installed by an external company at a cost of R25 million (Du Plessis, 2013). The total cost associated with this project was R67 million. Mine C pays the company a reduced premium for the electricity generated by their internal combustion engines. These internal combustion engines are expected to generate electricity-savings of R1.20 million per year (Creamer, 2013). The methane generators can be seen in Figure 48.

Figure 48: Generator set at Mine C gold mine (Creamer, 2013)

Interpretation of savings

The methane recovery and power-generation project underperformed significantly. This can be attributed to the quality of the methane recovered and inefficiencies in the methane collection process. The performance of this project will however increase as the methane concentration in the mining section used as a reservoir will increase over time.

The savings of the Mine C methane recovery project were realised from May 2013 and the electricity tariff of the corresponding year was used to analyse the savings. The savings associated with this project installation is R3.20 million/annum. At a cost of R67 million, the payback period for this project will be 20.54 years. With optimal operation and capacity expansion, this payback period is expected to decrease.

The Benchmark funding from Eskom is R5.25 million/MW. With a project saving of 1 MW, the funding that could have been used for the project implementation is R5.25 million. This project is not feasible from the ESCO’s point of view as the funding available is much less than the project capital. This project was only feasible by involving a third party to supply the generators for free.

In conclusion, this project saves the client R3.3 million/annum and the pollutant saving can be seen in Table 14. It reduces the carbon dioxide produced by power stations but produces carbon dioxide by burning methane. In this table, the carbon dioxide-reduction is the carbon dioxide-reduction equivalent of the methane reduction.

Table 14: Methane power generation environmental impact reduction

Material	Weight/kWh	Unit	kg/year
CO_2	835.0	[g]	104494286
SO_2	4.9	[g]	30738
NOx	636.0	[mg]	3980
Si	20.0	[mg]	125
Al	11.5	[mg]	72.0
Ca	2.0	[mg]	12.5
K	1.0	[mg]	6.3
Mg	1.0	[mg]	6.3
P	1.0	[mg]	6.3
I	0.9	[mg]	5.3
Fe	0.7	[mg]	4.4
Ti	0.7	[mg]	4.4
Na	0.5	[mg]	3.1
F	490.2	[µg]	3.1
Ba	230.0	[µg]	1.4
Cl	200.0	[µg]	1.3
Ge	67.5	[µg]	0.4
B	62.0	[µg]	0.4
V	61.5	[µg]	0.4
Zn	55.0	[µg]	0.3
Mn	46.0	[µg]	0.3
Ni	34.5	[µg]	0.2
Cr	25.5	[µg]	0.2
Pb	18.5	[µg]	0.1
As	18.0	[µg]	0.1
Cu	16.0	[µg]	0.1
Co	9.5	[µg]	0.06
Mo	7.5	[µg]	0.05
Sn	4.5	[µg]	0.03
Te	3.5	[µg]	0.02
Br	3.0	[µg]	0.02
U	2.5	[µg]	0.02
Be	2.0	[µg]	0.01
W	1.6	[µg]	0.01
Cd	0.5	[µg]	0.003
Hg	0.1	[µg]	0.001

It is clear that this project does not have significant electricity-reduction advantages. It does however reduce the methane expelled from the mine significantly. This reduces the amount of greenhouse gasses produced by the mine. Carbon dioxide can also be converted to methane, which can be used as energy storage (Sato *et al.*, 2013). This energy storage is discussed in Appendix C.

4.6.Optimisation of Air Networks (OAN) project

Savings strategy

The very first electricity-reduction measure that should be implemented is to fix the air leaks. These leaks can account for the loss of between 10% and 30% of the total compressed air produced (Efficiency, Energy, and Renewable Energy, 2004).

As with water usage, the air requirement throughout the day varies significantly. During the drilling shift, large amounts of air are used in conjunction with the high water usage. The air powers the drill while the water cools the drill for effective operation. Typically the compressed air pressure required by the drills is 550 kPa.

During the blasting shift, the pressure requirement is reduced. Loading boxes have 400 kPa as the highest required pressure. Even if the loading boxes are not in the process of loading rock into hoppers, they still require this pressure to remain closed. Additionally the refuge chambers should be supplied with air at all times to ensure the safety of workers, but this air pressure requirement is only 200 kPa (Marais, 2012; Schroeder, 2009). During the sweeping shift, the rock loaders are the main air consumers and require 450 kPa.

Typically the most compressed air is consumed during the drilling shift, while the sweeping shift and blasting shift consumes less air (Marais, 2012; Schroeder, 2009). A typical air consumption and pressure profile can be seen in Figure 49. The blue area represents the sweeping shift, the green area the drilling shift and the yellow area the blasting shift.

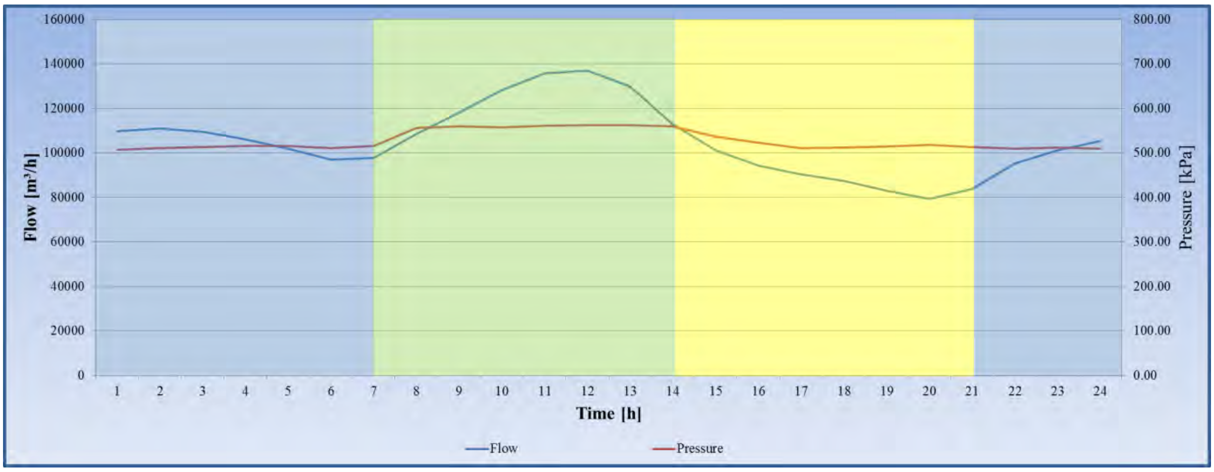


Figure 49: Typical air flow and pressure required by a shaft

From Figure 49 it is evident that the flow requirement during the drilling shift is significantly higher than the flow requirement during the other periods of the day. It can also be seen that the supplied pressure is significantly higher than the minimum required pressure during the blasting shift. The required pressure during the drilling shift is only 400 kPa but a pressure of higher than 500 kPa is supplied.

Theoretically only the refuge chambers consume air during the blasting shift. The drills should not consume air during the blasting shift and the pressure for the loading boxes is only to keep them shut, which does not consume high volumes of air. However the air to the drills is not shut off and large air leaks occur in the piping system. To reduce the air escaping to the atmosphere through these leaks, it is necessary to reduce the pressure supply to the shaft. This can be done by reducing the number of compressors supplying the mine with air (Marais, 2012; Schroeder, 2009).

This strategy alone is usually not enough. These compressors consume in excess of 4 MW of electricity and if one is switched off, the pressure drops too radically. To allow a compressor to be switched off, it is necessary to reduce the total air flow to the mine as well. The simplified correlation between the flow, pressure and power was seen in Equation [1.1]. From this equation it was evident that a reduced pressure supply to the mine levels results in the reduction of flow and power consumption.

To reduce the air flow, valves are installed on the individual levels as well as the main air supply line (if the shaft is part of an air network). This enables a reduction in flow such that some of the compressors can be switched off and the pressure reduced. A typical installation of an optimisation of air networks (OAN) project on a simplified mine air network can be seen in Figure 50.

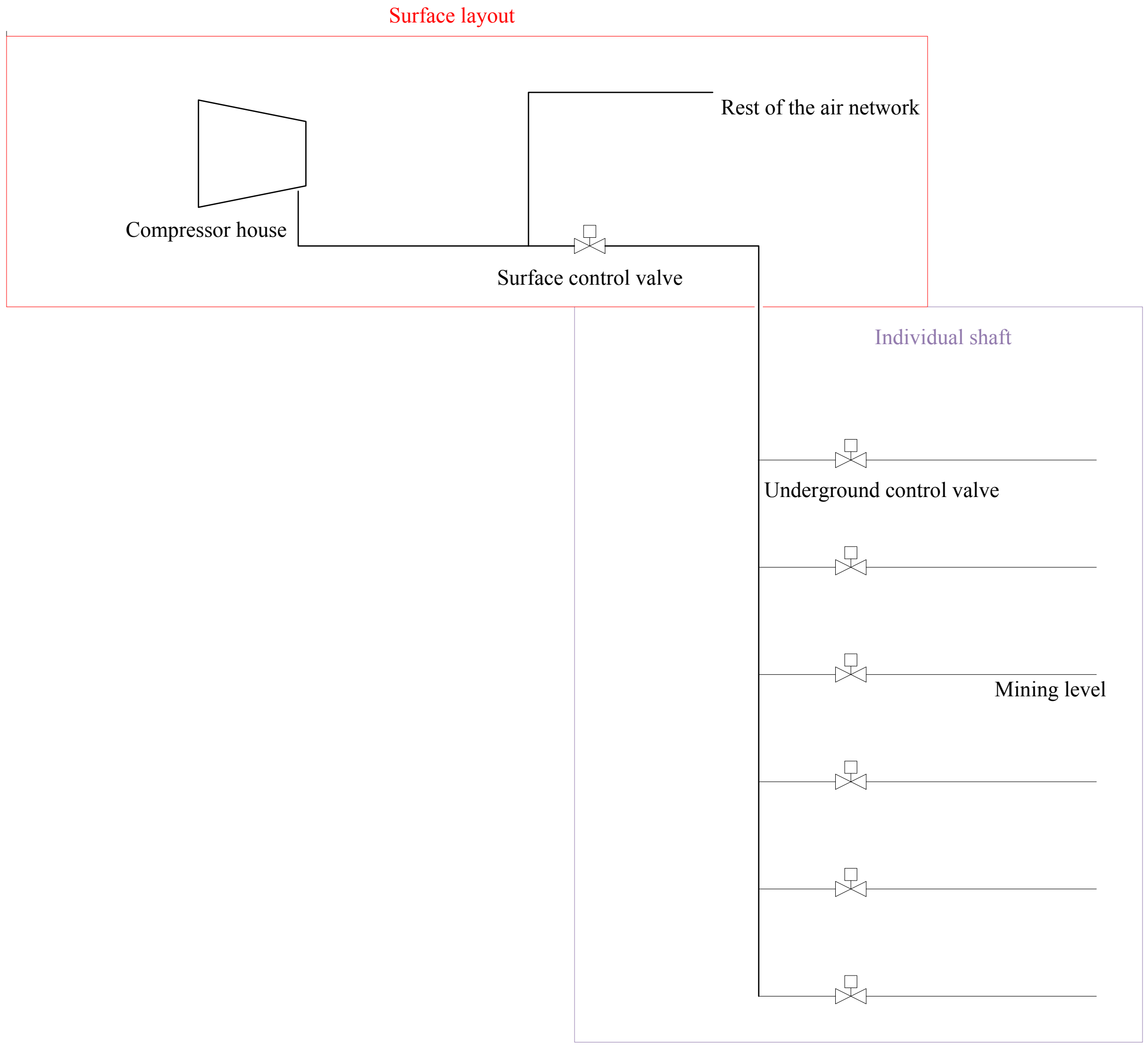


Figure 50: Typical OAN installation

Multiple compressors can be present inside a compressor house and more than one compressor house can be found on a single air network. Installation of a surface control valve ensures that the required pressure is achieved on the mine surface. As the air descends into the mine, auto-compression causes the pressure to increase.

The surface friction of the pipe on the other hand decreases the pressure. During high flow periods, this effect is increased. Equation [4.1] and [4.2] (Venter, 2012) show the effect of auto-compression and pipe friction (Darcy-Weisbach equation combined with pipe loss equation) respectively.

$$\Delta p = \rho g \Delta H \quad [4.1]$$

Where,

Δp = The pressure increase of the air [Pa]

ρ = The density of the air [kg/m^3]

g = Gravitation [m/s^2]

ΔH = The height difference between the surface and the specific level [m]

$$\Delta p = (\frac{fl}{d} + K_l)\frac{\rho v^2}{2} \quad [4.2]$$

Where,

Δp = The pressure decrease of the air [Pa]

f = The Darcy-Weisbach friction coefficient [no unit]

l = The length of the pipe [m]

d = The hydraulic diameter of the pipe [m]

K_l = The friction loss factor associated with pipe geometry [no unit]

ρ = The density of the air [kg/m^3]

v = The velocity of the air [m/s]

From Equation [4.1] it is evident that the pressure increase is dependent on the height difference and that the auto-compression between the levels will differ. From Equation [4.2] it can be seen that the pressure loss due to friction is dependent on the length and diameter of the pipes, the pipe layout and the speed of the air (Joubert, 2010). If the size of pipeline down the shaft has been chosen correctly, the effect of auto-compression will be larger than the pressure loss due to friction and pipe geometry.

Simulated saving

To determine the flow reduction that can be achieved, it is firstly necessary to investigate the underground air layout of Mine A. This can be seen in Figure 51.

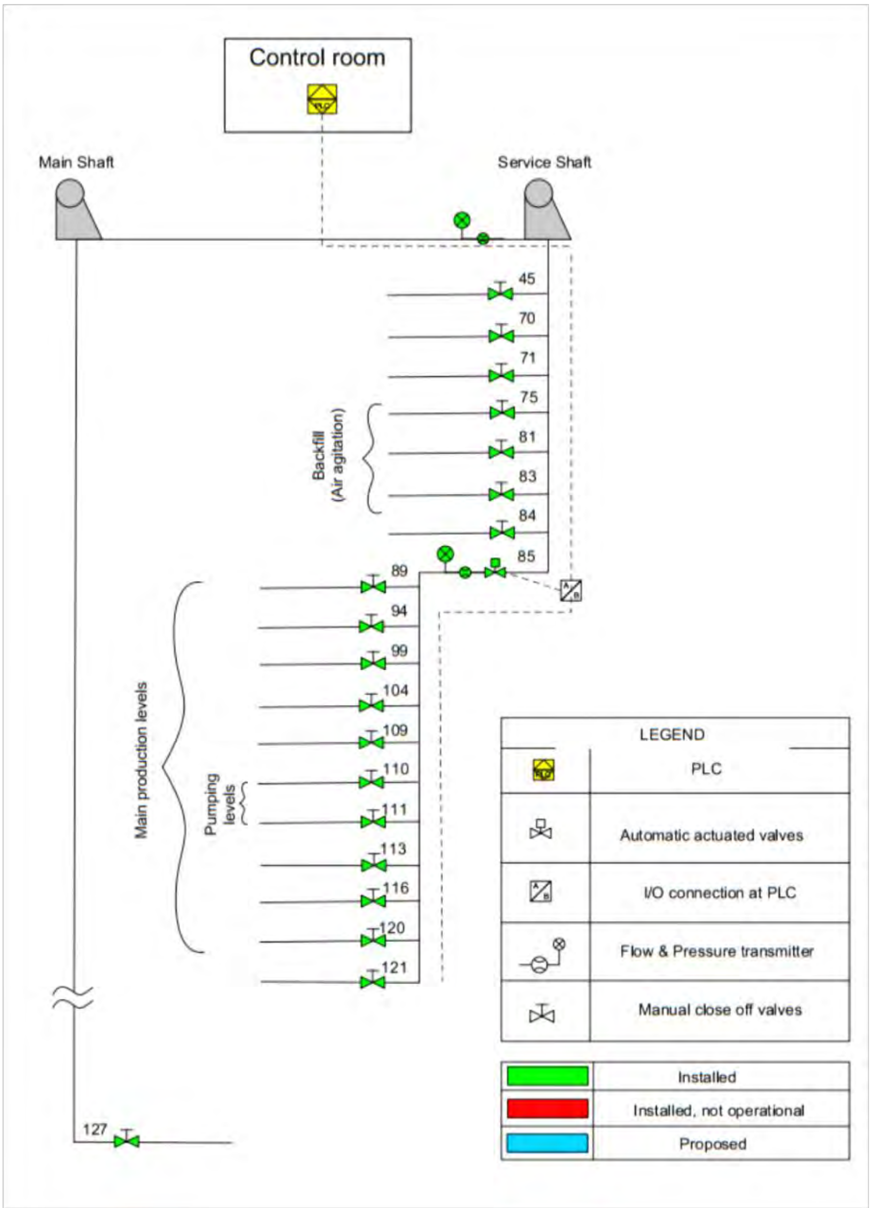


Figure 51: Mine A air network layout

From Figure 51 it is evident that the main production levels only start at level 89. As a result these levels will consume significantly more air than the other levels. There were valves installed on the levels before the implementation of the project, but these had to be controlled manually. There is however a control valve installed on the main line that throttles the flow to the production levels. It will be necessary to determine the ideal pressure set-point for each of these valves. This pressure increase from surface to level 85 can be seen in Figure 52.

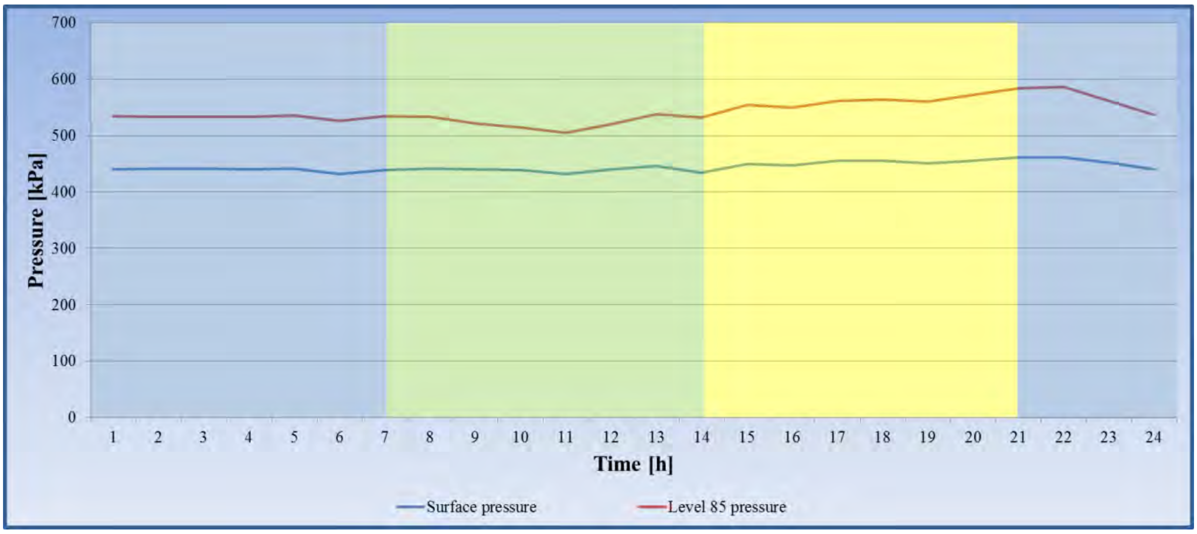


Figure 52: Mine A pressure profile

From Figure 52 the auto-compression created by the depth of the mine can be seen. The auto-compression varies throughout the day, with the pressure increase high in the blasting period (shown in yellow) and less during the drilling period (shown in green). This variance can be explained by the increased friction during the high flow periods and the decreased friction during the low flow periods.

The average auto-compression created by the height differential during peak periods is 110.1 kPa. It is known that the required pressure at the drilling levels (that start at level 89) is 400 kPa. Therefore the pressure requirement on surface is theoretically 110.1 kPa below 400 kPa, which is 289.9 kPa. This means that the shaft pressure and consequently the shaft flow can be significantly reduced as the pressure is currently 453.3 kPa.

To determine the savings, it is necessary to measure the baseline flow. The project installation finished on 15 February 2011 and the baseline data was drawn for the period preceding this date. The baseline flow from 15 December 2010 to 15 February 2011 can be seen in Figure 53.

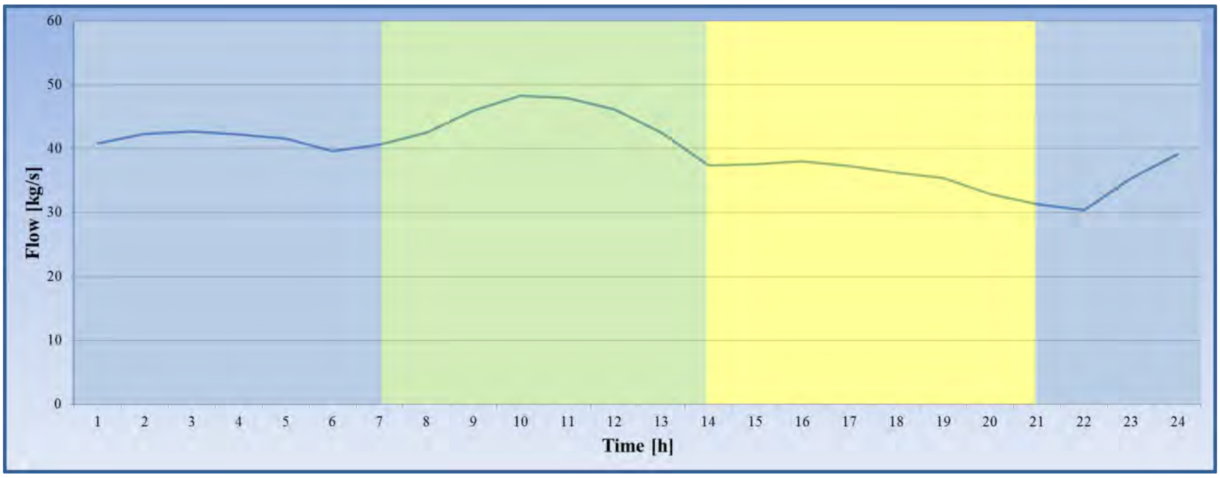


Figure 53: Mine A baseline airflow

From Figure 53 it can be seen that Mine A has a typical air usage profile with a reduced flow during the blasting period. It is now necessary to determine the flow reduction after the pressure has been lowered to the required pressure. For determining this reduced flow, a simplified simulation is done using the KYPipe 2010 airflow software. Equation [1.1] can then be used in conjunction with this simulation to determine the savings.

The average pressure of the shaft during the blasting shift is 453.3 kPa and the air flow is 35.5 kg/s. This can be simulated using the KYPipe software which is shown in Figure 54. The supply pressure is simulated as an endless reservoir at the required pressure. The outlet is simulated as a reservoir at atmospheric conditions. The shaft and all other air restrictions are simulated as a valve that restricts the flow. By lowering the supply pressure to the value of 289.9 kPa a theoretic flow reduction can be determined. This reduced flow is shown in Figure 55.

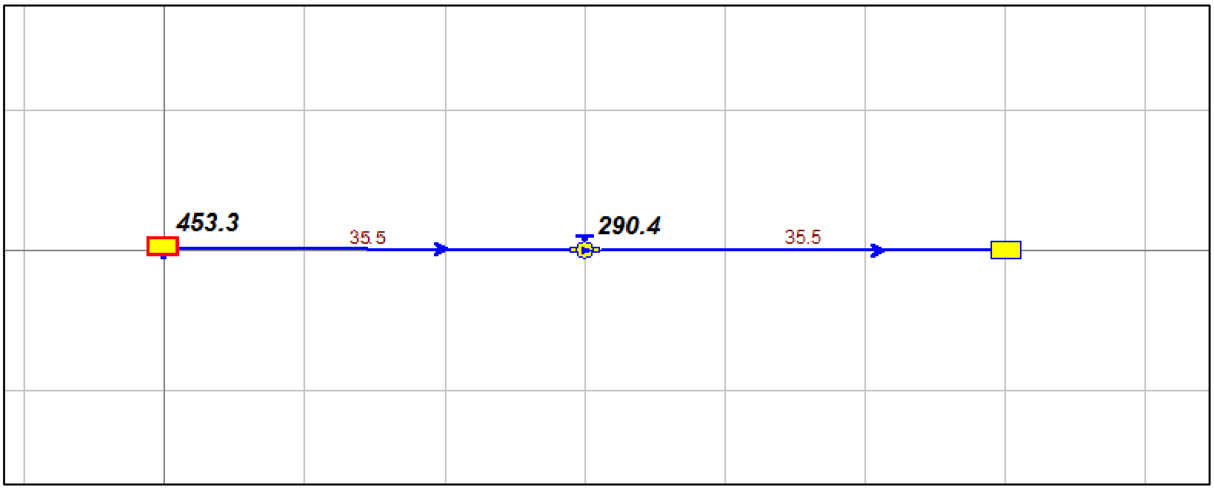


Figure 54: OAN Baseline simulation
The flow is measured in kg/s while the pressure is specified in kPa.

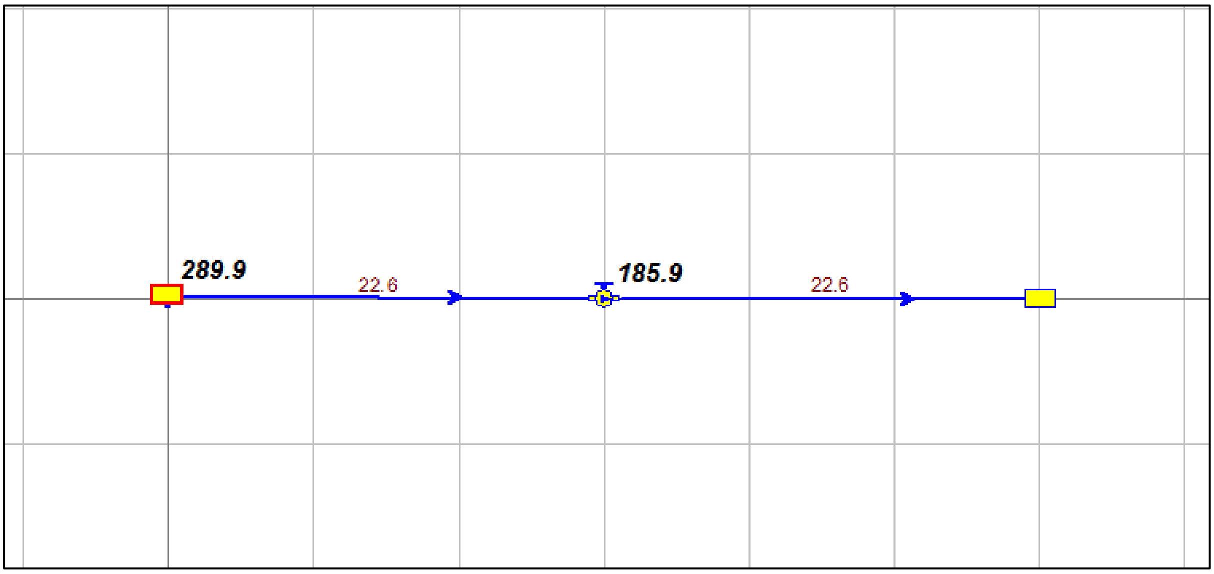


Figure 55: Reduced flow simulation
The flow is measured in kg/s while the pressure is specified in kPa.

From the simulation in Figure 55 it is evident that by reducing the pressure supply to the system the flow will be reduced to 22.6 kg/s. The theoretical savings can then be determined using Equation [1.1] as shown below:

$$Saving = \dot{m}_b c_p T_{in}\left(\left(\frac{p_{baseline}}{p_{atm}}\right)^{\frac{k-1}{k}} - 1\right)/\eta - \dot{m}_s c_p T_{in}\left(\left(\frac{p_{proposed}}{p_{atm}}\right)^{\frac{k-1}{k}} - 1\right)/\eta$$

$$\Delta P = 35.5 \text{ X } 1.005 \text{ X } 300 \text{ X } \left(\left(\frac{453.3+87}{87}\right)^{\frac{1.4-1}{1.4}} - 1\right)/0.8$$
$$- 0.8 \text{ X } 22.6 \text{ X } 1.005 \text{ X } 300 \text{ X } \left(\left(\frac{289.9+87}{87}\right)^{\frac{1.4-1}{1.4}} - 1\right)/0.8$$

$$\Delta P = 9164 - 4431.2$$

$$\Delta P = 4722.7 \text{ kW}$$

This saving is the theoretical saving that can be achieved if the pressure can be reduced to exactly 400 kPa on the first production level. This saving does not take into account the actual compressor size that can be switched off or the surface leaks. Additionally this saving cannot be achieved throughout the day, but only in the blasting shift, which constitutes a third of the day. If the saving is calculated on an hourly basis for 16 hours the savings is 1.57 MW which is 9.8% of the total power usage. The baseline power usage for this project is 16.02 MW.

4.7.OAN results and interpretation

Verification of simulated savings

The valves on each level then ensure that the output pressure of that level is correct. This allows each level to be regulated at a different pressure depending on the level's air consuming equipment. The valve control is done using a PLC on each level and is controlled to maintain a pre-set output pressure. Using this strategy allows compressors to be stopped or at least the guide vanes to be adjusted to reduce power consumption (Booysen, 2010). The installations on this project can be seen in Figure 56.

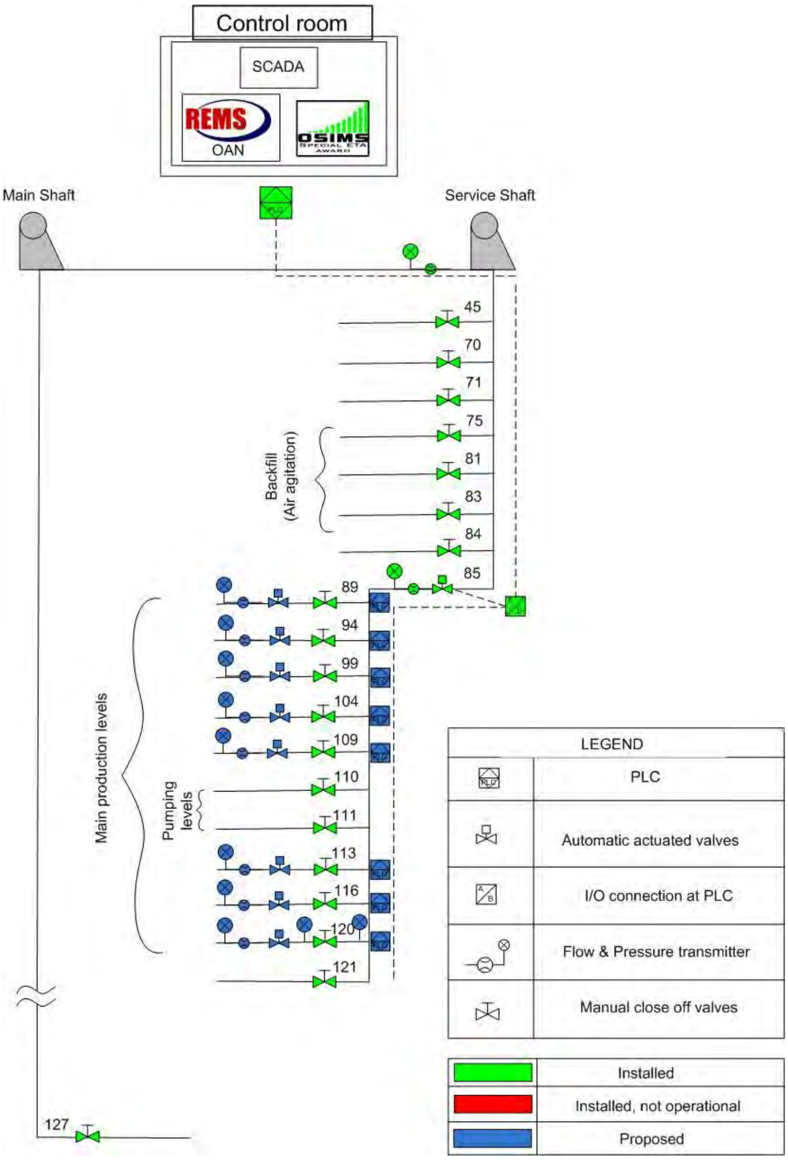


Figure 56: Mine A OAN installation

It can be seen in Figure 56 that valves were installed on each of the main production levels. At the time of project implementation, level 121 was still in the development phase. The pressure sensors were installed downstream of the valves to ensure the correct delivery pressure is supplied to each level. The valves are then controlled according to these pressure measurements.

Flow meters were also installed to quantify the flow reduction on each level. The valves were controlled using PLCs that are connected to the SCADA system through a fibre optic network. This control strategy allowed a significant reduction in flow requirements and pressure supply.

The compressor that could be stopped due to the lower pressure requirement and the associated flow reduction has a power consumption of 3.32 MW. This compressor could be stopped during most of the blasting shifts. A smaller compressor with a power consumption of 3.10 MW could be stopped on certain days during the blasting shift. The savings achieved with this project can be seen in Figure 57.

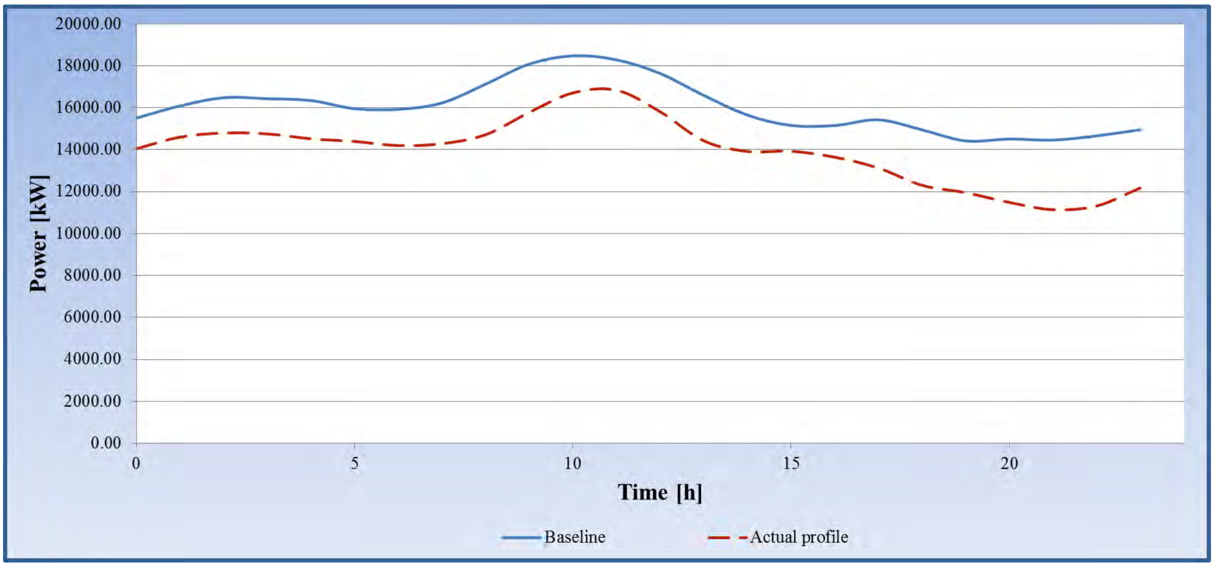


Figure 57: OAN project savings

From Figure 57 it can be seen that savings were realised throughout the day. Increased savings were achieved from 16:00 to 24:00. Savings were achieved through the drilling period because excess pressure was supplied during this period – these pneumatic drills only require 500 kPa to operate. The pressure supply to the mine was too high and could be reduced.

Pressure oversupply often happens when the mine only measures the pressure on the surface. This does not take into account that auto-compression happens while the air travels to the individual levels. Depending on the depth, flow and layout of the mine, this auto-compression can be in excess of 100 kPa.

As stated, the baseline power usage on the compressors was 16.02 MW. The savings vary from 1.86 MW in the drilling shift to 2.67 MW in the blasting shift and 1.67 MW in the sweeping shift. This is consistent with the compressors that were switched off during the project assessment period. The average savings that was achieved is 2.07 MW.

Interpretation of savings

This is higher than the simulated saving of 1.57 MW. The savings during the blasting shift were lower since the largest compressor that could be switched off was 3.32 MW. However, the overall savings were higher since it was not anticipated that savings could be achieved during the sweeping and drilling shifts as well. The total savings were 12.9% of the original baseline power consumption. This confirms that significant savings can be achieved by optimising the compressed air supply.

The total cost associated with this project was R4.15 million. The installation of the Mine A OAN project was done in 2011 and the electricity tariff of the corresponding year was used to analyse the savings.

The savings associated with this project installation is R7.25 million/annum. At a cost of R4.15 million the payback period for this project will be 209 days. It should be noted that the ESCO installing this project also makes a profit that will increase the cost and payback period. The Benchmark funding from Eskom is R5.25 million/MW. With a project saving of 2.07 MW the funding that could have been used for the project implementation is R10.87 million.

In conclusion, this project saves the client R7.25 million/annum without spending any capital. The project cost Eskom R2 million/MW (excluding ESCO profit) in comparison to the R20 million it would have cost them to install the power generation capacity. And finally, the pollutant saving can be seen in Table 15.

Table 15: Power station environmental impact reduction by OAN project on Mine A

Material	Weight/kWh	Unit	kg/year
CO_2	835.0	[g]	10815159
SO_2	4.9	[g]	63628
NOx	636.0	[mg]	8238
Si	20.0	[mg]	259
Al	11.5	[mg]	149
Ca	2.0	[mg]	26
K	1.0	[mg]	13
Mg	1.0	[mg]	13
P	1.0	[mg]	13
I	0.9	[mg]	11
Fe	0.7	[mg]	9.2
Ti	0.7	[mg]	9.1
Na	0.5	[mg]	6.5
F	490.2	[µg]	6.3
Ba	230.0	[µg]	3.0
Cl	200.0	[µg]	2.6
Ge	67.5	[µg]	0.9
B	62.0	[µg]	0.8
V	61.5	[µg]	0.8
Zn	55.0	[µg]	0.7
Mn	46.0	[µg]	0.6
Ni	34.5	[µg]	0.4
Cr	25.5	[µg]	0.3
Pb	18.5	[µg]	0.2
As	18.0	[µg]	0.2
Cu	16.0	[µg]	0.2
Co	9.5	[µg]	0.1
Mo	7.5	[µg]	0.1
Sn	4.5	[µg]	0.06
Te	3.5	[µg]	0.05
Br	3.0	[µg]	0.04
U	2.5	[µg]	0.03
Be	2.0	[µg]	0.03
W	1.6	[µg]	0.02
Cd	0.5	[µg]	0.01
Hg	0.1	[µg]	0.001

4.8. Conclusion

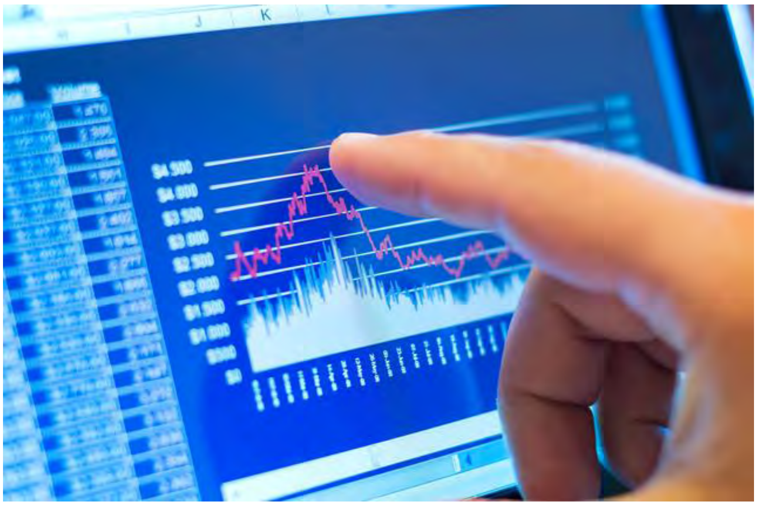
It is evident from the projects proposed in this chapter that significant potential exists to reduce the electricity consumption and air pollution of the gold mining industry. The savings simulations were effective at predicting the end performance of the projects. It was shown that it is feasible to implement the electricity-reduction projects as environmental impact reduction projects.

The turbines project has large electricity-generation implications. This reduces the electricity required from the Eskom grid. Methane burning projects have significant electricity-generation implications. In addition to the indirect air pollution-reduction created in this way, the direct air pollution of methane is reduced by a factor of 20. The compressed air project also showed how the compressed air requirements of a mine can be reduced. This reduced the electricity consumption and associated air pollution of the air network.

It must now be shown how these projects can be effectively implemented on other sites. This will be done by the utilisation of a novel sustainability framework. These six projects will form the database for the projects implemented with the sustainability framework. This can be expanded to include unlimited projects. With these projects identified and understood, operational indicators that can aid in project identification can be specified.

It is now necessary to asses these projects in an integrated manner to assess their financial feasibility. This must include electricity- and environmental impact reduction payback periods as these projects aim to reduce both.

5. Sustainability framework



In this chapter, projects are analysed based on their electricity-saving payback periods. This analysis is then expanded to integrated project analyses, enabling the guidelines for the novel sustainability framework to be specified. This chapter also investigates how the data for this framework must be acquired and what the framework looks like.

5.1.Introduction

In previous chapters, integrated electricity- and environmental impact reduction projects were specified and discussed. These projects form the basis of a project database that can be expanded and loaded to the sustainability framework. This is an implementation framework for environmental impact-reducing projects on mines.

The sustainability framework will allow the automatic identification of environmental impact -reducing projects. Understanding how these projects work also supports the identification of operational indicators that can be used to identify these projects.

In this chapter, the role of the ESCO will be discussed. The optimal project identification and implementation procedure will be specified. This chapter also analyses the specified projects in an integrated manner to determine a combined payback period. Finally the data acquisition for the project identification is specified and the sustainability framework is shown.

5.2.Outline of the mining structure

Mining operations use water and electricity among other resources. In terms of water, typical water usage includes the cooling of air to maintain desirable conditions underground and ensuring that the drills do not overheat while drilling. While 4.7% of all the water in South Africa is used in the mining industry, that industry produces 10% of all the effluent water in South Africa (Cloete *et al.*, 2010).

In terms of electricity, typical large electricity consumers on mines include compressors, pumps, refrigeration machines and gold plants. The South African mining industry consumes 13.1% of the electricity generated in South Africa (Africa, 2012). It is important to investigate how the water and air pollution reduction strategies can be integrated into a sustainability framework.

It is necessary to quantify the amount of pollution to determine whether and where these pollution-reduction projects should be implemented. For the environmental impact reduction effort, an integrated sustainability framework is proposed to measure the pollution impact of the mine.

The reports generated by the sustainability framework must be monitored by a third party (ESCO) to assess the situation and propose the necessary reduction strategies. This will allow the ESCO to make calculated decisions regarding the projects to be implemented on the specific mine. For this sustainability framework to be effective the data must be easily available and up to date. The mining system can be summarised as seen in Figure 58.

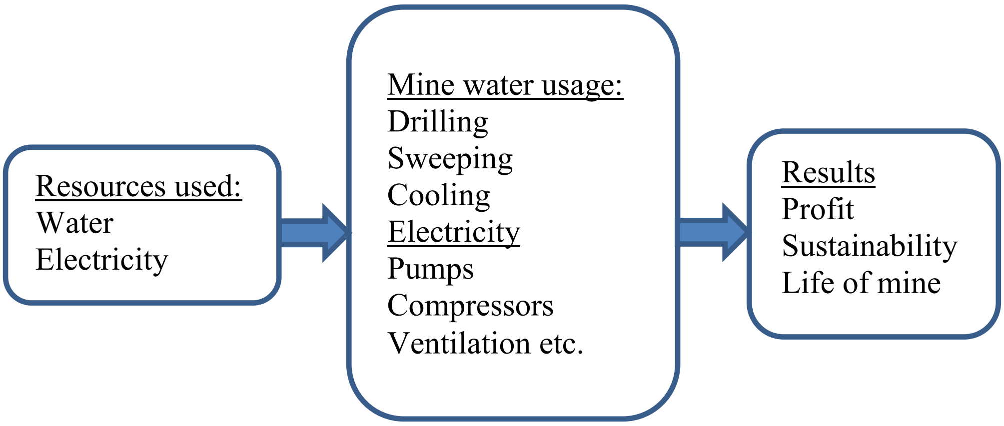


Figure 58: Basic outline of the mining system

Since water and electricity were identified as the resources that are at risk because of the mining system, the sustainability framework is limited to these two resources. Using the framework, it becomes possible to investigate the effect of the usage of these resources on the profitability, sustainability and the life of the mine.

The legislative documents pertaining to pollution in the gold mining industry are as follows:

- The Environmental Conservation Act (ECA) (Number 73 of 1989)
- The National Water Act (NWA) (Number 36 of 1998)
- The Air Quality Act (AQA) (Number 39 of 2004)

The Department of Environmental Affairs (DEA) and the Department of Water Affairs (DWA) administer this legislation for the Ministry of Water and Environmental Affairs. The Environmental Management Inspectorate has also recently become responsible for enforcing this legislation. Fines have been established for breaching one of these acts and are listed below:

- Up to R 1 million and/or 1 year imprisonment for breaching the ECA;

- Up to R 5 million and/or 5 years imprisonment for breaching the AQA; and
- Up to R 10 million and/or 10 years imprisonment for breaching the NWA.

These fines serve as motivation to ensure pollution is kept to a minimum. The state owns all fresh water in South Africa and authorisation must be obtained if used for any other reason except permitted water usage. In continuing, it is necessary to specify how environmental impact-reducing projects can be identified.

5.3.Project operational indicators

For the identification of environmental impact-reducing projects it is necessary to establish operational indicators. It was stated that there is a need for a novel system that identifies specific projects by analysing these operational indicators. The first project that the sustainability framework should be able to identify is the pumping project.

Pumping project identification

To determine whether a pumping project is feasible, it is necessary to analyse the pumping profile. To implement this project it must be established whether some or the entire pumping load can be shifted from the peak periods.

This can be done by simply measuring the total pumping power consumption of each pumping station. If this average usage is above 2 MW (which is the minimum feasible project size for a load shift project) a project should be considered.

The first step is to measure the peak period power consumption relative to the average power consumption. Typically when a pumping project has been installed, the power consumption in the peak periods is at least less than 50% of the average power consumption during the off peak and standard periods.

Although this will give a good estimate of project feasibility, it must still be considered whether the load can be shifted to other periods than the peak period. During the pumping project, more water is pumped to the surface in the period preceding the peak period.

This allows less water to be pumped to the surface in the peak period. As a result it must be assessed whether there is capacity to run more pumps in the period from 04:00 to 07:00 and 13:00 to 18:00. This can easily be done by measuring the peak power consumption of each pumping station and comparing this value to the average consumption in the periods mentioned.

The final consideration is whether the dams on the levels will be sufficient to store the water during the peak period. This is done by calculating the average flow pumped out of the mine during the peak periods. Dividing this value by the dam capacity, the time it takes for the dam to fill up is calculated. If this value is longer than 2 hours, a pumping project should be considered.

By combining these two calculations, pumping project scope can easily be estimated to determine whether a fully fletched investigation is warranted.

WSO project identification

Mines use different mining techniques that influence their water usage, quantity and efficiency. Additionally the different mining stages consume varying amounts of water. For these reasons the absolute water usage of the mine does not verify the likelihood of scope for a WSO project.

Depending on the mining operation, the water usage per ton of gold ore mined on high production mines can be more than three times higher than the lower producing mines. Water usage figures per ton of ore mined for some South African gold mines can be seen in Table 16.

Table 16: Water usage per ton of ore mine of mines in the Witwatersrand (Vosloo, 2008)

Mine	Actual tonnage	Underground water usage (Ml)	kl/ton
Mine A	15 500	38	2.45
Mine B	4 815	20	4.15
Mine C	4 600	6	1.3
Mine D	8 000	20	2.5
Mine E	3 233	12	3.71
Mine F	3 200	4	1.25
Mine G	9 078	20	2.2

From Table 16 it is evident that changing the system operation can reduce the water usage per ton by up to three times. Typical water usage per gold ore mined is 2 kl/ton with the most efficient mines operating at close to 1.2 kl/ton. Ultimately the goal will be to operate mines as efficiently as possible. The possibility of the need for a WSO project is high if the water usage per ton of ore is higher than 1.5 kl/ton.

It is also necessary to ensure that the total water usage is high enough to warrant an investigation. A minimum average water usage of 100 l/s is required to ensure the savings will be 1 MW or more.

To identify the possibility of a WSO project requires only the total monthly water usage and ore milled figures. These point to the possibility of a successful WSO project, from where a formal investigation can commence. Quantifying this ratio on a monthly basis is essential to the development of a sustainability framework.

CA project identification

The next project that requires operational indicators for project identification is the CA project. This project is more complex than the previous projects and as a result requires far more investigating and measurement to verify project scope. Typical measurements that are required to determine the exact saving that a CA project will be able to achieve include:

- The hot water flow from underground;
- The temperature of the hot water from underground;

- Ambient conditions;
- The flow through the pre-cooling towers;
- The pre-cooling tower efficiency (dependent on the inlet and outlet temperature and flow of the water and air);
- The evaporator water flow;
- The inlet and outlet temperature of the evaporator water;
- The refrigeration machine's COP;
- The condenser flow;
- The temperature difference between the condenser tower inlet and outlet flow;
- The feedback water flow between the chill dam and the refrigeration machine inlet;
- The chill dam temperature;
- The BAC water flow;
- The BAC airflow;
- The outlet condition (temperature and humidity) of the BAC air; and
- The chill water consumption of the shaft.

Although the investigation of the CA project scope is extensive, the identification of this project can be simplified significantly. The essence of the CA savings is based on the unnecessary pumping of the feedback water between the chill dam and refrigeration machine. To identify this project, this feedback flow and the total evaporator flow is measured.

A ratio is then determined between these flows. If the feedback flow is more than 20% of the evaporator flow, this usually verifies the need for further investigation into a potential CA project.

Finally it is necessary to measure the BAC outlet conditions. If this temperature drops to a value below 8°C (wet bulb) without a change in flow it will be necessary to assess the potential of a CA project. If this is the case, it shows that overcooling is done on the air supply to the mine. It also warrants further investigation into a CA project.

Turbine project identification

The next project that needs operational indicators that can be used to identify a possible project is the turbine project, where it is necessary to investigate the water extraction efficiency. The extraction efficiency of a mine is determined by the ratio between the theoretical electricity needed and the actual electricity used to extract the water.

Implementing projects that regenerate electricity from the water that is sent down a mine from the surface can improve the dewatering efficiency by up to 100% (Vosloo, 2008). The dewatering efficiency of some mines in the Witwatersrand region is compared in Figure 59.

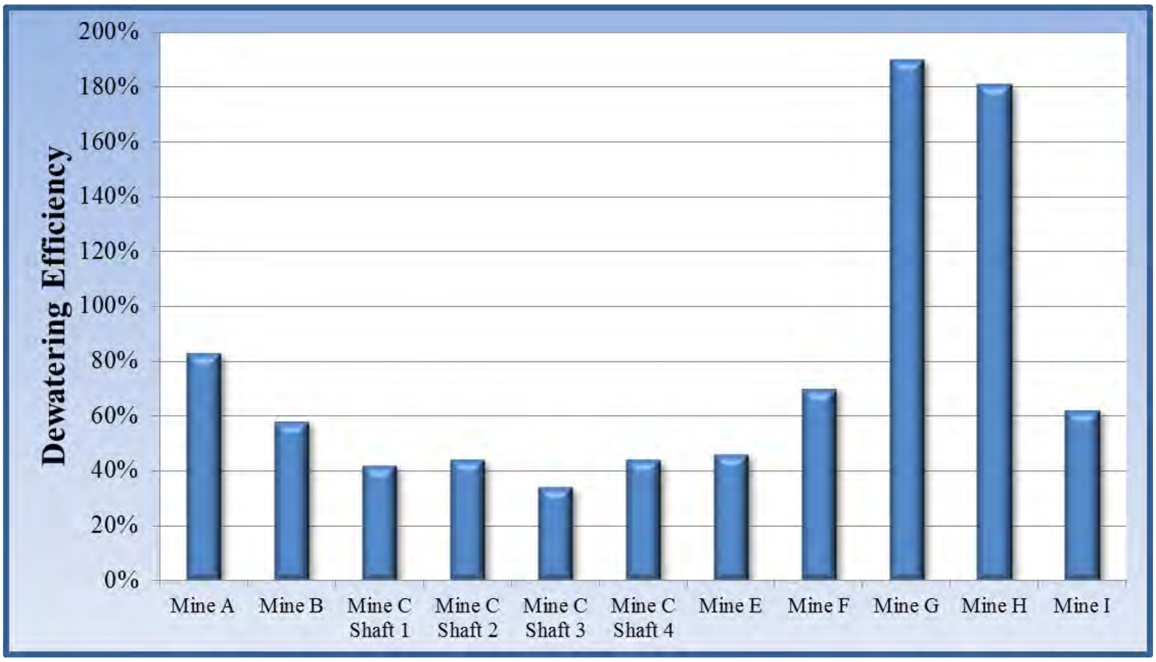


Figure 59: Water extraction efficiency of mines in Witwatersrand (Adapted from Vosloo, 2008)

From Figure 59 it can clearly be seen that the extraction efficiency of Mine G and Mine H is higher than the other mines. Mine G has installed a three pipe system and Mine H water turbines. From the extraction figures it is evident that these systems increase the extraction efficiencies considerably. It should be noted that the turbines at Mine A had not been installed when Figure 59 was compiled.

To identify the potential of a methane power generation project it is then necessary to measure the theoretical power consumption and compare it to the actual power consumption. This is the dewatering efficiency. The calculation can be seen in Equation [5.1] and [5.2]:

$$\eta_e = \frac{P_{theory}}{P_{actual}} \qquad [5.1]$$

$$\eta_e = \frac{\rho g Q H}{P_{actual}} \qquad [5.2]$$

Where,

η_e = The dewatering efficiency [%]

P_{theory} = The theoretical power needed to extract the water from the mine [kW]

P_{actual} = The actual power used to extract the water from the mine [kW]

ρ = The density of the water [kg/m^3]

g = The gravitational acceleration [m/s^2]

Q = The dewatering flow rate [l/s]

H = The head that the pump needs to overcome [m]

To determine the instantaneous flow rate it will then be necessary to measure the flow rate of the water being pumped from the mine. In addition to this, the instantaneous electricity consumption to extract the water should also be measured. This will allow the extraction efficiency to be calculated in real time to identify a potential site for a turbine project at a mine. Additional considerations as to how deep the mine is and where the water is consumed will come into consideration to determine the feasibility of this project.

Methane power generation project identification

The next project that must be identified is the methane power generation project. This is a straight forward measurement that can be done on the extraction air of the return airway. A measurement of the methane concentration in the air exiting the mine must be taken. Typically these sensors are not installed. This necessitates the installation of these sensors as part of the sustainability framework.

To determine the electricity that can be generated using the combustible gasses in the extraction air, it is firstly necessary to measure all the combustible gasses present in the air.

During the methane measurement it will also be necessary to measure the concentration of ethane, butane, propane, carbon monoxide and hydrogen. If these concentrations are known the electricity generation capacity can be calculated. (To do this calculation it will be necessary to use the heat of combustion for each of the gasses generated in gold mines.)

From this table of measured data, the power generation capacity of the air can be calculated. The total airflow and the concentration of each of these gasses must be measured to do this calculation. This will allow the environmental impact reduction system to determine the exact power generation capacity.

Compressed air project

The identification of the compressed air project is based on a pressure oversupply. To determine whether this is the case, a measurement of the pressure supply to the mine must be taken. Ideally this pressure measurement should be taken on the first production level, as this is the minimum pressure the mine will need to operate effectively.

If this pressure is more than 50 kPa above the required pressure for each shift, a project should be investigated. These pressures are usually 400 kPa for the blasting shift, 450 kPa for the sweeping shift and 500 kPa for the drilling shift.

The ESCO monitors the necessary KPIs to ensure effective operation. Figures like the water and air usage per ton of ore hoisted gives an excellent indication of the present resource wastage on mines.

5.4.Consolidated reporting values

The sustainability framework should be capable of facilitating the environmental impact reduction of mining. This system should generate environmental reports and provide continuous monitoring of the following values identified by the GRI:

- Total water used;
- Water quality and location of discharge;
- Direct and indirect greenhouse gas emission weight;
- Emission of gasses that deplete the ozone; and

- SO, NO and other dangerous gasses and particles.

These values constitute the bases of a successful EMS on generic companies. In the mining industry these need to be expanded to a system that is not only beneficial to the environment, but also to the typical deep-level gold mine. For this reason it is also necessary to report on the following factors:

- Ore mined;
- Ore grade;
- Amount of metal contained by the ore;
- Waste rock;
- Clean water usage;
- Quality and amount of effluent water produced;
- Energy usage;
- Chemical usage;
- Cyanide consumption; and
- Greenhouse gas emissions.

Hilson & Nayee (2002) states the importance of continually monitoring the environmental impact as doing once-off environmental audits give a limited view of the mine's impact. This study identifies the need to generate reports on environmental impacts of mines and involving an ESCO to monitor this. The ESCO can then analyse project potential based on the following measurements:

- Water usage per ton hoisted;
- The dewatering efficiency;
- The peak pumping power consumption, compared to the average power consumption;
- Dam capacity reserve;
- Feedback water flow measurement;
- BAC outlet temperature;
- Total airflow on the RAW extraction;
- The methane and other carbon gasses concentrations; and
- Air pressure supply to levels.

5.5.Integrated project prioritisation

Using the sustainability framework as a decision model enables investigation of the implementation cost and savings associated with each project. The first step is to analyse projects on their electricity-savings alone. This allows a payback period to be determined for each individual project. Shorter payback-periods help motivate the implementation priority to Eskom since they have limited funds available for DSM implementation.

The savings and cost associated with the numerous projects identified for environmental impact reduction, has been quantified. This allows a decision framework for determining the suitable project implementation strategy. This decision framework can be seen in Table 17. (Note that at the time of publication, the benchmark Eskom-IDM funding was R5.25 million/MW for energy efficiency, R3.5 million/MW for peak clip and R3.5 million/MW for load shift.)

Table 17: Environmental impact reduction decision model

Use less electricity										
Energy efficiency initiative	Cost [R million]	Electricity-saving	Carbon dioxide-reduction [ton/year]	Sulphur dioxide reduction [ton/year]	NOx reduction [ton/year]	Other particle reduction	Water saving [Ml]	Cost saving [R million]	Eskom-IDM funding [R million]	Payback period [months]
Water supply optimisation	1.95	4.28	22362	132	17	1.10	1135.2	12.05	22.47	2
Optimisation of air networks	4.15	2.07	10815	64	8	0.51	0	7.25	10.87	7
Cooling auxiliaries	5.19	2.06	10763	63	8	0.50	0	8.89	10.82	7
Pumping projects	6.08	15.61	43758	0	0	0.00	0	15.49	54.60	5
Generate more electricity										
Energy efficiency initiative	Cost [R million]	Electricity-saving	CO_2 reduction [ton/year]	SO_2 reduction [ton/year]	NOx reduction [ton/year]	Other particle reduction	Water saving [Ml]	Cost saving [R million]	Eskom-IDM funding [R million]	Payback period [months]
Turbine projects	6.41	2.26	12017	71	9	0.58	0	7.63	12.08	10
Methane generation	67.00	1.00	114494	31	4	0.25	0	3.22	5.25	250

This table shows that by selecting the right environmental impact reduction projects, the payback period on these projects can be well below a year. In the long run these projects realise massive savings. It can be seen that the projects saving electricity have significantly shorter payback periods than the projects generating electricity. The payback period for the turbine project would also have been significantly longer if the turbines needed to be installed and not refurbished.

This shows that specific focus should be on reducing the present electricity usage rather than trying to generate electricity. This is not because the savings from electricity generation projects are insignificant, but because the equipment installation costs are much higher. To reduce the capital investment required, it is proposed to involve the suppliers of the equipment. The equipment can then be supplied for free by the supplier and the electricity can be bought from the supplier at a reduced cost, as in the case of Mine C's methane power generation.

It was shown that the projects identified show significant electricity- and environmental impact reduction potential. When assessing these projects, mines concentrate on the cost saving associated with electricity usage reduction. Feasibility is then determined by analysing the capital expenditure and payback period.

This study proposes that the analyses of these projects should also be based on the pollution prevention advantages gained from these projects. To achieve this, it will be necessary to quantify the pollution advantages in monetary terms. As such, it is necessary to investigate the costs involved with cleaning AMD and removing carbon dioxide from air.

The most common method of removing AMD from mine water is the lime neutralisation process. This is an effective method of reducing the metal content of mine effluent water. The limestone reacts with the heavy metals to form metal hydroxides (Coetzee *et al.*, 2010). Neutralisation can also be done by other chemicals as shown in Table 18.

Table 18: Neutralisation chemicals (Adapted from DWAF, 2008)

Parameter	Lime	Soda ash	Caustic soda
Chemical formula	$Ca(OH)_2$	Na_2CO_3	$NaOH$
Solubility at 30°C	1.53	568	1190
Consumption of pure product per g of H_2SO_4	0.76	2.16	0.82
Increase in hardness per g of H_2SO_4 in g $CaCO_3$/l	1	0	0
Product from reaction with H_2SO_4	$CaSO_4$	$Na_2SO_4+2NaHCO_3$	Na_2SO_4
Reaction time	Slow	Rapid	Rapid
Cost	Low	High	High

These metal hydroxides are insoluble and precipitate from the water, allowing the collection of these metals. The base metals can even be removed from this precipitate for other applications. Disposing of these heavy metal hydroxides is however an expensive process (Wang *et al.*, 2013).

The heavy metals are completely precipitated at a pH of 9. For this reason the limestone is added until the pH of the effluent water reaches 10 (Wang *et al.*, 2013). To increase the pH of the water from 3 to precipitation levels, 250 mg/l of limestone is used (Da Silviera *et al.*, 2009). To reduce the pH, sulphuric acid can be added until it reaches a pH of 7 again (Wang *et al.*, 2013).

Limestone is generally used for this neutralisation process because of its low cost. There are however significant drawbacks to this neutralisation process. These can be seen below (DWAF, 2008):

- As can be seen in Table 18 there is a constant build-up of $CaSO_4$. This increases the hardness of the water and reduces the re-usability. As a result, the maintenance on refrigeration machines and pumps increases due to the erosion created by the water.
- The reaction time is very slow and the precipitation of the heavy metals is not necessarily in the settling dams.
- The process requires the water to have a reduced pH for the addition of lime to precipitate the metals. This creates a situation where the metals do not precipitate if sulphuric acid is not present in the mine water.

The operating cost of neutralising one cubic meter of water with the lime neutralisation process is R1.40 (Coetzee *et al.*, 2010). This is the cost associated with the reuse of water in mines. The quantity of recycled water at two large mining companies in South Africa is respectively 60% and 91%.

If an average recycled percentage of 75.5% is used, the water treatment cost per water saved can be calculated. This means that in the case of the WSO project, the saving of 1 135 Ml per year will also realise another water treatment cost saving of R1.2 million. To purify water to drinking quality will require further processing.

Mine A's water usage for the year 2012 was 2 738 Ml. It was shown that the water saving achieved on Mine A was 12.1% of the total water usage. If it is assumed that there is a linear relation between the mine water consumption and the potable water supply, the water supply was also reduced by 12.1%. Additionally it is assumed that only 10% of the water supplied to the mine is utilised for drinking and the rest is used for mining.

The cost of water in the Witwatersrand region in South Africa is R6.32/kl (November 2013). This gives an additional financial saving of R1.89 million in water supply costs. As mentioned earlier, the mine effluent can also be sequestrated in wetlands (Kalin *et al.*, 2006), but these are scarce in South Africa, so this is not a viable option.

Continuing investigating the potential savings made possible by implementing projects from the sustainability framework, it is now necessary to quantify both the environmental impact cost and financial cost associated with carbon dioxide removal from the air. This is a complex calculation as typically the removal of carbon dioxide is done at power stations, by preventing the carbon dioxide from entering the atmosphere. This carbon can then be stored in aquifers. A typical method employed at the power stations for removing the carbon dioxide is by Monoethanolamine (MEA) scrubbing (Jung *et al.*, 2013; Romeo *et al.*, 2008). The process is shown in Figure 60.

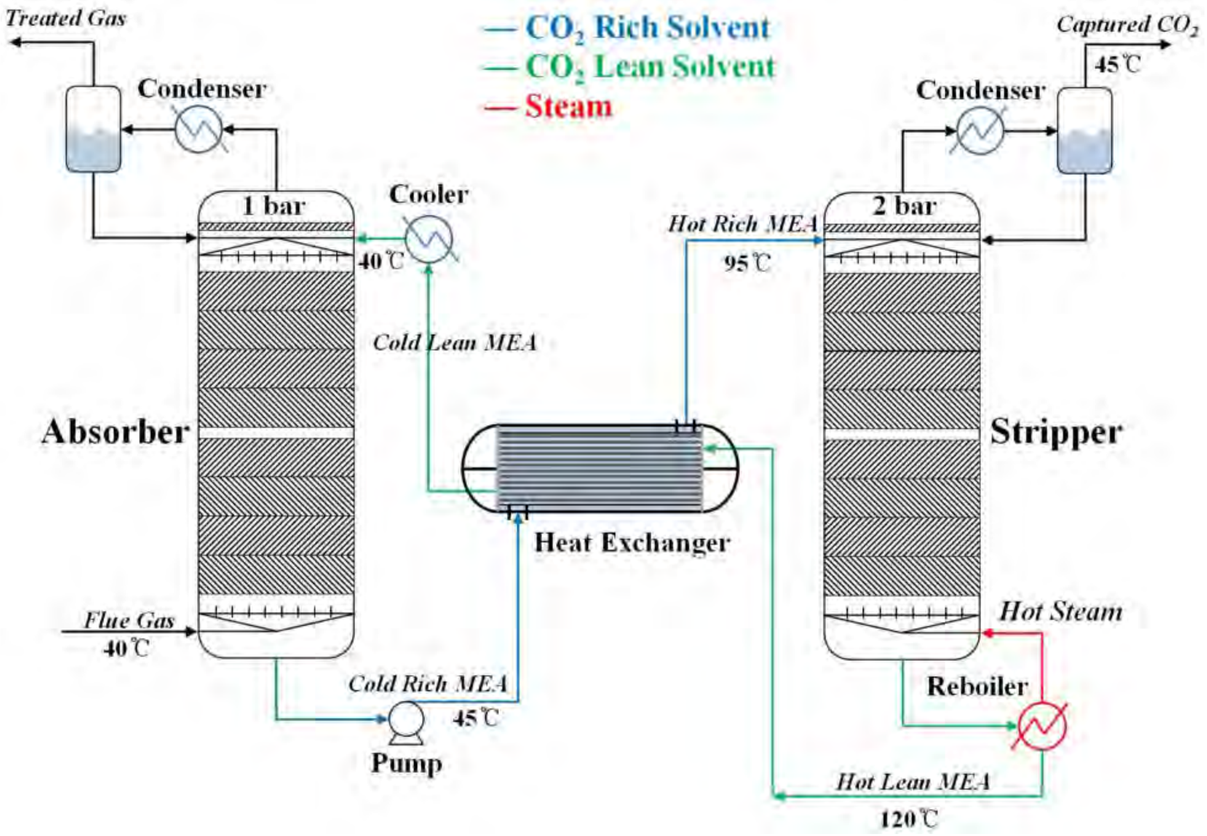


Figure 60: MEA scrubbing process (Jung *et al.*, 2013)

Carbon dioxide-rich air flows through the absorber from the bottom. MEA filters through the air from the top absorbing the carbon dioxide. The carbon dioxide-rich MEA then flows through a heat exchanger before being heated in the stripper. This boils the carbon dioxide from the solution and the carbon dioxide is then captured and stored. The MEA is cooled in the same heat exchanger before repeating the cycle (Jung *et al.*, 2013).

The operation cost of this process is R807.40/tCO_2 (with the Rand/Euro exchange rate at R14.68 per Euro as on 18 January 2014) (Romeo *et al.*, 2008). This brings the annual carbon dioxide removal cost to R4.22 million/MW. If the water saving, water purification and carbon removal cost are all taken into account, the payback periods of these projects change significantly. This can be seen in Table 19.

Table 19: Project prioritisation with regards to electricity and pollution saving

Use less electricity												
Energy efficiency initiative	Cost [R million]	Electricity-saving	Carbon dioxide-reduction [ton/year]	Sulphur dioxide reduction [ton/year]	NOx reduction [ton/year]	Other particle reduction	Water saving [Ml]	Cost saving [R million]	Eskom-IDM funding [R million]	Tax incentives funding [R million]	Carbon credit funding [R million]	Payback period [months]
Water supply optimisation	1.95	4.28	22362	132	17	1.10	1135.2	33.18	**22.47**	4.72	1.69	1
Optimisation of air networks	4.15	2.07	10815	64	8	0.51	0	19.98	**10.87**	2.28	0.82	3
Cooling auxiliaries	5.19	2.06	10763	63	8	0.50	0	17.58	**10.82**	2.27	0.81	4
Pumping projects	6.08	15.61	43758	0	0	0.00	0	50.82	**54.60**	0.00	3.30	1
Generate more electricity												
Energy efficiency initiative	Cost [R million]	Electricity-saving	CO_2 reduction [ton/year]	SO_2 reduction [ton/year]	NOx reduction [ton/year]	Other particle reduction	Water saving [Ml]	Cost saving [R million]	Eskom-IDM funding [R million]	Tax incentives funding [R million]	Carbon credit funding [R million]	Payback period [months]
Turbine projects	6.41	2.26	12017	71	9	0.58	0	17.33	**12.01**	2.54	0.91	6
Methane generation	67.00	1.00	114494	31	4	0.25	0	95.66	5.25	1.10	**8.63**	8

From this table it can be seen that the payback periods for the different electricity-saving projects are more than halved when the electricity- and environmental costs for all pollution-saving projects are considered. This emphasizes just how effective the electricity reduction projects are, as the payback periods are less than four months. The payback period for the methane power-generation project is reduced from 250 months to 8 months when the environmental impact reduction advantage is considered as well. If the benchmark for project implementation is a 12 month payback period, this makes the methane power-generation project viable.

If these projects are evaluated on their electricity-reduction or environmental impact reduction effects alone, they would not necessarily be implemented on mines. But by looking at these projects in a consolidated manner, their true value is highlighted.

It can be seen that the Eskom-IDM funding model is the preferred option for all projects except the methane power-generation project. It is deduced that electricity-savings projects should be implemented under the Eskom-IDM funding model and special consideration should be given to electricity-generation projects. This shows that the third party that should be involved with these project implementations should be a registered ESCO.

Integrated assessment of these projects is not currently possible as the ISO 14001 and ISO 50001 standards are not integrated for the mining industry. This means that project savings must be motivated through one of these standards. As a result projects are disregarded based on their electricity- or environmental impact reduction capabilities exclusively.

5.6.Data acquisition

The data for each site where this sustainability framework is implemented must be viewed by the ESCO for analysis. To do this it is necessary to consolidate the data onto one central system. It is recommended that this system is located at the offices of the ESCO for ease of access, and must be of suitable specification to ensure the data can be retrieved consistently. The data acquisition method used for the sustainability framework can be seen in Figure 61.

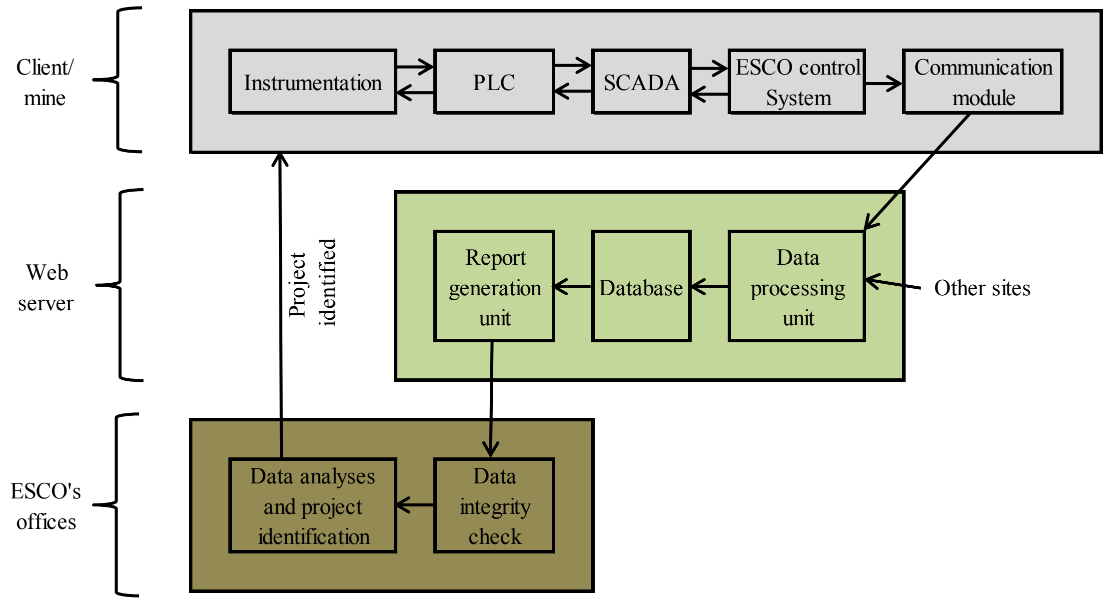


Figure 61: SCADA data acquirement schematic (Adapted from Goosen, 2013)

The schematic in Figure 61 shows how the information from each site reaches the ESCO. The sensor instrumentation takes the measurement on site. This sensor then sends a signal to the PLC via an Ethernet connection where the measurement is processed into a meaningful value. These values are communicated to the mine's SCADA system, from which the information is read by the ESCO's on site control system via an Object Linking and Embedding (OLE) for Process Control (OPC) connection.

This control system is expanded to form part of the final environmental impact reduction project implementation. From this control system, the information is transmitted via a truteq connection to a processing unit. Here it is converted to data and stored on an online server to enable online access.

The online server compiles this data into reports that are sent to the ESCO to ensure that the data is reliable. If the data exceeds certain limits, the sustainability framework flags it to ensure that these values are assessed by the ESCO. If the data is correct and has in fact exceeded the limits, it can be used by the sustainability framework to identify project potential for projects to be implemented on the mine.

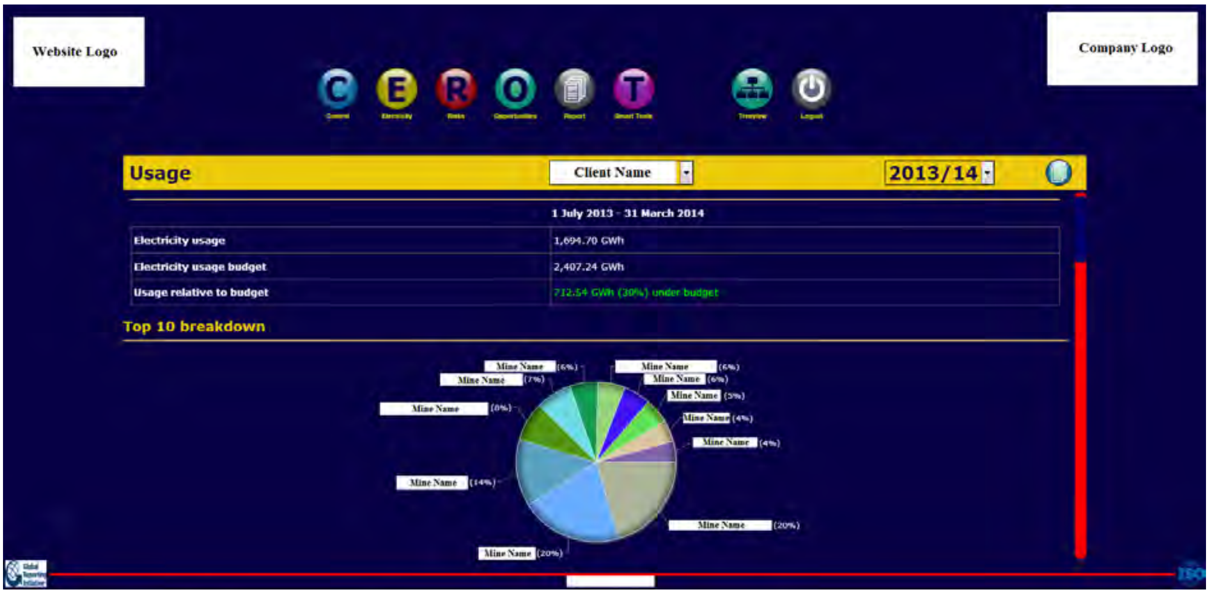
Some of the data cannot be measured with instruments and must be manually added by the mines. It is important to ensure that this is done promptly; automated email reminders sent on a repeating schedule will facilitate this.

To assess the clients' electricity usage, Eskom bills can be requested with permission from the client. This will allow reliable electricity usage figures to be received. This will also assist the ESCO in creating a system that will eventually enable the mine to become ISO 50001 compliant.

5.7.Sustainability framework

Data is acquired from three different sources, namely, the clients' Eskom accounts, the mines SCADA system and data that must be manually added to the database by the mine. It is important to ensure the integrity of the data, which is complicated by the reliance on the client's data management provider. Working in collaboration with this provider allows consistent data availability and uploading and retrieval of the latest data.

Using this information, potential project sites for energy savings can be highlighted by monitoring key operational indicators. The sustainability framework starts by identifying the large energy-consuming sites of a mining company using a holistic approach to the company's electricity consumption. An overview dashboard of these processes is shown in Figure 62.



1 July 2013 - 31 March 2014	
Electricity usage	1,694.70 GWh
Electricity usage budget	2,407.24 GWh
Usage relative to budget	712.54 GWh (30%) under budget

Figure 62: Energy usage per mine

With each mine's individual electricity consumption and the total consumption known, a budget is assigned to the electricity usage. The baseline electricity consumption is compared to the present year's electricity consumption. A budget is assigned for compliance to the ISO 50001 standard and can be seen in Figure 63.

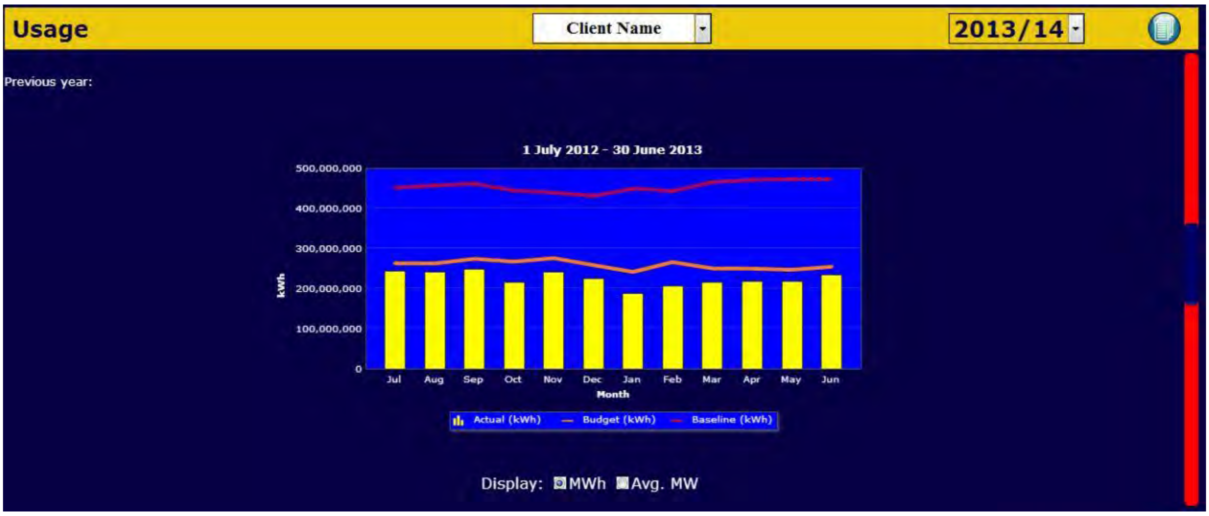


Figure 63: Electricity consumption budget

The electricity cost saving achieved by these projects can be quantified by the ESCO. These project savings can be seen in Figure 64.

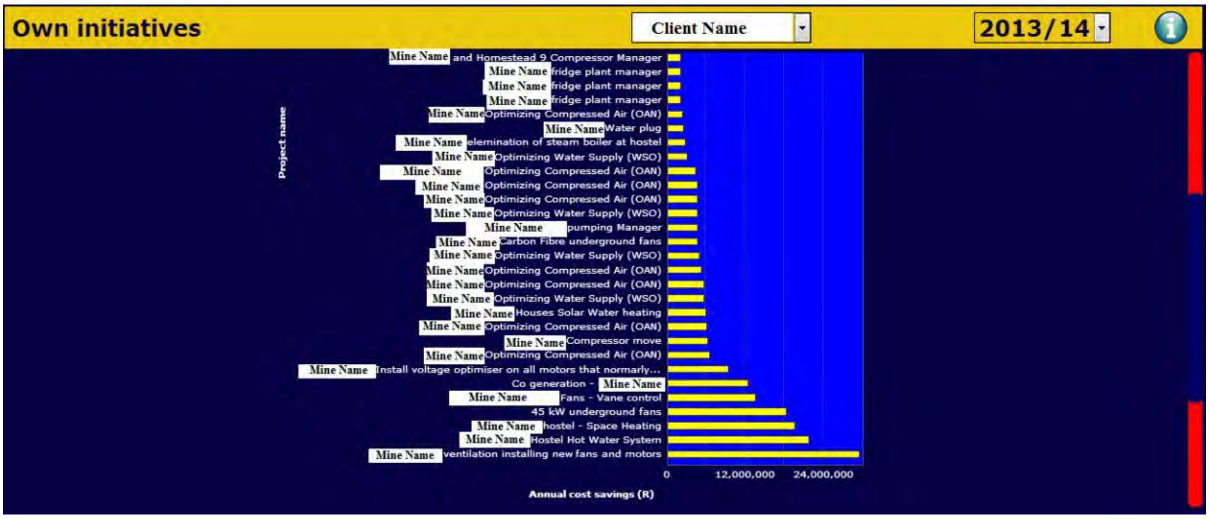


Figure 64: Project electricity costs savings

Knowing the savings achieved by each individual project allows the carbon dioxide-reduction potential to be quantified. The carbon credit potential can be seen in Figure 65. In conjunction, there is also the risk of carbon tax that can be levied on Eskom for carbon dioxide production. This will inevitably be transferred to the client and creates a financial risk to high electricity-consuming clients. This risk is quantified in Figure 66.

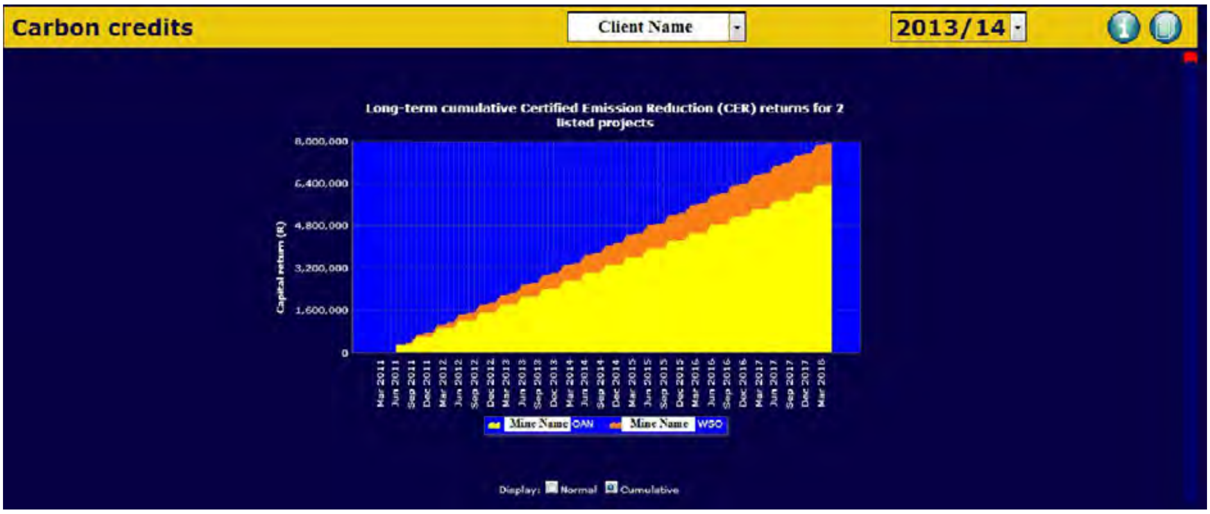


Figure 65: Carbon credits from two electricity-reduction projects

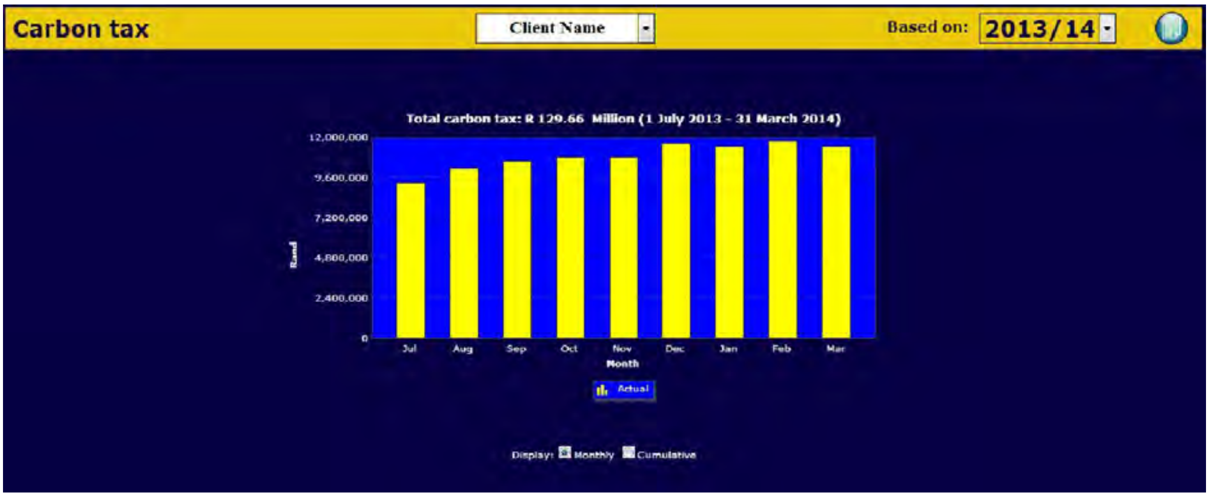


Figure 66: Carbon tax risk quantification

This sustainability framework allows the monitoring of current project performance on a monthly and weekly basis. The monthly monitoring of these projects can be seen in Figure 67.

Figure 67: Monthly project monitoring

In Figure 67 it can be seen that each project is monitored individually. Grey blocks indicate months where no data was received or the project was still in the implementation phase. Green blocks indicate months where data was received and the project target was achieved. Red blocks indicate months where data was received but the project did not achieve its electricity-savings target. The weekly project monitoring can be seen in Figure 68.

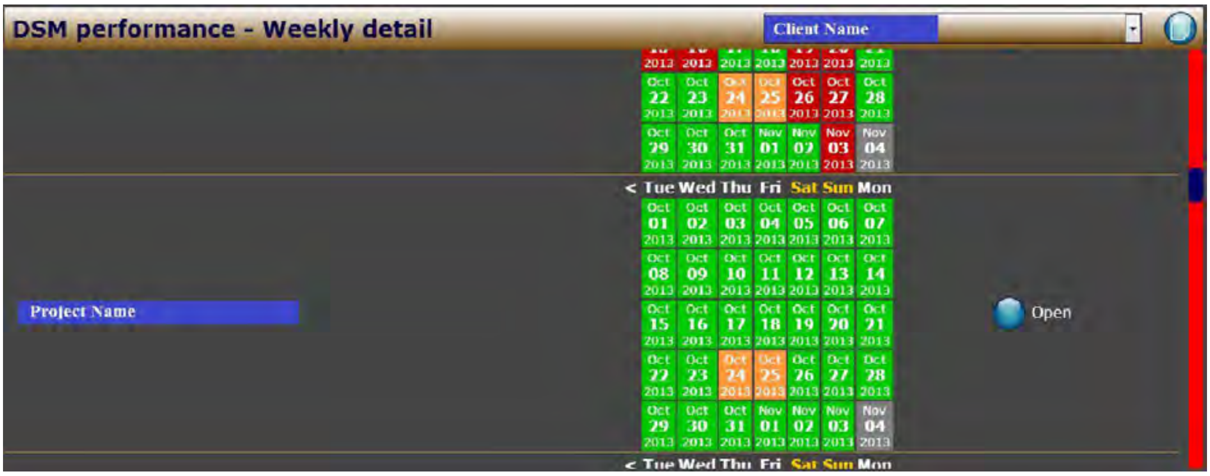


Figure 68: Weekly project monitoring

In Figure 68 the red, green and grey blocks again represent the same conditions as in Figure 67. However this is done on a daily basis. The orange blocks represent days that something hampered the project performance which was out of the ESCO’s control. These are known as condonable days. In Figure 69 it is shown how project performance is monitored in the long term.

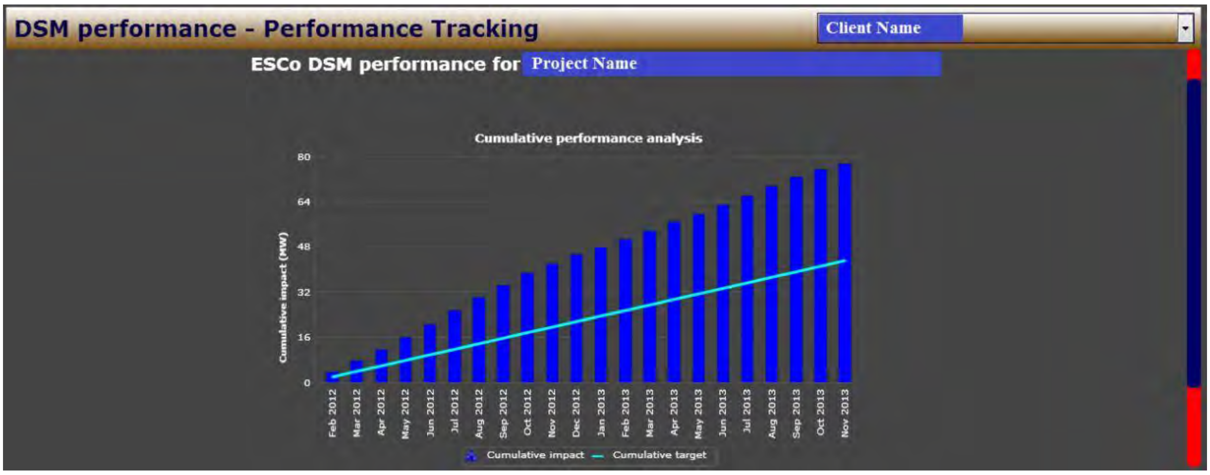
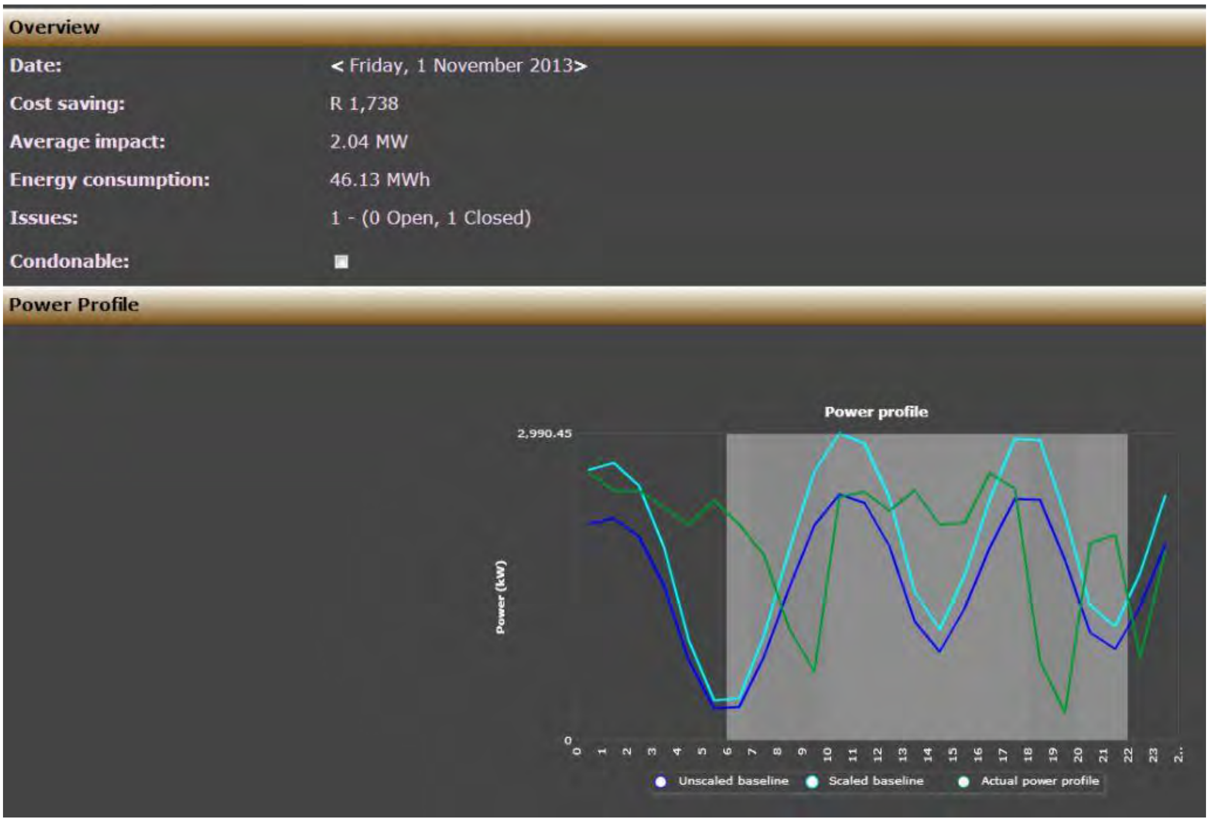


Figure 69: Cumulative target tracking

This allows the cumulative performance of a project to be compared to what the total savings should have been. This is very important as some projects have seasonal effects. An example of such a project is the CA project. In the winter the atmospheric temperatures are lower, which allows for larger savings on the BAC water supply.

Each project’s performance can be monitored individually. This helps SANEDI with the project performance analyses. Project monitoring aids the ESCO with project performance tracking and also allows maintenance to be done on the projects. It will eventually also help quantify the carbon tax that must be paid to Eskom.

In Figure 70 the load shift performance achieved by a pumping project can be seen. In Figure 71 the energy-efficiency performance of a WSO project is shown, compared to the energy-efficiency performance of a CA project, in Figure 72, and the same of an OAN project, in Figure 73.



Overview

Date: < Friday, 1 November 2013>

Cost saving: R 1,738

Average impact: 2.04 MW

Energy consumption: 46.13 MWh

Issues: 1 - (0 Open, 1 Closed)

Condonable: ☐

Power Profile

Figure 70: Pumping project savings monitoring

water supply optimisation

Overview

Date: < Wednesday, 26 March 2014>

Cost saving: R 24,791

Average impact: 2.34 MW

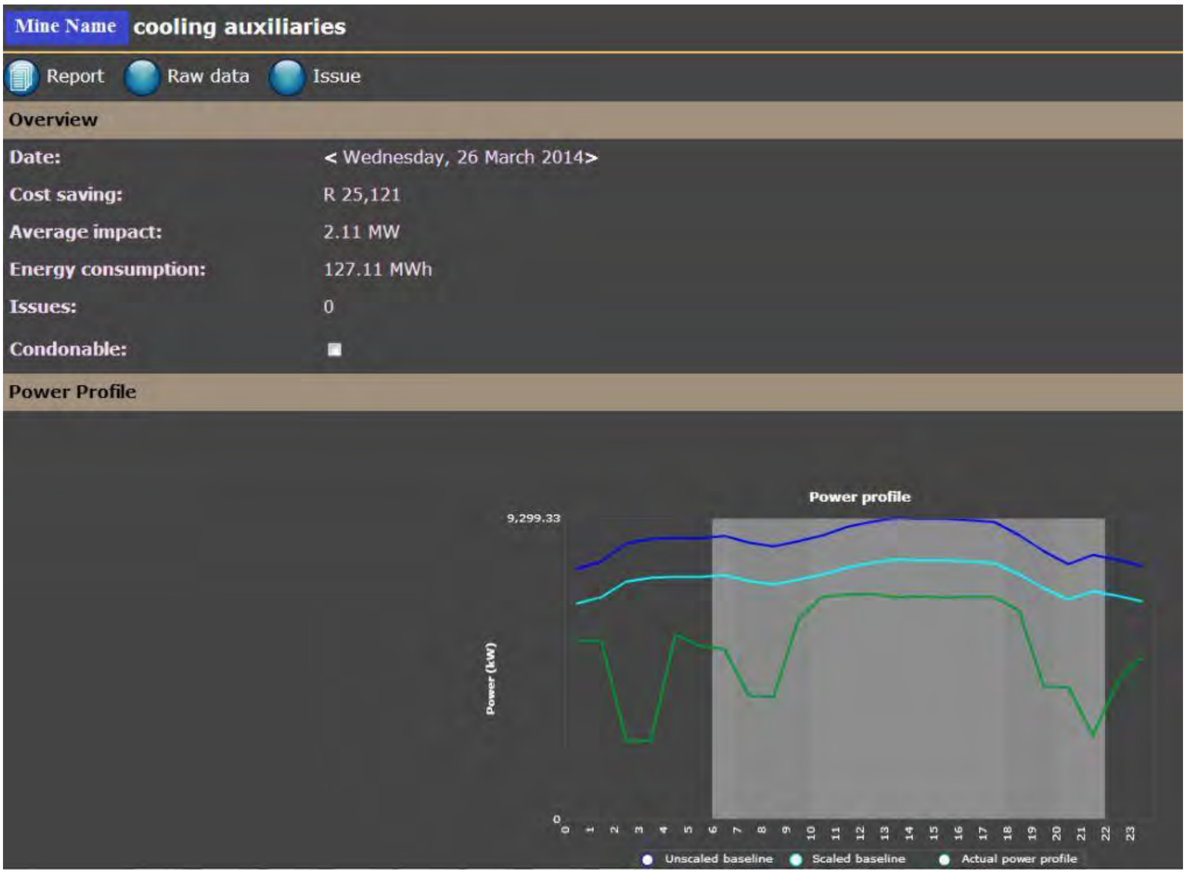
Energy consumption: 225.46 MWh

Issues: 0

Condonable: ☐

Power Profile

Figure 71: WSO project savings monitoring



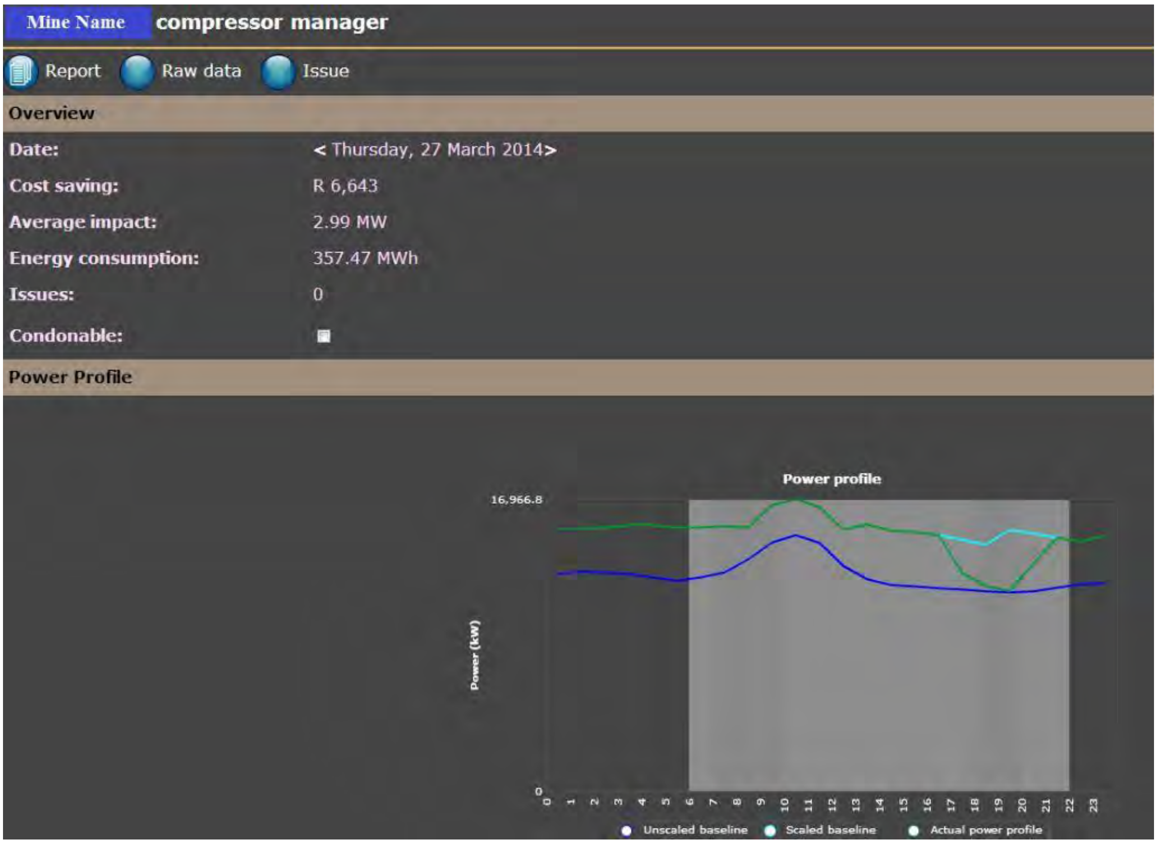
Mine Name: cooling auxiliaries

Overview

Date: < Wednesday, 26 March 2014>
Cost saving: R 25,121
Average impact: 2.11 MW
Energy consumption: 127.11 MWh
Issues: 0
Condonable: ☐

Power Profile

Figure 72 CA project savings monitoring



Mine Name: compressor manager

Overview

Date: < Thursday, 27 March 2014>
Cost saving: R 6,643
Average impact: 2.99 MW
Energy consumption: 357.47 MWh
Issues: 0
Condonable: ☐

Power Profile

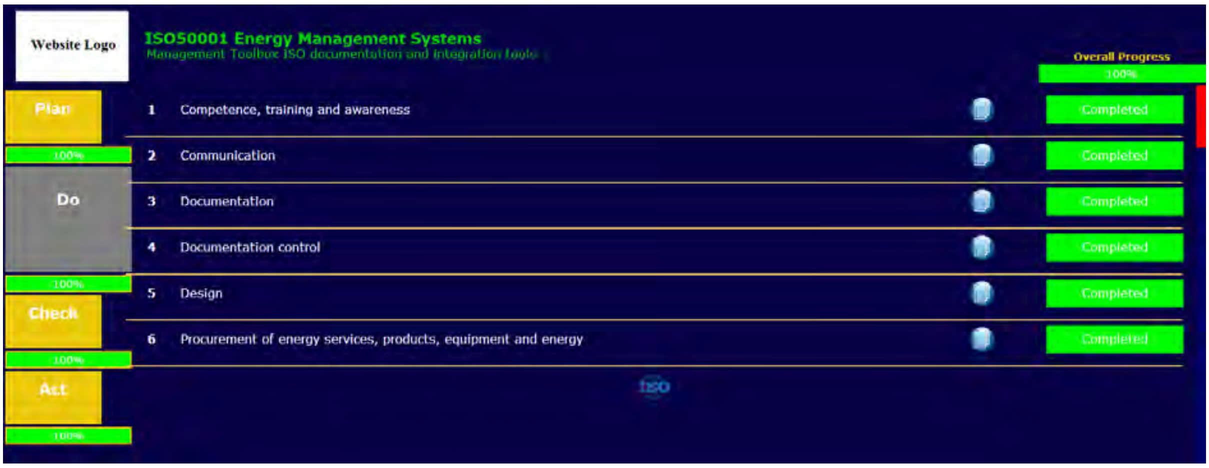
Figure 73: OAN project savings monitoring

In each figure, the blue line represents the baseline for each project. Factors like increased production do however alter what the current baseline should be. For this reason, the original project baseline is scaled to match the changing conditions. This scaled baseline is shown in turquoise. The actual electricity-consumption profile is then shown in green. It can clearly be seen that the WSO and CA projects are energy-efficiency projects. The pumping project is a load shift project and this OAN project example is of a peak clip project.

To comply with the ISO 50001 standard, documentation for each step of the plan-do-check-act phases must be generated. This sustainability framework aids the mine in generating these documents and shows the progress of each phase. Standard answers are required from the user, which allows the automatic generation of reports. The documentation required for each step is shown in Figure 74, Figure 75, Figure 76 and Figure 77.

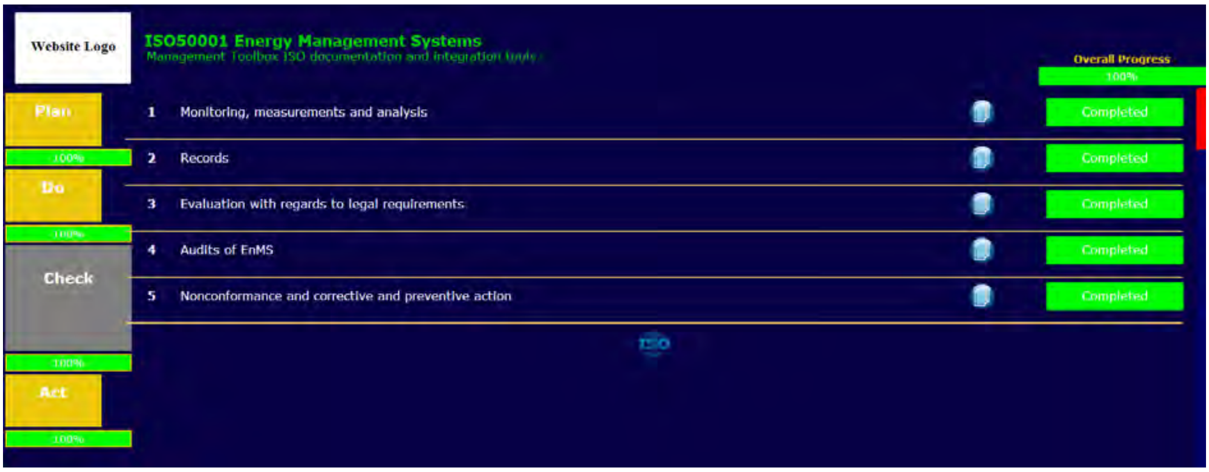
1 Top management Completed
2 Management representative Completed
3 Energy policy Completed
4 Energy management team Completed
5 Legal requirements Completed
6 Energy review Completed
7 Energy baseline Completed
8 Objectives, targets and energy performance indicators (EnPIs) Completed
9 EnMS Action plan Completed

Figure 74: Documentation for the *plan* phase



1 Competence, training and awareness Completed
2 Communication Completed
3 Documentation Completed
4 Documentation control Completed
5 Design Completed
6 Procurement of energy services, products, equipment and energy Completed

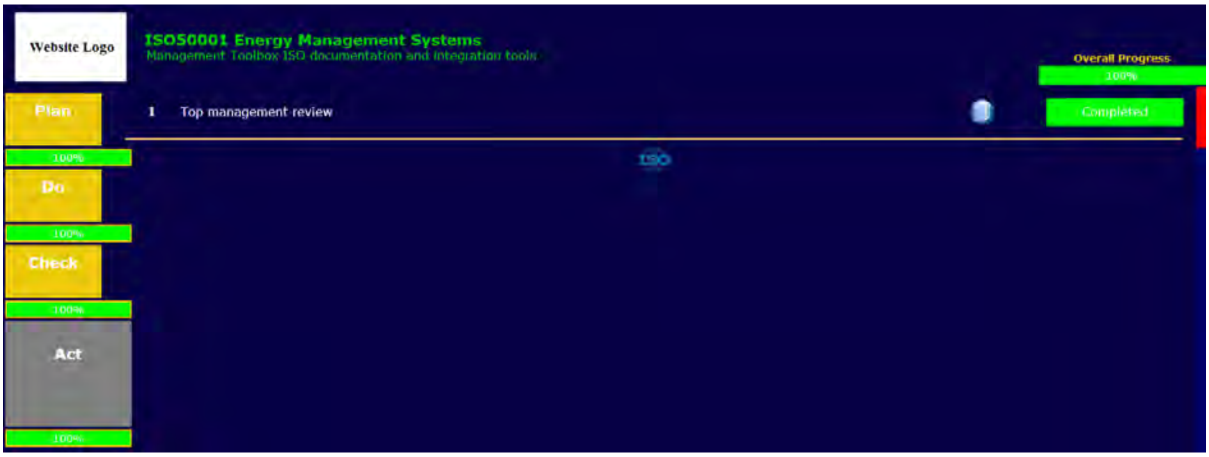
Figure 75: Documentation for the *do* phase



ISO50001 Energy Management Systems
Management Toolbox ISO documentation and integration tools

1 Monitoring, measurements and analysis
2 Records
3 Evaluation with regards to legal requirements
4 Audits of EnMS
5 Nonconformance and corrective and preventive action

Figure 76: Documentation for the *check* phase.



ISO50001 Energy Management Systems
Management Toolbox ISO documentation and integration tools

1 Top management review

Figure 77: Documentation for the *act* phase

It can be seen that the sustainability framework aids the mine in achieving ISO accreditation. It also allows the identification of project potential and monitors the required project performance. Examples of the reports that are generated by the framework are shown in Appendix D.

5.8. Validation and results of this framework

At the start of this study, specific problems with the current operation of EMSs were identified. The success of this study must be measured against these problems. To do this, each of the current EMS problems is stated and it is shown how this issue was addressed. This validates the objectives of this study.

There is a need for EMSs on mines (Mudd, 2007)

This study developed the framework for a successful sustainability framework based on the shortcomings identified by previous authors. Insufficiencies identified in this study were also addressed.

Environmental impact reduction is not a priority (Mudd, 2007)

This study showed how environmental impact reduction on mines can be done without shifting the mine’s priority from production maintenance to environmental impact reduction. This was done by involving an ESCO to do the project identification and implementation, at a reduced cost to the mine.

There is no environmental reporting standard (Jones, 2010)

This study consolidated the reporting values necessary for successful sustainability reporting. This included the values measured to assess project potential and all the necessary KPIs for sustainable mining.

Too much pollution is created in mines (Durand, 2012)

This study proposed projects that can reduce the environmental impact of mining. It quantified the effect of these projects and their implementation. Operational indicators were identified that are used to identify these projects. This streamlined the implementation of these projects which will reduce the environmental impact of mines.

Becoming ISO 14001-compliant does not ensure pollution reduction (Hilson & Nayee, 2002)

This study proposed a novel sustainability framework that reduces the pollution production of mines without the need of obtaining ISO 14001 compliance.

Implementing an ISO 14001 accredited system does not give the mine a competitive edge (Hilson & Nayee, 2002)

This study showed how implementing environmental impact reduction projects give a mine a competitive edge. This was evident from the electricity cost reduction gained by these projects.

Project examples should be given to mines (Hilson, 2000)

This study proposed numerous projects that have been successfully implemented on mines that can reduce the pollution created by mines. These projects were explained in detail. This study also discussed the implementation process and costs.

The project technologies are not available to the mines (Hilson, 2000)

By involving an ESCO it was shown how these technologies can be made available to mines. ESCOs have the know-how to implement these projects. This removes the responsibility from the mine as ESCOs implement the projects, arranges funding and takes responsibility for the savings.

Pollution monitoring should be improved (Durand, 2012)

By incorporating the necessary reporting values with a superior sustainability framework and data capturing methods, pollution monitoring will be improved. Implementing this sustainability framework helps with the monitoring of project performance. This ensures that SANEDI can monitor the energy reduction performance of projects. The risk of carbon tax can also be quantified and project performance can be reported to Eskom’s M&V team.

Monitoring of pollution reduction should be done continually (Hilson & Nayee, 2002)

This system will measure the performance of these projects continually via the use of the mine’s SCADA system. Additional measurement will also be incorporated by the ESCO implementing the projects to assess project potential and identify pollution.

Funds for pollution reduction projects are not readily available (Hilson, 2000)

This study investigated alternative funding models for pollution reduction projects in order to identify the most promising solution. It was shown that Eskom-IDM is still the most feasible method of funding these projects.

Workers do not want to identify projects as they are afraid it might make them redundant (Hilson, 2000)

This study showed how the responsibility of project identification can be removed from mine workers. By analysing the operational indicators specified, these projects will be identified automatically.

The manpower to identify projects is limited (Hilson, 2000)

By automating this identification process, the manpower required for pollution project identification is reduced. The implementation is also done by the ESCO to further reduce the requirements from the mine.

Third parties should get involved with the implementation of these projects (Hilson & Nayee, 2002)

A third party in the form of an ESCO was involved in the project implementation. This removed the responsibility from the mine to focus on production.

The mine needs assistance with the implementation of projects (Hilson, 2000)

A support system for environmental impact reduction projects is proposed in the form of an ESCO.

Electricity and environmental management should be done on an integrated basis (O'Donnell *et al.*, 2013)

This study analysed projects on an integrated payback period to determine project feasibility. Showing that environmental impact reduction cost saving can make projects feasible.

The ISO 50001 environmental standards are relatively new, since it was only published in 2011. The ISO concept is not new, but electricity management has only recently become a priority. This is as a result of the drastic electricity cost increases by Eskom. To become ISO 50001 and ISO 14001-compliant it was shown that the following needs to be addressed:

- Continual electrical efficiency/environmental impact reduction improvement.
- Reviewing the energy usage/environmental impact at set intervals.
- Documenting the entire energy/environmental impact reduction process.
- Measuring energy/environmental performance indicators.
- Setting energy/environmental impact reduction targets and implementing projects to reach and maintain these targets.

The sustainability framework specified in this study fulfils all these requirements and can help a mine become ISO 50001 compliant. The ISO 14001 standard was developed and implemented since 2004. This has allowed for enough time for companies to start implementing ISO 14001-compliant systems. As a result 91% of mines in South Africa have adopted an ISO 14001-compliant system. On the other hand, mines have not yet started implementing ISO 50001 compliant management systems, because the concept is still new.

This study has also shown that environmental impact reduction and electricity-reduction walk hand in hand. This just emphasises the need for sustainability management integration. Currently the viability of projects is analysed base on their environmental impact reduction or electricity-reduction potential. This study analyses the performance of projects based on both these factors as it affects their implementation feasibility.

As part of this implementation it will be necessary to install the necessary instrumentation to measure the pollution produced by these mines. This will create a mutually beneficial situation where mines identify the largest polluters and ESCOs identify electricity reduction projects. The basic integration of this system can be seen in Figure 78.

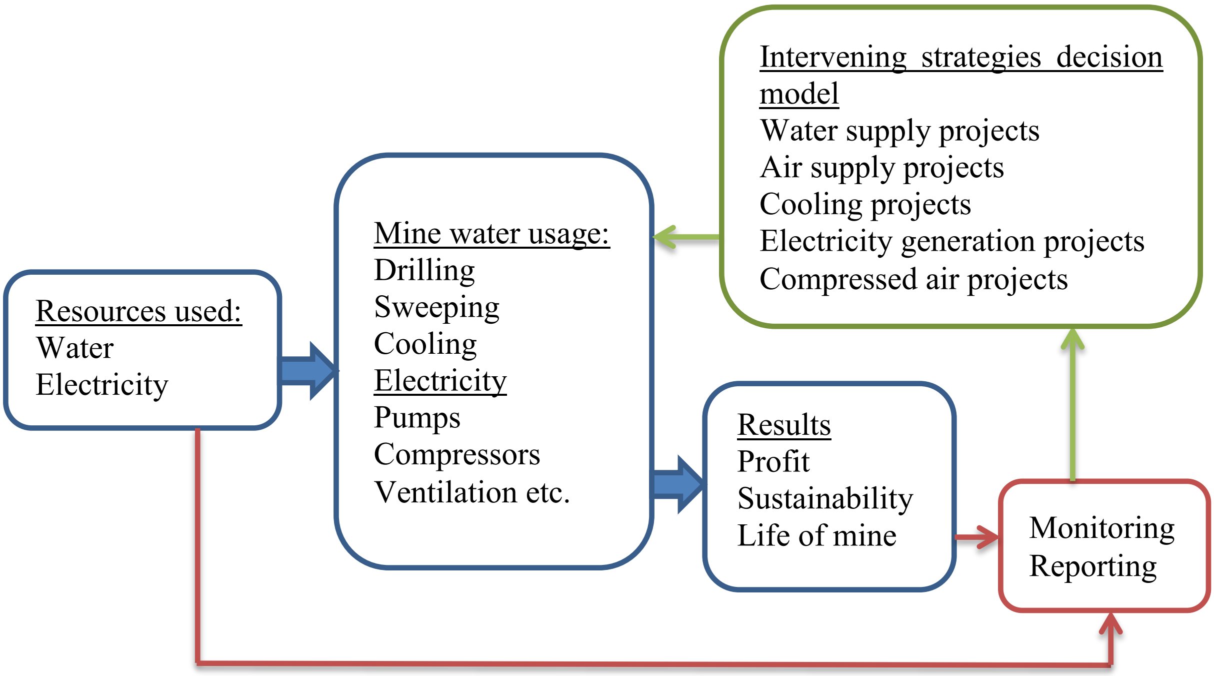


Figure 78: Outline of the study

The effect is quantified, monitored and reported on in order to trend these values over time. Since the usage of the resources is dependent on the production of the mine, the usage of these resources should be trended against the production values. The best measure of production is the tons of ore hoisted. This allows conclusions regarding the effectiveness of their use by measuring and reporting these values. A project decision flowchart can be seen in Figure 79.

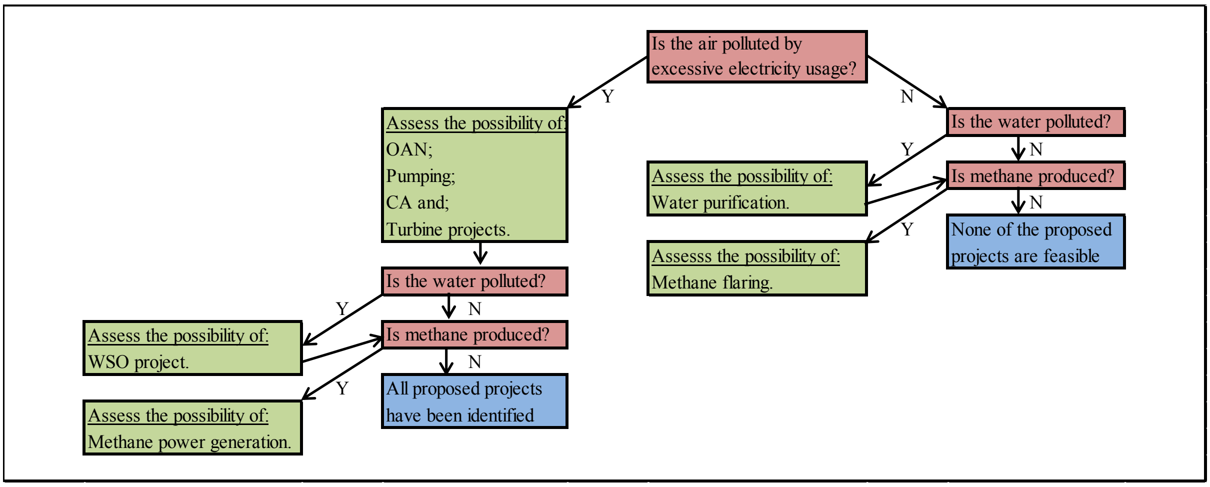


Figure 79: Project decision flow chart

Except for the methane power generation project, all the projects implemented by this study, was done on the same mine. The results achieved by this study can be extracted to the rest of the mines in South Africa scaled to production. Mine A produced 14.17 tonnes of the 197.9 tonnes mined in South Africa during 2011.

It is therefore assumed that the energy efficiency results of 11.8 MW (total performance of the projects without including the methane power generation project) achieved by the projects can be extrapolated. By this assumption 150.8 MW energy efficiency can be achieved on gold mines across South Africa.

With the same reasoning the 15.6 MW load shift is extrapolated to deliver a load shift on the rest of South African mines of 217.9 MW. These projects can also achieve a yearly carbon dioxide-reduction of 3 million tonnes and water consumption reduction of 15.9 Gl.

It is important to ensure that the measured results on these projects are correct. The achieved saving on each project is validated by Eskom. As stated an M&V team is assigned to each project to ensure the stated savings was achieved. To determine this saving, Eskom electricity measurements are used. This is the same measurements used to bill the mine on their electricity consumption.

As part of the project however, redundant power loggers are installed on the mine. These measurements are compared to Eskom bills to ensure that the project savings is measured correctly. The variance of these loggers and the Eskom bills are less than 2%. As such it is assumed that the results measured, are correct and represent the true savings achieved by each project.

5.9.Conclusion

In this chapter the sustainability framework was specified as well as its practical relevance within the mining system. Operational indicators were then identified that will streamline the implementation of these projects.

This allowed the evaluation of environmental impact-reducing projects based on the electricity-saving payback periods, extrapolated to environmental impact reduction savings. Using these values, an integrated payback period could be calculated, which revealed the true value of these projects.

Knowing the environmental impact reduction achieved by these projects allowed them to be assessed based on different funding models. It was shown that, with only one exception, the Eskom-IDM model is still the most feasible option.

The chapter then investigated the data acquisition strategy and discussed present progress on the development of this sustainability framework. Developing this framework allowed the testing of the feasibility of the framework and determining whether it addressed all the problems identified by this study. It was shown that developing this sustainability framework will ensure environmental impact reduction.

6. Conclusion

In this chapter conclusions are drawn regarding the success of the proposed sustainability framework. A comparison is done between the desired and achieved results of the system, and recommendations are made for further study.

6.1.Review of the study

It was seen that the pollution created by mines is having a serious negative effect on the environment. It was thus stated that the environmental impact of mines should be reduced in order to ensure the sustainability of deep-level gold mining in South Africa.

The mining system was in need of an EMS that measures and manages the environmental impact reduction of mines. Numerous EMSs were identified but none has been effective in the mining industry. Mostly, they are aimed at achieving ISO 14001 compliance which does not benefit the mine. In this study, a novel sustainability framework was specified. The sustainability framework was an adaptation of presently available EMSs, specifically tailored to the specific needs of a deep-level gold mine.

Insufficient environmental impact reduction systems decrease the drive to implement environmentally friendly technologies. Additionally, mines are struggling to remain profitable because of strikes, low profit margins associated with the low gold price and the weak exchange rate of the South African Rand.

It was therefore deduced that implementation of the sustainability framework will only be successful if it offers financial benefits to the mine. For this reason the link between electrical efficiency and environmental impact reduction was investigated. This study then identified six projects that were capable of reducing the pollution created by mines and/or reduced the electricity consumption of mines. All of these projects showed environmental impact reduction, although not all of the projects had a favourable payback period.

The environmental impact reduction from each project was investigated and financial and environmental savings were estimated. These projects were implemented at mines and the implementations discussed extensively. These projects were consolidated into a database for electricity- and environmental impact reduction projects that can be utilised in the mining industry.

All six these projects were implemented on mines and significant environmental impact reduction was achieved. This allowed verification of the electricity-savings to confirm that the savings are achievable. Energy efficiency of 11.8 MW and a load shift of 15.6 MW were achieved by the implementation of these projects. An environmental impact reduction was also achieved by reducing the water consumption by 1135 Ml and a carbon dioxide emission reduction of 214 205 tons.

The sustainability framework does not merely measure the environmental impact, but also has the ability to propose specific projects based on operational indicators. This takes into consideration the project payback period and extent of environmental impact reduction.

Understanding these projects allowed the identification of operational indicators that can be monitored continuously. Acceptable ranges for these operational indicators were specified; indicators outside the specified ranges highlight the scope for potential implementation of environmental impact-reducing projects. This potential is then quantified and displayed to the ESCO and the client. This system utilises the SCADA system to gain access to the mine’s data. This will allow the sustainability framework to streamline the project implementations.

It was determined that ESCOs would benefit from the implementation of environmental impact reduction projects. The study then looked at the sustainability framework as part of the energy efficiency project identification done by ESCOs.

Eskom has created a situation where they are delaying supplying the full electricity requirement while they build their new power plants (Kusile and Medupi). This means that the mines reduce their operating cost because of the reduced electricity consumption and resulting reduced maintenance cost. Maintenance cost saving as a result of electricity reduction projects is however left for further study. Most importantly, the pollution created from electricity generation and usage by mines is drastically reduced. This is an ideal situation that benefits all parties involved.

The specifications identified by this study allowed the development of a novel framework for environmental impact reduction. It was shown that mines require more than complying with the ISO 14001 standard to allow them to benefit from environmental impact reduction projects. The competitive edge achieved by implementing these projects is a reduction in operational costs, mainly from reduced electricity usage from implementing projects from the sustainability framework.

ESCOs benefit from the electricity-savings achieved by the environmental impact reduction projects. They acquire funding from Eskom to implement these projects, reducing the financial burden on the mine. ESCOs will also drive and implement these projects which ensure that the mines do not incur unnecessary operating costs. Not only can the project investigation be done free of charge to the mine, but also the sustainability framework implementation and project installation.

Present reporting values were investigated to determine what mines are reporting on. This was then expanded by analysing other authors' literature to determine what additional values should also be reported on. This was consolidated with the operational indicators to specify the values that the sustainability framework should include.

The study investigated different funding models to determine the most effective way of gaining additional funding for mine environmental impact reduction. An energy-efficiency project was analysed based on the different available funding options. It was determined that Eskom-IDM funding through an ESCO is the best funding option for energy-reduction projects.

All of the projects were then analysed based on the Eskom-IDM funding model. Since the funding CERs are dependent on carbon dioxide-reduction, projects were also analysed on the CDM funding model for comparison. This proved that electricity-savings funding is superior to carbon credit funding for these projects.

This study went further to prioritise the projects based on their combined payback period. This allows decision making regarding the implementation order and priority of projects if more than one project is identified simultaneously. This can easily be the case when the EMS is first installed on a mine. This prioritisation was done based on an integrated analysis approach.

In this study it was shown that environmental compliance used to be a burden for the staff at mines. At most mines the perception has shifted and environmental compliance is seen as a way of ensuring sustainability. This study has taken this perception further to show that ultimately, environmental impact reduction projects offer a competitive edge by significantly reducing operating costs.

6.2.Recommendations for further study

Although comprehensive research was done for this study there are still areas that require further research. These include:

1. The effect of airborne metals should be investigated. It was shown that heavy metals are produced in the electricity-generation process, but research regarding the effect of these metals was lacking. It should be investigated to see if these metals settle on the ground and what distances they can cover. Most importantly, the effects of inhaling the heavy metals should be investigated.
2. More electricity-, cost- and environmental impact reduction projects should be identified and included in the sustainability framework. An increase in project identification rates creates a decrease in operating costs.
3. Climate change caused by electricity use and water pollution is the highest threat to human existence. These two pollutants are created extensively in the mining industry, although there is still the potential of investigating other pollutant types. These can all be systematically incorporated into the electricity and environmental impact management system. These should have both an energy- and environmental benefit to be effectively integrated into this system.
4. Electricity-reduction projects also have maintenance cost reduction advantages. It is recommended that this be investigated to further motivate the implementation of electricity-reduction projects.
5. The effect that load shift projects have on the water quality, equipment maintenance and efficiency of the system should be investigated.

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Appendix A – CA project temperature effect

To ensure that the CA project savings is sustainable it is necessary to verify that the CA project does not negatively affect the atmospheric conditions underground. More specifically, it is necessary to measure the temperature and relative humidity of the air supplied to the working areas. A test was done on Mine B to do this verification. Mine B was supplied with regular BAC flow for three days. The CA project then started regulating the BAC flow control. This flow comparison can be seen in Figure 80.

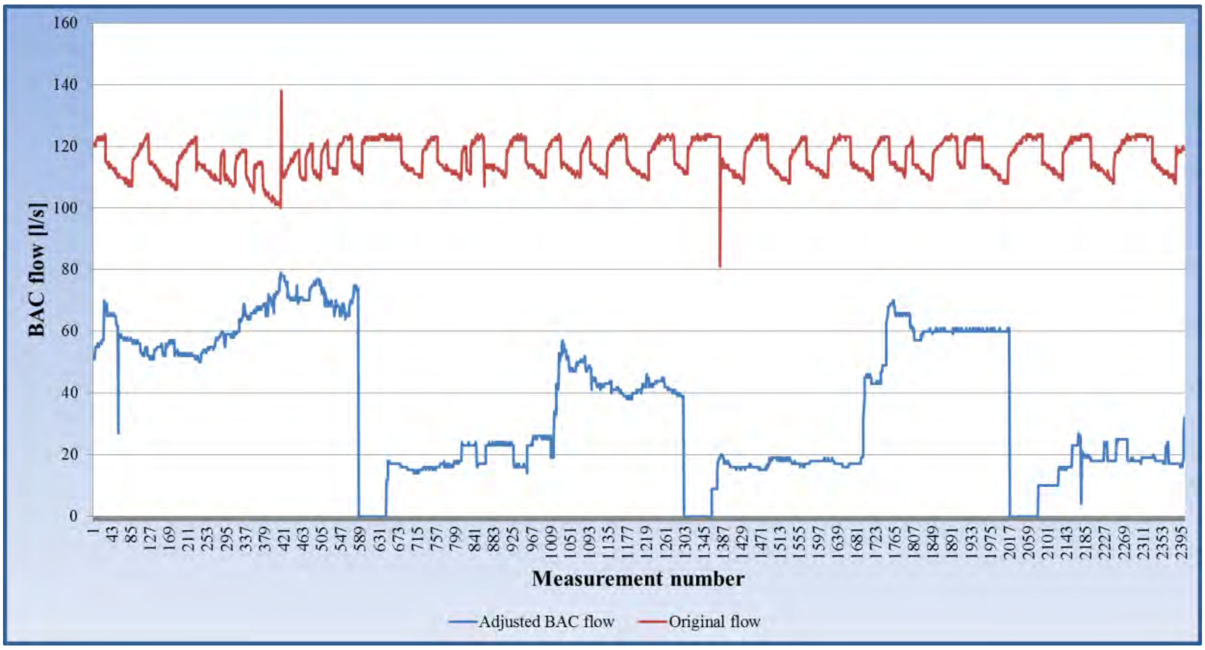

Figure 80: BAC flow during CA testing

It can be seen from Figure 80 that the flow was drastically reduced. Approximately 700 measurements were taken each day starting at 07:00 on the first day. It can be seen that the flow through the BAC was stopped from 18:00 to 20:00 each day. The temperature on the outlet of the BAC can now be investigated to determine the temperature and humidity changes in the air going underground. This can be seen in Figure 81.

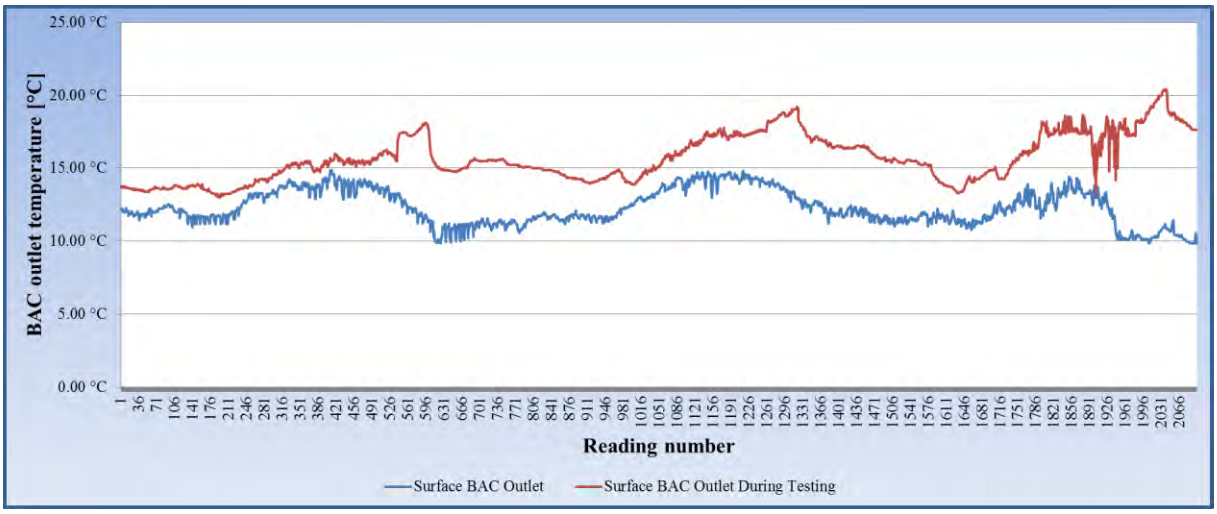

Figure 81: BAC outlet temperature

From Figure 81 it can be seen that there is a significant increase in temperature on the BAC outlet. With the flow reduced, the average temperature increased from 12.3°C to 15.8°C. On Mine B the air travels down the shaft to level 75 from where it goes through an underground BAC before being distributed to the levels. This BAC has two inlets from two different mining sections. The temperature and relative humidity on the inlets of this BAC was measured before and after testing and can be seen in Figure 82 and Figure 83.

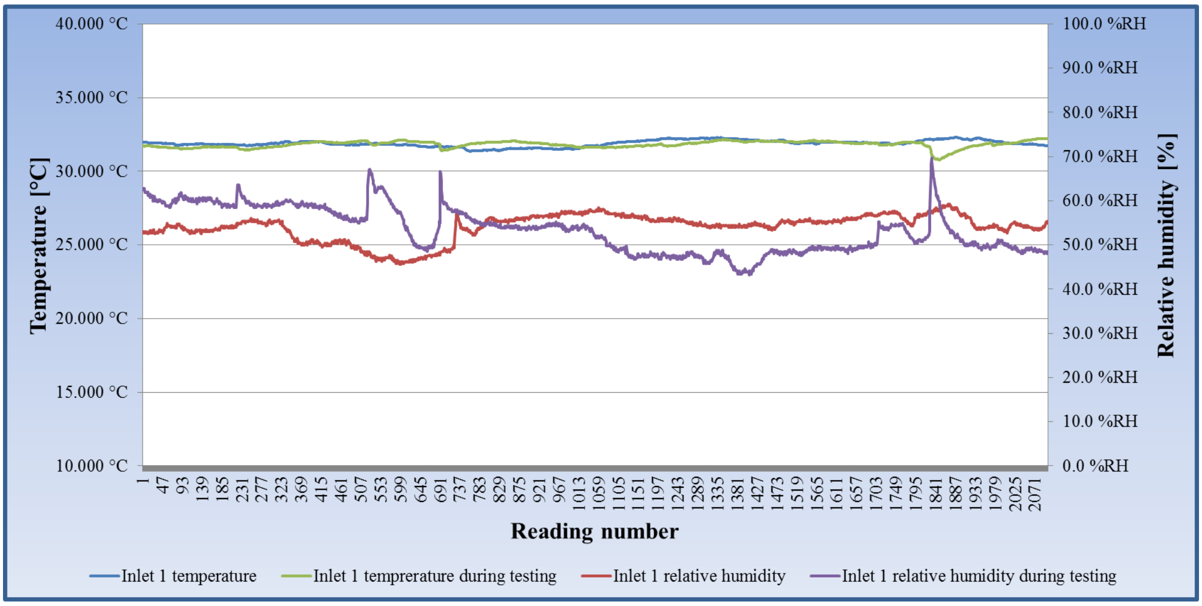

Figure 82: Underground BAC inlet 1

Figure 83: Underground BAC inlet 2

From Figure 82 and Figure 83 it is seen that the dry bulb temperatures are approximately the same as before the flow reduction. It is however evident that the relative humidity has been reduced. The temperatures increased from 31.9°C to 32.1°C and the relative humidity dropped from 52.6%RH to 49.1%RH. The mining regulations specify a wet bulb temperature of 32.5°C as the maximum operating conditions.

At 31.9°C and 52.6%RH the original wet bulb temperature is 24°C. During testing of the CA project the average wet bulb temperature decreased to 23.5°C. This shows that working conditions actually improved with the decreased flow. This is a result of the fact that the air going underground is less humid. This verifies that the decreased flow does not negatively affect the working conditions.

Appendix B – Dissipater valves for turbines

The valves needed to dissipate the flow parallel to the turbines are expensive. This is due to a large pressure build-up in the columns supplying these turbines. Additionally the large pressure drop across the valves causes cavitation if precautionary measures are not taken. This phenomenon can be seen in Figure 84.

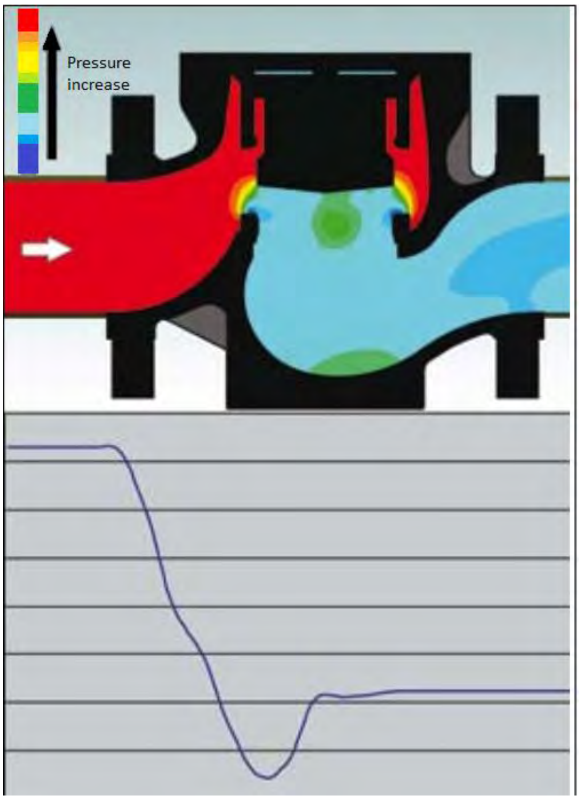

Figure 84: Pressure drop through a globe valve (Flowserve, 2006)

From Figure 84 it can be seen that there is a sudden pressure drop immediately after the valve before the pressure stabilises. This pressure drop causes the water to change to the vapour phase. When the pressure then stabilises these water vapour bubbles collapse.

This causes damage to the valve casing and is known as cavitation. Typically this is rectified by placing anti-cavitation valve trim around the plug of the globe control valve that manages the pressure profile of the water (Flowserve, 2006; Joubert, 2010). This trim adds significant costs to valve installations and can be seen in Figure 85.

Figure 85: Anti-cavitation trim

Appendix C – Electricity storage

To show how electricity storage schemes can reduce the pollution produced by power stations, it is necessary to analyse the electricity consumption of South Africa. The typical Eskom demand profile can be seen in Figure 86.

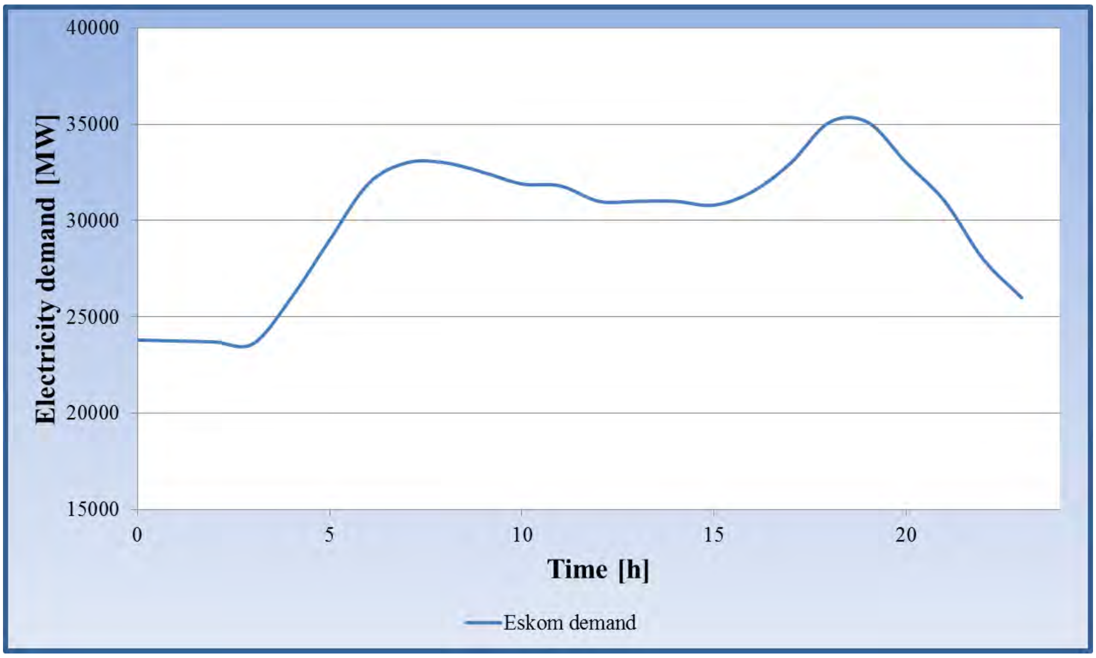

Figure 86: Typical Eskom demand profile

From Figure 86 it is evident that the electricity demand is the highest during the period from 18:00 to 20:00. The high tariff charges during this period serve to demotivate electricity users from consuming electricity during this period. The morning peak from 07:00 to 10:00 is also charged at a higher rate.

The early morning electricity consumption is low and excess generation capacity is available here. This allows Eskom to store electricity in water pumping schemes. During the peak demand this stored electricity can then supplement the electricity grid (Eskom, 2010). The basic operation of these schemes is shown in Figure 87.

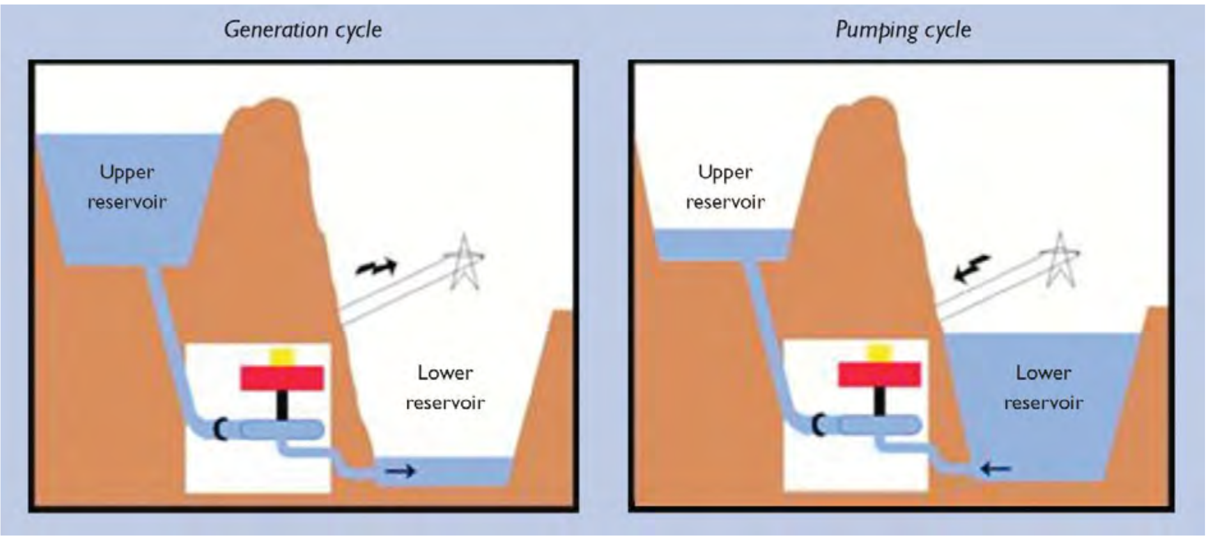

Figure 87: Water pumping storage scheme operation (Eskom, 2010)

Typical examples of these schemes include Drakensberg, Palmiet and Ingula pumped water storage schemes. These allow Eskom to supply more electricity during the peak demand periods. It also has the additional benefit of allowing Eskom to determine which power stations to utilise to store electricity. This has significant environmental impact reduction benefits. To fully understand how it can be beneficial we must investigate the power generation capacity in South Africa. This can be seen in Figure 88.

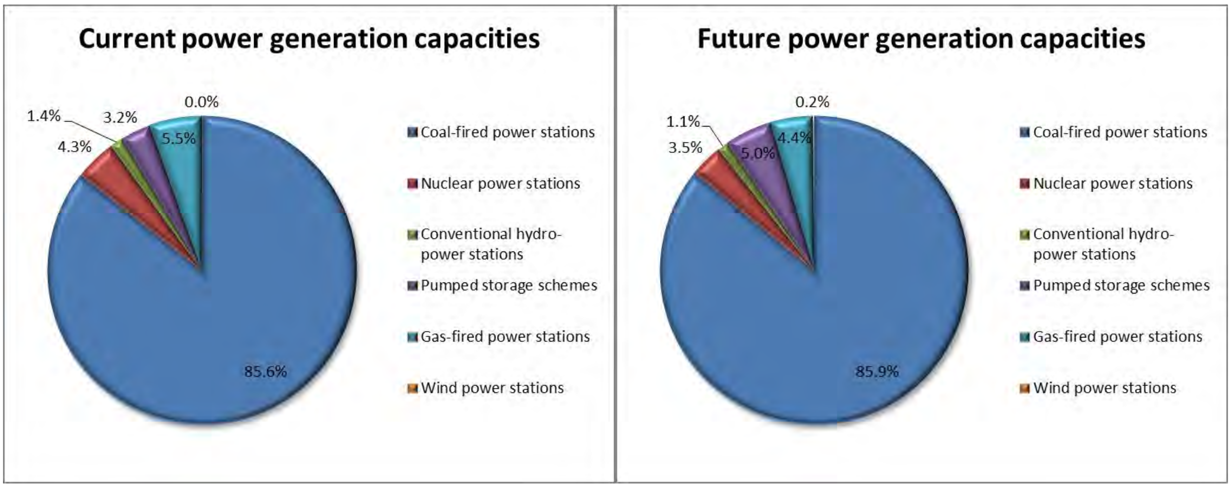

Figure 88: South Africa's power generation capacities

The generally assumed carbon dioxide generation for coal-fired power plants is 973 kg/MWh (Akorede *et al.*, 2012). For gas-fired turbines (known as Combined-Cycle Gas Turbine (CCGT) technology) this value is 488 kg/MWh (House of Parliament, 2011). Additionally the low carbon technologies also produce anthropogenic GHGs that can be quantified in carbon dioxide equivalent emissions (CO_2eq). For nuclear power generation this is 26 kgCO_2eq/MWh (House of Parliament, 2011). For wind turbine power generation this is 9 kgCO_2eq/MWh (Pehnt, 2006). Finally for hydro-power power stations this value is 2 to 13 kgCO_2eq/MWh (House of Parliament, 2011)

It can also be seen that the current storage capacity is 3.2% of the total power supply and this will be expanded to 5%. By expanding this capacity, more of the power generation is shifted from the peak periods to the off-peak periods as shown in Figure 89.

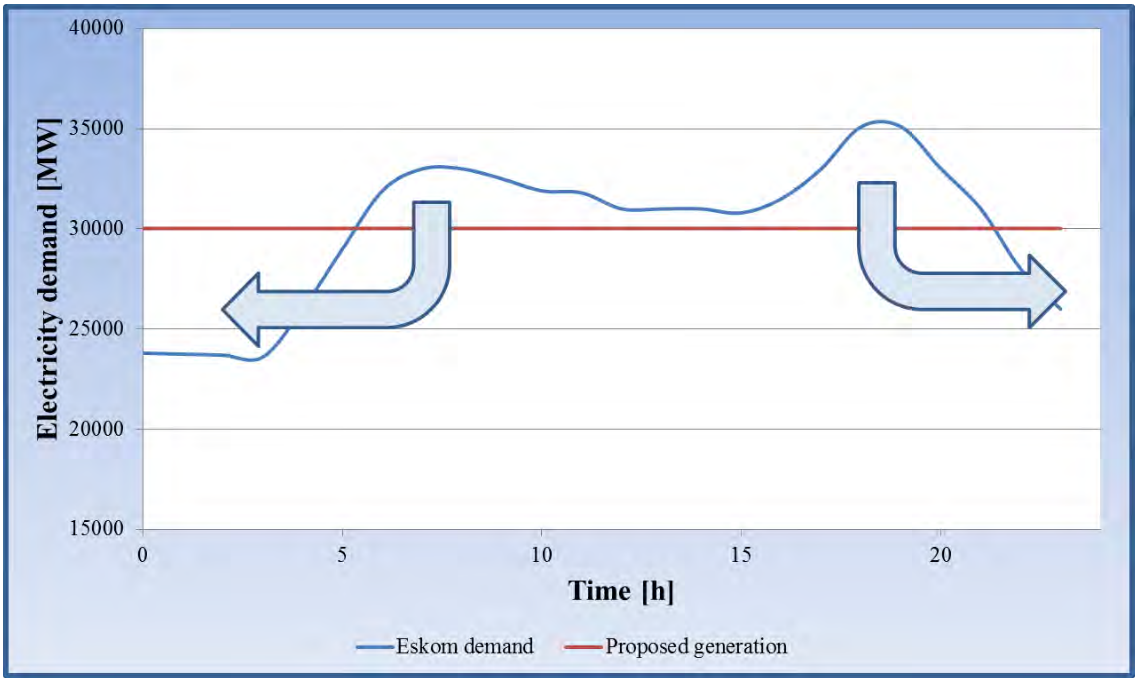

Figure 89: Pumped storage scheme power generation load shift

Another example of electricity storage is methane storage in saline aquifers. As stated the burning of methane in air produces carbon dioxide as shown in Equation [7.1]. Carbon dioxide still attributes to climate change and the production of the gas should be minimised.

$$CH_4 + 2O_2 = CO_2 + 2H_2O \qquad [7.1]$$

To reduce the impact of carbon dioxide, it can be stored in natural reservoirs. This is proposed as a means of limiting the damage done by the burning of fossil fuels. Carbon dioxide gas can be stored in saline aquifers to be converted to methane. This is presently the most promising technology for mitigating the effect of carbon dioxide production (Sato *et al.*, 2013).

These aquifers are available around the globe and carbon dioxide can be pumped into the aquifers. An electrical current is supplied to the saltwater in the aquifer that dissociates it into hydrogen and oxygen. This allows the reaction of the carbon dioxide with the hydrogen to form methane that can be used as a recycled energy source (Sato *et al.*, 2013). This reaction can be seen in Equation [7.2] (Sato *et al.*, 2013).

$$CO_2 + 4H_2 = CH_4 + 2H_2O \qquad [7.2]$$

Because methane is less soluble than carbon dioxide, methane is released into the aquifer in the gas phase. Methane is also lighter than carbon dioxide which allows it to separate to the top. The carbon dioxide is then in contact with the water which allows it to dissolve and react with the hydrogen as it is produced. This process can be seen in Figure 90.

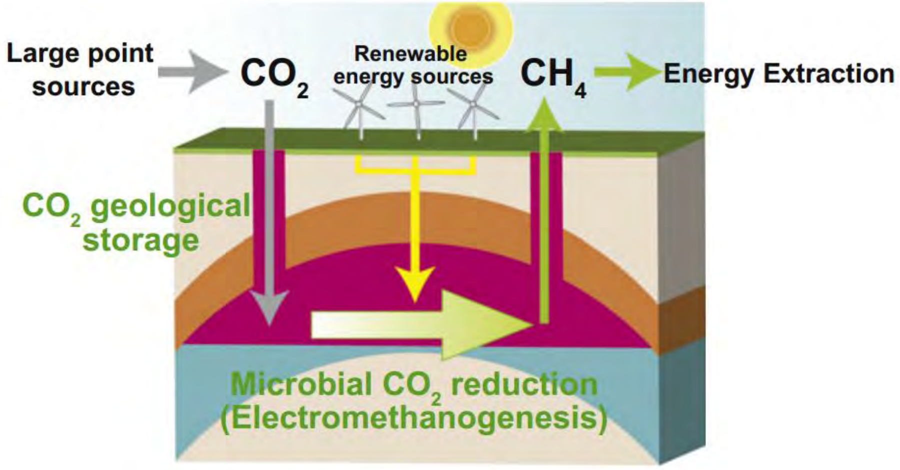

Figure 90: Methane production from carbon dioxide-reduction (Sato *et al.*, 2013)

The power source for the dissociation of the water can typically be supplied by renewable power sources (Sato *et al.*, 2013). Excess power that is generated by power stations can also be used for this application. This allows the storage of excess electricity, similar to water storage schemes. The amount of water that can be pumped to heights to generate potential energy, is however limited.

During the standard and off-peak periods, electricity can be stored for usage during the peak periods. The carbon dioxide to methane conversion process allows for sustained power generation without the production of any greenhouse gasses.

This creates a situation where the most environmentally friendly power generation methods/power stations can be used throughout the day. By doing this, the electricity generated by older power stations that do not have technologically advanced air cleaning processes can be minimised. This is similar to the environmental savings achieved by a pumping project's load shift.

Appendix D – Reports

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ACTION PLAN

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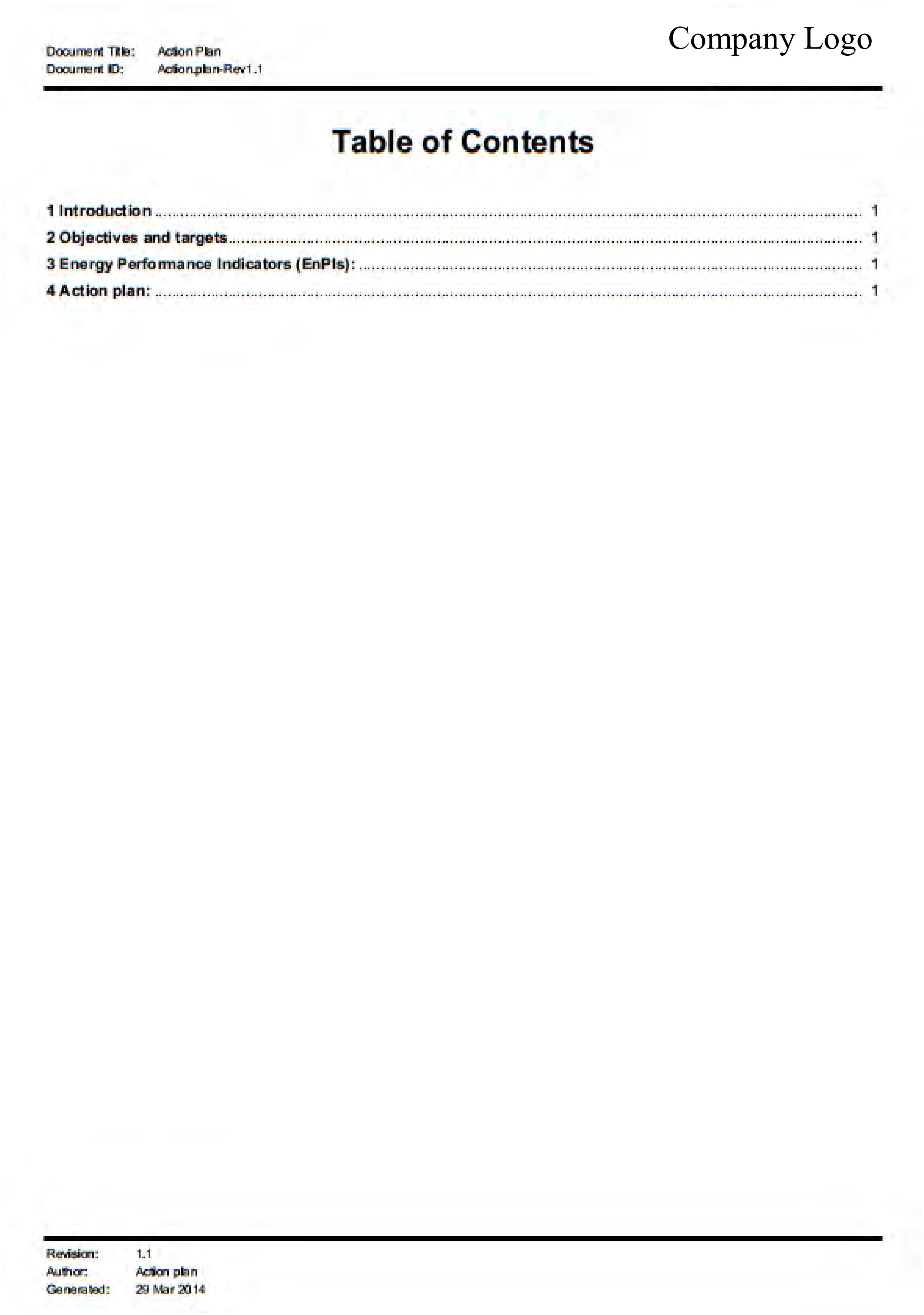

Company Logo

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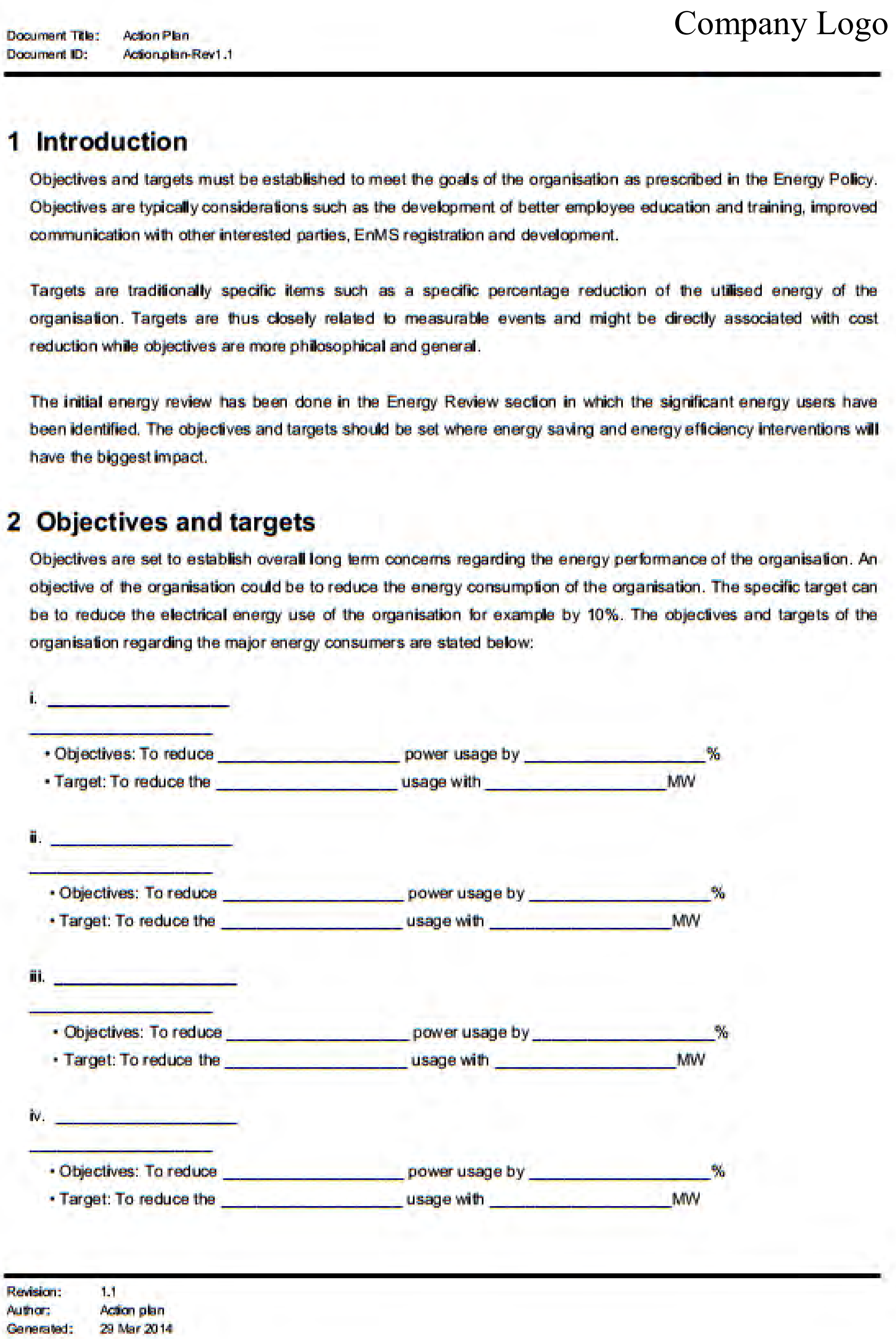

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1 Introduction

Objectives and targets must be established to meet the goals of the organisation as prescribed in the Energy Policy. Objectives are typically considerations such as the development of better employee education and training, improved communication with other interested parties, EnMS registration and development.

Targets are traditionally specific items such as a specific percentage reduction of the utilised energy of the organisation. Targets are thus closely related to measurable events and might be directly associated with cost reduction while objectives are more philosophical and general.

The initial energy review has been done in the Energy Review section in which the significant energy users have been identified. The objectives and targets should be set where energy saving and energy efficiency interventions will have the biggest impact.

2 Objectives and targets

Objectives are set to establish overall long term concerns regarding the energy performance of the organisation. An objective of the organisation could be to reduce the energy consumption of the organisation. The specific target can be to reduce the electrical energy use of the organisation for example by 10%. The objectives and targets of the organisation regarding the major energy consumers are stated below:

i. ____________________
____
- Objectives: To reduce ____________________ power usage by ____________________%
- Target: To reduce the ____________________ usage with ____________________MW

ii. ____________________
____
- Objectives: To reduce ____________________ power usage by ____________________%
- Target: To reduce the ____________________ usage with ____________________MW

iii. ____________________
____
- Objectives: To reduce ____________________ power usage by ____________________%
- Target: To reduce the ____________________ usage with ____________________MW

iv. ____________________
____
- Objectives: To reduce ____________________ power usage by ____________________%
- Target: To reduce the ____________________ usage with ____________________MW

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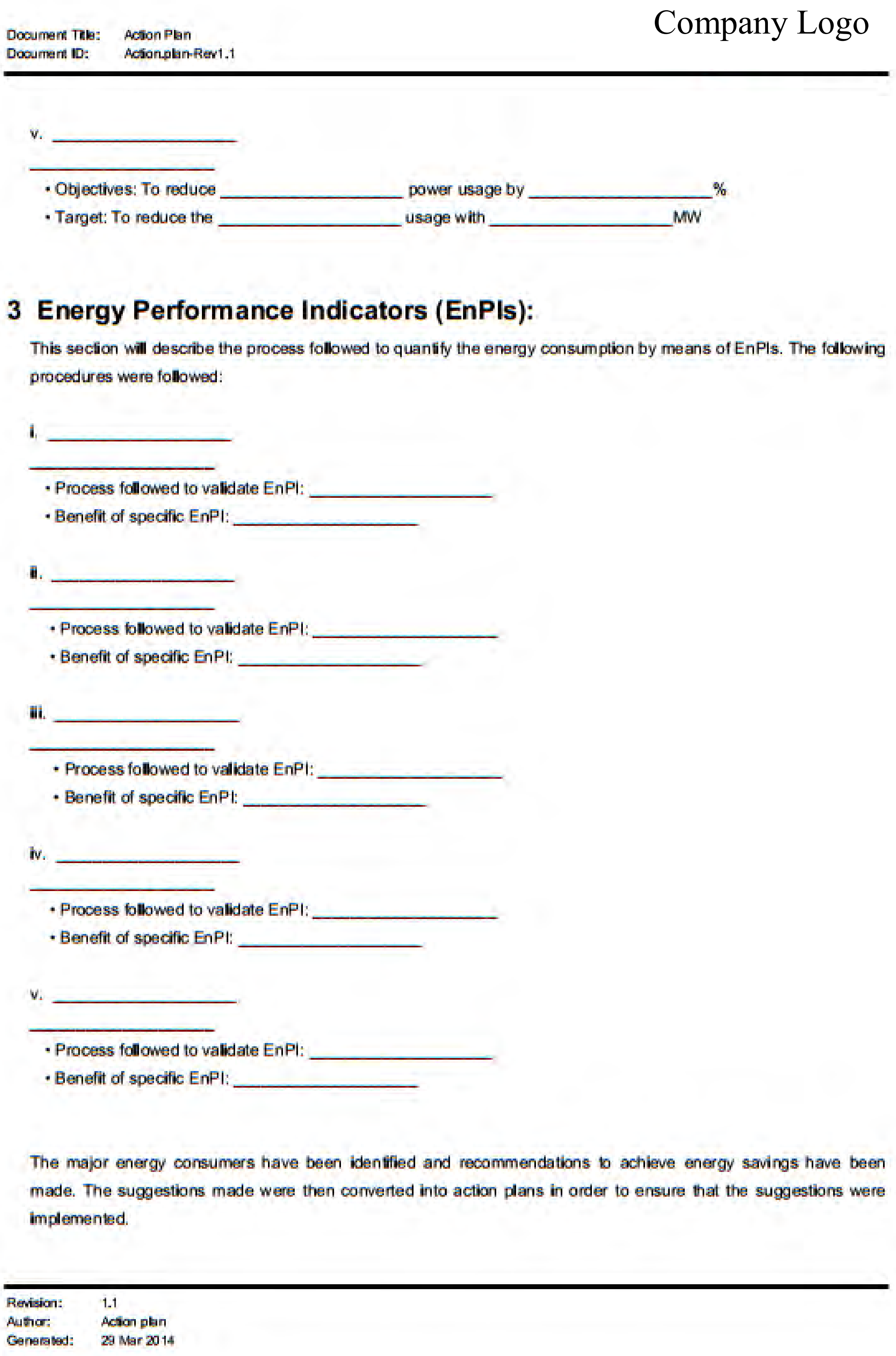

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v. ____________________

____

- Objectives: To reduce ____________________ power usage by ____________________%
- Target: To reduce the ____________________ usage with ____________________MW

3 Energy Performance Indicators (EnPIs):

This section will describe the process followed to quantify the energy consumption by means of EnPIs. The following procedures were followed:

i. ____________________

____

- Process followed to validate EnPI: ____________________
- Benefit of specific EnPI: ____________________

ii. ____________________

____

- Process followed to validate EnPI: ____________________
- Benefit of specific EnPI: ____________________

iii. ____________________

____

- Process followed to validate EnPI: ____________________
- Benefit of specific EnPI: ____________________

iv. ____________________

____

- Process followed to validate EnPI: ____________________
- Benefit of specific EnPI: ____________________

v. ____________________

____

- Process followed to validate EnPI: ____________________
- Benefit of specific EnPI: ____________________

The major energy consumers have been identified and recommendations to achieve energy savings have been made. The suggestions made were then converted into action plans in order to ensure that the suggestions were implemented.

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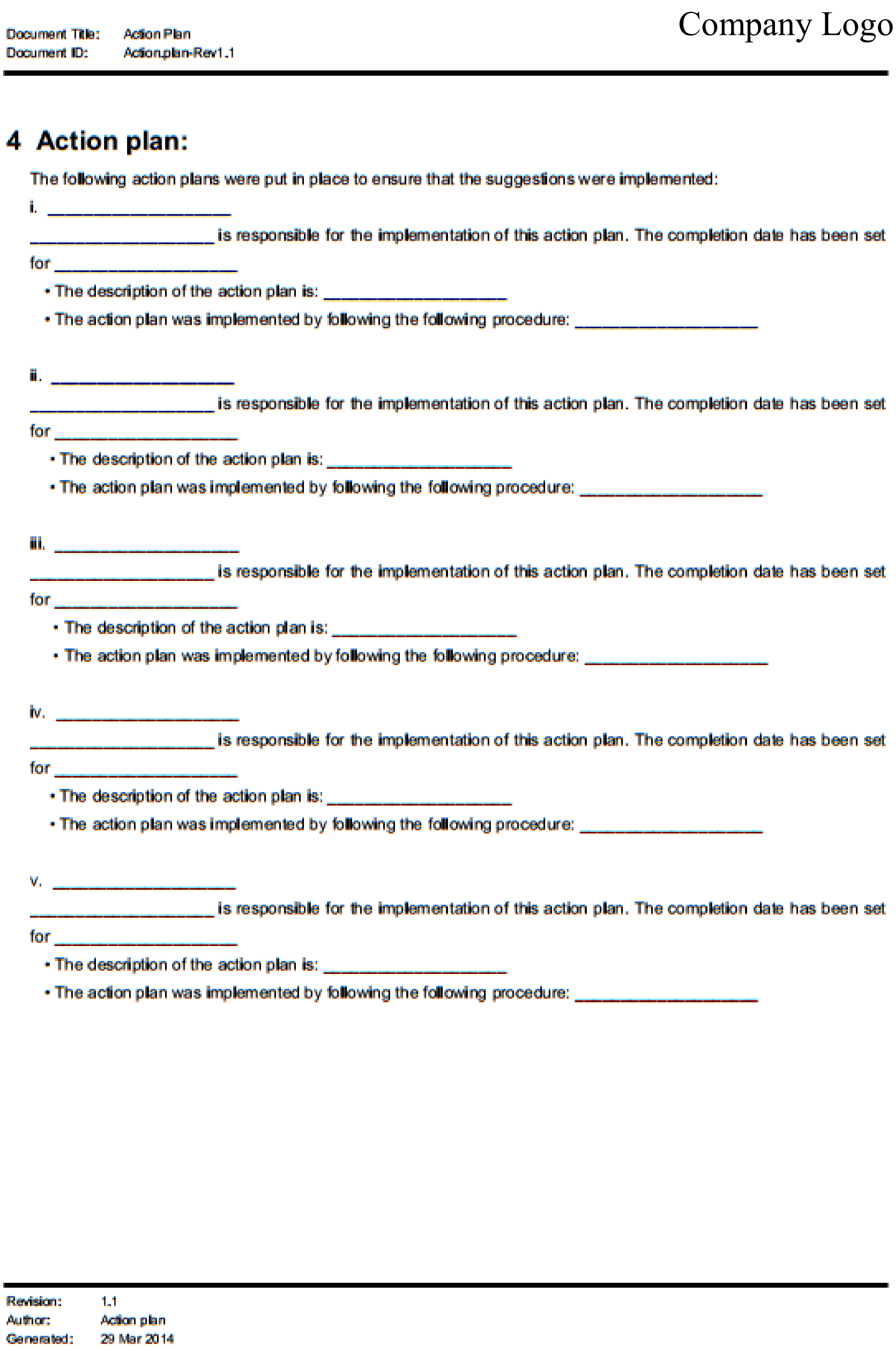

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4 Action plan:

The following action plans were put in place to ensure that the suggestions were implemented:

i. ____________________

____________________ is responsible for the implementation of this action plan. The completion date has been set for ____________________

- The description of the action plan is: ____________________
- The action plan was implemented by following the following procedure: ____________________

ii. ____________________

____________________ is responsible for the implementation of this action plan. The completion date has been set for ____________________

- The description of the action plan is: ____________________
- The action plan was implemented by following the following procedure: ____________________

iii. ____________________

____________________ is responsible for the implementation of this action plan. The completion date has been set for ____________________

- The description of the action plan is: ____________________
- The action plan was implemented by following the following procedure: ____________________

iv. ____________________

____________________ is responsible for the implementation of this action plan. The completion date has been set for ____________________

- The description of the action plan is: ____________________
- The action plan was implemented by following the following procedure: ____________________

v. ____________________

____________________ is responsible for the implementation of this action plan. The completion date has been set for ____________________

- The description of the action plan is: ____________________
- The action plan was implemented by following the following procedure: ____________________

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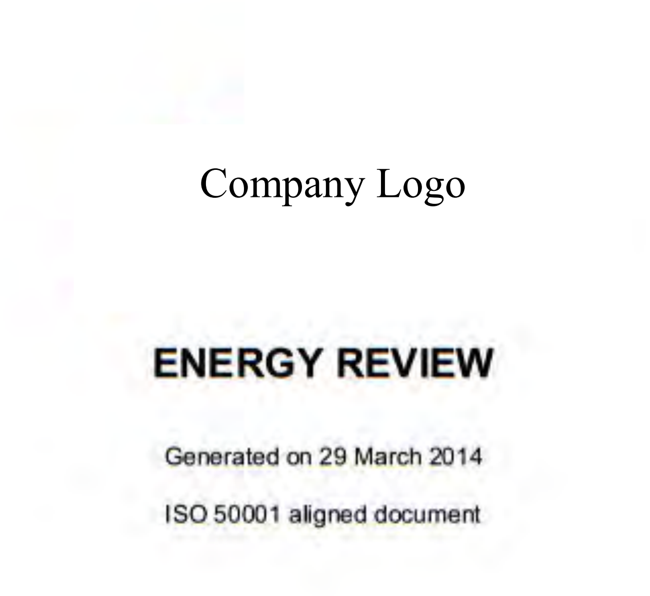

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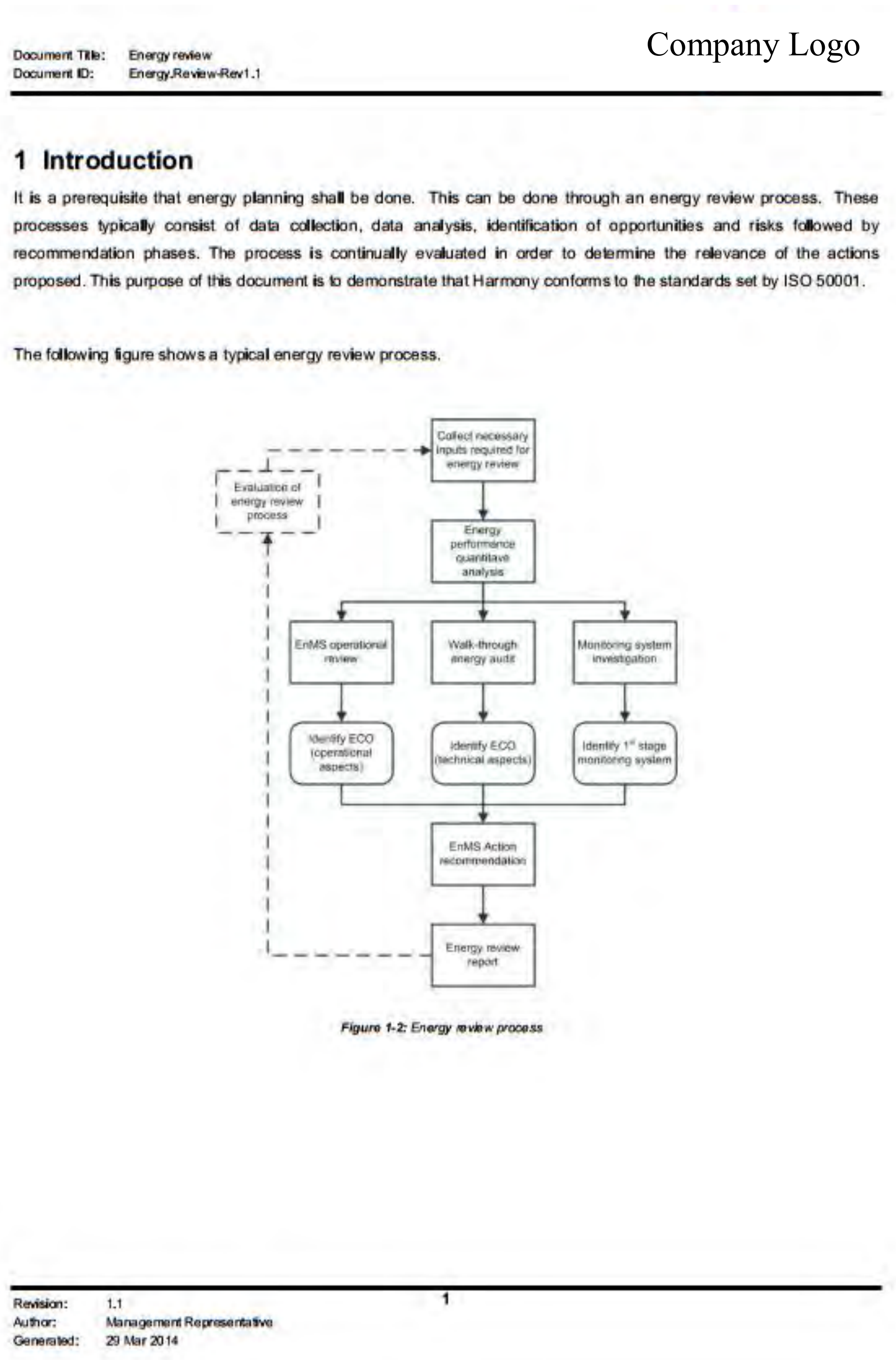
ENERGY REVIEW

Generated on 29 March 2014

ISO 50001 aligned document



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1 Introduction

It is a prerequisite that energy planning shall be done. This can be done through an energy review process. These processes typically consist of data collection, data analysis, identification of opportunities and risks followed by recommendation phases. The process is continually evaluated in order to determine the relevance of the actions proposed. This purpose of this document is to demonstrate that Harmony conforms to the standards set by ISO 50001.

The following figure shows a typical energy review process.

Figure 1-2: Energy review process

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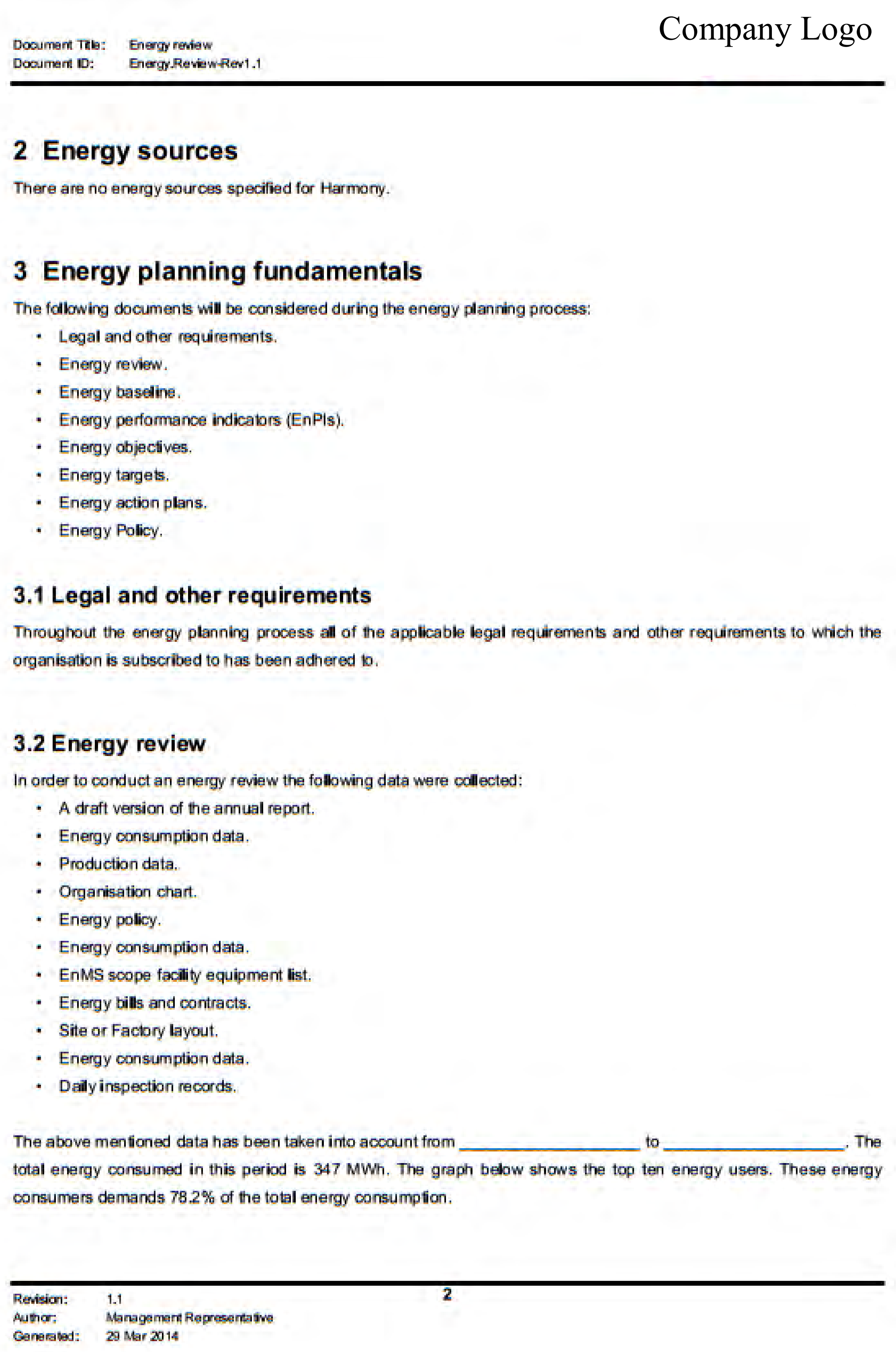

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2 Energy sources

There are no energy sources specified for Harmony.

3 Energy planning fundamentals

The following documents will be considered during the energy planning process:

- Legal and other requirements.
- Energy review.
- Energy baseline.
- Energy performance indicators (EnPIs).
- Energy objectives.
- Energy targets.
- Energy action plans.
- Energy Policy.

3.1 Legal and other requirements

Throughout the energy planning process all of the applicable legal requirements and other requirements to which the organisation is subscribed to has been adhered to.

3.2 Energy review

In order to conduct an energy review the following data were collected:

- A draft version of the annual report.
- Energy consumption data.
- Production data.
- Organisation chart.
- Energy policy.
- Energy consumption data.
- EnMS scope facility equipment list.
- Energy bills and contracts.
- Site or Factory layout.
- Energy consumption data.
- Daily inspection records.

The above mentioned data has been taken into account from ____________________ to ____________________. The total energy consumed in this period is 347 MWh. The graph below shows the top ten energy users. These energy consumers demands 78.2% of the total energy consumption.

2

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Appendix E – Three pipe system

An alternative to installing turbines in the water supply column is the three pipe system, which are more efficient than turbines (Vosloo *et al.*, 2011). The three pipe system relies on the pressure in the water supply to pump the hot water to surface (Janse van Vuuren, 2009). A representation of how the technology works can be seen in Figure 91.

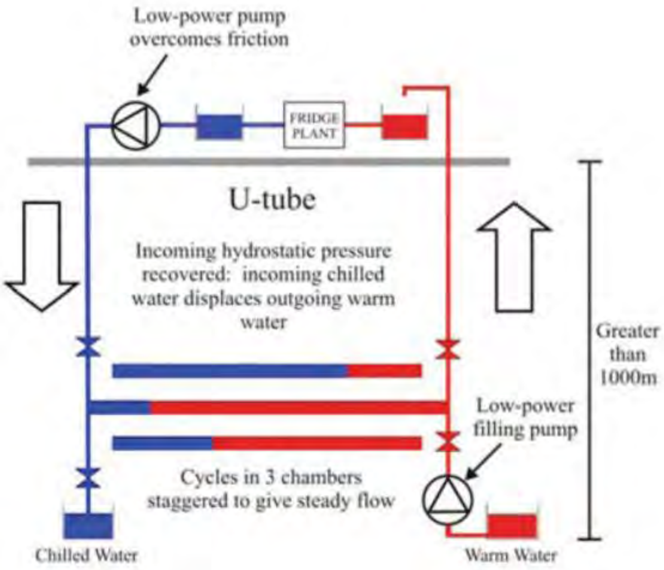

Figure 91: Three chamber pumping system (Adapted from Fraser & Le Roux 2007)

The grey line in Figure 91 represents the surface of the mine. Cold water (Shown in blue) is sent down the shaft. The depth of the mine causes the water to build up pressure. This pressure, in conjunction with the low power pump, pumps the water to surface (Fraser & Le Roux 2007; Janse van Vuuren, 2009). The low power pump compensates for the pressure drop caused by friction in the pipes.

The three pipes are filled with cold water alternately while the hot water is displaced to the surface, aided by the small filler pump. The cold water in the pipes is then replaced with warm water from the underground hot dam while the cold water flows to the underground chill dam. The process is then repeated. The system does unfortunately have the following disadvantages:

- The valves require regular maintenance.

- The valves that regulate the flow have to handle excessive pressures and make the system expensive and complex (Vosloo *et al.*, 2011).
- The implementation can take up to four years (Vosloo *et al.*, 2011).
- All the water must flow through the three pipe system and if the system is down, the mine can flood. As a result redundant water extraction pumps need to be installed to ensure this does not happen. This forces the mine to pay for two separate water extraction systems (Fraser & Le Roux, 2007).
- The fissure water entering the mine ensures that the water that must be pumped from underground is always more than the water sent down the shaft. This must be done through the separate pumping network, as the volume pumped out by the three pipe system can only be as much as the volume sent down.
- The utilisation of these systems typically only range between 51 and 82% (Vosloo *et al.*, 2011).
- The hot water and cold water mixes. This heats up the cold water from the refrigeration machines. This temperature increase has not yet been quantified and as a result is not usually considered when stating the efficiency of these systems.
- Water hammer can occur if the system is not managed correctly. The pressure caused by the water hammer can exceed the maximum rating of the pipe columns causing pipe bursts.