Applying a benchmark method to identify utility cost-saving opportunities on a platinum mine

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

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Graduation: May 2022

Student number: 25042009

ABSTRACT

Title:	Applying a benchmark method to identify utility cost-saving opportunities on a platinum mine
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Keywords:	Energy consumption, Benchmarking, Surface ventilation power, Production, Compressed air, Compressor power, Potable water

South Africa’s energy and water demands are more significant than the supply thereof. This higher demand means Eskom cannot deliver enough power to South Africa. Furthermore, South Africa is a water-scarce country and water is a non-renewable resource that should be used wisely.

Eskom built the Medupi power station to increase its supply. The construction cost of this power station was very high in comparison with previous power stations. High tariff increases were implemented to maintain the construction of the power station. Between 2008 and 2018, a total accumulative tariff increase of three times above inflation was implemented. As South African mines are the largest consumers of energy, these high tariff increases affected them the most and threatened their profitability.

South African mines play an essential role in the economy. The reason being is that if the mines have an increase profits, more taxes are payable to the South African Revenue Services. Therefore, if the mines struggle, the economy will also start to struggle.

Mines have various high energy consumers with motors up to 15 MW. By lowering its energy consumption, more profits can be made with high energy costs. Benchmarking mines can indicate where there is potential for lowering water and energy consumption.

Few studies have discussed energy benchmarking on deep-level mining. No studies were found regarding the benchmarking of potable water on deep-level mining. However, there were studies that evaluated compressed air benchmarking on deep-level platinum mines.

The objective of this study was to create these benchmarks on a specific platinum mine. From these benchmarks, energy and water savings opportunities were identified. For the opportunities noted, projects were implemented. The goal of these projects was to decrease the intensity benchmarks and lower the case study mine's utility expenditures.

For the study objective to be accomplished, verified benchmarks had to be created first. By obtaining data from five shafts, the benchmarks could be verified. The data included compressed air flow, surface ventilation fan power, rock winder power, potable water consumption, service water consumption, production data, active haulage length, and employee numbers.

The highest correlation and lowest standard deviation for different data sets were calculated to ensure verified benchmarks were used. From the best data set comparison, benchmarks were created for different periods. These different period benchmarks revealed inefficiencies from irregularities and high intensities.

The compressed air intensity was compared with production and had a total intensity benchmark of 11.29 $m^3/(h \cdot ton)$. The surface extraction fans obtained a total benchmark intensity of 50.2 W/m compared with active haulage length. An irregularity was seen on the shafts' benchmark, where one shaft did not stop a 1 200 kW fan and 650 kW fan on Sundays.

The total intensity benchmark for underground energy was 437.5 W/ton. The Eskom peak period benchmark for the rock winders was 118 W/ton. A total intensity of 119 l/day/capita was calculated for underground potable water. The total service water pumped to the surface had a total intensity benchmark of 51 W/ton.

From the benchmarks created, irregularities were noticed, which resulted in savings opportunities that were implemented to reduce the intensities. The total saving achieved for the specific case study mine was estimated to be R2.7 million per annum. It was concluded that the study objective was met as the mine's expenses were lowered.

ACKNOWLEDGEMENTS

Thank you to the following whose contributions were crucial to the success of this study:

- My heavenly Father for giving me the ability to complete this study.
- My parents, for all the support.
- Energmanage (Pty) Ltd and its sister companies for the financial support.
- Dr Willem Schoeman, Dr Johann van Rensburg, Dr Neil Zietsman, and Dr Jean van Laar for the knowledge and academic support.

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NOMENCLATURE

Symbol	Description	Units
ρ	Density	kg/m^3
E_p	Potential energy	J
g	Gravitation acceleration	m/s^2
h	Height	m
m	Mass	kg
P	Power	W, kW, MW or GW
Q	Flow	m^3/s
V	Volume	m^3

UNITS OF MEASURE

Unit	Description
J	Potential energy
kg	Mass
kg/m^3	Density
kW/ton	Power intensity (kilowatts per ton)
l	Litre
l/(h·ton)	Water consumption intensity (litre per hour per ton)
m	Height
m/s^2	Gravitation acceleration
m^3	Volume
$m^3/(h·ton)$	Compressed air intensity (cubic metres per hour per ton)
m^3/s	Flow
W, kW, MW or GW	Power

ABBREVIATIONS

Abbreviation	Definition
GDP	Gross domestic product
PGM	Platinum group metal
SARS	South African Revenue Services
SCADA	Supervisory control and data acquisition
VSD	Variable speed drive
W&E	Water and effluent

CHAPTER 1 – INTRODUCTION

1.1 Background

1.1.1 South African deep-level mining

Gold and platinum are South Africa's largest exported commodities producing the most significant income [1-5]. However, platinum group metals (PGMs) deliver a higher income than gold with the most significant reserves [6-7]. According to Stats SA, PGMs contributed 42% of the total mineral sales between August 2020 and January 2021. The rest of the minerals included coal (17.54%), iron ore (14.22%), and gold (13.1%), which have reduced drastically in the last few decades. The remaining percentage includes chromium, copper, manganese, nickel, building materials, and non-metallic minerals [6].

This significant income assisted South Africa, especially during the Covid-19 pandemic. Anglo American Platinum reported a six-month profit of R46 billion. The result was R16.6 billion taxes paid to the South African Revenue Services (SARS), which helped South African households and businesses to survive financially after the COVID-19 pandemic.[1]

Mines further provide a significant amount of employment [1, 8]. Askham and Van der Poll reported that the mining industry contributed 457 698 jobs to employment in 2015 [7]. It is well known that South Africa has the world's deepest mines, with PGM mines ranging between 400 m and 1 300 m [1, 4, 9-11]. These depths lead to a higher demand for employment [12]. Many jobs were lost during the last couple of years due to the closure of unsustainable mines [1, 4, 8, 13]. These job losses affected not only employees, but also their five to 10 dependants [7]. This loss of employment shows that mining plays a crucial role in South Africa's financial stability and employment. For this to continue, mines must be sustainable.

Resources such as water and energy are required to produce these commodities. Water is a non-renewable resource, and energy is becoming increasingly expensive. Therefore, these resources should be used wisely and effectively to ensure a mine's sustainability [4-5, 8, 14].

[1] H. Wasserman. "Astounding mining profits are saving SA, helping to heal history," *News24*, 02 Aug. 2021. Available: https://www.news24.com/fin24/opinion/helena-wasserman-astounding-mining-profits-are-saving-sa-helping-to-heal-history-20210802, [Accessed: 18-08-2021].

1.1.2 Energy and water security in South Africa

It is a well-known fact that Eskom has been implementing load shedding since 2008, which results in Eskom not supplying enough power to South Africa [15-16]. Creamer reported that 13% of South African households do not have electricity as the supply is too low.[2] Medupi power station was built to assist with the power shortage [17]. Komati power station is being transformed into renewable energy as it is nearing its end of life. The completion of these power stations will increase the supply energy and ensure the delivery of more sustainable energy.[3] Some of South Africa's biggest platinum mines (such as Sibanye Stillwater, Anglo Platinum, and Implats) started approving the installation of 795 MW of renewable power, such as solar power. The installation thereof will further supply the mines with more sustainable energy and relieve strain from Eskom's grid [16, 18].[4]

South Africans are currently extremely aware of the energy problems they are experiencing due to load shedding. However, what they are not as aware of is the fact that the water supply is also a huge concern.[5, 6] South Africa is in fact a water-scarce country, and the problem could affect South Africa sooner than other countries.[6] As recently as 2016–2018, the term 'day zero' became quite well known – especially after Cape Town's water supply became critical, which led to water restrictions [19]. This water crisis is not only a South African, but also a global problem [19-22].[7]

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[2] T. Creamer. "From a coal-to-gas conversion to a microgrid factory, Eskom builds Komati's just energy transaction case," *Engineering News*, 03 Aug. 2021. Available: https://www.engineeringnews.co.za/article/from-a-coal-to-gas-conversion-to-a-microgrid-factory-eskom-builds-komatis-just-energy-transaction-case-2021-08-03, [Accessed: 18-08-2021].

[3] A. Areff. "After billions in cost overruns, design flaws, delays and load shedding, Medupi is finally complete," *Fin24*, 02 Aug. 2021. Available: https://www.news24.com/fin24/economy/eskom/after-billions-in-cost-overruns-design-flaws-delays-and-load-shedding-medupi-is-finally-complete-20210802, [Accessed: 06-08-2021].

[4] F. Njini and J. Thornhill. "Platinum giants eye solar power as a green answer to load shedding," *News24*, 23 Jul. 2021. Available: https://www.news24.com/fin24/companies/platinum-giants-eye-solar-power-as-a-green-answer-to-load-shedding-20210723, [Accessed: 08-08-2021].

[5] S. Venter. "Our taps are running dry: Demand exceeds supply in large parts of SA," *City Press*, 28 Oct. 2019. Available: https://www.news24.com/citypress/news/our-taps-are-running-dry-demand-exceeds-supply-in-large-parts-of-sa-20191028, [Accessed: 20-08-2021].

[6] H. Roman. "Analysis: Liquid asset: What is South Africa doing to safeguard its water resources?," *News24*, 14 May 2021. Available: https://www.news24.com/news24/analysis/analysis-liquid-asset-what-is-south-africa-doing-to-safeguard-its-water-resources-20210514, [Accessed: 10-08-2021].

[7] M. Sizani and J. Stent. "Port Elizabeth's Day Zero: A result of poor planning and a failure to fix leaks," 22 Sept. 2020. Available: https://www.news24.com/news24/southafrica/news/port-elizabeths-day-zero-a-result-of-poor-planning-and-a-failure-to-fix-leaks-20200922, [Accessed: 10-08-2021].

The finite water consumption is overlooked due to the lower consumption cost [21-22]. Stats SA reported that mining was the fourth-largest water consumer in 2013. Mine water consumption follows after municipalities, households, and commercial users, which means that mining can affect water security in the future [7, 23]. The potable water expenditure of the specific platinum mine used as a case study in this research is only 2% of its total expenditure. In the change houses, potable water is used for drinking as well as showering. At the shafts, potable water is sometimes used to replenish the service water supply.

Not only do mines use potable water, but they also affect aquifer water. The demand for aquifer water has increased over the last few decades as farmers and local communities use it [24]. Tunnels and stopes due to mining development converge with these aquifers, thus removing the aquifer water from the local community. This convergence results in the water flowing into the tunnels and stopes. The mining process contaminates the aquifer water, making it inconsumable [7, 16, 25]. This especially becomes a problem if mines are left abandoned, whereafter aquifer water should be treated for chemicals, which is an expensive process. Instead, this water could have been used directly by the local communities [7].

It is evident that mining activities do play an essential role in the consumption of finite water – not only of potable water, but also aquifer water. Although the consumption of aquifer water is the result of the mining process, it cannot be avoided due to the sustainability of the mine. This places emphasis on the reduction of potable water.

1.1.3 Platinum production process

The platinum production process starts with the ore mining process. For these operations, pneumatic drills are used to drill holes into the rockface. After the holes are drilled, explosives are placed in the holes and blasted. The blasted ore is transported to the surface, whereafter the ore is sent from the shaft to the concentrators. When the ore arrives at the concentrators, mills crush the ore into fine particles. The particles are treated with chemicals, a process known as froth floatation, which produces a concentrate. The concentrate is dried and melted in an electric furnace at a temperature of 1 500°C. Iron and sulphur are removed before the PGMs are separated from the base metals to deliver a product of high purity [2]. This entire process is shown in Figure 1.

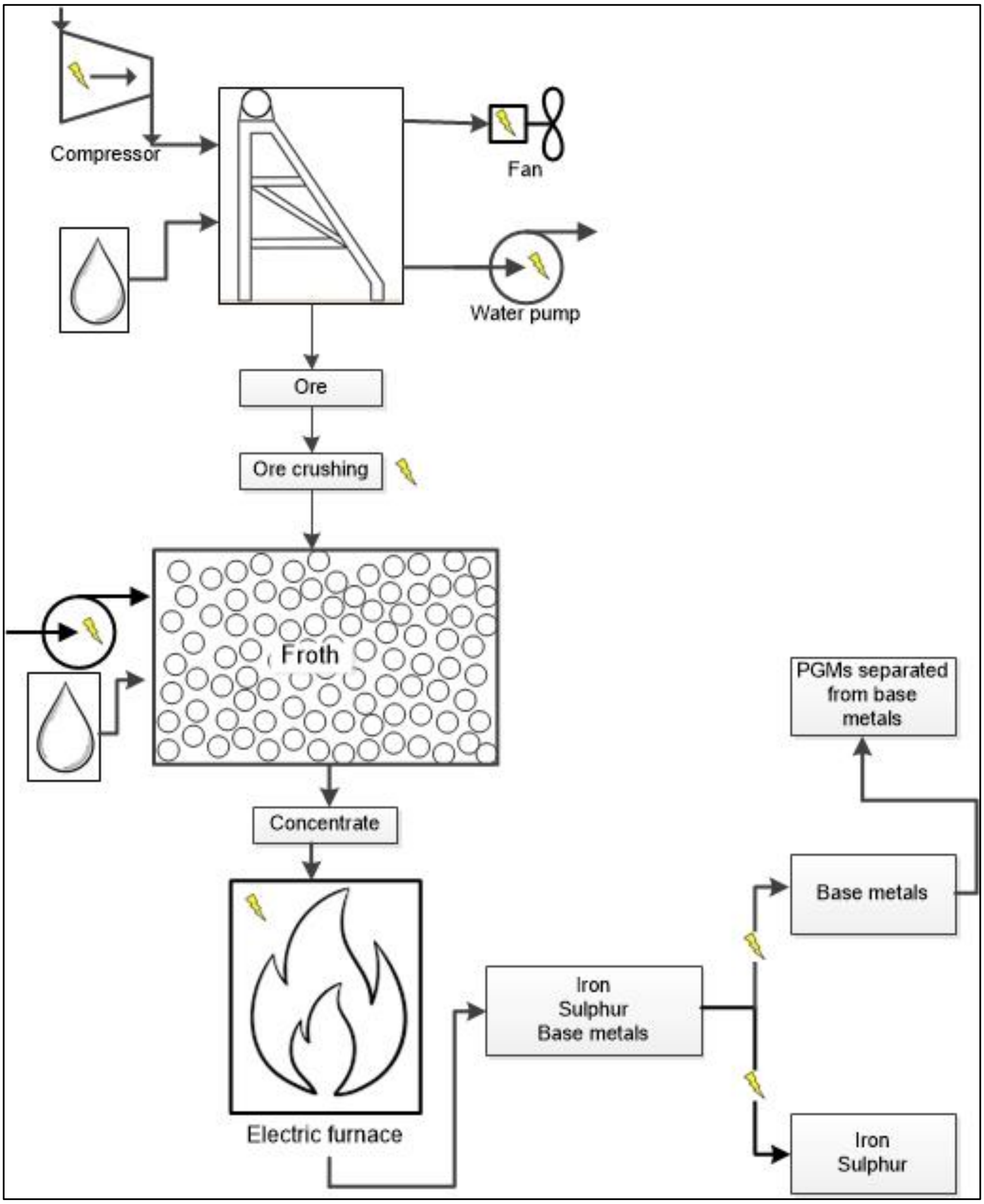

Figure 1: PGM production process [2]

Note that platinum production requires energy. Figure 1 indicates the processes that require energy with thunderbolts. Figure 1 can be grouped into three sections as each section have different operations. These sections are the shafts, concentrators, and remainder. The output of the shafts are the hoisted ore tons. Concentrators crush the ore to deliver the concentrate, whereafter it is melted in the electric furnace. After the concentrate is melted, the impurities are removed to deliver the PGMs. The melting and separation are seen as the remainder.

1.1.4 Energy consumption on deep-level mines

Figure 2 shows the utility cost breakdown between the shafts, concentrators, and remainder for the specific case study platinum mine. The shaft consumes 52% of the energy expenses, the concentrators 30%, and the remainder 18%. The remainder includes the process after the concentrators and offices.

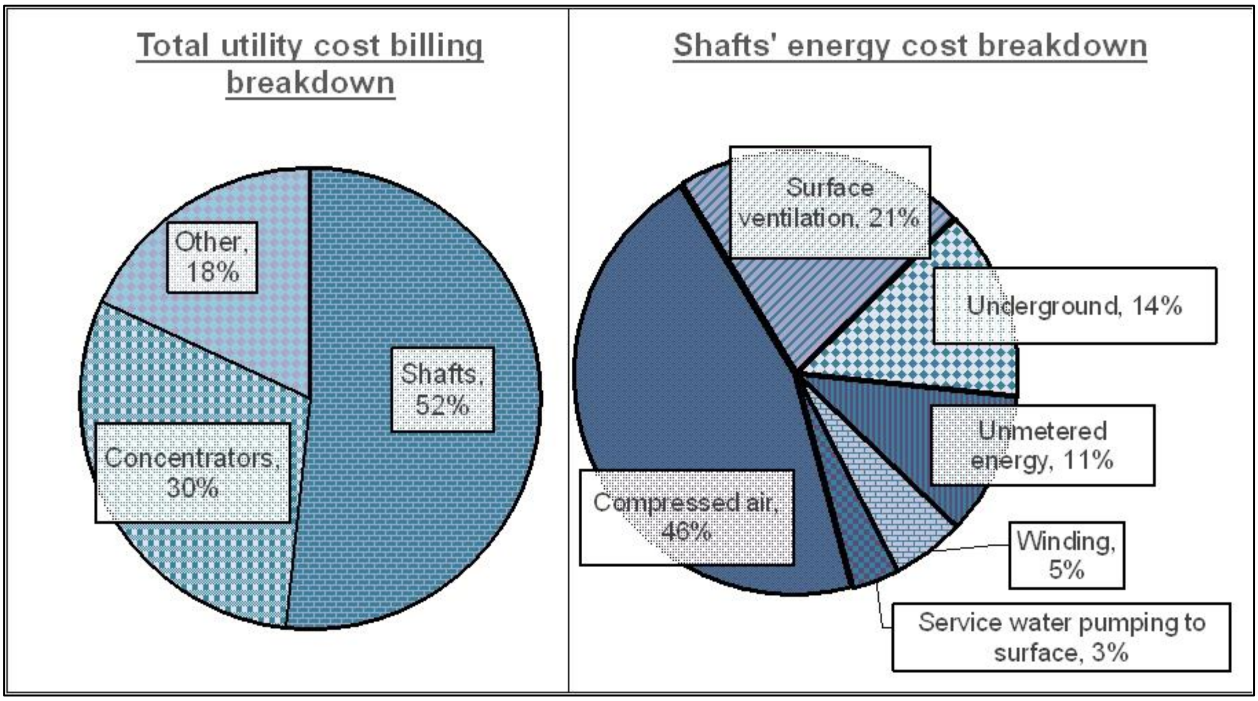

Figure 2: Total utility billing breakdown (shaft, concentrators, and remainder)

Compressors are the most significant expenditure at 46% of the total energy expenditure as seen in Figure 2. The installation capacity of these compressors range between 1 MW and 15 MW [4, 26]. On the specific mine, ventilation comprises 21% of the utility cost breakdown with the installed capacity ranging between 110 kW and 1.5 MW. Underground energy consumes 14% of the utility cost. Furthermore, there is unmetered energy consumption due to various equipment, which accounts for 11% of the total electricity expenditure. Transporting the ore to the surface consumes 5%, and the service water pumping consumes only 3% of the total electricity expenditure.

Figure 2 shows that all the processes require energy. It was discussed that these energy requirements comprise large installed capacities up to 15 MW, contributing to mines being the most energy-intensive industry [27]. However, taking away the energy from one of the parts will reduce production considerably, which will lead to a significant loss in profit. Not only can platinum mines not function without Eskom's energy, but Eskom is also playing an essential role in mines' profit margins. These profit margins affect the sustainability of mining companies [28-29].

Since mines are considerably energy-intensive, increases in tariffs cost the mines a significant amount of money. Suppose Eskom implements a tariff increase more prominent than 10%, the mines are affected significantly (10% is the increase on all products and services a company budgets for). For example, in 2009, Eskom increased its tariffs by 30%. If the mines only planned for a 10% increase in tariffs, this would have been a R400 000/MW larger unbudgeted energy expenditure. Figure 3 shows the accumulative percentage energy cost increase between 2008 and 2018.

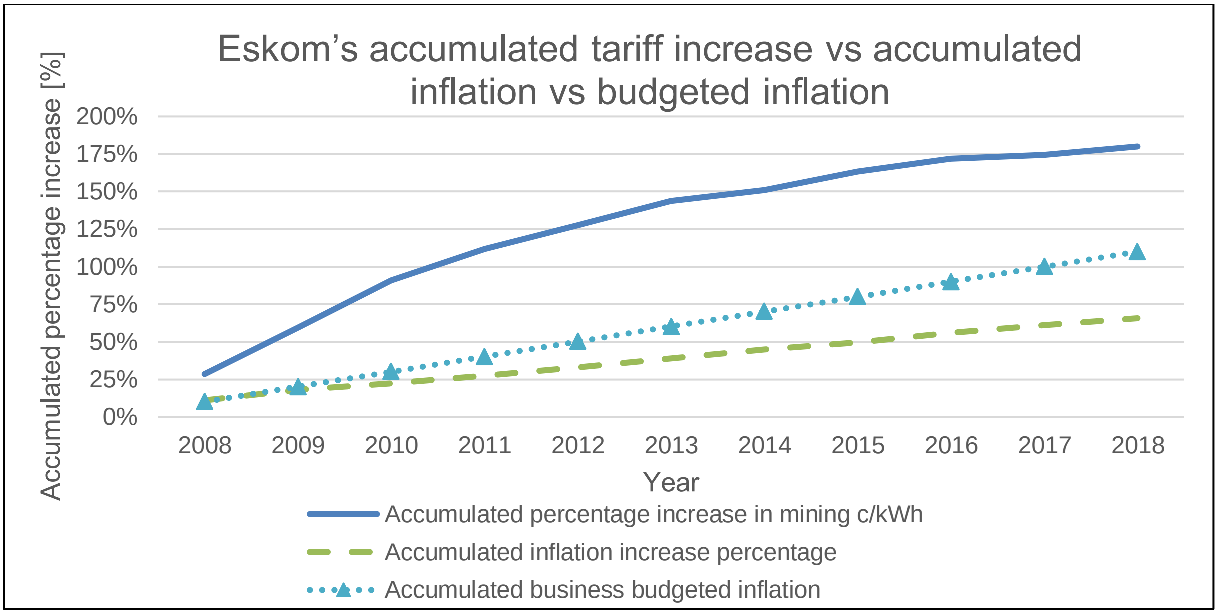

Figure 3: Eskom's accumulated tariff increase vs accumulated inflation vs budgeted inflation [30-31][3, 8, 9]

In total, between 2008 and 2018, the Eskom increases remained accumulatively far above inflation. Not only were they far above inflation, but if the mines budgeted a 10% per annum increase, Eskom would have also been accumulatively far above the budget as seen in Figure 3.[3, 8, 9] The total accumulated percentage tariff increases between 2008 and 2018 are close to three times more than the accumulative inflation. A 1.67 ratio is noted between the accumulative budgeted inflation and the accumulative energy tariff increase in 2018. This ratio would have resulted in the mine being R4.6 million/MW under budget annually if they created a 10-year financial plan. Take note that the R4.6 million is per megawatt. A one-megawatt consumption is still small for a mine. If the energy cost had gone up proportionally with inflation, the mine would have overbudgeted with an annual cost of R680 000/MW, which would have been profit in 2018.

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[8] Eskom. "Historical average price increase," Available: www.eskom.co.za/CustomerCare/TariffsAndCharges/Pages/Tariff_History.aspx, [Accessed: 10-08-2021].

[9] A. O'Neill. "South Africa: Inflation rate from 1986 to 2026," *Statista*, 25 May 2021 Available: https://www.statista.com/statistics/370515/inflation-rate-in-south-africa/, [Accessed: 27-06-2021].

This accumulative tariff increase shows that Eskom tariffs affect mines significantly and that energy expenditures cannot be planned [31].

From Figure 3 it seems as if the tariff increase slope decreased closer to 2018, thereby reducing the gap between Eskom's tariff increases and inflation. A gap closure would benefit mines as Eskom would have to implement a lower than inflation increase. However, this was not true as in 2021, Eskom again requested a 15% tariff increase. This tariff increase was implemented on 1 April 2021 to recover previous years' unpaid debt.[10, 11] Once again, mines had to increase their energy budget as the Eskom increase was above the planned increase of 10%, which lowered the planned profit.

To make accommodation for these tariff increases, the energy consumption should be lowered. Lowering a mine's energy consumption is not easy, and an analysis should be completed to identify reduction opportunities. By benchmarking various systems, inefficiencies can be identified quicker and easier, which will result in cost savings.

1.2 Mining operations overview

This study was done on a specific case study at a platinum mine that comprises five shafts. Three of these shafts are vertical shafts and the other two shafts are incline shafts. All these shafts use the conventional mining method. All five shafts receive the following utilities to be operational:

- Compressed air (comprises three compressed air rings with multiple compressors per ring).
- Service water.
- Potable water (going underground and to the change house).
- Electricity.

The following energy subunits are measured on all five shafts:

- Surface fan energy.
- Underground energy.
- Rock winder energy (vertical shafts only).

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[10] M. Van Der Merwe. "Eskom gets green light to hike tariffs by over 15%," *Fin24*, 16 Feb. 2021. Available: https://www.news24.com/fin24/economy/eskom/eskom-gets-green-light-to-hike-tariffs-by-over-15-20210216, [Accessed: 09-08-2021].

[11] S. Khumalo. "Energy regulator to oppose Eskom's judicial review of tariffs decision," *News24*, 10 May 2021. Available: https://www.news24.com/fin24/economy/eskom/energy-regulator-to-oppose-eskoms-judicial-review-of-tariffs-decision-20210510, [Accessed: 09-08-2021].

The following sections give the specific mine's total consumption in half-hourly intervals and explains the consumption. As the potable water was only retrievable in daily intervals, no half-hourly profiles could be created.

Compressed air consumption

On the specific mine, the shafts' compressed air networks are connected, which is called a compressed air ring. Figure 4 explains this network. The top of the figure shows a few compressors in a compressor house (sometimes there are multiple compressor houses per compressed air ring). The compressors are considered the supply side. These compressors are connected to one single pipe. The airflow is delivered from the compressor houses to the shafts, which are considered the demand side.

At the shaft on the surface, there are main valves and bypass valves. The main valve are open/ close valves. The bypass valves are control valves that control the pressure downstream of these valves. The air flows into the shafts to the underground levels. On the specific mine, all the active shafts have valves on the levels. Some shafts have additional bypass valves, which are manual ball valves to ensure there is continuous flow to the refuge bays.

The compressed air consumption can be broken down into two main sections: the demand side and supply side. The supply side comprises compressors that deliver the compressed air to the shafts. Zietsman showed that the coefficient of determination between flow and compressor power is 0.9643 [1]. This correlation means that the power can be reduced by reducing the flow [1].

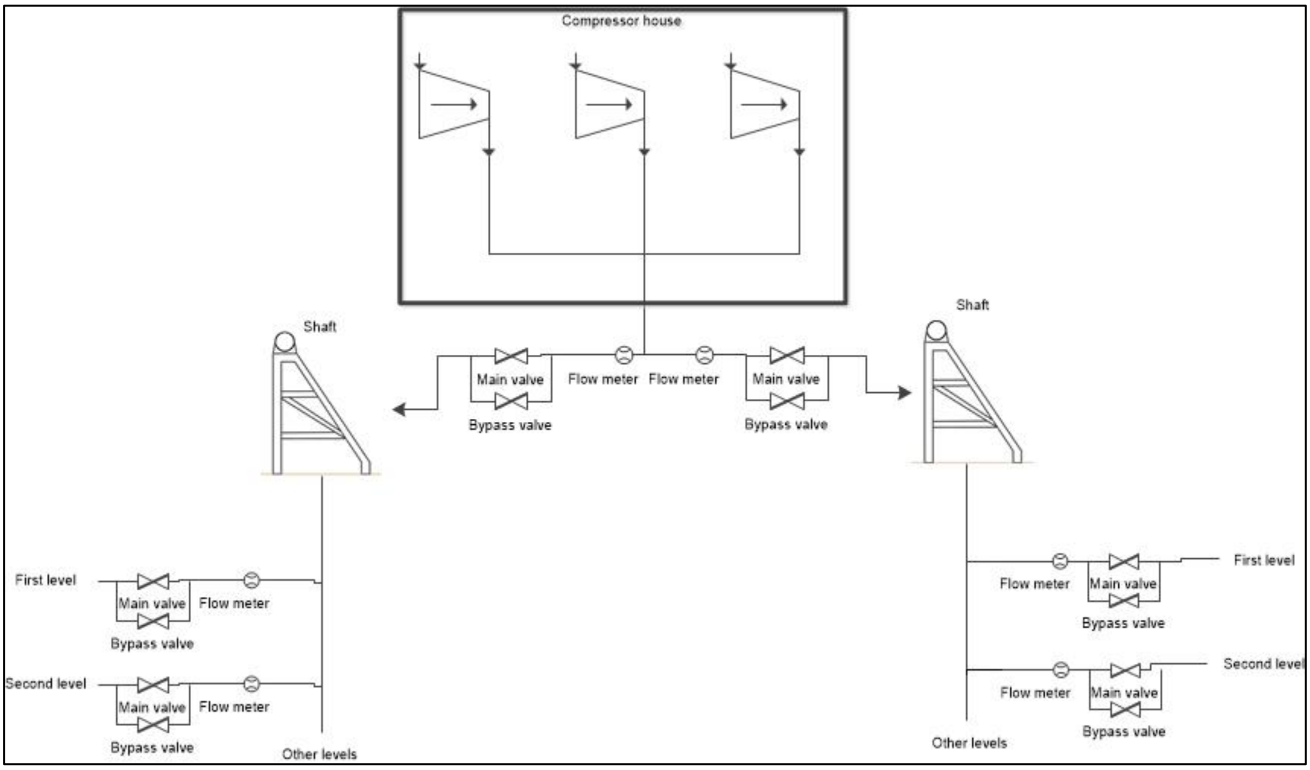


Figure 4: Compressed air ring explanation

Figure 5 explains the demand side. This figure shows the total half-hourly consumption for the specific mine. November 2020 was used to calculate the period seen in Figure 5. Over 24 hours, the compressed air is separated into three shifts, namely:

- Drilling shift.
- Blasting shift.
- Evening and morning shift (sweeping/cleaning shift).

All the compressed air equipment is used for the blasting process (mining) [1]. For the drilling shift, pneumatic drills are used to drill holes into the face. During the blasting shift, explosives are placed into the drilled holes and exploded. For the cleaning/sweeping shift, the blasted production is loaded into electric locomotives using loaders and loading boxes. Table 1 and Figure 6 show the requirements of the specific pneumatic equipment used for production.

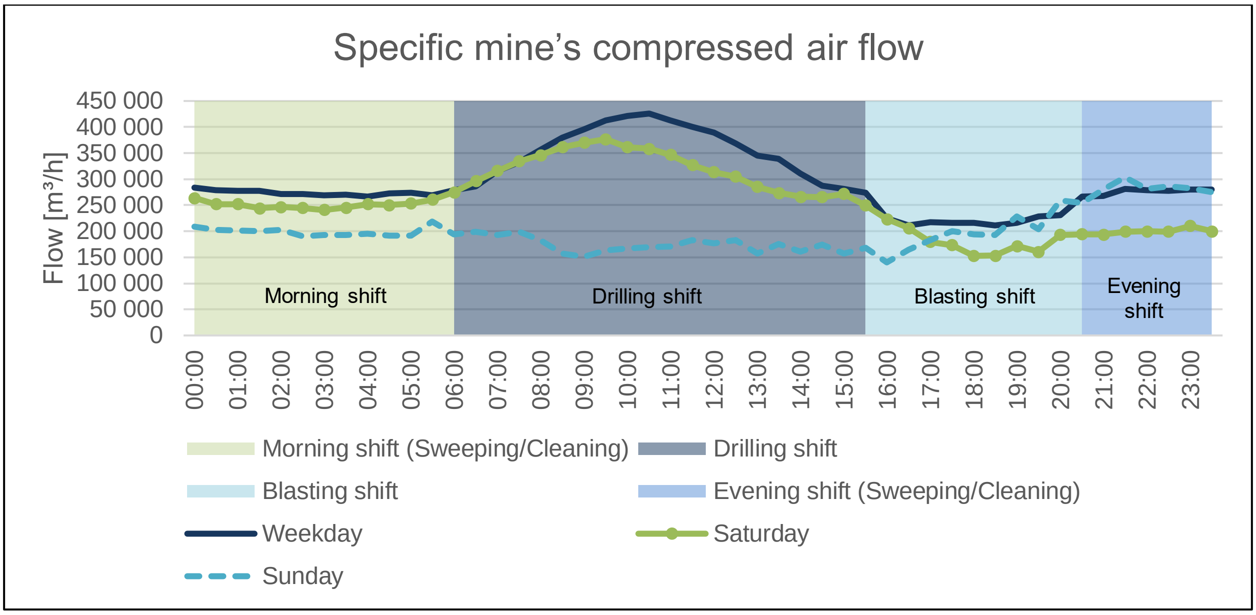


Figure 5: Specific mine's total compressed air consumption profile (including shifts) (adapted from [1, 5])

Figure 5 indicates that the morning shift takes place from 00:00 till 06:00. The drilling shift is indicated from 06:00 till 15:30. Thereafter, a reduction in compressed air is noted from 15:30, which indicates the start of the blasting shift. The blasting period's consumption comprises refuge bays requiring a positive pressure to prevent smoke, dust and gases from entering. An increase in compressed air is once again indicated from 20:30, which is the end of the blasting shift and the start of the evening shift.

Figure 5 shows that the minimum consumption takes places during the blasting period. The consumption during the morning and evening shift is similar due to the process being the same for the respective shifts. The maximum flow is indicated during the drilling shift, which is the result of the large number of drills being used as well as the supply pressure being increased.

Table 1 and Figure 6 show the pressure requirements of the different equipment.

Table 1: Pneumatic equipment information [1, 4]

	Pneumatic drills	**Pneumatic loading boxes**	**Pneumatic loaders**	**Refuge bays**
Shift	Drilling	Drilling and sweeping	Cleaning shift	All shifts
Pressure requirements [kPa]	450–620	400–500	350–450	150–200
Flow requirements [kg/s]	0.12	0.004–0.1	0.8	< 0.06

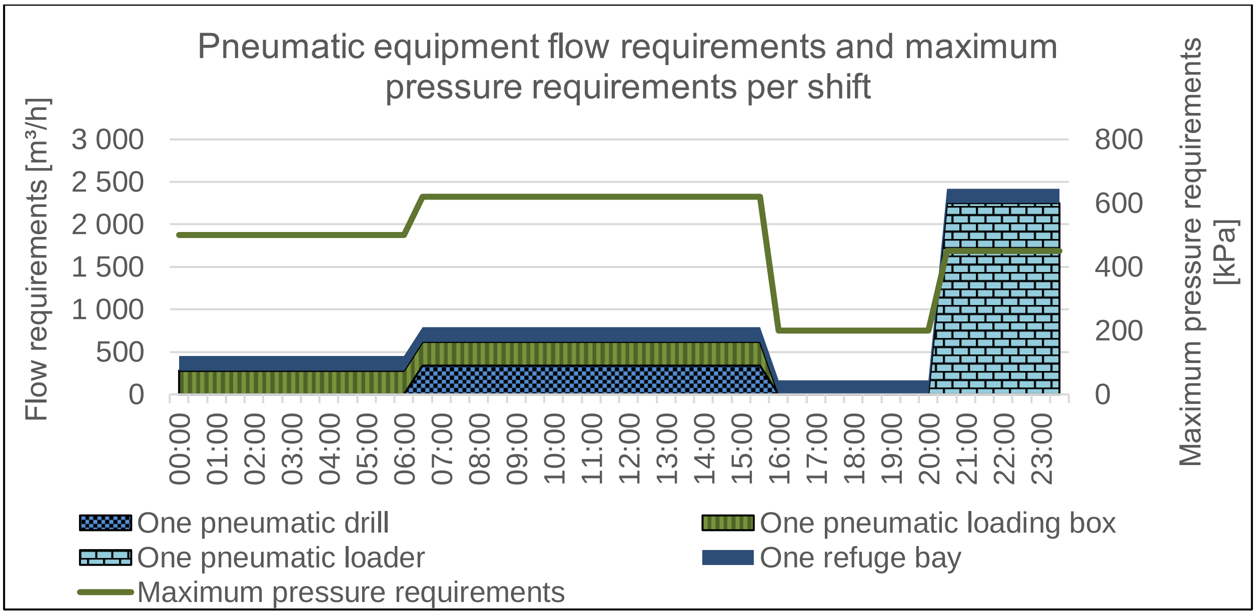


Figure 6: Equipment flow and maximum pressure requirements

Comparing Figure 5 and Figure 6 shows a difference in flow from 20:30. Figure 6 shows a more significant consumption as one pneumatic loader requires more flow than one drill. Figure 5 shows more flow during the drilling period because of multiple drills per level, and only one loader can be operational per half level. Another factor contributing to the flow is the required pressure for the loader and drilling machine. The drilling machine requires more pressure, contributing to the leak rate also increasing. The maximum number of loaders per level is four (UG2 East, UG2 West, Merensky East, Merensky West), where the drills would be significantly more, as they are not limited.

As discussed above, pneumatic drills are used for drilling. Table 1 shows that the pneumatic drills require an immense amount of flow as well as the highest pressure. The pneumatic boxes are boxes at the top of the sidewall of the haulage (primary travelway) that are operated pneumatically. The operations include opening and closing the loading boxes through an air cylinder. The openings of the boxes allow the ore to fall into the locomotive bucket, known as a hopper. These loading boxes require the least amount of air but the second-highest pressure as shown in Table 1.

Figure 7 shows a photo of a pneumatic loader in operation. The pneumatic loader moves on a railway as well. It scoops the blasted waste on the ground with the loader bucket and then pneumatically throws it into a locomotive at the back of the loader. Loaders require the second-largest amount of flow, but do not require such high pressure as the loading boxes.

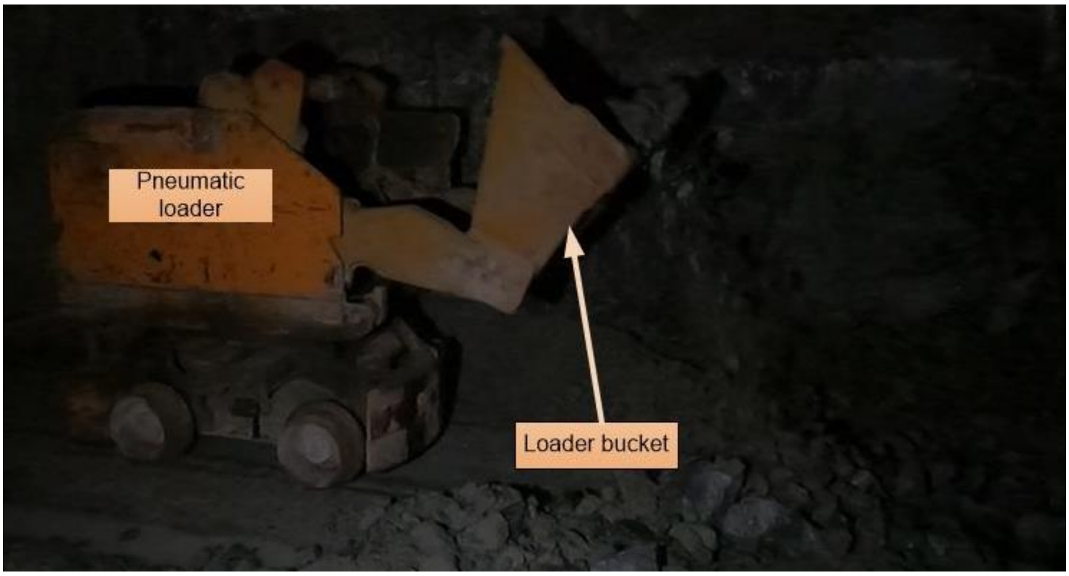


Figure 7: Photo of loader

The refuge bays are open pipes that deliver fresh air to areas underground in case of emergencies. There is often a ball valve in the refuge bay with a hole in the ball to deliver continuous flow and lower excess pressure. This continuous flow is crucial as the refuge bays are designed for emergency cases.

The last user comprises leaks and unauthorised consumption, such as open-ended pipes for cooling down the environment. Zietsman showed that this is probably the most significant consumer. If consumption must be decreased, these leaks/unauthorised consumption must be repaired [1]. Benchmarking can help identify where the most considerable potential is to locate these leaks/unauthorised consumption.

Surface ventilation fan energy

Cilliers stated that the virgin rock temperature increases by approximately 12°C per kilometre of depth in deep-level mines [4]. This rise in temperature means that cooling requirements increase as the shaft depth increases. A wet-bulb temperature of 27.5°C may not be exceeded for suitable working environments [4, 44-45]. Warm air should be replaced with ambient air if mining operations take place at less than 700 m. If the mining depth is deeper than 700 m, alternative strategies, such as fridge plants, are required [4, 46].

However, the vertical shafts of the specific study's mine have surface extraction fans and no alternative cooling methods. This ventilation further ensures that fresh air is delivered to the shaft. This fresh air replaces flammable gases, such as methane and dust.

The vertical shafts comprise vent shafts and upcasts as shown in Figure 8. Ambient air is pulled from a vent shaft to lower levels and then to the upcast shaft. From the upcast shaft, the air is extracted back to the ambient conditions with the energy of a large fan. With the assistance of booster fans, the air particles on the levels are extracted to the vent shaft.

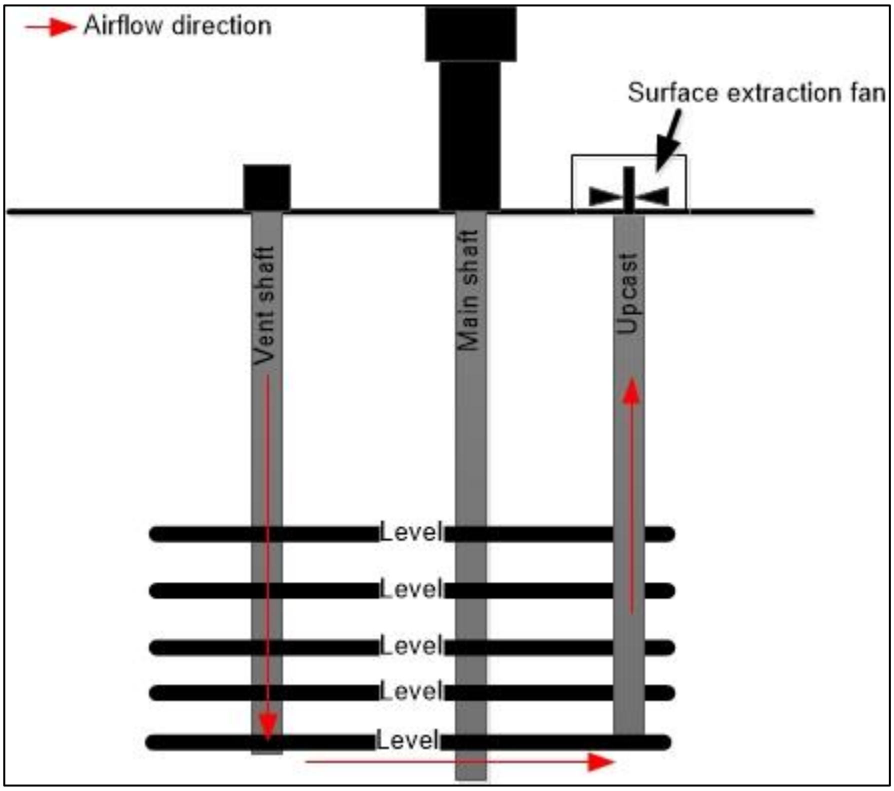


Figure 8: Surface extraction fan explanation [4]

This displacement of air particles requires a large amount of energy produced permanently [47-49]. Figure 9 gives the average power profiles of the specific mine's total power consumption of the extraction surface fans. November 2020 was used as the period to create the profiles.

Figure 9 shows that the power consumption remains constant during weekdays. Except from 16:30, there is a slight decrease in power. This decrease is the result of the guide vanes closing. From 21:00, the guide vanes open, resulting in the energy consumption increasing once again. Saturday's power consumption before 16:00 is lower than the average weekday power. This lower power consumption is due to the fans being stopped on Friday afternoons already during off weekends. On Saturday, on average, a few fans are stopped from 17:00. These fans are then started Sunday at 12:00.

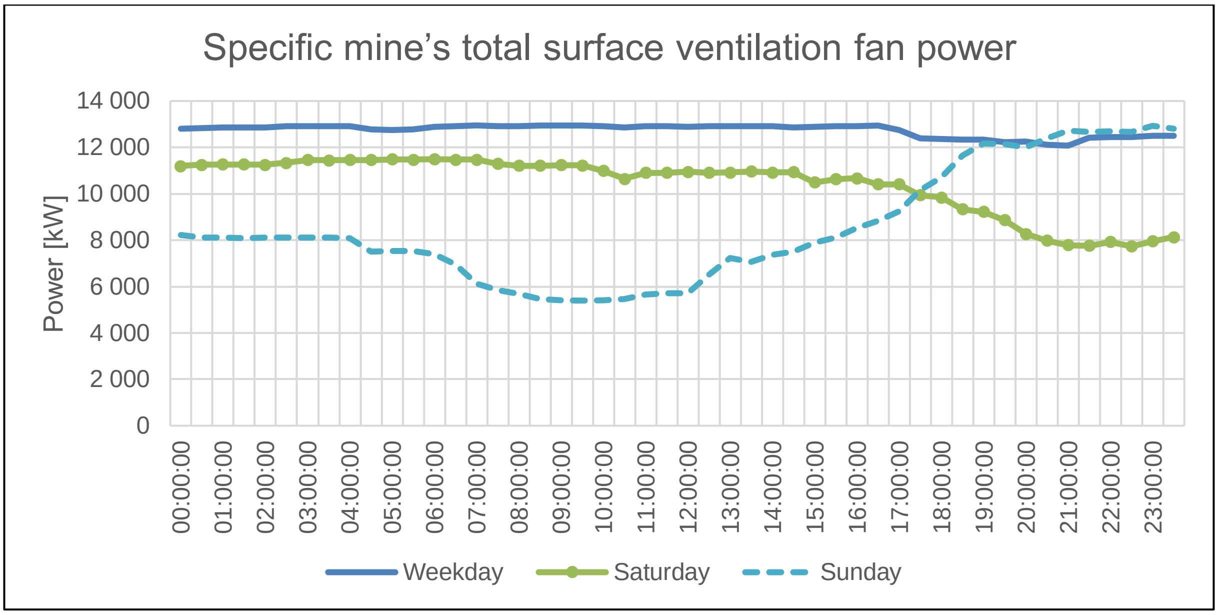


Figure 9: Specific mine's total surface ventilation fan power profiles

Underground energy

The underground power consumption comprises various consumers such as spindle pumps, booster fans, battery bays, conveyors, and shaft dewatering pumps. On the study's platinum mine, these energy consumers are not split, but the total consumption is measured. Figure 10 shows the profiles of the total power of all the shafts for a weekday average, Saturday average, and Sunday average. Once again, November 2020 was used to calculate these profiles. It would have been easier for possible reduction identification if the different consumers were separated according to pumping, mining, and ventilation. With these consumers not being split and only total underground energy being measured, it is not easy to see if a reduction project has been implemented.

Figure 10 shows that there are two peaks in 24 hours for the average weekday profile. The peak between 06:00 and 20:00 correlates with the drilling shift. The two peaks show that the energy consumption correlates with the shifts. These power peaks also indicate that human activity influences underground power consumption.

The dewatering pumps and conveyors are the only equipment that can be optimised/controlled to show an energy reduction. They are also the more significant energy consumers. For the dewatering pumps, energy will increase as the service water supply increases. The service water demand increases with the drilling shift as the pneumatic drills also require service water to cool down the drills.

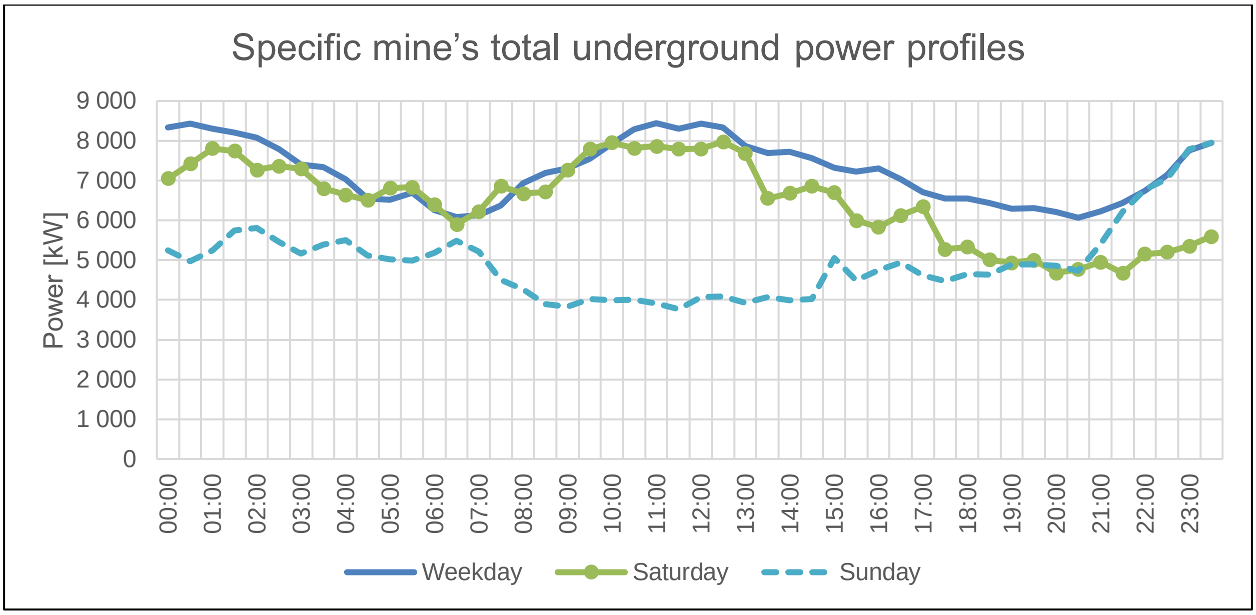


Figure 10: Specific mine's total underground power profiles

The conveyors may also be stopped during shift changeovers as no ore will be thrown on the conveyor. Stopping the conveyors will reduce energy as inclines have a very long conveyor with numerous motors to displace the large mass.

The Saturday profile has only one peak between 06:00 and 19:00, as the peak between 00:00 and 06:00 is from the Friday evening shift. The Sunday profile shows the baseload energy (fans, battery bays and lights) between 00:00 and 20:00 when the sweeping shift starts again.

Rock winder energy

Rock winders are used to transport platinum/gold to the surface. Engineering principles ($E_p = m \times g \times h$) show that mass and height influence the energy consumption of the transported ore. Figure 11 shows the weekday, Saturday, and Sunday average profile profiles. November 2020 was used to calculate these profiles.

The weekday energy consumption, shown in Figure 11, indicates that the maximum energy consumption is between 02:00 and 07:00. As explained in the compressed air consumption section above, drilling takes place between 06:00 and 15:00. From 15:00 till 21:00, the ore is blasted and transporting starts taking place after 21:00 (for the sweeping cleaning shift). It takes a few hours to transport the ore from the face to the station to be loaded into the rock winder. The time it takes to transport the ore explains why the maximum weekday energy is consumed between 02:00 and 07:00. The amount of ore to be transported starts reducing from the drilling shift.

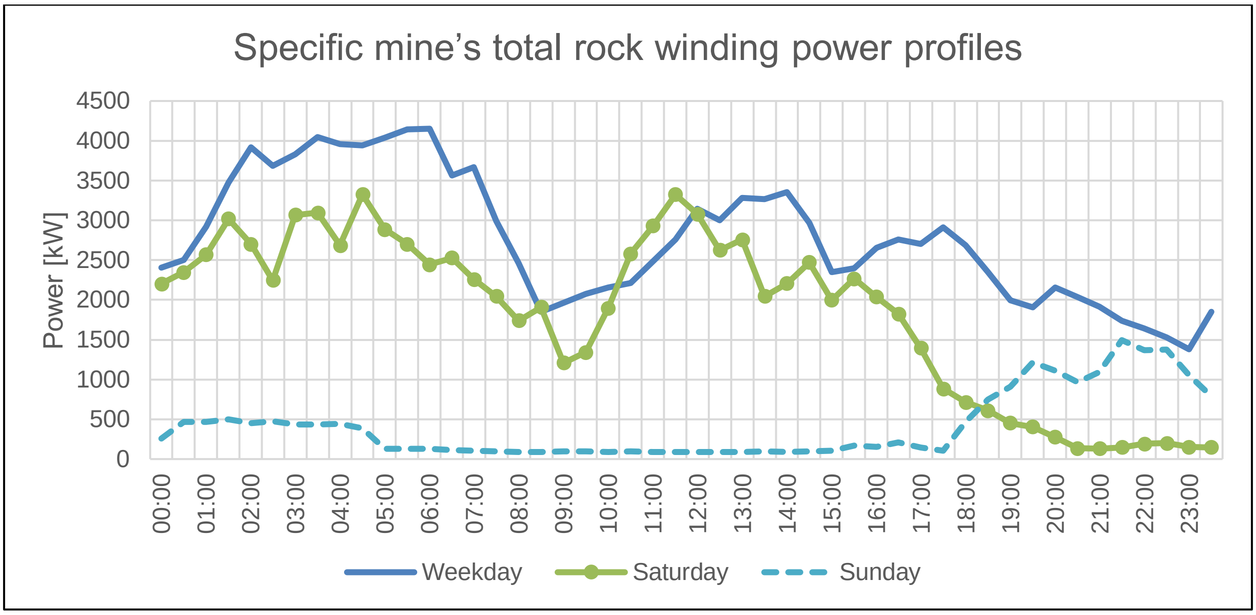


Figure 11: Specific mine's total rock winder power profiles

For the Saturday profile between 02:00 and 05:00, the ore transported is still from Friday's blast. The shift change takes place between 06:00 and 09:00, resulting in a decrease in energy. After 18:00 on Saturdays, operations stop and only start again from 17:30 on Sundays, when the rock winder starts operating once again, removing the ore still from the Saturday blast.

Service water consumed underground

As discussed above, service water is used to cool down the drills. Service water is created by recirculating the water to reduce the amount of potable water used. A water reticulating system diagram is shown in Figure 12 to explain the process. The diagram shows two pipelines (red and green). The first is the water consumed underground by the drills (red pipeline). The water is not only used by the drills but is also used to spray the walls for dust suppression and to lower the temperature of the walls [7].

The second pipeline is where the water is pumped/flowing to the shaft bottom dam. For this process, the levels also contain small pumps (from 7.5 kW) to assist with the flow back to the station. After the water reaches the shaft bottom dam, it is pumped back to the surface. The water reticulation system does not always start from the surface but may also start from an upper level.

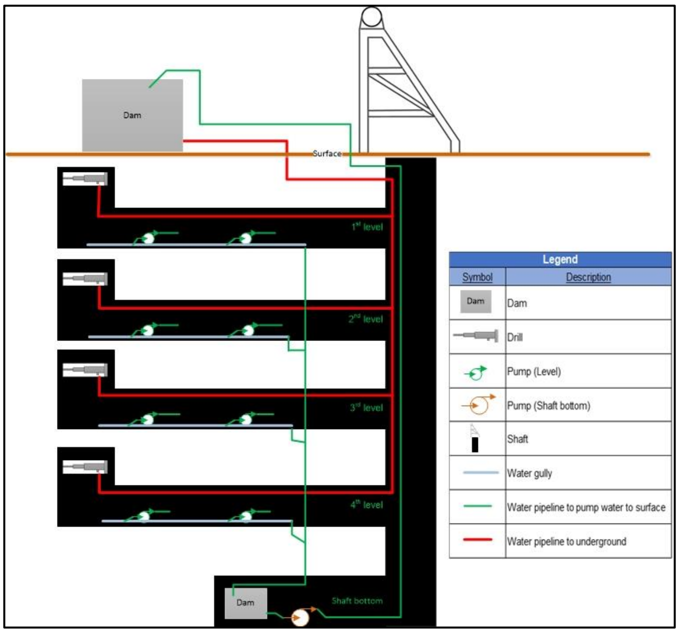


Figure 12: System diagram of water reticulation system

Figure 13 shows the average consumption of a weekday, Saturday, and Sunday. November 2020 was used as the period for creating these average profiles. It is noted that the consumption increases during the drilling shift on a weekday and Saturday. This increase in consumption is due to the drills consuming water. After the blasting period and Sunday evenings, the demand increases again because the walls are sprayed to lower the temperature and suppress the dust. This higher consumption continues until 02:00 in the morning. From 02:00, a few level valves close, reducing the consumption. The Sunday profile shows that many leaks can be managed, as the consumption is close to the weekday and Saturday morning profiles.

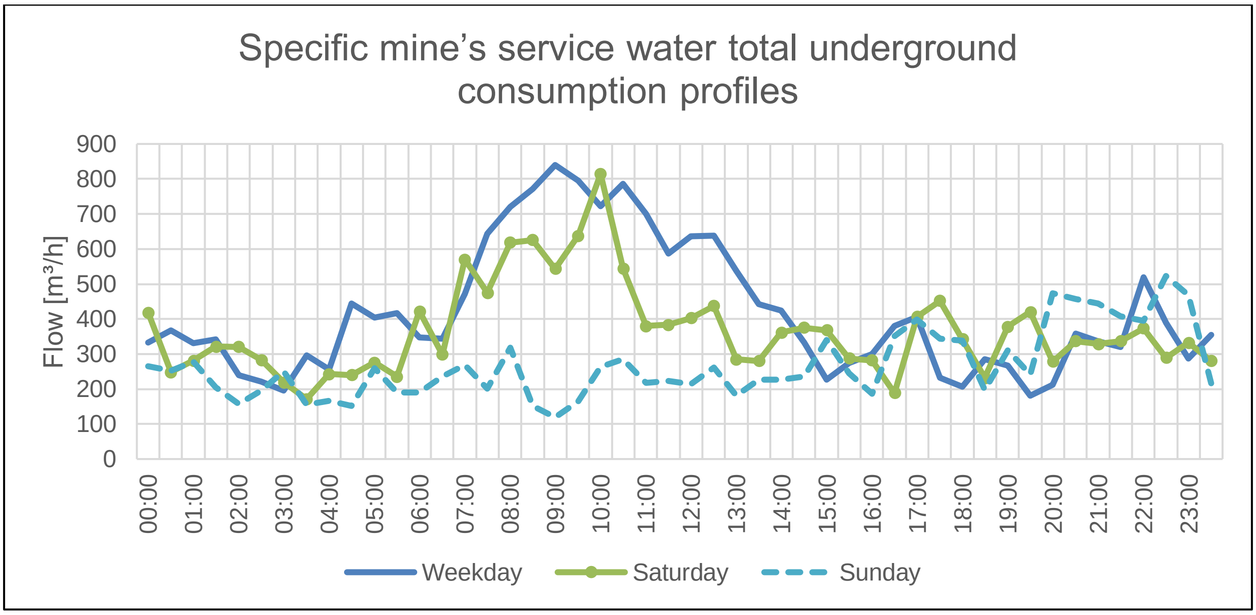


Figure 13: Specific mine's service water consumed underground profiles

Service water pumped to the surface

As mentioned in the above section, service water is recirculated to reduce the amount of potable water used. Pumps that consume energy should be started for this water to be recirculated. Figure 14 gives the flow profiles for these pumps, which were calculated using November 2020 data.

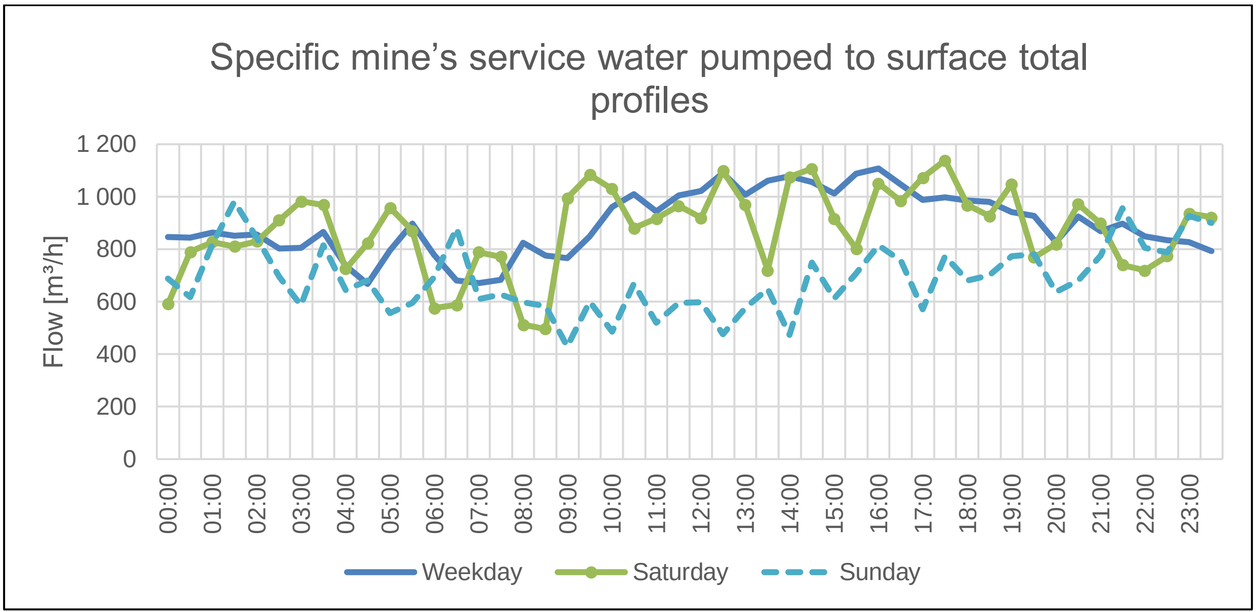


Figure 14: Specific mine's service water pumped to surface total flow profiles

Comparing Figure 13 and Figure 14 shows that Figure 14 pumps out more water than consumed underground. This higher pump flow is due to aquifer water that filters through the ground [25]. These profiles can also be transformed to power profiles using the following formula:

Equation 1: Transforming flow to power

$$P = \frac{\rho \times g \times Q \times h}{1000}$$

The weekday profile in Figure 14 shows that the pumped flow starts to increase from 09:00. This increase in flow is three hours after the drilling shift starts. It takes a few hours for the water to be circulated to the shaft bottom, where most of the pumps are, pumping the water to the surface. Even through the blasting period, the water pumped to the surface remains high. It only starts to decrease after the blasting period. The same can be seen with the Saturday profile. The flow remains high during the early morning hours for the Sunday profile, but decreases until 08:00 and then increases drastically at 20:00.

1.3 Previous studies on utility benchmarking

Benchmarking studies have been done widely in the commercial, industrial as well as mining industries. Numerous studies were found on energy benchmarking and a few on water benchmarking. This section discusses the benchmarking study types as well as previous studies done on deep-level mining.

1.3.1 Benchmarking types

During the literature study, different benchmarking types were noted. These benchmarks were all created to accomplish the same goal, namely, to identify inefficiencies. The benchmarks noted include load shaping baseline, intensities, and regression. The literature of the different benchmarks will be discussed below.

Load shaping baseline

The load shaping baseline benchmarking type was used by Park *et al.* [28] to benchmark different types of building energy. In total, they used data of 3 829 buildings, which included residential and non-residential buildings in various parts of the world. Universities were classified as non-residential buildings.

The objective of this study was to determine the load profiles of various building types. From these energy profiles, Park *et al.* evaluated periods during which energy consumption could be lowered. They started by identifying three fundamental hourly energy load shaping profiles, whereafter they clustered the data. A machine learning program was used to determine the number of clusters (building types). The clusters were calculated by subtracting each data point from the midday data point. The last step was to distinguish between the clusters to obtain average profiles and then determine the potential scope for improvement [28].

A positive aspect of this study is that it considered temperature in the profiles. A large number of the buildings were in the United States. Park *et al.* further included buildings in the western area of Australia as well as European buildings, which had different climate conditions [28].

The novelty of their study was to look at shorter time intervals. A couple of years ago, energy readings could only be obtained from Eskom bills. There has been an improvement lately in metering, which enabled energy readings to be available up to every half hour. This improvement allows period energy monitoring and increases the number of systems that can be monitored [28, 32-33]. This improves monitoring and maintenance, which will in turn also assist with dealing with failures promptly and allow costs to be avoided [34].

Intensities benchmarking

The intensities benchmarking type was used by Morgenstern *et al.* [35], Timma, Skudritis, and Blumberga [34], Du Plooy [5], and Wang *et al.* [36]. Intensities benchmarking comprises dividing the usage (inputs) by the deliverables/outputs. The consumer with the highest intensity is considered the most inefficient.

Morgenstern *et al.* benchmarked acute hospitals, which they divided into departmental areas [35]. They aimed to explore how meaningful energy benchmarks could be constructed for hospitals. Morgenstern *et al.* found that previous studies could not be used because they did not consider the type of service the hospitals delivered. Per agreement, different hospitals deliver different services – meaning that they use different types of large energy-consuming equipment [35]. Morgenstern *et al.* did on-site measurements at wards, day clinics, laboratories, radiotherapy and many more to create consumption intensities (energy divided by floor area). It was found that the wards and day clinics had lower consumption intensities. Theatres, laboratories and radiotherapy sectors showed higher consumption [35].

A recommendation from this study would be to consider other variables apart from the floor area. The energy would further vary depending on the number of patients/staff. However, the new approach of looking at different departments would assist with future hospital benchmarking studies.

The objective of Timma *et al.* was to bring awareness to potential energy saving in supermarkets [34]. The authors created a benchmark analysis on a supermarket in Latvia. It was decided to create intensities with the amount of energy used per customer. The results showed that the specific energy consumption ranged between 1.06 kWh and 1.73 kWh per consumer [34]. This energy consumption range was wide, which showed there was a high variance. Timma *et al.* noted that the variance was caused by various technological and climate factors. In addition, Timma *et al.* stated that the most crucial factor was the behavioural factor [34]. However, the behavioural factor should not play a role in benchmarking as it varies too much. If a well-developed benchmark has been created, the variance would be minor. It was recommended that other factors than the number of customers, such as the number of products or floor area, should have been tested instead. Moreover, different benchmarks should have been created for the different climate conditions for a supermarket to act accordingly. It was further found that refrigeration equipment is the largest energy consumer in supermarkets [34]. With refrigeration being the most significant consumer, climate factors play a significant role. These climate factors motivate that different intensities should have been created as well.

Du Plooy created intensities for compressed air usage on levels on a platinum shaft. The objective of this study suggested localised benchmarking to locate and manage factors that contributed to the deterioration of compressed air network inefficiency [5]. Du Plooy created intensities in his study to find local deteriorations. The creation of the intensities comprised dividing the average compressed air consumption by the average daily production. However, this was a time-extensive exercise as the underground flow meters were faulty and downstream air pressure had to be measured to determine the flow. This study will be discussed later as it is relevant literature to this study [5].

Wang *et al.* [36] used product-based and process-based benchmarking of coal production. The objective of their study was to discover coal's high energy efficiency potential through benchmarking. This benchmarking was done by creating intensities. The product-based intensities comprised dividing the total energy consumption of raw coal by the total raw coal production. In other words, the energy consumed [kg] was divided by the coal produced [kg]. This intensity was the energy efficiency of raw coal production. To determine the electricity efficiency during coal production, they divided the electricity consumed by the total coal production. The unit for the electricity efficiency product-based efficiency was kilowatt-hour per ton [36].

The term 'process-based' refers to the energy consumed per unit of work. This process referred to the primary ventilation system, primary hoisting system, primary drainage system, and the primary pressure system. The intensity was also calculated by dividing the energy consumed by the workload. Each process had its own workload. For example, the workload of the primary ventilation systems was the ventilation quantity (m^3) multiplied by the pressure (Pa) [36].

Wang *et al.* found that the energy use during raw coal production could be reduced by 23%. This reduction is equivalent to a 16–33 million tons of coal equivalent saving over the entire China [36]. Although Wang *et al.* calculated the process-based efficiencies, they mainly concluded on the product-based efficiency. Wang *et* al. could have left out the process-based efficiency calculations as the product base efficiency was the most relevant to their objective.

Regression

There are multiple different regression benchmarking methods. The literature revealed linear regression (most common), Gaussian kernel regression, and quantile regression [37]. It was found that linear regression is the foundation of other benchmarking in some cases. For example, the coefficient of determination (r^2) is often used to calculate the correspondence between the inputs and outputs.

Linear regression entails collecting and scatter-plotting data, with the consumption (inputs) preferably on the y-axis and deliverables on the x-axis. From the scatter plot, a linear regression line is drawn. The consumer above the linear regression line is the inefficient consumer.

This type of benchmark was used by Zhou *et al*. [37]. Their study's objective was to propose a data-driven approach to benchmark the air-conditioning energy performance of residential rooms. The process started by building a regression model. From this regression model, the rooms were clustered together based on the areas and usual air-conditioning set points. Thereafter, the rooms were benchmarked based on their predicted power consumption [38].

The results of Zhou *et al.* were 85.1% accurate in the cross-ventilation test [38]. Zhou *et al.* concluded that the benchmark was valid and tested. This validation means a remarkable study was done and can be used for future references.

Summary

Three main benchmarking types were found in multiple studies, namely load shaping, intensities, and regression. Regression consisted of a few subsections, including linear regression, Gaussian kernel, and quadratic regression, which were implemented and tested in the study by Zhou *et al.*

Load shaping benchmarking is a different type of benchmarking as it evaluates each half hour to identify inefficiencies. The study by Park *et al.* [28] was good as it was novel; however, more inefficiencies can be identified if period benchmarks are used instead of daily benchmarks. The negative side of load shaping benchmarking is that it is time-consuming and many calculations have to be done.

The intensities benchmarking type was found to be used the most often. This method entails dividing the outputs by the inputs, which quickly shows where the inefficiencies are. The negatives of this benchmarking type are that there is no clear indication that the correct parameters have been used to ensure the inputs correlate with the outputs.

The last benchmarking type is regression. Linear, Gaussian kernel and quadratic regression were seen in studies of which linear regression is most common. The Gaussian kernel regression is complicated and requires time-consuming calculations, whereas the quadratic regression uses linear regression as base calculation, which again is starting to be time-consuming. Linear regression is the easiest method for determining if there is a correlation between two parameters. The correlation factor is often used to verify the benchmark. Also, it can be challenging to identify the most inefficient area as the distance between the linear line and the different areas is not always accessible and noticed by a quick observation.

1.3.2 Deep-level mining benchmarking studies

As seen in Table 3, few studies have been done on deep-level mining, and none of these studies investigated compressed air, surface fans power, underground power, winding energy, service water consumption, and potable water altogether on a platinum mine.

This next section discusses the benchmarking studies that have been done on deep-level mining. It includes how the methodology was developed and gives an opinion of the studies.

Du Plooy (2019) and Du Plooy et al. (2019) [5, 9]

Du Plooy created a localised benchmark by measuring the pressure at various points on a level of a platinum shaft. The pressure drop was used to determine the flow rate on the level. Du Plooy used Cilliers's PhD study to claim a relationship between compressed air flow and production [4]. His verification included measuring the airflow on each level with an expensive portable flow meter. However, it can be time-consuming to measure the pressure at various points on every level. After calculating the flow from pressure measurements, intensities (average flow rate divided by average production) were multiplied by a factor as the pressures were measured at various time intervals.

Figure 15 shows results that Du Plooy found. He concluded that 13-level (13L) was the most inefficient. This result was reasonable as the consumption was far more than the production. The intensity of this level was roughly 44 m³/(h·ton). An average intensity of 21 m³/(h·ton) was calculated for the entire shaft.

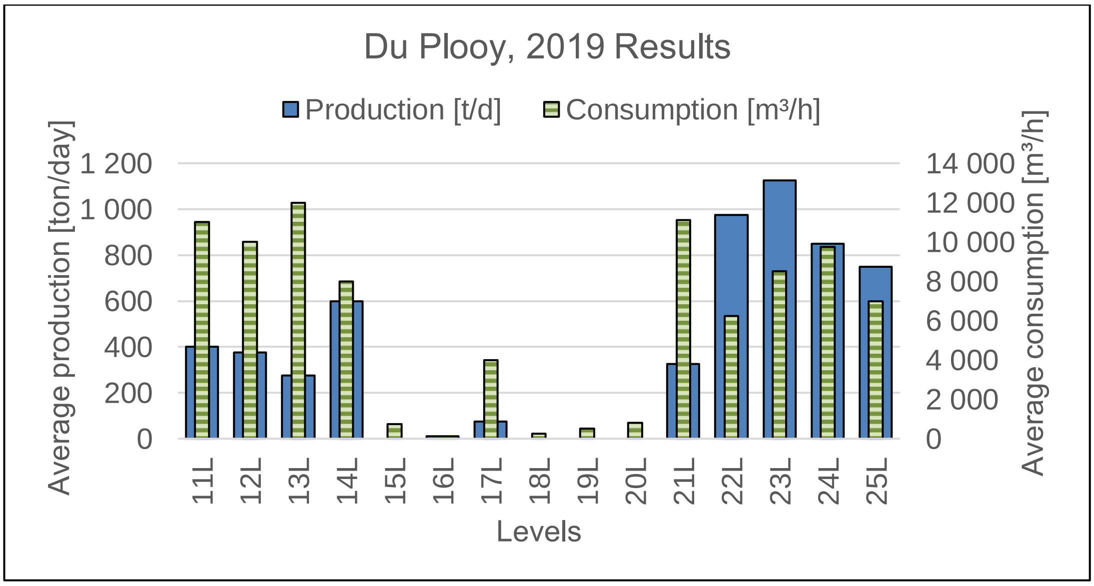


Figure 15: Du Plooy's (2019) results(adapted from [5, 9])

As stated above, Du Plooy's method can be time-consuming as manual audits have to be conducted on each level. It is not ideal that the audits are time-consuming [14]. Du Plooy further only created intensities for the compressed air system on the platinum mine and no other systems.

Cilliers (2016) [4]

Cilliers's doctoral thesis is extremely descriptive and is excellent literature for benchmarking studies. Cilliers listed and explained all the reasons for the consumption well. The study was further well verified and validated. Cilliers referenced two studies in his literature study that discussed benchmarking on deep-level mines, namely Van der Zee [39] and Tshisekedi [40]. Van der Zee and Tshisekedi's studies are discussed below.

Van der Zee (2014) [39]

Van der Zee benchmarked compressed air, water supply and pumping, and refrigeration. These items were compared with the mine operation's size, mine profit contribution, mining technology, mine depth, and production [39].

During Cilliers's discussion of Van der Zee's study, Cilliers stated that ambient conditions had to be considered as well. With the water supply and pumping, Cilliers noted that there was no correlation item to benchmark these utilities [4].

Tshisekedi (2008) [40]

Tshisekedi benchmarked platinum and gold mines [40]. Tshisekedi decided that creating intensities with total yearly energy consumption compared with production would assist in identifying inefficiencies. Figure 16 gives Tshisekedi's results.

Tshisekedi did not find a correlation between mine depth and energy consumption as shown in Figure 16. However, Tshisekedi did show that gold mines are more efficient than platinum mines at shallow depths [40]. These findings are possible as Tshisekedi included the processing plant in his study. Furthermore, platinum requires more processing to produce one ounce of platinum [2].

There is a significant difference between the intensities of shallow and medium depth gold mines. The intensity reduces again at a depth shallower than 4 000 m and increases at a depth of deeper than 4 000 m. Cilliers also benchmarked a gold mine with a depth of 4 000 m. He stated that this mine is located in Carletonville [4]. The platinum intensity also decreases as it goes deeper than 2 000 m. Cilliers stated that energy and depth would correlate if single systems were compared on mines [4]. To conclude, the processing plant decreased the correlation of the energy in comparison with production.

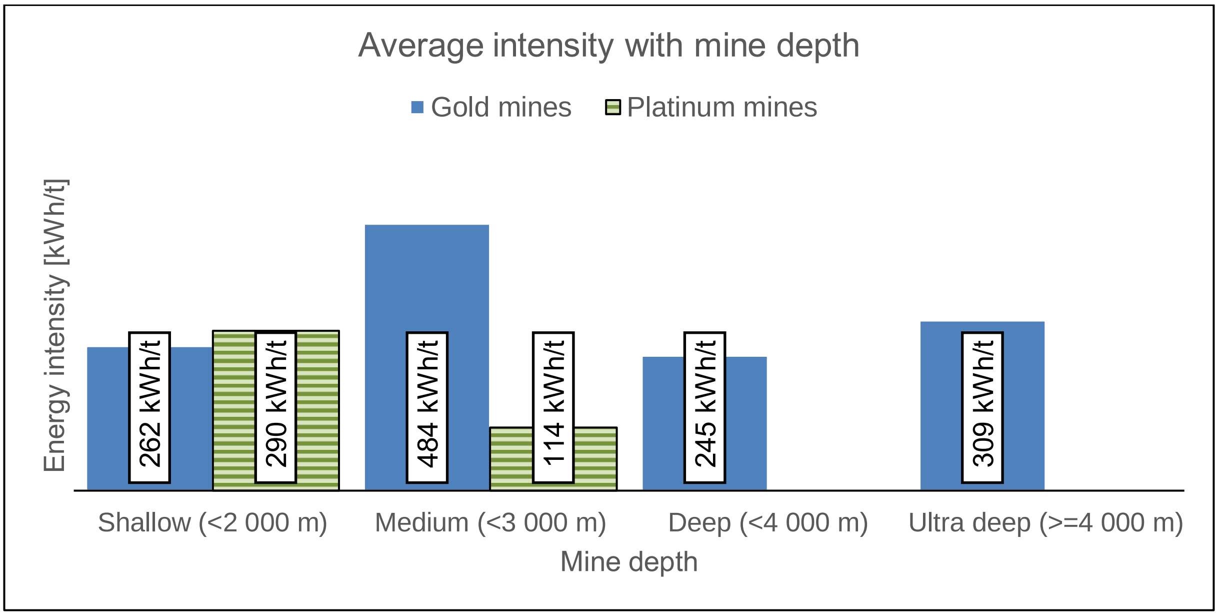


Figure 16: Tshisekedi's results (adapted from [4])

Cilliers developed a novel method for benchmarking mines using the LINEST function to verify and validate his benchmark [4]. The LINEST function creates a straight line, which can, in turn, make it difficult to decide which shaft is the furthest away from this straight line. This method is challenging to understand and time-consuming to implement. Time can be crucial as considerable cost savings can be achieved when perfect, time-consuming benchmarks are developed.

Table 2 lists the items benchmarked by Cilliers [4]. Table 2 further notes the items Cilliers found important for calculating his energy requirements.

Table 2: Cilliers's items for calculating energy requirements

Benchmarked consumer	Items used to calculate the energy requirement
Compressed air	Shaft depth, production
Cooling systems	Shaft depth, production
Dewatering system	Fissure water flow rate, depth of the mine, production
Ventilation system	Shaft depth, production
Hoisting system	Shaft depth, production

It can be deduced that Cilliers's results were mainly calculated from gold mines as Cilliers stated the mines he benchmarked, which are all within gold mining areas. The deep-level conventional mining process is the same on platinum and gold mines; however, the construction and layout thereof differ. For example, the layouts can differ regarding compressed air pressure. Since some gold mines are deeper than platinum mines, the auto-compression of gold mines could be more on the levels. Compressed air pressure is required to deliver production, which means the energy requirements can differ between gold and platinum shafts.

1.3.3 Benchmark summary

As previously stated, a wide range of studies has been done on commercial and industrial benchmarking. This study uses a benchmarking method on deep-level mines – more specifically on platinum deep-level mines. Few studies investigated benchmarking on a deep-level platinum mines.

As discussed above, water is a non-renewable resource; therefore, it is important to minimise water consumption. To decrease water consumption, inefficiencies should be identified, which can be done by benchmarking water consumption. Park *et al.* showed that benchmarking with intervals can also be used to identify inefficiencies [28].

Table 3 summarises the studies that correspond with benchmarking. Table 3 shows that there is a clear gap in studies done on platinum utility benchmarking. Only Vermeulen *et al*. benchmarked compressed air usage on gold and platinum mines [8]. Furthermore, only Lehmann *et al*. benchmarked water usage [41]. Table 3 clearly demonstrates in the seventh column that there is a novelty for creating benchmarks for different periods on a platinum mine. Only one study was done where compressed air was benchmarked per half hour interval.

Table 3: Previous benchmarking studies [state of the art]

Ref.	Commercial, industrial energy benchmarking	Deep-level mining energy benchmarking	Platinum deep-level energy mine benchmarking	Water consumption benchmarking	Period/shift benchmarking	Energy or water benchmarking per period/shift on deep-level platinum mines	Description of reference
[4]	■	■	■				Mostly gold mine benchmarking
[5]		■	■				Compressed air on a platinum mine
[8]		■				■	Compressed air on platinum and gold mines
[9]		■	■				Compressed air on a platinum shaft
[28]	■				■		Grouped buildings according to load profile
[29]	■						Water and effluent(W&E) companies
[41]	■			■			Student housing benchmarking (W&E)
[34]	■						Energy intensities for supermarkets
[42]	■						Brazilian banks were benchmarked
[35]	■						Acute hospitals energy consumption
[36]		■					Benchmarking coal production
[37]	■						Residential air-conditioning
[43]	■						Buildings energy using quantile regression

Legend	
Discussed	■
Not discussed	

1.4 Need for the study

1.4.1 Problem statement

The background section explained that Eskom is struggling to deliver a sustainable energy supply. It was also made clear that water is a vital resource that should be used with care as it is a non-renewable resource. South African mines are large consumers of both energy and water. If focus can be placed on mines, Eskom can deliver energy more effectively to the entire South Africa and water usage can be decreased.

1.4.2 Aim of the study

Gold and platinum are South Africa's most significant commodities as these mines are the deepest. However, these mines are struggling to remain profitable. Some mines have multiple shafts. If platinum shafts are benchmarked during different periods (weekdays, Saturdays, and Sundays), opportunities can be noted where cost and energy savings can be achieved. This study aims to identify high utility consumption and implement a process to lower these utilities achievable through benchmarking.

If platinum mines shafts are benchmarked, opportunities would be revealed for decreasing utilities. Therefore, benchmarking studies were included in the background as a proposed solution for lowering utilities. It was found that creating intensities for benchmarking was the most common method as well as the quickest. Fortunately, energy and water metering has improved over the last couple of years, allowing benchmarking to be done during different periods and identifying inefficiencies more easily.

The last section of the background explained a specific platinum mine's utility consumption. Utilities that are measured and that can be benchmarked include compressed air consumption, surface fan energy, underground energy, winder energy, potable water going to the change house and underground, and service water going underground as well as being pumped to the surface.

1.5 Dissertation overview

Chapter 1

Chapter 1 started by explaining how energy and water usage is essential. Literature showed different methods for identifying inefficient usage of these utilities. From the overview and literature, a need and a problem statement were derived.

Chapter 2

The derived need and problem statement from Chapter 1 will be used to discuss the method for developing a solution in Chapter 2. Chapter 2 will explain each step that should be followed to obtain similar results.

Chapter 3

Chapter 3 is the results chapter. This chapter will explain how the compressed air, surface ventilation fan power, rock winder power, potable water, and service water benchmarks were calculated. The chapter will discuss how the specific mine’s shafts were compared with these calculated benchmarks and how inefficiencies were identified. Furthermore, the chapter will discuss the projects that were implemented to lower the inefficiencies. These decreases in inefficiencies will be used as a validation of the benchmarking method.

Chapter 4

Chapter 4 will summarise the dissertation. The chapter will include recommendations for future work at the end of the chapter.

CHAPTER 2 – DEVELOPMENT OF IDENTIFICATION STRATEGY

2.1 Introduction

In Chapter 1, benchmarking was found to be the best method for identifying savings opportunities. Chapter 2 explains the methodology that was followed to develop the benchmark. This final result should lead to the identification of savings opportunities. Figure 17 shows the process of how the solution would be obtained.

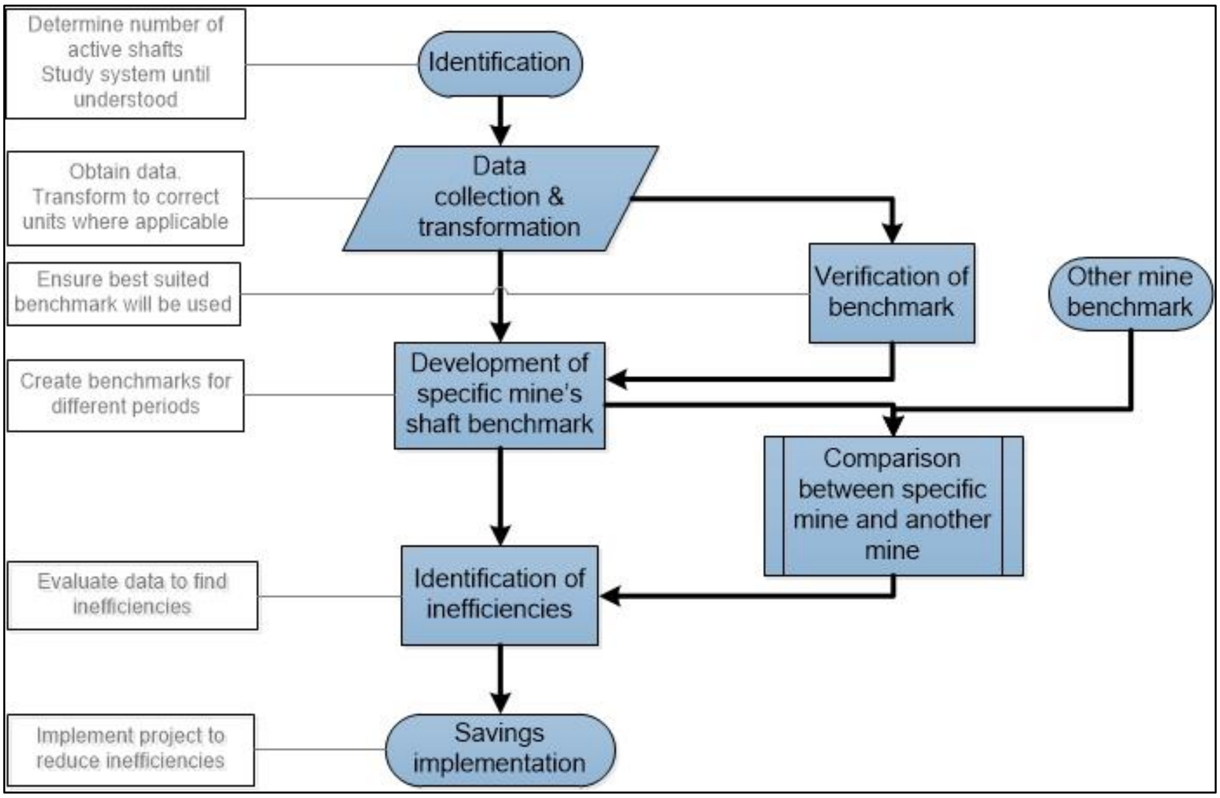


Figure 17: Methodology flow chart

The development of the planned solution was changed slightly from Cilliers's study [4]. He also started by identifying model mines, which included determining which mines had to be used. Cilliers further evaluated if the model mines had corresponding high demand systems. For this study, one case study mine with variable systems was benchmarked.

Cilliers's second step in his methodology was data acquisition, which is also used in this study. The third step entailed verifying the correlation. It was decided that as no new benchmarking method would be developed in this study, the correlations would be used to verify the planned creation of the benchmarks.

Cilliers's last step was obtaining benchmarks functions. As stated above, this study is not a new benchmarking method; the next step was the benchmark creation. After the benchmarks have been created, inefficiencies should be identified. Thereafter, projects should be implemented to lower these inefficiencies.

2.2 Shaft and utility identification

Identification is the first step in the methodology. Identification includes the following sub-steps:

1) Determine which shafts can be compared.
    a. Determine which shafts are active.
2) Investigate what the measured consumers of all these shafts are.
3) Determine the items that are measured on the shafts. It is also important to note what is not measured on some shafts.
    a. Remove the items that are not measured on most of the shafts.
    b. Group measured items.
4) Study and understand the different measured consumers.

For this study, five active shafts were found. The measured consumers included the following items (as discussed in Chapter 1):

- Compressed air.
- Surface ventilation fan energy.
- Winding energy (includes rock winders).
- Potable water.
- Service water.

There was potential to include underground energy, but as mentioned in Chapter 1, it would be challenging to implement and notice a reduction in energy usage if a project has been implemented.

The data for the number of employees was also requested. The items mentioned above are the input variables. The following output data was also collected from the mine:

- Production.
- Active haulage length.
- Mine depth.

2.3 Data collection and transformation

Data collection and transformation is the second step in the methodology. This step includes transforming the data collected into an appropriate format. This transformation includes changing the flow units into energy units if possible, but the transformation is possible if the different systems are understood. The understanding includes knowing all the contributors. This building of knowledge explains why the identification step in the methodology is important.

It was decided to calculate the average of all the consumers. By averaging a large amount of data, the outlaying data impact was minimalised. The average units used were:

- Compressed air – m^3/h.
- Surface ventilation fan power – kW.
- Winding power – kW.
- Potable water – kl/day (only daily data could be retrieved).
- Service water – both m^3/h and kW.
- Production – ton/day.
- Employees – fixed total number (only one value was available for each shaft).
- Active haulage length – m (fixed value was used as historical development was not available).
- Mine depth – m.

Correctness of data

The planned benchmarks to be created should not be influenced by faulty metering. Therefore, the calibration of the meters had to be evaluated. Faulty spikes in meters can be minimalised by calculating the averages over long periods.

Compressed air

The calibration of the surface compressed air flow meters should be evaluated often as the shafts receive compressed air from a compressed air ring. The motivation for calibrating ring-fed compressed air is for billing purposes. On the specific mine, the total cost of the compressor operations was divided per shaft by dividing the total usage of the specific shaft by the total usage of all the shafts on the ring.

The first step is to evaluate whether a flow meter is faulty. The purpose is to establish if the valve operations and flow correlate. If a valve closes, the flow should decrease. This evaluation can already be established by evaluating Figure 5. The flow profile shows that if the downstream pressure of the valve is decreased, the flow also decreases. If the flow meter was faulty, this profile would have been more constant or would have had large spikes.

The second step is to do a mass balance of the shafts. Unfortunately, most underground compressed air flow meters are faulty as the calibration of these meters has no direct financial impact on the shafts. This statement was established by closing the levels valves resulting in a high continuous flow consumption. However, Shaft DE3 on the specific mine did ensure the underground level flow meters remained calibrated.

Figure 18 shows a month's total flow consumption on the surface and a stacked column with all the levels of total monthly consumption. The total surface consumption was almost 11 Mm³, and the sum of the levels monthly total was about 9.5 Mm³. The accuracy of the underground level flow meter is roughly 85% of the surface flow meter. What is seen here is that the values of the different flow meters correspond well.

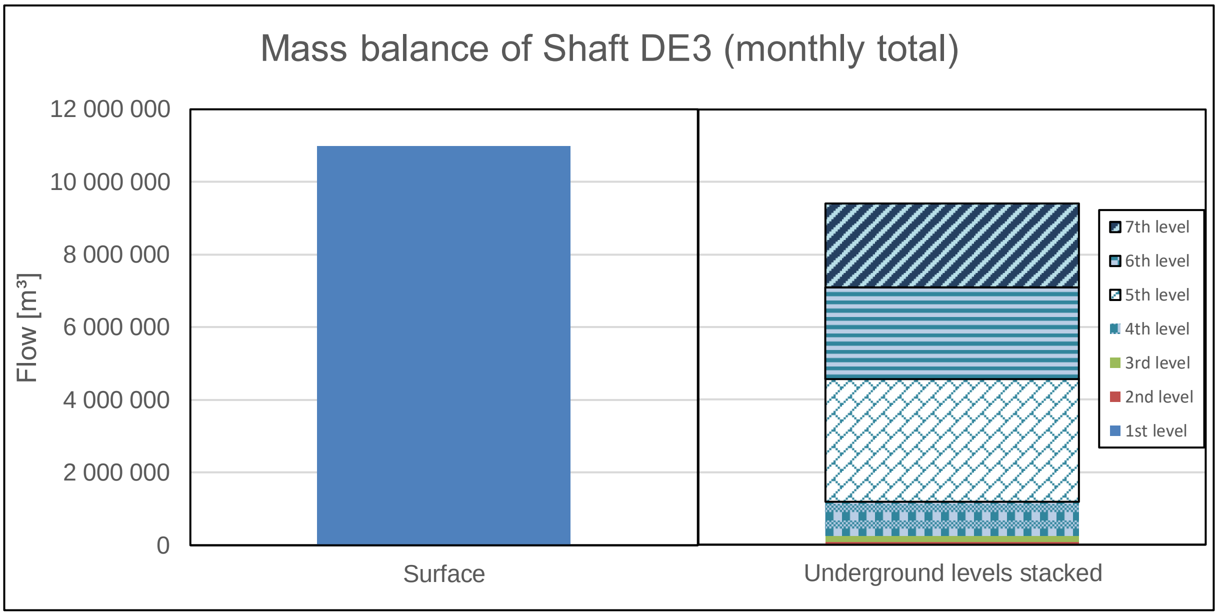


Figure 18: Mass balance of Shaft DE3 to determine flow meter accuracy

On Shaft VE4, a portable flow meter was installed downstream of the permanent flow meter. The permanent flow meters installed on the shafts calculate the flow by measuring a pressure difference, whereas the portable flow meter calculates the flow from a temperature difference. Figure 19 shows the results of the comparison of the flow meters. There was a 10% error at most, which is neglectable.

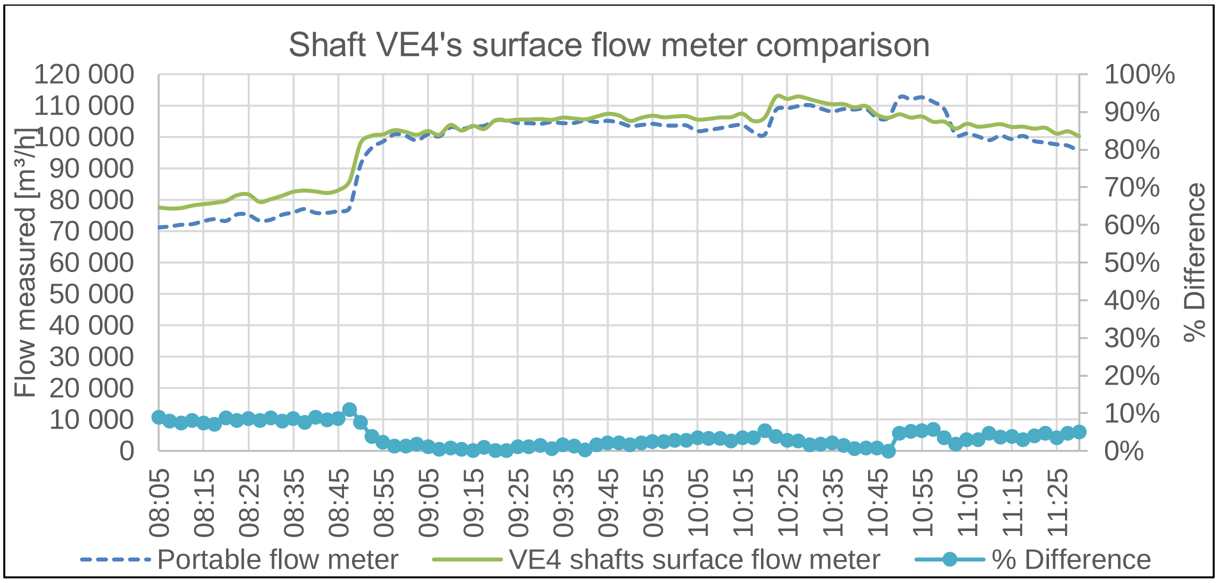


Figure 19: Shaft VE4's flow meter comparison

It can be seen that the shaft's surface flow meters were calibrated and reliable benchmarks could be created with the compressed air flow.

Power meters

An external company monitors the power meters at the case study mine. They are responsible for calibration as part of their services. A method to gauge the accuracy of the power meters is to evaluate the meter readings against the motor's installed capacity. Shaft VE4's fans are used as an example. Two 650 kW fans, as seen in Figure 20, are connected to one power meter. The average power consumption profile of these two fans is shown in Figure 21. It can be seen that the average power consumption increased between 15:00 and 22:00. This increase in power was due to the fans' guide vanes opening to 100%.

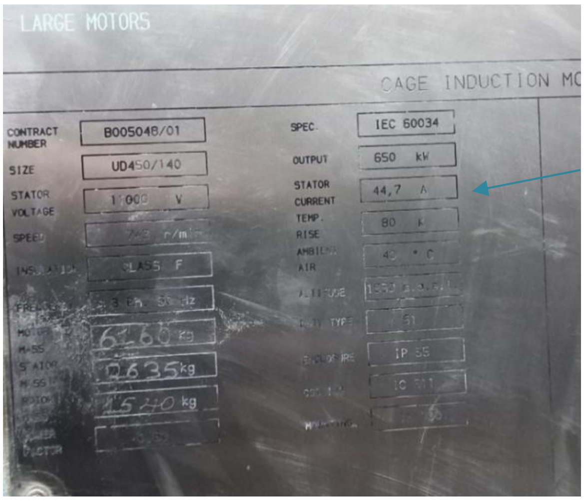


Figure 20: Shaft VE4's fan motor installed capacity

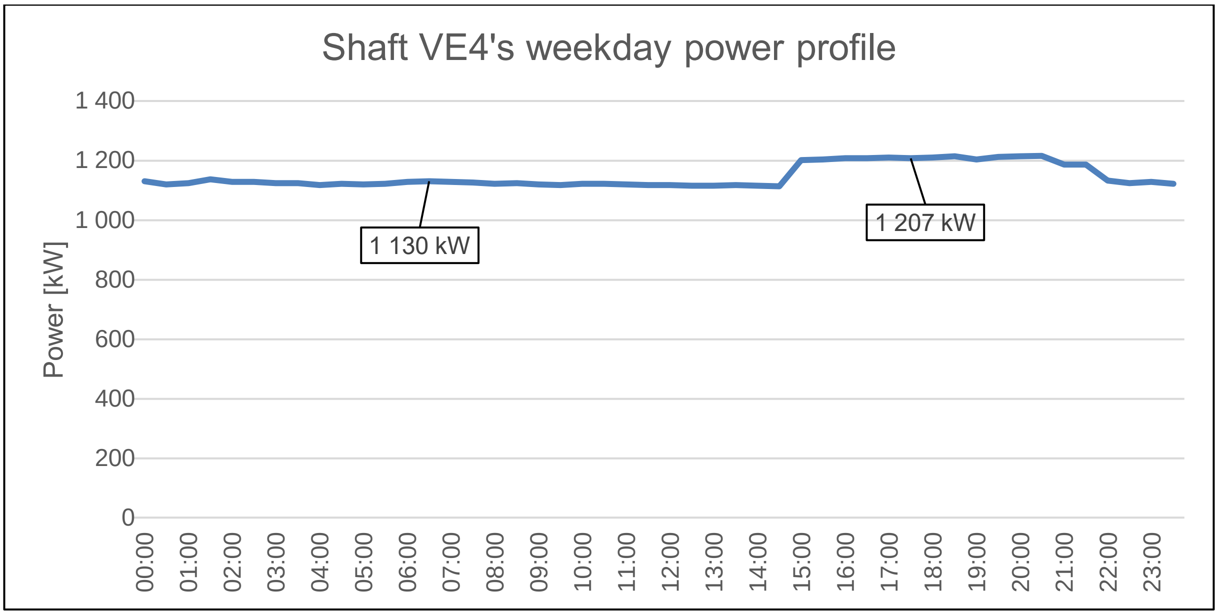


Figure 21: Shaft VE4's fans' power profile

Figure 21 shows that when the guide vanes were at 70%, the power was 1 130 kW, and at 100%, the power was 1 207 kW. If the installed capacity seen in Figure 20 is multiplied by two, it equals 1 300 kW. Comparing the installed capacity with the power meter reading gave 89%, which was caused by motor inefficiency and a slight reduction in area/flow due to the guide vane installation. It was concluded that the power meters were well calibrated.

Potable water meters

The water meters are mechanical as seen in Figure 22. These mechanical meters either work or do not work. However, to obtain these readings on the supervisory control and data acquisition (SCADA) system, meter readings are done by sending an electric pulse to the mechanical meter. This pulse is seen as a photo taken on the meter, sending the signal back to the meter. If the signal is not sent on the daily resolution, the next day's reading would be more, but the readings can never be faulty.

Figure 22: Photo of mechanical flow meter

Service water flow meters

For the service water consumed underground, the calibration of the surface flow meter must be evaluated once again by doing a mass balance. After doing the mass balance on Shaft VE4, it was found that 85% of the surface flow meter was measured underground. The mass balance is shown in Figure 23.

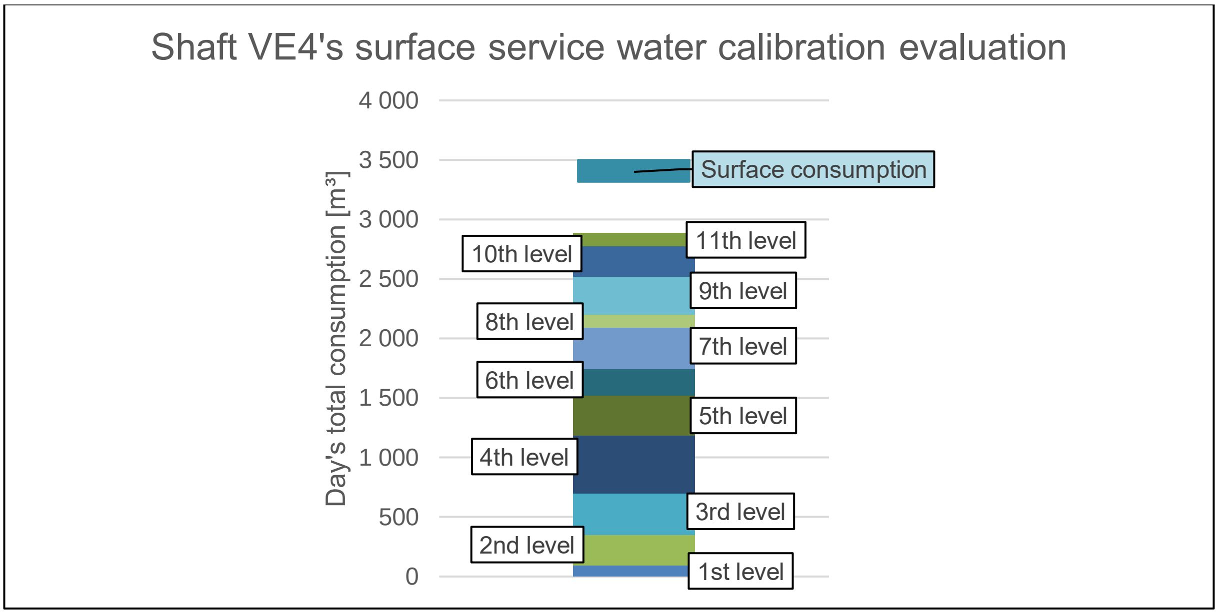


Figure 23: Mass balance of Shaft VE4's underground service water consumption

Figure 23 shows that the total surface flow is above the sum of the levels' total flow. The difference between the sum of the total levels' flow and the total surface flow is 15%. This 15% is in the range to be adjacent to one another.

It is further noted that the fourth level is one of the largest consumers, followed by the fifth and ninth levels. These levels consist of two half levels. The first level has the lowest consumption, which can be another verification of the meter's accuracy. The low consumption is a result of only one half level consuming flow and the half level's lifetime being completed.

2.4 Verification of benchmark

The verification of the benchmarks is a subprocess of the methodology. From the data collection and transformation, the relationship ('relationship' is used as it should connect in some manner, but it is the correlation factor) and the consistency of various months of the different consumers and outputs were evaluated. The most consistent item with the most substantial relationship was used as the best benchmark. Table 4 uses an example to explain how the relationship was calculated:

Table 4: Example table explaining the relationship calculation for verifying the benchmark

Shaft	Average compressed air flow [year's average]	Average daily production [year's average]
A	20 000 m³/h	60 000 ton/day
B	56 234 m³/h	70 000 ton/day
C	9 765 m³/h	90 000 ton/day
D	30 958 m³/h	15 000 ton/day
E	17 682 m³/h	80 000 ton/day
F	26 348 m³/h	23 000 ton/day
Linear coefficient of determination		
0.053		

Table 4 shows that the entire period (February 2019 to February 2020) was used to calculate the average consumption for both the flow and production. All the shafts were compared to calculate the linear coefficient of determination. This example relationship was not good, as it was deficient. The closer the value is to one, the stronger the correlation is.

The consistency was determined by calculating the standard deviation of various months' coefficients of determination. An example is again used to explain this in Table 5:

Table 5: Example table for explaining consistency determination

Month	Coefficient of determination between the average compressed air flow and the average production of Shaft A to Shaft F
Feb 19	0.053
Mar 19	0.100
Apr 19	0.060
May 19	0.040
Jun 19	0.058
Jul 19	0.049
Aug 19	0.090
Sep 19	0.064
Oct 19	0.042
Nov 19	0.054
Feb 20	0.055
Standard deviation	0.019

The standard deviation (σ) was used to calculate the consistency of the relationship. A lower standard deviation means a more consistent relationship. A wrong consistency of the relationship will also be seen if the meters used are not calibrated. Figure 24 shows why the standard deviation should be close to zero.

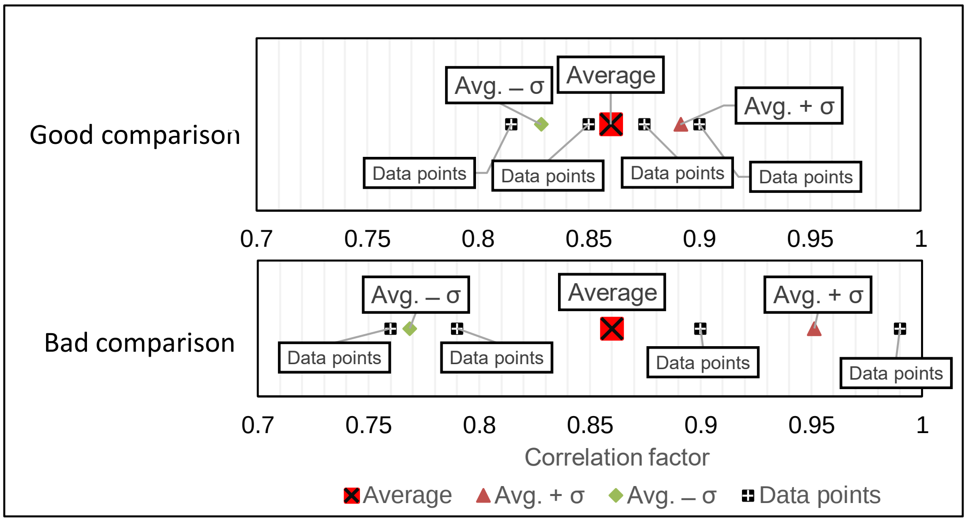


Figure 24: Example to explain a good and bad standard deviation (consistency)

In Figure 24, the linear coefficient of determination is the average symbol. There are four data points on each comparison. These data points are the different months' coefficients of determination. It can be seen on the good comparison that these data points are close together, whereas the bad comparison's data points are more spread out. With these data points, the standard deviation was calculated as well. It is known that the standard deviation indicates how close the standard deviation is to the average, which is why the standard deviation can be added or subtracted from the average.

To ensure a verified benchmark is used, the coefficient of determination should be close to one and the standard deviation should be close to zero. A bad correlation factor is below 0.65 and a bad standard deviation is higher than 0.15. There should further be a direct relationship between the compared items. Some initiative and understanding are required to establish the relationship. Appendix A gives the monthly correlation factor with the calculated standard deviation of the best-suited comparisons.

2.5 Benchmark development

It was found in Chapter 1 that using intensities is the best and fastest method to benchmark. Park *et al*. and Liu *et al*. stated that metering has improved over the last couple of years, resulting in monitoring in smaller intervals [28, 32].

For this study, the data was taken and averages were calculated for different periods. Some data, such as production and potable water averages, could only be separated based on daily intervals as these were the smallest resolution intervals data that was available for the study. Furthermore, there were fixed values such as mine depth, employee number, and active haulage length. The values were divided as is into the data that could have been broken into periods. For example, the average compressed air consumption consumed during the blasting period was divided by the total daily average production.

Data was used from February 2019 till February 2020, excluding December and January. Averages were calculated for different periods as metering allowed the intensities to be expanded. The following period averages were calculated:

- Total average:
  - Saturday average.
  - Sunday average.
  - Weekday average.
    - Drilling shift average.
    - Blasting shift average.
    - Morning and evening shift (cleaning/sweeping) average.
    - Eskom peak period average.

2.6 Identification of inefficiencies

After the benchmarks have been created, inefficiencies can be created. If the inputs are divided by the outputs, the intensities with the highest value are the most inefficient. Two methods are used to identify inefficiencies if similar periods are grouped. These two methods are explained using Figure 25.

Two period groups can be created, namely:

- Weekday, Saturday, and Sunday.
- Morning and evening (sweeping/cleaning) shift, drilling shift, blasting shift.

The total average should be evaluated separately (this can also be used to show which shaft should be focused on more). The Eskom peak period is a group on its own as it falls within the blasting shift.

The two methods for identifying inefficiencies are the highest intensity method and the irregularities method (using Figure 25 as an example):

Highest intensity

This method regards the shaft with the highest intensity as the most inefficient, meaning that it has the most opportunity for improvement. For Period 1, it is Shaft 2. For Period 2 and Period 3, it is Shaft 1.

Irregularities

During this method, different periods are examined on each shaft. In Figure 25, Period 3 shows potential for improvement, as Period 3's intensity is higher than Period 1 and Period 2's intensity. These are irregularities as Shaft 1 and Shaft 2's Period 3 is the lowest.

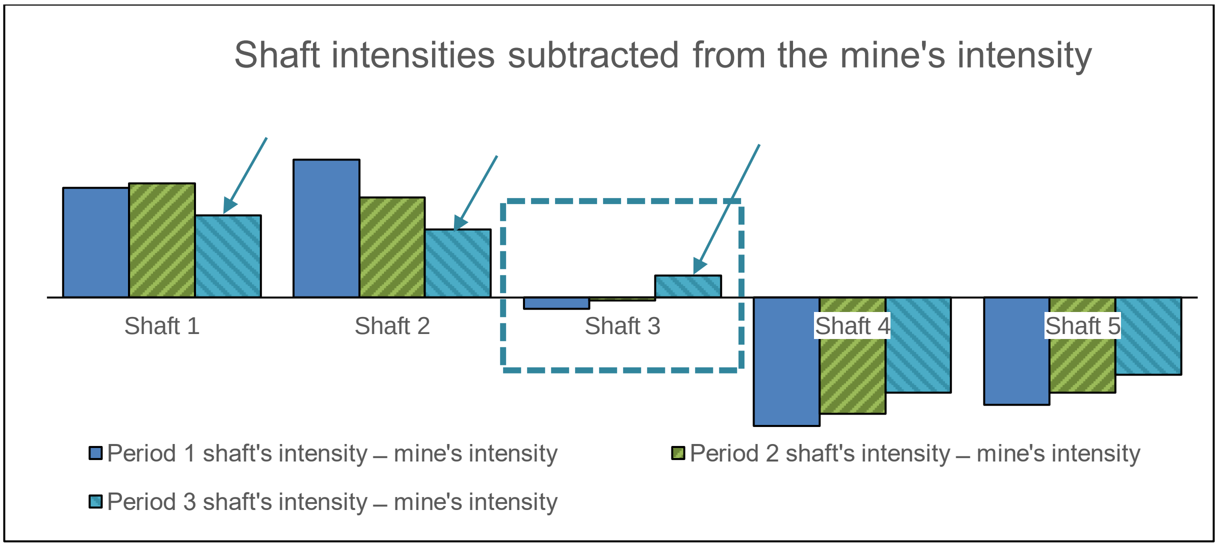


Figure 25: Illustration of how inefficiencies are identified

2.7 Savings implementation/benchmark validation

The type of savings implementation depends on the type of utility consumed. Decreasing the compressed air pressure decreases the flow as well [5, 9]. Flow and compressor power have a linear correlation, meaning the energy decreases as the flow reduces [1]. By installing guide vanes, motors require less torque to rotate, resulting in a power reduction [50]. Reducing the energy during the Eskom peak period can further lead to cost savings, as Eskom's power is the most expensive during these periods. For potable water, either the valve should be closed or leaks should be repaired. Service water reduction can be achieved by decreasing the pressure, closing the valve, or repairing leaks. If there is no known method for implementing savings, the system should be studied further.

2.8 Conclusion

The method for developing the problem's solution was derived from Cilliers's study. The first step in the methodology is identification, which includes the benchmarking of the shafts and their utilities. From the identification thereof, the utility data of the different shafts can be obtained. This data is used to create possible benchmarks, with the best-suited benchmark being derived from the verification process. The verification process includes using the best correlation factor with the lowest standard deviation.

Thereafter, the specific mine's period benchmarks are created from the verified benchmarks. For the identification of inefficiencies, the shafts should be compared with these benchmarks. From the inefficiencies, projects should be implemented to lower the intensities and validate the benchmarks.

CHAPTER 3 – RESULTS

3.1 Introduction

Chapter 3 is divided into three main sections. The first section includes obtaining and verifying that the correct benchmark is being used. The second section contains the benchmarks, and the last section validates the benchmarks. This process was followed for all the different utilities. The utilities were ranked from the most significant expenditure to the lowest expenditure as follows:

1) Compressed air consumption.
2) Surface fan power consumption.
3) Rock winder power (only includes the rock winders as this winder is measured the most).
4) Potable water consumption.
5) Service water consumption.

For the benchmark verification section, several comparisons were made for numerous consumers on the specific mine. Not all these comparisons are discussed in this study to shorten the study. It was further decided to benchmark the consumptions that would show the most impact. The other comparisons with the correlation factor and the standard deviation are given in Appendix A.

After the best-suited benchmarks are found in the verification section, the intensity benchmarks can be created in the calculated benchmark section. The first step is to show the different benchmark intensities for the specific mine. After the benchmarks are shown, the shaft's comparisons to these benchmarks are evaluated. This evaluation shows where and when there are possibilities for improvement. The evaluation is done for all the verified comparisons.

The last step entails validating the benchmarks. This validation comprises discussing case studies that show the inefficiency and explaining how the intensities were lowered for all the consumers.

Table 6 explains the heading level and describes the headings to improve Chapter 3 comprehension.

Table 6: Chapter 3 heading layout

Heading level	Heeding	Heading description
1	Utility benchmarked	Compressed air, Surface fan power, rock winder power, ext.
2	Verification	Finding a best-suited comparison
2	Calculated benchmarks	Discuses calculated benchmark intensities as well as inefficient shafts for different periods
3	Identifying of inefficient shafts	Identify inefficiencies for different periods
4	Total consumption	Uses total consumption average to create intensities
4	Daily comparison	Uses weekday, Saturday and Sunday averages to create intensities
4	Shift comparison	Uses the weekday shifts averages to create intensities
4	Eskom peak period comparison	Uses the weekday Eskom peak period averages to create intensities
4	Utility summary	Summarises inefficiencies found for different periods
3	Mine comparison	Compares calculated benchmarks with another mine using total consumption average
2	Benchmark validation	Validates that the calculated benchmarks can be used to identify inefficiencies. Not only to identify inefficiencies but also to lower them.

3.2 Compressed air consumption

As discussed in Chapter 1, compressed air is used for drilling, loading ore, and supplying refuge bays. The different equipment requires different pressures and flows.

3.2.1 Benchmark verification

Table 7 shows all the compared benchmarks tested for compressed air consumption. As discussed in Chapter 2, three things are essential for creating a verified benchmark. The correlation factor should be close to one, the standard deviation close to zero, and the compared items should have a relationship.

Table 7: Compressed air consumption – benchmarks tested

Compressed air consumption [m³/h]				
Compared with	Unit of comparison	Correlation factor	Standard deviation of correlation factor	Comment
Rock winder power	[kW]	0.889	0.043	No direct connection.
Underground power	[kW]	0.339	0.063	Bad correlation.
Production	[ton]	0.932	0.027	Good correlation factor and standard deviation.
Mine depth	[m]	0.039	0.008	Bad correlation factor.
Active haulage length	[m]	0.931	0.011	Good correlation factor and standard deviation, but fixed active haulage length were used.
Underground employees	[–]	0.862	0.044	Not all employees used compressed air, meaning the relationship is not entirely relevant.

Legend:	Lowest number	Average number	Highest number

The rock winder and production go together as seen with the rock winder's power benchmarks. Multiple factors influence underground power, resulting in a low correlation factor. The mining depth gives a consistent correlation factor, but the correlation factor is low. Active haulage length could also be used as this would indicate the number of leaks. The problem with this comparison is that the active haulage length was taken as a fixed value, meaning that over the months, no development was done to extend the length of the levels. This is not entirely true. Furthermore, as mentioned in Table 7, not all underground employees are consumers of compressed air. Production is the best option to use because this is the only reason why compressed air is consumed. It delivers a good correlation factor and a standard deviation. Du Plooy also found that flow compared with production is the most appropriate key performance indicator [5].

3.2.2 Calculated benchmarks

Average daily production was found to be the best-suited item to compare with compressed air. The benchmarks for the compressed air for the different periods are shown in Figure 26. The average flow was divided by the average daily production for the different periods. As the production resolution was only retrievable in daily intervals, the shifts' benchmarks were also divided by the average daily production.

Figure 26 shows the specific mine's compressed air consumption benchmarks. The benchmarks are the intensities of the average compressed air consumption divided by average production. Saturday had the highest intensity. This intensity indicated when there was considerable potential for decreasing consumption. The shifts showed where the most potential was to decrease the weekday intensity. The drilling shift consumed the most compressed air, followed by the morning and evening shift, and the last shift, with the lowest intensity, was the blasting shift.

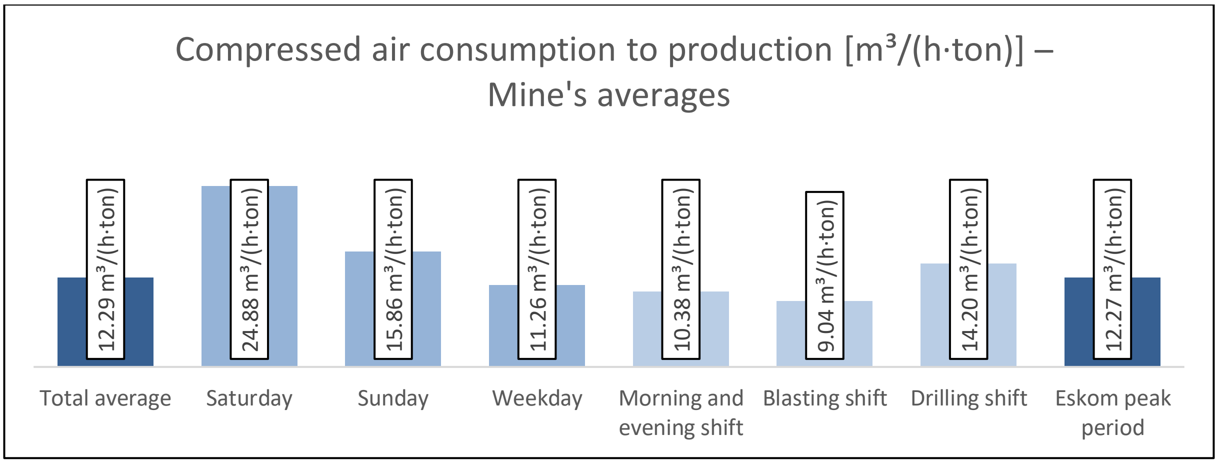


Figure 26: Compressed air consumption – benchmarks

In Du Plooy's study, the average level compressed air intensities varied between 13.33 $m^3/(h \cdot ton)$ and 53.33 $m^3/(h \cdot ton)$ [5, 9]. Figure 26 shows that the benchmarks fall in the range of Du Plooy's minimum and maximum level intensity. Although some intensities are slightly lower than 13.33 $m^3/(h \cdot ton)$, it is clear that there is a correspondence between the intensities of the different studies.

3.2.2.1 Identification of inefficient shafts

Comparing the above benchmarks with the shaft's intensities showed the potential to decrease the compressed air benchmarks. Breaking it down into different shifts further showed when there was potential for lowering the consumption. This breakdown is discussed below, starting with the total consumption intensity.

Total consumption comparison

The first graph shows which shaft was the most inefficient. This graph was created with the total average, which can be seen in Figure 27. The shafts' intensities were subtracted from the benchmarks shown in Figure 26. This benchmark value was 12.29 $m^3/(h \cdot ton)$, meaning the zero line in Figure 27 is equivalent to this benchmark. This calculation improves clarity regarding whether the shafts are above or below the benchmarks.

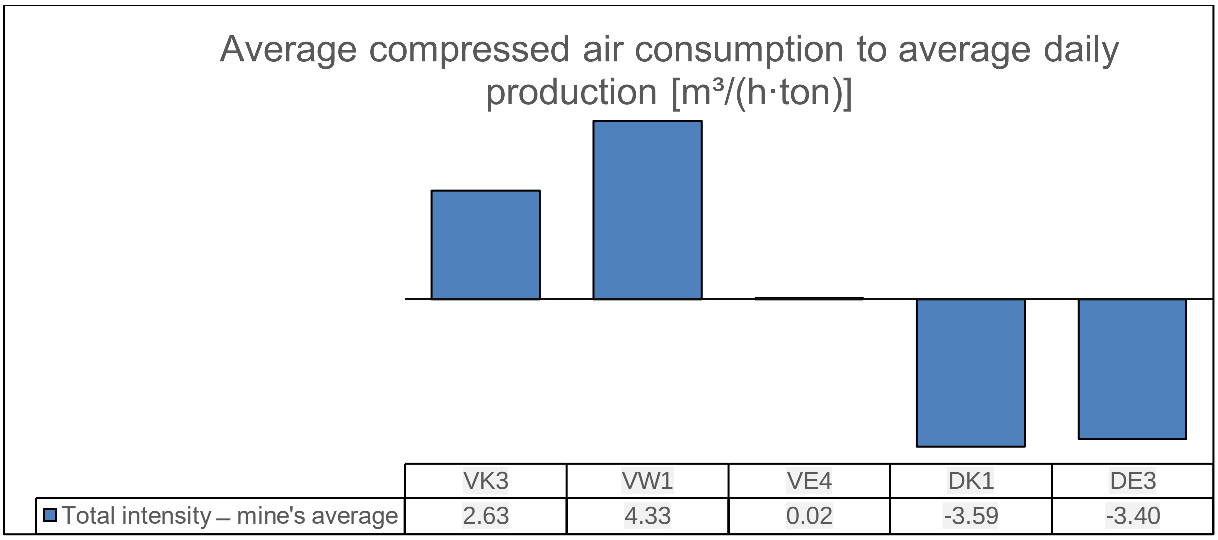
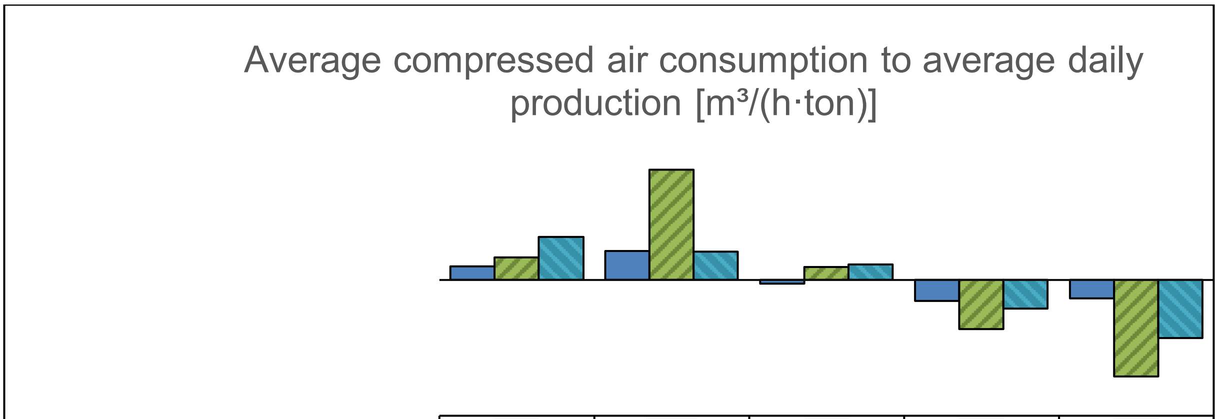


Figure 27: Compressed air consumption – total intensity

Shaft VW1 was the most inefficient. The second-most inefficient shaft was Shaft VK3, which was 2.63 $m^3/(h \cdot ton)$ above the mine's benchmark. Shaft VE4 was close to the benchmark, but slightly higher. Both Shaft DK1 and Shaft DE3 were below the benchmark. Shaft DK1 was the most efficient shaft with an intensity of 3.59 $m^3/(h \cdot ton)$ lower than the benchmark.

Daily comparison

The focus was placed mainly on Shaft VW1 with the breakdown of the total intensity. The weekday, Saturday, and Sunday shafts with intensities above or below benchmarks are given in Figure 28. However, with Shaft VW1 having the highest intensity, it does not mean that the other shafts did not have scope for improvement. The weekday, Saturday and Sunday benchmark intensities were 11.26 $m^3/(h \cdot ton)$, 24.88 $m^3/(h \cdot ton)$, and 15.86 $m^3/(h \cdot ton)$, respectively.



	VK3	VW1	VE4	DK1	DE3
Weekday intensity – mine's average	2.02	4.29	-0.50	-3.13	-2.68
Saturday intensity – mine's average	3.30	16.25	1.90	-7.28	-14.18
Sunday intensity – mine's average	6.33	4.16	2.26	-4.21	-8.54

Figure 28: Compressed air consumption – weekday, Saturday, and Sunday intensities

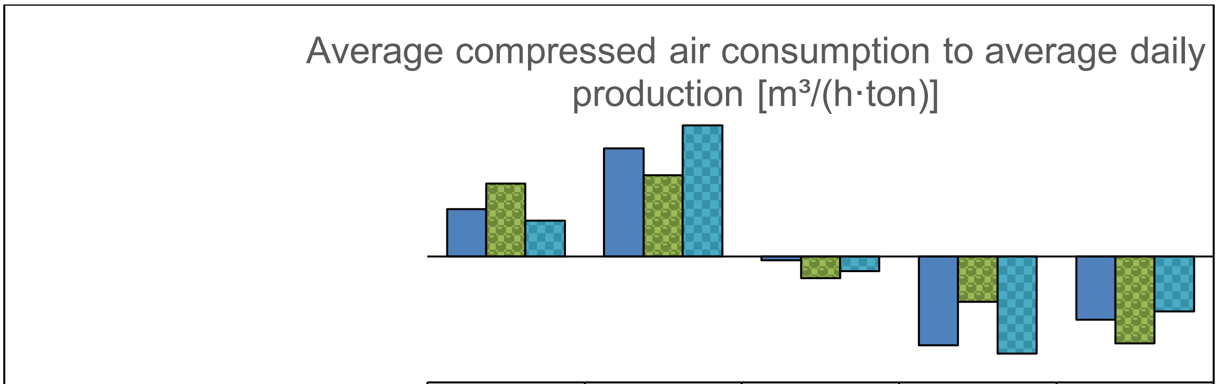
Figure 28 is a breakdown of Figure 27. For all three periods, Shaft VK3 remained above average. It is essential to note that Shaft VK3's Sunday intensity was further above the benchmark than the Sunday intensities of the other shafts. The high Sunday intensity could be the result of valves not controlling underground or a higher set-point pressure. The cause for this intensity being far above the benchmark had to be investigated.

Shaft VW1's weekday intensity was also higher than the other shafts' weekday intensities. However, more potential was observed for Shaft VW1's Saturday intensity. It was easily noted that the Saturday intensity was an outlier that required attention. An approximate cost of this outlier was calculated to be R2 400/year for each ton of ore. Evaluating Shaft VE4 showed that the weekday intensity was slightly lower than the benchmark. Both the Saturday intensity and Sunday intensity were above the benchmark. However, the Sunday intensity was slightly more.

For the decline shafts, all the periods were below the benchmark. Shaft DE3 was more efficient for the Saturday and Sunday periods. These lower intensities were the result of a lower set point after the Saturday drilling shift.

Shift comparison

Figure 29 breaks the weekday period down into three different shifts. The benchmarks from Figure 26 for the morning/evening shift, blasting shift, and drilling shift were 10.38 $m^3/(h \cdot ton)$, 14.2 $m^3/(h \cdot ton)$, and 9.04 $m^3/(h \cdot ton)$, respectively.



	VK3	VW1	VE4	DK1	DE3
Morning & evening shift intensity – mine's average	1.88	4.30	-0.14	-3.52	-2.51
Blasting shift intensity – mine's average	2.89	3.23	-0.87	-1.80	-3.46
Drilling shift intensity – mine's average	1.42	5.20	-0.59	-3.87	-2.18

Figure 29: Compressed air consumption – weekday shift intensities

The complete overview of Figure 29 shows that all the shifts of Shaft VW1 were the furthest above their benchmarks. This overview was the result of Figure 28. The cause could have been that Shaft VW1 had the highest wastage, such as open-end pipes, which had to be investigated further.

Shaft VK3's blasting shift was higher above the benchmark than other shifts. Shaft VK3 always had the highest intensities during periods where it had to be the lowest. Once again, the cause could have been the underground valves not working correctly, which had to be investigated further.

Shaft VE4's intensities remained below the benchmarks. The blasting shift was the furthest below the benchmark. The drilling shift was the second-most efficient shift and, lastly, the morning and evening shift was the least efficient shift. It would have been better if the drilling shift were the most inefficient as this is the period during which the consumption is the highest.

Shaft DK1 must improve its efficiency during the blasting shift as the blasting shift should be the most efficient. For all the shifts except the blasting shift, Shaft DE3's intensities were above Shaft DK1's intensities. This intensity difference showed that focus had to be placed on Shaft DK1's blasting shift intensity.

Eskom peak period comparison

Figure 30 evaluates how the shafts attempted to reduce costs due to an increase in tariffs. The compressed air compared with production benchmark intensity was 12.27 $m^3/(h \cdot ton)$.

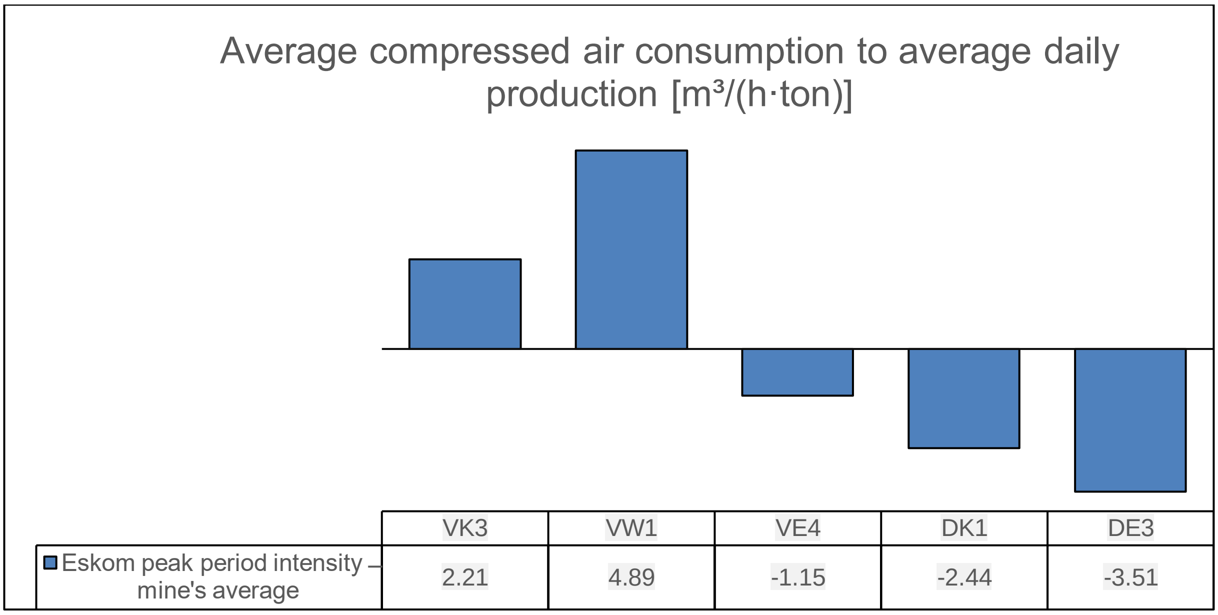


Figure 30: Compressed air consumption – Eskom peak period shafts intensities

The benchmark for Figure 30 was 12.27 m³/(h·ton) as shown in Figure 26. The most inefficient shafts during the Eskom peak period were ranked as follows (from most to least efficient):

1) Shaft VW1.
2) Shaft VK3.
3) Shaft VE4.
4) Shaft DK1.
5) Shaft DE3.

Shaft DE3 reduced its pressure set point the most during the Eskom peak period, resulting in its efficiency.

Compressed air inefficiencies summary

Table 8 summarises the inefficiencies noticed for the compressed air. The vertical and incline shafts with the highest intensity are indicated, as well as some irregularities noticed. One of these inefficiencies will be used as a case study in which the compressed air will be reduced.

Table 8: Compressed air to production inefficiencies summary

Period	Benchmark [m³/(h·ton)]	Most inefficient shaft	Irregular inefficiencies
Total	12.29	Vertical: VW1 Incline: DE3	–
Weekday	24.88	Vertical: VW1 Decline: DE3	–

Period	Benchmark [m³/(h·ton)]	Most inefficient shaft	Irregular inefficiencies
Saturday	15.86	Vertical: VW1 Decline: DK1	Decline shafts showed a reduction in intensity; vertical shafts showed an increase.
Sunday	11.26	Vertical: VK3 Decline: DK1	Shaft VK3 indicated a large increase in inefficiency. Other shafts' Sunday intensities decreased from Saturday (VE4 shaft also showed a slight increase).
Morning/evening shift	10.38	Vertical: VW1 Decline: DE3	Large difference between Shaft DK1 and Shaft DE3.
Drilling shift	9.04	Vertical: VW1 Decline: DE3	Shaft VW1 increased the benchmark significantly.
Blasting shift	14.20	Vertical: VW1 Decline: DK1	DK1 was less efficient than the morning and evening shift.
Eskom peak period	12.27	Vertical: VW1 Decline: DK1	–

3.2.2.2 Mine comparison

For a clearer understanding of the comparison, the specific mine was compared with another mine as well. If opportunities could not be seen on the specific mine and the other mine's intensities were lower, then different platinum mines could be investigated for improving the specific mine. This comparison with a different platinum mine is shown in Figure 31.

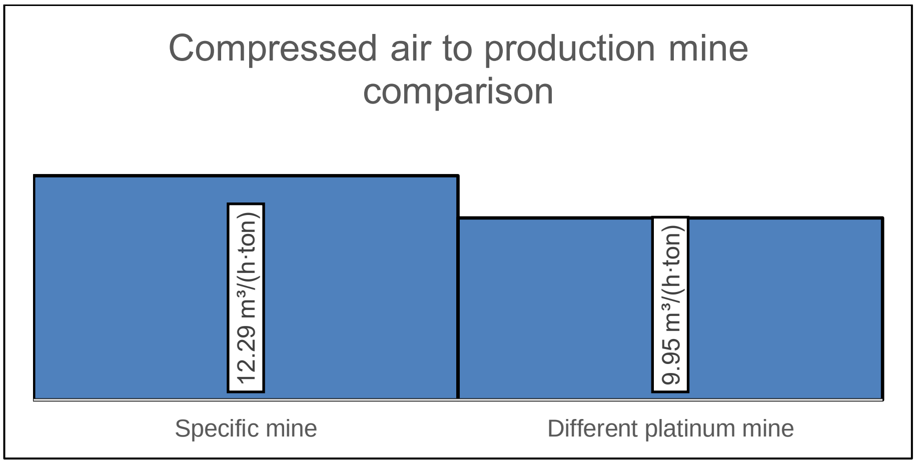


Figure 31: Compressed air to production mine comparison

Figure 31 shows that the specific case study mine investigated during this study had a higher intensity than the other platinum mine. Therefore, the compressed air consumption of this specific mine should be reduced by 2.34 m³/(h·ton).

Du Plooy found in his literature study that the compressed air consumed to produce one ton has more than doubled. Although this statement is accurate, it applies to gold specifically [5]. The depth of a shaft does have an effect on compressed air consumption. This impact with shaft depth is shown in Figure 31 as Shaft DE3 and Shaft DK1 are shafts with depths less than 500 m. The rest of the shafts are more than 700 m deep, and they are significantly more inefficient.

3.2.3 Benchmark validation

As previously mentioned, Shaft DK1 and Shaft DE3 are decline shafts. When these two shafts' morning and evening shift intensities were compared, Shaft DE3 was more inefficient as shown in Figure 27. This benchmarking led to the case study in which the intensity of Shaft DE3 was lowered by decreasing the compressed air set point from 5.5 bar to 5.2 bar during the sweeping/ cleaning shift.

The target set point was 4.5 bar, which was achieved by lowering the set point with 0.1 bar each week. Lowering the set-point pressure also reduced the leak rate. If the loader operators complained, the set point had to be reverted to the previous set point. This set-point reduction process is indicated in Figure 32.

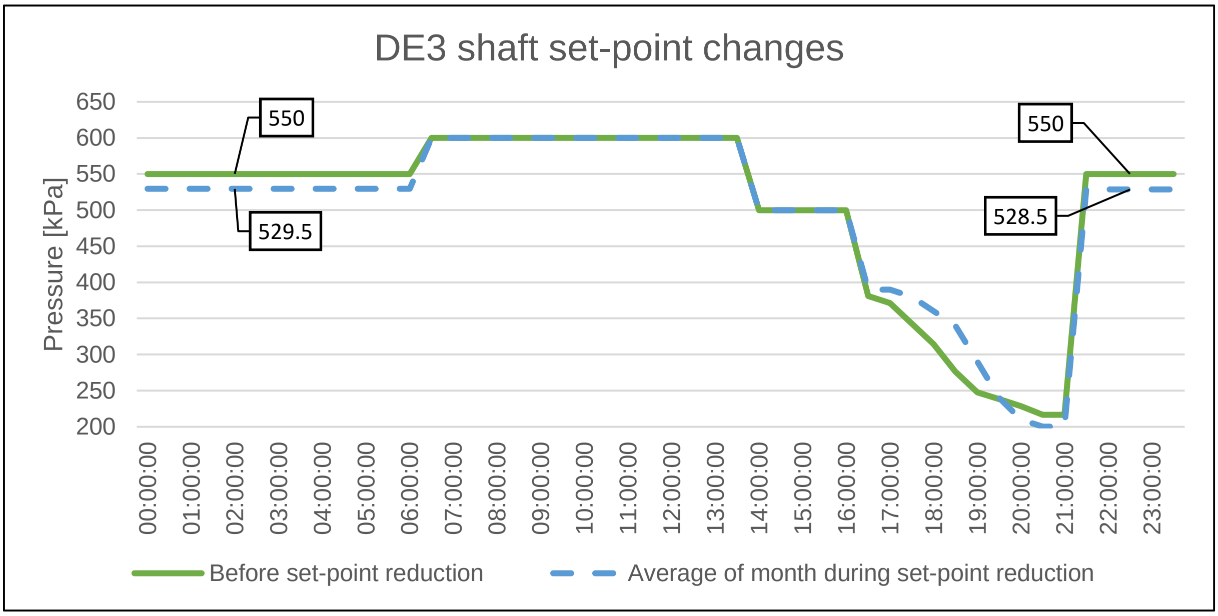


Figure 32: Shaft DE3's set point before reduction process started and for the month of the process

The average set point during the month of the set-point reduction test gave a decimal number of 0.5 (529.5 kPa and 528.5 kPa). Figure 32 indicates lower set points between 00:00 and 06:00 and between 21:00 and 24:00. This shows processes that reduced the set points. Figure 33 indicates how the flow reduced as an effect of the set-point reduction.

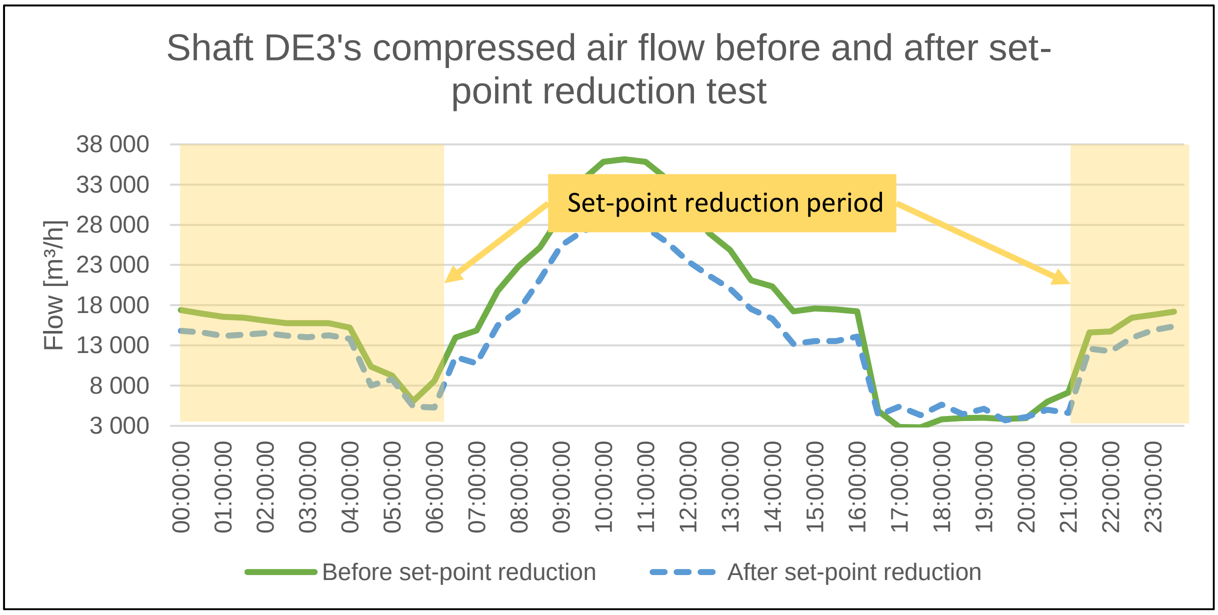


Figure 33: Shaft DE3's flow reduction resulting from set-point reduction

Figure 33 indicates a flow reduction during the period when the set point was reduced. This reduction ranges between 1 200 m³/h and 3 100 m³/h. It is also noted that the baseload remained the same between 16:00 and 21:00, indicating that a leak repair could not cause the reduction.

As stated above, the aim was to reduce the set point to 4.5 bar. If this could be achieved, it was determined by an in-house simulation program that the 4.5 MW compressor at Shaft DE3 could be stopped outside of the drilling shift.

Shaft DE3 is on a compressed air ring with Shaft VE4. They are 7 km away from each other. From Shaft VE4, the compressed air pipe reduces from 600 mm to 350 mm. The described layout can be seen in Figure 34. The current and proposed compressor operations are shown in Figure 35 and Figure 36.

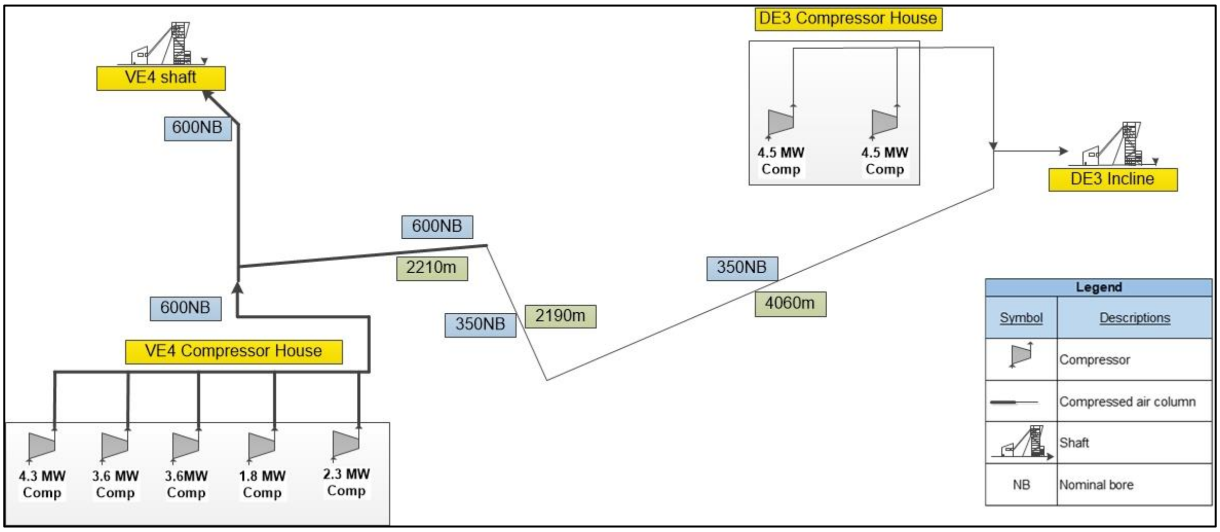


Figure 34: Compressed air layout

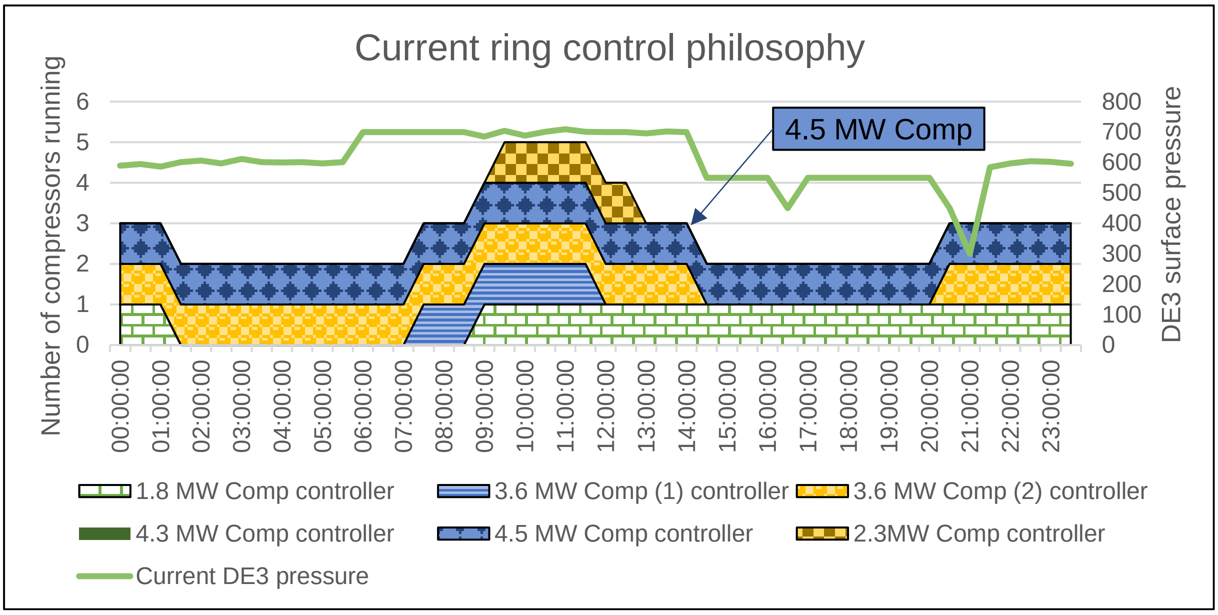


Figure 35: Current ring compressor operations, including Shaft DE3's pressure

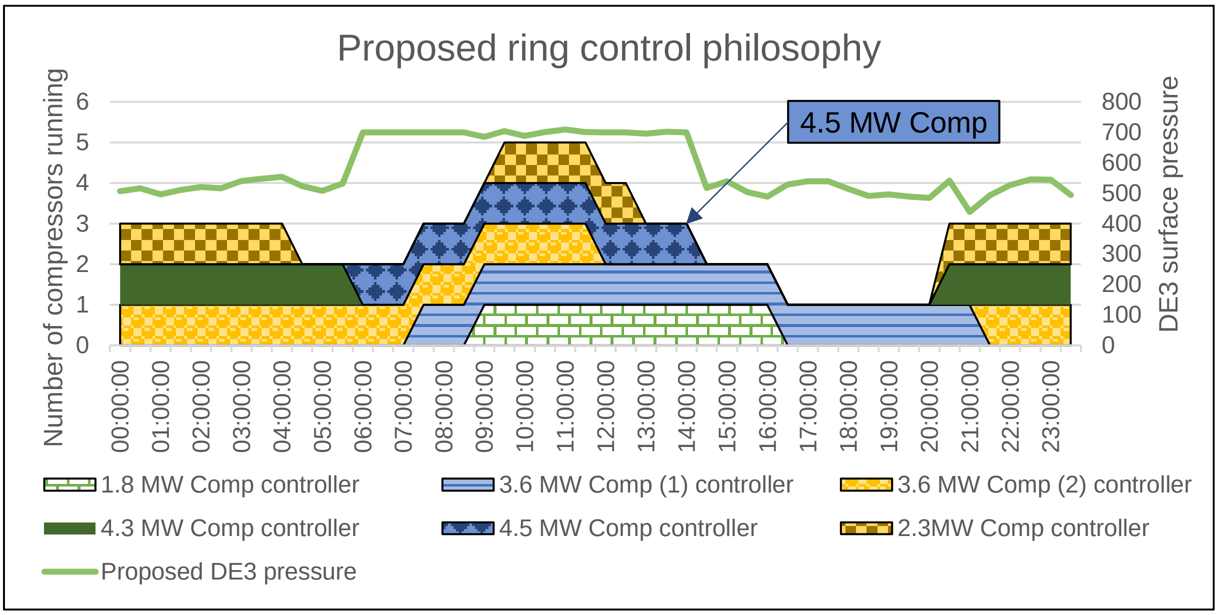


Figure 36: Proposed ring compressor operations, including Shaft DE3's pressure

Figure 36 shows that the 4.5 MW compressor ran for the entire day without stopping. The pressure that Shaft DE3 received outside of the drilling shift was 5.5 bar. As seen in Figure 36, the 4.5 MW compressor was stopped in the simulation for the proposed operations. The operations remained the same as the current operations during the drilling period. For the proposed operations, the simulation revealed that Shaft DE3 would still receive a pressure of 4.8 bar outside the drilling shift if compressor operations were changed at Shaft VE4 as shown in Figure 36. Since the compressor operations were changed, this not only resulted in a compressed air reduction, but also an energy reduction. The decrease in power, determined through the simulation, is shown in Figure 37.

Figure 37 shows the power profiles of the current operations and the proposed power, calculated from a simulation. It can be seen that the power consumption remained the same during the drilling shift, as no compressor operations changed during the drilling shift. A significant power reduction is noted during the blasting period. For the sweeping/cleaning shift, a power reduction is also indicated. Currently, the estimated annual saving is R2.5 million if the 4.5 MW compressor can be stopped.

The implementation of the set-point reduction to 4.5 bar is still in process, as the loader operators are resistant to the lower pressure. The resistance is not apparent, since the loader operators of Shaft DK1 operate the loaders at a pressure of 4.1 bar. If Shaft DE3's set point is reduced to 4.5 bar, the loaders receive a pressure of 4.3 bar.

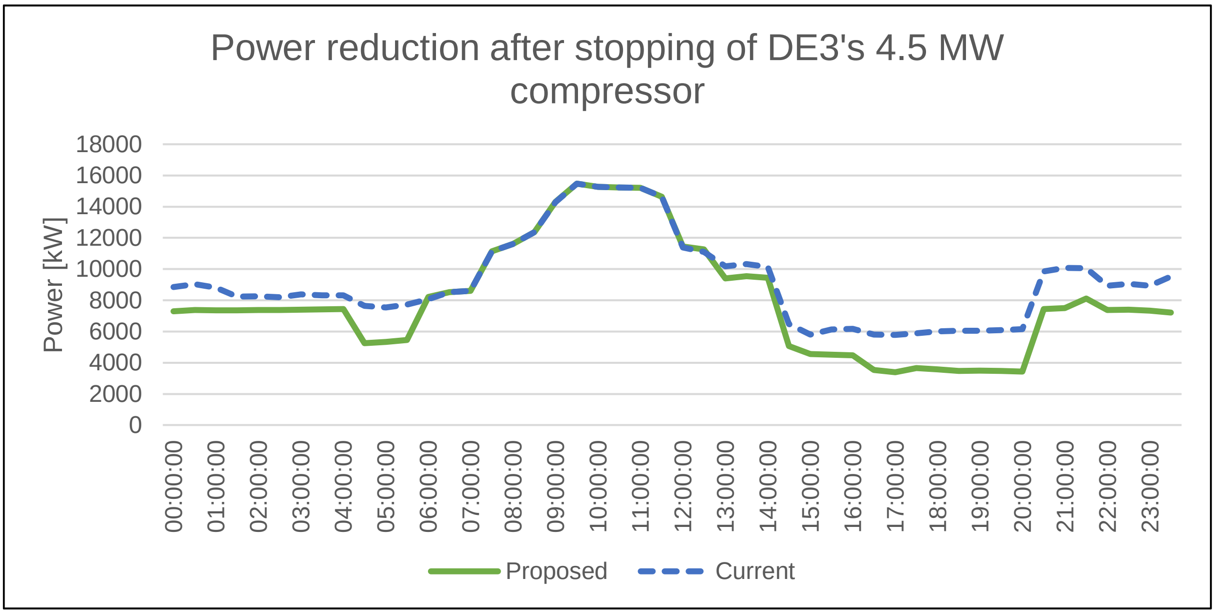


Figure 37: Proposed power reduction if Shaft DE3's 4.5 MW compressor is stopped

The next step to achieve the R2.5 million savings is to replace the pneumatic loaders with electro-hydraulic loaders. This will allow the set point to be reduced to 4.0 bar and show a decrease in compressed air consumption, as the pneumatic loaders consume the most significant air, as discussed in Chapter 1. The cost of an electro-hydraulic loader is R950 000. Four of these loaders are required, resulting in a payback period of less than two years. All of these findings resulted from noting that Shaft DK1 was more efficient than Shaft DE3.

Thus far, a reduction in intensity was shown by lowering the set point from 5.5 bar to 5.2 bar outside the drilling shift. This reduction in the intensity is shown in Figure 38. The shaft's benchmark intensity and the benchmark were before the case study was implemented. The case study intensities were after the project was implemented.

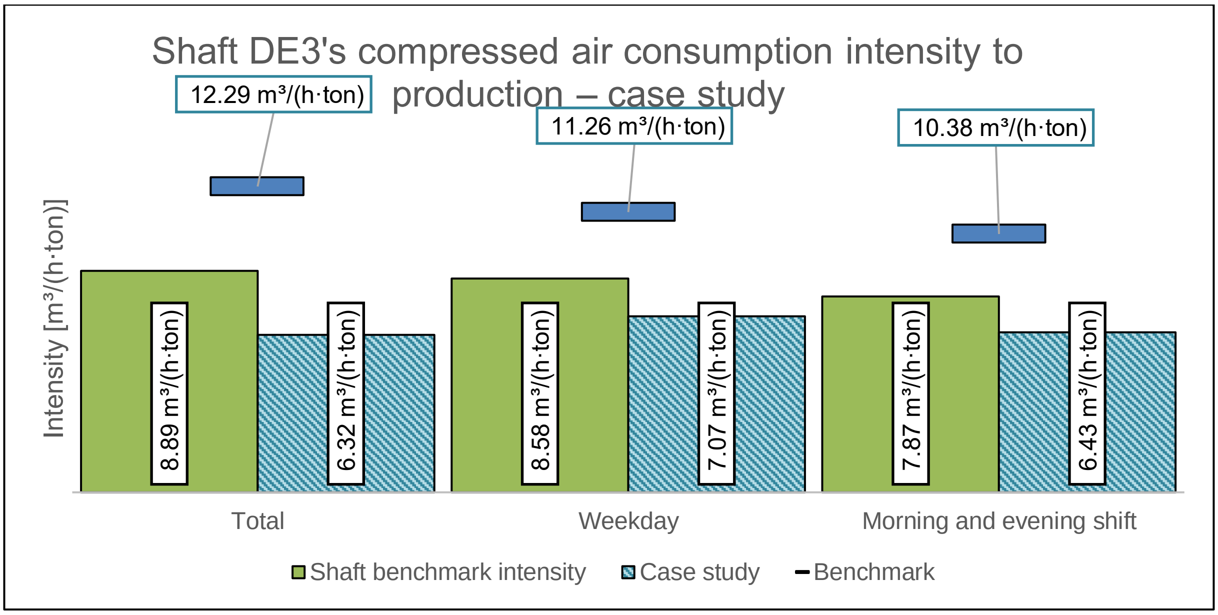


Figure 38: Shaft DE3's compressed air consumption intensity – case study

The set-point reduction lowered the total intensity by more than 2 m³/(h·ton). This decrease in intensity resulted from a decrease in the morning and evening shift's intensities, which lowered the weekday intensity. Initially, Shaft DE3 was the most inefficient decline shaft, but Shaft DE3's intensity was lowered below Shaft DK1's intensity due to the set-point reduction. Inefficiencies were identified by comparing the incline shafts separately from the vertical shafts using the highest intensity. This identification validates the benchmarking method.

3.3 Surface ventilation fan power

The specific mine's benchmark comprises only of surface ventilation fans and has no fridge plants to cool the air. These ventilation fans deliver fresh air underground and dilute harmful gases.

3.3.1 Benchmark verification

Table 9 summarises the benchmarks considered for identifying inefficiencies in the surface fan's power.

Table 9: Surface ventilation fan power – benchmarks tested

Surface ventilation fan power [kW]				
Compared with	Unit of comparison	Correlation factor	Standard deviation of correlation factor	Comment
Compressed air consumption	[m³/h]	0.933	0.007	Not connected directly.

Surface ventilation fan power [kW]				
Compared with	Unit of comparison	Correlation factor	Standard deviation of correlation factor	Comment
Production	[ton]	0.75	0.055	Production did not increase with an increase in surface fan power.
Underground Potable water consumption	[m³/day]	0.979	0.154	Bad standard deviation.
Mine depth	[m]	0.091	0.011	Bad correlation factor.
Active haulage length	[m]	0.836	0.008	Good comparison.
Underground employees	[–]	0.732	0.037	Bad correlation factor and did not increase with one another.

Legend:	Lowest number	Average number	Highest number

Although the potable water going underground had a good correlation factor, the consistency of the comparison was not good. The second-best correlation factor derived was the comparison with compressed air consumption. The comparison was consistent. The fault with this comparison is that the surface fan power will not increase if the compressed air consumption increases. The same goes for the production.

Active haulage length was a good comparison because the correlation factor was high and consistent. This comparison was also good because if the length increases a significant amount, the temperatures will too. Moreover, if the temperatures increase, more fan power will be required, meaning both will increase with one another.

The mine depth comparison resulted in a nasty correlation factor. The issue with the underground employees was that the number of employees did not remain fixed. Moreover, the fan power did not increase or decrease with the number of employees. The conclusion was that the active haulage length had to be used for the comparison.

3.3.2 Calculated benchmarks

Figure 39 shows the intensities' benchmarks.

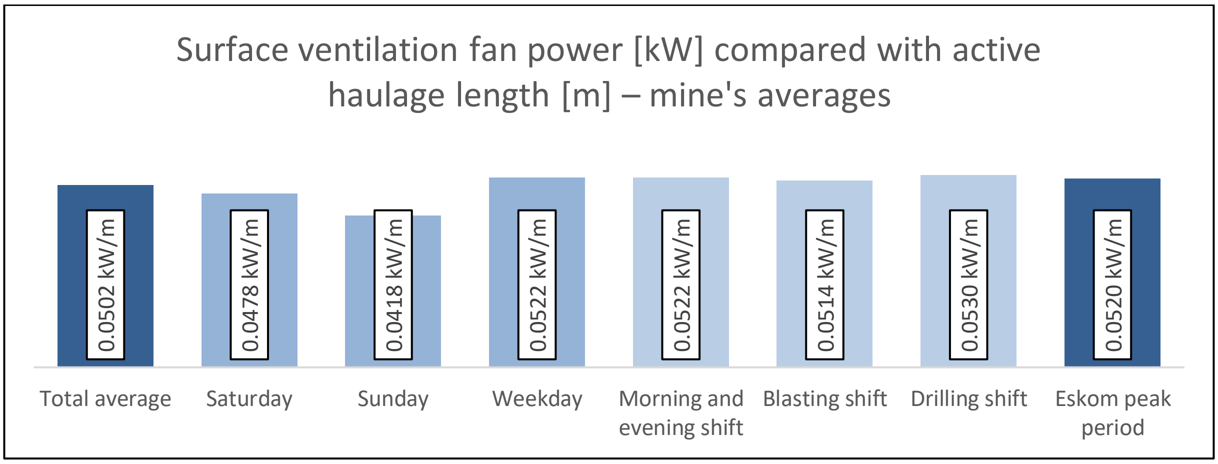


Figure 39: Benchmarks for different shifts for surface fan's average power

Figure 39 shows the intensities of the surface fan power divided by the fixed total active haulage length. It can be seen that the total average benchmark intensity was 0.0502 kW/m. The weekday intensity had the highest intensity.

The shifts had similar intensities as the weekday. This comparison in intensities was a result of the fan power profiles having constant power profiles as shown in Figure 9. The weekday benchmark could be lowered first, followed by Saturday and then Sunday, because the fans were stopped Saturday after the drilling shift and then only started Sunday evening again.

3.3.2.1 Identification of inefficient shafts

Inefficiencies on the fans could be caused by an oversupply of air during different periods. The ratios between the different periods should be monitored.

Total consumption comparison

Figure 40 indicates where the shafts' energy consumption resides compared with the benchmark. If it is under the zero line, it is below the benchmark. The benchmark intensity was 0.0502 W/m.

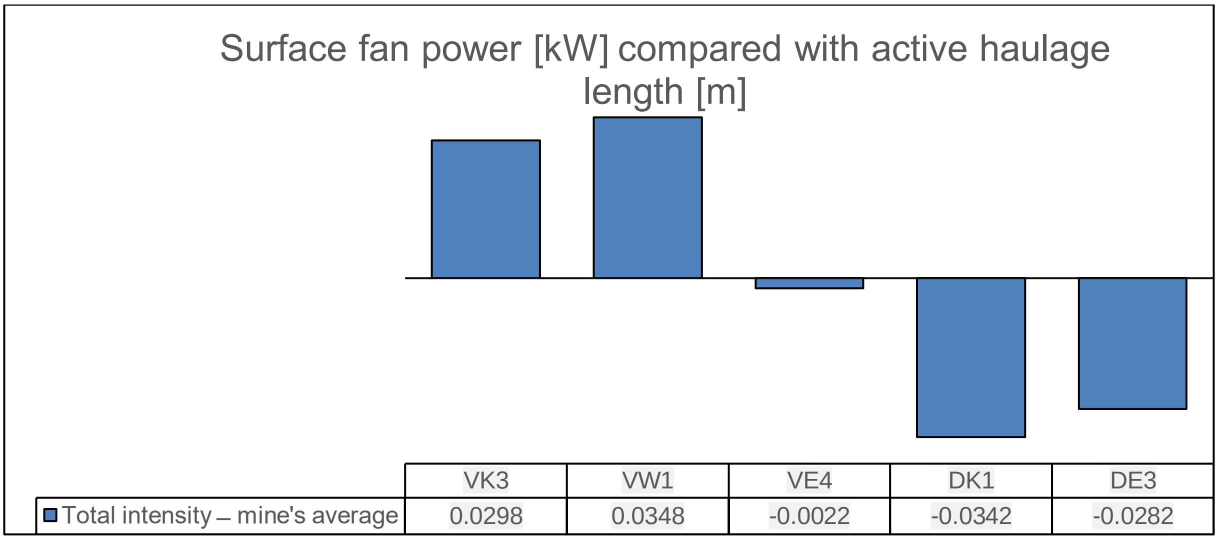


Figure 40: Shafts' total surface fan power intensity subtracted from the total average intensity

Shaft VW1 was identified as the most inefficient as seen in Figure 40. Shaft VK3 had a slightly lower intensity than Shaft VW1. The third-most inefficient shaft was Shaft VE4, being slightly below the benchmark. Again, the decline shafts were far below the average intensity, with Shaft DK1 being the most efficient.

Daily comparison

Figure 41 shows where the focus should be placed to lower Shaft VW1's intensity. This graph only indicates the weekdays, Saturdays, and Sundays. Their benchmark intensities were 0.0522 W/m, 0.0478 W/m, and 0.0418 W/m, respectively.

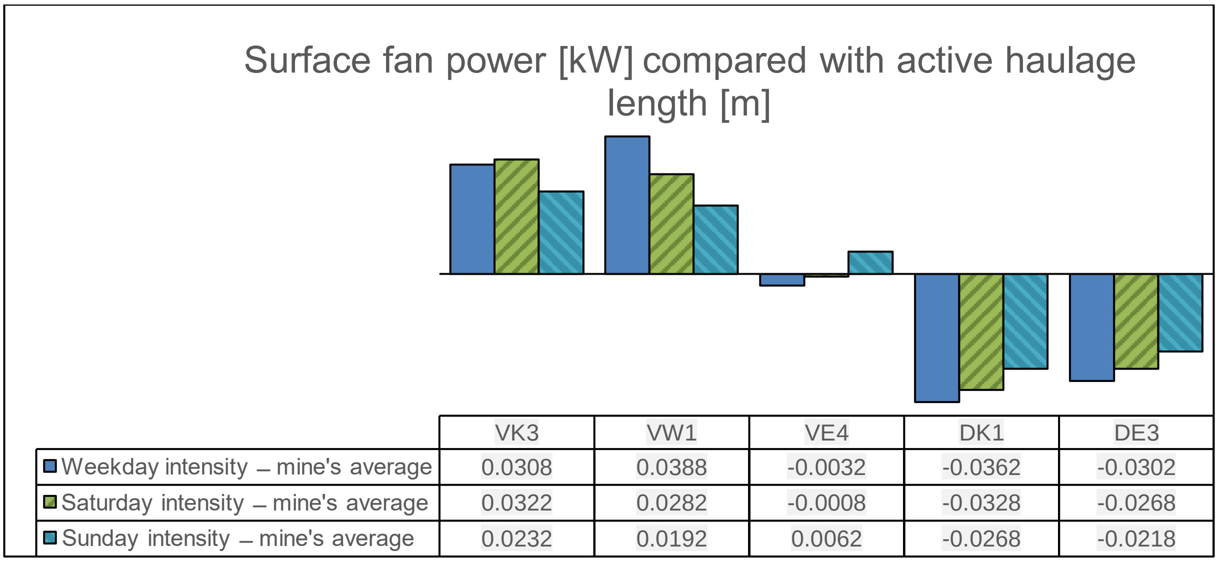


Figure 41: Surface ventilation fan power – weekday, Saturday, and Sunday intensities below or above benchmark

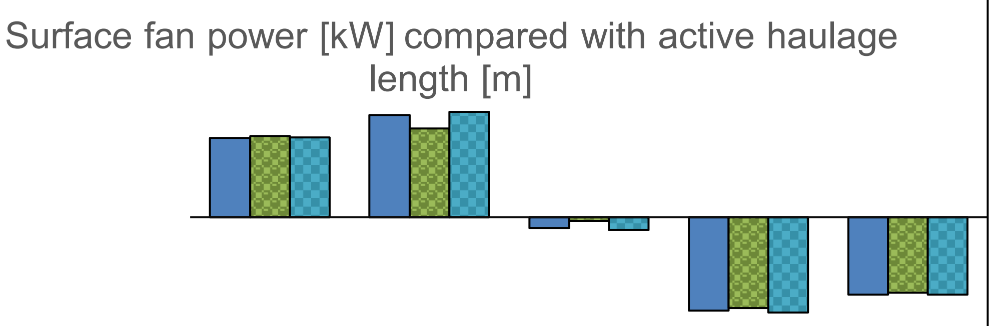
Shaft VW1 should concentrate on decreasing its weekday intensity. For Saturday and Sunday, its intensities were below that of Shaft VK3. Shaft VE4's highest intensity was during Sunday. Shaft DK1 had the most efficient consumption for weekdays, Saturdays, and Sundays. Shaft DK1 and Shaft DE3's efficiencies decreased from the weekday to Saturday and then Sunday. This reduction was caused by the benchmark decreasing and Shaft DE3 and Shaft DK1's intensities staying stable. There might be some opportunity to decrease their intensities during these periods as well.

Shift comparison

The weekday intensities are expanded in Figure 42. The morning and evening shift's benchmark intensity was 0.0522 W/m, the drilling shift's benchmark intensity was 0.0530 W/m, and the blasting shift's intensity was 0.0514 W/m.

Figure 42 shows that all of Shaft VW1's weekday shift was the most inefficient. They could have run one fan too many or a smaller fan could have been installed. This inefficiency meant that their total weekday consumption should decrease.

Shaft VW1 reduced its fan power the most during the blasting shift compared with other shafts' own intensities. If the mechanical ability of the fans allows it, they should reduce the power even more [with the possibility of installing a variable speed drive (VSD)]. The other shafts remained at a constant consumption above and below the average.



	VK3	VW1	VE4	DK1	DE3
Morning & evening shift intensity – mine's average	0.0308	0.0398	-0.0042	-0.0362	-0.0302
Blasting shift intensity – mine's average	0.0316	0.0346	-0.0014	-0.0354	-0.0294
Drilling shift intensity – mine's average	0.0310	0.0410	-0.0050	-0.0370	-0.0300

Figure 42: Surface ventilation fan power – weekday shift intensities above or below the benchmark

The intensities of Shaft VK3 endured the same. For Shaft VE4, the highest intensity was the blasting shift, which was different from the other shafts. Shaft VE4 increased its fan power in the blasting shifts, whereas the other shafts decreased theirs. This increase in power during the evening peak was better as the morning peak period consumption was lower, resulting in a cost saving. The decline shafts were far below the benchmarks. Shaft DK1 was once again the most efficient.

Eskom peak period comparison

Figure 43 evaluates how the shafts attempted to reduce costs due to an increase in tariffs.

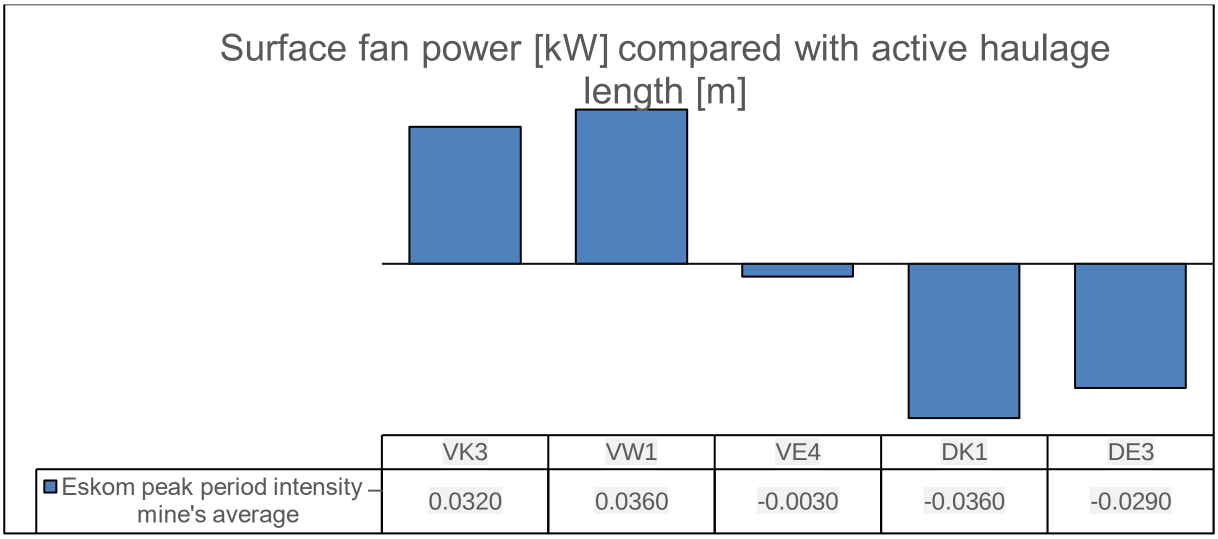


Figure 43: Surface ventilation fan power – Eskom peak period above or below the benchmark

Once again, Shaft VW1 implemented the slightest effort to reduce consumption during the Eskom peak period. Shaft VK3 was not far away from Shaft VW1. Shaft VE4, the most efficient vertical shaft, was slightly lower than the average intensity. Shaft DK1 reduced its energy the most.

Surface ventilation fan power inefficiencies summary

Table 10 summarises the inefficiencies noticed for the surface ventilation fan power. The vertical and incline shafts with the highest intensity are indicated, as well as some irregularities noticed.

Table 10: Surface ventilation fan inefficiency summary

Period	Benchmark [W/m]	Most inefficient shaft	Irregular inefficiencies
Total	50.20	Vertical: VW1 Decline: DE3	–
Weekday	52.20	Vertical: VW1 Decline: DE3	–
Saturday	47.80	Vertical: VK3 Decline: DE3	–
Sunday	41.80	Vertical: VK3 Decline: DE3	Shaft VE4 indicates an increase in intensity compared with the weekday and Saturday. Other shafts decrease on weekends.

Period	Benchmark [W/m]	Most inefficient shaft	Irregular inefficiencies
Morning/evening shift	52.20	Vertical: VW1 Decline: DE3	–
Drilling shift	53.00	Vertical: VW1 Decline: DE3	–
Blasting shift	51.40	Vertical: VW1 Decline: DE3	Blasting shift intensity increases for Shaft VE4.
Eskom peak period	52.00	Vertical: VW1 Decline: DE3	–

3.3.2.2 Mine comparison

Figure 39 revealed that the specific mine's total intensity was 50 kW/m. This total intensity included the average intensity of the five shafts of the one mine. Figure 44 compares this intensity with another shaft on another mine.

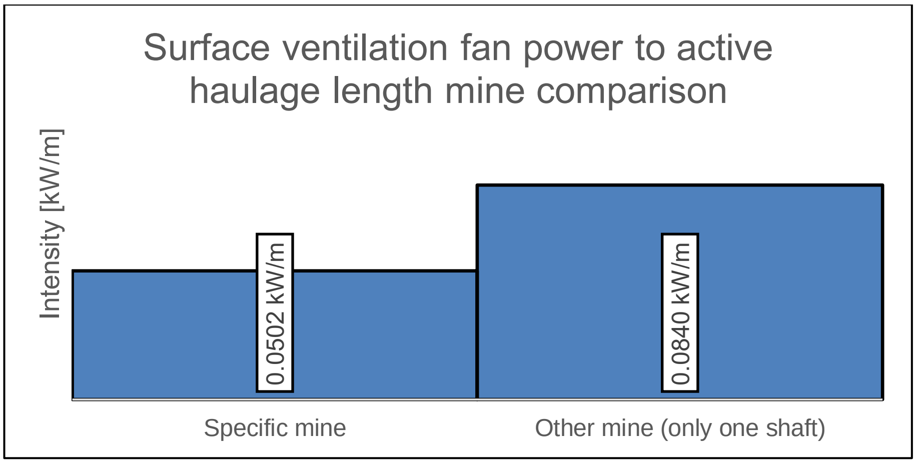


Figure 44: Surface fan power – comparison with another mine

Figure 44 shows that the chosen specific mine's intensity was less than the other mine's intensity. The other mine/shaft's intensity was 34 W/m more than the benchmarked mine. It should be investigated to consume less power.

3.3.3 Benchmark validation

It was noted in Figure 41 that the Sunday intensity was the worst for Shaft VE4. The other shafts' Sunday intensities were the best. Previously, Shaft VE4 ran four surface fans continuously during the benchmark period, which were only stopped for maintenance purposes. It was suggested to stop the fans after the Saturday drilling shift. The fan operations are shown in Figure 45.

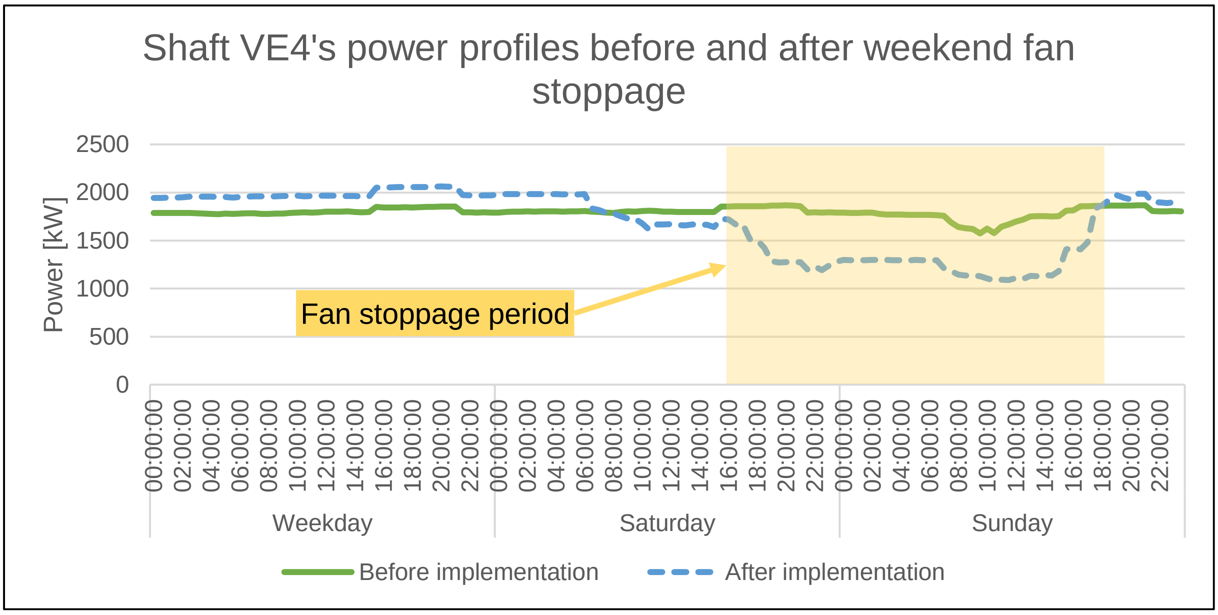


Figure 45: Shaft VE4's fan operations

Figure 45 indicates when the fans were stopped. The average data used for these profiles was from 1 February 2019 till 30 November 2019. The fan stoppage project was implemented on 25 July 2019, separating the before and after implementation.

An extensive range of average data was used, resulting in the profile being less consistent over the weekend. This inconsistency is due to the fans being stopped at different times, but an apparent decrease in power consumption was noted. However, for the weekday period, the power consumption increased. This increase is due to failing guide vanes as well as ventilation leak repairs. This project was an energy reduction project resulting in R1.4 million savings. The intensity decrease is shown in Figure 46.

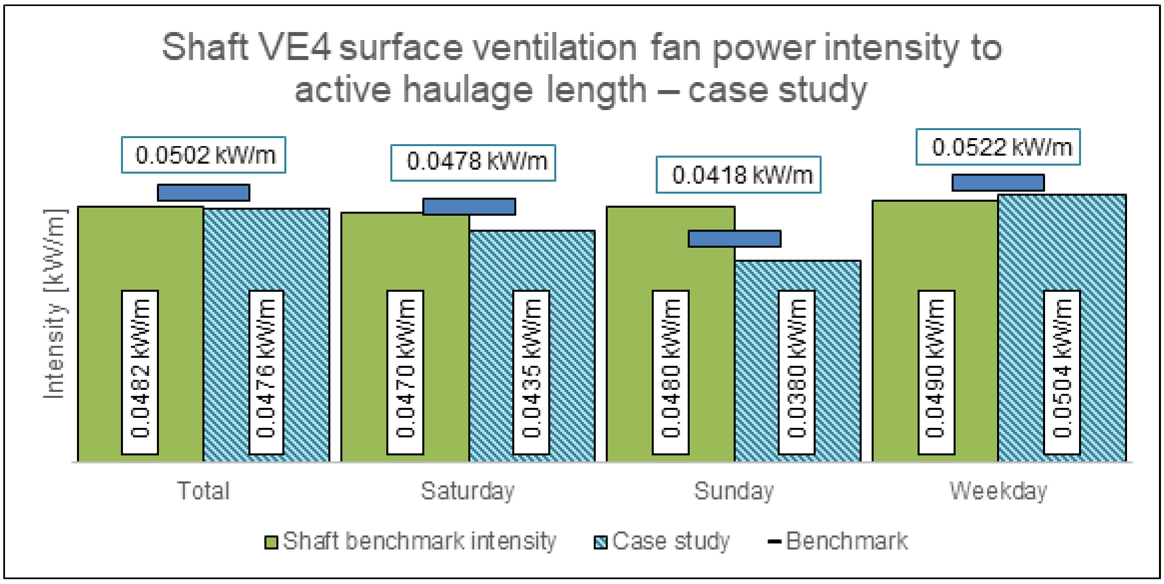


Figure 46: Shaft VE4's surface fan power intensity – case study

Figure 46 shows that the total shaft's intensity did lower slightly. Both remained under the benchmark. The Saturday intensity did reduce significantly when the fans were stopped after the Saturday drilling shift. The most considerable reduction is seen with the Sunday intensity. Previously, the Sunday intensity was over the benchmark; however, stopping the fans reduced the intensity to below the benchmark intensity, thereby validating that the benchmark can show inefficiencies during a specific period.

3.4 Rock winder power

The rock winder, being the fourth-most expensive consumer, was benchmarked and inefficient shafts identified. The decline shafts did not have rock winders, but used conveyors to transport the platinum to the surface. These conveyors' energy was not measured.

3.4.1 Benchmark verification

There were only a small number of items that could be used to compare the rock winder energy. These comparisons are given in Table 11. The comparison with the highest correlation factor was compressed air consumption. However, it also had the most inconsistent correlation factor, ranging between 0.846 and 0.932. The second-highest correlation factor for the comparisons was production with a correlation factor of 0.871. This correlation fell within the compressed air consumption range. Furthermore, the production comparison was the most consistent. The correlation factor ranged between 0.866 and 0.876. Both correlation factors were high. The comparison with the lowest correlation factor was mine depth, which was too low to use.

Therefore, production comparison was chosen as the benchmark to be used. This comparison made sense as the rock winder was only used to transport the platinum to the surface.

Table 11: Rock winder power – benchmark comparisons

Rock winder power [kW]				
Compared with	Unit of comparison	Correlation factor	Standard deviation of correlation factor	Comment
Compressed air consumption	[m³/h]	0.889	0.043	No direct connection.
Production	[ton]	0.871	0.0051	Good and consistent correlation factor.
Mine depth	[m]	0.204	0.024	Bad correlation factor.

Legend:	Lowest number	Average number	Highest number

3.4.2 Calculated benchmarks

Figure 47 shows the rock winder power to production benchmarks based on the mine's averages.

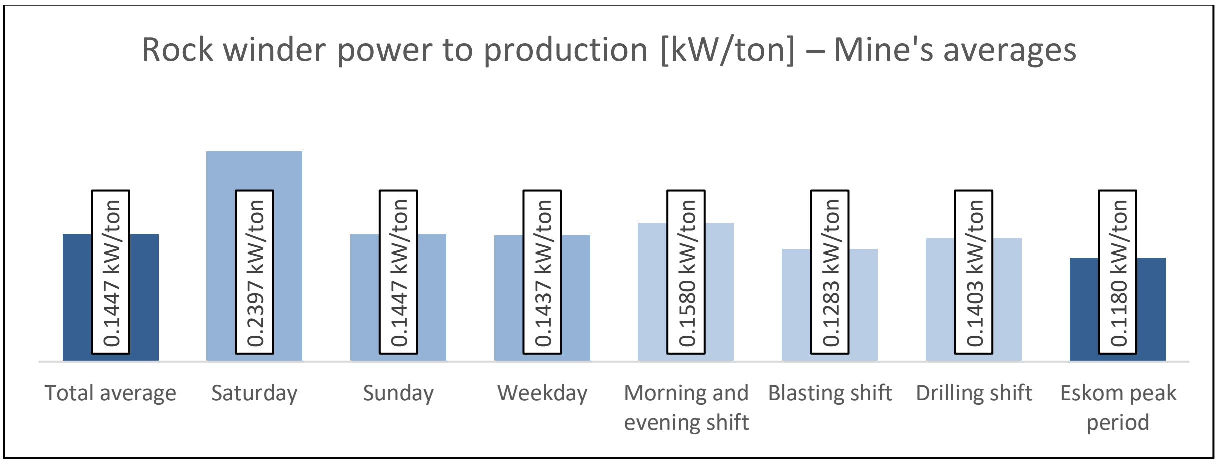


Figure 47: Rock winder power – benchmarks

The mine's benchmark was 0.1447 kW/ton. This benchmark means that for every ton that was transported to the surface, 145 W was used. Of all the benchmarks, the 240 W/ton consumed on Saturdays was the highest. There was not a significant difference between the weekday and Sunday benchmarks; however, the Sunday intensity was slightly higher. As productivity was supposed to be the lowest on Sundays, it should have had the lowest intensity. This was not the case for the Sunday intensity and should be investigated.

For the weekday shifts, the sweeping/cleaning shift used 158 W per ton transported. This benchmark is, on average, the time when the rock winders are used the most. It was also noticed that the blasting shift had the lowest intensity of the weekday averages. The last exciting and noticeable item was that the Eskom peak period had the lowest intensity. This low benchmark meant that the shafts did try to implement load shifting on the winders.

3.4.2.1 Identification of inefficient shafts

The rock winder is a closed system where no leaks can occur. The only possible inefficiency is the amount of mass that is transported. If the skips of the winder are not full, the higher energy consumption will be shown as an increase in movement should take place to transport the same amount of mass.

Total consumption comparison

Figure 48 shows overall which shaft did not use their rock winder as optimally as other shafts. The zero line of the benchmark intensity used for Figure 48 was 144.7 W/ton.

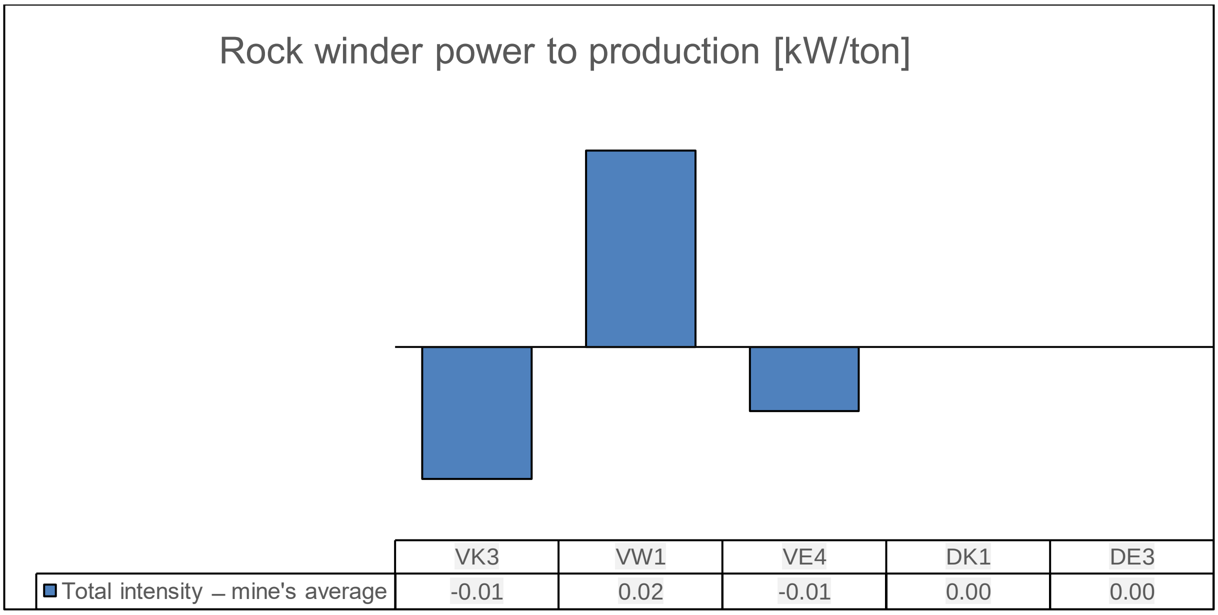
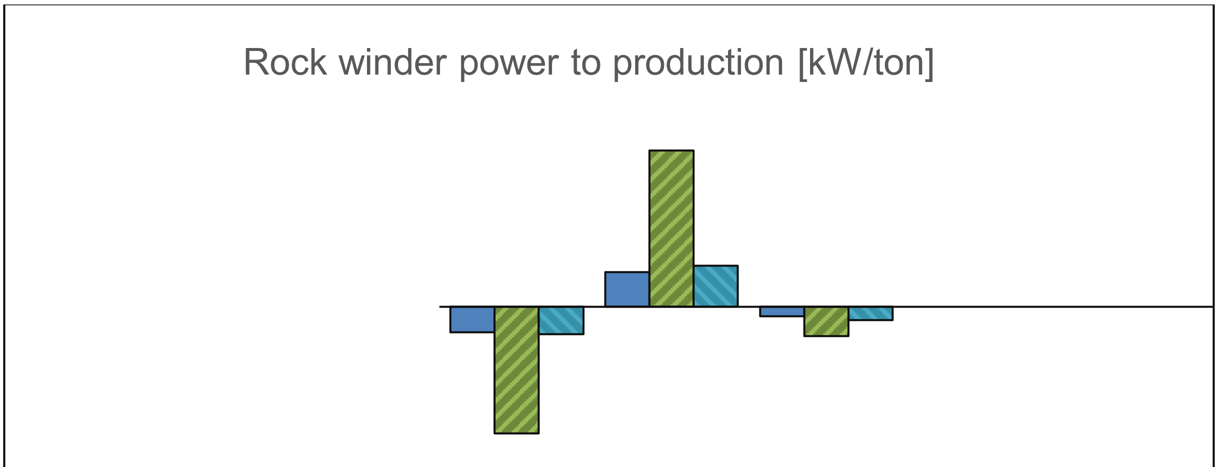


Figure 48: Rock winder power – shafts' total average intensities

Shaft VK3 was the most efficient shaft based on the total average. It was far below the total intensity benchmark. Shaft VW1 used 20 W/ton more power than the benchmark. It was the only shaft that was above average, meaning it increased the benchmark. Lowering Shaft VW1's consumption would decrease the benchmark accordingly. Shaft VE4 was 10 W/ton below the benchmark.

Daily comparison

On Figure 48, it was noted that Shaft VW1 did not use the rock winder optimally. Figure 49 evaluates when the winder could be used more optimally. The benchmark intensities used for the weekday, Saturday and Sunday intensities were 143.7 W/ton, 239.7 W/ton, and 144 W/ton, respectively.



	VK3	VW1	VE4	DK1	DE3
Weekday intensity – mine's average	-0.01	0.02	0.00	0.00	0.00
Saturday intensity – mine's average	-0.06	0.08	-0.01	0.00	0.00
Sunday intensity – mine's average	-0.01	0.02	-0.01	0.00	0.00

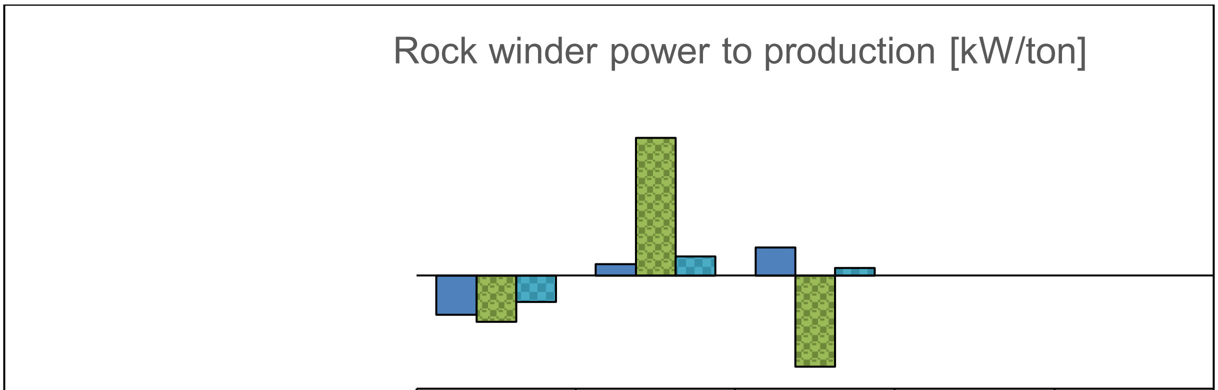
Figure 49: Rock winder power – weekday, Saturday, and Sunday's shaft intensities

The first thing noticed from Figure 49 is Shaft VW1's high Saturday intensity, which was the cause of the high Saturday intensity. A further evaluation showed that all Shaft VW1's intensities in Figure 49 were the most inefficient. Shaft VE4 was the second-most efficient shaft with all the above intensities, and Shaft VK3 had the most significant efficiencies, especially on Saturdays.

Shift comparison

Figure 50 shows the intensities of the weekday shifts. Re-evaluating Figure 39 showed that weekdays had the lowest benchmark. Less focus should be placed on reducing the weekday intensity than the Saturday and Sunday intensities. The focus should be placed on lowering Shaft VW1's Saturday and Sunday intensities. Nevertheless, the weekday intensities could be lowered during the following periods on the following shafts, seen in Figure 50.

For a further breakdown of the weekday inefficiency evaluation, Figure 50 was used to establish the cause of the high weekday inefficiency. The sweeping/cleaning shift, drilling shift, and blasting shift's benchmark intensities were 158 W/ton, 140.3 W/ton, and 128.3 W/ton, respectively.



	VK3	VW1	VE4	DK1	DE3
Morning & evening shift intensity – mine's average	-0.01	0.00	0.01	0.00	0.00
Blasting shift intensity – mine's average	-0.02	0.05	-0.03	0.00	0.00
Drilling shift intensity – mine's average	-0.01	0.01	0.00	0.00	0.00

Figure 50: Rock winder power – weekday shift shaft intensities

Figure 50 shows that Shaft VE4 had the most efficient intensity, namely the blasting shift intensity. This low intensity meant that Shaft VE4 reduced its energy consumption the most during the blasting period. Shaft VK3's intensity was also below the benchmark. However, Shaft VW1 was far above this benchmark. Not only was the blasting period of Shaft VW1 above the benchmark, but both the other shifts were as well. Shaft VE4's other intensities were also above average. On the other hand, Shaft VK3 was the most efficient as it reduced the benchmarks.

Eskom peak period comparison

Figure 51 was also used to evaluate Shaft VE4. This figure shows that Shaft VE4 was the most efficient in the Eskom peak period. The Eskom peak period fell directly in the blasting period, which had the lowest intensity in Figure 51. Figure 51 shows that Shaft VE4 load-shifted the energy consumption to the Eskom off-peak period (sweeping/cleaning shift) when the energy cost was the lowest. This shift in energy consumption was the most effective cost saving. Shaft VK3 did it as well, but not as effectively. The benchmark intensity used was 118 W/ton.

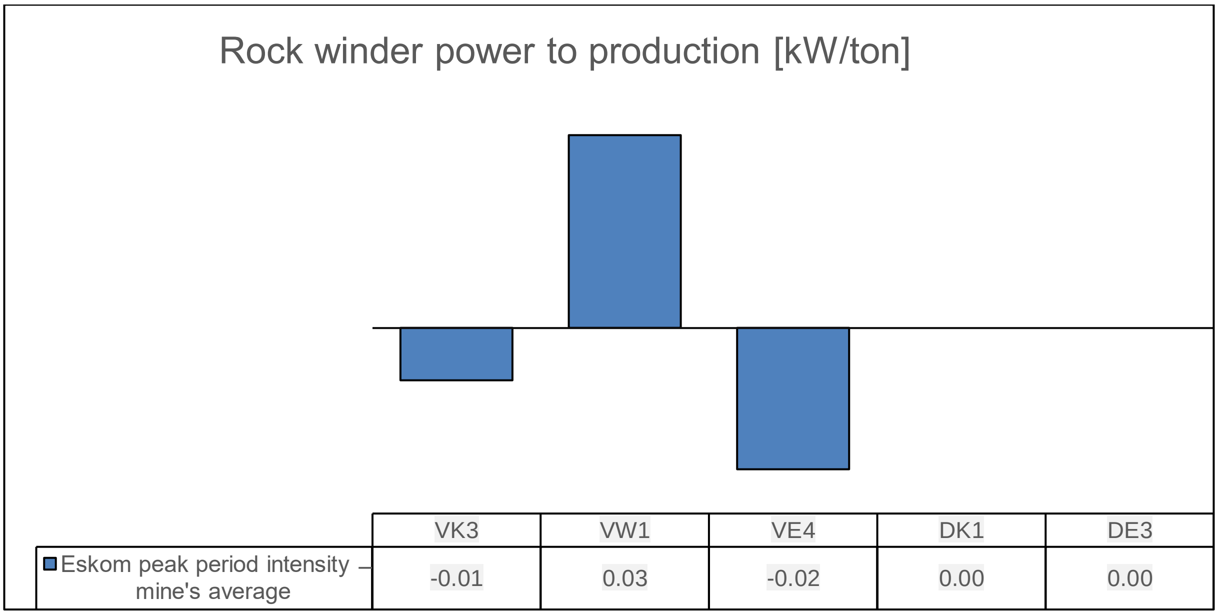


Figure 51: Rock winder power – Eskom peak period above or below the benchmark

As mentioned above, Shaft VE4 was the most cost-effective load-shifting shaft. Shaft VK3 did not implement load shifting as well as Shaft VE4. It did not seem as if Shaft VW1 implemented any type of load shifting. Its drilling shift intensity, Eskom's standard period energy cost, was the most inefficient.

Rock winder power inefficiency summary

Table 12 shows the most inefficient shaft. As Shaft VW1 remained the most inefficient shaft, except for the morning and evening shift, no irregularities were noted. There is a clear indication that Shaft VW1 is inefficient. Shaft VE4, being the most inefficient during the morning and evening shift, is not necessarily an inefficiency, as the load is shifted outside of the drilling shift.

Table 12: Rock winder power inefficiency summary

Period	Benchmark [W/ton]	Most inefficient shaft	Irregular inefficiencies
Total	144.70	Vertical: VW1	–
Weekday	143.70	Vertical: VW1	–
Saturday	239.70	Vertical: VW1	–
Sunday	144.70	Vertical: VW1	–
Morning/evening shift	158.00	Vertical: VE4	–
Drilling shift	140.30	Vertical: VW1	–
Blasting shift	128.30	Vertical: VW1	–
Eskom peak period	118.00	Vertical: VW1	–

3.4.2.2 Mine comparison

Figure 52 revealed that the total intensity for the rock winder power compared with production intensity was 145 W/ton. Figure 50 compares two shafts on a different mine.

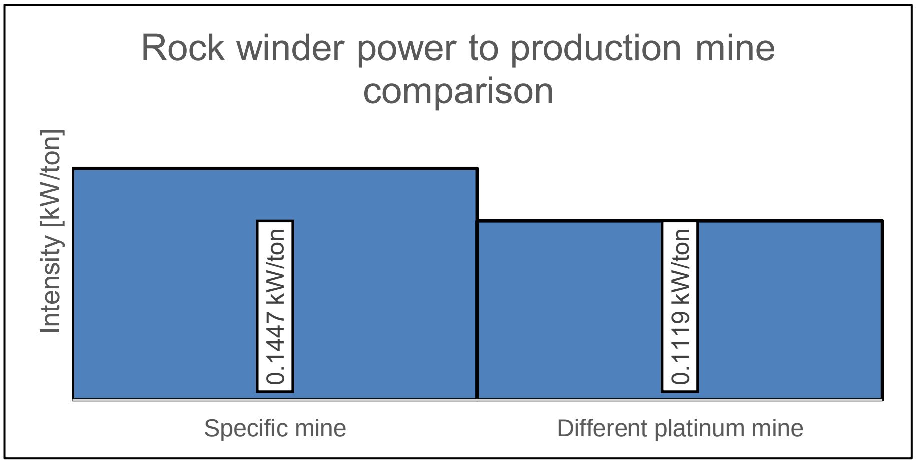


Figure 52: Rock winder power – total intensity compared with another mine

It is noticed that the benchmarked mine's intensity was higher than the other mine's intensity. The other mine's intensities could be broken down into shifts to determine where there was scope to reduce the W/ton. Nevertheless, looking at Figure 47 again shows that the rock winder should operate less on Saturdays.

3.4.3 Benchmark validation

Figure 51 showed that Shaft VW1 had the worst load-shifting result. For the case study, the Eskom peak average power was lowered. This power reduction during the Eskom peak period is shown in Figure 53.

Figure 53 indicates the Eskom peak periods. These periods include both the summer and winter peak times.[12] The periods used for these average profiles were July 2019 and March 2020, which were before lockdown started. It can be seen that during the morning peak period, there was a significant power reduction. The rock winder operators tried to minimise their operations during the Eskom peak periods; however, the operations are dependent on underground operations. This resulted in minimum power consumption during the morning peak period.

[12] Summer peak times: 07:00–10:00 and 18:00–20:00 (1 January–31 May and 1 September–31 December). Winter peak times: 06:00–09:00 and 17:00–19:00 (1 June–31 August).

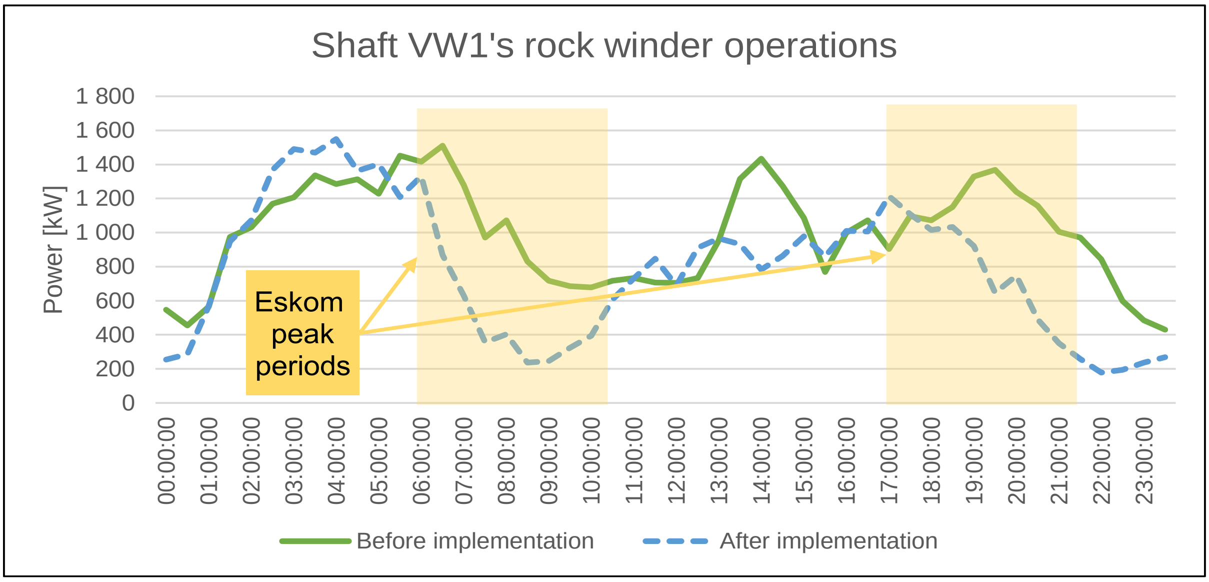


Figure 53: Shaft VW1's winder operations

For the evening peak, it can be noted that operations started to scale down earlier. The energy consumption was shifted to between 01:00 and 05:30. Shaft engineers are not always aware of what the impact of implementing load shifting on the rock winders will be. It does take convincing to implement load shifting as operators do not want to affect production negatively. Supplying operators with a potential cost-saving value motivates the implementation. For Shaft VW1, the annual cost-saving achieved was R497 107. The intensities are shown in Figure 54.

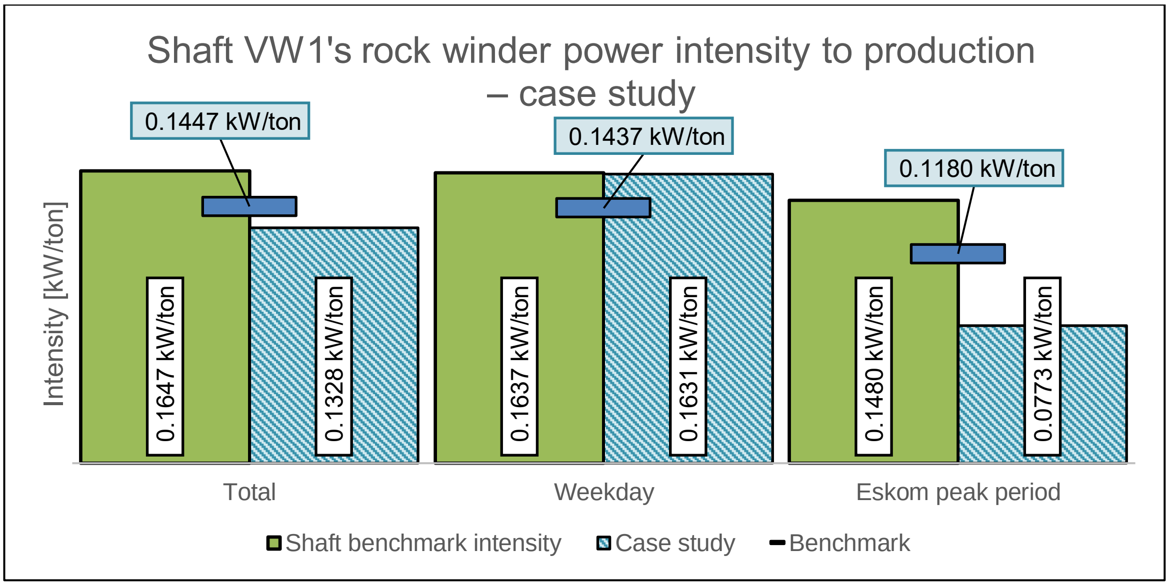


Figure 54: Rock winder to production – case study

The Eskom peak period intensity was investigated first. There was a significant decrease in average power consumption, which was almost half the previous benchmark of the shaft. The weekday intensity was also included to ensure that load shifting did not influence production. No difference in the intensity was noted. This further shows that this is a load-shifting project as the amount of power remained equivalent. The total intensity was included to verify that production was not influenced, but a surprising decrease in average power was revealed. The decrease should have come from the weekend operations.

3.5 Potable water consumption

Potable water is clean, consumable water that can be drunk. Chapter 1 discussed that this non-renewable resource is scarce and that mines consume a large amount of water. The water to the change house and the shafts underground was measured throughout all the shafts on the specific mine. This section is divided into two categories:

- Category A: The potable water to the change houses.
- Category B: The water going underground.

The water data could only be retrieved in a daily resolution. Therefore, the weekday intensities could not be broken down into shifts. The water to Shaft VK3's change house was also not measured.

CATEGORY A: POTABLE WATER TO CHANGE HOUSE

3.5.1 Benchmark verification for potable water to change house

The best-suited comparisons for creating benchmarks are given in Table 13. Only three variables were found as relevant comparisons, namely: underground employees, surface employees, and both types added together. The best-suited benchmark comparison was with all employees because both types of employees use water. The comparison with all employees had the second-highest correlation. It was also the second-most consistent comparison. The correlation factor ranged between 0.717 and 0.815.

Table 13: Potable water consumed at change house – benchmarks considered

Potable water to change house [m³/day]				
Compared with	Unit of comparison	Correlation factor	Standard deviation of correlation factor	Comment
Underground employees	[–]	0.754	0.05	Good comparison because the underground employees showered in the change houses after their shifts.

Potable water to change house [m³/day]				
Compared with	Unit of comparison	Correlation factor	Standard deviation of correlation factor	Comment
Surface employees	[–]	0.954	0.021	Not a good comparison as the surface employees used a minimal amount of potable water in the change house.
All employees	[–]	0.766	0.049	Both types of employees used potable water in the change house.

Legend:	Lowest number	Average number	Highest number

3.5.2 Calculated benchmarks for potable water to change house

The biggest consumer of the change house is showers. Employees returning to the surface usually take a shower before going home. Surface employees further consume this water by using toilets and drinking water.

Binks, Kenway and Lant calculated that the average water consumed per household person per day was 88.1 l. What was noticed in this article is that the average flow rate of one household was 4.4 l/min, where the average, excluding this household, was 8.23 l/min [51]. This difference in flow resulted in a decrease in the average. It is doubtful whether the change houses are equipped with these types of showerheads.

Lehmann, Khoury and Patel found that the average student consumes 123 l/person/day water, which is not for showering on its own, but total consumption [41]. Before Cape Town's water crisis, the average water consumption per person was 183 l/person/day, which dropped to 84 l/person/day. Brühl and Visser stated that Australians consumed up to 375 l/person/day before drought conditions [21]. This 84 l, 123 l, and 183 l can be compared with the potable water going to the change house. Not all employees shower, but most employees do contribute to consumption.

The specific mine's benchmark water consumption is shown in Figure 55. These values were compared with the benchmarks calculated in the literature discussed above.

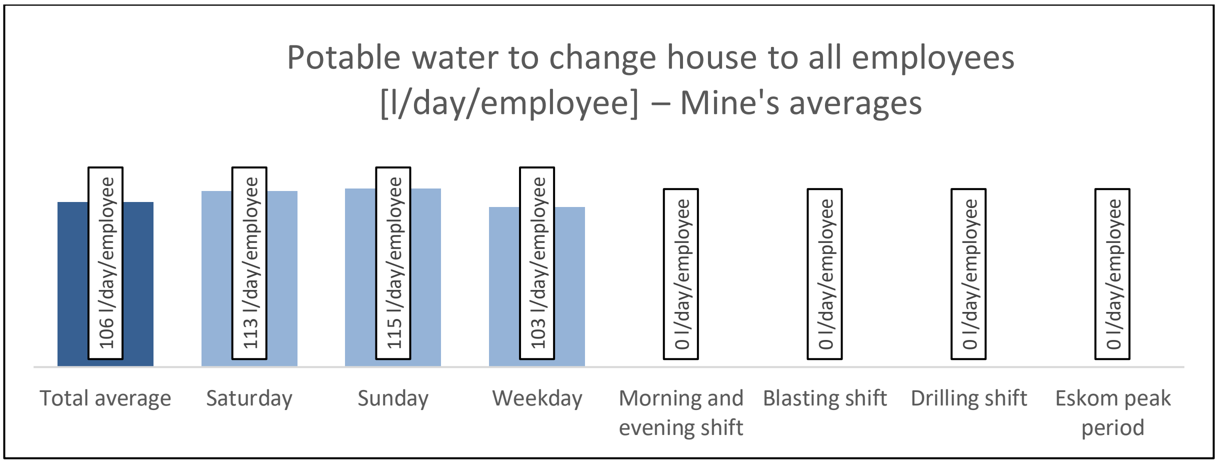


Figure 55: Potable water to change house – benchmarks

The total consumption intensity was 106 l/day/employee. This intensity is considerably less than the 183 l/day/employee mentioned previously. Take note that a fixed number of employees was used to create this intensity. The number of employees showering was possibly lower. Fewer employees showering means the intensity is probably higher. This increase would, however, give a suitable identification of which shaft is inefficient.

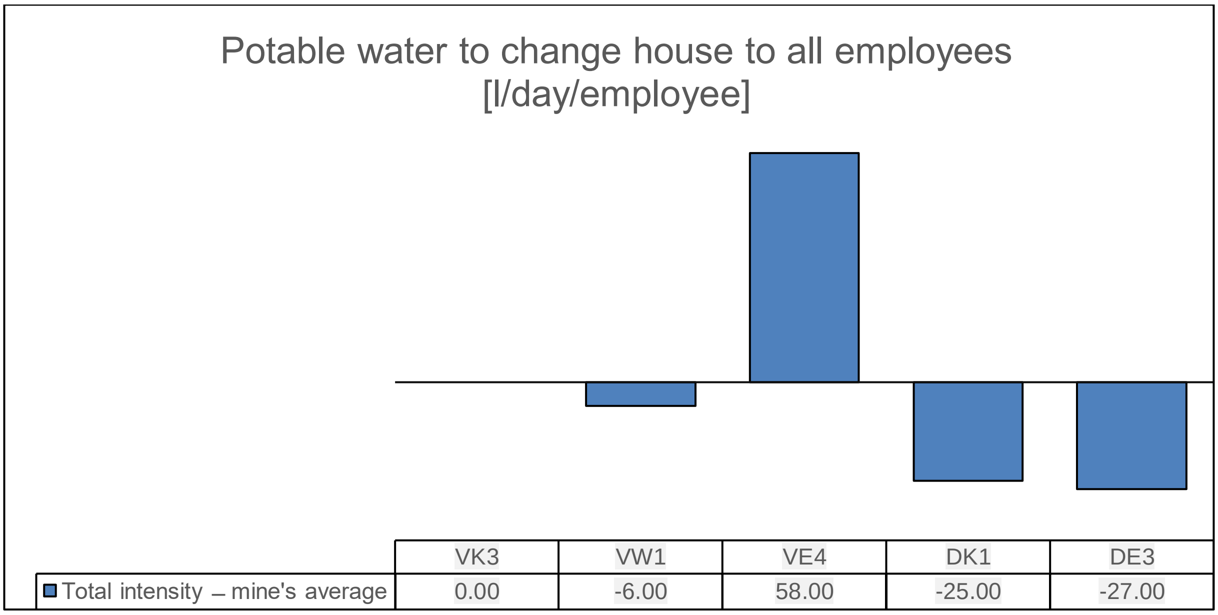
The Sunday intensity was the highest, followed by the Saturday benchmark, and the most efficient benchmark was the weekday intensity.

Identification of inefficient shafts

Inefficiencies can occur due to leaks or human wastage. Reduction will be shown if leaks are removed. Employees should be made aware of their water consumption.

Total consumption comparison

Figure 56 illustrates the shafts with the most significant wastage. This graph shows the total consumption per day divided by the number of employees. The benchmark intensity used for Figure 56 was 106 l/day/employee.

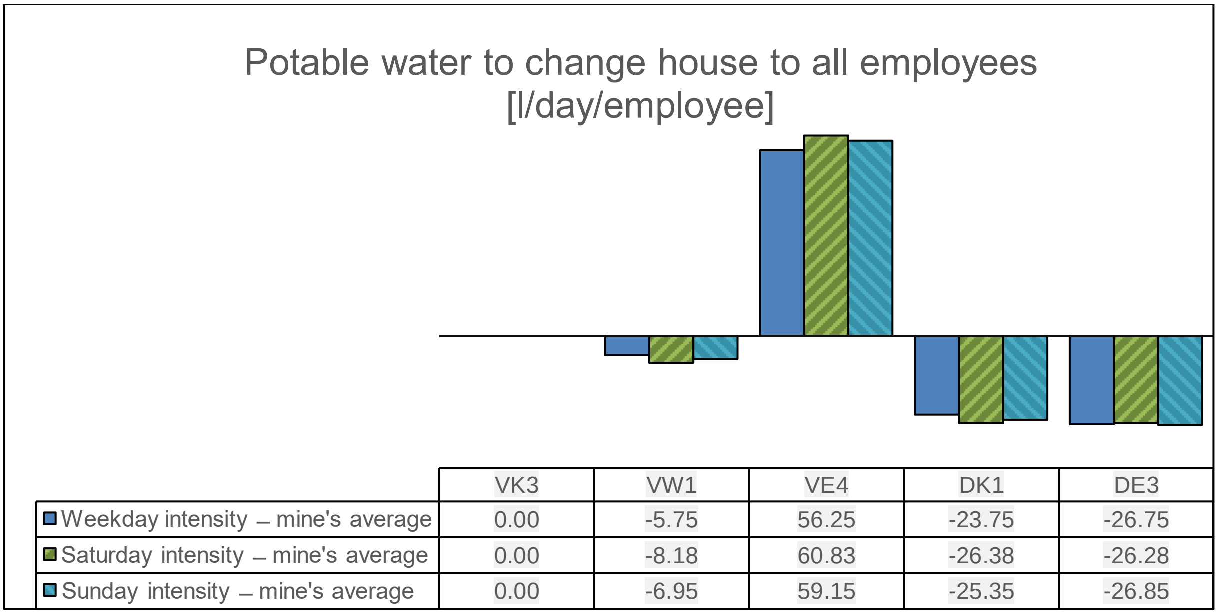


	VK3	VW1	VE4	DK1	DE3
Total intensity – mine's average	0.00	-6.00	58.00	-25.00	-27.00

Figure 56: Potable water to change house – shafts' total consumption intensity

Daily comparison

After Figure 56 was evaluated, Figure 57 was used to indicate the scoping period for improving the portable water to the change house. The weekday benchmark intensity was 133 l/day/employee. The Saturday and Sunday benchmark intensities were 115 l/day/employee and 103 l/day/employee, respectively.



	VK3	VW1	VE4	DK1	DE3
Weekday intensity – mine's average	0.00	-5.75	56.25	-23.75	-26.75
Saturday intensity – mine's average	0.00	-8.18	60.83	-26.38	-26.28
Sunday intensity – mine's average	0.00	-6.95	59.15	-25.35	-26.85

Figure 57: Potable water to change house – weekday, Saturday, and Sunday shaft intensities

Figure 56 clearly shows that Shaft VE4 was very inefficient. All the focus should be placed on reducing Shaft VE4's water consumption. This inefficiency was confirmed in Figure 57. All the other shafts remained below the benchmark, with Shaft DE3 being the most efficient.

Potable water to change house inefficiency summary

As discussed above, Shaft VE4 had the highest intensity throughout all periods. The intensities remained constant, resulting in minimal irregularities found. This is summarised in Table 14.

Table 14: Potable water to change house inefficiency summary

Period	Benchmark [l/day/employee]	Most inefficient shaft	Irregular inefficiencies
Total	106.00	VE4	–
Weekday	113.00	VE4	–
Saturday	115.00	VE4	–
Sunday	103.00	VE4	–

Mine comparison

For extensional purposes, the specific mine was compared with a different platinum mine. This comparison is shown in Figure 58.

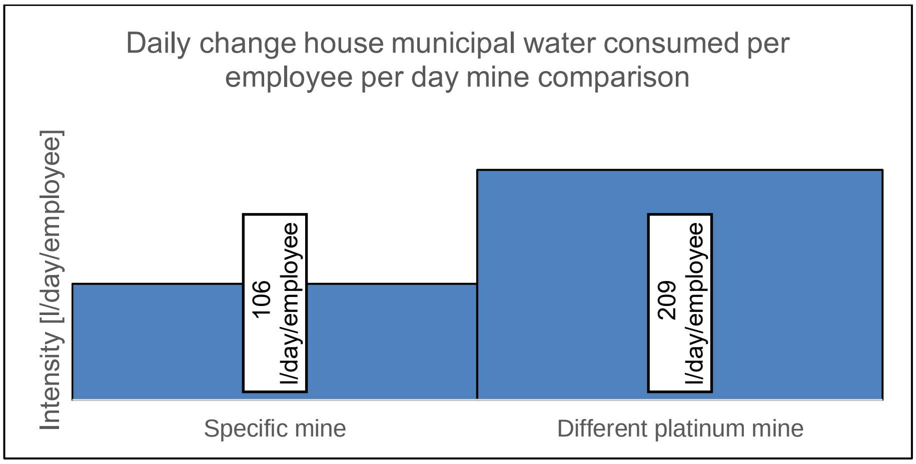


Figure 58: Potable water consumed per employee – comparison with another mine

When the specific mine was compared with another mine, it was concluded that the specific mine was considerably more efficient than the different comparison mine as seen in Figure 58. An investigation should be done on the different mine to reduce the potable water with at least 70 l/day/employee. They would then be close to the expected average consumption per person.

3.5.3 Benchmark validation for potable water to change house

The change house consumption is mainly due to showering. But once again, this is the human factor. Leaks should be spotted easily and repaired as soon as possible. A leak was found at the change house geyser on Shaft VW1. After this leak was found, the employees said they were aware of it and had been there for months. The geyser's vacuum seal broke, resulting in the water flowing out of the geyser permanently. A photo of the leak can be seen in Figure 59. Figure 60 shows the average daily consumption per month.

Figure 59: Photo of leak found at the geyser

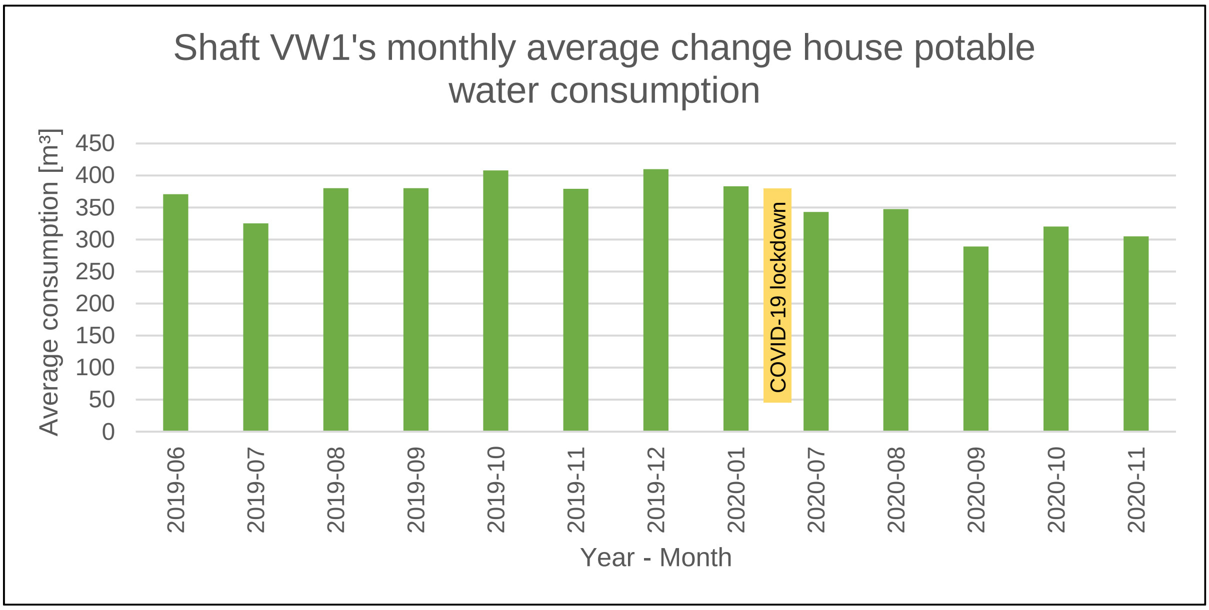


Figure 60: Shaft VW1's daily average per month

The leak was found during the last days of August 2020. From September 2020, a potable water reduction of 50 m^3 can be seen. Repairing the vacuum seal resulted in an estimated annual cost saving of R263 000. The decrease in intensities is shown in Figure 61.

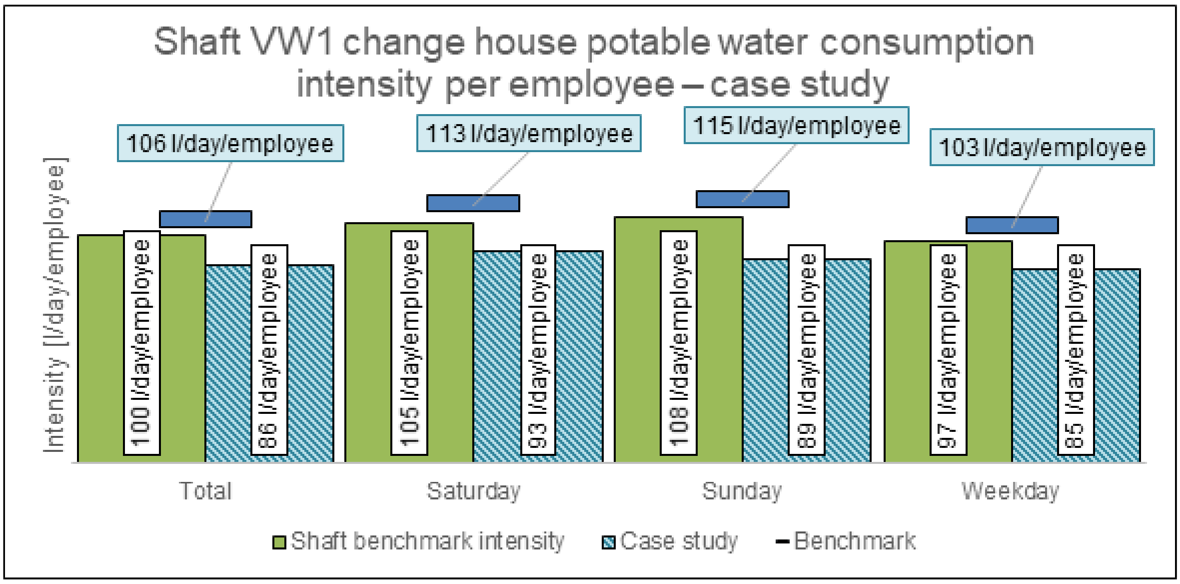


Figure 61: Potable water consumption to change house – case study

Figure 61 shows a complete reduction in the consumption per person per day at Shaft VW1. A total intensity reduction of 14 l/day/employee was achieved. The most significant reduction in water per person was noticed during the Sunday period. This reduction total equals 19 l/day/employee. As this was a water leak, this can be seen as a water reduction project. Not only was there a water reduction, but the power consumption of the geyser was also affected.

Although Shaft VW1 was not the most inefficient shaft, it did illustrate that the benchmark intensity would be lowered if leaks were repaired. This decrease in consumption could also be challenging as water consumption is human orientated.

CATEGORY B: POTABLE WATER TO UNDERGROUND

Potable water going underground is the water that employees drink when underground. Pipes go along the primary haulage way, with pipes connected to the main pipe with a valve to open for drinking purposes.

3.5.4 Benchmark verification for potable water consumed underground

The potable water consumed underground was compared with four other items as listed in Table 15. The first item was surface fan power, which was considered to evaluate whether the number of leaks influenced the underground temperatures. Production was the second comparison. Production was considered a good comparison as it also showed how many employees were underground. The third comparison, active haulage length, gave a suitable identification of the number of leaks. Lastly, the number of underground employees was compared with the potable water consumed underground. The correlation factor and the standard deviation of the correlation factor are given in Table 15.

Table 15: Potable water consumed underground – benchmarks considered

Potable water consumed underground [m³/h]				
Compared with	Unit of comparison	Correlation factor	Standard deviation of correlation factor	Comment
Surface fan power	[kW]	0.979	0.154	When one increased, the other did not, but the high correlation factor was interesting.
Production	[ton]	0.788	0.068	When one increased, the other did not. It was interesting to note the high correlation factor and that it was constant as well.
Active haulage length	[m]	0.823	0.19	The correlation factor did not stay constant.
Underground employees	[–]	0.713	0.111	The underground employees were the only consumers of this water when they drank it. This comparison was thus the best.

Legend:	Lowest number	Average number	Highest number

It can be seen in Table 15 that surface fan power had the highest correlation factor. This correlation factor was not a good comparison because it was not very consistent. The second-highest correlation factor was the active haulage length comparison. However, the consistency deteriorated compared with the surface fan power, making it a worse comparison. Production had the third-highest correlation factor and was also the most consistent, making it a good comparison to use. However, the best comparison was the reason why water is sent underground. The water is supplied to underground employees for drinking purposes. Although it had the worst correlation factor and was the second-most consistent, it was the best comparison.

3.5.5 Calculated benchmarks for potable water consumed underground

The water benchmarking was created easily for identifying leaks. Figure 49 shows the potable water consumed underground for drinking purposes. This benchmark was done by multiplying the number of employees by three litres per day. It is an easy calculation if the data is available. However, the approach shown in Figure 49 can be used if the data is not available in a daily resolution.

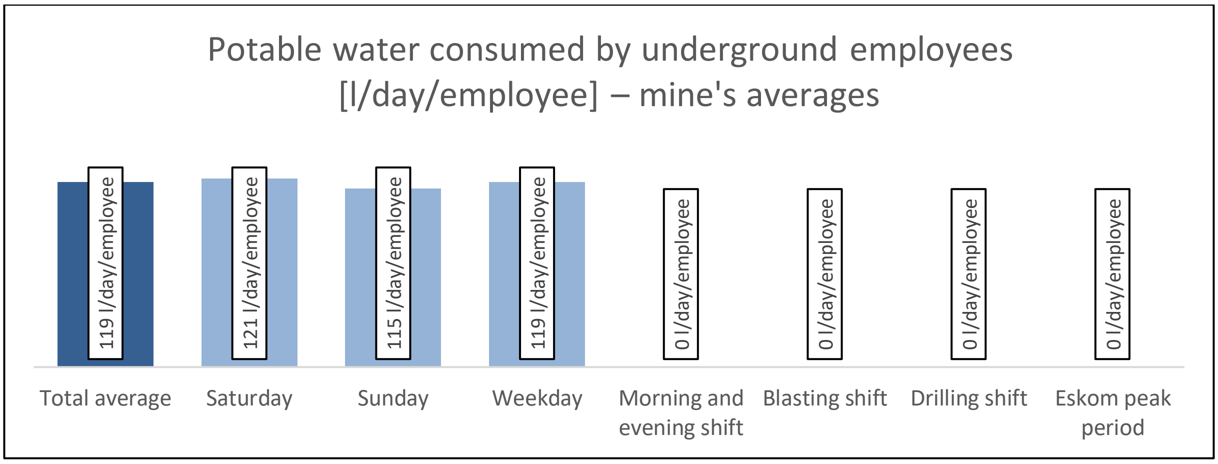


Figure 62: Potable water consumed underground – benchmarks

The first thing to consider while evaluating Figure 62 is that a person should drink two to three litres of water per day. The total average is significantly more than two to three litres per day. Therefore, there are many leaks or the water is consumed for other purposes as well. The total average benchmark was used to determine which shaft was the most inefficient.

After the most inefficient shaft was identified, the consumption was broken down into periods to determine when the consumption should have decreased. Figure 62 shows that Saturday's benchmark was the highest. The weekday's benchmark intensity was the second-highest intensity. After the weekday benchmark was the Sunday benchmark, consuming the least amount of water on average.

Identification of inefficient shafts

Once again, the inefficiencies could only be due to employees not using the water efficiently or due to leaks.

Total consumption comparison

This section was used to determine when and where the inefficiencies were. Figure 63 shows that Shaft VW1 was the most inefficient, followed by Shaft VK3 as the second-most inefficient, and lastly Shaft DE3. Shaft DE3 is the attractive intensity in this figure as it was more inefficient than vertical Shaft VE4.

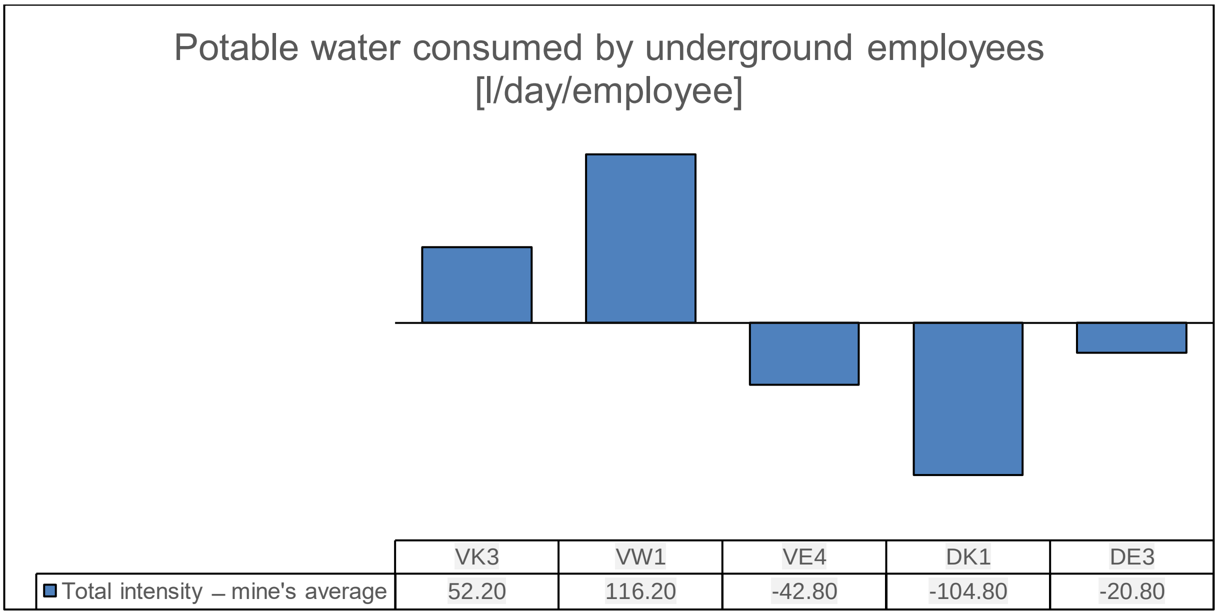


Figure 63: Potable water consumed underground – shafts' total underground intensities

Daily comparison

A breakdown of the total intensity graph is given as Figure 64 to establish when the inefficiencies occurred.

Figure 63 shows that VW1 was the most inefficient shaft. Figure 64 shows that Shaft VW1 was the most inefficient during all the periods. Saturday's intensity was the highest, which contributes to the high Saturday benchmark seen in Figure 62. Shaft VK3 was the second-most inefficient in Figure 63. All the periods remained the second-most inefficient in Figure 64. They had the highest intensity above the benchmark on Sunday, meaning they should reduce their Sunday consumption.

Shaft DE3 was the first shaft with all periods below the benchmarks. Its Saturday intensity was also the highest, also contributing to Figure 62. Shaft VE4 had a low weekday intensity, which was different from the other shafts. It should focus on decreasing its weekend consumption. Shaft DK1, the most efficient shaft, remained the most efficient during all the periods.

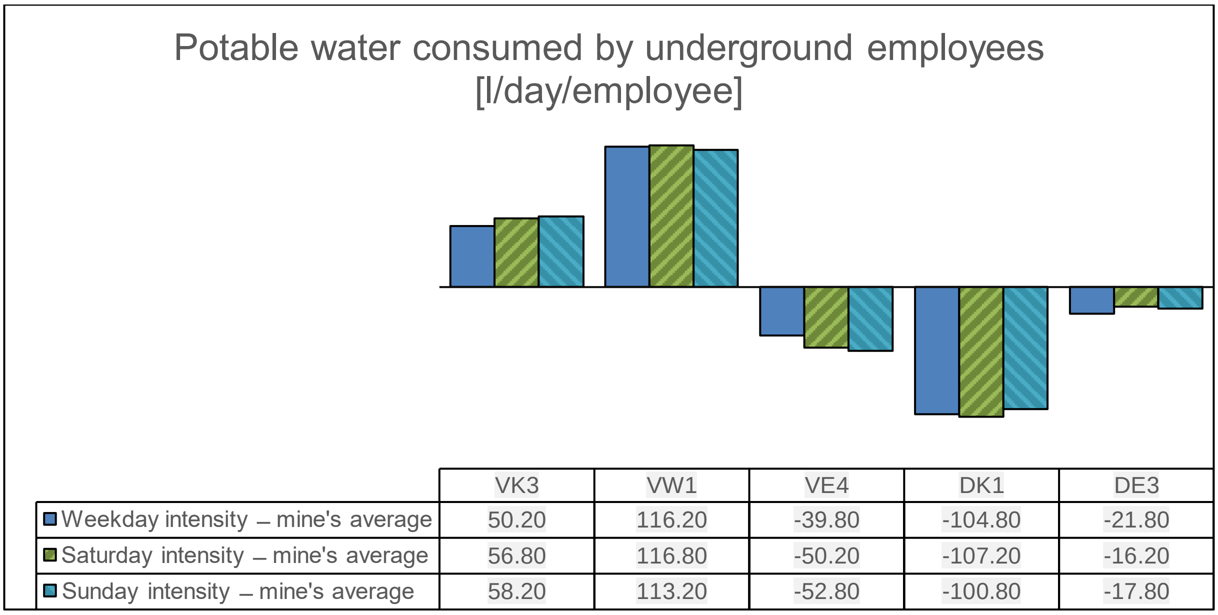


Figure 64: Potable water consumed underground – weekday, Saturday, and Sunday shaft intensities

Potable water for underground consumption inefficiency summary

As discussed above, Shaft VW1 had the highest intensity throughout all periods. The intensities remained constant, resulting in minimal irregularities found. This is summarised in Table 16.

Table 16: Potable water for underground consumption inefficiency summary

Period	Benchmark [l/day/employee]	Most inefficient shaft	Irregular inefficiencies
Total	119.00	VW1	
Weekday	121.00	VW1	
Saturday	115.00	VW1	
Sunday	119.00	VW1	

Mine comparison

For additional purposes, the specific mine was compared with a different mine. Suppose the specific mine did not perform effectively, then the different mine could be evaluated to determine whether it had a lower intensity.

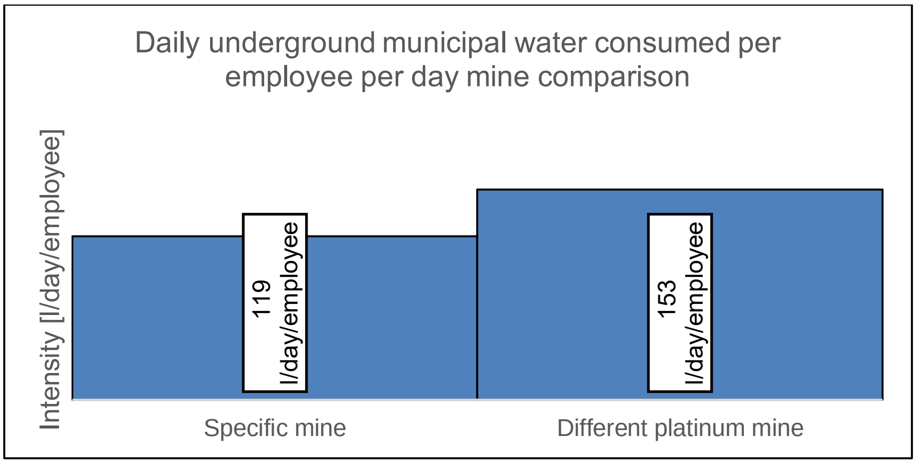


Figure 65: Potable water consumed underground per employee – comparison with another mine

As seen in Figure 65, the other mine's potable water should once again be reduced. This consumption was far above the specific mine and even higher than the average water each person should drink each day. This higher consumption resulted from leaks at the other mine. However, at the specific mine, there was still scope for improvement.

3.5.6 Benchmark validation for potable water consumed underground

The underground pipe network of the case study mine is extensively long [1]. The longer the pipe network, the more possibilities there are for leaks to appear. Furthermore, these pipes are not entirely fixed to the ground or wall, allowing movement to occur and increasing damage to the pipes, which results in leaks. Fixing these leaks would reduce consumption. Figure 66 shows the monthly breakdown of the average daily potable water consumed underground at Shaft VW1.

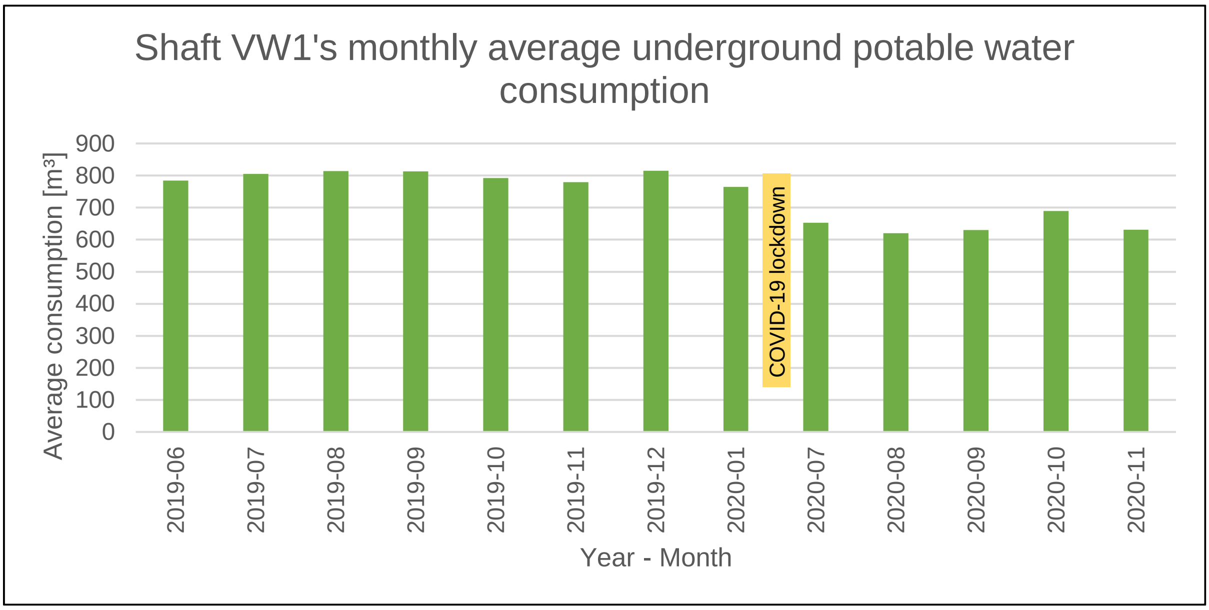


Figure 66: Shaft VW1's average underground potable water consumption monthly breakdown

Figure 66 shows a considerable reduction in potable water from July 2020. A large number of leaks was repaired during the Covid-19 lockdown. The average consumption reduced to close to 100 m³/day.

Figure 63 showed that Shaft VW1 was the most inefficient shaft as the total intensity was 116 l/day/person above the shaft's benchmark intensity. Figure 64 shows that all the periods' intensities exceeded the benchmark due to leaks. Some leaks were repaired underground, resulting in the case study seen in Figure 67.

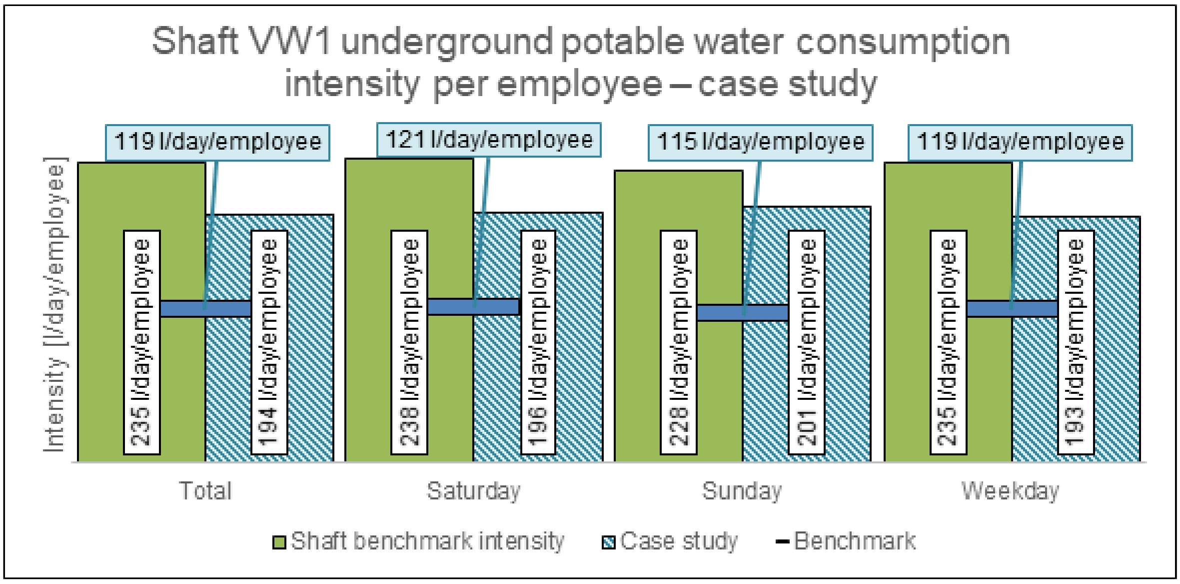


Figure 67: Potable water consumption to underground – case study

It is seen that all the periods' intensities were lowered, which was again due to repaired leaks. Although the intensity was still above the benchmark, a significant decrease was shown. The reduction did take a few months to show after repairing the leaks. This was a water reduction project, and the annual saving was estimated to be R500 000.

3.6 Service water consumption

The service water consumption was divided into two categories, namely:

- Category A: The actual consumption going underground.
- Category B: The average amount of water pumped to the surface.

The costs were calculated from the water pumped to the surface. If the consumption reduced, less water had to be pumped to the surface. The amount of water pumped to the surface was more than the water consumed at some shafts due to fissure water.

CATEGORY A: UNDERGROUND CONSUMPTION

3.6.1 Benchmark verification for underground consumption

The service water consumed underground was compared with five commodities. The first commodity was production, which was used as service water is connected to the drills, cooling the drill bits during drilling. For the second comparison, the active haulage length was used, which showed which shafts had more leaks. The third comparison was between the underground service water and the underground power consumed. This comparison was viable because the water had to be pumped underground – either back to the station or the surface. The underground employees also played a significant role in the service water consumption as they were responsible for opening and closing valves. Therefore, the underground employees were the fourth comparison. The last comparison was compressed air consumption. The service water and compressed air were used for the same reason during the drilling shift. There was a correspondence between the two commodities.

Table 17: Service water consumed underground – benchmarks considered

Service water consumed underground [m³/h]				
Compared with	Unit of comparison	Correlation factor	Standard deviation of correlation factor	Comment
Production	[ton]	0.698	0.092	Service water was mainly consumed on the drills, which made this a good comparison.
Active haulage length	[m]	0.575	0.049	Low correlation factor. However, this could be a good indication of the number of leaks on the different shafts.
Underground power	[kW]	0	0.001	Poor correlation. This correlation would have been interesting as the service water was pumped back to the station underground.
Underground employees	[–]	0.851	0.042	As with compressed air consumption, not all employees used the service water. (Low standard deviation was caused by a fixed number of employees used.)

Service water consumed underground [m³/h]				
Compared with	Unit of comparison	Correlation factor	Standard deviation of correlation factor	Comment
Compressed air consumption	[m³/h]	0.533	0.094	Since both were used for the same reason, the correlation factor should have been higher. The number of leaks might cause the difference. The correlation factor was too low and inconsistent to use.
Legend:	Lowest number	Average number	Highest number	

The correlation factors seen in Table 17 were ranked from high to low as follows:

1) Underground employees.
2) Production.
3) Active haulage length.
4) Compressed air consumption.
5) Underground power.

Underground employees had a low standard deviation and delivered the second-lowest standard deviation. This low standard deviation was caused as a fixed number of employees was used for all the months. Another comparison might be better as the standard deviation was not representative.

It can be seen that the production comparison, with the second-highest correlation factor, had a higher standard deviation of the comparisons. Although this was less consistent, it was still low. The correlation factor ranged between 0.606 and 0.79. The production comparison was better than the underground employees comparison. The production comparison was more representative as the water was used primarily for production reasons. Also, increasing the production with a large amount would have an impact on water consumption.

The active haulage length comparison had the third-highest correlation factor. The correlation factor ranged between 0.526 and 0.624. The high range still fell in the production comparison range. Although it was still in each other's ranges, fixed values was used once again for the active haulage length. Fixed values do influence the representativity of the data. The production comparison was still the best.

Comparing the service water consumption with the compressed air delivered the fourth-highest correlation factor. The compressed air comparison with production delivered high and consistent correlation factor values. For this reason, it was better to also use the production comparison directly rather than comparing it with water consumption.

No correlation was found between underground power and water consumption. This low correlation automatically disregarded the comparison and that the production comparison was the best comparison of the five comparisons.

3.6.2 Calculated benchmarks underground consumption

As it was found that comparing the service water to production was the most representative, the following benchmarks were delivered:

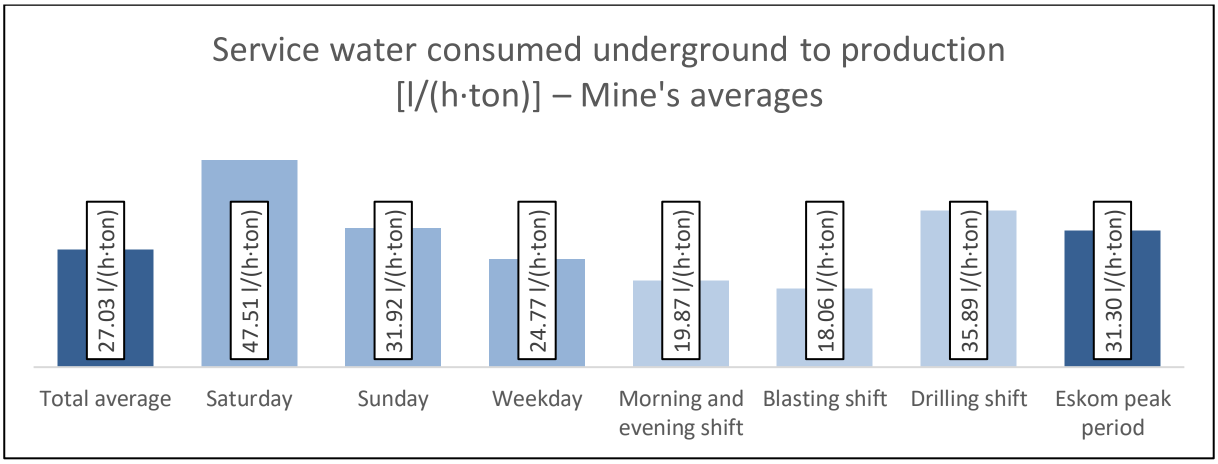


Figure 68: Service water consumed underground – benchmarks

Figure 68 shows that the mine's intensity for the service water comparison to production was 27 l/(h·ton). The Saturday benchmark intensity increased the mine's intensity as it was the highest. This intensity was very inefficient. The Sunday benchmark was also higher than the total benchmark, but lower than the Saturday benchmark. For the weekday benchmark, the drilling shift was the highest. This highest benchmark was understandable as the service water is primarily used during the drilling shift for drilling. The blasting shift was the most efficient.

Identification of inefficient shafts

Inefficiency can occur due to leaks. Leaks can be managed by either repairing or minimising/ managing them.

Total consumption comparison

The total consumption intensity for the service water consumed underground indicated which shaft was the most inefficient. These total intensities are given in Figure 69.

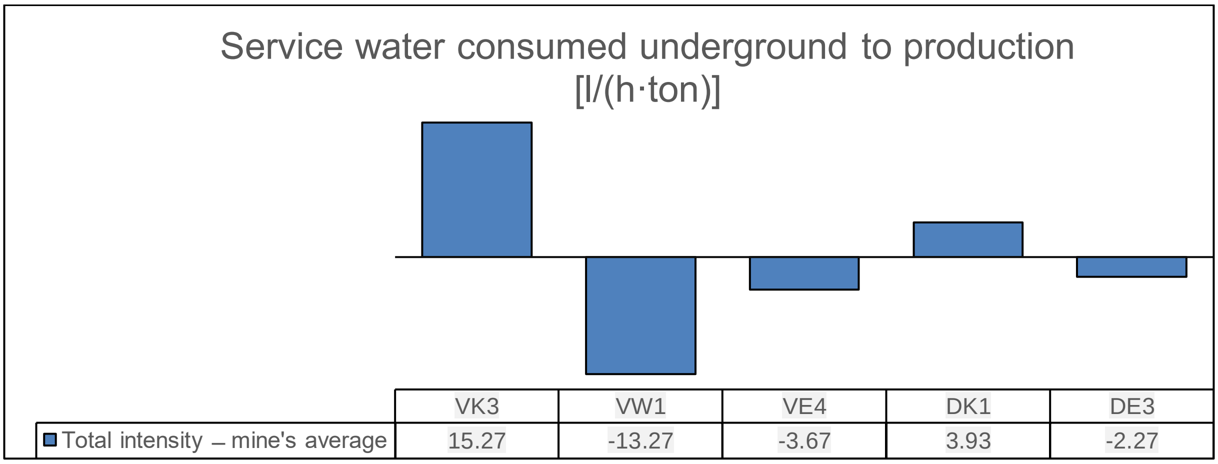
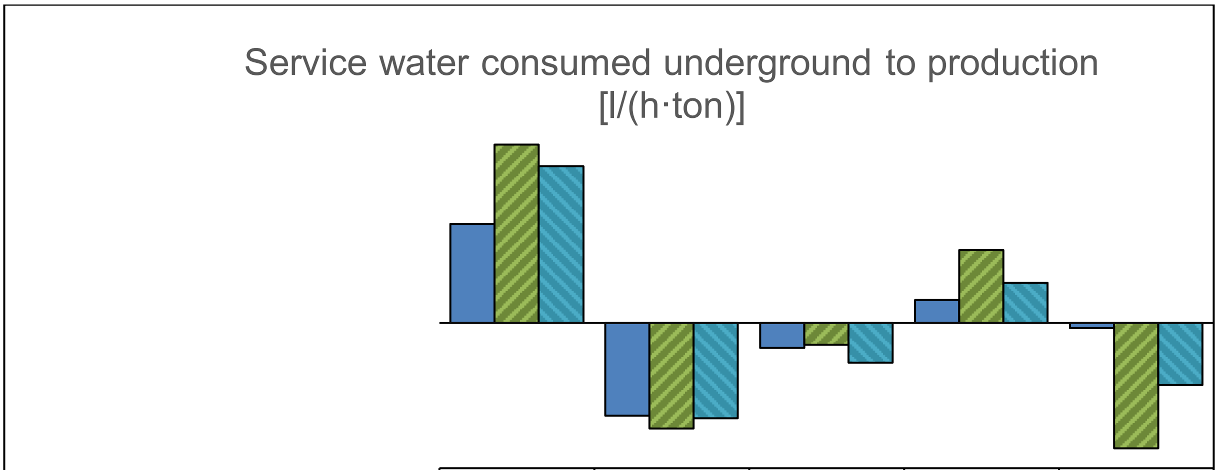


Figure 69: Service water consumed underground – shafts' total intensity

The total consumption intensity graph shows that Shaft VK3 was the most inefficient shaft. It consumed considerably more service water than Shaft DK1, which was the second-most inefficient shaft. Although Shaft DE3 was the third-most inefficient shaft, it was below the benchmark. The most efficient shaft was Shaft VW1, and Shaft VE4 was the second-most efficient.

Daily comparison

Breaking intensities into the period showed which period contributed the most to the inefficiency. This breakdown is shown in Figure 69.



	VK3	VW1	VE4	DK1	DE3
Weekday intensity – mine's average	13.69	-12.74	-3.42	3.15	-0.67
Saturday intensity – mine's average	24.63	-14.51	-2.97	10.08	-17.23
Sunday intensity – mine's average	21.56	-13.15	-5.43	5.57	-8.57

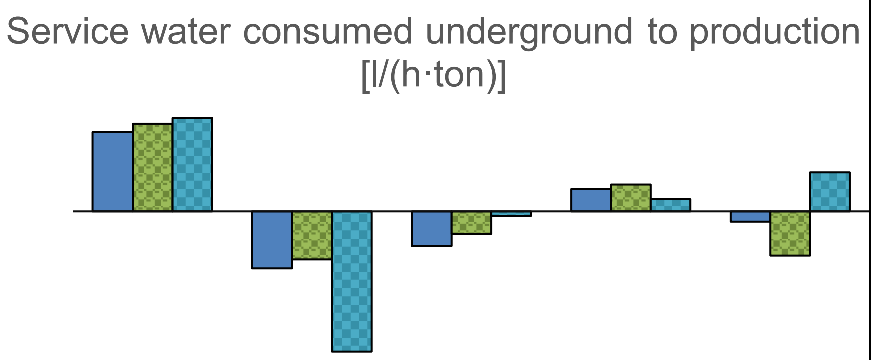
Figure 70: Service water consumed underground – weekday, Saturday, and Sunday shaft intensities

Figure 68 revealed that the weekday benchmark was lower than the Saturday and Sunday benchmarks. This difference in benchmarks meant there was not much potential for energy savings during the weekday. Although in Figure 70, it can be seen that Shaft VW1 and Shaft DE3's weekday intensities were the most inefficient compared with the Saturday and Sunday intensities. Figure 71 expands the weekday intensities seen in Figure 70.

Shift comparison

For a further breakdown of the weekday inefficiency evaluation, Figure 71 was used to establish the cause of the high weekday inefficiency.

As mentioned above, the weekday intensity was not higher than the Saturday and Sunday intensity in Figure 68. It was also noticed in Figure 70 that Shaft VW1 and Shaft DE3's weekday intensities should be evaluated. Evaluating Figure 71 showed that Shaft VW1's blasting intensity was higher than the other two intensities. The cause of this was due to not all the valves closing as they were supposed to. The same was seen at Shaft DK1. Shaft DK1 did not have control of underground valves on the SCADA as there were no actuators on the underground valves. This shortage of control made it more plausible to state that the underground valves were not closed during the blasting shift.



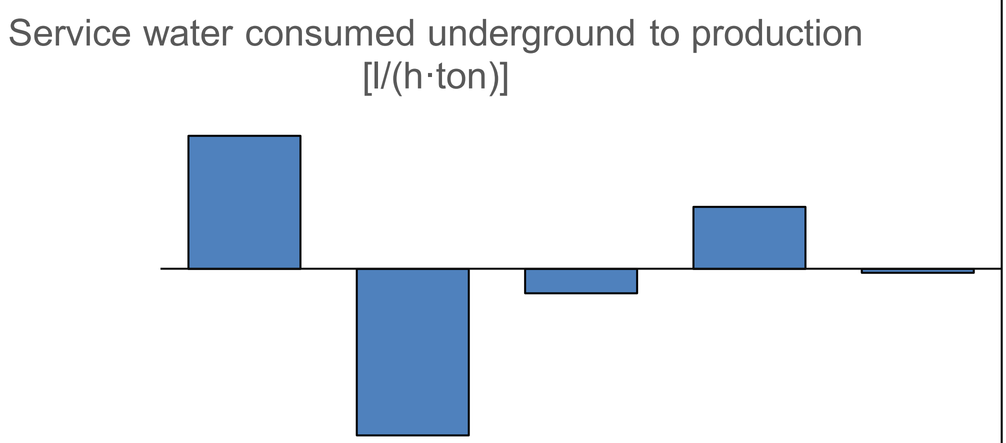
	VK3	VW1	VE4	DK1	DE3
Morning & evening shift intensity – mine's average	12.66	-9.08	-5.47	3.54	-1.64
Blasting shift intensity – mine's average	13.91	-7.68	-3.55	4.32	-6.99
Drilling shift intensity – mine's average	14.92	-22.34	-0.74	1.94	6.21

Figure 71: Service water consumed underground – weekday shifts' shaft intensities

Shaft DE3 showed a high drilling shift intensity. The drilling shift should have had a high intensity as the service water was used for the drills. Nevertheless, these intensities were compared with the other shafts, which meant that Shaft DE3 used more water during the drilling period than the other shafts. A good idea would be to determine the number of drills used underground, which might explain the cause.

Eskom peak period comparison

Figure 72 evaluates how the shafts attempted to reduce costs due to an increase in tariffs.



	VK3	VW1	VE4	DK1	DE3
Eskom peak period intensity – mine's average	14.65	-18.35	-2.71	6.84	-0.41

Figure 72: Service water consumed underground – Eskom peak period shaft intensity

Figure 72 shows that Shaft VK3 was the most inefficient. For a change, Shaft DK1 was the second highest, and the other three shafts were below the benchmark. Shaft VW1 was the furthest below the benchmark once again.

Service water for underground consumption inefficiency summary

A few irregularities were noticed regarding the service water consumed underground. To be more specific, Shaft DE3 showed more irregularities than the other shaft. The inefficiencies are summarised in Table 18.

Table 18: Service water for underground consumption inefficiency summary

Period	Benchmark [l/(h·ton)]	Most inefficient shaft	Irregular inefficiencies
Total	27.03	Vertical: VK3 Decline: DK1	
Weekday	24.77	Vertical: VK3 Decline: DK1	For Shaft DE3, there was a significant difference between the Saturday and Sunday intensities compared with the weekday intensity. This indicates that Shaft DE3 has the potential for a decrease in consumption during weekdays.
Saturday	47.51	Vertical: VK3 Decline: DK1	Shaft VK3, Shaft DK1, and Shaft VE4 showed an increase in intensities from the weekday intensity. This is irregular as the other shafts indicated a decrease.
Sunday	31.92	Vertical: VK3 Decline: DK1	Shaft VK3 and Shaft DK1 showed an increase in intensities from the weekday intensity. This is irregular as the other shafts indicated a decrease.
Morning/ evening shift	19.87	Vertical: VK3 Decline: DK1	Shaft DE3's morning/evening shift intensity was higher than the blasting shift's intensity due to the benchmark scaling (zero line = period benchmark intensity). This is irregular as the other shafts' morning/evening shift intensities were lower than the blasting shift's intensity.
Drilling shift	35.89	Vertical: VK3 Decline: DE3	–
Blasting shift	18.06	Vertical: VK3 Decline: DK1	–
Eskom peak period	31.30	Vertical: VK3 Decline: DK1	–

Mine comparison

For a further evaluation of the specific mine, benchmarks were compared with a different mine as well. If the different mine showed a lower benchmark, the different mine would be investigated to propose a scope for improvement on the specific mine.

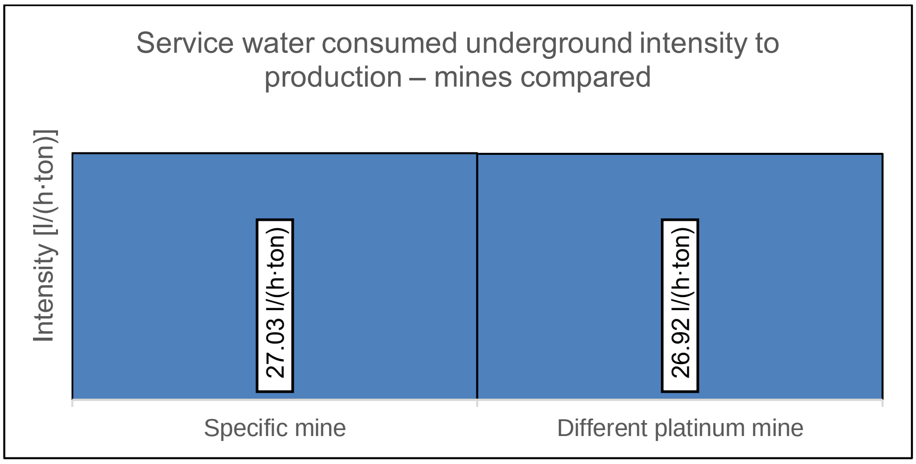


Figure 73: Service water consumed underground – mine's intensity comparison

Figure 73 shows that the other mine consumed slightly less service water underground, but the difference was irrespective. It can be stated with confidence that the service water consumption benchmark intensity was 27 l/(h·ton).

3.6.3 Benchmark validation underground consumption

Figure 71 showed the drilling shift was above the benchmark. However, it is difficult to change the drilling shift as this could influence production. The second-most inefficient shift was the morning and evening shift, which was still noticeably higher than the blasting shift. An investigation revealed that some other shafts closed the service water early morning. This closure of valves was suggested to Shaft DE3. Subsequently, the shaft changed the automated service water valve schedule to close between 02:00 and 04:00. Figure 74 shows the reduction in flow during this period.

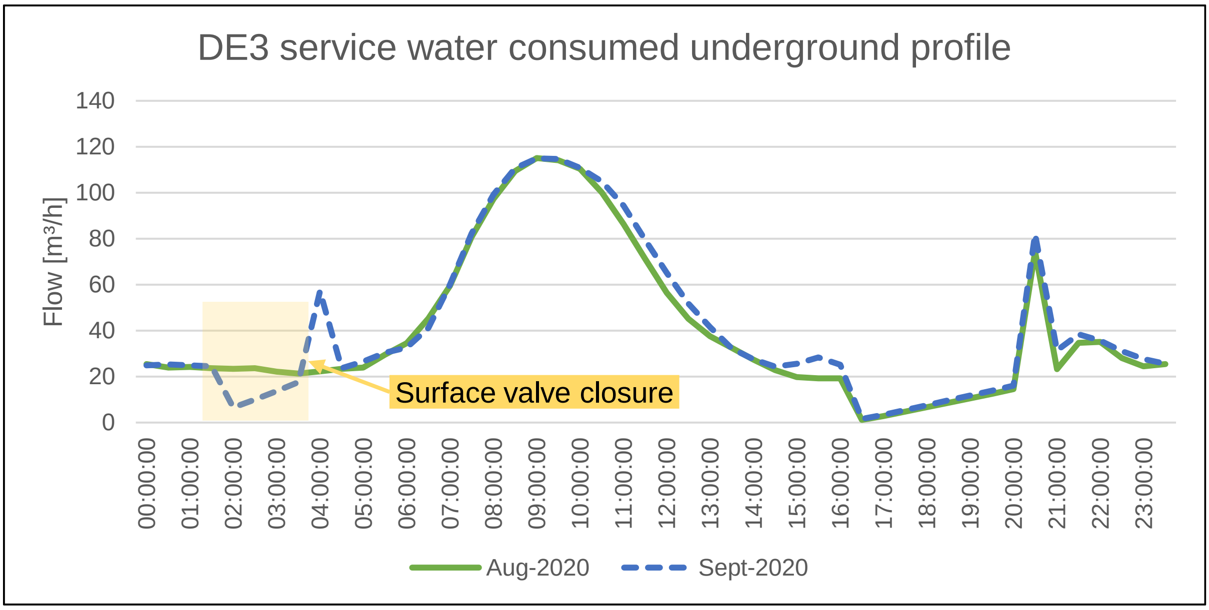


Figure 74: Shaft DE3's service water consumed underground profile – case study

Figure 74 shows that the service water reduced between 02:00 and 04:00. But at 04:00, the consumption spiked. This was the result of the pipes filling again after closing the surface valve. Figure 75 was created to evaluate whether there was a reduction in flow. The figure shows the total consumption between 00:00 and 06:00.

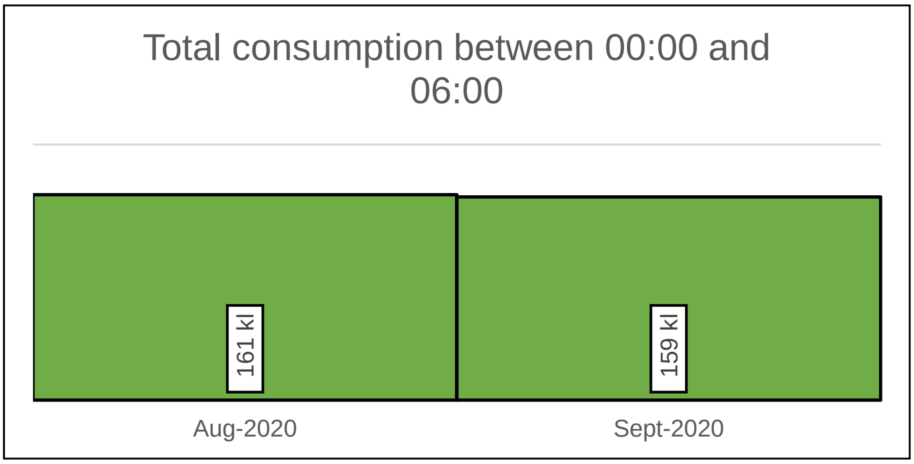


Figure 75: Shaft DE3's service water consumption total between 00:00 and 06:00 – case study

Figure 75 shows a 2 kl reduction in service water between 00:00 and 06:00 for September 2020. This reduction would lower the intensities, which can be seen in Figure 76.

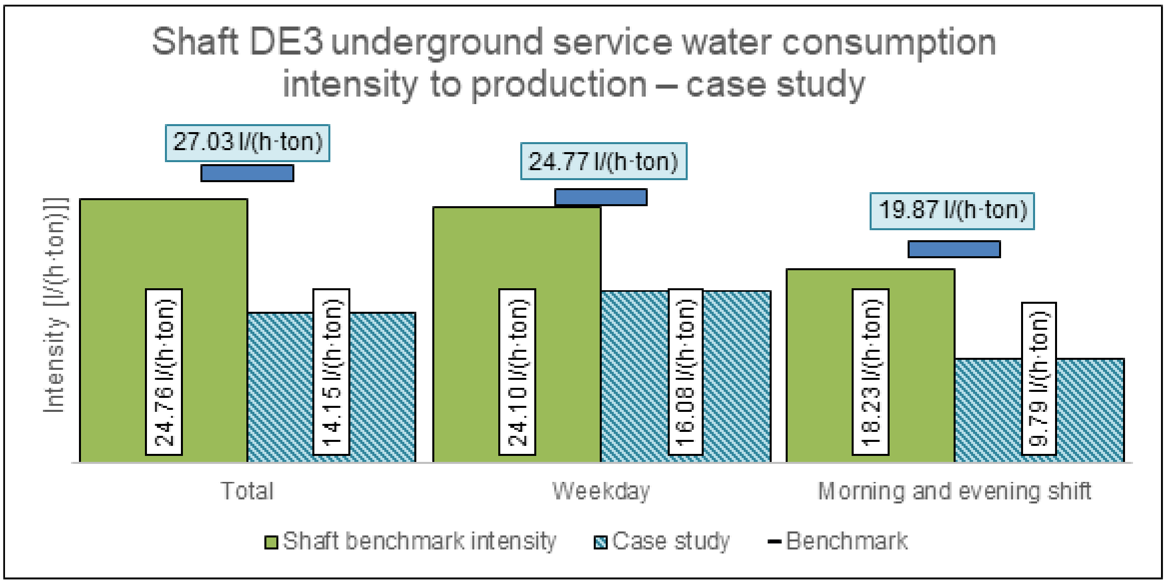


Figure 76: Service water underground consumption – case study

Figure 76 shows that there was a decrease in consumption in all three included periods. Almost half the consumption was reduced during the morning and evening shifts. This is slightly contradictory to Figure 75. The cause of this contradiction is an increase in production as well. However, the production and service water correlates: meaning if production increases, service water should also increase. During the early morning hours, the surface valve closure resulted in an estimated cost saving of R10 845 p.a., which was only for two hours during the weekday. This was once again a reduction project that was implemented as the pumping energy would be reduced.

CATEGORY B: PUMPED TO SURFACE

Water reticulation includes pumping water back to the surface. Cost/energy savings can be implemented individually on the pumping. The pumping would further show a more evident reduction in energy as this is a section on its own and not on various levels.

3.6.4 Benchmark verification for water pumped to surface

As explained in Chapter 1, the service water consumed is reused. The water consumed flows down to the lowest level in most cases, from where it is pumped to the surface. From there, it is again consumed underground. This reticulation is done to save water.

The service water pumped to the surface was compared with five commodities as seen in Table 19. The underground employees and compressed air consumption were replaced with the mine depth and service water consumption.

Table 19: Service water pumped to surface power – benchmarks considered

Service water pumped to surface power consumption [W]				
Compared with	Unit of comparison	Correlation factor	Standard deviation of correlation factor	Comment
Production	[ton]	0.868	0.061	Service water was mainly consumed on the drills, which made this a good comparison.
Active haulage length	[m]	0.73	0.037	A high constant correlation factor was obtained. Not all the water pumped to the surface was consumed by the levels. Some of the water was fissure water.
Mine depth	[m]	0.386	0.049	Constant value as the mine depth remained unchanged. This resulted in a constant standard deviation. However, the correlation factor was low.
Underground power	[kW]	0.025	0.015	This comparison evaluated whether the service water pumps might be the most significant contributor to underground power consumption. The correlation factor was too low for this.
Service water consumption	[m³/h]	0.876	0.048	High constant correlation factor. The service water consumed should be pumped to the surface. The inconsistency was caused by fissure water.

Legend:	Lowest number	Average number	Highest number

The correlation factors in Table 19 were ranked as follows:

1) Service water consumption (range: 0.828 to 0.924).
2) Production (range: 0.807 to 0.929).

3) Active haulage length (range: 0.693 to 0.767).
4) Mine depth (range 0.337 to 0.435).
5) Underground power consumption (range: 0.01 to 0.04).

The best comparison from Table 19 was with production. The other comparisons did not show a clear indication of how much water should be pumped according to the outcomes, which was production. The active haulage length comparison was also not viable as there was no existing pipe network with the pump flows that were compared.

3.6.5 Calculated benchmarks for water pumped to surface

As discussed above in the verification section, the comparison with production was the best. Figure 77 shows that a total average benchmark intensity of 51 W/ton of water was pumped to the surface. The Saturday and Sunday benchmarks were a significant cause of the high total intensity as both intensities were higher than the weekday benchmark intensities. These high intensities mean more focus could be placed on reducing the Saturday intensities.

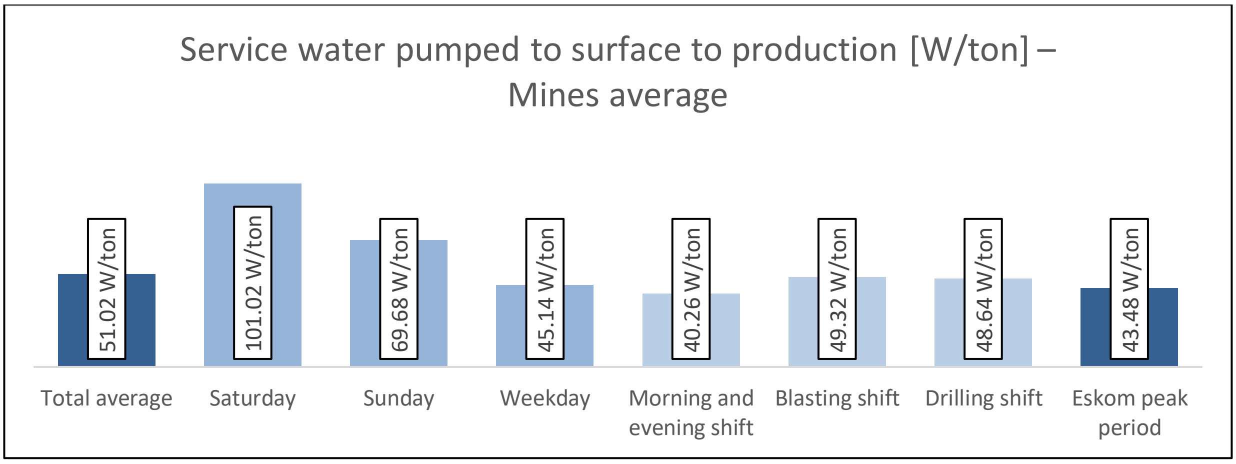


Figure 77: Service water pumped to surface – benchmarks

Furthermore, the blasting shift's benchmark intensity was higher than the sweeping/cleaning shift's intensity. This higher intensity was a contributor to the water that was still being consumed during the drilling shift. If the dams can handle it, there might be potential to pump the service water during the evening shift. This change in pumping time will lower the Eskom peak period's benchmark intensity.

The following graphs show which shafts were the highest contributors to the Saturday, Sunday and blasting shifts' benchmark intensities.

Identification of inefficient shafts

Inefficiencies can occur due to the service water, which is consumed underground, being wasted. The wastage occurs when there are leaks on levels. A big leak on a level flows down to the shaft bottom where it has to be pumped back up again, which means energy is consumed/wasted.

This section includes a physical motor that has to be running, but load shifting can also be proposed if dam capacities can handle load shifting outside the Eskom peak period. Before possible inefficiencies can be resolved, they should first be recognised, which is done below.

Total consumption comparison

The first identification of inefficiencies included looking at the complete picture to identify which shaft was the most inefficient.

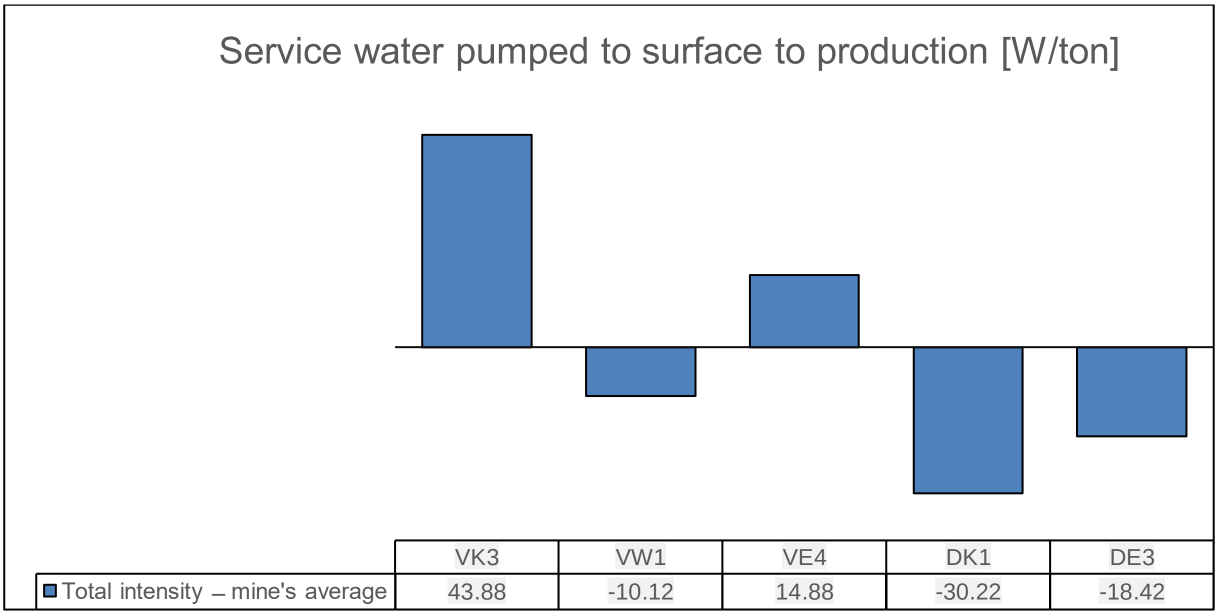


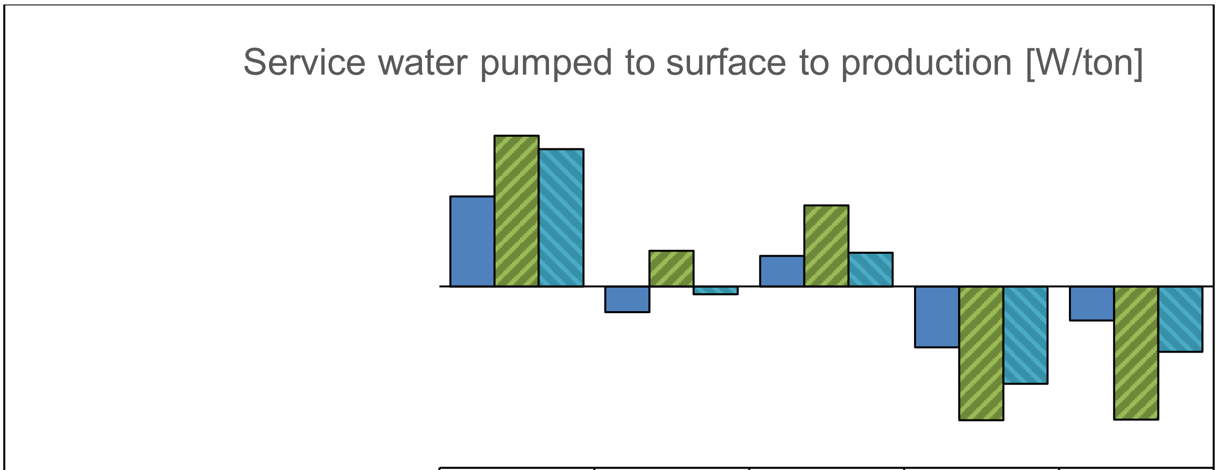
Figure 78: Service water pumped to surface – shafts' total intensity

Figure 78 shows that Shaft VK3 and Shaft VE4 increased the total benchmark intensity seen in Figure 77. The other shafts were below the benchmark intensity, with Shaft DK1 being the most efficient. Interestingly, Shaft DK1 had the most efficient intensity as it was the second-most inefficient in Figure 69. This efficient intensity resulted from water that did not have to be pumped as far to the surface. There might also have been less fissure water at Shaft DK1.

Daily comparison

Figure 79 shows the potential to decrease Shaft VK3 and Shaft VE4's total intensities by separating the weekday, Saturday, and Sunday intensities. As mentioned above, Shaft VK3 and Shaft VE4 were the most inefficient shafts. Figure 79 shows that these shafts' highest intensities were on Saturdays. The Sunday intensities were the second highest and the weekday intensities were the lowest.

This high weekend intensity resulted from the service water consumption not decreasing after the Saturday drilling shift. This high consumption was seen in the service water consumption graph, shown in Figure 55. The actuators are pneumatic actuators that did not always control as supposed to on both shafts. Electric actuators are better, as their operations are more effective.



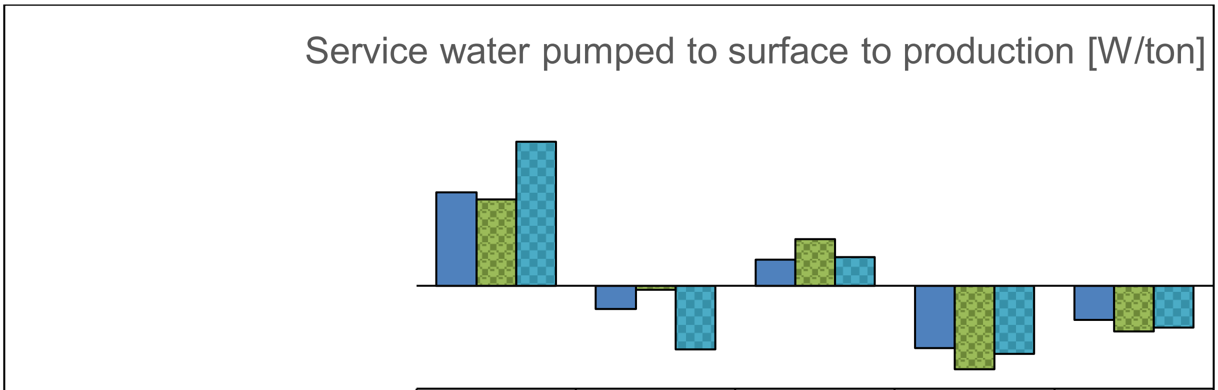
	VK3	VW1	VE4	DK1	DE3
Weekday intensity – mine's average	39.76	-11.44	13.46	-26.84	-14.94
Saturday intensity – mine's average	66.38	15.78	35.68	-59.12	-58.72
Sunday intensity – mine's average	60.42	-3.58	14.82	-42.88	-28.78

Figure 79: Service water pumped to surface – weekday, Saturday and Sunday intensity

Shaft VW1's highest intensity was also on Saturdays, but the Sunday intensity was below average. Furthermore, both Shaft DK1 and Shaft DE3 showed a significant reduction on Saturdays and Sundays.

Shift comparison

For a further breakdown of the weekday inefficiency evaluation, Figure 80 was used to establish the cause of the high weekday inefficiency.



	VK3	VW1	VE4	DK1	DE3
Morning & evening shift intensity – mine's average	36.24	-8.96	10.24	-24.26	-13.26
Blasting shift intensity – mine's average	33.48	-1.52	18.18	-32.42	-17.72
Drilling shift intensity – mine's average	56.06	-24.64	11.16	-26.44	-16.14

Figure 80: Service water pumped to surface – weekday shifts' intensities for pumping power

In the discussion of Figure 68, it was stated that the blasting shift's intensities were high benchmark intensities. Figure 71 shows that Shaft VW1 and Shaft VE4 had higher blasting shift intensities than the other two intensities. These two shafts were contributors to the high blasting shift's benchmark intensity seen in Figure 80. This high intensity was compared with the other two intensities, namely the drilling shift and the morning and evening shift's intensities. Their lowest intensity was the morning and evening shifts. This lower intensity meant there was scope to reduce the intensity of the blasting shift and increase the sweeping/cleaning shift.

Figure 80 further shows that although Shaft VK3 had a high blasting shift intensity, it was not the highest above the benchmark. The drilling shift had the highest intensity. Since the highest consumption was typical during the drilling shift, Figure 14 indicates that the service water flowed quickly to the shaft bottom.

The blasting shift's intensities were the lowest below the benchmarks for Shaft DK1 and Shaft DE3 as seen in Figure 80. For both shafts, the morning and evening shift intensities were the closest to the benchmark. This intensity indicated that these two shafts attempted to load shift the pumps that are pumping the water to the surface.

Eskom peak period comparison

Figure 81 evaluates how the shafts attempted to reduce costs due to an increase in tariffs.

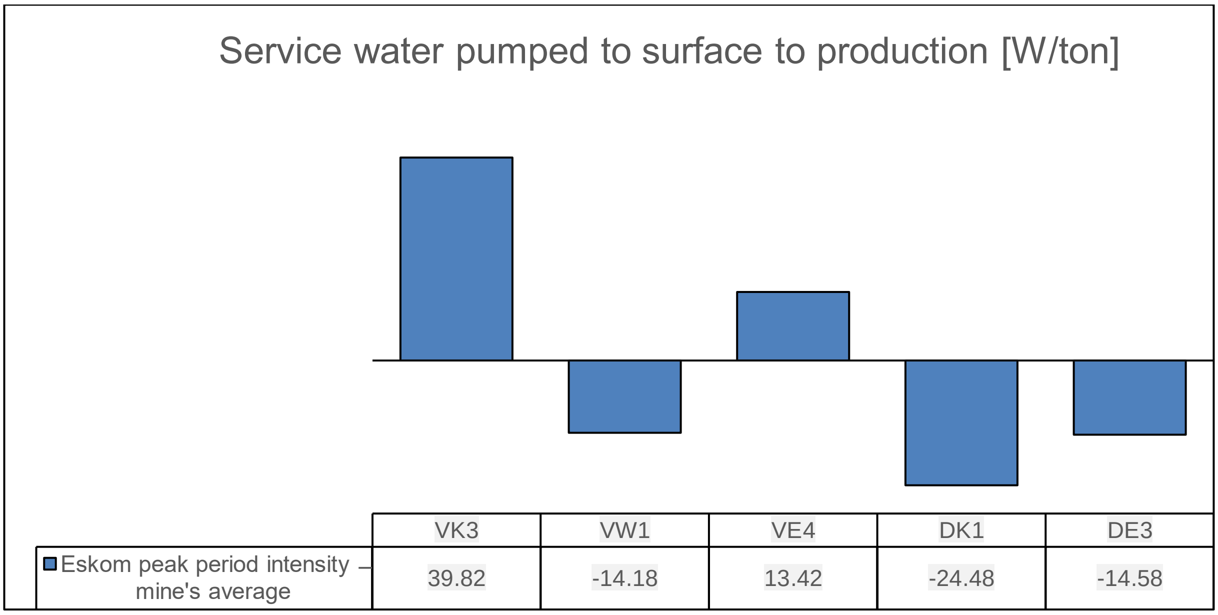


Figure 81: Service water pumped to surface – Eskom peak period intensity

As seen in Figure 80, Shaft VK3 and Shaft VE4 had the highest intensities during the blasting shift. As the Eskom peak period fell inside the blasting shift, the same could be seen in Figure 81. The inefficiency ranking started with Shaft VK3, followed by Shaft VE4. The third shaft on the inefficiently ranking was Shaft VW1, and the most efficient shafts were once again Shaft DE3 and Shaft DK1. DK1 load-shifted the most optimally.

Service water pumped to surface inefficiency summary

This summary should be compared with the service water consumed underground in the previous section. It was noticed that Shaft VE4 showed a significant change in intensities when the equivalent graphs, with the same period, were compared for the service water pumped to surface and service water consumed underground.

Table 20: Service water pumped to surface inefficiency summary

Period	Benchmark [W/ton]	Most inefficient shaft	Irregular inefficiencies
Total	51.02	Vertical: VK3 Decline: DK1	–
Weekday	45.14	Vertical: VK3 Decline: DE3	–
Saturday	101.02	Vertical: VK3 Decline: DE3	–
Sunday	31.92	Vertical: VK3 Decline: DE3	–

Period	Benchmark [W/ton]	Most inefficient shaft	Irregular inefficiencies
Morning/evening shift	19.87	Vertical: VK3 Decline: DE3	–
Drilling shift	35.89	Vertical: VK3 Decline: DE3	VK3 shaft was the only vertical shaft with a drilling shift intensity.
Blasting shift	18.06	Vertical: VK3 Decline: DE3	Shaft VE3 and Shaft VW1 showed an increase in blasting shift intensity where the other shafts showed a decrease.
Eskom peak period	31.30	Vertical: VK3 Decline: DE3	–

Mine comparison

For further inefficiency identification, the specific mine was compared with a different mine as well. This comparison was done to show whether there was still much scope for improvement. If the different mine was significantly more efficient, the different mine's operation would be evaluated in deeper detail to identify any further opportunities for improvement.

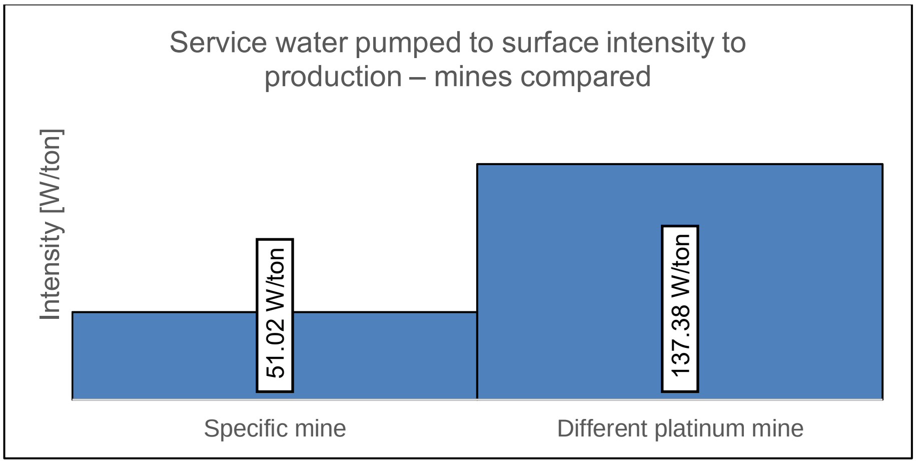


Figure 82: Service water pumped to surface – comparison with mine's intensity

Figure 82 compares the intensity of the specific mine's power of the service water pumped to surface with the intensity of another mine. This big difference in consumption could result from the potable water intensity being more prominent than the chosen specific mine's intensity. Further investigation would show a clear indication. This consumption affects the service water being pumped to the surface as the potable water leakage will also flow with the service water to the bottom of the shaft. The other mine might also have a more significant amount of fissure water, which cannot be reduced. The different platinum mine might have to consider another pipe configuration, where the water could be pumped to an upper level instead of to the surface.

3.6.6 Benchmark validation for water pumped to surface

Shaft VE4's service water consumption underground was below the benchmark as shown in Figure 69. The Sunday intensity was also the furthest below the benchmark for Shaft VE4. Comparing this to Figure 70, the Sunday intensity was more inefficient than the weekday intensity. Figure 69 and Figure 78 had to be compared as the service water consumed underground was the same water that had to be pumped to the surface.

The underground consumption also had to be evaluated to reduce the water pumped to the surface for this case study. The case study entailed replacing the pneumatic actuators with electric actuators. A pneumatic actuator requires a minimum pressure of 450 kPa and a minimum amount of water in the compressed air. It was noted that the pneumatic actuators did not always close completely, resulting in the levels still consuming water. Figure 83 shows the Saturday and Sunday profiles for the water consumed underground.

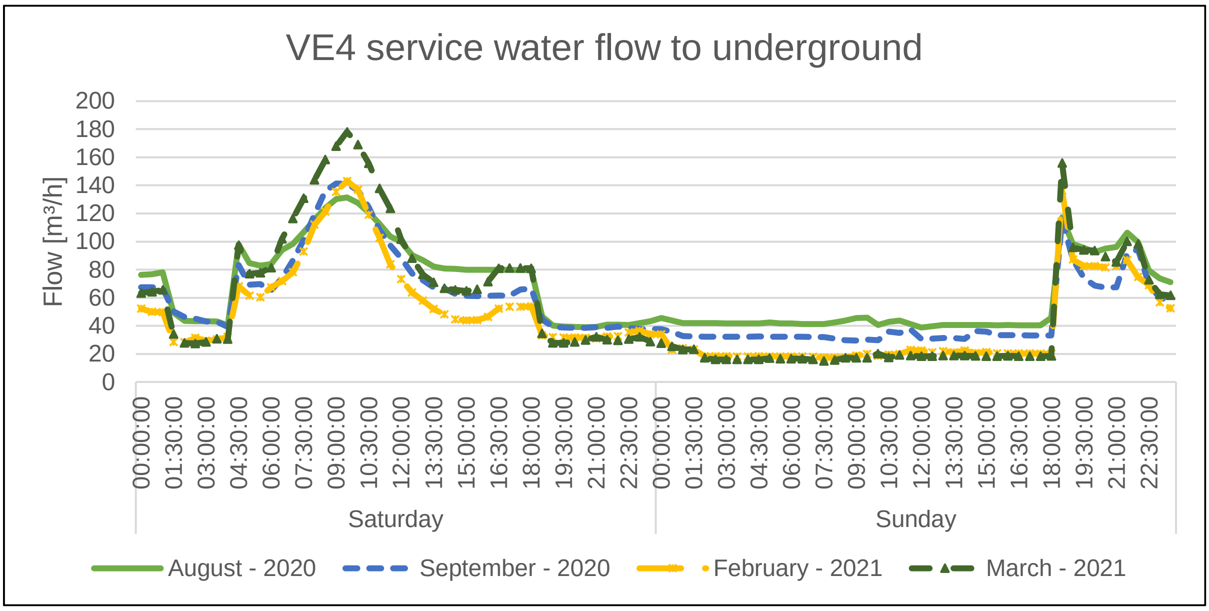


Figure 83: Shaft VE4's Saturday and Sunday service water pumped to surface profile – case study

Figure 83 shows a reduction in average flow for February 2021 and March 2021 compared with August 2020 and September 2020. This project was implemented over a few months, and a valve and actuator were replaced depending on whether working capital was available. Figure 84 shows the total of both Saturday and Sunday's average consumption for the specific months.

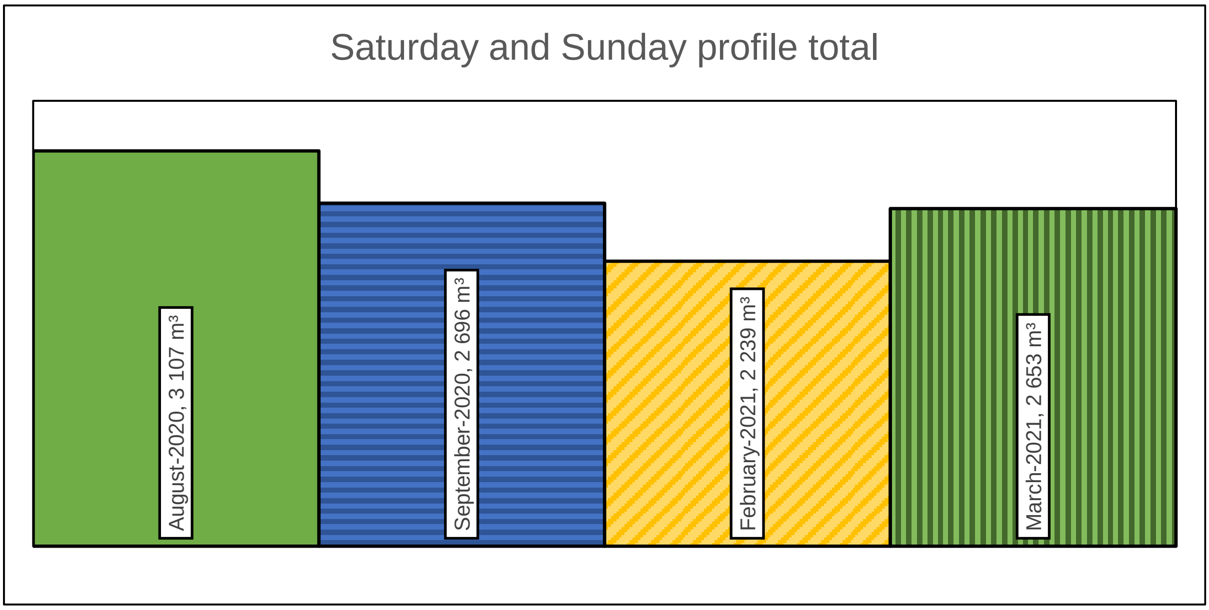


Figure 84: Average total weekend service water consumed underground – case study

Figure 84 further shows a lower consumption for both February 2021 and March 2021 than for August 2020 and September 2020. Figure 85 and Figure 86 convert the flow to power.

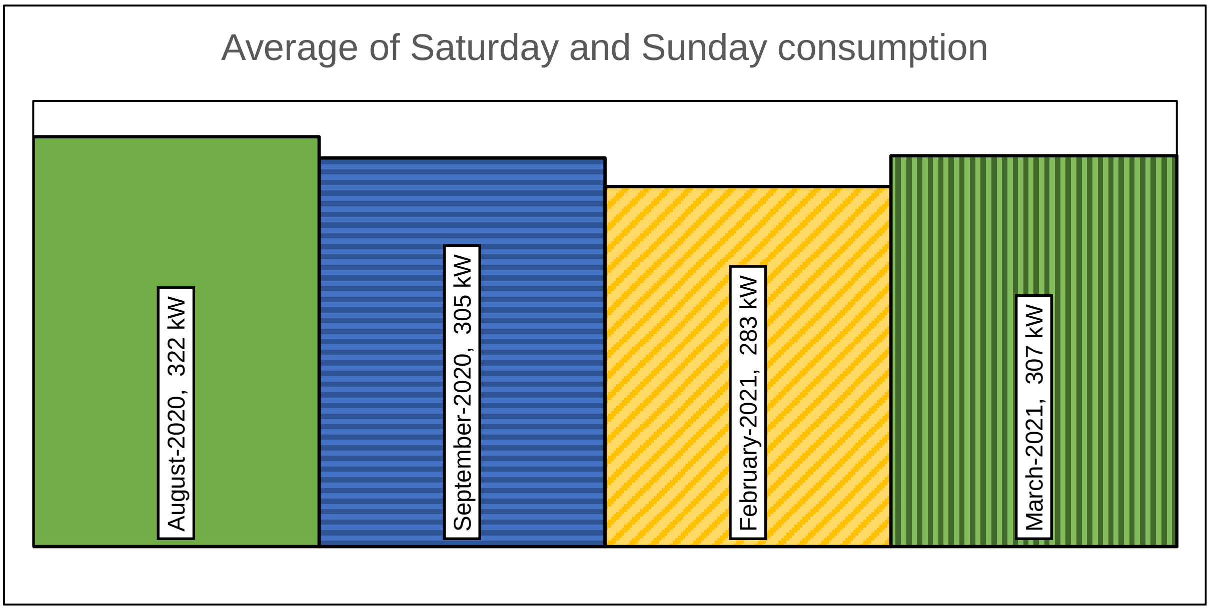


Figure 85: Average total weekend service water pumped to surface power – case study

Figure 85 shows a reduction in average power between August 2020 and March 2021. However, the average power for March 2021 was higher than for September 2020. This difference was the result of more fissure water in March 2021, as the water sent underground was less as shown in Figure 84. Figure 86 examines this difference further.

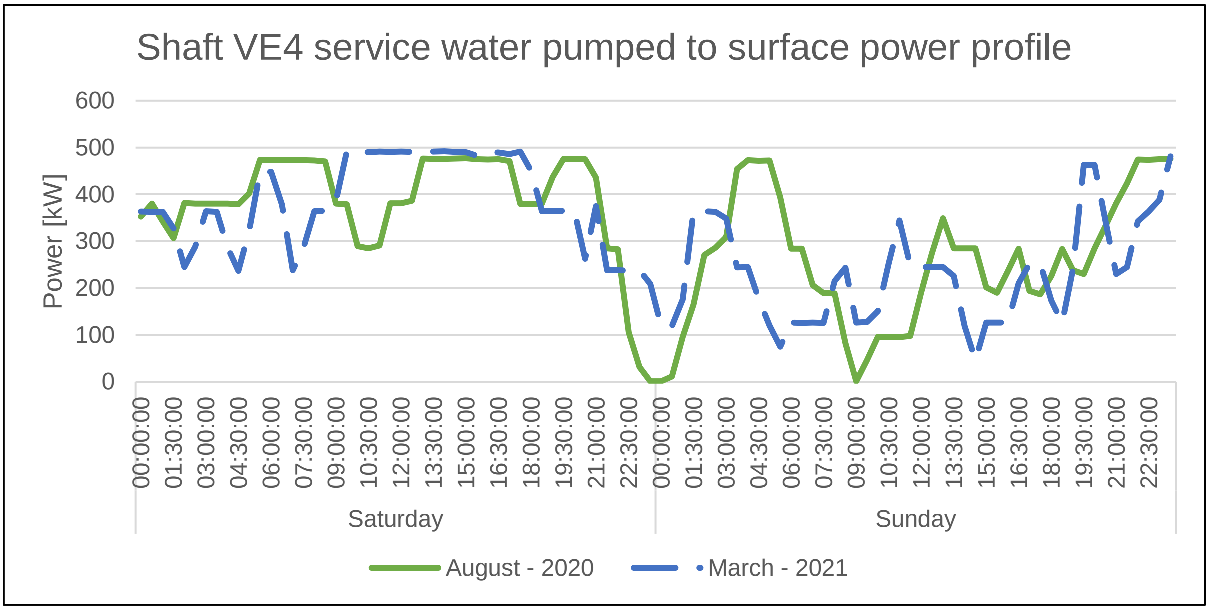


Figure 86: Average weekend power profile of service water pumped to surface – case study

As shown in Figure 85, there was an increase in average power during March 2021 compared with September 2020. It was proven that the cause was due to fissure water. Figure 86 shows that during the August 2020 period, the pumping of the water could be stopped, but this was not possible in March 2021, which increased the average power. The reduction in intensity is shown in Figure 85. The April 2021 average was used for these intensities.

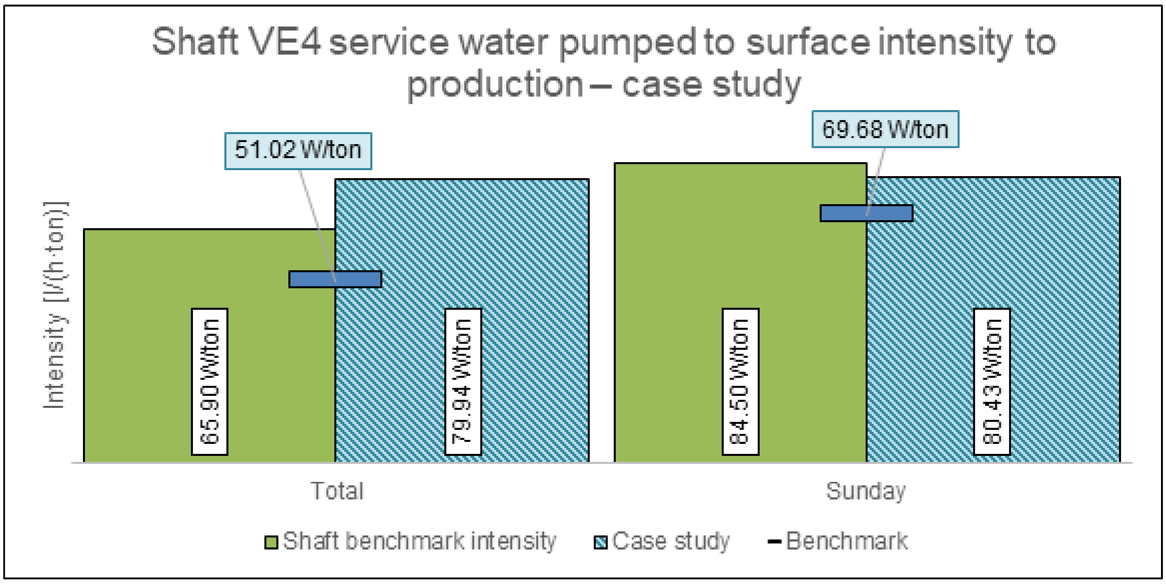


Figure 87: Intensity of service water pumped to surface – case study

Figure 87 shows that the total intensity increased due to more significant consumption/more leaks. However, the Sunday intensity did show a decrease, thereby moving it closer to the benchmark. This decrease was the result of the valves closing completely. The figure shows a 4 W/ton improvement, which resulted in cost and energy savings. This saving further demonstrated that not only one intensity should be evaluated to indicate scope for improvement.

Replacing the pneumatic actuators with electric actuators resulted in an estimated cost saving of R55 000 per annum only for the Sunday period. This savings was an energy reduction project as the amount of water that had to be pumped to the surface was reduced. The blasting shift's savings were excluded as the water reduction would not occur directly during the blasting period, but rather after the blasting shift.

3.7 Conclusion

Chapter 3 discussed the results for the intensities created for the specific case study mine. The starting process was to obtain the best-suited intensities to ensure the intensities were verified. With these verified intensities, benchmarks were created for different periods to evaluate when and where to lower the total mine's intensity. The last section of the benchmarks was validated by implementing case studies, resulting in cost saving after implementing projects.

For the verification process, four of the six benchmarked consumers were compared with production. These comparisons were plausible as there should be a comparison between the input utilities and the output, namely production. The other two benchmark consumers, namely the surface fan power and the potable water consumption, were compared with active haulage length and number of employees.

The benchmarks were calculated for all the periods. The most inefficient shafts can be noted from all the graphs; however, as discussed in Chapter 2, the potential for improvement cannot only be noted from the highest intensities. Noting irregularities is further a method for identifying potential space for improvement.

The third section of Chapter 3 was the validation section. For this section, case studies validated that the intensities would be lowered if projects were implemented. On all the utilities, projects could be implemented to lower the intensities.

A complete summary of most results is given in Table 21. Note that verified benchmark intensities could be calculated for all the utilities. Although the shafts with the highest intensities were not used in all the case studies, irregularities from different periods' benchmarking showed potential for improvement. The inefficiencies found showed that the study objective was reached where inefficient operations were noted. Projects were implemented for these inefficiencies to lower the intensities resulting in cost and energy savings, which lowered the intensities.

The strengths of this study are that numerous opportunities for improvement were identified. Not only was it noted that the shafts were inefficient, but it was also demonstrated when the intensities could be lowered. It was established that the shafts with the highest intensities had scope for improvement. Furthermore, it was confirmed that comparing different periods could show opportunities where irregularities were identified.

The biggest weakness of the result was that it became evident that the decline shafts were more efficient than the vertical shafts. It was further noted that shaft depth and haulage length, which were kept constant for all the months, played a role in the intensity of the shafts. Therefore, irregularities should also be investigated.

The number of employees was also kept constant. If the actual numbers were available, it would have been better and more accurate to use the changing values. Nevertheless, for this study, those numbers were not available.

The items that this study benchmarked were validated. Most verifications corresponded with literature such as Cilliers [4], Du Plooy [5], Du Plooy *et al*. [9], and Zietsman [1]. New items, such as the potable water consumed underground and in the change house, were added in the study. There is furthermore a difference in how the items were monitored compared with Cilliers's study. Items, such as the underground energy required equipment, were separated in his study.

Table 21: Results conclusion

Benchmark consumer	Best-compared consumer	Correlation factor	Standard deviation	Total average benchmark	Shaft with highest total intensity	Another mine higher intensity (yes/no)	Shaft with the implemented case study	Period for implemented case study
Compressed air [m³/h]	Production [ton/day]	0.932	0.027	11.29 m³/(h·ton)	VW1	No	DE3	Sweeping/ cleaning
Surface fan power [kW]	Active haulage length [m]	0.836	0.008	50.20 W/m	VW1	Yes	VE4	Saturday/ Sunday
Rock winder power [kW]	Production [ton/day]	0.871	0.0051	144.70 W/ton	VW1	No	VW1	Eskom peak period
Potable water to change house [m³/day]	Total number of employees	0.766	0.049	106 l/day/capita	VE4	Yes	VW1	All
Potable water going underground [m³/day]	Underground employees	0.713	0.111	119 l/day/capita	VW1	Yes	VW1	All
Service water consumed underground [m³/h]	Production [ton/day]	0.698	0.092	27.03 l/(h·ton)	VK3	No	DE3	Sweeping/ cleaning
Service water pumped to surface [W]	Production [ton/day]	0.868	0.061	51.02 W/ton	VK3	Yes	VE4	Sunday

CHAPTER 4 – CONCLUSION

4.1 Summary

South Africa's water and energy demands are higher than the supply thereof. The supplier of South Africa's energy, Eskom, is struggling to supply only 87% of South African households due to it not being able to keep up with the current demand. Load shedding has been implemented, resulting from the supply not reaching the demand.

South Africa is a water-scarce country. A few years ago, the term 'day zero' became well known to South African Capetonians. Day zero means that there would be no water left in dams in the local community. This water scarcity influences the entire South Africa, motivating that water should be used wisely as it is a non-renewable resource.

South African mines are large consumers of both water and energy. Not only do they consume a large amount, but they should also remain profitable. If their demand is lowered, it will assist with the demand for other industries and households and make the mines more profitable.

Eskom has started to build a new power station to increase the supply of energy. With this new build, energy tariffs have increased to continue with the building operations. A tariff increase of three times greater than inflation was implemented between 2008 and 2018, which threatens the profitability of mines. If mines in 2007 only planned for a yearly 10% inflation increase, they would have underbudgeted with R4.6 million/annum/megawatt in 2018.

South Africa's gold and platinum mines contributed significantly to South Africa's economy, especially during the Covid-19 pandemic. PWC reported that Anglo American paid R16.6 billion to SARS in taxes during the Covid-19 pandemic. For this reason, it is essential to make South African mines as profitable as possible. Therefore, gold and platinum mines should decrease their water and energy demands. This decrease in utilities can happen by benchmarking different shafts to identify potential opportunities.

With measuring equipment improving over the last couple of decades, it has become easier to monitor subsystems. Not only can subsystems be measured, but the resolution of data has also improved. This improvement means that energy consumption can be viewed live, which allows benchmarking to be done for different periods.

Different benchmarks methods were found during the evaluation of previous literature. The three main categories include load shaping baseline benchmarking, regression benchmarking, and intensities benchmarking. Intensities benchmarking was the most common benchmarking method. It is easy to calculate, as well as quick and easy to identify potential inefficiencies.

Previous studies on deep-level mine benchmarking were mainly done on gold mines. Benchmarking on platinum mines was mostly done on compressed air and no other subsystems. Although Cilliers developed a new benchmarking method, he only implemented it on a gold mine. Overall, this was good literature.

Most studies made it clear that shaft depth plays a vital role in the efficiency of a deep-level mine. However, Du Plooy took a different approach and benchmarked levels of compressed air consumption to identify the level that is the most inefficient. This method assists in identifying leaks on shafts, but it is very time-consuming if metering is incorrect. Furthermore, high-pressure demand would not be identified easily if levels are benchmarked on their own.

From all the literature, it is clear that mines should be sustainable for South Africa to grow. For mines to be sustainable, they must be profitable. Sustainability can be accomplished if utilities to the shaft, which consumes 52% of the specific platinum mine's utility costs, are lowered.

The objective of this study was to create benchmarks for a specific platinum mine. If inefficiencies were identified quickly, the specific platinum mine could avoid large expenditures. The study objective included identifying the inefficiencies to implement saving projects to lower these inefficiencies.

The specific platinum mine mentioned above measured its compressed air consumption, surface ventilation fans, underground energy consumption, rock winder energy, potable water to the change house, potable water consumed underground, service water consumed underground, and the service water pumped to the surface.

The methodology included understanding all the shafts and their systems. For the next step, data was collected. It was decided that the average of the data unit would be used for the benchmarks as the average consumption eliminated outliers. With the monthly averages, the correlation factors were calculated between different consumers and outputs for each month. The standard deviation was calculated to form the correlation factors, whereafter the average of all the months' correlation factors was calculated. The highest average correlation factor and lowest standard deviation of all the consumers were considered the best comparison for creating benchmarks. This low standard deviation and high correlation factor further verified the benchmarks. The results for the best-suited comparisons can be seen in Table 22. Included in the table is the correlation factor and the standard deviation. Conditional formatting was used in both columns, with the colour becoming darker as the value increases.

Table 22: Verified benchmark summary table

Benchmark consumer	Best-compared consumer	Correlation factor	Standard deviation
Compressed air [m³/h]	Production [ton/day]	0.932	0.027
Surface fan power [kW]	Active haulage length [m]	0.836	0.008
Winding power [kW]	Production [ton/day]	0.871	0.0051
Potable water to change house [m³/day]	Total number of employees	0.766	0.049
Potable water going underground [m³/day]	Underground employees	0.713	0.111
Service water consumed underground [m³/h]	Production [ton/day]	0.698	0.092
Service water pumped to surface [W]	Production [ton/day]	0.868	0.061

Table 22 shows that compressed air production had the best correlation factor and the third-best standard deviation. Service water consumed underground best-compared output was production as well. The correlation factor was the lowest and the standard deviation the second highest.

From the verified comparisons, the benchmarks were created with the average consumption. Benchmarks were calculated for different periods, including total average, Saturday average, Sunday average, weekday average, weekday drilling shift average, weekday blasting shift average, weekday cleaning/sweeping shift average, and the Eskom peak period average.

The total average was compared with a different platinum mine. This comparison evaluated how much potential for savings could be found on the specific platinum mine. Intensities with average consumptions were created to determine which mine was more efficient as shown in Table 23. It can be seen that the total average intensities of the different platinum mine were higher than the specific platinum mine's intensities. The specific platinum mine was more inefficient regarding the compressed air, rock winder energy, and service water consumption.

Table 23: Summary of mine with higher intensity

	'X' for mine with higher intensity	
	Specific mine studied	Different platinum mine
Compressed air	X	
Surface fan power		X
Rock winder power	X	
Potable water to change house		X
Potable water going underground		X
Service water consumed	X	
Service water pumped to the surface		X

Table 23 shows the specific mine's benchmarks for all the different periods. Conditional formatting was used to identify the periods with the highest benchmark intensities more easily. The higher the intensity benchmark, the darker the blue.

Note that most of the Saturday benchmarks were the highest. For the potable water consumed in the change house, the Sunday intensity was the highest. However, this intensity is highly questionable as the minimum number of people was working during this period. During the drilling shift, the surface ventilation fan had the highest benchmark intensity.

Table 25 displays the shafts that had the highest intensities during the different periods. Shaft VW1 had the highest intensities for most of the consumers and most of the periods. Shaft VK3 service water was a concern, and focus should be placed on this. Shaft VE4's change house water consumption was another concern.

The benchmarks were validated by searching for the highest intensities or irregularities. A case study was created from the noticed inefficiencies and projects were implemented, which lowered the intensities. The reduction in the intensities validated the benchmarks. This validation was done on all the measured utilities except the underground power consumption.

Table 26 summarises the findings completed for the validation process. For compressed air, an estimation of only R12 000 per annum could be achieved. Although this is a small amount, the project is ongoing and the set point should be reduced to 450 kPa. This further set-point reduction can result in savings of R2 million per annum.

The other surprising saving was the potable water consumed underground. Numerous leaks were repaired to achieve savings over a few months. These savings were not achieved immediately. Except for the rock winder load-shifting project, a cost savings project, all implemented projects were reduction savings, meaning either water consumption or energy consumption was reduced.

Table 24: Summary of benchmark intensities

Average of shafts intensities							
	Compressed air to production [m³/(h·ton)]	Surface ventilation fan power to active haulage length [kW/m]	Rock winder power to production [kW/ton]	Potable water to change house compared with the total number of employees [l/day/capita]	Potable water going underground compared with underground employees [l/day/capita]	Service water going underground to production [l/(h·ton)]	Service water pumped up to surface compared with production [W/ton]
Total	11.29	0.0502	0.1447	106	119	27.03	51.02
Saturday	24.88	0.0478	0.2397	113	121	47.51	101.02
Sunday	15.85	0.0418	0.1447	115	115	31.92	69.68
Weekday	11.26	0.0522	0.1437	103	119	24.77	45.14
Sweeping/cleaning shift	10.38	0.0522	0.1580			19.87	40.26
Blasting shift	9.04	0.0514	0.1283			18.06	49.32
Drilling shift	14.20	0.0530	0.1403			35.89	48.64
Eskom peak period	12.27	0.0520	0.1180			31.30	43.48

Legend	Efficient	Average	Inefficient

Table 25: Summary of the most inefficient shaft for different utilities

Most inefficient shafts							
	Compressed air to production	Surface ventilation fan power to active haulage length	Rock winder power to production	Potable water to change house compared with the total number of employees	Potable water going underground compared with underground	Service water going underground to production	Service water pumped up to surface compared with production
Total	VW1	VW1	VW1	VE4	VW1	VK3	VK3
Saturday	VW1	VK3	VW1	VE4	VW1	VK3	VK3
Sunday	VK3	VK3	VW1	VE4	VW1	VK3	VK3
Weekday	VW1	VW1	VW1	VE4	VW1	VK3	VK3
Sweeping/cleaning shift	VW1	VW1	VE4			VK3	VK3
Blasting shift	VW1	VW1	VW1			VK3	VK3
Drilling shift	VW1	VW1	VW1			VK3	VK3
Eskom peak period	VW1	VW1	VW1			VK3	VK3

Legend	VW1	VK3	VE4

Table 26: Validation conclusion

Benchmark	Case study shaft	Case study period	Project implementation	Shaft benchmark for the period	New intensity	Intensity reduction	Estimated annual savings
Compressed air consumption to production	DE3	Morning and evening (sweeping/ cleaning)	550 kPa to 520 kPa set-point reduction	7.87 $m^3/(h\cdot ton)$	6.43 $m^3/(h\cdot ton)$	1.44 $m^3/(h\cdot ton)$	R12 000
Surface ventilation fans to active haulage length	VE4	Sunday	Weekend fan stoppage	47.0 W/m	43.5 W/m	3.5 W/m	R1 400 000
Rock winder to production	VW1	Eskom peak period	Load shifting	148.0 W/ton	77.3 W/ton	70.7 W/ton	R497 107
Potable water to change per day per capita	VW1	Total	Leak repair	100 l/day/capita	86 l/day/capita	14 l/day/capita	R263 000
Potable water consumed underground per day per capita	VW1	Total	Leak repair	235 l/day/capita	194 l/day/capita	41 l/day/capita	R500 000
Service water consumed underground to production	DE3	Morning and evening (sweeping/ cleaning)	Surface valve closure early mornings	24.76 l/(h·ton)	14.15 l/(h·ton)	10.61 l/(h·ton)	R10 845
Service water pumped to the surface to production	VE4	Sunday	Pneumatic actuator replacement	84.5 W/m	80.4 W/m	4.1 W/m	R55 000

4.2 Recommendations for future studies

For future work, the following suggestions are made:

1) **Separate platinum mines' incline and vertical shafts**

   It was noted that there was a clear difference in intensities for the vertical and incline shafts. If more data for incline and vertical shafts can be obtained, the incline and vertical shafts can be separated, giving a more explicit identification of the incline shafts where potential energy and cost savings may be.

2) **Create different intensities for different shifts**

   This study took the average consumption of the blasting period and divided it by the average daily production. However, no ore is produced during the blasting period. Perhaps for the blasting shift, another intensity type could be created.

3) **Period average production**

   As mentioned above, the average daily production was used for this study. More accurate results can be obtained if half-hourly production is used for different periods.

4) **Underground energy benchmark**

   No noticeable savings project could have been implemented on the specific mine in this study. Recommended future work includes developing another benchmark for the total underground energy, where noticeable energy savings could be implemented.

5) **Consider more than one output**

   This study comprised only one item considered to create utility benchmarks, such as production. However, production is not the only output of utility consumption. Active haulage length is another output as the length can be developed.

The method of benchmarking is standard. Nevertheless, the approach was slightly different as different periods were evaluated. This approach can be implemented in other industries as well, as inefficiency were revealed from the irregularities. It can also be used as a benchmark comparison when another mine efficiency is evaluated. No literature showed the benchmarking for different periods on a platinum mine, where this study did include the different periods instead of the comprehensive benchmark.

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APPENDIX A: BEST COMPARISONS' MONTHLY CORRELATION FACTORS

Average compressed air flow to average production

Table 27: Compressed air to production – monthly correlation factor

Month	Correlation factor
February 2019	0.913
March 2019	0.898
April 2019	0.928
May 2019	0.940
June 2019	0.952
July 2019	0.927
August 2019	0.931
September 2019	0.943
October 2019	0.934
November 2019	0.925
February 2020	0.853
Standard deviation	0.027

Total average compressed air flow to total average production correlation factor: 0.836.

Surface ventilation fan power to active haulage length

Table 28: Surface ventilation fan power to active haulage length – monthly correlation factor

Month	Correlation factor
February 2019	0.837
March 2019	0.836
April 2019	0.834
May 2019	0.836
June 2019	0.843
July 2019	0.840
August 2019	0.839
September 2019	0.837
October 2019	0.836
November 2019	0.826
February 2020	0.814
Standard deviation	0.008

Total average surface ventilation fan power to total average production correlation factor: 0.836.

Average rock winder power to average production

Table 29: Rock winder power to average production – monthly correlation factor

Month	Correlation factor
February 2019	0.950
March 2019	0.948
April 2019	0.910
May 2019	0.857
June 2019	0.858
July 2019	0.863
August 2019	0.849
September 2019	0.848
October 2019	0.775
November 2019	0.836
February 2020	0.853
Standard deviation	0.051

Total average rock winder power to total average production correlation factor: 0.871.

Potable water to change the house to the total number of employees

Table 30: Average potable water consumption to the total number of employees – monthly correlation factor

Month	Correlation factor
February 2019	0.802
March 2019	0.817
April 2019	0.856
May 2019	0.841
June 2019	0.869
July 2019	0.754
August 2019	0.732
September 2019	Missing data
October 2019	Missing data
November 2019	0.840
February 2020	Missing data
Standard deviation	0.049

Total average daily consumption to the total number of employees correlation factor: 0.766.

Potable water consumed underground compared with underground employees

Table 31: Potable underground water consumption to the total number of underground employees – monthly correlation factor

Month	Correlation factor
February 2019	0.482
March 2019	0.700
April 2019	0.686
May 2019	0.763
June 2019	0.789
July 2019	0.744
August 2019	0.765
September 2019	Missing data
October 2019	Missing data
November 2019	Missing data
February 2020	Missing data
Standard deviation	0.105

Total average daily consumption to the total underground number of employees correlation factor: 0.766.

Average service water flow to underground to average production

Table 32: Underground service water consumption to production – monthly correlation factor

Month	Correlation factor
February 2019	0.796
March 2019	0.642
April 2019	0.600
May 2019	0.523
June 2019	0.575
July 2019	0.718
August 2019	0.750
September 2019	0.779
October 2019	0.738
November 2019	0.640
February 2020	0.755
Standard deviation	0.092

Total average flow to underground compared with total average production correlation factor: 0.698.

Average service water flow to the surface compared with production

Table 33: Service water pumped to the surface compared with production – monthly correlation factor

Month	Correlation factor
February 2019	0.924
March 2019	0.857
April 2019	0.826
May 2019	0.721
June 2019	0.773
July 2019	0.822
August 2019	0.886
September 2019	0.876
October 2019	0.870
November 2019	0.905
February 2020	0.896
Standard deviation	0.061

Total average flow to the surface compared with total average production correlation factor: 0.868.

APPENDIX B: SUMMARY OF ALL COMPARISONS' CORRELATION FACTOR AND STANDARD DEVIATION

Table 34: Comparisons done for study

Y-axis	X-axis	Correlation factor	Standard deviation
Rock winder average power [kW]	Shaft average airflow [m^3/h]	0.89	0.043
Rock winder average power [kW]	Average production [ton]	0.96	0.085
Rock winder average power [kW]	Mine depth [m]	0.20	0.164
Shaft total average power [kW]	Average main potable water [m^3/h]	0.78	0.212
Shaft total average power [kW]	Mine depth [m]	0.00	0.183
Shaft total average power [kW]	Underground employees	0.99	0.004
Shaft total average power [kW]	Surface employees	0.96	0.012
Shaft total average power [kW]	All employees	0.99	0.004
Underground average power [kW]	Shaft average airflow [m^3/h]	0.32	0.125
Underground average power [kW]	Average production [ton]	0.44	0.162
Underground average power [kW]	Average underground potable water [m^3/h]	0.06	0.019
Underground average power [kW]	Mine depth [m]	0.17	0.037
Underground average power [kW]	Active haulage length [m]	0.29	0.138
Underground average power [kW]	Underground employees	0.02	0.011
Underground average power [kW]	All employees	0.02	0.012
Surface fan average power [kW]	Shaft average airflow [m^3/h]	0.93	0.007
Surface fan average power [kW]	Average production [ton]	0.77	0.047
Surface fan average power [kW]	Average underground potable water [m^3/h]	0.98	0.154
Surface fan average power [kW]	Mine depth [m]	0.09	0.395
Surface fan average power [kW]	Active haulage length [m]	0.84	0.055
Surface fan average power [kW]	Underground employees	0.73	0.037
Shaft average airflow [m^3/h]	Rock winder average power [kW]	0.89	0.043
Shaft average airflow [m^3/h]	Underground average power [kW]	0.32	0.129
Shaft average airflow [m^3/h]	Average production [ton]	0.95	0.021
Shaft average airflow [m^3/h]	Mine depth [m]	0.04	0.008
Shaft average airflow [m^3/h]	Active haulage length [m]	0.93	0.011
Shaft average airflow [m^3/h]	Underground employees	0.86	0.044
Average main potable water [m^3/h]	Shaft total average power [kW]	0.78	0.127

Y-axis	X-axis	Correlation factor	Standard deviation
Average main potable water [m^3/h]	All employees	0.63	0.105
Average change house potable water [m^3/h]	All employees	0.81	0.049
Average underground potable water [m^3/h]	Underground average power [kW]	0.06	0.019
Average underground potable water [m^3/h]	Surface fan average power [kW]	0.98	0.154
Average underground potable water [m^3/h]	Average production [ton]	0.79	0.068
Average underground potable water [m^3/h]	Mine depth [m]	0.04	0.103
Average underground potable water [m^3/h]	Active haulage length [m]	0.82	0.190
Average underground potable water [m^3/h]	Underground employees	0.73	0.092
Average underground potable water [m^3/h]	All employees	0.69	0.237
Service water consumed underground [m^3/h]	Average production [ton]	0.698	0.092
Service water consumed underground [m^3/h]	Active haulage length [m]	0.575	0.049
Service water consumed underground [m^3/h]	Shaft average airflow [m^3/h]	0.533	0.094
Service water pumped to surface [kW]	Average production [ton]	0.868	0.061
Service water pumped to surface [kW]	Active haulage length [m]	0.73	0.037
Service water pumped to the surface [kW]	Underground employees	0.947	0.018
Average production [ton]	Mine depth [m]	0	0.315

APPENDIX C: BENCHMARK INTENSITY CALCULATION METHOD

Step 1: Calculating averages

Step 1 includes calculating each shaft smallest unit (m^3/h, kW, m^3/day, ton/day) monthly average for February-2019 till February 2020, excluding December 2019 and January 2020. This should be done for all named periods, namely total average, Saturday average, Sunday average, ext. Table 35 is an example table of the monthly compressed air consumption, where no periods were excluded. Table 36 is an example table with the correlating average production. The month can be evaluated the data, as incorrect data may occur.

Table 35: Example table of monthly average compressed air consumption [m^3/h]

Month	DK1	DE3	VK3	VW1	VE4
February-2019	20 710	18 822	113 024	79 440	66 110
March-2019	21 537	17 102	108 321	87 234	66 481
April-2019	23 696	17 110	108 735	81 699	60 813
May-2019	21 664	17 937	109 280	83 602	64 544
June-2019	25 570	18 826	109 714	80 191	66 171
July-2019	27 027	18 186	110 111	78 186	60 312
August-2019	24 054	14 928	103 601	75 459	60 433
September-2019	23 249	13 964	98 078	75 984	61 464
October-2019	23 546	13 575	96 041	82 876	59 014
November-2019	18 726	14 912	95 999	79 484	64 533
February-2020	28 578	12 148	106 708	93 870	72 058
Average	23 487	16 137	105 419	81 639	63 812

Table 36: Example table of monthly average hoisted tons per day

Month	DK1	DE3	VK3	VW1	VE4
February-2019	3 472	2 005	7 830	4 518	5 566
March-2019	3 254	1 794	6 250	4 522	4 937
April-2019	2 828	1 559	5 917	4 122	4 206
May-2019	3 093	1 956	6 934	5 482	4 946
June-2019	3 154	2 029	7 447	5 578	5 696
July-2019	3 781	1 911	7 897	5 422	5 992
August-2019	3 439	1 772	7 535	4 978	5 403
September-2019	2 853	1 681	6 607	4 298	4 168
October-2019	3 092	1 961	7 269	4 937	4 863
November-2019	2 801	1 938	6 880	4 526	5 386
February-2020	2 972	1 786	5 928	3 415	5 277
Average	3 158	1 854	6 954	4 709	5 131

Step 2a: Calculating standard deviation

The second step includes calculating the standard deviation of the correlation factor, ensuring a consistent correlation. The correlation factor should be calculated for each month over the various shafts. The standard deviation is then calculated using the monthly correlation factors. The calculations were done with Excel's RSQ and STDEV functions.

Table 37: Example table of monthly correlation factor to calculate the standard deviation.

Month	Correlation factor
February-2019	0.8542
March-2019	0.8577
April-2019	0.9091
May-2019	0.9656
June-2019	0.9607
July-2019	0.8913
August-2019	0.9173
September-2019	0.9231
October-2019	0.9016
November-2019	0.8812
February-2020	0.6547
Standard deviation	0.0839

<u>Step 2b: Calculating corelation factor</u>

The correlation factor was calculated using all the months total average, as seen in Table 35 and Table 36. Table 38 shows what data was used for calculating the correlation factor. The RSQ function was used again.

Table 38: Example table used for calculating correlation factor

Shaft	Average airflow [m³/h]	Average production [ton/day]
DK1	23 487	3 158
DE3	16 137	1 854
VK3	105 419	6 954
VW1	81 639	4 709
VE4	63 812	5 131
Corelation factor		0.9070

Suppose an excellent standard deviation and corelation factor is calculated. In that case, the comparison is viable and can calculate a benchmark intensity.

<u>Step 3: Calculating benchmark intensity</u>

Table 39 shows how the results of the intensity were calculated. This was done by dividing the average flow by the average production. The average of the shafts intensity was used as the benchmark.

Table 39: Example table indicating how the intensity was calculated

Shaft	Average airflow [m³/h]	Average production [ton/day]	Intensity (Airflow/production) [m³/h·ton]
DK1	23 487	3 158	7.44
DE3	16 137	1 854	8.70
VK3	105 419	6 954	15.16
VW1	81 639	4 709	17.34
VE4	63 812	5 131	12.44
Average intensity (Benchmark intensity)			12.21

APPENDIX D: DATASET CONTAINING PERIOD AVERAGES

In this section, the period averages are given. These averages were calculated from a large data set.

Table 40: Average compressed air consumption for different periods

Average compressed air consumption [m³/h]					
	VK3	VW1	VE4	DK1	DE3
Total	105 291	80 416	62 988	27 641	16 536
Saturday	106 236	73 978	62 284	28 559	14 927
Sunday	83 876	52 195	53 496	22 648	8 951
Weekday	109 476	89 112	66 228	30 234	17 843
Morning & Evening shift	101 040	84 118	63 027	25 519	16 352
Drilling shift	128 711	111 186	83 788	38 434	24 976
Blasting shift	98 338	70 304	50 276	26 927	11 607
Eskom peak period	119 333	98 323	68 458	36 560	18 212

Table 41: Average surface fan power for different periods

Average surface ventilation fan power [kW]					
	VK3	VW1	VE4	DK1	DE3
Total	5 142	4 390	1 900	461	475
Saturday	5 138	3 944	1 876	458	456
Sunday	4 202	3 186	1 833	456	433
Weekday	5 328	4 724	1 917	463	489
Morning & Evening shift	5 297	4 785	1 898	463	484
Drilling shift	5 361	4 848	1 895	465	497
Blasting shift	5 338	4 463	1 967	462	484
Eskom peak period	5 362	4 581	1 933	462	493

Table 42: Average rock winder power for different periods

Average rock winder power [kW]			
	VK3	VW1	VE4
Total	908	775	707
Saturday	668	570	523
Sunday	240	226	164
Weekday	1 076	925	853
Morning & Evening shift	1 186	928	1 031
Drilling shift	1 084	842	882
Blasting shift	926	1 016	592
Eskom peak period	912	828	609

Table 43:Average potable water consumption to change house for different periods

Average change house potable water consumption [m³/day]				
	VW1	VE4	DK1	DE3
Total	352	622	194	121
Saturday	369	661	207	133
Sunday	380	660	213	134
Weekday	343	606	188	116

Table 44: Average potable water consumption consumed underground for different periods

Average underground potable water consumption [m³/day]					
	VK3	VW1	VE4	DK1	DE3
Total	1 051	793	274	33	142
Saturday	1 096	805	257	32	153
Sunday	1 068	771	224	32	141
Weekday	1 039	795	287	33	141

Table 45: Average service water consumption for different periods

Average service water consumption [m³/h]					
	VK3	VW1	VE4	DK1	DE3
Total	294	65	120	98	46
Saturday	272	59	104	93	42
Sunday	202	49	78	73	29
Weekday	317	69	131	104	50
Morning & Evening shift	268	62	89	87	38
Drilling shift	419	78	216	141	88
Blasting shift	264	59	89	83	23
Eskom peak period	379	74	176	142	64

Table 46: Average power of service water pumped to surface for different periods

Average power of service water pumped to surface [kW]					
	VK3	VW1	VE4	DK1	DE3
Total	660	193	338	66	60
Saturday	631	210	318	68	59
Sunday	492	172	249	52	50
Weekday	700	193	360	68	63
Morning & Evening shift	630	179	311	59	56
Drilling shift	863	138	368	83	68
Blasting shift	682	274	415	63	66
Eskom peak period	687	168	350	71	60

Table 47: Average daily production for different periods

Average production [ton/day]					
	VK3	VW1	VE4	DK1	DE3
Total	7 056	4 838	5 117	3 177	1 861
Saturday	3 770	1 799	2 326	1 622	1 395
Sunday	3 780	2 607	2 953	1 944	1 223
Weekday	8 242	5 730	6 155	3 721	2 079

Table 48: Active haulage lengths

Active haulage length [m]					
	VK3	VW1	VE4	DK1	DE3
Total	64164	51840	39500	29600	21750

Table 49: Number of underground employees

Number of underground employees					
	VK3	VW1	VE4	DK1	DE3
Total	6161	3380	3608	2285	1450

Table 50: Total number of employees

Total number of employees					
	VK3	VW1	VE4	DK1	DE3
Total	6423	3526	3800	2387	1525