Modelling of electricity cost risks and opportunities in the gold mining industry

LF van der Zee
12663425

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Promoter: Dr R Pelzer

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Abstract

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Author: Mr. L.F. van der Zee
Supervisor: Dr. R. Pelzer
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Carbon tax, increased reactive power charges, tariff increases and the Energy Conservation Scheme (ECS) are some of the worrying electricity cost risks faced by large South African industries. Some of these proposed cost risks are not enforced as yet, but once approved could threaten company financial viability and thousands of jobs.

Managing multiple cost risks associated with electricity consumption at several mines can be laborious and complex. This is largely due to circumstantial rules related to each potential electricity cost risk and unique mine characteristic. To limit the electricity cost risks for a mining company, clear strategies and focus areas need to be identified.

No literature was found that provides a simplified integrated electricity cost risk and mitigation strategy for the South African gold mining industry. Previous studies only focused on a single mine or mining subsystem. Literature pertaining to potential risks is available, however the exact impact and mitigation on the gold mining industry has yet to be determined.

The aim of this study is to accurately predict the impact of electricity cost risks and identify strategies that could alleviate their cost implications. Electricity consumption and installed capacities were used to benchmark mines and categorise them according to investigated risks. The benchmarked results provided an accurate starting point to identify best practices and develop electricity cost saving strategies. This study will highlight the additional benefits that can be obtained by managing electricity usage for a group of mines or mining company.

Newly developed models are used to quantify savings on pumping, compressed air and cooling systems. To manage and report on the potential risks and mitigation, an ISO 50001 based energy management system was developed and implemented. The applied and developed models can also be adjusted to review and manage the potential cost risks on other types of mines.

Derived risk and mitigation models were further used to quantify the impact on one of the largest gold mining companies in South Africa. These models indicate a potential annual price increase of 12%, while mitigation strategies could reduce the electricity consumption by more than 7%. Mitigation savings resulted from proposed projects as well as behavioural change-induced savings due to improved management. Over a five-year period the projects identified could result in electricity costs savings of between R675-million and R819-million.

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Nomenclature

General:

g	Gram
J	Joule
K	Kelvin
m	Metre
t	Tonne
W	Watt
Wh	Watt-hour

Energy Conservation Scheme:

A	Customer's total annual electricity allocation (MWh)
B	Customer's annual electricity allocation in respect of reference loads (MWh)
C	Customer's annual electricity allocation with post reference loads (MWh)
C_{ECS}	Total monthly electricity consumed (kWh)
CBc	ECS Control Band charge (R/kWh)
D	Customer's new connections or additional loads (MWh)
DBc	ECS Disincentive Band charge (R/kWh)
E	Customer's investment allocations or adjusted investment allocations (MWh)
E_{ECS}	Electricity cost with ECS penalties (Rand)
E_{Normal}	Electricity cost without ECS penalties (Rand)
PBc	ECS Punitive Band charge (R/kWh)
Rc	Reference consumption allocated (kWh)
Tc	Eskom tariff charge (R/kWh)

Reactive power:

AC	Administration charges (R)
AE	Active energy charge (R/kWh)
EL	Environmental levy charge (R/kWh)
NA	Network access charge (R/kVA/month)
ND	Network demand charge (R/kVA/month)
P	Real power (kW)
pf	Power factor (-)
Q	Reactive power (KVar)
RE	Reactive energy charge (R/kVArh)
RS	Electrification and rural subsidy (R/kWh)
S	Apparent power (kVA)
TN	Transmission network charges (R/kVA/month)

Pumping:

α	Flow coefficient (-)
ρ	Fluid density (kg/m^3)
ε	Pumping system efficiency (-)
Eps	Daily energy used to extract water from the pump station (J)
g	Gravity acceleration constant (m/s^2)
h	Total head of the pumping station (m)
M	Mass of water pumped (kg)
P_{inside}	Pressure inside the pipe (Pa)
$P_{outside}$	Pressure outside the pipe (Pa)
Q	Volumetric flow (m^3/s)
$\text{E}_{\text{Theoretical}}$	Calculated pumping energy required, excluding losses (kWh)
E_{Actual}	The actual pump electrical energy consumed (kWh)
$cos\varphi$	Load power factor (-)

I_L	Line current (A)
V_L	Line voltage (V)

Compressed air:

$w_{comp,in}$	Energy required to compress a unit mass of air (kJ/kg)
$\dot{m}_{air}$	Compressed air mass flow rate (kg/s)
η_{comp}	Compressor efficiency (-)
η_{motor}	Efficiency of the electrical motor (-)
F_{line}	Power to line pressure ratio (kW/kPa)
A	Minimum cross-sectional area (m^2)
$C_{discharge}$	Discharge coefficient (-)
k	Specific heat ratio (-)
n	Polytropic compression exponent (-)
$P_{electrical}$	Electrical power (kW)
$P_{electrical}$	Electrical power (kW)
p_{line}	Line pressure (kPa)
p_{line}	Line pressure (kPa)
p_1	Compressor inlet pressure (kPa)
p_2	Compressor discharge pressure (absolute pressure) (kPa)
R	Gas constant (287 J/kg.K)
T_{inlet}	Line temperature (K)

Cooling:

ΔT	Change in temperature (°C)
$\dot{m}$	Mass flow (kg/s)
$\dot{m}_{in}$	Inflow (ℓ/s)
$\dot{m}_{out}$	Outflow (ℓ/s)
$\dot{Q}_c$	Chiller rated cooling capacity (MW)
$\dot{W}_{rated}$	Pump or fan power rating (MW)

C_p	Specific heat constant (-)
COP	Coefficient of performance (-)
DL_1	Previous dam level (%)
DT_1	Previous dam temperature (°C)
DT_2	New dam temperature (°C)
Dv	Dam volume (m^3)
$EC_{chiller}$	Chiller electrical energy consumption (MWh)
$EC_{pump,fan}$	Pump or fan electrical energy consumption (MWh)
LF	Loading factor (-)
$m_{measured}$	Measured flow before VSD implementation (ℓ/s)
$m_{reduced}$	Reduced flow with VSD implementation (ℓ/s)
OH	Operating hours (h)
P_{pump}	Measured power usage of pump with measured flow (kW)
Q	Thermal energy (J)
$Q_{average}$	Electrical load of the plant (kW)
$Q_{installed}$	Installed capacity of the plant (kW)
t	Time (hour)
T_{in}	Temperature of inflow (°C)
T_{out}	Temperature of outflow (°C)
$VSD_{savings}$	Savings resulting VSD flow reduction (kW)

Modelling:

$E_{Savings}$	Electricity savings (kWh)
E_{Cost}	Electricity cost (R/kWh)
$DSM_{funding}$	DSM funding (R/kWh)

Abbreviations

3D	Three Dimensional
3CPFS	Three Chamber Pipe Feeder System
BAC	Bulk Air Cooler
CDM	Clean Development Mechanism
CER	Certified Emissions Reduction
COP	Coefficient Of Performance
DB	Dry Bulb
DEA	Department of Environmental Affairs
DME	Department of Minerals and Energy (South Africa)
DMP	Demand Market Participation
DR	Demand Response
DSM	Demand Side Management
ECS	Energy Conservation Scheme
EEC	Energy Efficient Certified
EEDSM	Energy Efficiency DSM
EGM	Electricity Growth Management
EMS	Energy Management Systems
ESCo	Energy Service Company
GHG	Greenhouse Gases
IDM	Integrated Demand Management
IPCC	Intergovernmental Panel on Climate Change
M&V	Measurement and Verification
MYPD3	Multi Year Price Denomination Three
NERSA	National Energy Regulator of South Africa

NERT	National Electricity Response Team
PCP	Power Conservation Program
PDCA	Plan-Do-Check-Act
PRV	Pressure Reducing Valve
PWM	Pulse With Modulation
RTC	Right To Consume
SANAS	South African National Accreditation System
SANEDI	South African National Energy Development Institute
SARS	South African Revenue Service
SCADA	Supervisory Control and Data Acquisition
TOU	Time Of Use
UNFCCC	United Nation Framework Convention of Climate Change
VRT	Virgin Rock Temperature
VSD	Variable Speed Drive
WB	Wet Bulb