ENERY USAGE – WORK PACKAGE 10

IMPACTS OF ESKOM TARIFF HIKES ON MINING UNIT COSTS AND ENERGY INTESNIVE ACTIVITIES ON THE MINING CYCLE

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PROGRAMME : LONGEVITY OF CURRENT MINES (LoCM)

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Report Structure

In 2015, the Mining Phakisa recognised the need to extend the life of gold and platinum mines through targeted Research and Development (R&D). To this end, the South African Mining, Extraction, Research, Development and Innovation (SAMERDI) was established. The objectives of the SAMERDI programme are to find solutions that will improve the competitiveness of the South African mining sector and to reposition the country as a leader in mining related R&D. The SAMERDI programme consists of six separate programmes that aim to ensure the sustainability of the mining sector through different areas of research.

As part of the Longevity of Current Mines (LoCM) programme, energy usage in existing narrow reef underground gold and PGM mines was identified as a focus area, as it is a significant contributor to operational costs. The overall aim of the energy usage project is to undertake a high-level study into potential energy cost savings in the mining industry. The output of this research project is presented in a series of four reports that cover the following topics

Report 1: Trends and impacts of Eskom tariff hikes on mining unit costs

1. Identify trends in Eskom electricity tariffs, and diesel 2014 – 2018)
2. Determine the impact that the tariff hikes have on mining unit costs
3. Investigate the impact that the Carbon tax could have on electricity prices
4. Determine energy intensive mining activities

Report 2: Use cases on alternative energy sources applicable to mining

5. Investigate opportunities offered by alternative energy sources and their possible applicability to mining activities

Report 3: Use cases on regenerative energy sources applicable to mining

6. Investigate opportunities offered by regenerative energy technologies and their possible applicability to mining activities

Report 4: Preliminary value proposition of alternative and/or regenerative energy sources applicable to the mining industry

7. Estimate the CAPEX and OPEX costs associated with the introduction of each energy source
8. Conduct a financial valuation to determine the value proposition of the alternate and/or regenerative energy source
9. Scope a further project for more detailed studies based on the preliminary value proposition.

Report 1: Executive Summary

Due to the reliance on electricity as the primary energy carrier, underground gold and platinum mines have a high exposure to rapidly rising electricity costs. This report chapter presents an analysis of the effects of increasing electricity, diesel and coal prices on costs of gold and platinum production.

Between 2005 and 2018, the average selling price of electricity in South Africa has increased by 430% (150 % excluding inflation). As commodity, prices are set by the global market this rapid increase in input costs has been difficult to absorb by the sector. Unfortunately, even if the operational challenges within Eskom are addressed, the cost of electricity is projected to continue to increase above inflation. Modelling presented by the Department of Energy indicates that the real price of electricity will increase by 70 % between 2019 and 2050. Eskom supply constraints also present a threat to the mining energy security, with load shedding in 2019 reaching 769 GWh.

This report concludes with a high-level overview of energy intensive surface and underground mining activities, in order to inform opportunities for alternative and regenerative energy sources. An outline of typical cooling and ventilation systems, surface operations, transport and water pumping is presented to contextualise the consumption of energy within mining operations.

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1 Introduction

1.1 The mining sector and energy in South Africa

The mining sector in South Africa is energy intensive requiring in excess of 200 PJ of energy annually for the extraction and processing of minerals. Over the past three decades, large underground mining operations (gold and PGM) have developed in the context of low electricity prices (below R0.5/kWh). Currently electricity is the primary energy carrier in the mining sector accounting for more than two-thirds of final energy consumption. Thus, the industry has a high exposure to increasing electricity prices as well as Eskom electricity generation constraints. The sector also accounts for a significant fraction of coal and diesel consumption by industry. Diesel prices are dependent on the international oil price as well as the ZAR/USD exchange rate, resulting in volatile energy costs. The price of coal supplied to local companies is also steadily increasing as the international price of coal spurs.

In contrast to other industrial sectors, the mining industry is a "price-taker" where commodity prices are set by the global market and cost increases cannot be transferred to the final product price (Chamber of Mines of South Africa 2018), making it particularly sensitive to increases in input costs due to the marginal nature of the industry. Therefore, it is critical to re-evaluate the status quo of energy generation and consumption by the mining sector and determine new opportunities to reduce energy costs, ensure energy security, improve energy efficiency and decrease carbon intensity.

In the context of rising electricity and fossil fuel prices, two global mega-trends are emerging based on energy efficiency and the rapidly decreasing costs of renewable energy generation. This report presents a high-level investigation of energy efficiency and renewable energy opportunities in underground mining operations.

It is important to contextualise changes in the energy consumption of the mining sector with structural changes within the South African mining sector, which historically developed around gold production. The contribution to Gross Value Added (GVA) of mining sub-sectors is presented in Figure 1: Contribution to GVA at 2016 prices between 1994 and 2018

, with the effects of inflation removed. Overall, the mining sector GVA has remained relatively constant over time, varying between ZAR 325-350 billion (constant 2016 ZAR). The GVA contribution of gold has decreased significantly, while metals (led by PGMs) have grown over the past 15 years. The changes in production output from the key mining sub-sectors of gold and PGMs are presented in Figure 2. Between 2000 and 2016 gold decreased by 67 %, while platinum increased by 22 % (EasyData 2019).

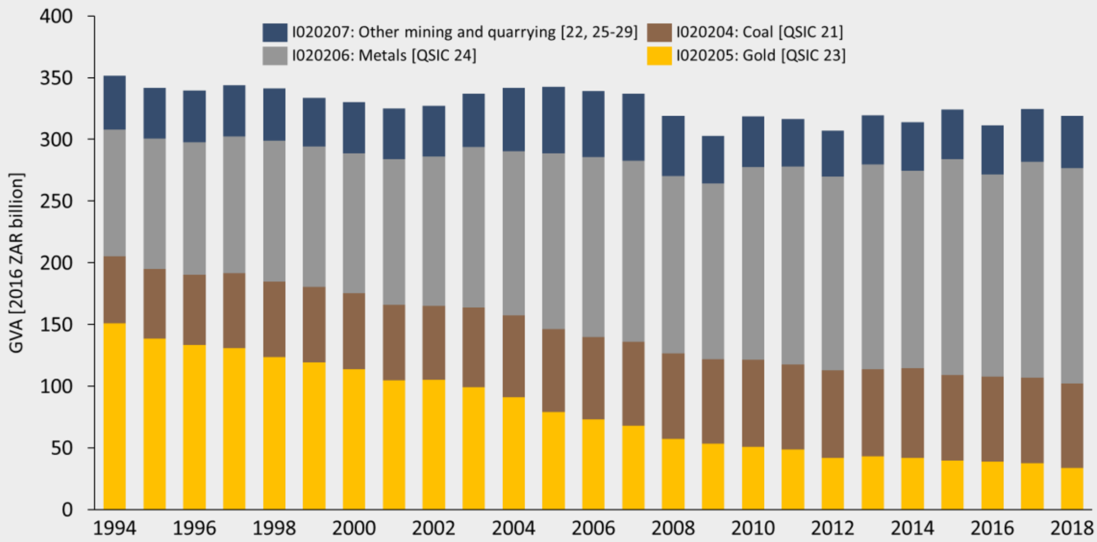


Figure 1: Contribution to GVA at 2016 prices between 1994 and 2018 (EasyData 2019)

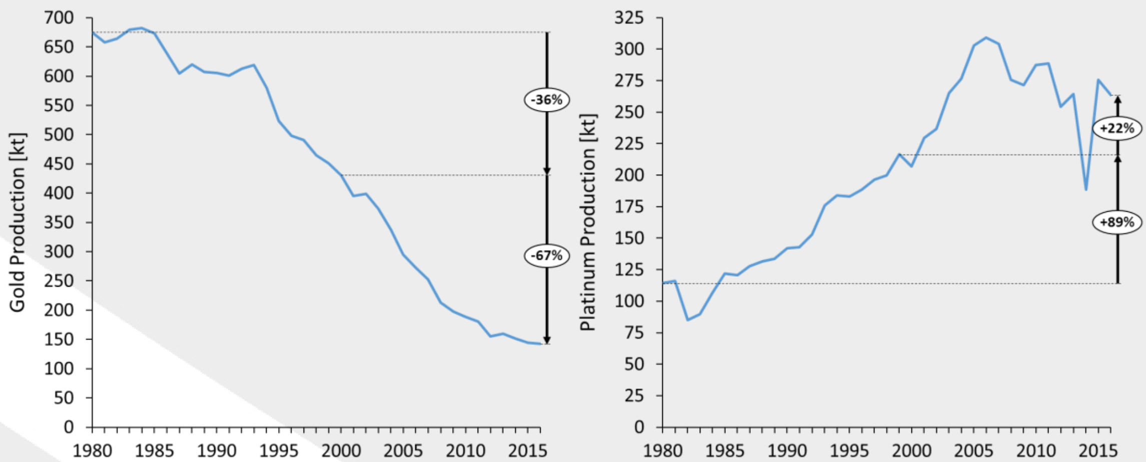


Figure 2: Annual production outputs from gold and platinum sectors (EasyData 2019)

2 Trends and impacts of Eskom tariff hikes on mining unit costs

2.1 Energy consumption analysis

The type of mining operation has a strong influence on the consumption of energy, both in terms of quantity and form of energy carriers. Underground gold and PGM mines are energy intensive and require a significant amount of electricity, while surface mines typically require a higher fraction of diesel. Coal is also consumed in the processing of minerals in mines that include pyrometallurgical plants. In the early 1990s the mining sector accounted for 44 % of industrial electricity consumption and 17 % of Final Energy Consumption (FEC) by industry (Department of Energy 2018). According to the latest Energy Balances by the Department of Energy (DoE), the sector now consumes 28 % of industrial electricity consumption and 16 % of industrial FEC (Department of Energy 2018). Despite the decrease in gold mining production and energy consumption, the mining sector remains the largest consumer of electricity second largest consumer of energy by heavy industry and in South Africa.

Figure 3 presents the FEC according to historical Energy Balances. Between 1992 and 2015, electricity consumption has remained relatively constant at 110-120 PJ, while diesel and coal consumption have been steadily increasing. As with other industrial sub-sectors, the DoE allocation of coal in the energy balances is inconsistent, varying significantly between years. The Energy Research Centre (ERC) conducted their own analysis for the base year 2006 and found that the DoE allocation of coal to the mining sector is underestimated (Energy Research Centre 2014). Thus, as indicated by the ERC, it is likely that annual coal consumption in the overall mining sector is between 30-50 PJ annually.

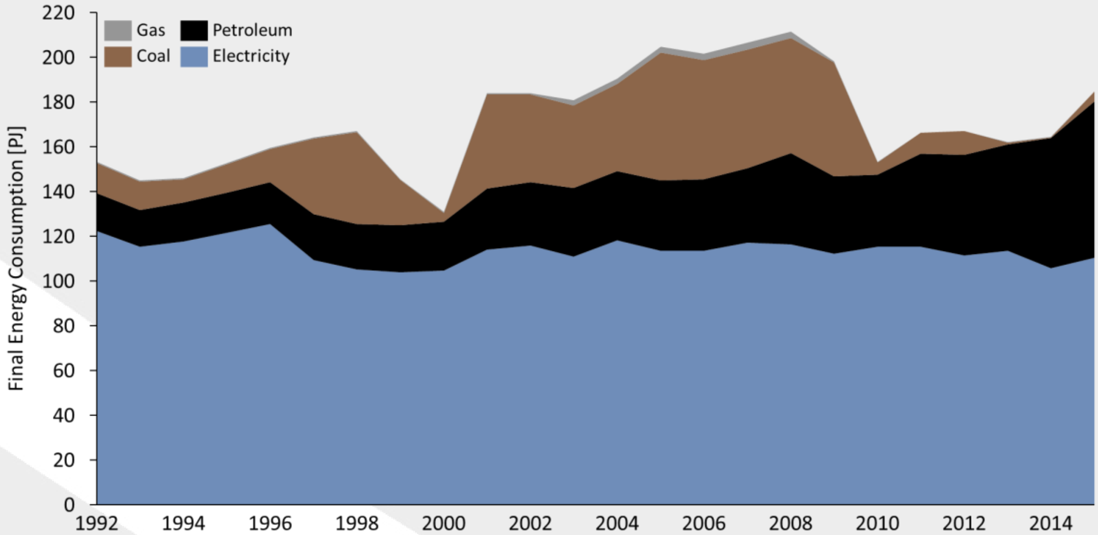


Figure 3: Energy balances for the South African mining sector (Department of Energy 2018)

Prior to 1997 Eskom released a breakdown on the electricity consumption within the mining sector. As indicated by Figure 4, electricity consumption from 1990 onwards was in the order of 30 TWh per year, which was predominantly from the gold and platinum sectors. Unfortunately, this data is no longer available from Eskom. In a recent submission to the National Energy Regulator of South Africa (NERSA) Eskom submitted a report compiled by Deloitte with a breakdown of electricity consumption in the mining sector up until 2008. The data presented in Figure 5 highlights the reduction in electricity consumption by the gold sector and increasing consumption of electricity by the platinum sector.

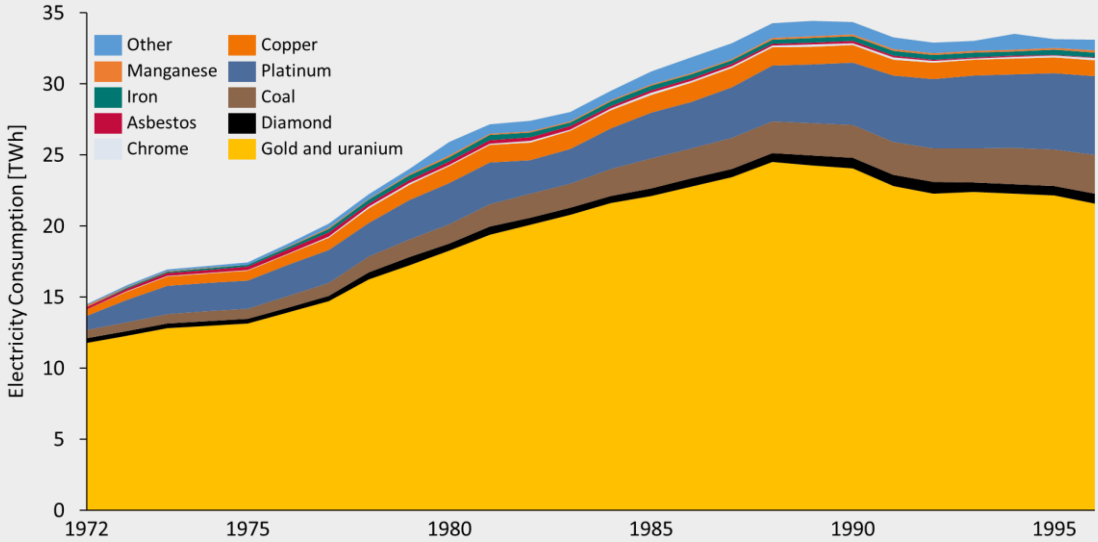


Figure 4: Breakdown of electricity consumption by the mining sub-sectors according to Eskom

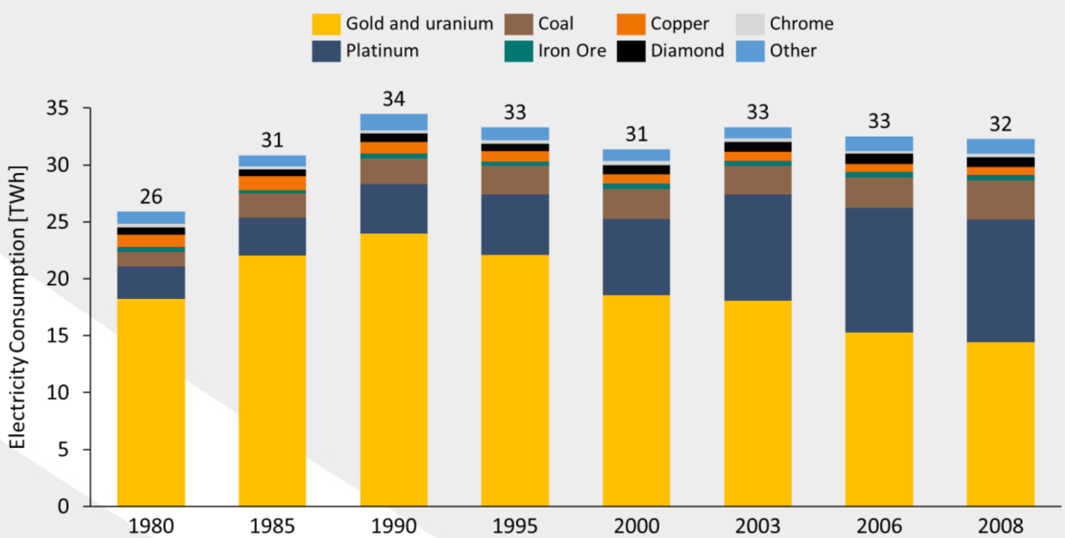


Figure 5: Electricity consumption by mining sub-sectors (Deloitte 2017)

2.2 Energy cost analysis

2.2.1 Energy price trends

As shown in Figure 6, real electricity prices (CPI adjusted) decreased between 1980 and 2008. However, with the electricity supply crisis of 2008, Eskom embarked on a large-scale capacity expansion plan, leading to rapidly rising electricity prices. In nominal terms, the average Eskom selling price of electricity has increased by 430 % between 2005 and 2018, which equates to a 150 % increase in real terms (constant 2016 Rand).

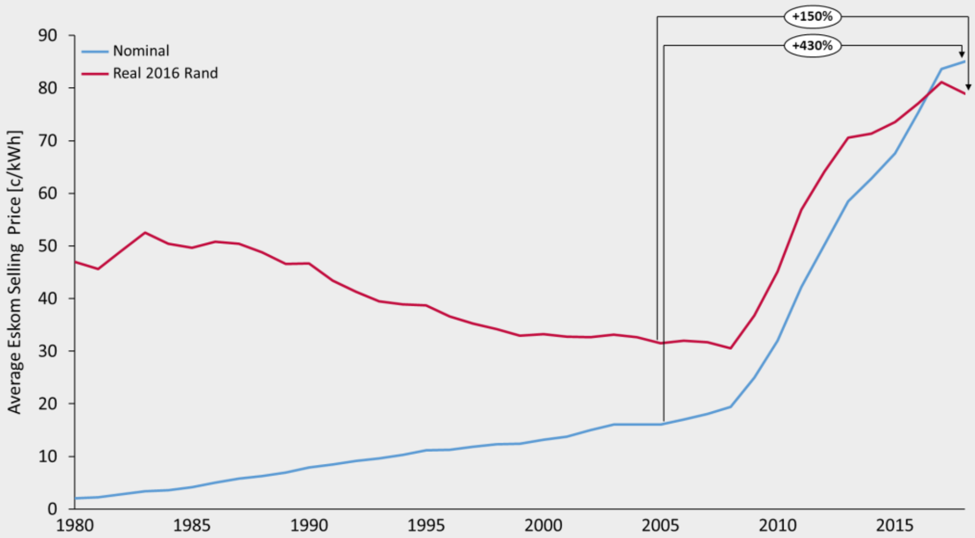


Figure 6: Average selling price of electricity between 1980 and 2018 (Eskom)

Unfortunately, even if operational challenges are addressed within Eskom, it is projected that the cost of electricity will continue to increase over the next two decades as the aging Eskom coal fleet is decommissioned and new generation capacity is commissioned. As shown in Figure 7, the current draft Integrated Resource plan for South Africa estimates that the cost of electricity will rise by 70 % in real terms between 2018 and 2050, which could result in many operations in the mining sector becoming unprofitable, unless significant changes are adopted.

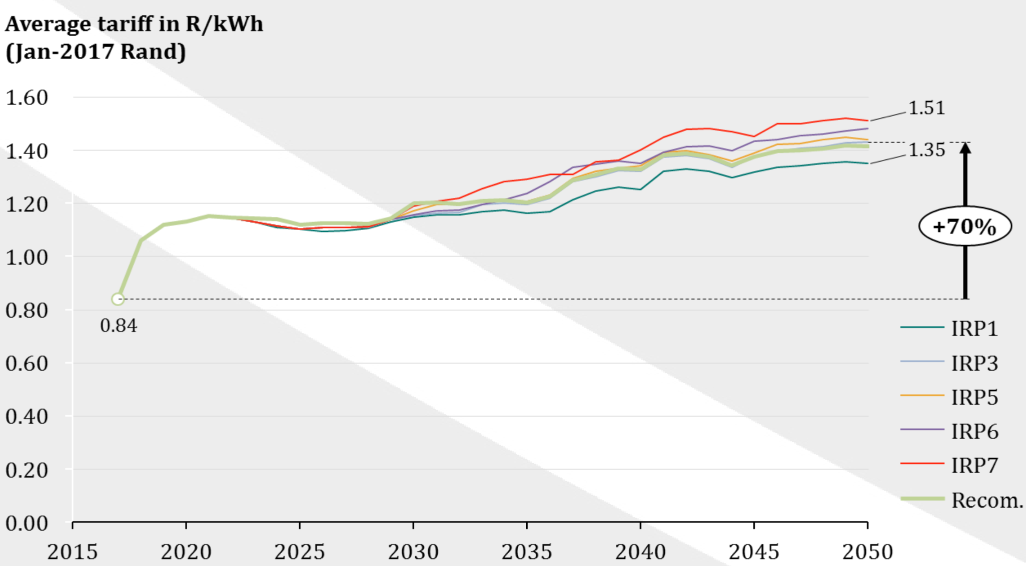


Figure 7: Projected real price of electricity (Department of Energy 2018)

The mining sector also makes extensive use of fossil fuels in the form of coal and diesel for transportation and minerals processing. Diesel prices are dependent on the international oil price and the ZAR/USD exchange rate. The wholesale diesel price between 2006 and 2019 is presented in Figure 8. In real terms, the price has not risen significantly, however the price is volatile and as the international oil price recovers, the price will continue to increase. The mining sector qualifies for rebates under the Diesel Fuel Refund System, which reduces costs in comparison to the wholesale price, although the future of the rebate system is not guaranteed.

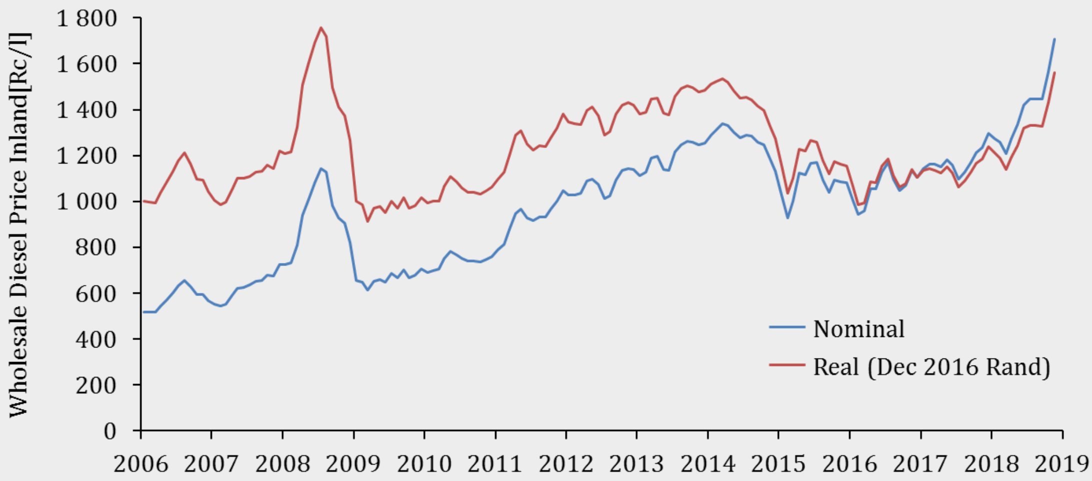


Figure 8: Variation in wholesale diesel price between 2006 and 2018

It is difficult to track the cost of local coal supply to industry due to confidential supply agreements, as well as the influence that transportation has on the coal price. The price of local and export coal according to the DoE is given in Figure 9. Local coal includes the low cost coal supplied to Eskom and is not likely to be representative of the price paid by the local industry. Thus, the export coal price is a better proxy for the price of coal. The prices given below exclude transportation costs for delivery, which can be significant (R200-800/ton depending on the plant location in South Africa).

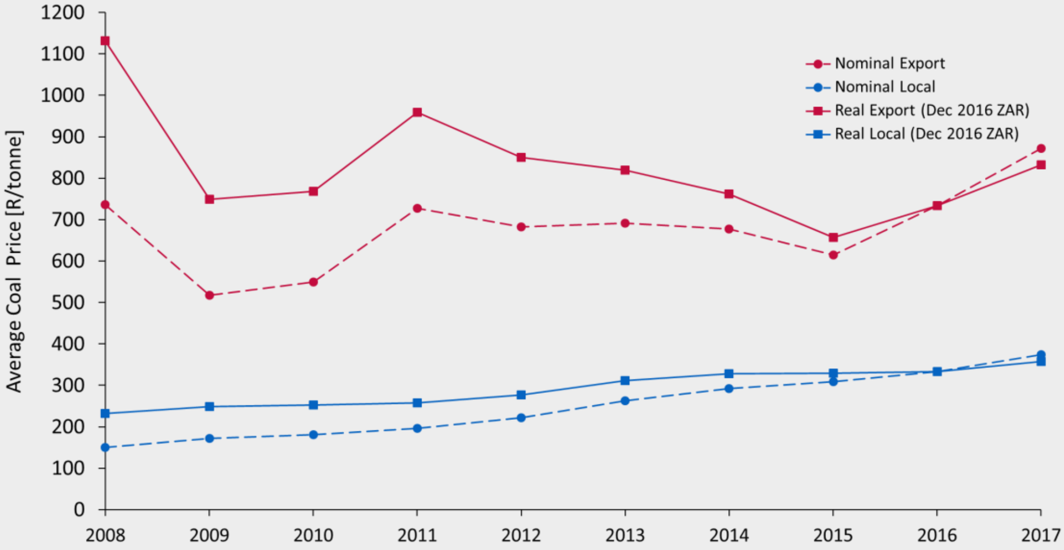


Figure 9: Coal prices as of January each year FOB/FOR (Department of Energy 2016)

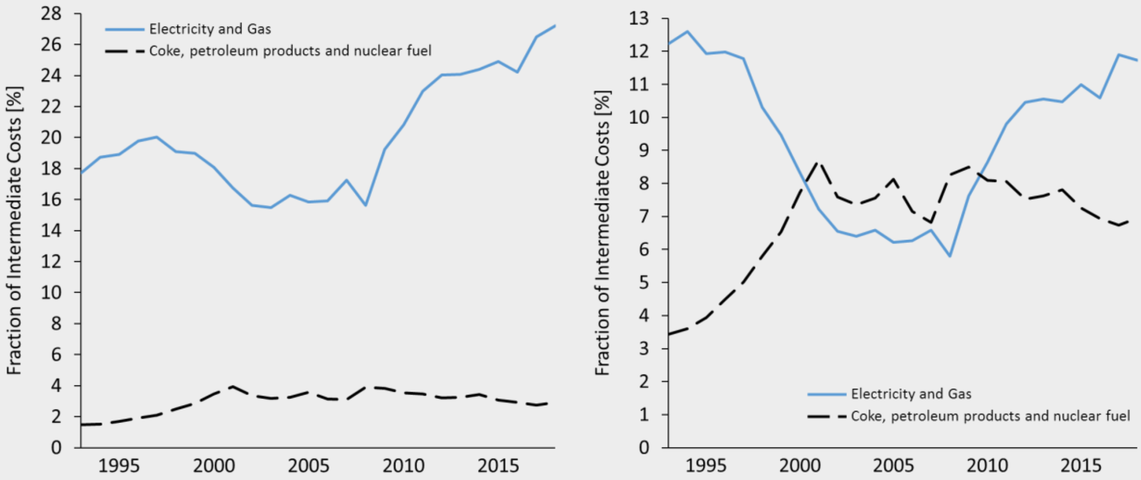
2.3 Effect of energy price increases on mining input costs

2.3.1 Statistics South Africa data

The industry Input-Output data from Statistics South Africa (Stats SA) can be used to assess the contribution of electricity to input costs in the mining sector. Intermediate consumption is defined as, *"Expenditure by enterprises on goods and services consumed as inputs in the production process"*, evaluated at the purchaser's price (EasyData 2019). Intermediate cost data from Stats SA can be extracted for the following categories for the gold and metals sectors:

- SIC41: Electricity and gas
- SIC331-333: Coke, petroleum products and nuclear fuels

As shown in Figure 10, increasing electricity prices above inflation for the past decade have resulted in an increasing intermediate costs, in both the gold and metal mining sectors. Currently electricity accounts for 26 % of intermediate costs in the gold sector and 11 % of the other metals sectors (assuming gas purchases are small compared to electricity). Coke and petroleum products account for 3 % of intermediate input costs in the gold sector and 7 % in the other metals.



(a) Gold (b) Metals

Figure 10: Contribution of utilities to intermediate costs (EasyData 2019)

Intermediate costs exclude levies, taxes and most importantly, employee compensation. Figure 11 shows that labour costs in the gold sector exceed intermediate input costs, while labour costs are lower than intermediate costs in the PGM sector. Thus, according to the published Stats SA data (excluding levies, taxes and rebates), electricity accounts for 10 % of costs in the gold sector and 7 % of costs in the PGM sector.

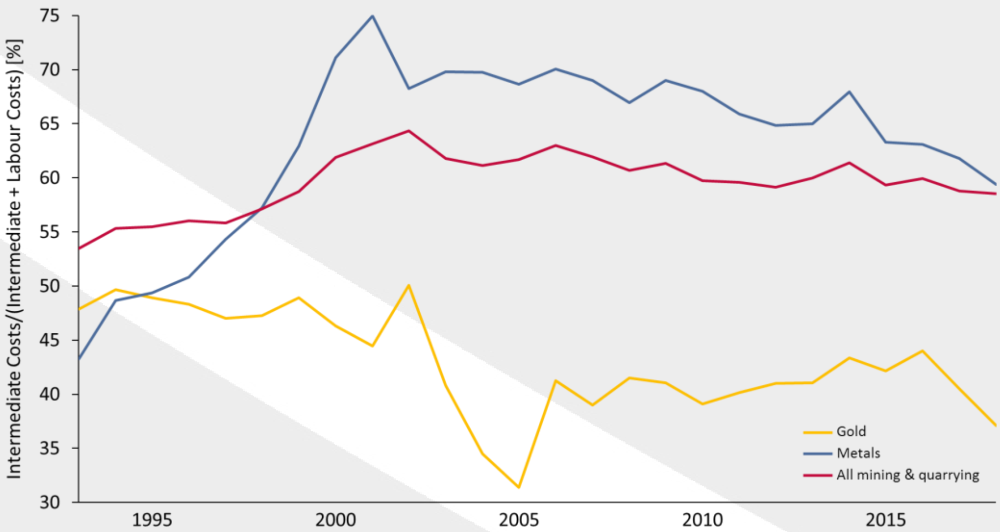


Figure 11: Intermediate and labour costs for various mining sub-sectors

2.3.2 *Mining industry costs data*

As part of the consultation process with NERSA over the Eskom Multi Year Price Determinations (MYPD) a number of mining companies have presented data that indicates the cost contribution of electricity. This section presents a range of figures presented to NERSA by the Chamber of Mines and individual mining companies.

Figure 12 indicates that the Chamber of Mines data on the cost contribution of electricity to total costs in the gold and platinum mining sector is notably higher than the numbers calculated from the Statistics South Africa data. However, the basket of costs contributing to utilities is not defined. The data presented in this figure includes electricity, labour, stores and others as the basket of total mining costs. In contrast, the Stats SA data, the utility costs are indicated as above 20 % of total system costs. Figure 13, which is based on data presented by Sibanye, closely agrees with the numbers provided by the Chamber of Mines presentation.

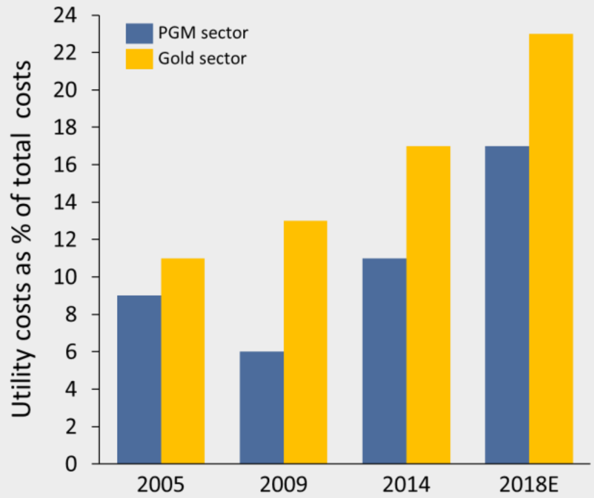


Figure 12: Electricity cost relative to total costs (Baxter 2015)

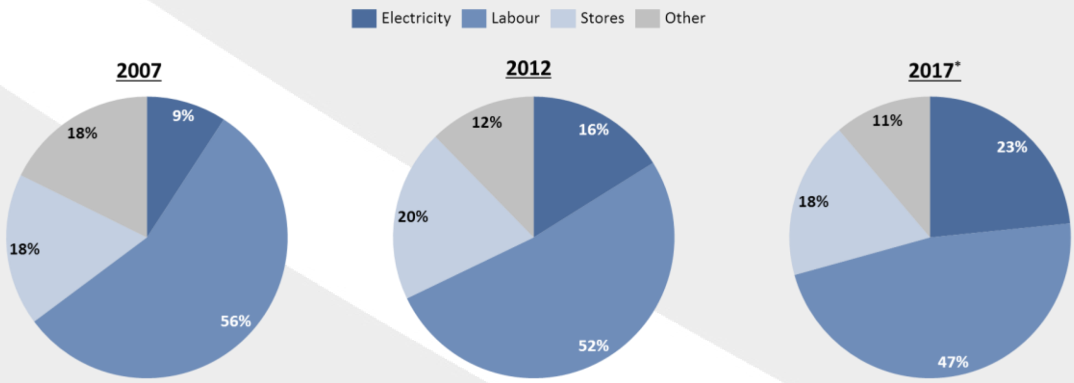


Figure 13: Cost contribution of electricity to mining operations for Sibanye (Turner 2013)

Statistical modelling by the Minerals Council of South Africa was conducted to determine the effects of electricity price increases on production, investment, profitability and employment. The data, as presented in Table 1, indicates that a 10 % in electricity price would result in a 4.2 % decrease in gold production.

Table 1: Effect of a 10 % increase in electricity price (Chamber of Mines 2018)

Production	*Investment*	*Employment*
-4.2%	-5.5%	-2.9%

Deloitte presented utility cost contributions to total costs for various gold and platinum mining companies. Figure 14 and Figure 15 also indicates that utility costs account for a higher fraction of costs that given by the Stats SA data for electricity. Unfortunately, the breakdown between water, electricity and other costs is not given for the utilities. There also no definition provide for what costs are included in utilities.

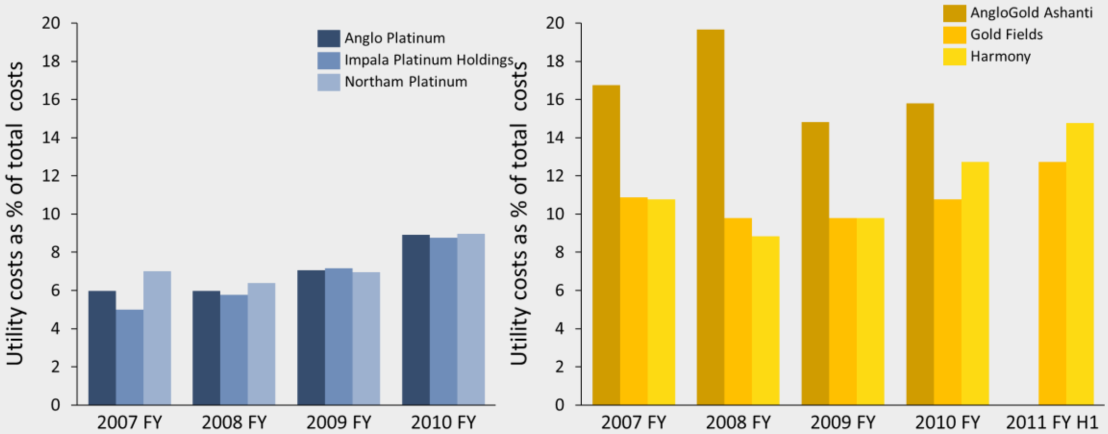


Figure 14: Share of electricity in total costs for various mining companies (Deloitte 2016)

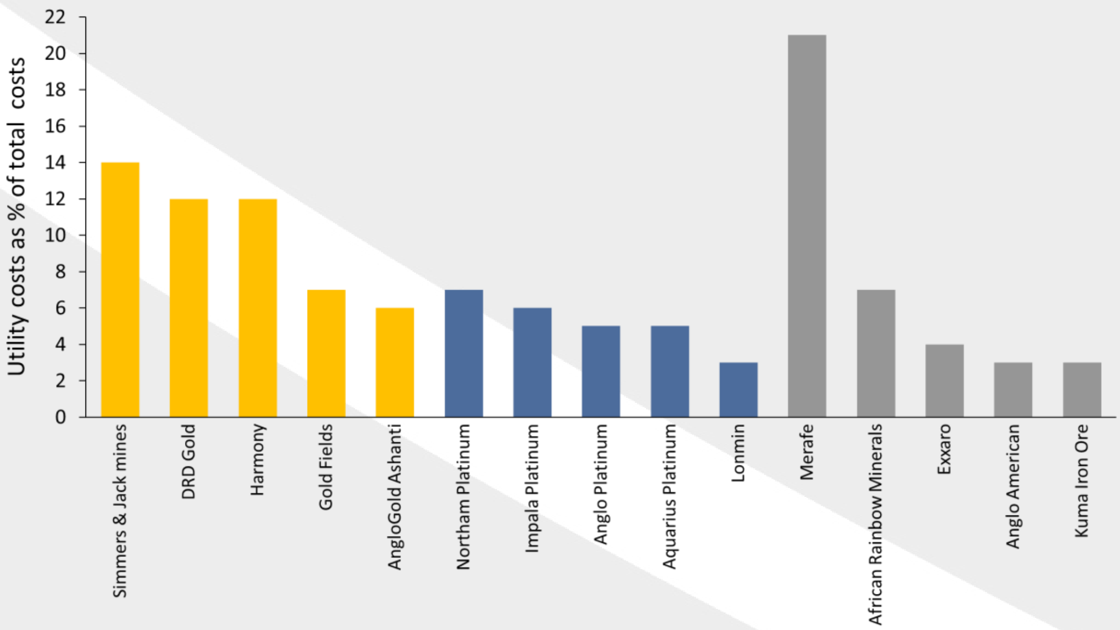


Figure 15: Share of electricity in total costs for mining companies for 2010 (Deloitte 2016)

2.3.3 *Mining industry energy intensity*

The relationship between ore grade and energy consumption in mineral processing is exponential. Several gold mines are now exploiting lower grades due to the depletion of higher grades that have been exhausted. Figure 16 illustrates the average grade of gold in ores mined in several countries, including South Africa. The average grade declined from approximately 12 g/t in the 1970s to approximately 5 g/t in the 2000s. If the average grade is to be extrapolated further into the future, it will be as low as 0.9 g/t by 2050. Mining lower grades requires greater consumption of energy, water, reagents and other consumables per unit of metal produced. In order to derive optimum value from the lower grades, optimisation is required.

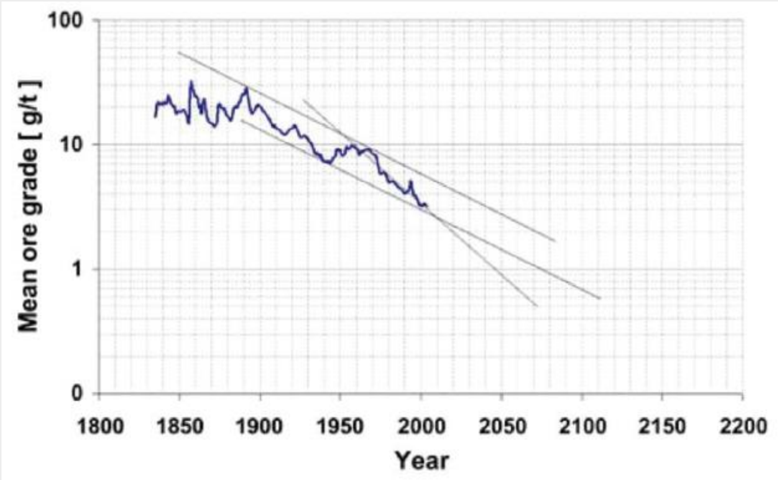


Figure 16: Arithmetic mean of the gold grade in ores mined in South Africa, Australia, Canada, Brazil, and the USA (Neingo and Tholana 2016)

Figure 17 presents the electrical energy intensity of mining operations per kton of production. This figure is based on the electricity consumption and production values, given previously in Figure 2 and Figure 5. The data indicates the overall growth in electrical energy intensity by gold sector in particular. However, the electrical intensity of the platinum sector is also steadily growing.

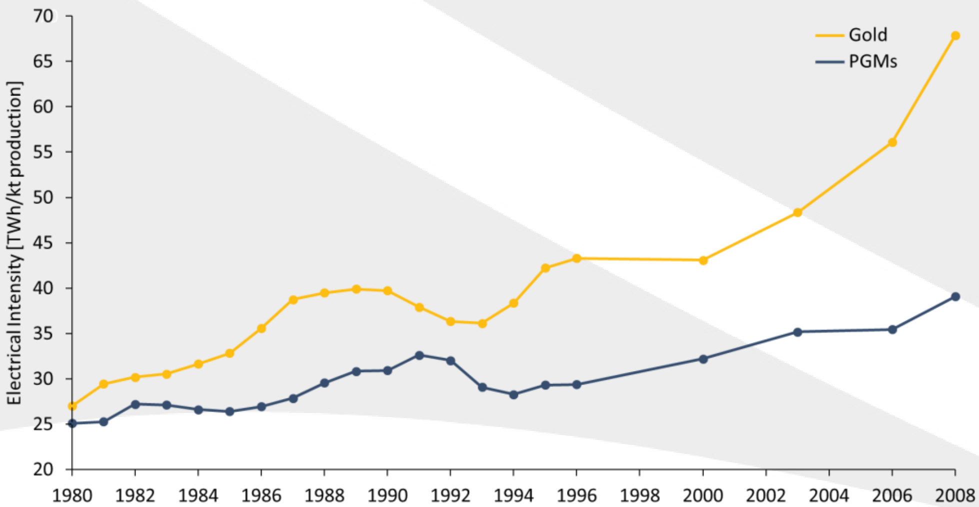


Figure 17: Electricity consumption per unit production (calculated)

2.4 Effect of carbon tax

2.4.1 Status quo of carbon emissions

The high carbon intensity of mining in South Africa is another challenge that must be addressed by the industry. The CO_2 emissions associated with various energy sources used in the mining sector are described in Table 2. Due to the heavy reliance of Eskom on coal-fired power stations, electricity in South Africa has a high carbon intensity in the order of 1 $kgCO_{2eq}$/kWh (including effect of grid losses). According to the Draft IRP the carbon intensity of the grid will decrease moving forward as coal fired power stations are decommissioned and new renewable energy generation plants are commissioned. The mining sector also makes extensive use of fossil fuels in the form of coal and diesel for transportation and minerals processing.

Table 2: CO_2 emissions associated with different energy sources based on input energy

Energy Source	kg CO_2 per kWh input energy*	Carbon Tax (Rc/kWh)
Coal	0.34	4.1
Natural Gas	0.20	2.4
Heavy Fuel Oil	0.28	3.4
Paraffin	0.26	3.1
Electricity	1.03	12.4
Diesel	0.27	3.2
LPG	0.23	2.8

*Emissions based on (Intergovernmental Panel on Climate Change 2006)

Based on the mining energy balances for 2015 from the DoE and assuming coal consumption of 30 PJ per annum, the tax liability of the mining sector can be estimated based on the initial carbon tax rate of R120/tCO_{2eq}. Table 3 indicates that the overall mining sector would incur R4.8 billion per year in carbon taxes. However, the initial phase of the carbon tax is designed to reduce the effect on companies until 2022. In this first phase, the following tax-free allowances are allowed (National Treasury 2017):

- A basic tax-free allowance of 60 %;
- An additional tax-free allowance of 10 % for process emissions;
- An additional tax-free allowance of 10 % for fugitive emissions;
- A variable tax-free allowance for trade-exposed sectors (up to a maximum of 10 %);
- A maximum tax-free allowance of 5 % for above average performance;
- A 5 per cent tax-free allowance for companies with a carbon budget;
- A carbon offset allowance of either 5-10 %; and
- The total tax-free allowances during the first phase (up to 2020) can be up to 95 %.

Thus, a rate of between 6-48 ZAR/tCO_2 will be levied. Another critical aspect of the initial carbon tax period is the introduction of the carbon tax will not have an effect on the price of electricity, which will be achieved through a tax credit. At the end of 2022, a review will be conducted on the effects of the carbon tax in order to decide upon future phases. It is unknown if the tax-free allowances will be continued.

Table 3: Carbon tax liability for the mining sector based on R120/tCO_2

Energy Source	kg CO_2 per GJ input energy	Carbon Tax (Rc/GJ)	Sector Energy Balance (PJ)	Sector Tax liability (billion R)
Coal	94	11.3	30	0.34
Natural Gas	56	6.7	0.2	0.001
Petroleum Products	75	9.3	70	0.65
Electricity	286	34.3	110	3.78
			Total	**4.77**

2.4.2 *Projected carbon intensity of the national grid*

The future carbon intensity of electricity can be calculated using the modelling software PLEXOS based on the proposed build out of new power generation sources from the draft 2018 Integrated Resource Plan. The results of two scenarios from the PLEXOS modelling conducted by the CSIR Energy Centre for the national grid are utilised in this work to estimate the projected carbon intensity of electricity up to 2050.

In both scenarios, a significant fraction of the aging coal fleet is replaced with low cost renewable generators such as wind and solar PV. In Scenario IRP1, the model is not required to build new coal fired power stations, whilst in Scenario IRP3, coal fired power stations that were contracted in the IRP 2010 are included in the model. Based on the energy sources it is possible to calculate the trajectory of carbon intensity of grid electricity in South Africa up to 2050 for each of these scenarios. The results presented in Figure 18 and Figure 19 indicate that if a carbon tax is levied on electricity in 2023 the mining sector would be liable for a carbon tax from electricity of close to R4 billion per year (excluding inflation increases). As the electricity sector is decarbonised, this would steadily decrease to between R0.3-R0.6 billion by 2050 (in real terms assuming a CPI adjusted carbon tax of R120/tCO_{2eq}).

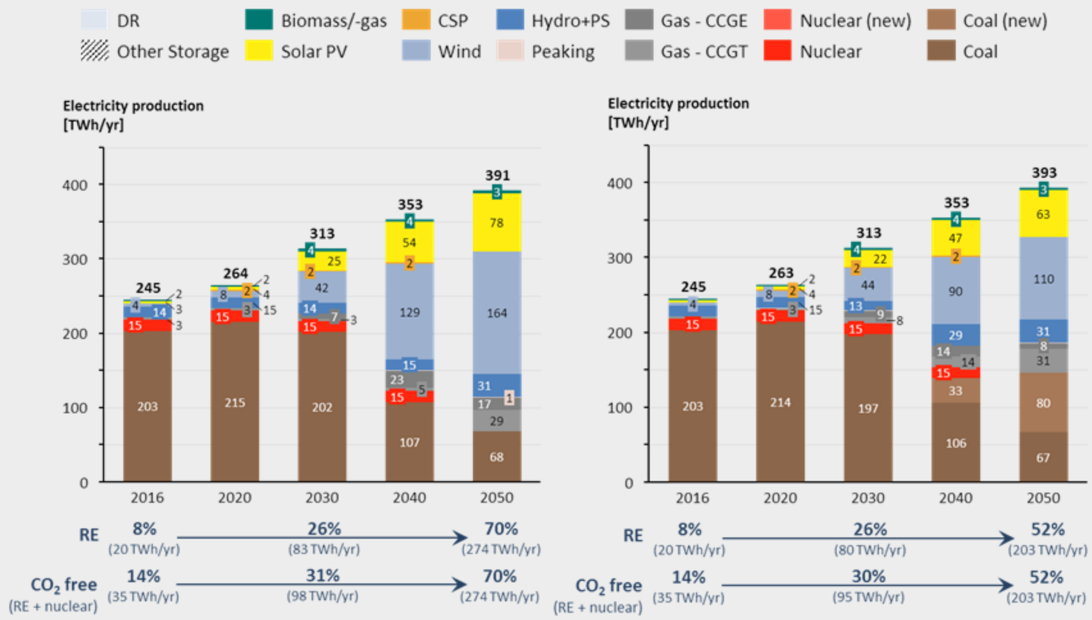


Figure 18: Energy mix associated with Scenario IRP1 (left) and Scenario IRP 3 (right)

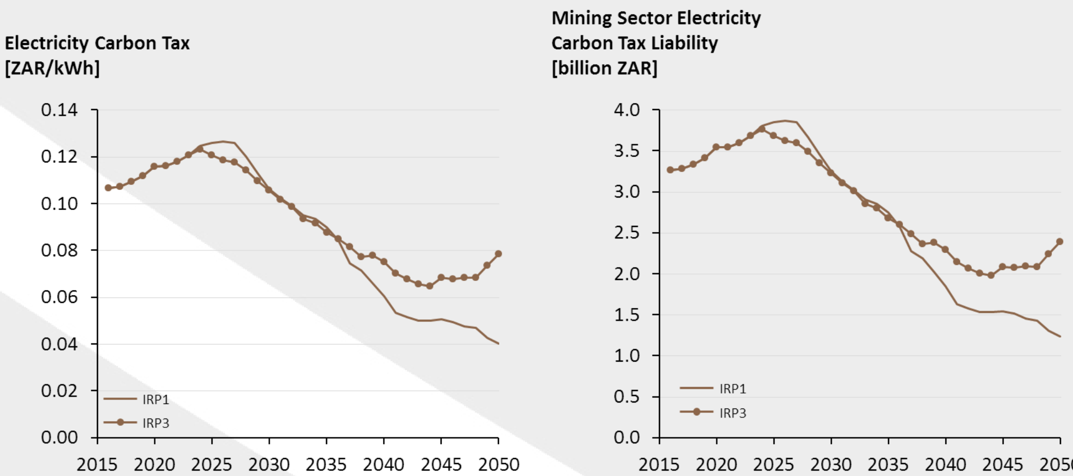


Figure 19: Carbon tax liability based on R120/tCO_2 and 110PJ per annum electricity consumption (excluding transmission losses)

2.5 Effect of Eskom supply constraints

In conjunction with rising electricity prices, large mining operations are also facing revenue losses due to an increased frequency of load shedding as Eskom struggles to meet demand due to planned and unplanned power station outages. The instances of loading shedding over the past decade are presented in Figure 20. Investigating alternative energy sources will allow mining companies to diversify the supply of energy to their operations and reduce the impact of possible future load shedding.

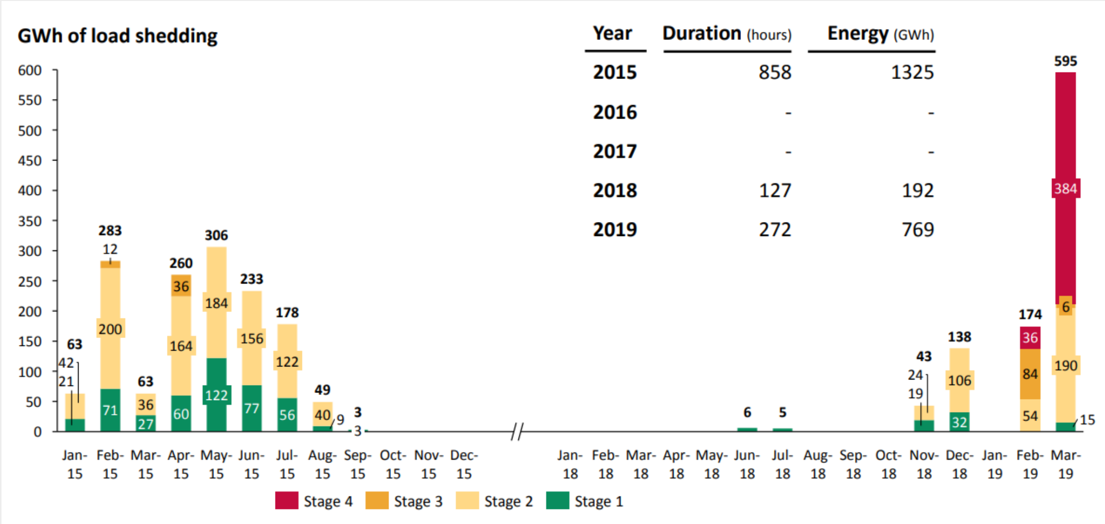


Figure 20: Load shedding implemented by Eskom between 2015 and 2019

3 Review of energy intensive mining activities

3.1 Introduction

This section discusses the mining cycle activities in conventional gold and platinum mines with a focus on energy intensive activities. Gold and platinum mines follow the same mining cycle, which constitutes drilling, blasting, early entry examination, support, cleaning, services (ventilation, pumping) and transport and logistics. Research studies indicate that the mining cycle activities consumed 82 % of the total energy in a gold mine and 51 % in a platinum mine (Tshisekedi 2008). Figure 21 shows the percentage energy consumption of each mining activity in a gold and platinum mine. The energy intensive activities that are further discussed are surface activities, transportation, stoping, water reticulation and ventilation.

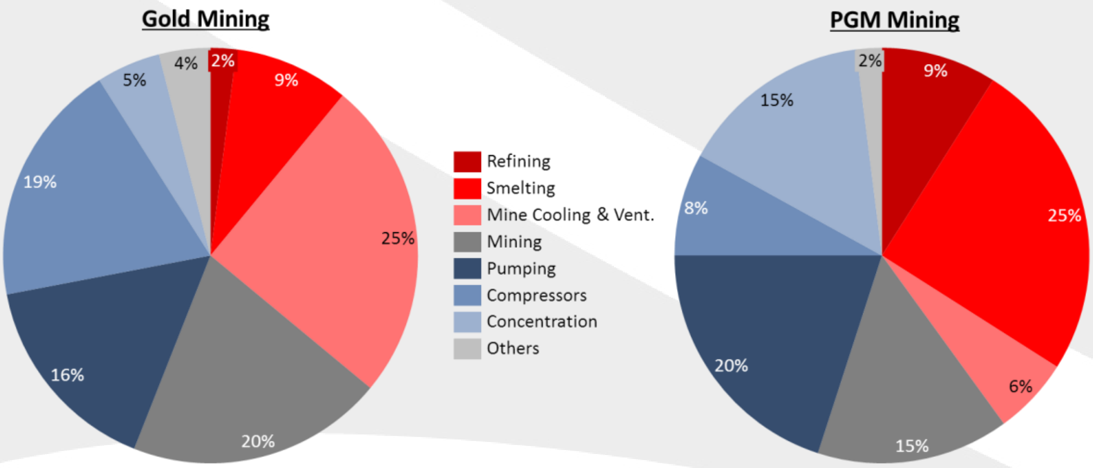


Figure 21: Energy consumption in gold and platinum mines (Tshisekedi 2008)

3.2 Surface activities

Surface activities include ventilation and refrigeration plants, surface buildings (offices and change rooms), grout plants, silos, workshops and the processing plant.

3.2.1 Refrigeration plants

In order to ensure a safe working environment, legislation requires the underground Wet Bulb (WB) temperature to be below 30 °C. As shown in Figure 22 and Figure 23, the intensity of cooling for the mine varies with the mining depth. In shallow underground mines, surface ventilation and bulk air-cooling are sufficient. However, the amount of cooling that can be provided to the inlet air steam is limited. Therefore, in deep level underground mines, additional chilled water, underground refrigeration plants and surface ice plants are used to supplement the inlet air-cooling.

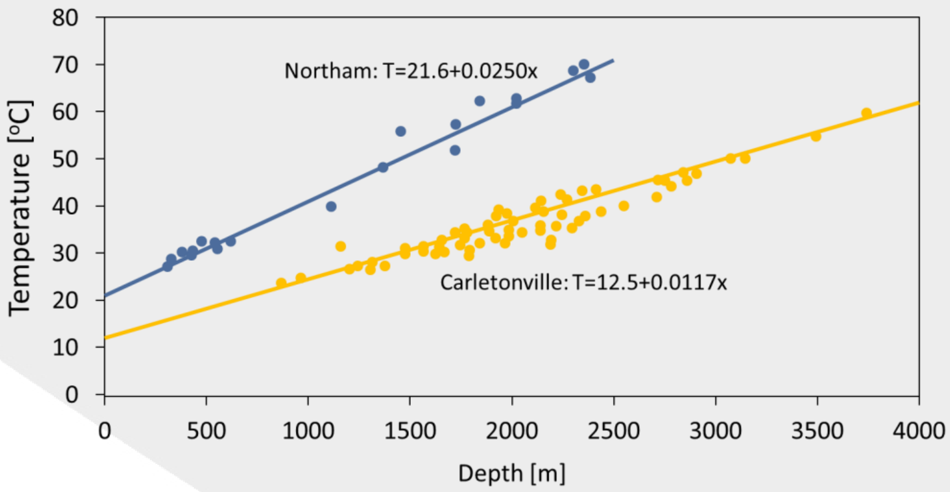


Figure 22: Variation in virgin rock temperature with depth (Jones 2018)

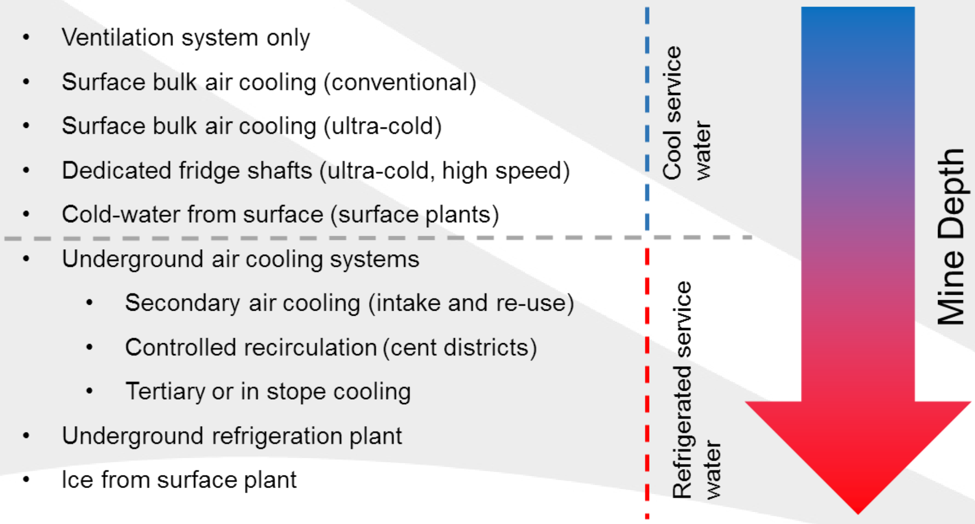


Figure 23: Cooling system requirements for underground mining (Karsten and Mackay 2012)

The layout for a cooling system for a typical underground mine includes a surface refrigeration plant that produces chilled water, surface water storage dams, a bulk air cooler for inlet air cooling and dehumidification, an underground energy recovery device, underground water storage dams and underground bulk air coolers for thermal loads. In some cases, the mine can also supplement the cooling with underground refrigeration plants.

The case study, presented in Table 4, highlights the typical operational and design parameters of a deep level underground gold mine. Kopanang is a gold mine that is located 170 km south-west of Johannesburg, on the boarder of Free State. It has a single shaft system at a depth of ~2600 m. It exploits the Vaal reef (VR) and the Crystalkop reef (CR).

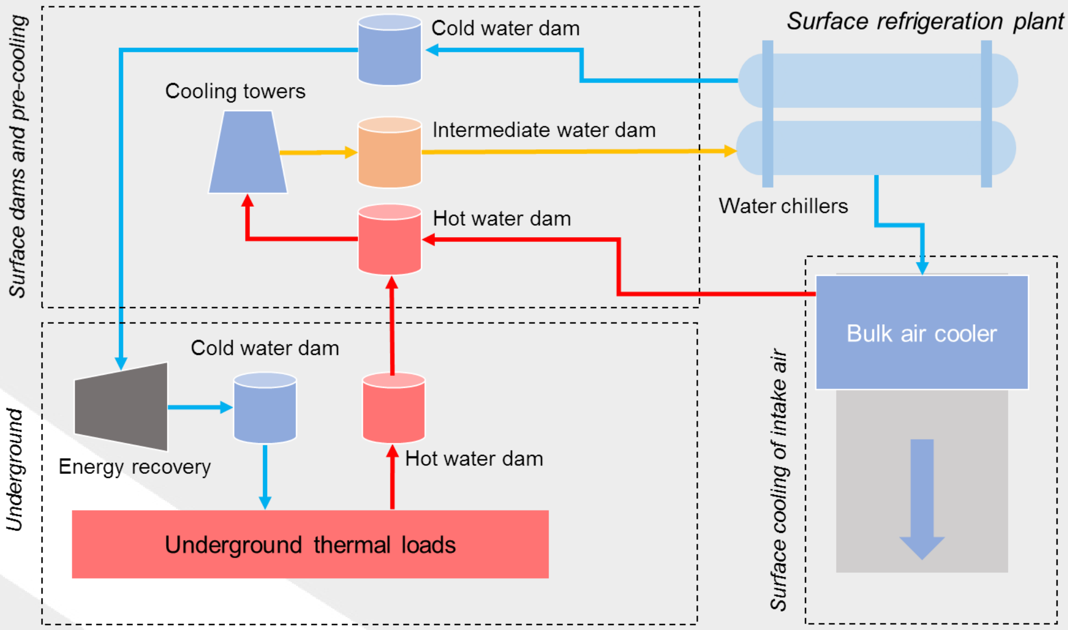


Figure 24: Surface refrigeration plant providing surface and underground cooling (Brake,2001)

The typical load profile across the year for the cooling plant is given in Figure 25. As expected, there is a seasonal variation in power demand from the cooling system, with lower inlet air temperatures and humidity available in winter, leading to a reduction in cooling demand. A comparison between the average hourly and average daily profiles indicates that the cooling system exhibits a number of peaks, as different chillers are started.

Table 4: Cooling system overview Kopanang mine (Schutte 2014)

Design temperatures	
Ambient dry bulb temperature	33.1 °C
Ambient wet bulb temperature	17.4 °C
Surface hot dam temperature	30 °C
Exit water temperature from cooling towers	24 °C
Surface intermediate dam temperature	9 °C
Exit water temperature from chillers (chilled dam temperatures)	3 °C
Design mass flowrates of chilled water	
Mass flow rate into surface cooling towers	360 kg/s
BAC chilled water flowrate	750 kg/s
Design flowrate through chillers	1250 kg/s
Thermal and electrical power	
Total installed chiller cooling capacity	39 MW_{th}
Total installed chiller electric load	7.1 MW_{e}
Installed electric load for cooling towers	0.14 MW pumps
	0.21 MW fans
Pump load through chillers (max)	0.66 MW
BAC pumps load	0.25 MW

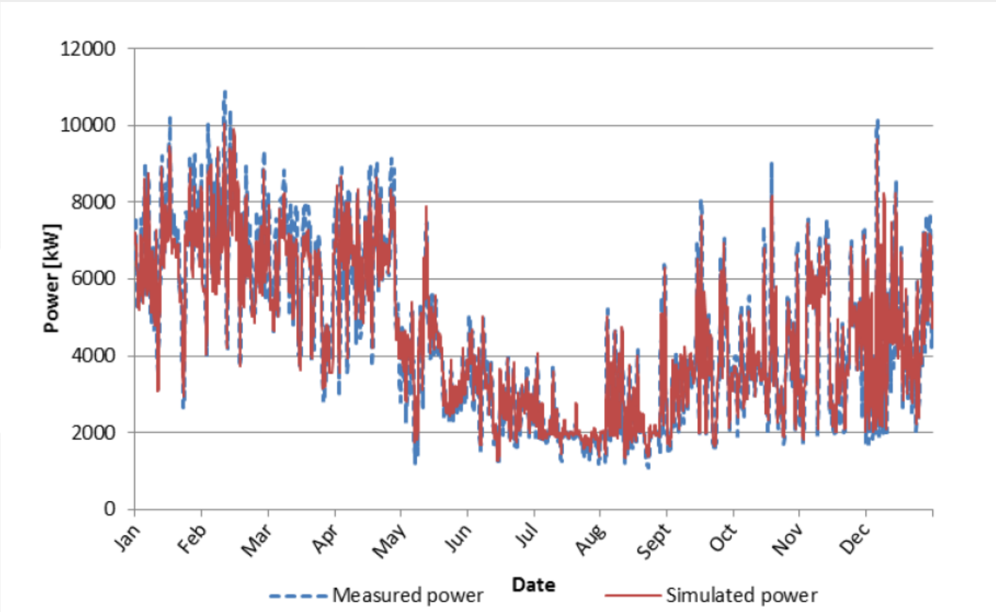


Figure 25: Average hourly cooling power consumption for Kopanang mine (Schutte 2014)

Ice systems to provide cooling

In order to reduce the pumping costs it is desirable to minimise the volume of chilled water that is pumped underground. Assuming an inlet chilled water temperature to the mine of 3 °C and an outlet water temperature of 25 °C, the cooling energy provided equates to 104 kJ/kg of water. In contrast if ice is utilised, entering the mine at 0 °C and leaving the mine as water at 25 °C a total 438 kJ/kg of cooling energy can be provided. Therefore, in order to achieve the same level of cooling the mass flow rate of water that is pumped back to the surface can be reduced by a fraction 4.75.

The reduction in pumping energy is particularly beneficial in deep level gold mining operations where the shaft depth is greater than 3000 m. Slush ice using vacuum ice machines or hard ice can be provided to the underground process. ERPM successfully operated a 5000 ton/day hard ice system to provide cooling to its far east shaft. Ice cooling is also currently utilised at Mponeng and Kloof (No. 3 and 4 shafts).

3.2.2 Ventilation

The main purpose of ventilation is to provide a sufficient quantity and quality of airflow such that a working place has a safe concentration of contaminants (McPherson 2009). This is done by forcing air through the downcast shaft, directing the air to the workings and then letting it exhaust through the up-cast shaft. Ventilation has a major contribution towards energy consumption in a gold and platinum mine. Where underground diesel vehicles are utilised particulate, CO and CO_2 emission levels must be carefully regulated by the ventilation system.

Primary ventilation

Primary ventilation includes all main fans installed on surface and booster fans underground to supply fresh air into underground working as well as exhaust contaminated air out of the mine. Table 5 shows the different specifications for main fans both axial and centrifugal.

Table 5: Main fan specifications

Equipment	Axial fans	Centrifugal fans
Blade tip/Impeller diameter	1.6 – 6.5m	Up to 5.5m
Volume flow	90-950 m^3/s	100-800 m^3/s
Pressure rise	500 – 12 000 Pa	1000 – 40 000 Pa
Drive power	100 – 10 000 kW	500 – 12 500kW
Efficiency	Up to 90%	Up to 90%

Surface (main) fans range from 200 kW to 1 MW. Typically, main fans run continuously and use grid electricity as an energy source. However, there have been developments in energy saving initiatives, which have led to a system of Ventilation On Demand (VOD). The concept of VOD is to direct the flow of air to only areas in the mine that are active and reducing supply to other areas (Wallce, Prosser and Stinnette 2014). VOD is not only used on primary ventilation but for secondary ventilation as well. The flexibility associated with VOD is well suited supply of electricity from VREG.

Another energy saving method for main fans is through the usage of inlet guide vane (IGV) control, which are adjustable static vanes installed at the at air stream entering the fan. The vanes help create a swirl of air around the impeller which ultimately helps in the power consumption of the fan. Figure 26 depicts the main fan power at Kloof Gold mine using this IGV control method showing a peak demand reduction.

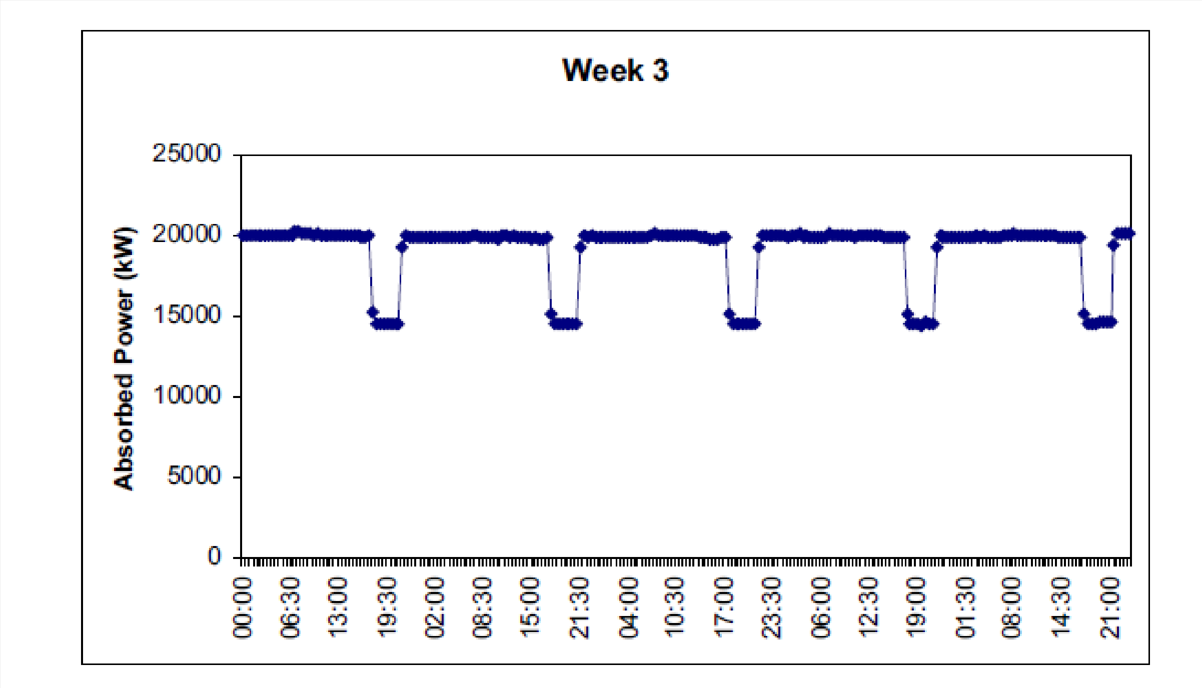


Figure 26: Typical power consumption of a main fan (Karsten and Mackay 2012)

Secondary ventilation

Secondary ventilation is the direction of airflow into working areas, this is done by usage of auxiliary fans, ventilation regulators, door, curtains, and brattices. The commonly used fans have a power rating of 25 - 200 kW and use electricity from the grid as an energy source. These fans can be used as force fans to push air towards a particular direction or as exhaust fans to pull contaminated air out of a working area, in some case both force and exhaust fans work simultaneously in the same working area.

VOD methods described in the section above are also used as way to save electricity for auxiliary fans in other instances the high efficiency motors are used to give optimum aerodynamic efficiency to the fan (Karsten and Mackay 2012).

3.2.3 Grout plant

Grouting is used to control subsidence, provide groundwater protection, backfill abandoned mine sub-surfaces and stabilize soil/foundation. A grout plant consists of grout pumps and mixing pumps. Both pumps can be powered by several energy sources, such as air pressure, hydraulic, electric and diesel. Figure 27 shows typical example of OEM specifications for grout pump and mixing pump. In some cases, grouting has been used subsidence has already begun to cause damage and in cases where sites are treated in advance to counteract potential subsidence.

Specifications

PUMPS	
Grout Pump	3CL6 progressing cavity
Colloidal Mixing Pump	2 X 3 X 6 diffuser-type centrifugal
PHYSICAL SPECIFICATIONS	
Air	
Weight	~1550 lbs.
Size	90"L x 60"W x 74"H
Power Required	300 cfm, 100 psi
Hydraulic	
Weight	~1550 lbs.
Size	90"L x 60"W x 65"H
Power Required	Dual circuit 12/12 gpm, 2400 psi
Electric/Hydraulic	
Weight	~2600 lbs.
Size	90"L x 60"W x 72"H
Power Required	25 HP, several voltages available
Diesel/Hydraulic	
Weight	~2650 lbs.
Size	86"L x 34"W x 41"H
Power Required	27 HP, Diesel/electric start

Figure 27: Specifications of grout pump and mixing pump (ChemGrout 2014)

3.2.4 Surface silos

Surface silos are typically used to store broken ore (reef and waste rock) transported from underground. Waste rock is dumped in stockpiles, which is also known as waste dumps. The reef is distributed to a plant for further processing. In a typical gold mine, the capacity of a silo is 2000 tonnes. Silos require electric energy to carry out its function of disturbing the ore to the plants. That function is usually carried out by the conveyor belt which utilizes energy to function.

3.2.5 Surface buildings

Surface buildings include offices and workshops. Offices are centre points of the mine where several managerial functions such as planning are conducted. They have different facilities for difference functions. These include change rooms, monitoring rooms, kitchens, storerooms etc. There are a number of activities and appliances that consume energy in offices. Workshops are generally used for routine maintenance and breakdown repairs for locomotives and other mobile machinery.

Surface buildings are powered by electricity from the grid. They generally do not consume significant energy compared to other surface mining activities. Hot water demand for ablution facilities is often a significant energy demand onsite. Solar systems can be utilised to supply hot water for the employees.

3.2.6 *Processing plant*

At the processing plant, gold and silver are extracted from the ore. Anon (2019) described ore processing as consisting following stages (Figure 28):

- crushing and grinding of the ore;
- addition of process water (generally decanted from the tailings pond) to form a slurry;
- addition of lime to the ore, and cyanide solution to the slurry, to leach the gold and silver into solution;
- addition of carbon to adsorb (attach) dissolved metals and remove them from the slurry;
- stripping the metals from the carbon by acid washing and circulation of a caustic cyanide solution;
- precipitation of the gold and silver by electro-winning;
- smelting of metal products into bars of ore bullion;
- pumping of the barren slurry (tailings) to the tailings storage facility; and
- The processing plant has the capacity to treat up to 1.25 million tonnes of ore per annum.

These stages can be further summarised according to the following stages:

- grinding and size classification to reduce the ore down to a fine particle size
- leaching and adsorption to extract the precious metals from the rock
- recovery of the precious metals to produce ore bullion bars

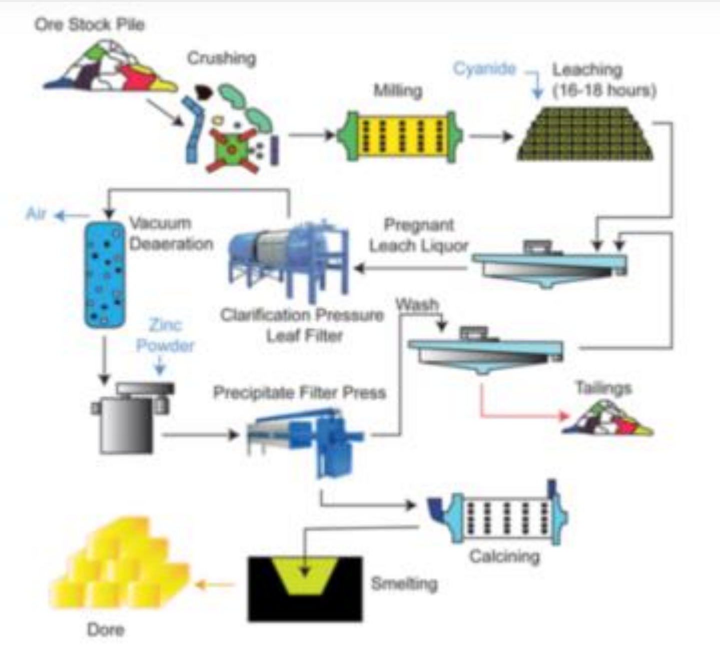


Figure 28: Processing plant steps (Anon 2019)

3.3 Transportation

A key indicator of the performance of a mine is its level of production, which is measured according to the amount of ore broken (particularly reef) and transported to surface in a month. Efficient and cost-saving initiatives on the ore transportation systems are imperative in ensuring that production is not compromised (Schoombee, Hamer and van Rensburg 2016). In order to ensure that personnel arrives at the workplace safely and in time, it is important to plan and design a transportation system that also meets the required production output of the mine (Webber-Youngman and van Heerden 2016).

Figure 29 illustrates a typical transport system at a gold and platinum mine. Transportation systems constitute vertical and horizontal (also known as tramming) transport. Vertical transport includes a rock and personnel winder, which transports reef, waste, personnel and materials from surface to the different underground levels. Horizontal transport includes rail bound trains called locomotives, which transport personnel and materials; hoppers, which transport reef, waste and material to and from stopes and development ends; conveyor belts and chairlifts.

Transportation systems are operated according to planned schedules and the mine's shifts. Generally, mines have a morning shift (06:00 – 14:00), afternoon shift (14:00 – 22:00) and night shift (22:00 – 06:00), however this does not apply to all mines. The ore transportation system is being utilised at approximately 72 % of the total capacity during an average day (C. Schoombee 2015). They are halted approximately twice a week for approximately four hours to conduct shaft and hoist examinations. The duration of the examinations are dependent on the length of the examination area, number of levels and the condition of the examined area. The purpose of these inspections is to determine if the shaft meets required standards. The ore transportation accounts for 16 % of the total electricity usage in a gold mine (Schoombee, Hamer and van Rensburg 2016).

Vertical transport: Winder

The basic operation of a winder system is to transport reef, material and personnel to and from surface to the different underground mining levels (De Villiers and Grobler 2007). A rock winder transports broken ore (reef and waste) using a skip and a man winder transports personnel and material using a cage. The winder cable connects to the skip and cage, movement occurs through the wounding and unwounding of this cable. The winder winds the winder cable, the sheave wheel guides the winder cable up and down the shaft and the winder motor drives the winding operation and the shaft tower houses the sheave wheel (De Villiers & Grobler, 2007).

The winder motor winds the one end of the rope and rewinds the other end of the rope simultaneously. The winding system enables an upward movement of one skip or cage at the one end of the rope, and at the same time, a downward movement of the other skip or cage at the other end of the rope. The skip and cage can reach a speed of 15 m/s. When the skip reaches surface, the rock is automatically thrown onto a conveyer belt that transports the ore to the plant (De Villiers & Grobler, 2007).

Winders are controlled using electricity at a power rating between 2600-4600 kW (De Villiers and Grobler 2007). The total electrical power required peaks as the load is accelerated and quickly drops as the conveyance reaches its constant transport velocity. This requirement is then reversed for the deceleration portion of the wind and the cycle is then repeated (Youngman 2012). The preferred and most accurate method for obtaining the electrical energy consumption of a rock winder is to install power meters on the electrical feeder of the winder system (Schoombee, Hamer and van Rensburg 2016). Although this method is preferred, it is time-consuming and requires capital expenditure to obtain and install these devices.

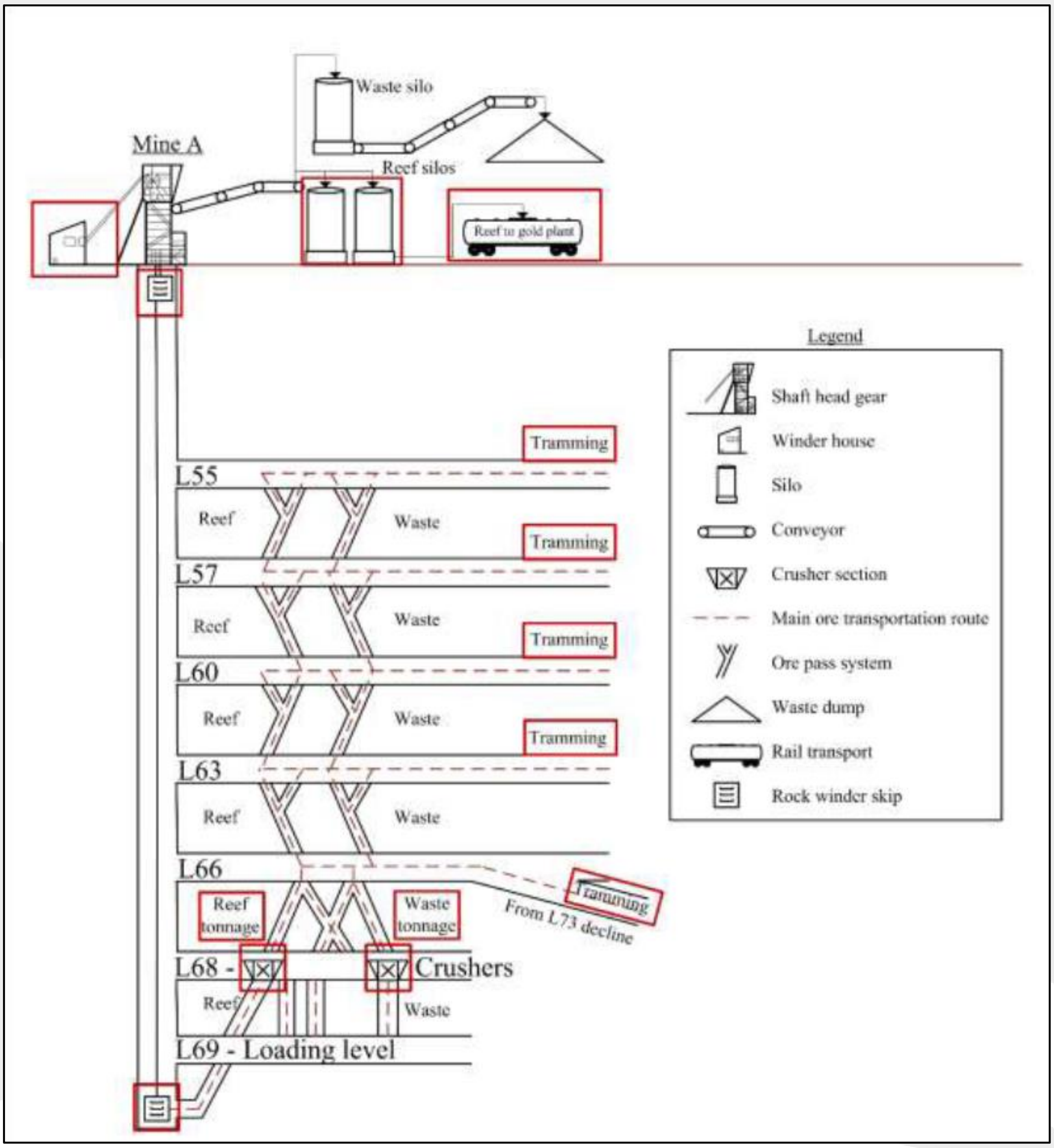


Figure 29: Underground transportation system (Schoombee, Hamer and van Rensburg 2016)

Horizontal transport: Rail bound transport

Rail bound transport includes locomotives that provide transport from the station to the working areas. The locomotive is deigned to have attachments for the transportation of personnel (man-carriage), material (material car), explosives (explosives car) and broken rock (hoppers). Hoppers are used to transport broken rock (reef and waste) from stopes and development ends to silos where it is loaded onto skips via skip feeders. Personnel are transported at speeds of 24-32 km/hr and materials at speeds of 16 km/hr (S. M. Rupprecht 2003). Ore production is higher during weekdays than on weekends, meaning that hoppers are operated the most at those times.

Locomotives used in gold and platinum mines are battery or diesel powered. Battery-powered locomotives are favoured over diesel due to the lack of emissions from them as well as the reduced complexity and maintainability. However, battery powered locomotives suffer lower productivity because of low on-board energy storage (and consequently low power), long recharging time (charging of batteries in the battery bay) and have a relatively high life-cycle cost because of short battery life (Miller, et al. 2012).

Locomotives are used only when personnel have to be transported to and from the shaft at specified times. They are parked when not in use. The batteries and diesel could be replaced with hybrid locomotives with regenerative braking functionality. When the train decelerates, power is pumped back into the batteries where it is stored for future use by the electric motors. The hybrid locomotive will not need spare batteries or a battery bay in which to charge them as the locomotive will use both its regenerative braking ability and the on-board generator set to maintain adequate charge in the battery to facilitate all tramming activities. Compressed natural gas and fuel cells could also be used as an alternative power source (Miller, et al. 2012).

Table 6 shows a comparison of power, energy capacity and operating time between battery and fuel-cell powered locomotives. Fuel cell powered locomotives have a higher energy capacity.

Table 6: Comparison of battery and fuel-cell powered locomotives (Miller, et al. 2012)

Parameter	Battery powered	Fuel cell powered
Power, continuous	7.1 kW	17 kW
Energy capacity	43 kWh	48 kWh
Operating time	6 hours (available)	8 hours
Recharge time	8 hours (minimum)	0.75 hours

Conveyor belts

Conveyer belts are used to transport the broken ore from underground between ore passes and from the ore passes to the flasks at the rock winder (Badenhorst 2009). They are considered an efficient means to transport rock over short to medium distances and can operate at steeper gradients than hoppers. Conveyors are flexible in their capabilities for receiving rock from one or more locations and are generally considered safe and reliable with a wide range of capacities (S. M. Rupprecht 2003). They are known to generate a considerable amount of heat which is dissipated into the atmosphere.

They are electrically powered and consume less energy than rail bound transport systems. They have a power rating of 15 to 160 kW (De Villiers and Grobler 2007). In several platinum mines, the reef ore passes have a limited surge capacity of ±250 tons of reef each, with most of the reef ore passes have to be tipped more than once per day (De Villiers and Grobler 2007). A typical conveyor belt used in a platinum mines has a belt width of 1.2 m, travels at a speed of 1.2 m/s, has belt length of 442-804 m (slope) and has a capacity of 600– 960 ton/hour.

Energy saving opportunities include installing sensors that enable the conveyor to run only when ore is loaded. The use of high efficiency motors improve the delivery of the same amount of power using less energy, resulting in reduced energy costs. The savings however, only range from 2 % to 8 % over traditional motors (Habasit America n.d).

Chairlifts

Chairlifts are used to transport personnel over short fixed distances, i.e. down inclined shafts or from one level to another. The riding chairs are either permanently attached, or simply hooked on and off a cable, which is guided by regularly spaced roller stations. They are electrically powered. Chairlifts are built with sensors such that they run only when personnel climbs on. This functionality serves as an energy saving property.

3.4 Stoping

In an underground narrow reef mine, stoping involves all the processes required to extract the ore from the mining face. The stoping process comprises of several activities that will ensure the safe extraction of ore. A majority of the underground mining operations make use of the drill-and-blast method for ore extraction. The activities discussed in this section are based on the drill and blast method.

3.4.1 Early entry examination

In a majority of the mines, blasting is used as a method of extracting broken ore from the solid mine face. Explosives are used to fragment and break the rock and eject it from the face area and get it ready for cleaning purposes. The use of explosives during a blast requires mine personnel to be evacuated from the panel/ stope for safety reasons. The shift that follows after the blast needs to conduct an extensive early entry examination before entering the working area. Early entry examination is the process of making the panel safe prior to commencing with work in the panel. This activity requires the use of water to wash the hangingwall and the footwall and the water usage in this regard will not be discussed in the report. It also includes ventilating the working area to dissipate the fumes generated from the blast.

3.4.2 Drilling

The drilling process involves creating holes on the mining face where explosives can be inserted and detonated. This is one of the most critical processes in the stoping process as the accuracy and speed of drilling will determine the success or failure to produce a conformant blast. A majority of the available stoping cycle time is utilised by the drilling process. In conventional platinum and gold operations, hand-held drill machines are used to drill the face.

A majority of the drill machines that are currently used underground are the pneumatic hand-held drill, namely the SECO S215 machine. This drill machine has remained relatively unchanged since its introduction to the mining industry in the early years of the 20th century. The machine is mounted onto a telescopic airleg and is connected to hoses, which provide it with water and compressed air. An example of the machine is shown in Figure 30 below.

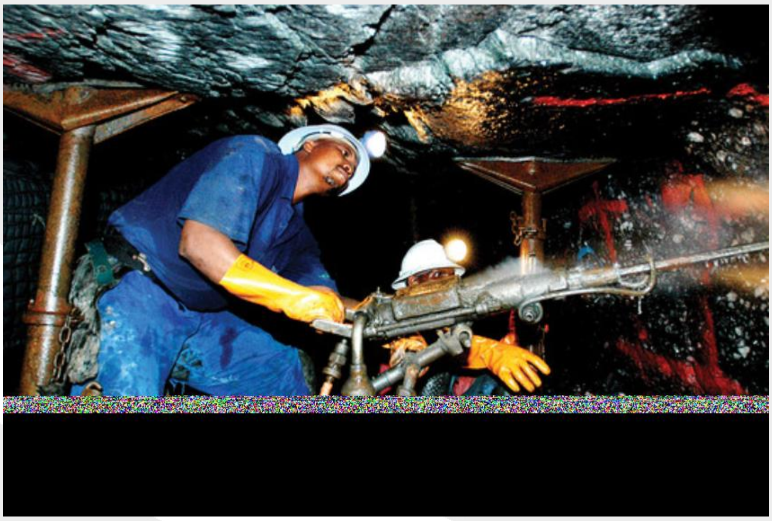


Figure 30: Drilling conducted using the pneumatic hand-held drill machine (Hart 2013)

In a typical 30 m panel, four rock drill machines would typically be used to drill the panel face. An example of a stoping layout with the drills connected to the compressed air is shown in Figure 31. The compressed air and water would be supplied from the cross-cut into the panel.

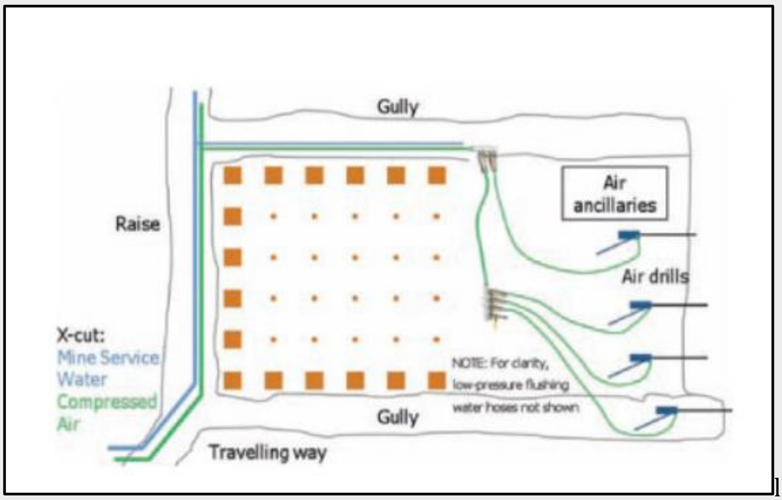


Figure 31: A pneumatic drilling stoping layout with drills connected (Petit P 2012)

Current Energy Source

A majority of the underground mines are still dependent on compressed air as a form of energy source for the hand held drills. Compressed air, from surface compressors, is supplied to a pressurised pipe network, located on the surface and underground. The compressed air system is highly inefficient and subsequently costly. A lack of maintenance of the ventilation pipes or leakages often results in a reduced air supply being provided at the stope face. Kreil (2014) found that the unit costs associated with compressed air were significantly higher than other energy sources.

There are several challenges presented by the use of compressed air as an energy source. The system is largely inefficient as estimates indicate that only 35 % of the produced air reaches the stope face. It is estimated that on most mines, a compressor would typically supply 600 kPa of compressed at a flow rate of between a 30 500 m^3/h to 170 000 m^3/h (Kriel 2014). A rule of thumb guidance indicates that 70/80 l/s is required to power each pneumatic drill. The following formula is given for calculating the energy required per drill (Fraser 2010):

$$E_{drill} = \int \dot{Q}_{air} \dot{W}_{comp} dt$$

In work done by (Fraser 2010), it is estimated that the following power requirements would be applicable to one rock drill in a worst case, mid case and a best case scenario.

Table 7: Applicable power and energy requirements for different case scenarios

	Worst Case	Medium Case	Best Case
Power to provide compressed air to 1 drill [kW]	23.4	15.9	11.6
Energy to provide compressed air to 1 drill [kWh]	409	183	63.8

In the above calculation, it was assumed that there are compressor leaks amounting to 16.5 hours for a worst case, 11 hours for a mid-case and 5.5 hours for a best case.

According to a benchmark study that was conducted, it is estimated that drilling accounts for 8.9 % of the energy consumption in underground deep gold mines. This is the third largest energy consumer after ventilation and hoisting (LCD Energy management Group 2009). The drilling process is therefore highly dependent on the supply of compressed air being consistent and efficient.

Load factor

A large portion of the available cycle time is taken up by the drilling process. A majority of the drills currently use underground use compressed air to function. It is estimated that more than 70 % of the total air supplied underground is used by the rock drills (Fraser 2010). In a typical gold and platinum conventional mine, all the stoping activities are scheduled on relatively the same time. The drilling activities in the various working areas would take place and the compressed air usage would subsequently peak at around the same time. This is demonstrated in Figure 32 below, which shows the typical schedule of a gold mine. In addition to the leaks that are observed along the ventilation system, this system becomes highly inefficient in terms of the amount of compressed air that is delivered at the panel face.

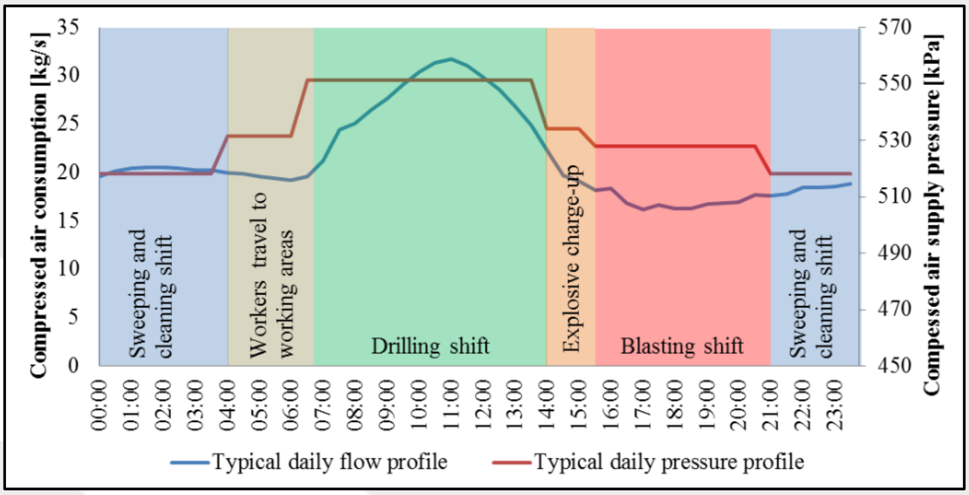


Figure 32: The operating schedule of a typical gold mine (Kriel 2014)

Alternative energy sources for drilling

Several alternative energy sources are available to curb the constraints that are introduced by compressed air. Alternative energy sources that can be used are hydro-power and electric power. These provide several advantages over compressed air, namely, faster drilling rates, higher productivity, reduced operating costs and having no dependence on compressed air.

3.4.3 Cleaning

Cleaning is a process that involves the removal of broken rock from a panel face and stope after a blast. It is an integral part of the mining cycle as an ineffective cleaning system negatively affects the productivity of the working area. The scraper winch machine is generally used for cleaning in conventional mines. It consists of a single or double drum that is connected to a scoop (scraper) by scraper ropes. In a majority of mines, the scraper winch models that are used are the 37 kW Taylor, LF-230 37 and the 55 kW JCF-212 winch (S. Rupprecht 2013).

In a conventional mine that utilises three 8-hour shifts, the scraper winch is primarily used during the night shift. This shift is dedicated for cleaning activities. Secondary cleaning is done during the morning shift to supplement the night shift cleaning. Scrapers are powered by electricity received from the national grid and can achieve a cleaning rate of 250-500 t/h when utilised (van der Merwe 2001). Due to the constraints and limitations associated with scraper cleaning, hydro-powered waterjet systems can be used as an additional measure to scraper cleaning. Waterjet cleaning is a cleaning system where high pressure water is used to move the broken rock. This cleaning system results in less water consumption than lower pressure systems. (S. Rupprecht 2013).

3.5 Water reticulation system

South Africa operates some of the deepest mines in the world reaching depths in excess of 3800 m, and therefore it is crucial to have an efficient water reticulation system. A mine's water reticulation system comprises of a water distribution system, dewatering system and refrigeration systems (Figure 33) however, this section focuses on the water distribution and dewatering system. Both systems use pumps to transport water to and from surface to underground working areas.

The water distribution system transports cold water from the refrigeration system on surface to underground using gravity and so obtaining kinetic energy. The de-watering system pumps this cold water, which eventually becomes hot, back to surface using large de-watering pumps. This forms a closed loop, as warm water pumped by the dewatering system is fed to the refrigeration system where it is cooled and recycled back to the mine (Murray 2000). Reduction of pumping and cooling needs results in water and energy savings.

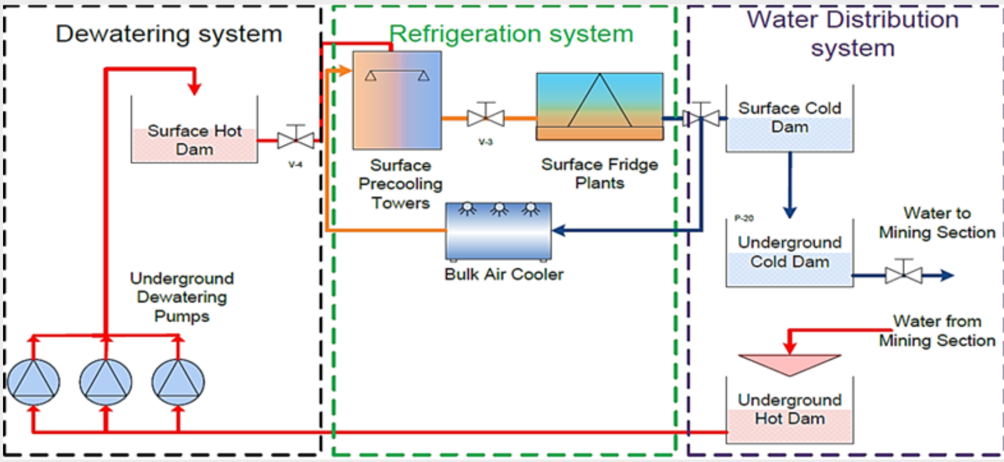


Figure 33: Typical mine water reticulation system (Murray 2000)

The cold water that gravitates its way from surface down the shaft is used to control the ambient temperature within the mine, drilling and in some cases for waterjet cleaning during the cleaning shift after blasting. Drinking water is a completely different system and so does not have any influence on the main reticulation system. Mines generally have two sets of storage dams, each consisting of a hot water dam for water that has been used and a chilled water dam for water that is still to be pumped to the working places. Additional underground fissure water also needs to be pumped out.

A SCADA system is used to control the pumps underground (Vosloo, et al., 2012). It allows the operator to see the pump running feedback, trip feedback and dam levels. He/she has the right to start and stop pumping.

Deep-level mines require multistage dewatering pumps that are able to pump large water volumes of up to 140 l/s against head pressures of up to 1 600 m (De Villiers and Grobler 2007). Pumping is electrical powered and consumes 14 % of energy usage in a gold mine (De Villiers and Grobler 2007). The installed capacity of the different sized pumps range between 900 – 3600 kW from mine to mine. There are several alternative energy sources that could be used for pumping, primarily using energy-regeneration technique such as the three chamber pipe feeder system (Youngman, 2012). A turbine could also be installed where the powered regained by this turbine, can then be used to either directly drive a pump or first be converted to electrical energy using a generator and then driving an electrical pump. If the power is converted into electrical energy, it does not only have to be used for pumps, but can be utilised in a number of ways (Murray, 2000). Shifting peak and standard time pumping periods to off-peak periods could save the maximum amount of costs on underground water pumping.

4 Conclusions

Electricity is the primary energy carrier for the gold and platinum sectors, accounting for approximately 25 TWh of FEC each year. Due the Eskom capacity expansion plan, the price of electricity has risen by 430 % in nominal terms (150 % in real terms) between 2015 and 2018. The latest draft of the DoE IRP indicates that the price of electricity will continue to increase above inflation between 2019 and 2050, even if the operational challenges within Eskom are addressed. This rapid increase in the electricity price has to potential to render a number of existing underground mining operations unprofitable if not addressed through seeking energy efficiency measures and alternative energy sources.

Section 3 of this report has quantified the effects of increasing electricity tariffs on existing gold and platinum mines. An analysis of Stats SA data indicated that electricity currently accounts for 26 % of intermediate input costs (excluding labour, taxes, rebates and levies) in the gold sector and 11 % of the other metals sectors. Coke and petroleum products account for 3 % of intermediate input costs in the gold sector and 7 % in the other metals. Sources from the mining industry in presentations to NERSA indicate that Utilities account for 23 % of total costs in the gold sector and 17 % of total costs in the platinum sector, but detailed sources for this data are not available at present and therefore it is difficult to compare with the official Stats SA data.

Section 4 of this report provided a high-level overview of energy intensive mining activities in gold and platinum mines. Opportunities exist for energy efficiency improvements, especially in the context of inefficient compressed air drilling systems, which could in future be replaced with electric drills or hydraulic systems. Electric loads in the cooling and ventilation systems have the potential to play a critical role in terms of creating a flexible energy system for the mine through a targeted Demand Side Management (DSM) programme. Ventilation and cooling currently accounts for an estimated 25 % of energy end-use on a gold mine and 6% on a platinum mine.

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