

Developing an electrical cost saving methodology for platinum plant auxiliary systems

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ABSTRACT

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The mining of platinum group metals (PGMs) contributes significantly to the South African economy. In 2020, the revenue generated from PGM mining accounted for 2.3% of the country's total gross domestic product (GDP) (R 101.3 billion). Despite this, the platinum mining industry is struggling to remain profitable and, as a result, unprofitable mining operations are closing.

To remain profitable, mining operations have had to undertake cost saving measures. It has been found that reducing electricity costs through load management and energy efficiency initiatives is an effective means of reducing operational costs. Such initiatives have been widely implemented on platinum mining operations. Implementation of such initiatives has, however, been limited on platinum processing plants despite the significant amount of energy consumed by this section.

In this study, a methodology was developed to identify feasible electricity cost saving opportunities on platinum processing plant auxiliary systems. The methodology was developed by combining and adapting existing benchmarking methodologies as well as energy audit procedures such as load inventory development, baseline analysis, and intensity analysis.

The adapted methodology allowed for plants with large auxiliary system energy intensities to be identified through high-level benchmarking. These plants were then analysed through a combination of baseline and intensity analysis. Baseline analysis was used to identify variable

auxiliary system loads suitable for load management whilst intensity analysis was used to identify auxiliary system energy efficiency opportunities.

The methodology was applied to three different platinum processing plants, namely a concentrator, tailings treatment plant, and smelter converter plant. This application was successful in identifying both load management and energy efficiency initiatives across all three plants.

Of the identified initiatives, five energy efficiency initiatives were implemented across the three platinum processing plants. In these initiatives, pumping and compressed air systems were optimised by stopping unnecessary equipment from running, which resulted in a combined estimated yearly electricity cost and consumption saving of R6.23 million and 5.44 GWh, respectively. These savings were achieved without negatively affecting plant production.

Results from the three case studies are an indication of the potential to obtain electricity cost savings on all South African platinum processing plants. It is estimated that, if the developed methodology were to be applied to all South African platinum processing plants, estimated yearly cost and energy savings of R80 million and 79 GWh could be achieved.

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NOMENCLATURE

Symbol	Description	Units
E	Energy	kWh, MWh, GWh
I	Current	A
N	Number	-
P	Power	kW, MW, GW
V	Voltage	V

LIST OF ABBREVIATIONS

BMR	Base metal refinery
GDP	Gross domestic product
IQR	Interquartile range
LF	Load factor
M&V	Measurement and verification
PF	Power factor
PGM	Platinum group metals
PMR	Precious metal refinery
ROM	Run-of-mine
RP	Rated power
SCADA	Supervisory control and database acquisition
TOU	Time-of-use
TTP	Tailings treatment plant
VSD	Variable speed drive

CHAPTER 1: INTRODUCTION AND LITERATURE

1.1 The status of the platinum mining industry in South Africa

According to the United States Geological Survey, over 90% of the world's platinum group metal (PGM) reserves are found in South Africa [1]. As a result, the country is the world's largest PGM producer, producing 70% of the global refined platinum in 2019 [2].

This production of PGMs, and in particular platinum, contributes significantly to South Africa's economic growth. In 2020, PGMs accounted for 28% of the country's total mining revenue [3]. This proportion is the largest of all commodities mined in South Africa and, as a result thereof, the production of PGMs contributed 2.3% (R101.3 billion) to the country's total gross domestic product (GDP) [3, 4]. Despite this, the production of refined PGMs has steadily declined from approximately 270 tonnes in 2015 to 230 tonnes in 2020 [4].

Reasons for this decrease in production include a 33% increase in year-on-year operational expenses, decreasing mineral prices and the global trade implications brought about by the COVID-19 pandemic [3-5]. As a consequence of the decrease in production and increase in operational costs, many platinum mining operations have been reporting low profit margins, with some operations being forced to close [6].

Mining operations are price takers, meaning that they cannot increase their commodity prices to compensate for these low profit margins. Instead, mining companies must sell their commodities at global market-related prices and so, to increase profit margins, PGM mining operations must decrease their operational costs [7-9].

1.1.1 Reducing costs on platinum mines

A typical South African PGM mining operation's cost breakdown is shown in Figure 1. The figure shows that employment benefits and contractor fees are the biggest operational costs of a PGM mining operation. This is due to the use of labour-intensive conventional mining techniques typically employed in South African underground mines [7, 10, 11].

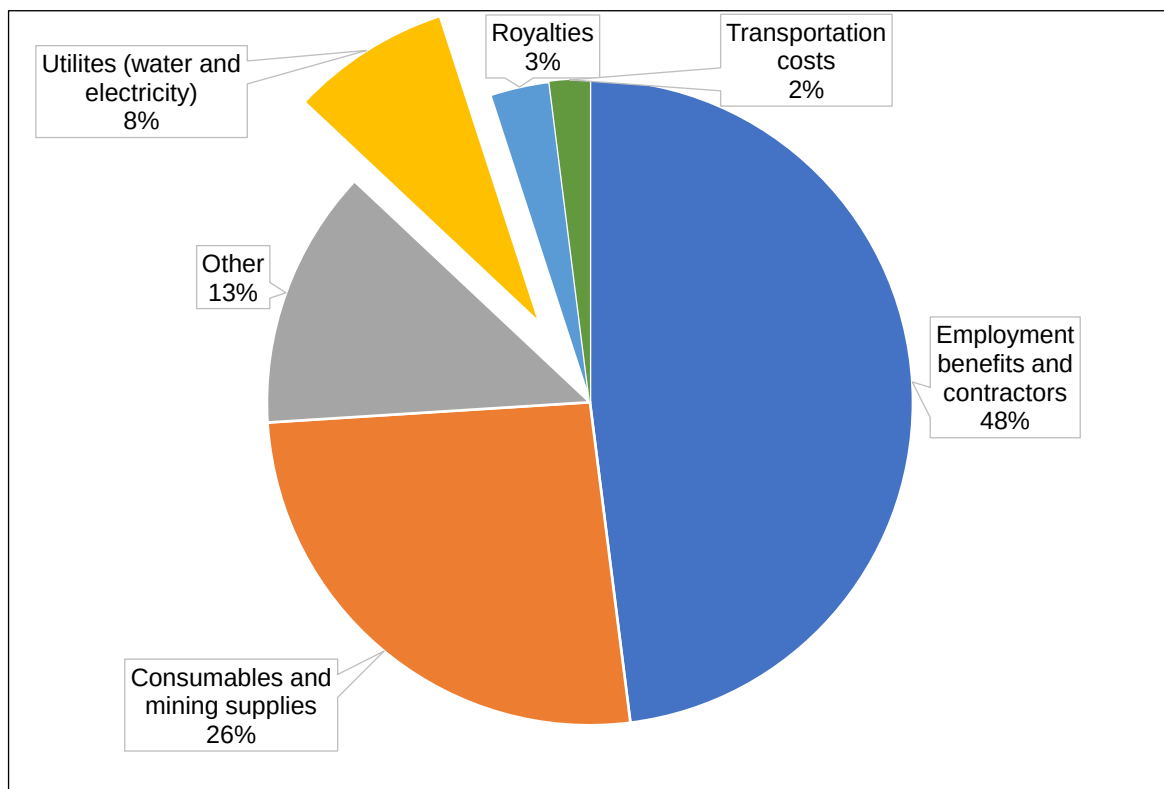


Figure 1: Operational cost breakdown of a typical PGM mining operation [3]

The large contribution of employment benefits and contractors shows that mining companies play an important role in providing employment in South Africa. The entire South African mining industry directly employed 451 427 people in 2020. This, however, represents a year-on-year decrease of 8 588 permanent employees in the sector [4].

The loss of permanent employment in the South African mining sector is a result of low profit margins, as discussed above. Figure 2 illustrates that over a 12-year period the total number of permanent employees in the mining sector has decreased by over 12%, adding to South Africa's unemployment rate of 42% [3].

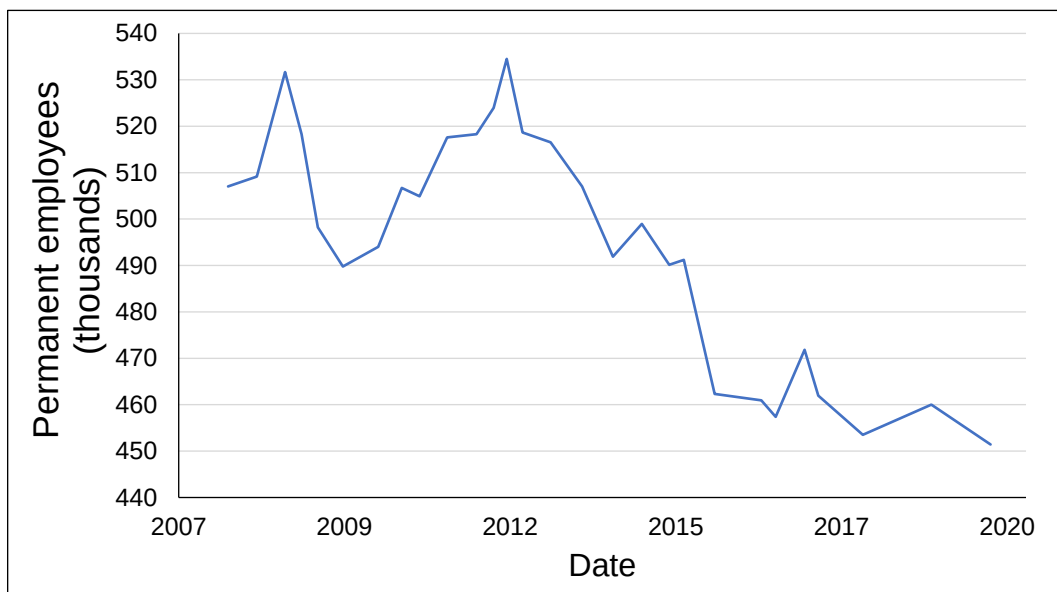


Figure 2: Number of permanent employees within the South African mining sector [3]

After employment benefits and contractors, the largest operational costs occurred by PGM mines are consumables and mining supplies, other expenses, and utilities, respectively. Utilities, which consist of the costs of water and electricity, contribute 8% of a typical PGM mine's total operational cost.

Utility costs can, however, account for up to 13% of a mine's total operational cost, with the cost of electricity accounting for more than 90% of the total utility cost [12, 13]. Therefore, the contribution of utilities, and in particular electricity, to the total cost of a mining operation remains significant even though previous research has shown that there is scope for mining operations to reduce their electricity costs [14-16].

The significance of electricity costs within the South African PGM industry has increased with Eskom electricity tariffs increasing by over 180% since 2008¹. This is substantial as a 1% increase in electricity tariffs can result in a 2.02% decrease in production [9].

This will lead to further decreases in profitability and more job losses. This is over and above the more than 15 000 jobs already lost during the period 2007 – 2021 that can be directly attributed

¹ Eskom Holdings. "Tariff history". [Online]. Available: https://www.eskom.co.za/CustomerCare/TariffsAndCharges/Pages/Tariff_History.aspx [Accessed 27 August 2021].

to increasing electricity costs [5]. There is therefore a need to decrease electricity costs on PGM mining operations.

1.1.2 Electricity cost saving initiatives on platinum mines

South African PGM mines are significantly affected by increasing electricity costs, as discussed in Section 1.1.1. It was also found that, of the major costs incurred by PGM mines, there is scope to reduce electricity usage and costs and therefore increase mine profitability [14-16].

A typical platinum mining operation's electricity usage breakdown is shown in Figure 3. The figure shows that the materials handling, processing, and compressed air sections of a typical mine are the largest electricity consumers. Together, these three sections account for 59% of a mine's total energy usage.

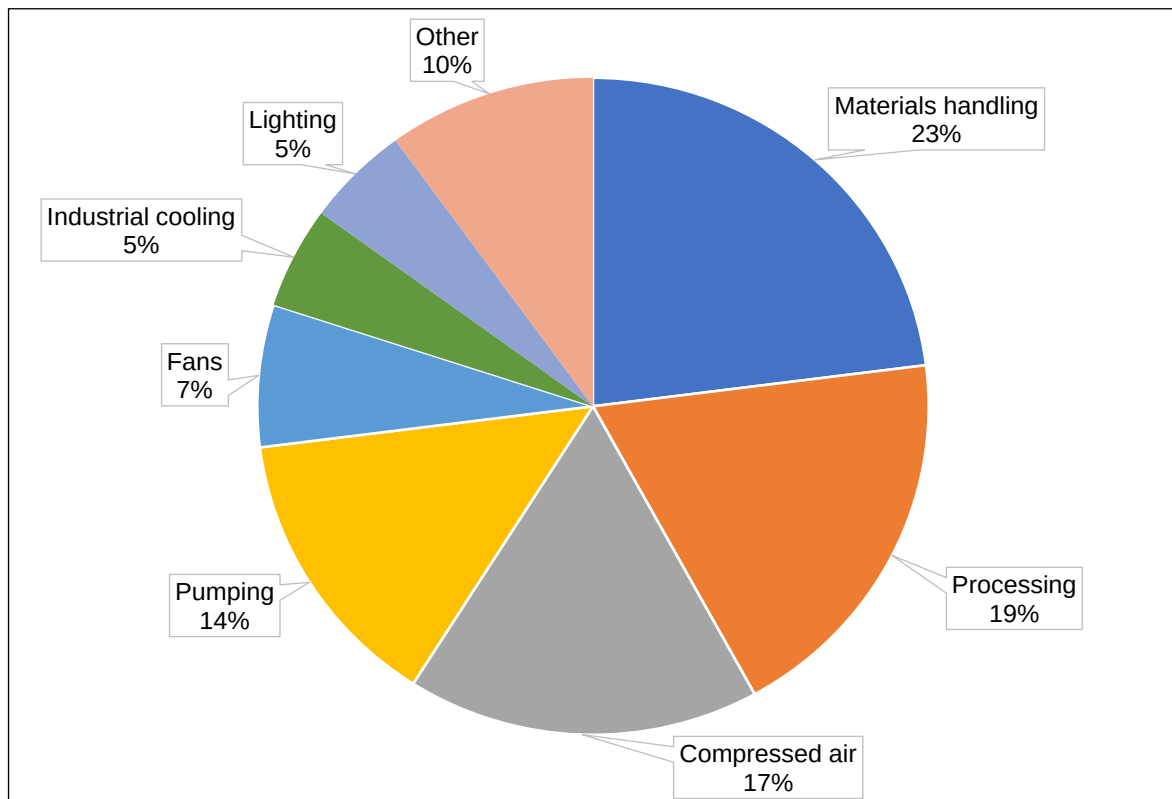


Figure 3: Electricity usage breakdown of a typical mining operation [17]

Historically, most electricity cost and consumption saving measures have been limited to mining operations [18, 19]. Previous works have shown that electricity savings can be achieved through the optimisation of pumping schedules and water reticulation systems [20-22], industrial cooling

systems [23-26], rock hoisting and material transfer systems [27-30] and compressed air networks [8, 31-34].

Despite the large contribution of processing systems to a mine's total energy consumption, limited literature exists detailing electricity cost saving measures on platinum processing plants. These plants include concentrators, tailings treatment plants, smelters, and refineries. This is due to the perception that obtaining electricity cost savings on platinum plants is difficult due to the constant operating nature of the plants [18, 19].

Previous works investigating electricity cost saving measures on platinum processing plants have concluded that cost savings cannot be achieved through load shifting of large comminution and smelting equipment [18, 19, 35]. The load shifting of this equipment is operationally infeasible as it results in disturbances to downstream processes thus reducing product grade and recovery. Furthermore, load shifting of equipment is financially infeasible as platinum plants operate continuously.

Milling and smelting, which are uninterruptible processes, contribute significantly to a plant's total electricity consumption. This is shown in Figure 4 for a platinum concentrator considered in this study, in which milling accounts for 53% of the total electricity usage. The remaining 47% of the concentrator electricity usage is consumed by systems auxiliary to the main milling process.

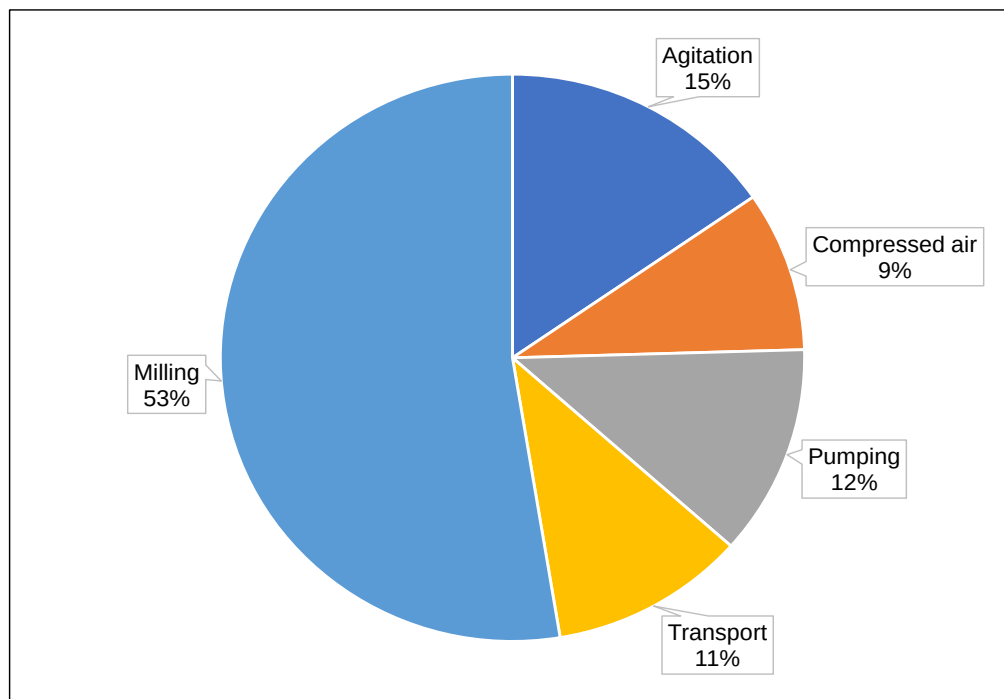


Figure 4: Electricity usage breakdown of a platinum concentrator observed as part of this study

These systems, referred to as auxiliary systems, include agitation, transport, compressed air generation and pumping systems. Unlike milling and smelting, these systems do not all operate continuously, and so electricity cost and consumption savings can be achieved through auxiliary system load management and energy efficiency initiative implementation [36].

1.2 Electricity consumption of auxiliary systems on platinum processing plants

The goal of platinum processing is to increase the platinum grade so that refined platinum can be sold for profit [37, 38]. This is typically achieved through two main process steps, namely concentration and refining, as shown in Figure 5.

The auxiliary systems discussed above are found throughout the various stages of platinum processing shown in Figure 5. In order to obtain electrical cost savings on these auxiliary systems, an understanding of how and where electricity is used during platinum processing is required.

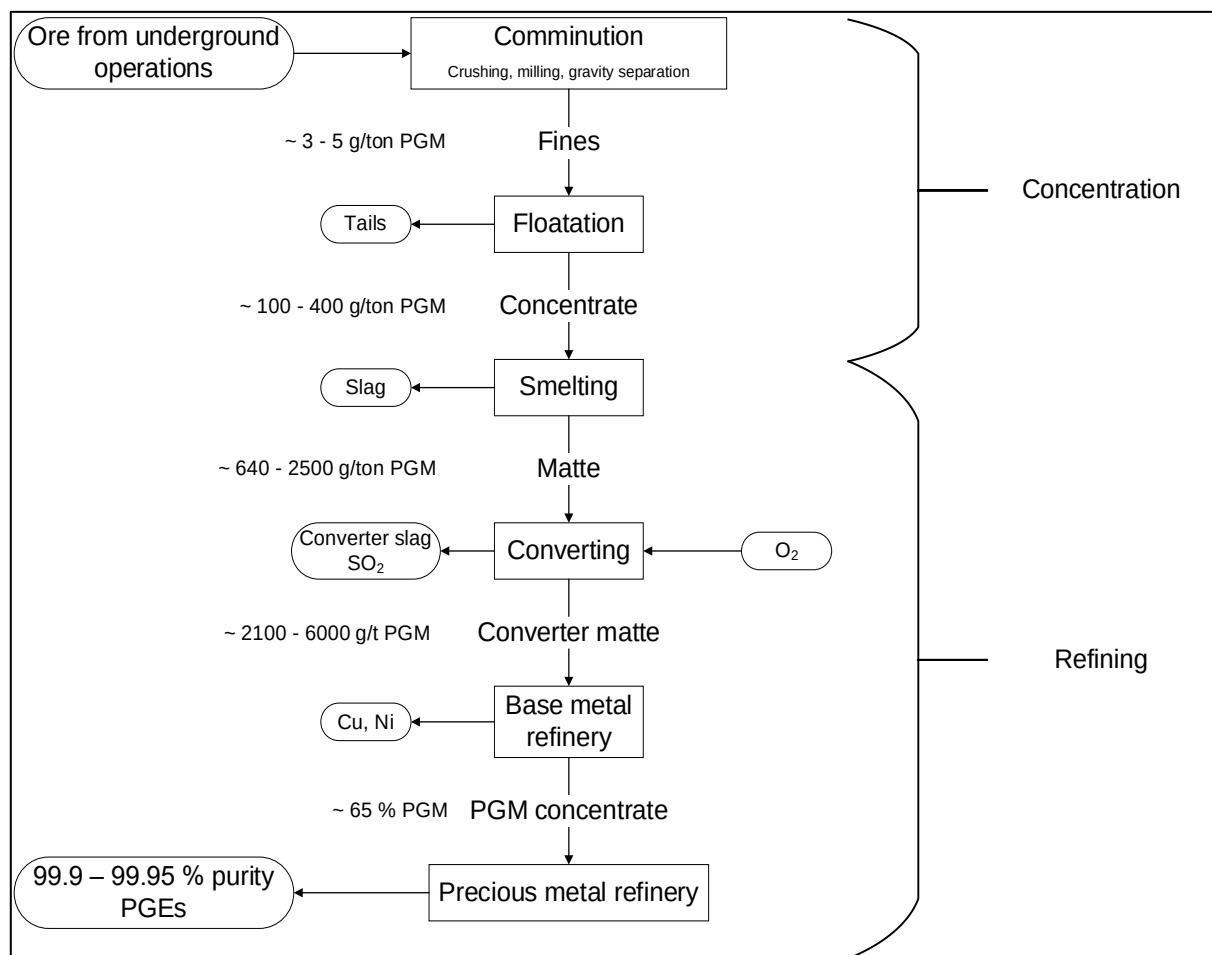


Figure 5: Typical platinum processing flow diagram [37, 38]

1.2.1 Transfer equipment

Transfer equipment is used to transfer material between the different stages of the platinum processing process shown in Figure 5. The specific equipment used to transfer materials varies as the conditions of the materials change. However, typical transfer equipment found on platinum processing plants can be separated into two main categories, namely conveyor systems and pumping systems [19].

Conveyor systems are typically used in conjunction with chutes, feeders, and trams to transport dry materials on platinum processing plants. As such, conveyors are used to transport ore from mining operations and stockpiles to plant silos as well as to transport ore from the silos to the mills [19], as shown in Figure 6.

The design of conveyor systems varies significantly based on the purpose of the system. Some design considerations include the type of material being transferred, site layout and material transfer rate [27].

Typically, the motors used to drive conveyor systems are oversized due to the high starting torque required to start the conveyors [27]. As such, these systems are large and energy intensive. Some installations have motors with installed capacities of up to 160 kW, with several motors being used to drive one conveyor [39].



Figure 6: Platinum plant ore transfer conveyors

Pumping systems, an example of which is shown in Figure 7, include pumps, launders, and pipelines. These systems are used to transfer material which has been diluted through the addition of water. As such, pumping systems on platinum processing plants typically transport slurries and are found in most platinum processing plants [19].

Both centrifugal pumps and positive displacement pumps such as plunger, piston, and piston diaphragm pumps, are used for slurry transport on platinum processing plants [40]. As with conveyor systems, the design of these pumping systems is dependent on the material being transported, the desired transfer rate, and the site layout.

Typical pumping systems are large and energy intensive with pump motor sizes varying from 8 kW up to 175 kW [19]. Figure 4 showed that the motors used to drive pumping systems account for 12% of the total energy usage of a platinum concentrator.



Figure 7: Platinum plant tails transfer pumps

1.2.2 Agitation

Flotation cells are used to separate the valuable PGMs from waste. The flotation process produces a waste stream referred to as the tails, as well as a concentrate with a PGM grade of 100 – 400 g/ton [37, 38]. Most South African PGM flotation cells are mechanically agitated using impellers, referred to as agitators [41].

Typical South African PGM agitators operate at an energy intensity of up to 10 kW/m^3 . This is significant as floatation cells can have volumes of up to 250 m^3 [41]. As such, mechanical agitators in floatation cells consume large amounts of energy.

Despite this large energy consumption, the scope to decrease the level of agitation in floatation cells is limited. Studies have found that increasing the level of agitation in a floatation cell generally increases the PGM recovery. Thus, cells with greater levels of agitation are more profitable than cells in which the agitation is decreased [41].

1.2.3 Compressed air

The main consumer of compressed air on platinum processing plants is pneumatic control equipment. In order to provide instrument air to the pneumatic control equipment, compressors with rated powers ranging from 160 kW to 1 000 kW are installed at processing plants, an example of which is provided in Figure 8. These compressors, which provide high-pressure, low-flow air, operate continuously and so can consume up to 18% of a platinum processing plant's total energy usage [18]. The large energy consumption of compressed air systems is worsened by the fact that these systems typically have an overall efficiency of 6.5% [42].



Figure 8: Platinum plant instrument air compressor

In addition to compressors, other compressed air systems found in platinum processing plants include blowers. Blowers are used to introduce air into floatation cells in order to create a suitable hydrodynamic environment in which fines floatation can take place [41]. Such blower motors typically range in size from 10 kW to 90 kW [19].

Blowers are also used during matte converting, as shown in Figure 5. During the matte conversion process, blowers supply oxygen to the system, allowing for the removal of sulphur as sulphur dioxide. These blowers are typically much larger than the blowers used for floatation and can have installed capacities of up to 600 kW [37, 38].

1.3 Existing electrical cost saving initiatives on plant auxiliary systems

Before discussing specific electrical cost saving initiatives on plant auxiliary systems, it is necessary to differentiate between the two main methods of obtaining electrical cost savings. These methods are load management and energy efficiency initiatives. Both methods are explained below.

1.3.1 Load management

Electrical utilities benefit from consumer electricity curtailment during high demand periods and so several strategies to encourage high demand period curtailment have been developed. Such strategies include Time-Of-Use (TOU) tariff structures, critical peak tariff structures and demand response programs [43]. In all these tariff structures, consumer electricity curtailment is encouraged by significantly increasing the cost of electricity during certain periods.

Load management is the principle of shifting electrical loads from more expensive tariff periods to less expensive periods, therefore minimising the high demand or peak-period electricity usage. As shown in Figure 9, load management initiatives shift electrical loads from more expensive tariff periods to less expensive periods. These initiatives are energy neutral meaning that they result in an electrical cost reduction but not an electrical consumption reduction.

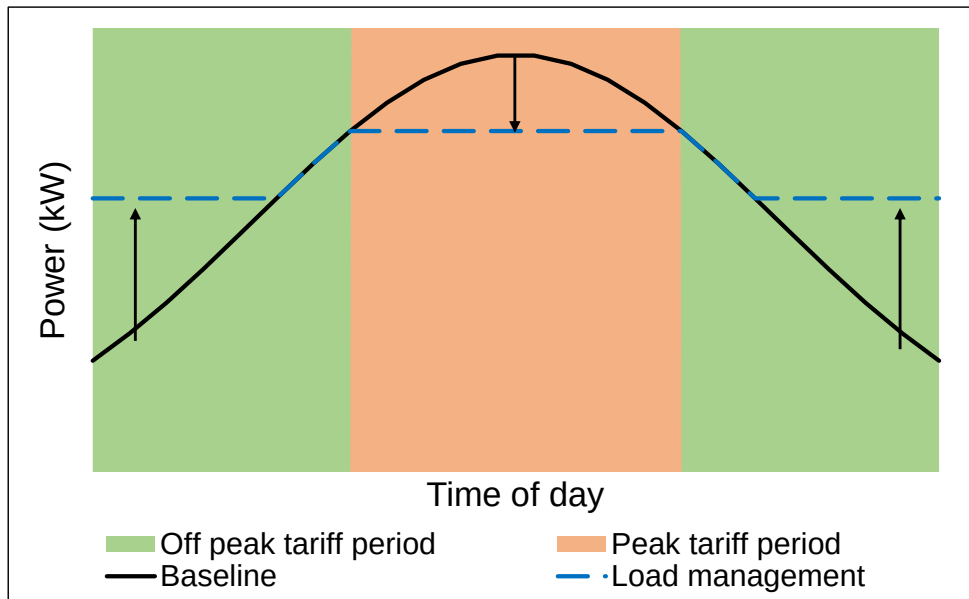


Figure 9: Power profile for a typical load management initiative [19]

1.3.2 Energy efficiency initiatives

A typical power profile for an energy efficiency initiative is shown in Figure 10. As illustrated in the figure, energy efficiency initiatives aim to decrease the power consumption of a specific process or piece of equipment. Therefore, energy efficiency initiatives decrease electricity consumption and cost, whilst production remains unchanged [19].

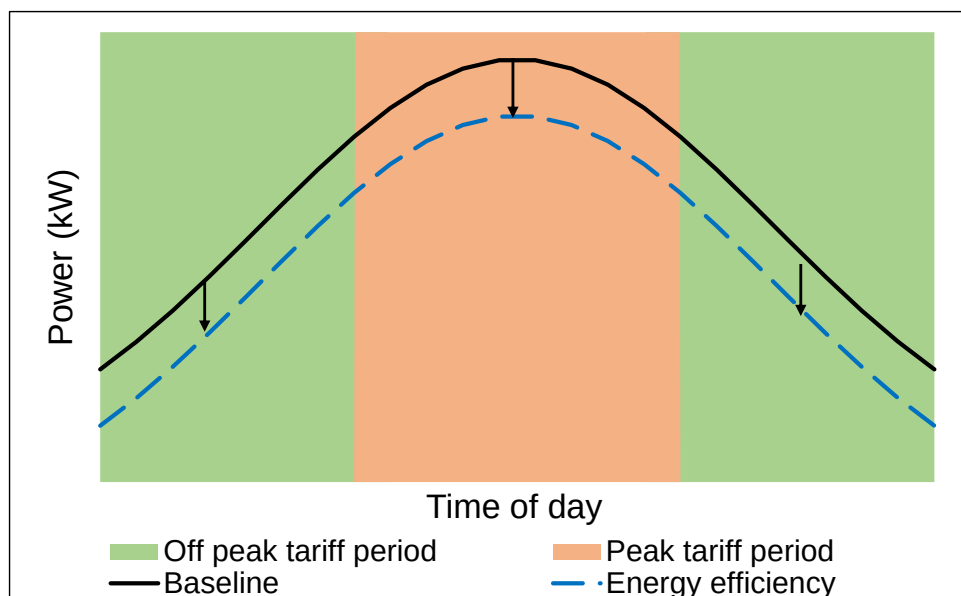


Figure 10: Power profile for a typical energy efficiency initiative [19]

Typically, energy efficiency is measured by specific energy consumption. For a platinum processing plant, energy efficiency would therefore be measured in kWh/ton of product. Over and above the electrical consumption and cost savings associated with energy efficiency initiatives, the initiatives also reduce the environmental impact of the process whilst increasing operational efficiency [44].

1.3.3 Evaluating electrical cost saving initiatives

Literature shows that, although not implemented on platinum processing plants, auxiliary system load management and energy efficiency initiatives have been realised across many other industrial process auxiliary systems. These processes include iron and steel making [36, 45, 46], fertilizer [47], cement [48-54], coal [27, 55], gold [18, 19], and ferro metal [56] processing plants. Within these industries, electrical cost and consumption saving initiatives have proved to be particularly relevant when electricity contributes significantly to the plant's total operational cost.

It is therefore clear that similar opportunities for auxiliary system electrical cost and consumption savings exist in the platinum processing industry. It is, however, necessary to investigate why such opportunities have not been previously implemented within the platinum processing industry. To do this, the priority of implementing electrical cost saving opportunities needs to be determined and then rated according to the relevant business factors.

South Africa has historically had low electricity costs and as such, electrical cost savings were not a priority in industries, including platinum mining and processing [33]. However, with above-inflation increases in electricity and more stringent environmental impact regulations, electrical cost and consumption savings have become more attractive to high consumption industries [57]. Despite this, identifying and implementing electricity cost saving initiatives is still a low priority business factor [48], as shown in Table 1.

Table 1: Importance of business factors to industry [48]

Business factor	Ranking (0 = least important, 5 = most important)
Meeting regulatory requirements	5
Meeting production schedule	4.5
Maintaining product quality and consistency	4.3
Keeping up with new or shifting market demands	3.3
Having a reliable, high-quality supply of electricity	3.3
Maintaining market niche	2.5
Keeping up technologically with competitors	2.3
Maintaining a happy and productive staff	2.3
Identifying and implementing electricity cost saving initiatives	1.3

The low priority of identifying and implementing electricity cost saving initiatives can be credited to deterrents usually faced when trying to implement these initiatives [51]. Such deterrents usually inhibit plant personnel from attending to the more important business factors. It is therefore necessary that, when identifying and implementing electrical cost saving initiatives on platinum processing plants, the following deterrents should be avoided [19, 51]:

1. **Limited capital:** Large capital is often required to implement electrical cost saving initiatives. This is a limiting factor when implementing electrical cost saving initiatives.
2. **Production concerns:** The main goal of a platinum processing plant is to maintain production quantity and quality. An electrical cost saving initiative which negatively affects production would not be accepted by plant personnel.
3. **Limited staff time:** Plant staff will prioritise production tasks over the implementation and maintenance of electrical cost saving initiatives.
4. **Information:** In some instances, plant-specific energy efficiency information may be available. However, the processing of this information is time consuming. In other cases, the information necessary to implement cost saving initiatives may not be available.
5. **Reliability:** To maintain production volume and quality, the reliability of equipment should not be compromised when implementing electrical cost saving initiatives.
6. **Inconvenience:** Smaller electrical cost saving initiatives may be viewed as an inconvenience by plant personnel. The reward of implementing such initiatives must be greater than the inconvenience caused to plant personnel who must implement and maintain the initiative.

With these historical deterrents in mind, a set of criteria has been developed. The criteria, when met, ensure that electrical cost saving investigations and initiatives do not compromise more important business factors such as meeting regulatory requirements and meeting the production schedule.

Moreover, the criteria can be used during the feasibility investigations of cost saving initiatives to quickly eliminate infeasible initiatives. In order for an electrical cost saving initiative to be considered feasible, the initiative should meet all four of the criteria listed below [18, 19]:

1. The electrical cost saving initiative should have a suitable payback period (less than 12 months); however, initiatives that require no capital expenditure should be prioritised.
2. The electrical cost saving initiative should be tested and implemented with minimal disturbance to the plant operation. Plant downtime should be avoided.

3. The electrical cost saving initiative should be feasible from an operations perspective. Complicated control requiring large amounts of instrumentation should be avoided.
4. The electrical cost saving initiative should not compromise plant production or quality.

It is emphasised that, when assessing electrical saving opportunities, all four criteria above must be satisfied if the initiative is to be implemented. By satisfying the criteria, the deterrents listed above will be avoided and as a result electrical cost savings on the auxiliary systems can be achieved.

Table 2 below lists the auxiliary system electrical cost and consumption saving initiatives identified through a literature review. The initiatives are evaluated according to the criteria developed above. The goal of the evaluation is to determine if such initiatives could be applied to platinum processing plants whilst avoiding the deterrents that have historically prevented their application.

Table 2: Evaluation of electricity cost saving opportunities on plant auxiliary systems

Ref.	Description	Energy saving	Requirements	1: Suitable payback	2: Minimal plant disturbance	3: Operational feasibility	4: Uncompromised production	Feasible for platinum processing plant
[36]	Energy efficiency optimisation of a steel blast furnace cooling system and load shift of a PCI plant.	Energy efficiency: 170 kW reduction. Load shift: 600 kW peak load shift.	Stopping of unnecessary equipment, implementation of load management control strategy.	Yes	Yes	Yes	Yes	Yes
[58]	Installation of energy efficient motors and VSDs on rolling mill fan and pump.	Fan: 1 400 MWh/year. Pump: 701 MWh/year. Payback period greater than 1 year.	Retrofit of existing plant motors.	No	No	Yes	Yes	NO
[45]	Iron plant compressor set-point reduction.	1 404 kW peak demand saving.	Simulation and test of compressor set-point reduction.	Yes	Yes	Yes	Yes	Yes
[55]	Load management of colliery conveyor systems.	Electricity cost reduction of 49%.	Implementation of load management control strategy.	Yes	Yes	Yes	Yes	Yes

Ref.	Description	Energy saving	Requirements	1: Suitable payback	2: Minimal plant disturbance	3: Operational feasibility	4: Uncompromised production	Feasible for platinum processing plant
[59]	Implementation of a framework to identify cost savings through operational changes to a steel plant's compressor plant.	16 837 MWh/year.	Prioritisation strategy to identify plant with greatest savings potential.	Yes	Yes	Yes	Yes	Yes
[27]	Load management of mine conveyor system.	Peak load shift of 1.7 MW to 3.6 MW.	Implementation of load management control strategy.	Yes	Yes	Yes	Yes	Yes
[53]	Installation of VSD on a cement plant's fans, dust collection system upgrade.	Fan: 3.277 MWh/year. Dust collection: 128 kWh/year. Payback period greater than 1 year.	Retrofit of existing plant motors.	No	No	Yes	Yes	NO
[49]	Upgrade to a cement plant pre-heater induced draft fan.	597 kW demand reduction. Payback period greater than 1 year.	Retrofit of existing plant motors.	No	No	Yes	Yes	NO

Ref.	Description	Energy saving	Requirements	1: Suitable payback	2: Minimal plant disturbance	3: Operational feasibility	4: Uncompromised production	Feasible for platinum processing plant
[47]	Load management of a fertiliser plant.	850 kW peak load shift.	Implementation of load management control strategy.	Yes	Yes	Yes	Yes	Yes
[60]	Load management of crushers.	Electricity cost reduction of 45%.	Implementation of load management control strategy.	Yes	Yes	Yes	Yes	Yes
[34]	Isolation of gold compressed air system from centralised ring.	840 kW energy efficiency for centralised ring. Payback period of 3 months.	Installation of isolation valve.	Yes	Yes	Yes	Yes	Yes
[35]	Load management of milling circuit using VSDs.	Decrease in energy required per ton milled.	Installation of VSDs on plant mills. Real time predictive control.	No	No	Yes	Yes	NO
[46]	Load management of a steel plant batch electric arc furnace.	Electricity cost reduction of 5.7%.	Optimised scheduling.	Yes	Yes	Yes	Yes	Yes

Ref.	Description	Energy saving	Requirements	1: Suitable payback	2: Minimal plant disturbance	3: Operational feasibility	4: Uncompromised production	Feasible for platinum processing plant
[61]	Construction of new compressed air generation system.	Decrease in specific energy consumption, Payback period greater than 1 year.	Installation of new compressors, control instrumentation and piping system.	No	No	Yes	Yes	NO
[61]	Steam trap replacement.	1897.42 MWh/year. Payback period of 0.74 years.	Installation of new steam traps.	Yes	Yes	Yes	Yes	Yes

Analysis of the table shows that energy efficiency opportunities that require large capital expenditure should not be considered for platinum processing plants. These opportunities often require the installation of new technologies which results in plant down time. Furthermore, the performance of these new technologies is not always guaranteed and so there exists the risk that payback periods may be longer than predicted.

Energy efficiency initiatives which require no capital or have small payback periods contain significantly less risk than those which require large capital and often require no plant down time for their implementation. As such, these initiatives meet all four criteria for implementation and so similar opportunities should be investigated on platinum processing plants.

The table also shows that load management strategies can be successfully implemented on plant auxiliary systems. Furthermore, these initiatives often require little to no capital inputs and can be easily implemented. Therefore, similar low capital, easy to implement opportunities for the load management of plant auxiliary systems should be investigated on platinum processing plants.

1.4 Electrical cost saving identification methodologies

A critical review of literature has shown that there is currently no method for the identification of load management and energy efficiency initiatives on platinum processing plant auxiliary systems. It was however seen in Section 1.3 that load management and energy efficiency initiatives have been identified and implemented on auxiliary systems in other industries.

The methodologies used to identify these initiatives fall into four main categories, namely benchmarking, energy auditing, baseline and energy intensity analysis and simulation. Each of these initiative identification methodologies will be discussed in more detail below. The applicability of the methodology to this study will also be reviewed.

1.4.1 Benchmarking

The practice of evaluating a system performance against a reference point is referred to as benchmarking [62]. In benchmarking practices, a reference point or goal is set. Thereafter, quantifiable performance indicators, such as specific cost per production, are determined and compared with the target. An example of this is shown in Figure 11, in which the specific comminution energy of ten gold processing plants is benchmarked [63].

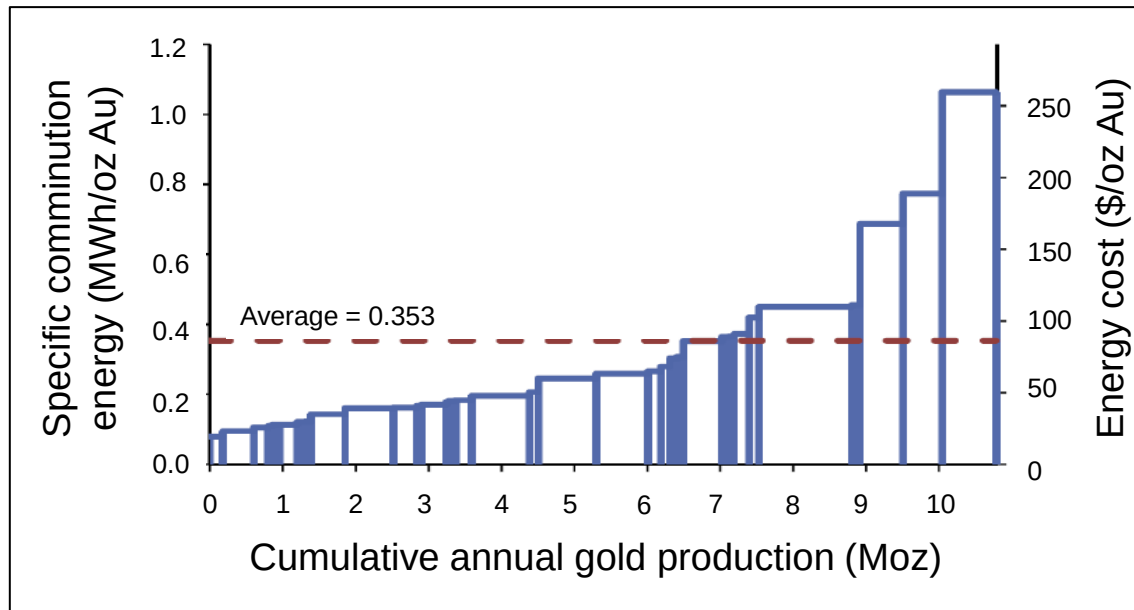


Figure 11: Specific comminution energy benchmarking of ten gold plants (adapted from [63])

This comparison provides an understanding of where the process being analysed is over or under performing. The goal of this is to then identify the areas in which a process is underperforming. These areas can then be prioritised for investigation so that the entire process efficiency is increased [11].

Benchmarking practices have been applied in various industries including the mining industry. In these applications, the specific energy consumption of processes has been compared. In some cases, the recommendations made by these comparisons were implemented, resulting in significant energy efficiency improvements [11].

In addition to the benchmarking of entire systems, benchmarking techniques have been successfully applied to identify and implement electrical cost saving initiatives on industrial auxiliary systems. Industries in which this has been implemented include deep-level mining [11], steel making [64] and gold processing plants [63]. As such, similar techniques can be used to identify electrical cost saving opportunities on platinum processing plant auxiliary systems.

1.4.2 Energy auditing, baseline analysis and intensity analysis

Conducting energy audits is a method widely used within industry to assess how energy is used within industrial facilities, and where energy is wasted within industrial facilities. This information is then used to identify opportunities for cost and energy savings. The basic procedure that all energy audits follow is shown in Figure 12. This procedure will be briefly described below but is reported on extensively in literature [42, 65].

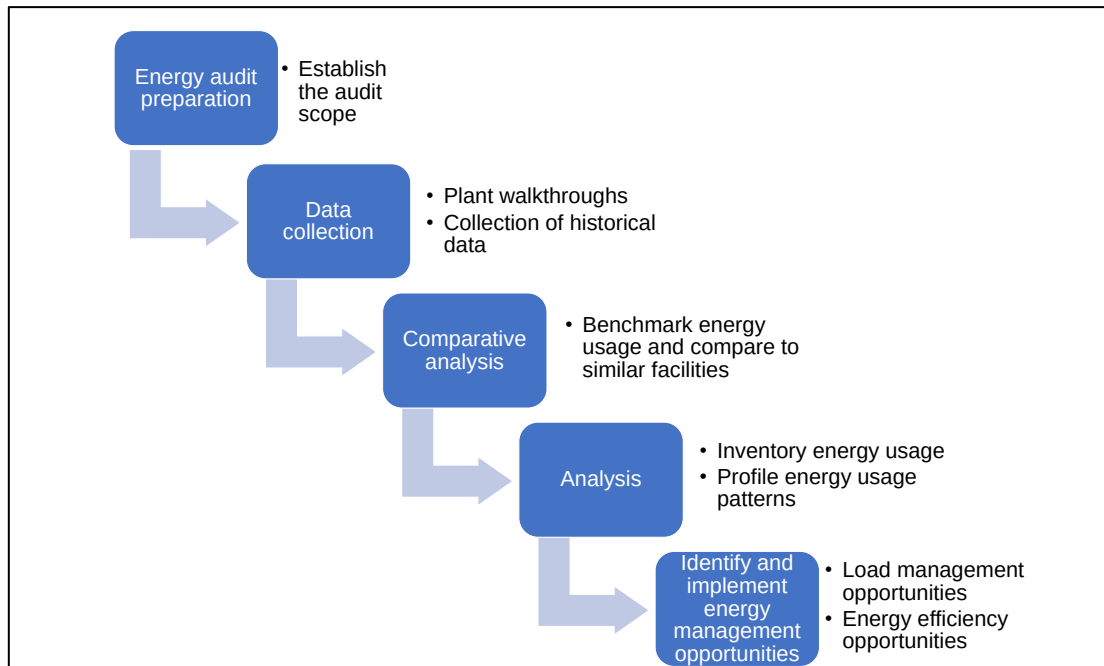


Figure 12: Overview of the energy audit procedure [42, 65]

As illustrated in Figure 12, the initial step when conducting an energy audit is the audit preparation, in which the energy audit scope is established. In this phase of the audit the following questions should be answered:

- What is the objective of the audit?
- What energy source will be audited?
- Who will be conducting the audit?
- Which sites are to be audited?
- What is the timeline for the audit?

Only when all these questions have been answered can the data collection phase of the audit commence. In this phase, all the data necessary to answer the above questions must be collected by the designated energy auditor.

To achieve this, a plant walkthrough must be completed. This will allow the auditor to become familiar with the plant layout and operations. Thereafter production and energy data must be collected. This data may include the daily tonnes produced by the plant as well as the electricity bills, motor lists and tag names [42, 65].

With this information, comparative analysis of similar systems can be conducted. The process followed to complete such analyses is benchmarking, as described in Section 1.4.1 above. As

before, the objective of the benchmarking of similar systems is to identify underperforming systems and prioritise these systems for further investigation [11].

The underperforming systems identified through the comparative analyses will then be further analysed. The two techniques through which these systems are analysed are baseline analysis and intensity analysis [42, 65].

Baseline analysis

Baseline analysis refers to the construction and analysis of graphs showing the load shape (kW) of a system, process, or piece of equipment over time. Such graphs are referred to as load profiles. When constructed for an entire plant, load profiles can be useful for determining the energy usage characteristics of the plant [42, 65].

The shape of the load profile depends on the characteristics of the system, process, or piece of equipment being analysed. Thus, load profiles are unique; however, certain information can frequently be derived from the profiles. This information is summarised in Table 3.

Table 3: Common information derived from load profiles [65]

Information	Description
Peak load	The time of day at which the maximum load occurs as well as the magnitude of the load can be determined.
Night load	The night load can be determined. If the system operates continuously, the night load should not differ from the day load.
Start-up	Equipment start-ups can easily be identified through analysis of the load profile.
Shutdown	Equipment shutdowns can easily be identified through analysis of the load profile.
Production	The effects of varying production should be evident in the load profile.
Problem areas	Problem areas, such as a short cycling compressor, can easily be identified through the load profile.

When conducting energy audits, the purpose of performing a baseline analysis, and therefore constructing load profiles, is to identify loads which are suitable for load management. Such initiatives have been widely reported on in literature. Energy audit and baseline analysis techniques have been used to identify load management opportunities on gold processing plants [18, 19], cement plants [51, 52], and steel mills [46].

From these applications, it is clear that energy auditing and baseline analysis are useful tools in identifying load management opportunities. Thus, these techniques will also be applied to identify similar opportunities on platinum plant auxiliary systems.

Intensity analysis

Like baseline analysis, intensity analysis is performed after the relevant data has been collected during the energy audit. The analysis is used to show the variation in system, process, or equipment energy usage with production. This is achieved through the use of intensity scatter plots in which energy usage is plotted on the y-axis whilst production is plotted on the x-axis [65, 66]. An example of this is given in Figure 13, in which a facility's monthly steam consumption is compared with the monthly production.

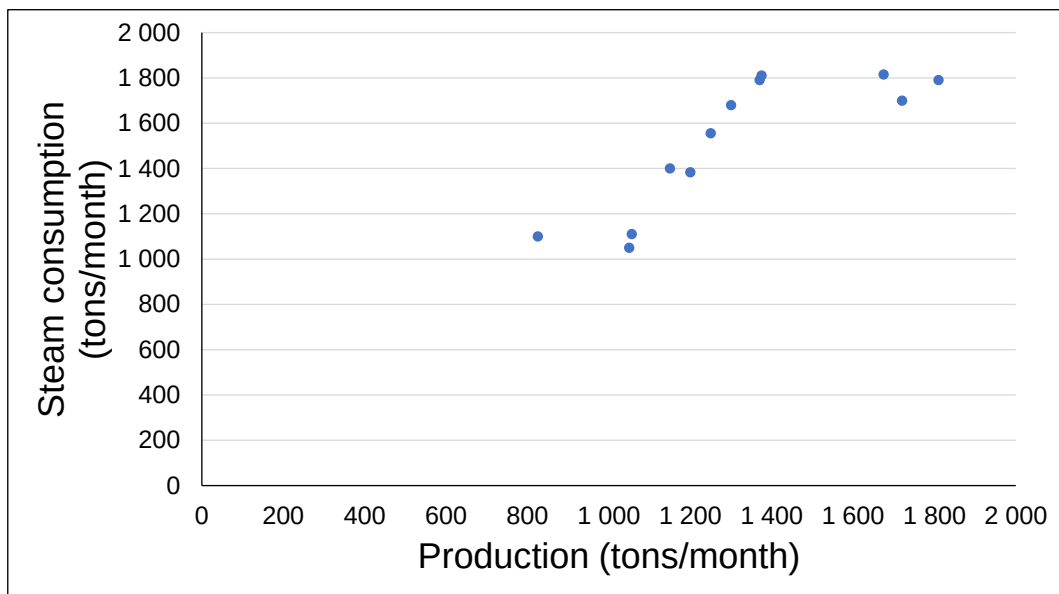


Figure 13: Steam consumption intensity plot (adapted from [66])

Alternatively, the daily energy intensity in terms of specific energy per production (e.g., kWh/ton) can be plotted on the y-axis, whilst time (e.g., day) is plotted on the x-axis. This provides a time-dependent intensity plot that illustrates how the system intensity varies over the measurement period [65, 66].

These plots allow for qualitative analysis of the energy-production relationship of the analysed system. When conducting an energy audit, the purpose of this is to identify systems in which there is weak energy control. These systems can be identified by observing areas in which energy consumption varies for the same production [65, 66].

As with baseline analysis, intensity analyses of industrial processes have been reported on in literature. Such analyses have been applied to successfully identify and implement energy efficiency initiatives in the cement [53], car manufacturing [61], dairy [67], water treatment [68], and metal fabrication [69] industries.

The literature reviewed has shown that intensity analysis has not yet been applied to identify energy efficiency opportunities on platinum processing plant auxiliary systems. However, as the method has been successfully applied to other industries, it will be used to identify auxiliary system energy efficiency initiatives as part of this study.

1.4.3 Simulation

Simulation techniques have been used across various industries to identify electrical cost saving opportunities. Often, simulations have been used in order to consider all operational constraints when assessing the feasibility of electrical cost saving initiatives. Such constraints include production forecasts, equipment reliability and equipment operational capacity.

The goal of assessing these constraints is to ensure that implemented initiatives do not negatively affect the overall plant production [19]. Furthermore, simulations ensure that the identified initiatives do indeed result in electricity cost and consumption savings [45].

Although all simulations are case specific, those used to identify and assess electrical cost saving opportunities follow the same simulation procedure. This procedure is provided below [70]:

1. Identify, formulate, and understand the problem to be solved through simulation.
2. Identify and collect the system data that will be needed for the simulation.
3. Develop the simulation model.
4. Validate the simulation model results.
5. Simulate scenarios using the validated model and interpret and implement the results.

This procedure has been applied to achieve electrical cost savings on plant auxiliary systems in industries such as gold processing [19], deep-level mining [27, 70], iron and steel making [45, 71], waste water treatment [72] as well as in commercial buildings [73, 74]. Despite these successful implementations, simulation of systems with the goal of achieving electrical cost and consumption savings has limitations. These limitations include:

- Simulations require accurate input data in order to model plant processes and return accurate simulation results [70].
- All simulations make use of assumptions and so, if simulation assumptions are not satisfied, the simulation results will be incorrect [70].
- Many simulations are simulated for steady state conditions and so simulation results are not accurate when real-world conditions vary from the steady state conditions [19].

- Many software suites used for simulation are not open source and so simulation techniques are not always accessible to plant personnel [75].

Due to these limitations, simulation techniques will not be used to identify cost saving opportunities in this study. Instead, a simplified approach will be followed in which benchmarking, and baseline and intensity analysis methods as described above will be used.

1.5 Problem statement

South African platinum mining operations are struggling with low profit margins due to increasing operational costs and decreasing production. In order to remain profitable and prevent mine closures, mining operations must decrease their operational costs. One such area in which operational costs can be decreased is electricity.

Historically, most of the work to decrease the electricity costs of platinum mining operations has been focussed on underground mining. Despite the fact that platinum processing plants typically consume 19% of the total electricity usage of a platinum mining operation, very little research has been done into reducing plant electricity costs.

This is because there exists a general perception that cost savings cannot be achieved on platinum processing plants due to the inability to load shift large comminution and smelting equipment. Furthermore, it is believed that electricity savings cannot be achieved due to the constant operating nature of these plants.

It has, however, been observed that platinum plant auxiliary systems, namely compressed air, transport, pumping, and agitation systems, consume a large fraction of a plant's total electricity usage. Such auxiliary systems have been optimised through load management and energy efficiency initiatives in other industries. However, no methodology exists for the identification of similar opportunities on platinum processing plants.

There therefore exists a need to develop a methodology to identify electricity cost saving initiatives on platinum processing plant auxiliary systems.

1.5.1 Study objectives

The primary objective of this study is to develop a methodology to identify electrical cost saving opportunities on platinum processing plant auxiliary systems. The methodology must be generic to all platinum processing plants. In order to achieve this, this study aims to develop, implement, and verify a methodology to:

1. Benchmark and prioritise platinum processing plant auxiliary systems for further investigation.
2. Identify load management opportunities on platinum processing plant auxiliary systems.
3. Identify energy efficiency opportunities on platinum processing plant auxiliary systems.

1.5.2 Scope of the study

The study scope is limited to the investigation of South African platinum processing plants. More specifically, the scope is limited to the investigation of electrical cost and consumption saving initiatives on platinum plant auxiliary systems. These auxiliary systems include compressed air, transport, pumping, and agitation systems.

1.6 Overview of dissertation

Chapter 1

Chapter 1 consists of a brief overview of the platinum mining industry in South Africa, as well as the challenges facing the industry. This is followed by a literature review of initiatives which were successful in reducing plant auxiliary system electricity costs. A review of the methodologies used to successfully identify and implement these initiatives is also provided. The overview and literature review provided in this chapter is used to formulate the problem statement and study objectives.

Chapter 2

In Chapter 2, a generic methodology is developed to address the need identified through Chapter 1. The methodology developed in this chapter includes a benchmarking method to determine which platinum processing plant to prioritise for further investigation. Thereafter, a method to identify load management and energy efficiency initiatives on platinum processing plants is developed.

Chapter 3

In this chapter, the methodologies developed in Chapter 2 are validated. The benchmarking and load management and energy efficiency identification methods are applied to real-world case studies. The cost savings achieved from the implementation of the methodology are then quantified.

Chapter 4

A summary of the study is presented in Chapter 4. The study objectives are reviewed whilst recommendations for future work are made.

CHAPTER 2: DEVELOPMENT OF A COST SAVING METHODOLOGY

2.1 Overview of methodology

In Chapter 1, it was found that obtaining electrical cost savings on the milling and smelting sections of platinum plants is not feasible. However, electrical cost savings may be achieved through load management and energy efficiency initiatives on platinum processing plant auxiliary systems.

Implementation of such initiatives on platinum processing plant auxiliary systems has not been reported on in literature. As such, this chapter will provide a methodology for the identification of load management and energy efficiency initiatives on platinum processing plant auxiliary systems.

The methodology developed to identify cost saving opportunities on platinum processing plants is based off a typical energy audit process. The process is, however, adapted to be specific to platinum processing plants and so incorporates high-level benchmarking, baseline analysis, and intensity analysis. An overview of the platinum plant specific methodology is shown in Figure 14.

The preliminary stage of the methodology requires the collection of the necessary plant data and measurements. Thereafter, the benchmarking of plant auxiliary system energy usage of multiple processing plants will be performed. This will allow for direct comparison of plant performance and so will reveal which plant to prioritise for further investigation.

Once the preliminary stage is completed, electrical baselines will be developed and analysed to identify load management opportunities on the auxiliary systems. Similarly, electrical intensities will be developed to identify auxiliary system energy efficiency opportunities. The saving opportunities identified will then be evaluated against certain criteria. If the opportunities meet all criteria, they will be implemented, and the cost savings achieved will be verified.

The methodology is developed to be generic to all platinum processing plants. However, in order to illustrate key points throughout the chapter, a specific concentrator is used to represent a typical plant. Due to confidentiality agreements with platinum producers, the plant used in the chapter cannot be identified.

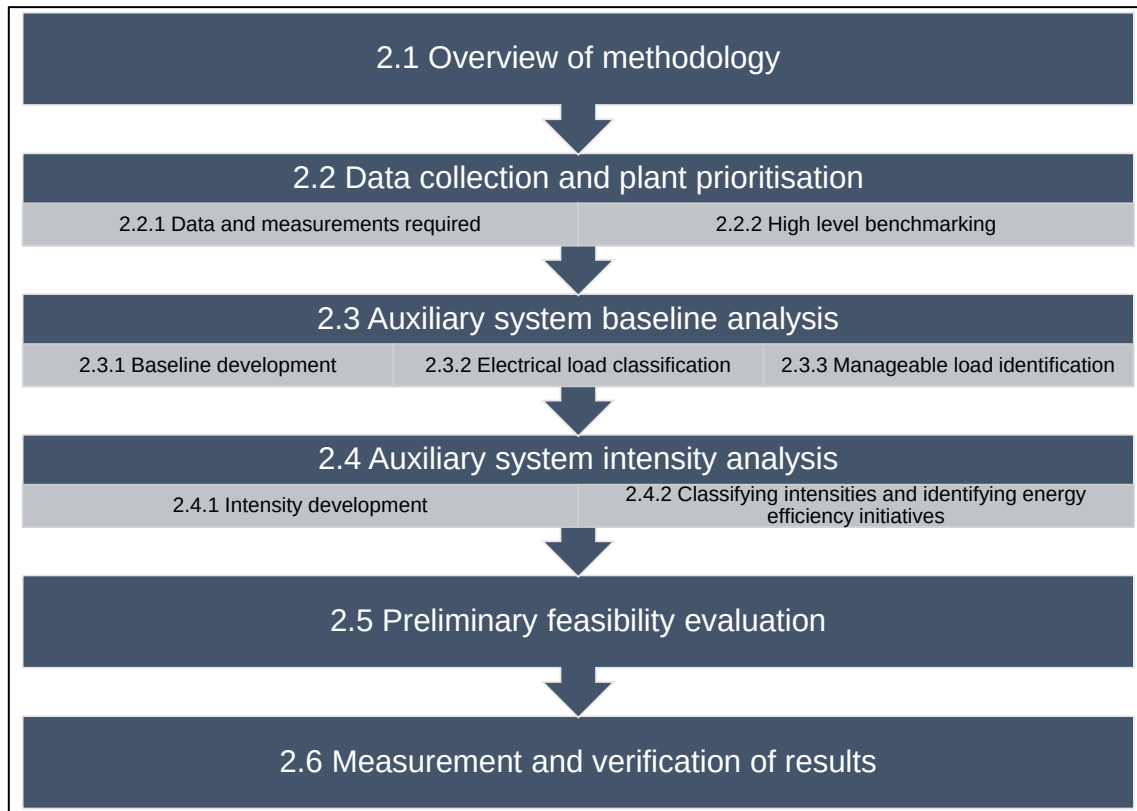


Figure 14: Overview of methodology derived throughout Chapter 2

2.2 Data collection and plant prioritisation

2.2.1 Data and measurements required

The initial step of the methodology to identify auxiliary system electrical cost saving opportunities is the collection of necessary data and measurements. This data collection can be achieved by conducting an energy audit. Although platinum processing makes use of various energy sources, this methodology will focus specifically on electrical energy audits [65].

The goal of energy audits on platinum processing plants is to compile an electrical load inventory in which the magnitude and type of load is identified [19]. This will then be utilised to identify cost saving opportunities on plants.

As platinum plants vary, an initial plant walkthrough must be completed. This is performed to gain understanding of the specific plant layout as well as to identify and separate the auxiliary systems from the uninterrupted milling and smelting systems [65].

Once the auxiliary systems have been identified, further analysis is necessary to identify electrical cost saving opportunities. To do this, adequate and accurate auxiliary system power data must

be collected. Due to the large number of electrical motors on a platinum plant, it is recommended that only motors with a rated power larger than 75 kW are considered for further analysis. The motor rated powers can be obtained from the motor nameplates observed during the walkthrough assessment or from plant motor lists.

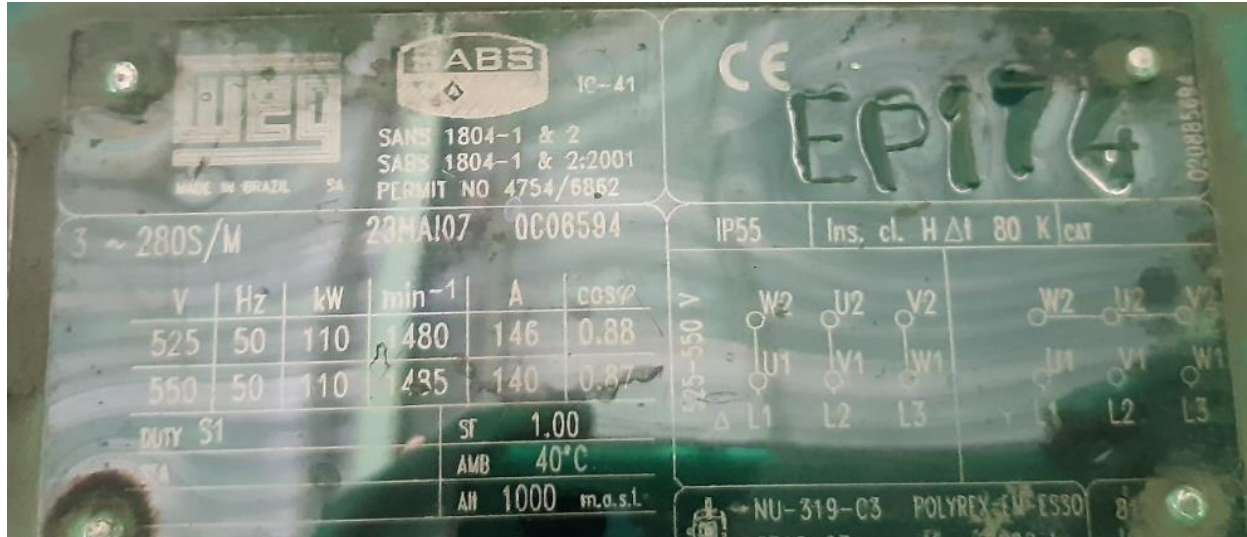


Figure 15: Example of a motor nameplate for a platinum plant conveyor motor

Platinum plants are normally well instrumented for process control purposes. Therefore, the power data needed to compile the electrical load inventory can mostly be obtained from the plant Supervisory Control and Database Acquisition (SCADA) system. However, not all auxiliary system motor powers will be monitored. Therefore, current measurements as well as running statuses can be used to estimate the power consumption, as per Equations 1 [76] and 2 [77], respectively.

$$P_{three\ phase\ system} (kW) = \frac{\sqrt{3} \times V \times I \times PF}{1000} \quad (1)$$

$$E (kWh) = N \times RP \times PF \times operating\ hours \quad (2)$$

Here:

- P is power (kW).
- V is voltage (V).
- I is current (A).

- PF is power factor (%).
- E is energy (kWh)
- N is the number of motors.
- RP is the motor rated power (kW).

If a particular auxiliary motor has no instrumentation, the power consumed by the motor can be determined using a clip-on power transducer [42].

After compiling the electrical load inventory, the auxiliary system electrical loads will have been classified according to their magnitude and type of load. The next step in the methodology is to identify which platinum plant to prioritise for further investigation. This is achieved through high-level benchmarking.

2.2.2 High-level benchmarking

Mining operations often consist of multiple platinum processing plants. As identifying electrical cost saving opportunities is a resource-intensive process, a means to prioritise the processing plant with the largest electrical cost saving potential is required.

One such method to achieve this is benchmarking, in which the performance of the processing plant is evaluated against a reference [62]. This is done by comparison of specific, measurable indicators such as cost per production.

Benchmarking methods have previously been applied to the mineral processing industry, with Ballantyne and Powell comparing the energy usage of gold comminution circuits. The energy usage was compared using an energy intensity, calculated as energy usage per ounce of gold produced [63].

A similar benchmarking method will be used in this study whereby the energy usage of plants will be compared through intensities. However, as this study aims to identify the cost saving opportunities on auxiliary systems, the energy required for milling and smelting will be excluded such that only auxiliary system energy usage is considered.

Plant mills and smelters are large, energy-intensive pieces of equipment and so most will have power meters. Therefore, obtaining an energy intensity excluding the power required for milling and smelting can easily be achieved by subtracting the power required for milling and smelting from the total power consumption of the plant. Therefore, Equation 3 will be used to benchmark the energy usage of platinum processing plants.

$$\text{Energy intensity} = \frac{\text{Energy usage of plant excluding milling and smelting (kWh)}}{\text{tons milled}} \quad (3)$$

The energy intensities resulting from Equation 3 will then be plotted on a bar graph, an example of which is shown in Figure 16. The average intensity of all the processing plants on the mining operation will also be shown.

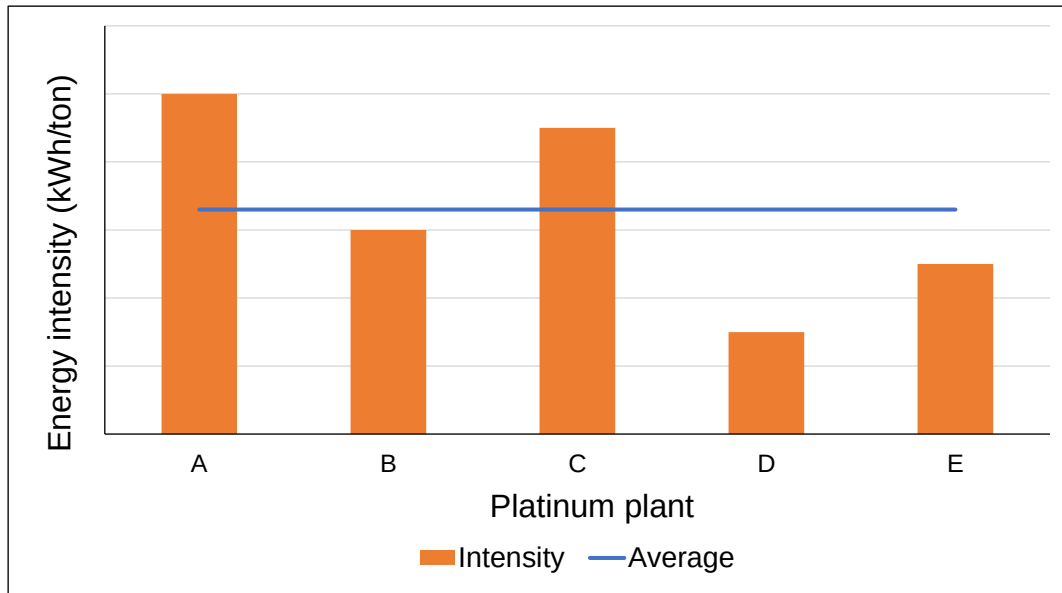


Figure 16: Benchmarking energy intensities of five platinum processing plants

The figure clearly shows that, of the five platinum plants analysed, plant A has the most energy-intensive auxiliary systems and is well above the average intensity of the mining operation. Thereafter, plants C and B have the greatest auxiliary system energy intensities, respectively. Thus, the plants should be prioritized for further investigation according to the methodology in this order.

Once the plant to be prioritised has been identified, the next step in the methodology is to determine the electricity usage trends of the plant auxiliary systems. This is achieved through baseline analysis [19].

2.3 Auxiliary system baseline analysis

Baseline analysis is a fundamental part of any energy audit [78]. In this section, the baseline analysis methodology is applied specifically to platinum processing plant auxiliary systems. The auxiliary system baseline analysis is performed after the relevant data is collected during the initial

platinum plant investigation. The stage in the methodology at which the baseline analysis is performed is reshown in Figure 17.

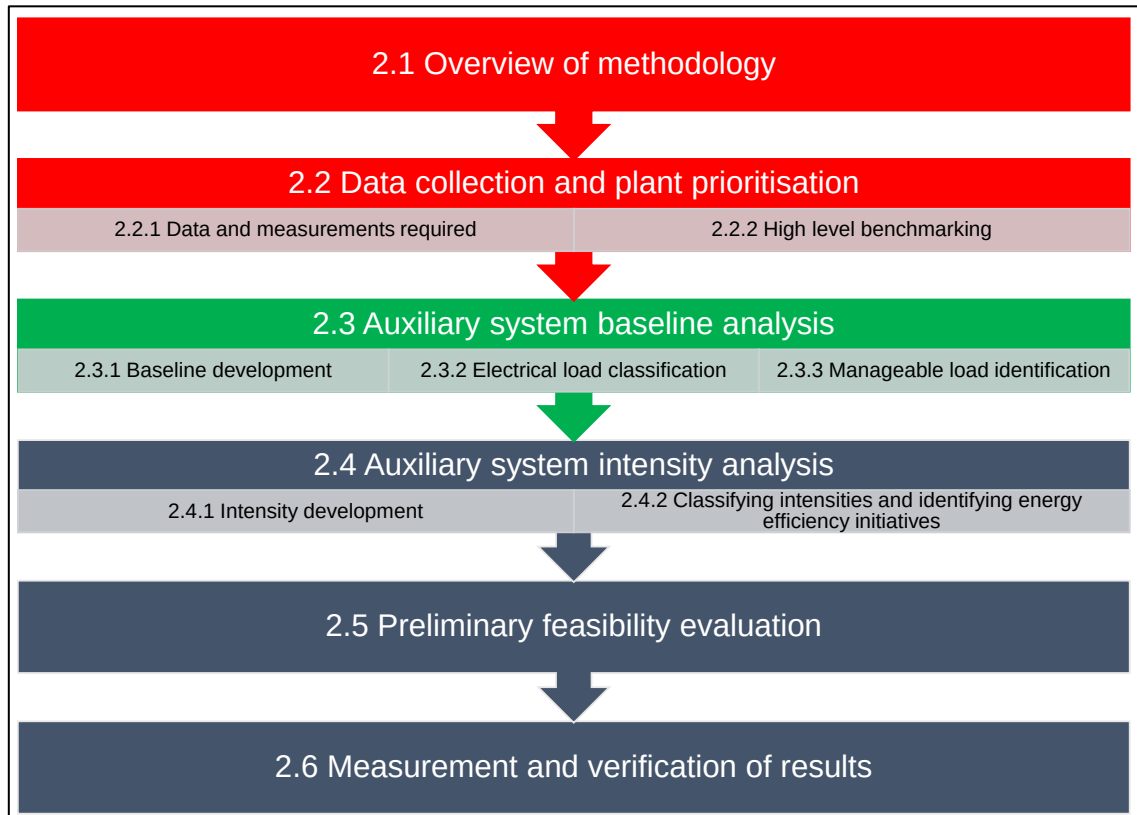


Figure 17: Auxiliary system baseline analysis stage of the methodology

The objective of the auxiliary system baseline analysis is to identify manageable loads through the construction of load profiles [42, 78]. The baseline analysis is also used to identify usage trends while simultaneously providing baselines from which to measure the impact of future electrical and cost saving initiatives [19].

2.3.1 Baseline development

Baseline analysis refers to the construction of an average baseline profile showing the load shape over a period of time. When constructed for an entire facility, baselines can be used to characterise the facility by identifying peak load periods as well as variable loads [66].

It is recommended that baseline profiles be constructed from power and production data collected over a period of at least three months. Moreover, the period that is used to construct the baseline should be representative of “normal operation”. As such, no extreme disturbances to normal production should occur during the baseline period.

Baselines can be developed for all energy sources used during platinum processing. However, Table 4 shows that electrical energy is the main energy source used in platinum production. Therefore, the scope of this study will be limited to electrical energy, and analysis of other energy sources will not be performed.

Table 4: Energy source share of platinum production [79]

Fuel type	Mining (%)	Concentration (%)	Smelting (%)	Refining (%)	Total share in production (%)
Electricity	70	99	70.8	33	72
Diesel/petrol	30	1	0.3	1	11
Coal	0	0	25.5	66	16
Natural gas	0	0	3.4	0	1

The first step in conducting a baseline analysis of a platinum processing plant is to quantify the energy usage of the plant. As the objective of this study is to identify cost saving opportunities of platinum plant auxiliary systems, the energy usage should be classified according to the auxiliary systems. This is illustrated in Figure 18.

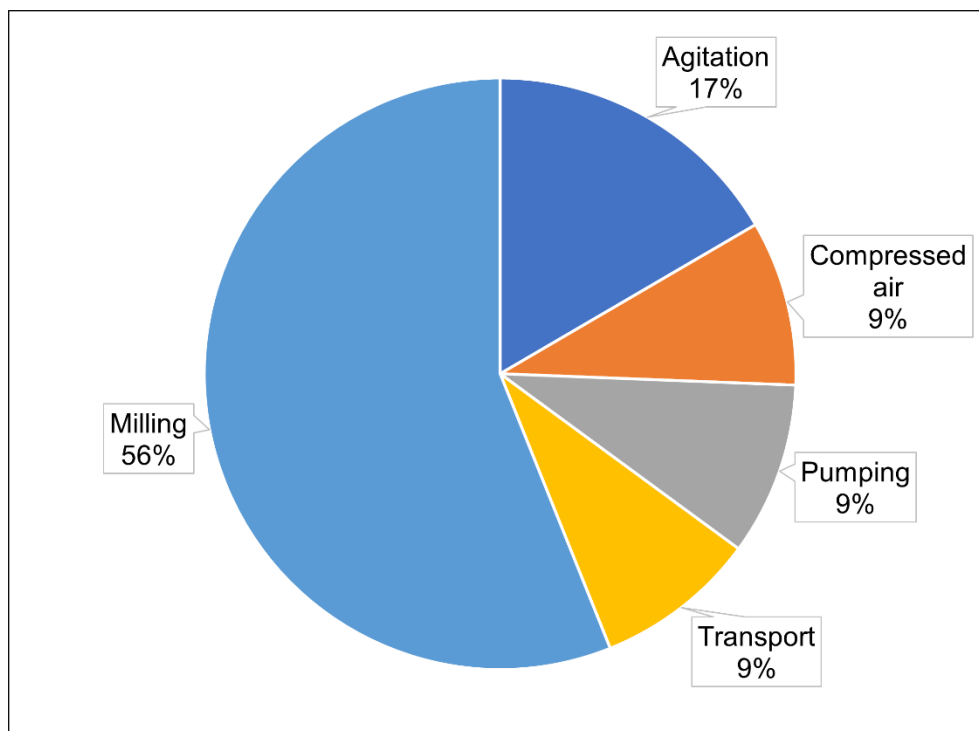


Figure 18: Electrical energy usage of a platinum concentrator observed as part of this study

From the figure it is noted that milling is the most energy-intensive system of a typical platinum processing concentrator whilst auxiliary systems account for 44% of the plant's total electricity usage. Therefore, auxiliary systems consume a large portion of the total electricity supplied to the

concentrator. As such, it is worthwhile continuing with the auxiliary system baseline analysis in order to identify potential auxiliary system saving opportunities.

After quantitatively assessing the magnitude of plant auxiliary system electricity usage, the usage characteristics should be qualitatively assessed. As baseline analysis can be used to identify variable loads, the principal qualitative factor to consider when performing a baseline analysis is Time-of-use (TOU) energy consumption [19].

Figure 19 illustrates the baseline electricity usage of a platinum concentrator (A) as well as the baseline electricity usage of only the auxiliary systems of the same concentrator (B). In the figure, baseline profiles are shown for all TOU days of the week, namely weekdays, Saturdays, and Sundays. These profiles are used to show the trends in electricity usage over a 24-hour period.

From the figure it can be seen that, when averaged over the baseline period, the total plant electricity consumption is relatively constant for all TOU days. The auxiliary system baseline profiles are also mostly constant but do show more variability than the total system, particularly on Saturdays and Sundays.

It should also be noted that the total concentrator and auxiliary systems of the concentrator operate on average at approximately 89% and 84% of the maximum demand observed during the baseline period. This once again shows that the auxiliary system loads have greater load variability than the total plant. To further investigate the load variability, a more detailed view of the auxiliary system baselines is given in Figure 20.

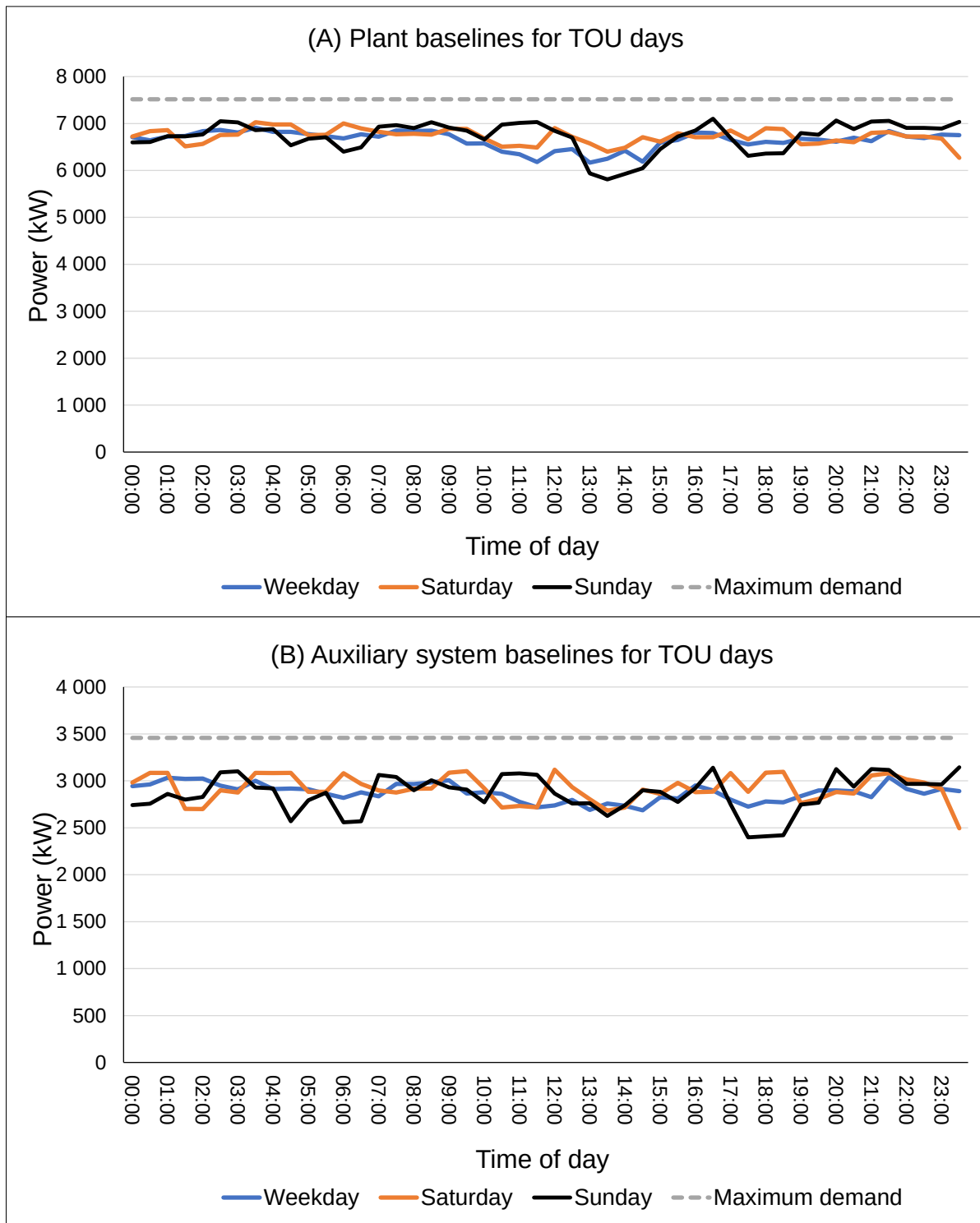


Figure 19: TOU day baseline profiles for (A) a platinum concentrator observed as part of this study and (B) the auxiliary systems of the same platinum concentrator

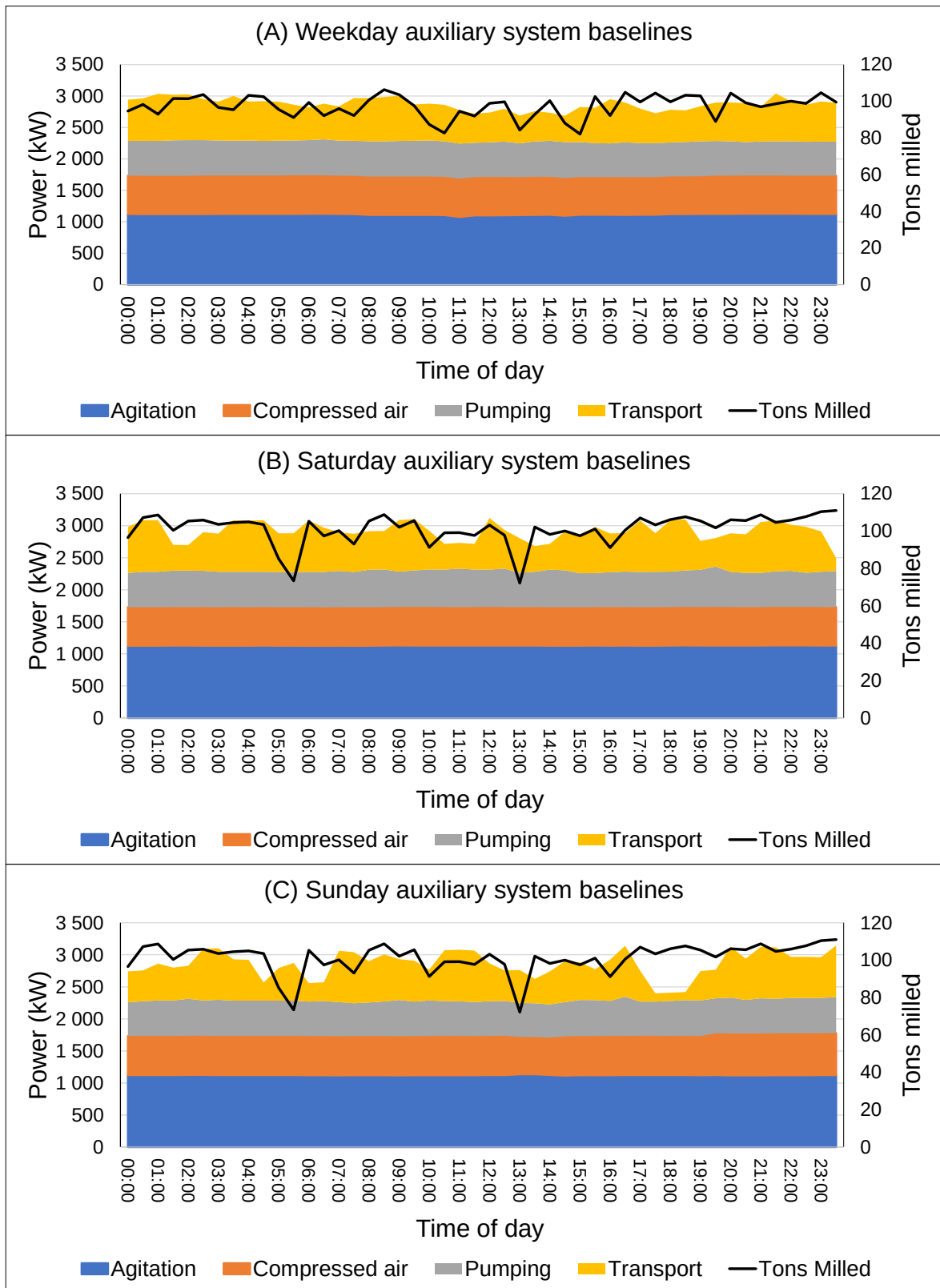


Figure 20: Auxiliary system baseline profiles of a platinum concentrator observed as part of this study for (A) weekdays, (B) Saturdays, and (C) Sundays

Figure 20 illustrates that certain auxiliary system loads are constant throughout the day, whilst other auxiliary system loads vary significantly. The figure also shows that the load variability seen in the baseline profiles is not a result of varying production. This is indicated by the average tons milled per TOU day fluctuating with seemingly little impact on the average power consumption. To understand these baseline profiles and further investigate saving opportunities on platinum processing plant auxiliary systems, the trends of certain loads seen in Figure 20 must first be classified.

2.3.2 Electrical load classification

Cost savings can be achieved by load management of electrical loads, where load management refers to the shifting of load from more expensive tariff periods to cheaper tariff periods, as per the TOU tariff structure. Not all electrical loads are suitable for load management and so loads must be classified before continuing with load management investigations. The main classification in identifying manageable loads is variable and fixed loads.

A variable load refers to equipment that is scheduled or part of an interruptible or batch process. Ideally, variable loads are caused only by variations in production. A fixed load refers to a load that is always drawn, regardless of the production of the facility. Fixed loads represent the unavoidable minimum load that is drawn and as such these loads are considered uninterruptible [65]. Variable and fixed loads are illustrated in Figure 21.

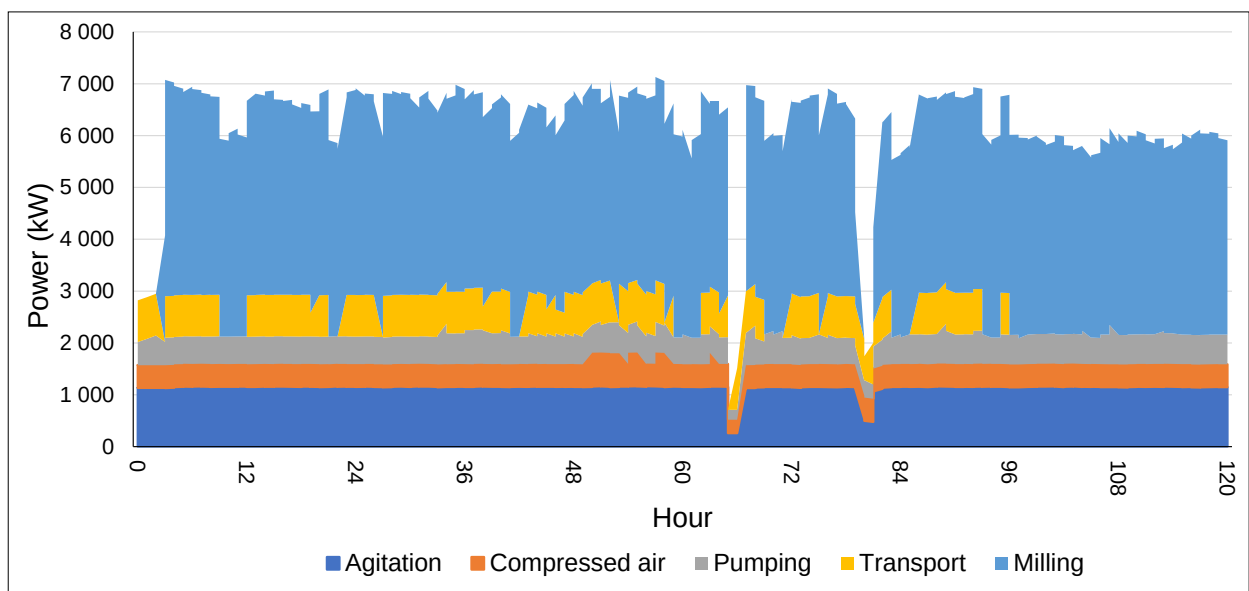


Figure 21: 120-hour load profile of a platinum concentrator observed as part of this study

In Figure 21 the power measurements over a 120-hour period for a platinum concentrator are shown. The figure shows both the milling section of the concentrator as well as the auxiliary systems. When the power measurements are not averaged over a baseline period, significant variance in electrical load is observed. For example, the milling and transport sections of the concentrator show significant variance throughout the entire period. Furthermore, the milling section of the concentrator is completely stopped for maintenance stops from hours 64 to 66 and 80 to 82.

It is, however, noted that all the auxiliary systems, apart from transport, have almost constant load profiles with only minor disturbances observed during the measurement period. Even during the two maintenance stops the agitation, compressed air and pumping systems draw load. As such, these loads can be classified as fixed loads, whilst milling and transportation can be classified as variable loads.

In addition to the graphical classification of fixed and variable loads, the calculation of auxiliary system load factors can be used as a tool to classify loads. The term load factor (LF) refers to the energy consumed relative to the maximum energy that could have been consumed if the maximum demand observed during the measurement period had been observed during the entire period.

LF is an easy method to determine if a load is variable or fixed, with a high LF indicating that energy is consumed at a constant rate, whereas a low LF indicates more load variability. The LF is usually expressed as a percentage, the calculation of which is shown in Equation 4 [42].

$$LF = \frac{kWh \text{ measured in period}}{Max \text{ kW} \times \text{hours in period}} \times 100 \quad (4)$$

The LF over the 120-hour measurement period for each auxiliary system shown in Figure 21 is given in Table 5 below. In the table, it is seen that transport systems have the lowest LF (63%) which confirms the graphical classification of variable and fixed loads.

Table 5: Load factors of concentrator auxiliary systems

Auxiliary system	LF (%)	Load type
Agitation	98	Fixed
Compressed air	69	Fixed
Pumping	71	Fixed
Transport	63	Variable

2.3.3 Manageable load identification

Manageable loads refer to electrical loads that can be scheduled to not operate at peak tariff periods according to the TOU tariff structures. This is often achieved through machine scheduling, in which certain high power consuming equipment is turned on or off according to the TOU tariff [42].

Fixed loads operate continuously and have near-constant load profiles and so they are not suitable for load management. Instead, variable loads are suited to load management, the aim of which is to reduce TOU energy costs. There are, however, certain criteria that must be met before a variable load can be classified as a manageable load. These criteria are [18]:

1. **Uncompromised production:** Cost savings achieved through TOU optimisation will be negated by loss in revenue if the plant production decreases due to load management.
2. **Storage capacity:** By definition, load management initiatives will result in disturbances to the process. To successfully implement load management initiatives, there must be sufficient upstream and downstream storage capacity to attenuate any disturbances.
3. **Increased production in optimal TOU periods:** Load management will result in some loads being clipped during peak TOU tariff periods. The lost production during peak tariff periods should be compensated for by increased production during optimal TOU periods.

When identifying load management opportunities of variable loads, it is critical that the above criteria are met. It is also important to understand the relevant TOU electrical tariff structure. Understanding the tariff structure will allow for the correct identification of load scheduling options.

Most mining companies in South Africa are billed for electricity consumption according to the Eskom Megaflex TOU tariff structure. This tariff structure is used as it encourages strategic load management [80]. The TOU tariff periods for both the high demand and low demand seasons of the Megaflex tariff structure are shown in Figure 22 below. The tariff structure is given in more detail in Appendix A.

The Megaflex high demand season occurs during the months June, July and August whilst the low demand season occurs for the remainder of the year. For both demand seasons, the tariff structure has three TOU days, namely weekdays, Saturdays, and Sundays. For each TOU day the structure also has three billing periods, namely peak, standard, and off-peak. The peak billing period is the most expensive period and off-peak the least expensive period.

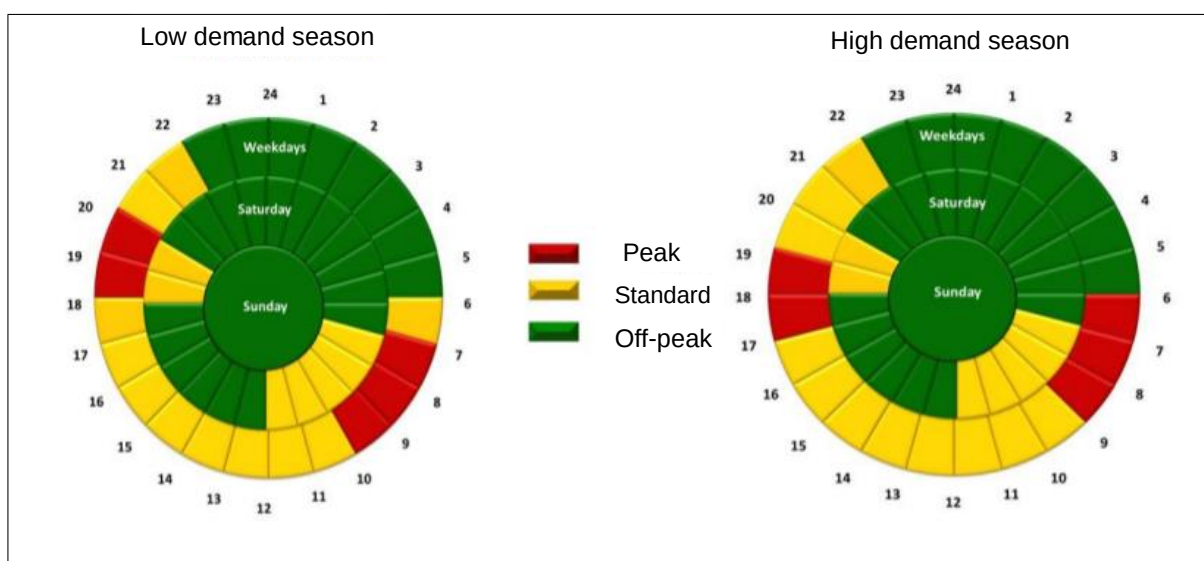


Figure 22: High and low season Megaflex tariff structure²

During the low demand season, peak periods are approximately 200% more expensive than off-peak periods. During the high demand season, this value increases to approximately 500%. When compared with standard periods, the peak periods are roughly 140% and 300% more expensive for the low and high demand seasons, respectively.

The goal of load management is to shift load from the more expensive TOU tariff periods to less expensive periods. For the Megaflex tariff structure, this can be achieved through the following load management strategies [19]:

- I. **Weekend load shift:** For both the high and low demand season, Sunday TOU days consist of only off-peak billing periods whilst Saturdays consist only of off-peak and standard billing periods. Electrical cost savings can be achieved by shifting load from weekdays to Saturdays or (preferentially) Sundays.
- II. **Weekday night-time load shift:** Weekday nights (low demand: 20:00 – 07:00, high demand: 19:00 – 06:00) consist of only off-peak and standard tariff periods. Electrical cost savings can be achieved by shifting weekday daytime loads to the night.

² Adapted from Eskom Enterprises “Tariffs and Charges Booklet 2020/2021.” [Online]. Available: https://www.eskom.co.za/CustomerCare/TariffsAndCharges/Pages/Tariffs_And_Charges.aspx [Accessed 14 March 2021].

- III. Weekday mid-day load shift:** Weekday mid-day periods (low demand: 10:00 – 18:00, high demand: 09:00 – 17:00) consist of only standard tariff periods. Electrical cost savings can be achieved by shifting weekday daytime loads to mid-day periods.

Although specific to the Megaflex tariff structure, similar load management strategies to those listed above can be developed for other TOU tariff structures. All that is required is an understanding of the billing periods of the tariff structure.

To identify manageable loads, loads must be variable so as to allow for scheduling through the above-mentioned load management strategies (I, II, III). Furthermore, the variable loads must satisfy the load management criteria (1, 2, 3). The types of loads identified in Section 2.3.2 are evaluated according to these criteria and load management strategies in Table 6.

Table 6: Evaluation of plant loads to identify manageable loads

Plant system	Load classification	Load management criteria satisfied	Applicable load management strategies
Milling	Variable	2, 3	-
Agitation	Fixed	3	-
Compressed air	Fixed	-	-
Pumping	Fixed	2, 3	-
Transport	Variable	1, 2, 3	II, III

From Table 6 it is observed that, for a typical platinum plant, only transport systems are suited to load management. Furthermore, it is also observed that only load management strategies II and III are applicable. This is because most transport systems do not have sufficient upstream and downstream storage capacity to make use of a weekend load shift. It is further noted that, although milling is a variable load, load shifting of mills is not feasible, as discussed in Chapter 1.

The baseline analysis performed in Section 2.3 is used to identify manageable electrical loads. For the identified manageable loads, further analysis is required to determine if the selected load management strategy can be implemented successfully. This is, however, case specific and so cannot be handled generically due to the variation in plant design and operation. The further analysis of load management opportunities will be discussed in Chapter 3.

Baseline analysis has further revealed that most auxiliary systems on a typical platinum plant are fixed loads and so are not suitable for load management. Therefore, an alternative method to load management must be developed to identify electricity and cost saving opportunities for plant fixed loads.

2.4 Auxiliary system intensity analysis

In Section 2.3 a methodology to identify load management opportunities on platinum plant auxiliary systems was developed. It was seen that most auxiliary systems do not meet the criteria required for load management. Instead, an alternative method to identify electricity and cost saving opportunities for plant auxiliary systems must be developed. One such method is intensity analysis. The stage of the methodology at which the intensity analysis is performed is shown in Figure 23.

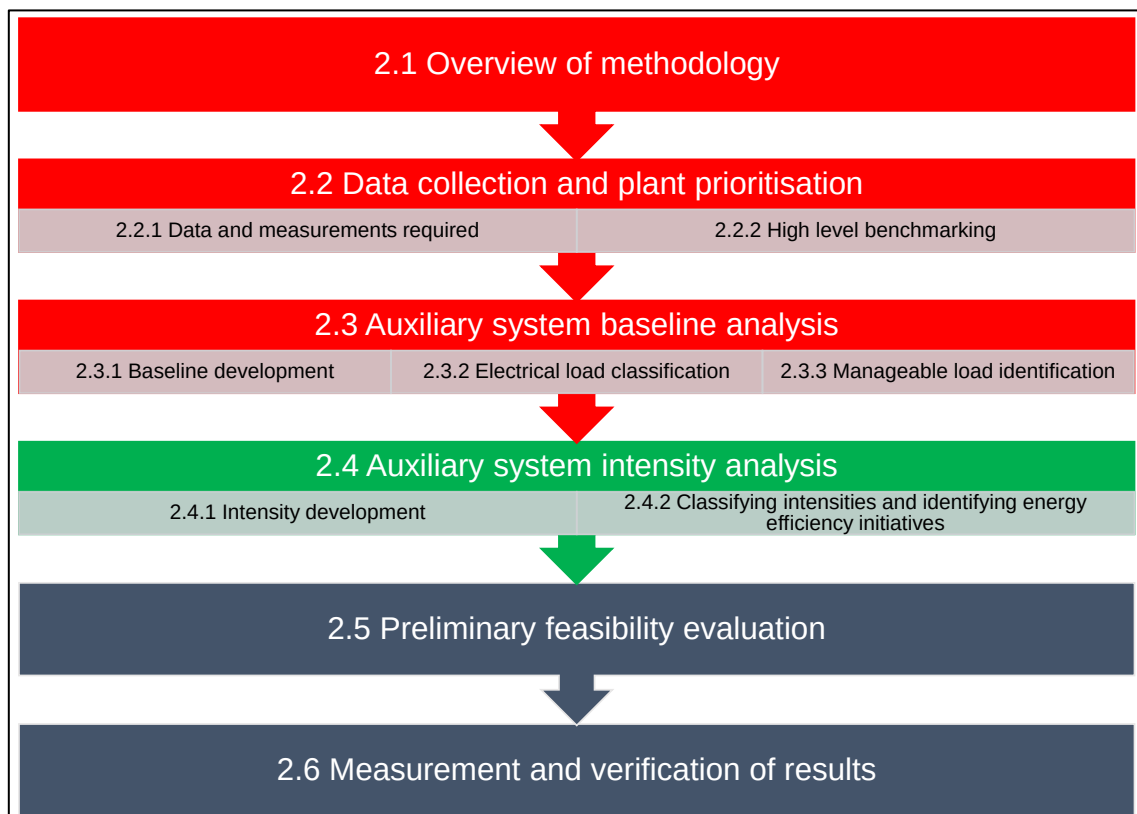


Figure 23: Auxiliary system intensity analysis stage of the methodology

Similar to baseline analysis, intensity analysis forms part of a standard energy audit. However, where the objective of baseline analysis was to identify manageable auxiliary system loads, the objective of intensity analysis is to identify auxiliary system energy efficiency opportunities [66].

2.4.1 Intensity development

Intensity analysis refers to the construction of diagrams which relate the plant production to the plant energy consumption [66]. This can be done in the form of scatter diagrams which show the plant production as an independent variable on the x-axis, whilst energy is plotted as the

dependent variable on the y-axis. These scatter diagrams are independent of time and are instead used to assess energy usage patterns that emerge when relating actual energy consumption to a given production [66]. An example of an intensity scatter plot is shown in Figure 24 below, in which the daily power consumption of a concentrator pumping system is plotted against the daily tons milled by the concentrator.

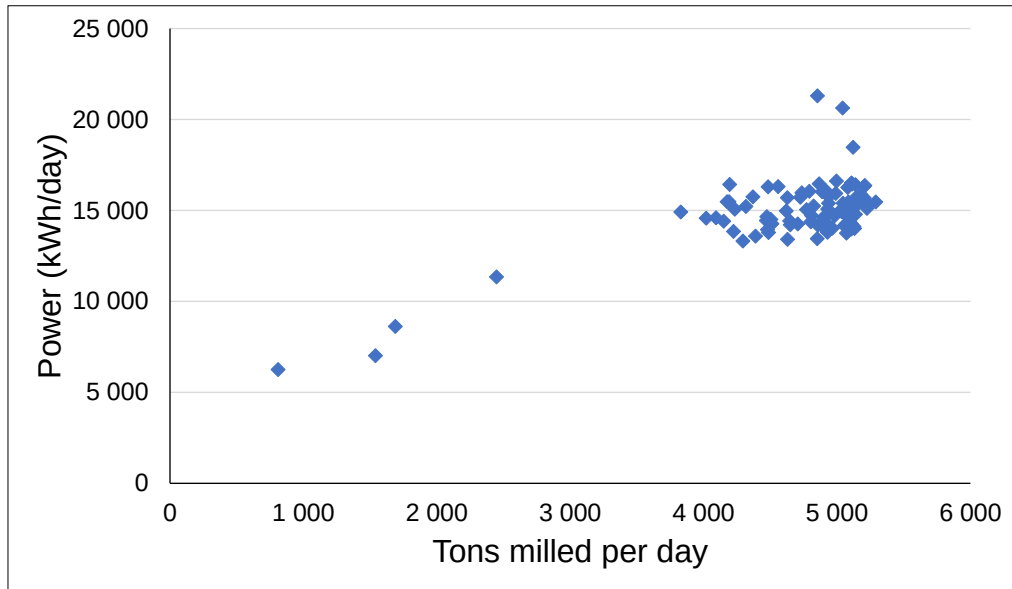


Figure 24: Intensity scatter plot for a platinum concentrator pumping system observed as part of this study

Furthermore, to provide information on how the plant intensities vary with time, the intensities can also be plotted over a measurement period. These diagrams, referred to as time-dependent intensity plots, are used to identify sustained periods of good or poor energy management, and can be constructed for all energy sources [66].

As seen in previous sections, electricity is the main energy source of platinum processing plants and so the scope of this study is limited to electrical energy. Therefore, the energy intensity of a platinum plant auxiliary system can be defined as the energy usage of the auxiliary system divided by the total tons milled or smelted, provided mathematically in Equation 5. An example of a time-dependent intensity plot for a concentrator pumping system is shown in Figure 25.

$$\text{Energy intensity} = \frac{\text{Energy usage of auxiliary system (kWh)}}{\text{tons milled or smelted}} \quad (5)$$

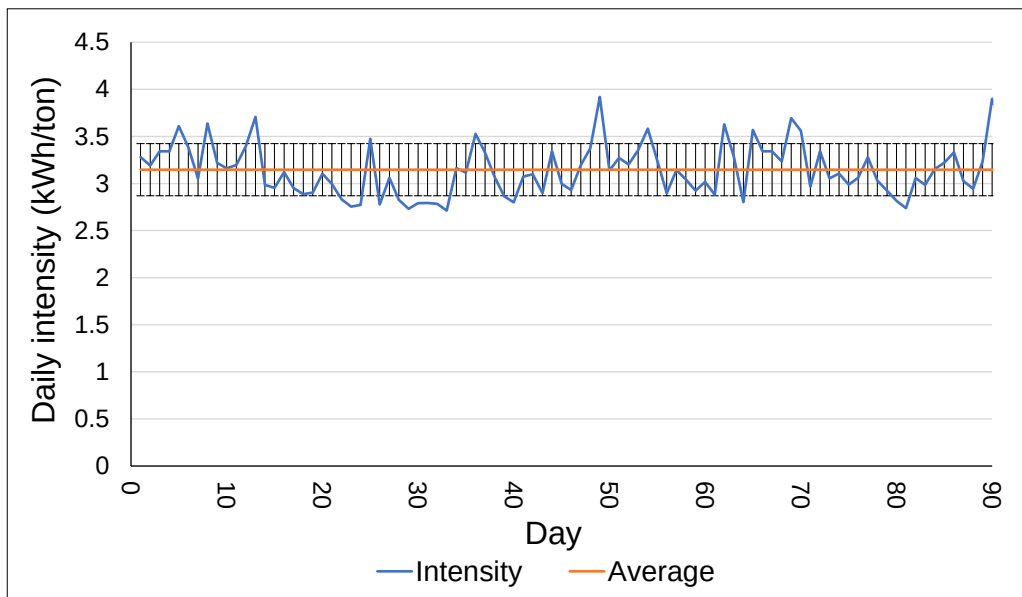


Figure 25: Time-dependent intensity diagram for a platinum concentrator pumping system observed as part of this study

To construct the intensity plots shown above, all production and power data is required. This data is obtained as per the methodology described in Section 2.2. As with the baseline analysis, it is recommended that the intensity plots be constructed over a period of at least three months that represent “normal operation”.

More specifically, to construct intensity scatter plots similar to that shown in Figure 24, the daily power consumption and tons milled for each plant analysed must be collected. As with the baseline analysis, the power consumption should be split according to the different auxiliary systems. This will then allow for the intensity of each auxiliary system to be independently assessed in order to identify energy usage patterns.

Once the scatter diagrams have been constructed, time-dependent intensity diagrams, such as that shown in Figure 25, should be developed. It is necessary to develop such diagrams as analysis thereof will allow for the identification of periods in which the system energy usage is lower than the system average energy usage.

To achieve this, the daily energy intensity (kWh/ton milled) should be calculated and plotted for each day of the measurement period. The standard deviation of the energy intensity, which is a measure of the average scatter of the energy intensity [66], should also be plotted as error bars on the average intensity.

It should be noted that the term error bars is used in order to be consistent with terminology used in graph plotting software suites such as Microsoft Excel. The error bars shown in the figure above and throughout the document do not actually represent measurement error, but instead represent the standard deviation of the energy intensity data around the average energy intensity.

For normally distributed data, 68% of all data would fall within one standard deviation of the mean [81]. As such, intensities falling outside of a single standard deviation of the mean would represent periods in which the deviation of the system energy intensity from the mean is greater than average [66]. Therefore, such periods would represent days in which the system energy intensity is significantly higher or lower than the average energy intensity. This, in turn, would represent periods of either good or poor energy management of the auxiliary system concerned.

This information will be used to qualitatively assess the energy intensity diagrams to identify potential energy efficiency initiatives. This is explained in more detail in Section 2.4.2. As with the scatter plots, this process should be done for all auxiliary systems.

When constructing the time-dependent energy intensity diagrams, it will be necessary to remove outliers that skew the data. Typically, outlier data points occur when plant production is low due to maintenance stops. The decreased production does not result in an equivalent decrease in power usage as some loads are fixed or are perceived to be fixed. As a result, the energy intensity for days on which maintenance occurs is much higher than the average energy intensity, as seen in Figure 26. It should be noted that the four outliers labelled in the figure correspond to the four low production (less than 3 000 tons) days seen in Figure 24.

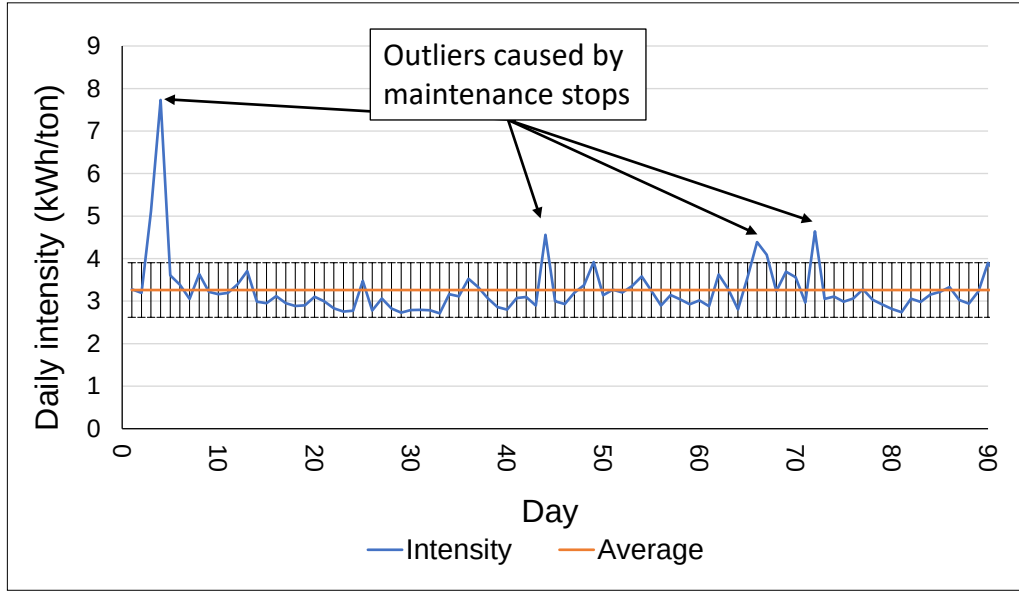


Figure 26: Time-dependent intensity diagram showing outliers

The outliers identified in Figure 26 are defined as being one-and-a-half times the interquartile range (IQR) greater than the upper fourth or one-and-a-half times the IQR less than the lower fourth [81]. This is shown mathematically in Equations 6 to 8.

$$IQR = upper\ fourth - lower\ fourth \quad (6)$$

$$Outlier > upper\ fourth + 1.5 \times IQR \quad (7)$$

$$Outlier < lower\ fourth - 1.5 \times IQR \quad (8)$$

When constructing the time-dependent intensity diagrams, the outliers that are removed should be replaced by the value of the upper fourth if the outlier is identified through Equation 7. Conversely, outliers should be replaced by the value of the lower fourth if identified through Equation 8. It should be noted that low production causes outliers to be greater than the upper fourth and so outliers will seldom, if ever, be removed according to Equation 8.

As mentioned previously, the process of generating intensity scatter plots and time-dependent energy intensity diagrams should be completed for all plant auxiliary systems. This will ensure that any possible auxiliary system energy efficiency initiatives are subsequently identified when qualitatively assessing the plots to identify electricity cost saving opportunities.

2.4.2 Classifying intensities and identifying energy efficiency initiatives

The diagrams generated through the energy intensity analysis process should be qualitatively analysed. The goal of this analysis is to identify opportunities in which electricity cost savings can be achieved through the identification of potential energy efficiency initiatives.

To illustrate the qualitative assessment of intensity diagrams, the intensity diagram of a platinum concentrator pumping system given in Figure 24 is reshown below in Figure 27. In the figure, four distinguishable characteristics of the figure are pointed out.

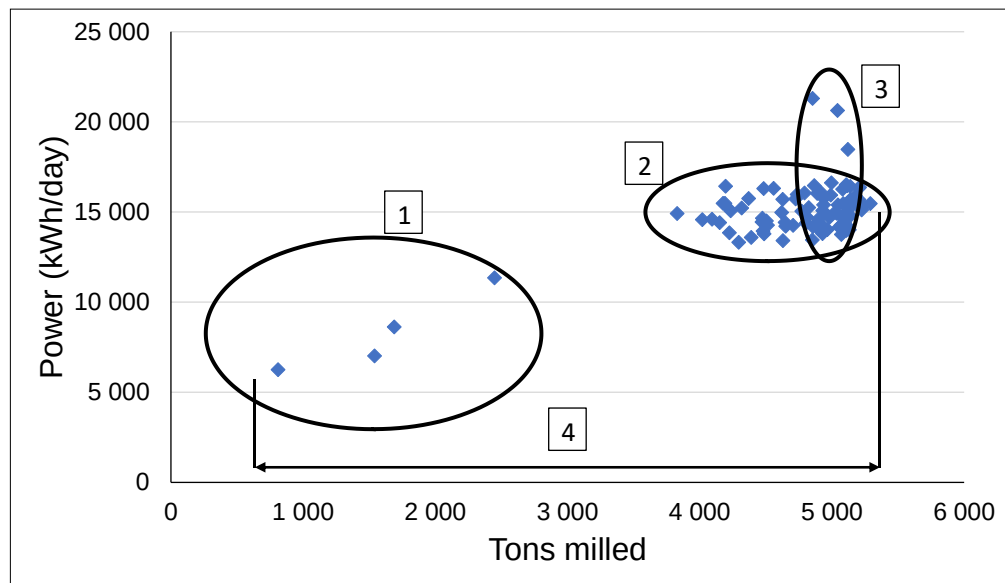


Figure 27: Qualitative analysis of pumping system intensity diagram

In Figure 27, the circled area labelled “1” represents days in which production is significantly lower than normal production, shown by the clusters labelled “2” and “3”. Although the four data points in area 1 consume less power than clusters 2 and 3, these data points cannot be considered for further analysis as they are not indicative of a normal production period. Furthermore, the four data points in area 1 represent the four outlier data points that skewed the energy intensity diagram shown in Figure 26. These points were removed from the data set to produce the energy intensity diagram shown in Figure 25.

Horizontal scatter can be seen in area 2. This indicates that the power consumed by the pumping system is relatively constant. This is despite large variance in the plant production, with minimum and maximum tons milled during this period of 3 828 tons and 5 232 tons respectively. It is expected that, for the same system, when production increases or decreases, the power consumption should increase or decrease by a rate determined by the relationship between power

usage and production [66]. Therefore, the horizontal scatter shown in area 2 can indicate that, above a certain production, there is a minimum fixed load that must be drawn.

Vertical scatter is demonstrated in area 3. In this area, the production remains relatively constant; however, the power consumed per day by the pumping system varies by up to 7 845 kWh. This is an indication of poor control and energy management as, for any given production, one would expect the power consumption to remain constant [65].

The scatter seen in area 3 occurs near the maximum tons milled observed during the measurement period. Therefore, plant production was met during this period. However, as indicated by the vertical scatter, to meet the same production target, different equipment was operated, or the same equipment was operated for varying times. It is logical that, if production was met with less power consumed on one day, that day's operation merits further investigation and, if found to be feasible, should become the norm for all days of similar production [66].

Therefore, energy efficiency opportunities can be identified in area 3 by analysing the equipment operated on the day in which the least power was consumed and comparing it with an average day. When handled on a case-by-case basis, this will allow for energy efficiency initiatives to be identified through the identification of certain pieces of equipment to be stopped.

The final label shown Figure 27, label 4, indicates that during the measurement period plant production varied significantly. Normally, it can be difficult to maintain energy use at optimum levels for plants with large production variations [65]. However, as discussed above, the data points found in area 1 are outliers caused by plant stoppages. The actual production data is therefore shown by areas 2 and 3. Therefore, for this plant, actual production does not show large variation. This will be the case for most platinum processing plants. It is, however, worthwhile to verify that production scatter is due to outliers before continuing with the intensity analysis.

After qualitative analysis of the intensity scatter diagrams, the time-dependent intensity diagrams should be analysed. Once again, the goal of the analysis is to identify energy efficiency initiatives. To demonstrate the analysis, Figure 25 is reshowed in Figure 28.

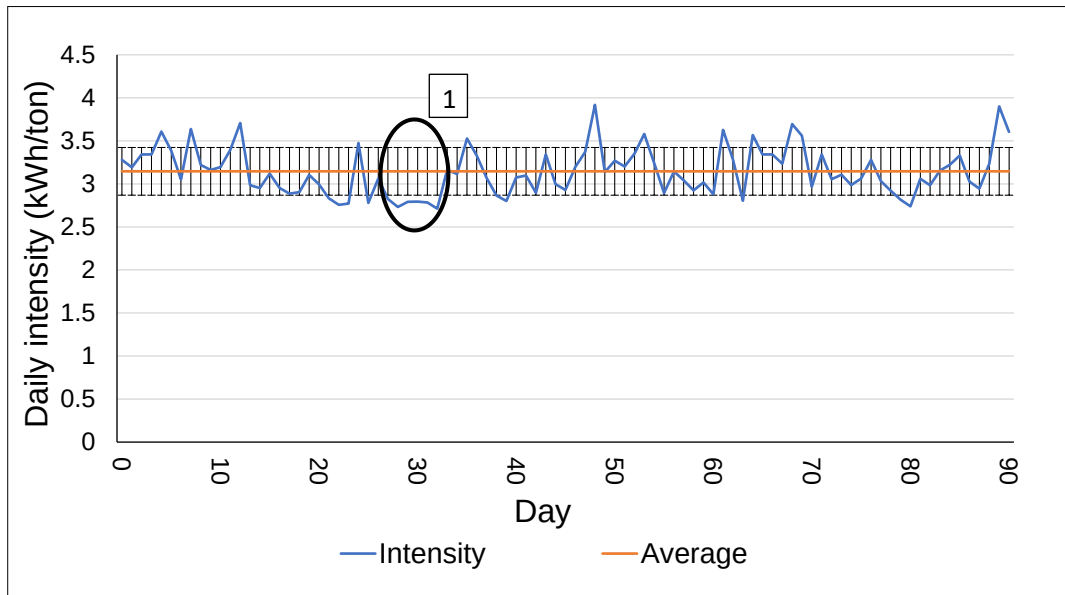


Figure 28: Qualitative analysis of pumping system time-dependent intensity diagram

In the figure, the daily intensity over the entire measurement period is shown along with the average intensity throughout the period. The error bars in the figure represent the standard deviation of the intensity.

The purpose of plotting the standard deviation as errors bars is to filter out measurement variability when identifying low intensity periods [81]. Therefore, only when the intensity is greater than one standard deviation below the average intensity, will the period be considered for further analysis.

One such period is shown in area 1. During this period, the intensity was greater than one standard deviation below the average intensity for five consecutive days. This indicates a sustained period of good energy management.

This area corresponds to five low power consumption days in area 3 of Figure 27. Therefore, the time-dependent intensity diagram confirms that which was observed in the intensity scatter diagram. During the measurement period there were days in which plant power consumption was low whilst production was high.

Therefore, by using intensity scatter plots in conjunction with time-dependent intensity plots, potential energy efficiency opportunities can be identified by identifying high-production, low-power consumption days and making such days the proposed norm for future operations.

This is illustrated for the pumping system in Figure 29. In the figure, a high-production, low-consumption day power profile, identified through the intensity analysis, is shown alongside the average power profile. From the figure, a reduction in power consumption is observed, with the high-production, low-consumption day consuming approximately 1 275 kWh less than the average day. As such, it is clear that by making the high-production, low-consumption day the norm for operations, energy efficiency savings will be realised.

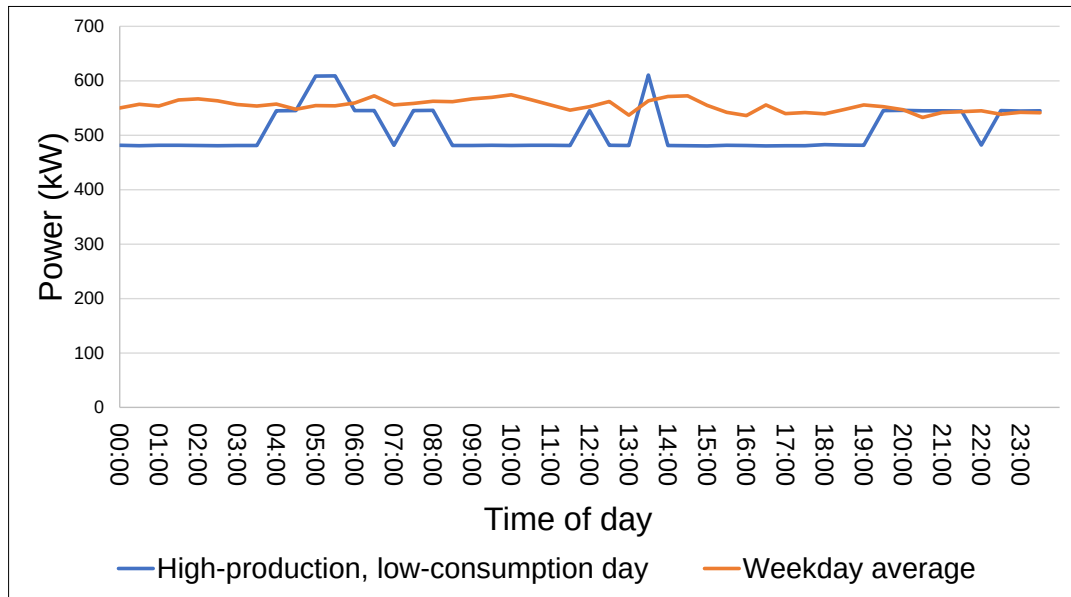


Figure 29: Comparison of pumping system high-production, low-consumption day and weekday average power profiles

The intensity analysis performed above is used to identify potential energy efficiency initiatives by identifying days in which the power consumed by an auxiliary system is low whilst production remains high. Such days are then proposed as the norm, which will allow for unnecessary equipment to be stopped, resulting in electricity and cost savings.

As with baseline analysis, further investigation into exactly what equipment can be stopped is case specific and will be discussed in Chapter 3. However, before discussing such cost saving initiatives, it is necessary to evaluate the feasibility of all identified initiatives.

2.5 Preliminary feasibility evaluation

Through the baseline and intensity analyses, both load management and energy efficiency initiatives would have been identified. For the examples shown as part of the development of the methodology, a possible conveyor load shift and pumping energy efficiency initiative have been identified.

As stated above, these initiatives should be evaluated on a case-by-case basis. The first step in this evaluation is to apply the criteria for implementing electrical cost saving initiatives as discussed in Chapter 1. By doing so, infeasible initiatives will be quickly identified and eliminated. The criteria developed in Section 1.3.3 are reshown below [18, 19]:

1. The initiative should have a suitable payback period.
2. The initiative should be tested and implemented with minimal disturbance to the plant operation.
3. The initiative should be feasible from an operations perspective. Complicated control requiring large amounts of instrumentation should be avoided.
4. The initiative should not compromise plant production or quality.

If the identified initiatives do not satisfy all of the criteria above, the initiative should be eliminated. To determine if the identified initiatives satisfy the criteria, it may be necessary to gather more information than that which was obtained during the data collection phase of the methodology. Additional information that may be collected includes:

- Site layouts.
- Current control philosophies.
- Critical process parameters to be maintained.
- Equipment operating schedules.

With this information, infeasible initiatives will easily be identified. For example, if there is insufficient storage capacity, a conveyor load shift will be infeasible. When performed on a case-by-case basis, the application of the criteria will eliminate infeasible initiatives allowing more time for the investigation and implementation of feasible initiatives. This will be demonstrated in Chapter 3.

2.6 Measurement and verification

The goal of this study is to identify and implement cost saving initiatives on platinum processing plant auxiliary systems. To show that these cost savings have indeed been achieved, measurement and verification (M&V) techniques must be used [82].

The objective of M&V is to provide an impartial, transparent, and repeatable process to assess and quantify the impact of electrical cost saving initiatives. This is achieved through a three-stage process, namely the pre-implementation stage, implementation stage, and post-implementation stage. The cost savings achieved are calculated by comparing the measured electricity

consumption demand during the pre-implementation stage with the post-implementation consumption and demand. This is done after the initiative is implemented and is shown mathematically in Equation 9 [82].

$$\begin{aligned} kW \text{ savings} = & (Pre - implementation \text{ demand}) \\ & - (Post - implementation \text{ demand}) \pm Adjustments \end{aligned} \quad (9)$$

The process followed to generate the pre-implementation stage demand profiles, or the baseline profiles, is the same as that followed when performing the initial baseline analysis described in Section 2.3. Therefore, after the completion of the baseline analysis, baseline profiles will have been constructed for all auxiliary systems.

After a specific initiative has been implemented, the post-implementation demand profile should be compared with the baseline profile as per Equation 9. It may be necessary to make adjustments to the kW savings achieved. This is, however, handled on a case-by-case basis and so cannot be discussed generically.

Using the relevant electricity tariff structure, the cost and consumption saving achieved by the implementation of the initiative can then be determined. This is shown for a TOU tariff structure in Equations 10 and 11 respectively.

$$Cost \text{ saving} = \sum_{i=1}^n kW \text{ savings}_i \times Cost_i \times Time_i \quad (10)$$

$$Consumption \text{ saving} = \sum_{i=1}^n kW \text{ savings}_i \times Time_i \quad (11)$$

Here:

- *Cost saving* is the electrical cost saving achieved (R).
- *n* is the number of TOU tariff periods.
- *kW_i* is the demand saving achieved during TOU tariff period *i*.
- *Cost_i* is cost of electricity (R/kWh) during TOU tariff period *i*.
- *Time_i* is the number of hours during TOU tariff period *i*.

- *Consumption saving* is the electrical consumption saving achieved (kWh).

Although Equations 10 and 11 are specific to a TOU tariff structure, electrical cost savings can be determined for all tariff structures. All that is required is an understanding of the tariff structure under consideration.

2.7 Verification of methodology

In Section 1.3, existing auxiliary system load management and energy efficiency initiatives in industry were identified and evaluated. Thereafter, in Section 1.4, the methodologies used to identify these opportunities were discussed.

The discussion in Section 1.4 showed that these methods, namely benchmarking, energy auditing, baseline and intensity analysis, and simulation, had all been successfully applied to obtain electricity cost and consumption savings on plant auxiliary systems. It was, however, seen from the discussion that such methods had not yet been applied to platinum processing plants.

As these methods had resulted in the successful implementation of electricity cost and consumption saving initiatives, it was believed that similar methods could be applied to platinum processing plants. Thus, Chapter 2 presented a platinum processing plant specific methodology to identify and implement electricity cost and consumption saving initiatives.

The methodology developed in Chapter 2 combined the use of high-level benchmarking, energy auditing and baseline and intensity analysis into one generic method for platinum processing plants. For reasons discussed in Section 1.4, the use of simulation was not considered in this study.

Thus, the methodology presented in this chapter is an adaption and combination of existing methodologies which have been successful in their goal of identifying saving opportunities. It is therefore believed that the methodology developed in this chapter will yield similar results when applied to platinum processing plants.

2.8 Conclusion

In Chapter 1, a need was identified to reduce the electricity cost and consumption of platinum plant auxiliary systems. A literature review was preformed, and it was seen that there is currently no methodology to identify electrical cost and consumption saving opportunities on these systems. Therefore, the objective of this chapter was to develop a generic method that can be used to identify electricity cost saving initiatives on platinum plant auxiliary systems.

Platinum operations often consist of multiple processing plants. As such, a methodology was developed in Section 2.2 to identify the plants with the greatest auxiliary system energy intensity. This identification was achieved through high-level benchmarking of plant auxiliary systems. Plants with the greatest auxiliary system energy intensity were then prioritised for further investigation through baseline and intensity analysis.

In Section 2.3, a generic baseline analysis method was developed for platinum processing plants. The method was developed to identify auxiliary system load management initiatives. Similarly, in Section 2.4, a generic intensity analysis method was developed to identify energy efficiency initiatives.

Section 2.5 presented a set of criteria that all initiatives identified through the baseline and intensity analysis should meet. The criteria ensures that plant production is not negatively affected by the implementation of the identified initiatives. The criteria also serve as a method to quickly identify and eliminate infeasible initiatives.

Initiatives that satisfy the criteria presented in Section 2.5 can then be implemented. The methods used to measure and verify the electrical and cost savings of implemented initiatives were discussed in Section 2.6.

In the next chapter, results obtained during the implementation of the methodology to identify load management and energy efficiency initiatives on platinum processing plants are reported on.

CHAPTER 3: RESULTS AND DISCUSSION

3.1 Introduction

In Chapter 1, a need was identified to develop a methodology to identify electrical consumption and cost saving initiatives on platinum processing plant auxiliary systems. A literature review revealed that such a methodology did not exist for platinum processing plants. Thus, a methodology specific to platinum processing plants was developed in Chapter 2.

To validate the methodology that was developed in Chapter 2, the methodology will be applied to a South African platinum mining operation. The mining operation to which the method will be applied consists of the following processing plants:

- Four operational concentrators.
- Three concentrators under care and maintenance.
- One tailings treatment plant.
- One smelter.
- One base metal refinery (BMR) and one precious metal refinery (PMR).

Due to confidentiality agreements with the mining operation, the exact location and names of the plants cannot be disclosed. Instead, all plants will be referred to by non-descriptive names throughout the chapter (e.g., Concentrator A).

3.2 High-level benchmarking

Chapter 1 showed that benchmarking techniques have been used in many industries to identify inefficient or underperforming equipment, processes, or plants. The identified areas could then be prioritised for further investigation. Although successful in other industries, such techniques have not been applied to platinum processing plant auxiliary systems.

Thus, objective 1 of this study is to develop, implement, and verify a methodology to benchmark and prioritise platinum processing plant auxiliary systems for further investigation. As such, a benchmarking technique for platinum plant auxiliary systems was developed in Section 2.2. To validate the methodology, the methodology was applied to benchmark the mining operation's four operational concentrators.

As per the methodology, only the concentrator auxiliary systems were benchmarked. This was achieved by excluding the power consumed by the plant mills when developing the energy intensity benchmarks.

The results of this high-level benchmarking are shown in Figure 30 below. In the figure, the average auxiliary system intensity over a measurement period of three months is plotted for each concentrator. The average intensity of all four concentrators is also shown.

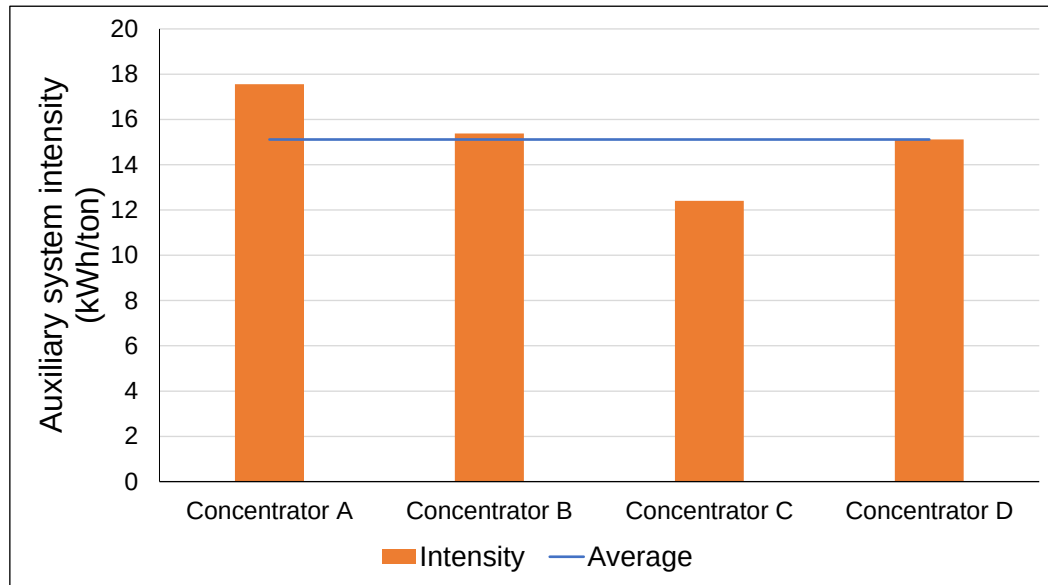


Figure 30: High-level benchmarking of four platinum concentrator auxiliary systems

From Figure 30 it is clear that Concentrator A has the most energy intensive auxiliary systems. This means that, to process the same mass of ore, the auxiliary system energy usage of Concentrator A is greater than any other concentrator on the mining operation. As such, Concentrator A should be prioritised for further investigation. Thereafter, Concentrator B and Concentrator D should be prioritised for investigation in that order.

Concentrator C is the most energy efficient concentrator, with an auxiliary system intensity of 12.4 kWh/ton of ore processed. This is well below the mining operation's average of 15.1 kWh/ton of ore processed. Therefore, Concentrator C should be the lowest priority for further investigation.

To demonstrate the value of applying the benchmarking technique developed in this study, namely benchmarking of only the auxiliary systems, a benchmark of the entire plant power consumption is provided in Figure 31.

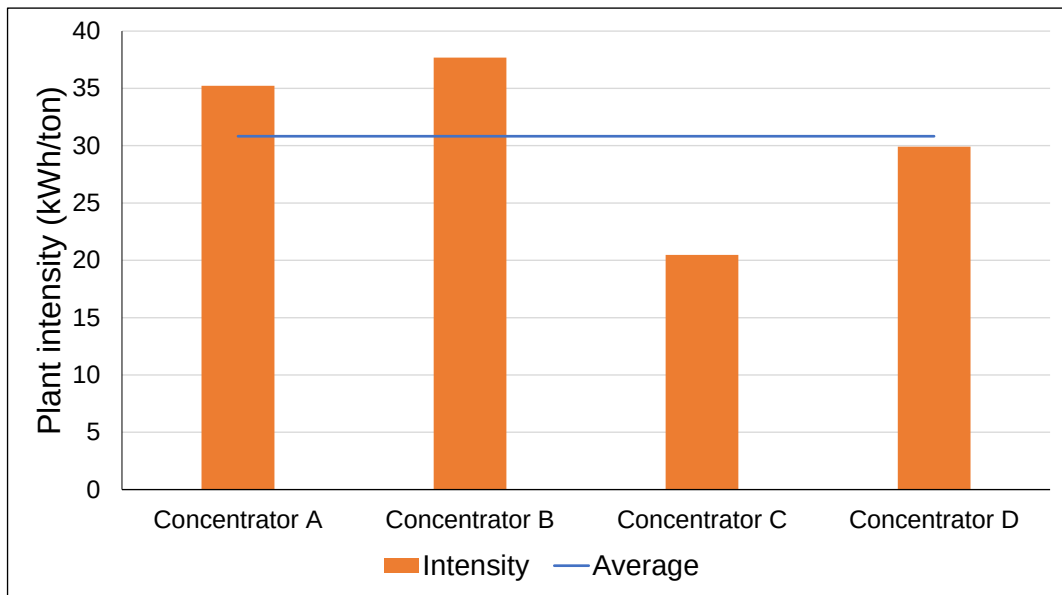


Figure 31: High-level benchmarking of four platinum concentrators

Figure 31 shows that Concentrator B is the most energy intensive when the entire plant, including the milling section, is considered. However, as was shown in Chapter 1, obtaining electrical consumption and cost savings on the milling section of plants is infeasible. Thus, even though Concentrator B is the most energy intensive plant, the scope to obtain electrical cost savings through auxiliary system optimisation may not be as great as Concentrator A.

This demonstrates that, if not benchmarking only the auxiliary system energy usage as per the methodology developed in this study, the plant with the greatest energy intensity does not necessarily have the greatest auxiliary system energy intensity. Thus, if the benchmarking methodology developed in this study is not applied, the incorrect plant may be prioritised for further investigation.

3.3 Initiative identification

Objective 2 of this study is to develop, implement and verify a methodology to identify load management opportunities on platinum plant auxiliary systems. Similarly, objective 3 of this study is to develop, implement, and verify a methodology to identify energy efficiency initiatives.

The methodology to achieve these objectives was developed in Section 2.3 and Section 2.4 respectively. In this section, the developed methodology will be applied to real-world case studies, the purpose of which is to validate the methodology. Furthermore, to show that the methodology can be generically applied to all platinum processing plants, case studies will be shown for a concentrator, a tailings treatment plant, and a smelter converter plant.

3.3.1 Concentrator A

From the high-level benchmarking performed in Section 3.2, it was seen that Concentrator A has the most energy intensive auxiliary systems when compared with the mining operation's other operational concentrators. As such, Concentrator A was prioritised for further investigation. As per the methodology, the next stage of the investigation of Concentrator A is the application of the auxiliary system baseline analysis method. The results of the application are shown in Figure 32 and Figure 33.

In Figure 32, the average weekday auxiliary system power profiles over a three-month measurement period are provided. The average Saturday and Sunday profiles are provided in Appendix B. Figure 33 illustrates the 120-hour load variability diagram for the concentrator.

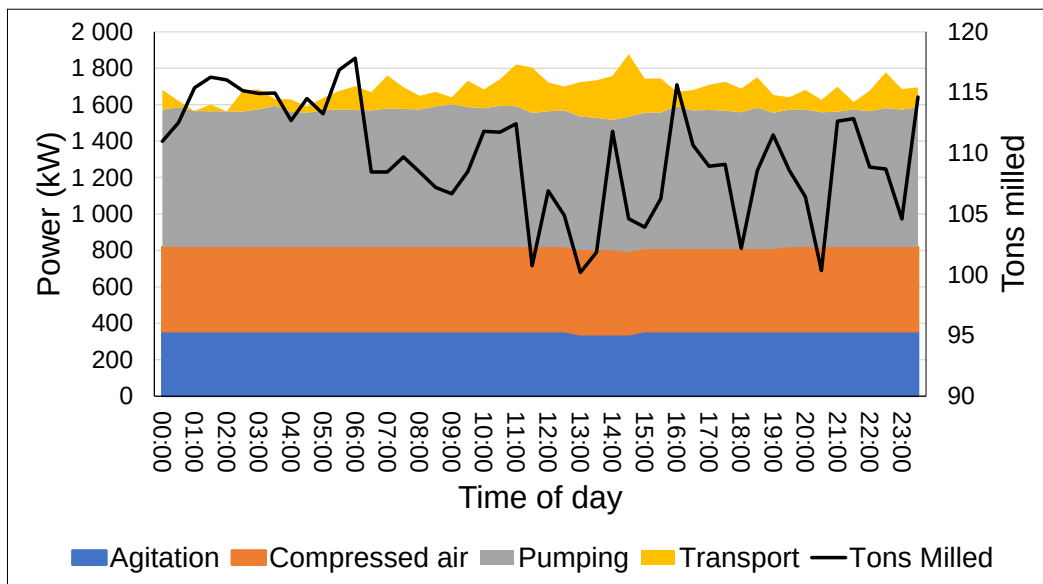


Figure 32: Concentrator A average weekday auxiliary system power profiles

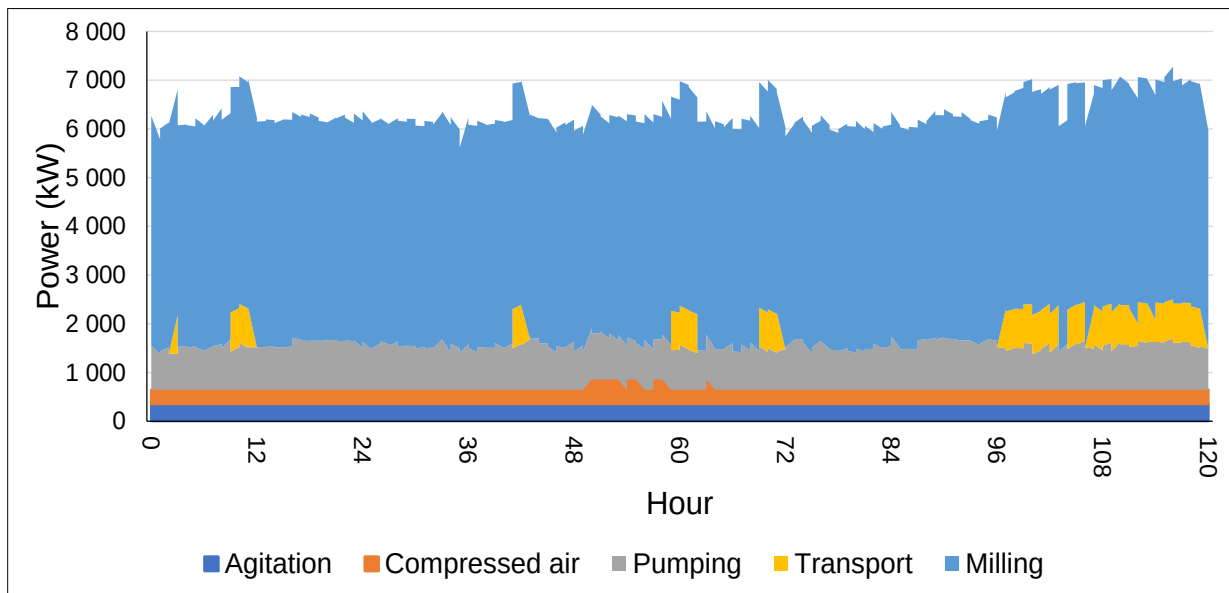


Figure 33: Concentrator A 120-hour load variability diagram

Analysis of the average weekday auxiliary system profiles showed that, even for varying plant production, the energy consumed by the agitation, compressed air and pumping systems remained almost constant. The only auxiliary section which displayed significant load variability is transport.

This is confirmed by Figure 33 in which significant variance is seen in the transport system load. Over the 120-hour period, the transport system started and stopped eight times. Furthermore, from Table 7 it can be seen that the transport system has a LF of 26%. This confirms that the transport system is a variable load. Conversely, the high load factors and constant load profiles of the other plant auxiliary systems indicate that these systems are fixed and so not suited to load management.

Table 7: Concentrator A auxiliary system load factors

Auxiliary system	LF (%)	Load type
Agitation	99	Fixed
Compressed air	82	Fixed
Pumping	83	Fixed
Transport	26	Variable

As the transport system is a variable load, it may be suitable for load management and so should be evaluated according to the load management criteria developed in Section 2.3.3 after which the preliminary feasibility criteria of Section 2.5 should be applied.

However, before evaluating the system against these criteria, an understanding of the system is required. This understanding, which is obtained from the plant walkthrough during the data collection stage of the methodology, is briefly described below.

The transport system of Concentrator A consists of four ore stockpiles. The ore from the stockpiles is manually fed by operators onto six conveyors which transport the ore to four silos. From the silos, ore is transported to the plant to be milled and processed. The transport system is represented schematically in Figure 51 of Appendix B.

With this knowledge, the load shift criteria of Section 2.3.3 are evaluated in Table 8.

Table 8: Evaluation of load shift criteria for Concentrator A transport system

Criteria	Comment	Does the system meet criteria
Uncompromised production	Loading of ore onto the conveyors is a manual process. As such, the risk exists that operators will not load ore when required (i.e., during off-peak tariff periods). This may lead to ore shortages in the silos feeding the plant.	No
Storage capacity	The silos shown in Figure 51 provide enough storage capacity to allow for weekday-night and weekday-midday load shifts.	Yes
Increased production in optimal TOU periods	The mass loaded onto the conveyors shown in Figure 51 can be increased to accommodate for the shifting of load.	Yes

Table 8 shows that, due to the risk of compromised plant production, the Concentrator A transport system is not suited to a load shift. As not all the load shift criteria were satisfied, the initiative is infeasible and so there is no need to further evaluate the initiative against the preliminary feasibility criteria of Section 2.5.

It can therefore be concluded that, due to the manual loading of ore onto the conveyor system, Concentrator A is not suited to load management initiatives. However, as seen by the high-level benchmarking, the concentrator does have potential to achieve electrical consumption and cost savings. Thus, the auxiliary system intensities are analysed.

As per the methodology developed in Chapter 2, the intensity analysis requires the construction of the auxiliary system intensity plots. These plots are shown for the Concentrator A compressed air and pumping systems in Figure 34 and Figure 35 respectively.

Analysis of the two diagrams shows that, for both the compressed air and pumping systems, there is vertical scatter when the plant processed between 5 000 and 6 000 tons of ore per day. This is shown in the figures by the area labelled 2.

This indicates that, for both systems to process the same mass of ore, different equipment is operated, or the same equipment is operated for varying durations. Thus, energy initiatives can be implemented to ensure that, to achieve the same production, unnecessary equipment is not operated.

Conversely to the compressed air and pumping systems shown below, the agitation system intensity plot, provided in Figure 52 of Appendix B, does not show power variation for varying production. As such, the agitation system can be classified as a fixed load and will not be further investigated in this section.

In addition to the intensity plots shown below, the time-dependent intensity plots for the compressed air and pumping systems of Concentrator A are provided in Figure 36 and Figure 37. In the figures, the daily intensity for each system as well as the average intensity over the measurement period is shown. The standard deviation of the average intensity is also indicated by error bars.

It should be noted that in the time-dependent intensity plots provided, the outliers, labelled as area 1 in the intensity scatter plots, have been removed according to Equations 6 to 8. These outliers have been removed as, in this area, production is less than normal as a result of maintenance stops. Plots in which the outliers are included are provided in Figure 53 and Figure 54 of Appendix B.

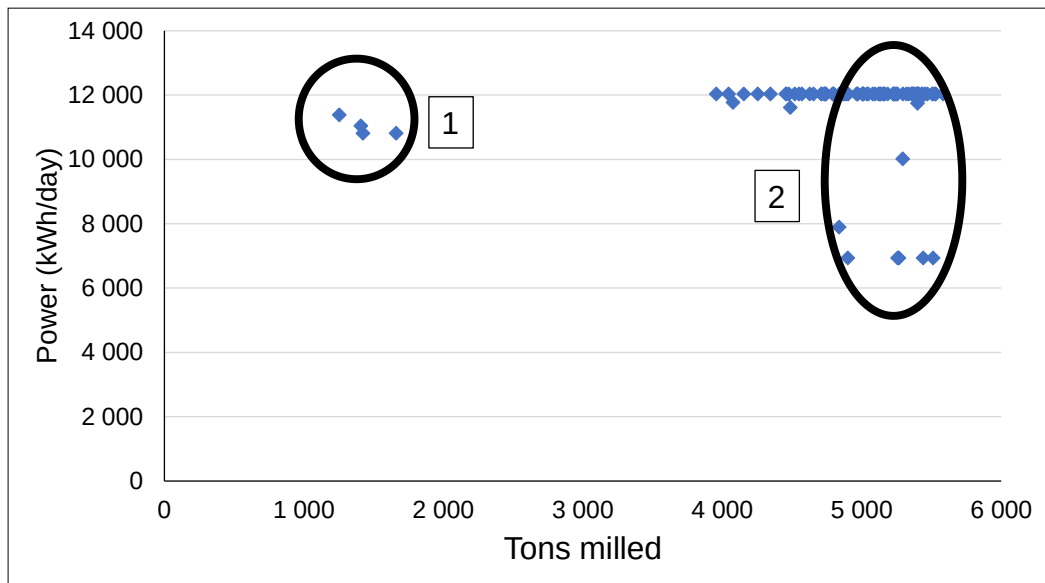


Figure 34: Concentrator A compressed air system intensity plot

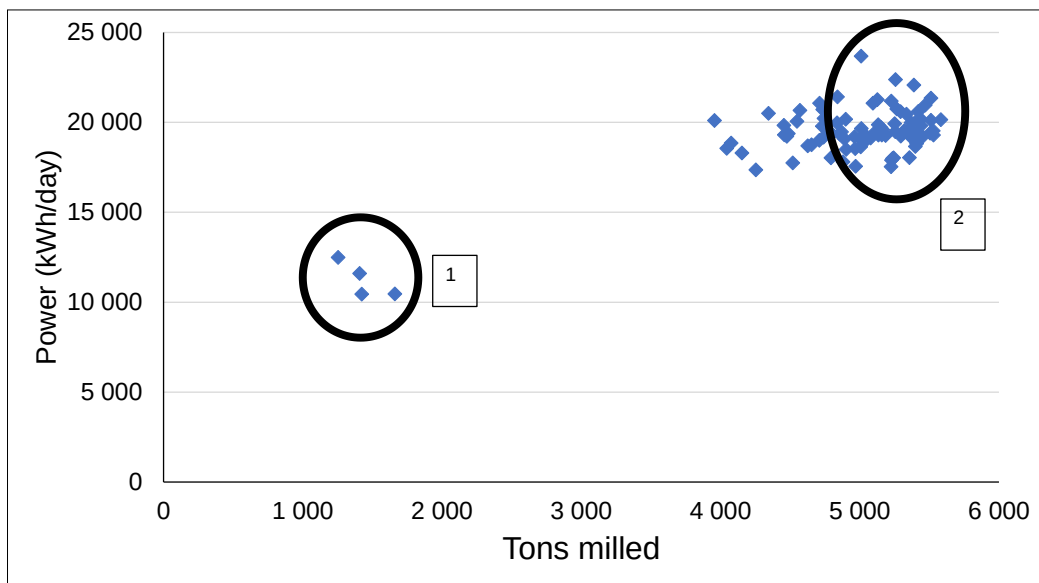


Figure 35: Concentrator A pumping system intensity plot

Analysis of the time-dependent intensity plots reveals that, from day 83 to 89, the compressed air intensity was more than one standard deviation lower than the measurement period average intensity. Similarly, from day 49 to day 51 and day 55 to day 60, the pumping system intensity is more than one standard deviation less than the average intensity.

For both systems, the days identified represent sustained periods in which the system energy intensity is significantly lower than the average. As such, this confirms that, to achieve the same

production, different equipment is operated, or the same equipment is operated for varying durations.

These results are in agreement with that which was identified through the analysis of the intensity plots. Thus, it may be possible to implement energy efficiency initiatives on the compressed air and pumping systems.

To implement energy efficiency initiatives, it is necessary to identify what equipment is causing the increased electricity consumption for a given production. This equipment will then be investigated further.

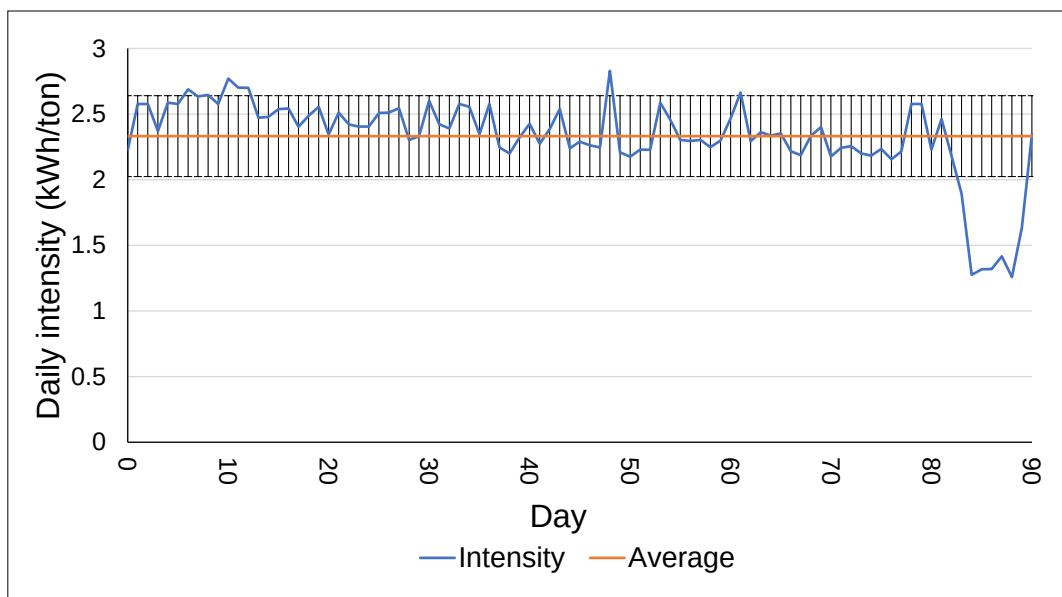


Figure 36: Concentrator A compressed air system time-dependent intensity plot

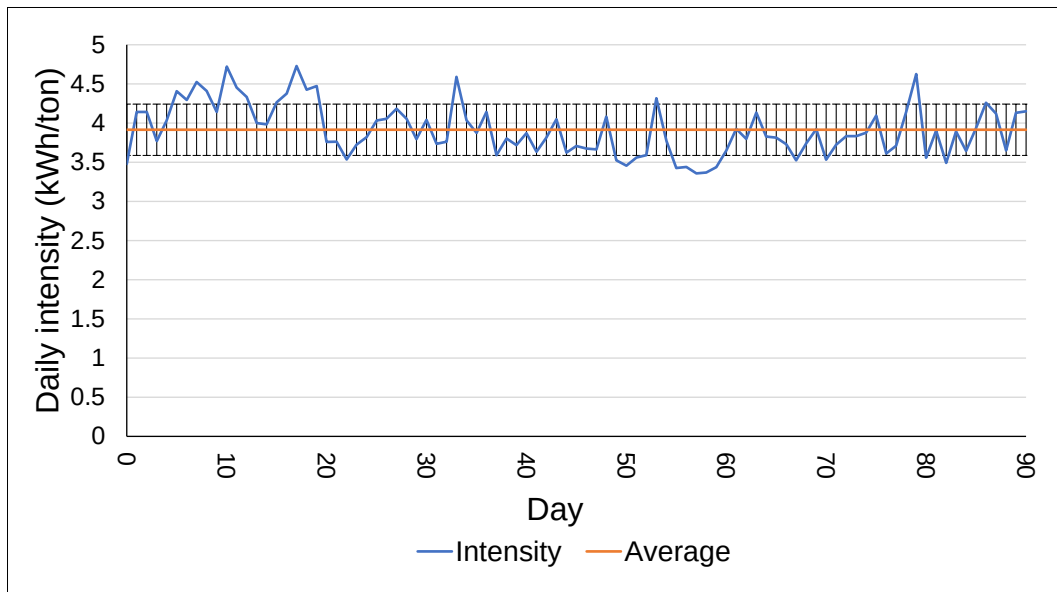


Figure 37: Concentrator A pumping system time-dependent intensity plot

As per Section 2.4.2 of the methodology, to identify the equipment causing increased electricity consumption, the average weekday power profile must be compared with a day in which production was met with lower-than-average electricity consumption, referred to as the high-production, low-consumption day. Comparison of the profiles and the individual motors which make up the profiles will then reveal what equipment may be running unnecessarily. The comparison of the high-production, low-consumption and average weekday profiles for the compressed air and pumping systems is provided in Figure 38.

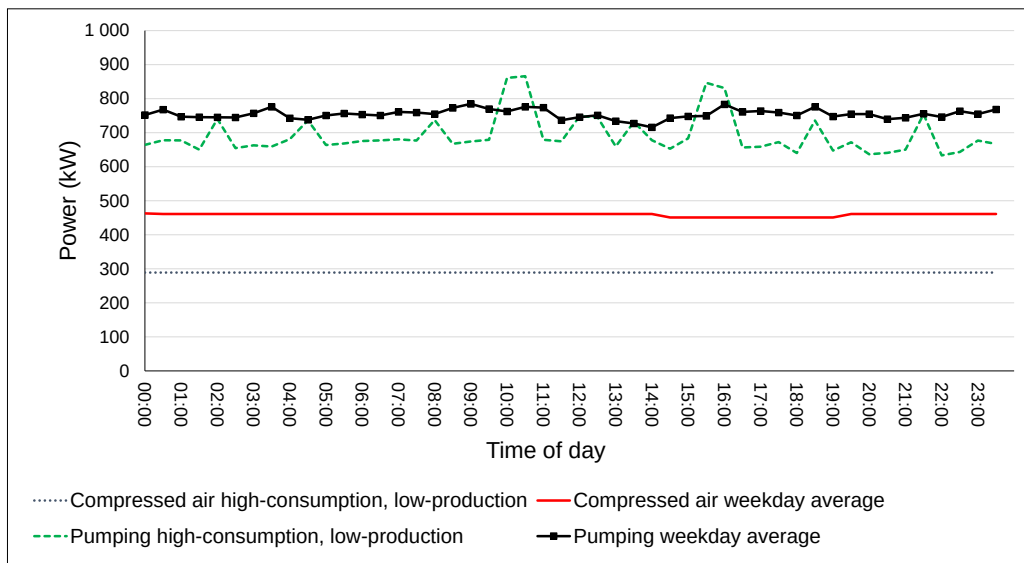


Figure 38: High-consumption, low-production and average weekday power comparisons for Concentrator A compressed air and pumping systems

From comparison of the individual motor powers which make up the average day and the high-production, low-consumption day power profiles shown in Figure 38, the motors running unnecessarily have been identified. The results of this are summarised in Table 9.

Table 9: Unnecessary Concentrator A motors running identified by comparison of high-production, low-consumption day to average day

System	Average weekday	High-production, low-consumption day	Potential energy efficiency initiative
Compressed air	Two compressors operated throughout the day.	One compressor operated throughout the day.	Permanently stop one compressor such that only one compressor runs at any given moment.
Pumping	Six pumps controlled by operators were run continuously, even when the tanks they drain were empty.	The six pumps controlled by operators were stopped when the tanks were empty.	Implement level control to stop pumps from running when the tanks are empty.

In Table 9, the potential energy initiatives identified through analysis of the auxiliary system intensities have been reduced to two specific energy efficiency initiatives. The initiatives were identified through comparison of the high-production, low-consumption and average power profiles. These potential initiatives are:

- Permanently stopping one compressor.
- Implementing level control to prevent pumps from running when the tanks they drain are empty.

To determine if the potential initiatives can be implemented, the initiatives must be evaluated according to the feasibility criteria developed in Section 2.5.

However, before evaluating the initiatives against the criteria, an understanding of the current system operation is required. With this understanding, the proposed system operation as well as the requirements for such an operation can be developed. This process is summarised in Table 10 below. As before, understanding of the current system is achieved through a plant walkthrough as well as through discussion with plant personnel.

Table 10: Requirements for Concentrator A energy efficiency initiative implementation

Initiative	Current operation	Proposed operation	Requirements for implementation
Compressed air	Two 250 kW compressors operate in a duty and standby configuration. The duty compressor starts up automatically according to a pressure set point.	One compressor can be permanently stopped by lowering the pressure set point of the standby compressor. Thus, the standby compressor will only start up when the duty compressor fails.	Lower the standby compressor set point such that it does not start up whilst the duty compressor is running.
Pumping	Six pumps (4 x 22 kW, 2 x 15 kW) are started and stopped according to the tank level by operators.	Pumps should start and stop automatically based on the tank level which the pumps drain.	Programme level control to automatically start and stop the pumps.

With the requirements for implementation provided in Table 10, the potential initiatives can then be evaluated against the feasibility criteria developed in Section 2.5. If all criteria are met, the initiative can be considered feasible and should be implemented. The evaluation of the initiatives is provided in Table 11.

Table 11: Evaluation of Concentrator A proposed initiatives against feasibility criteria

Criteria	Initiative	
	Lower the standby compressor set point	Programme level control to automatically start and stop the pumps
1: Suitable payback	No capital is required for the initiative.	No capital is required for the initiative.
2: Minimal plant disturbance	Implementing the initiative requires reprogramming the compressor set point. This can be done whilst the plant is operating.	Implementing the initiative requires PLC programming. This can be done during a planned plant shut. No additional down time is required.
3: Operational feasibility	The control strategy remains unchanged.	The control strategy is simple, with pumps starting and stopping according to the tank level. Additionally, the implementation of automatic control ensures operators have fewer systems to control.
4: Uncompromised production	Plant production will be unaffected by the initiative.	Plant production will be unaffected by the initiative. Pumps will only stop when the tanks they drain are empty.
Feasible	Yes	Yes

From Table 11, it is clear that both proposed energy initiatives satisfy all the criteria and so both initiatives are feasible. As such, the initiatives were implemented on Concentrator A. The results of the implementation are summarised in Table 12.

In the table, the cost and consumption savings achieved by implementing the initiatives were calculated according to the measurement and verification methodology provided in Section 2.6. Sample calculations for one day are shown in Table 27 and Table 28 of Appendix B for the compressor and pump initiatives respectively.

Table 12: Cost and consumption savings from Concentrator A initiative implementation

Initiative	Implementation duration	Cost and consumption saving	Estimated yearly cost and consumption saving
Lower the standby compressor set point.	5 months (summer TOU months).	R249 000 0.35 GWh	R960 000 0.84 GWh
Programme level control to automatically start and stop the pumps.	At the time of writing, this initiative was still in the process of being implemented by site personnel.		R500 000 0.44 GWh

The total estimated yearly cost and consumption savings achieved at Concentrator A by the implementation of the energy efficiency initiatives summarised in Table 12 is R1.46 million and 1.28 GWh, respectively. These initiatives were identified through the application of the methodology developed in Chapter 2.

3.3.2 Tailings treatment plant

To show the applicability of the methodology developed in Chapter 2 to all platinum processing plants, the method was applied to identify electrical consumption and cost saving opportunities on a platinum tailings treatment plant (TTP).

Platinum TTPs are similar in their design to platinum concentrators. However, as TTPs reprocess the concentrator tailings streams, most TTPs do not have any solids transport equipment. Instead, pumps are used to transport slurries throughout the plants.

This is evident in the auxiliary system baseline analysis as well as the 120-hour load variability profile, shown in Figure 39 and Figure 40 respectively. From the figures it is noted that, due to the lack of a transport system, the pumping system contributes a larger share of the total plant's energy usage when compared with Concentrator A.

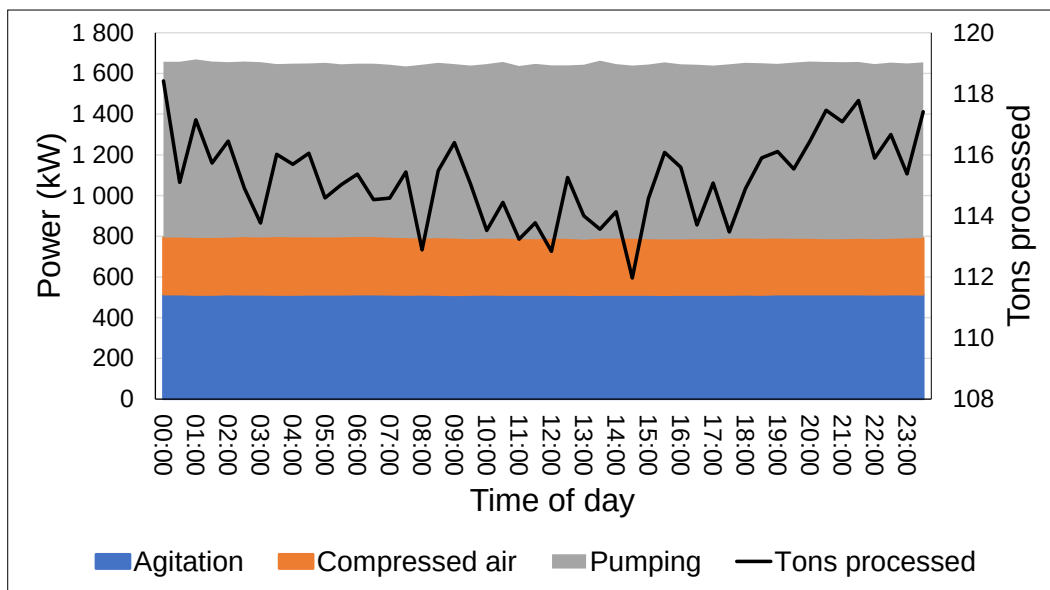


Figure 39: TTP average weekday auxiliary system power profiles

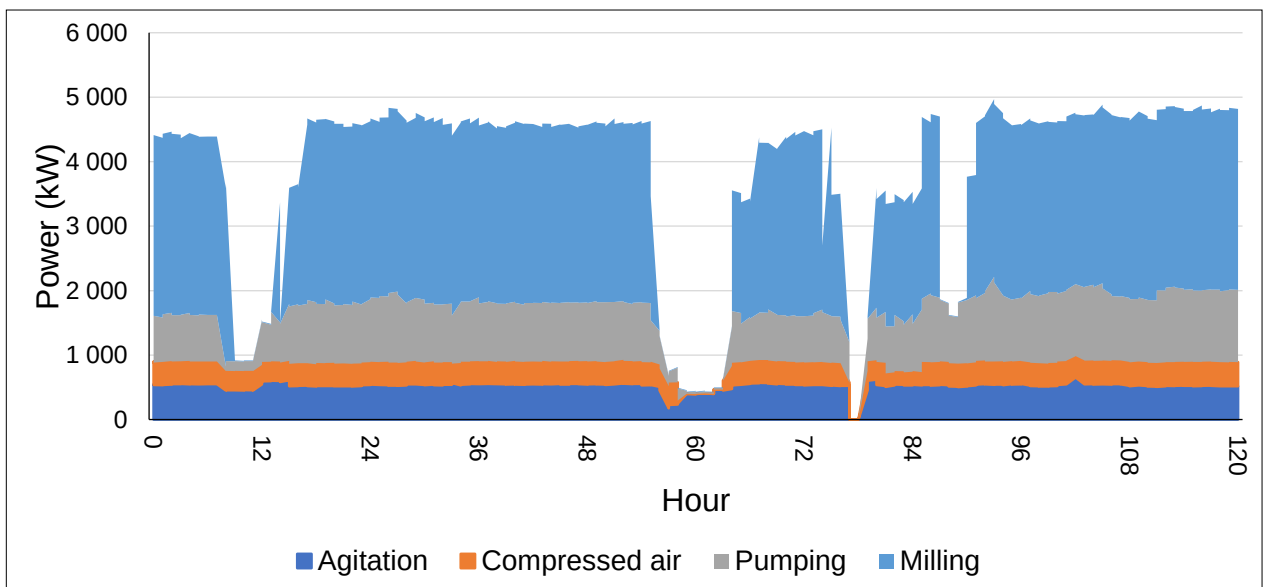


Figure 40: TTP 120-hour load variability diagram

Analysis of the average weekday auxiliary system power profiles shown in Figure 39 shows that the TTP auxiliary systems show little variability with load. This is also true when analysing the average Saturday and Sunday profiles provided in Figure 55 and Figure 56 of Appendix B. This is despite variations in the tons processed by the plant.

The lack of variation in auxiliary system load is confirmed in Figure 40 in which it is seen that, if the milling section of the plant operates, the auxiliary systems operate at a near-constant load.

This is, however, not the case when the plant milling section does not operate. The auxiliary system loads when the milling section does not operate appear to display significant variance. Therefore, to determine if loads are fixed or variable, the LF for each system must be considered. This is shown in Table 13.

Table 13: TTP auxiliary system load factors

Auxiliary system	LF (%)	Load type
Agitation	80	Fixed
Compressed air	88	Fixed
Pumping	63	Variable

The high LFs of the agitation and compressed air systems show that these systems are fixed loads and so are not suited to load management. The pumping system does, however, show significantly more variance than the other auxiliary systems, indicated by the LF of 63%. Therefore, the pumping system may be suited to load management initiatives and so the system is evaluated against the load management criteria developed in Section 2.3.3.

As discussed above, each plant is unique and so, before evaluating the system against the load management criteria, an understanding of the plant is required. This understanding is achieved through the plant walkthrough during the data collection phase of the investigation.

Table 14: Evaluation of load shift criteria for TTP pumping system

Criteria	Comment	Does the system meet criteria
Uncompromised production	If pumps are stopped for extended periods, particulate matter will settle in tanks, compromising the product quality.	No
Storage capacity	The TTP upfront surge tank does not have enough storage capacity to allow for a load shift.	No
Increased production in optimal TOU periods	The TTP upfront surge tank often overflows as the plant does not have the capacity to process all the material that is delivered from upstream concentrators. Therefore, the plant pumps currently operate at full capacity and cannot increase production in optimal tariff periods.	No

After evaluation of the TTP against the load shift criteria, it is clear that the plant auxiliary systems are not suited to load management initiatives. However, as was seen with Concentrator A, there may still be opportunity to identify and implement energy efficiency initiatives on the plant auxiliary systems. These initiatives are identified through an intensity analysis.

The results of the intensity analysis are presented in the form of intensity scatter plots for the compressed air and pumping systems in Figure 41 and Figure 42 respectively. From the figures,

it is seen that, when processing between 5 000 and 7 000 tons per day (indicated by the area labelled 2), there is significant variance in the power consumed. This is true for both auxiliary systems. Conversely, the agitation system, shown in Figure 57 of Appendix C, does not show significant power variance for a given production. Therefore, the agitation system will not be further investigated.

The compressed air and pumping system variance is further illustrated in Table 15 in which the daily power consumed by the auxiliary systems and the daily tons processed for two days are compared. The table shows that, for a -0.49% change in tons processed, the compressed air power consumption increases by 37.08%. Similarly, an 8.24% decrease in production results in a 97.64% increase in power consumption for the pumping system.

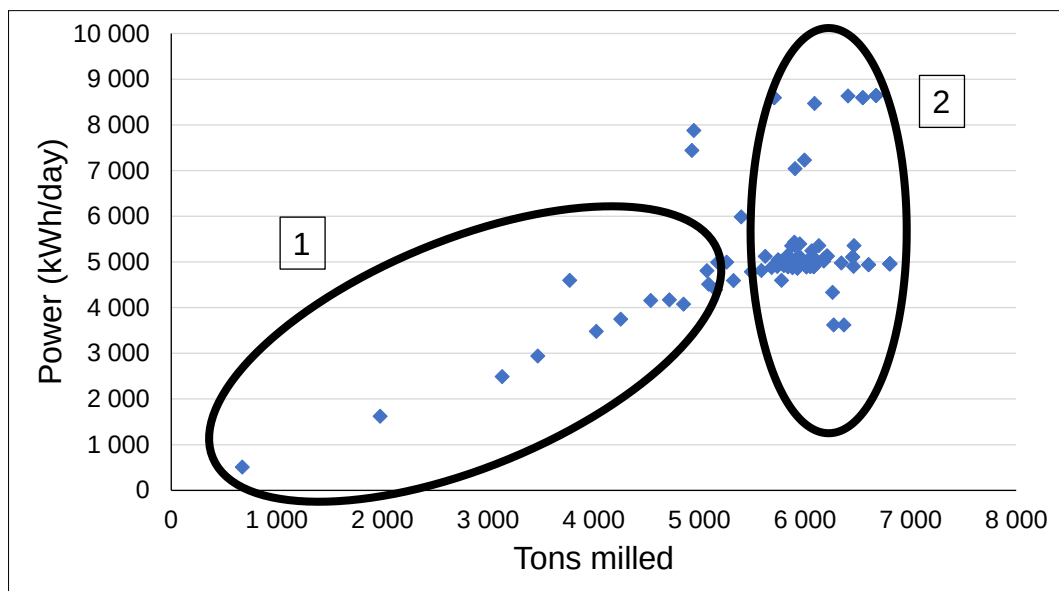


Figure 41: TTP compressed air system intensity plot

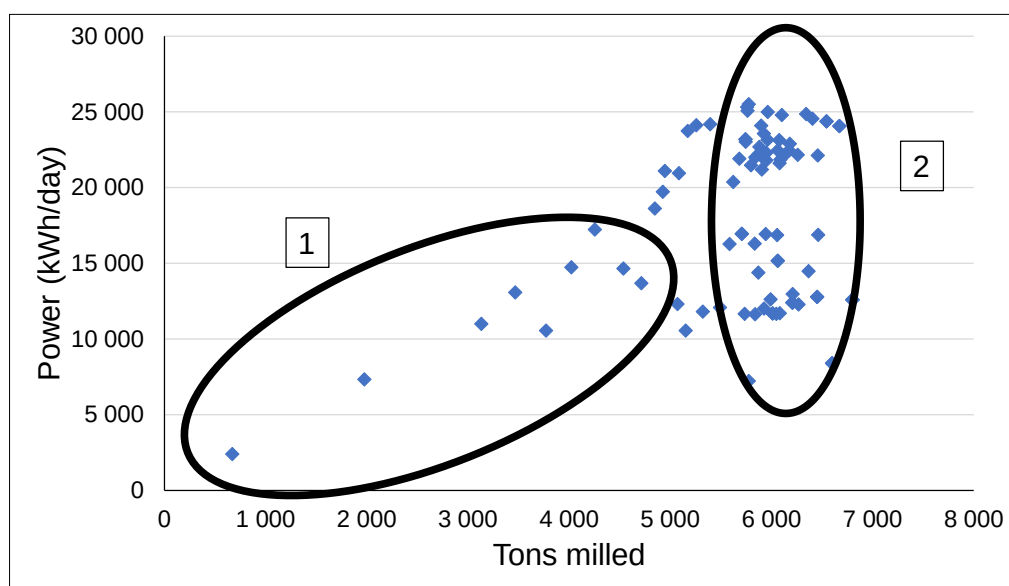


Figure 42: TTP pumping system intensity plot

Table 15: Power variance of TTP compressed air and pumping systems

	Compressed air			Pumping		
	Day 1	Day 2	Variance (%)	Day 1	Day 2	Variance (%)
Tons processed	6 367	6 336	-0.49	6 601	6 057	-8.24
Energy (kWh)	3 910	5 359	37.08	7 297	14 442	97.64

As with concentrator A, this is indicative of weak energy management. As a result of this weak energy management, different equipment is operated, or the same equipment is operated for varying durations to process the same mass of tailings. Thus, there may be potential to implement energy efficiency initiatives to ensure that unnecessary equipment is not operated.

To verify that which was observed in the intensity scatter plots, the time-dependent intensity plots with outliers removed for the TTP compressed air and pumping systems are given in Figure 43 and Figure 44. The outliers are shown in the areas labelled 1 in the above figures and time-dependent intensity plots in which the outliers are included are provided in Figure 58 and Figure 59 of Appendix C.

From analysis of the time-dependent plots it can be seen that, during the first 24 days of the measurement period, the pumping system intensity was at least one standard deviation lower than the average intensity. Similarly, the compressed air system was lower than one standard

deviation below the average intensity for more than one day on four separate occasions during the measurement period.

This represents sustained periods in which the energy intensity is significantly lower than the average intensity observed during the measurement period. This observation confirms that, to meet the same production target, different equipment is operated, or the same equipment is operated for varying durations.

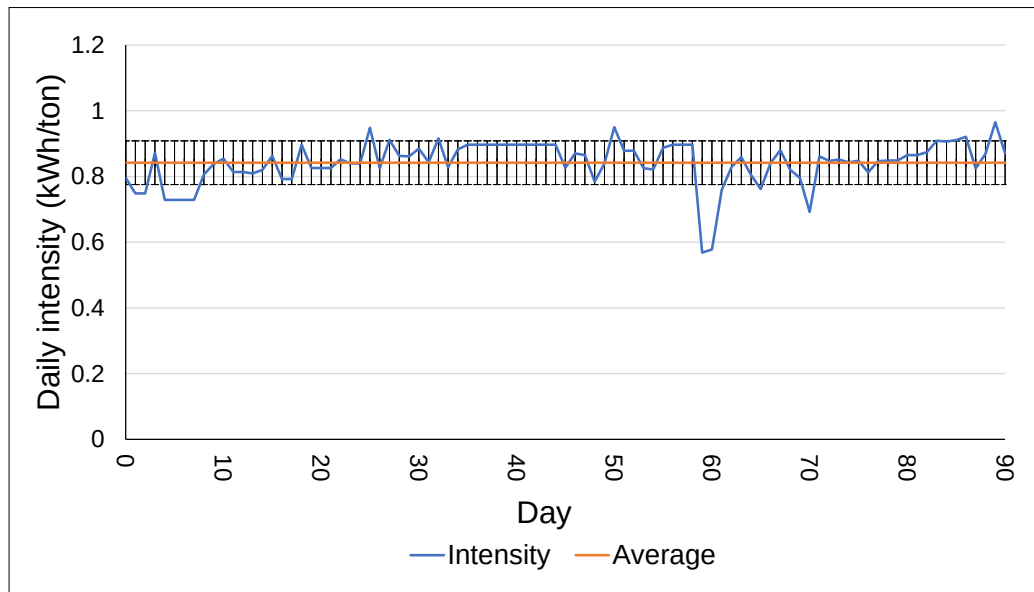


Figure 43: TTP compressed air system time-dependent intensity plot

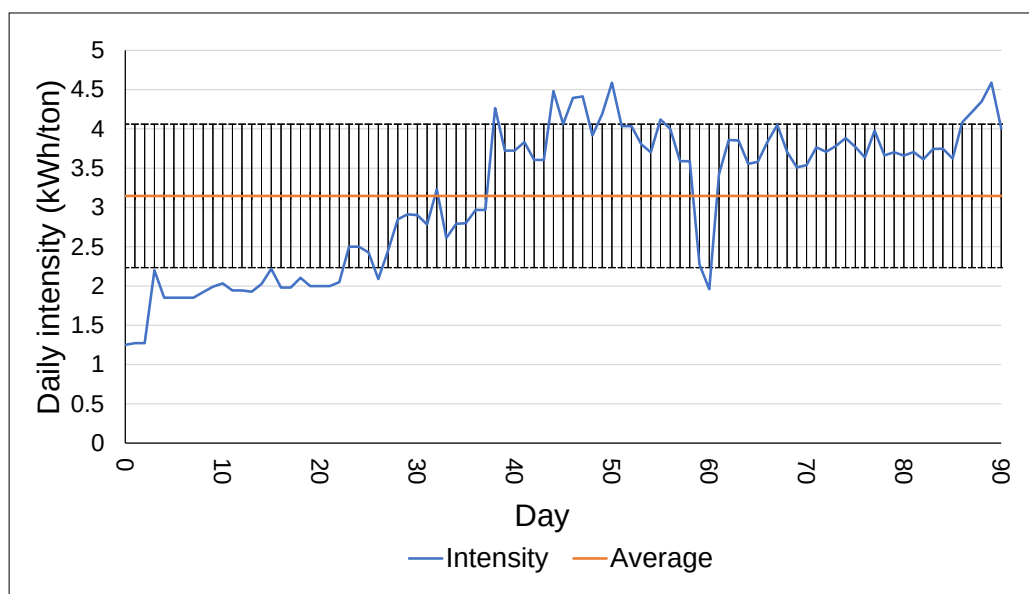


Figure 44: TTP pumping system time-dependent intensity plot

From these results it is clear that there is scope to implement energy efficiency initiatives on the TTP compressed air and pumping systems, the objective of which is to prevent equipment from operating unnecessarily. To implement such initiatives, it is, however, necessary to identify the equipment causing the increased electricity consumption for a given production.

As with Concentrator A, the equipment running unnecessarily is identified by comparing the average weekday power profile with a day in which production was met with lower-than-average electricity consumption, referred to as the high-production, low-consumption day. From this comparison, the individual motors which may be running unnecessarily will be identified. This comparison is shown for the TTP compressed air and pumping systems in Figure 45.

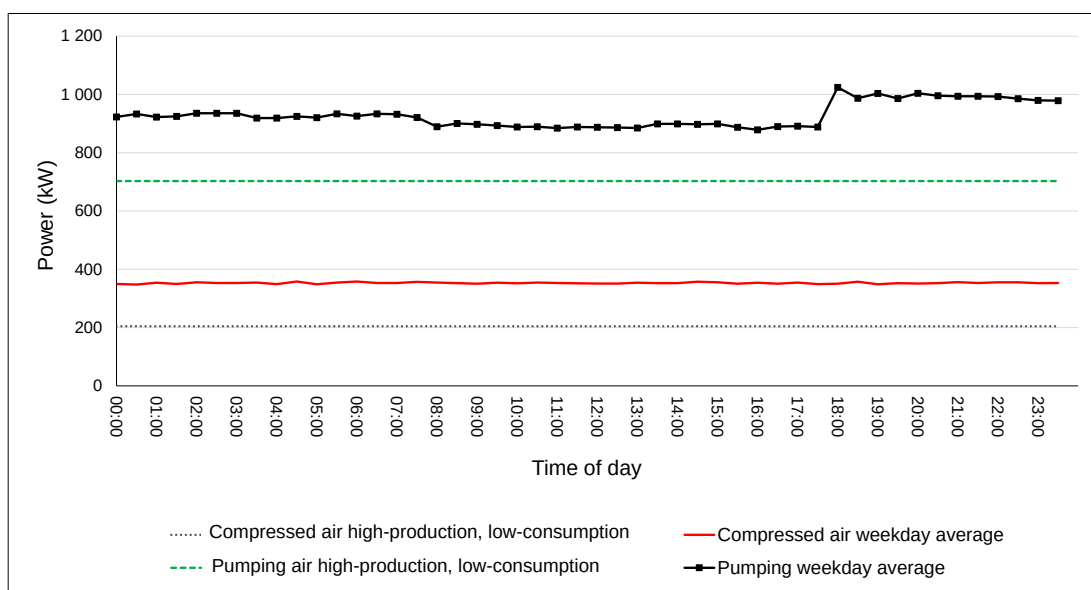


Figure 45: High-production, low-consumption and average weekday power comparisons for TTP compressed air and pumping systems

When comparing the average weekdays to the high-production, low-consumption days, there are large differences in the power consumed by the TTP auxiliary systems. From analysis of the individual motors which make up the profiles shown in the figure, the motors running unnecessarily have been identified. The results of this are summarised in Table 16.

Table 16: Unnecessary motors running identified by comparison of high-production, low-consumption day to average day

System	Average weekday	High-production, low-consumption day	Potential energy efficiency initiative from comparison
Compressed air	Two compressors operated throughout the day. Compressors are set to operate in a duty/standby configuration and not a master/slave configuration.	One compressor operated throughout the day.	Permanently stop one compressor such that only one compressor runs at any given moment.
Pumping	Both tails transfer pumps operate continuously.	Only one tails transfer pump operates.	Implement control to ensure that only one tails transfer pump operates. This can only be implemented if the volume of tails to be transferred can be handled by a single pump. If the tails volume increases, the additional pump will start
Pumping	Both deslime cyclone overflow pumps operate continuously.	Only one deslime cyclone overflow pump operates.	Implement control to ensure that only one deslime cyclone overflow pump operates. This can only be implemented if the pressure and flow requirements of the cyclone are maintained by only one pump.

In Table 16, the potential energy initiatives identified through analysis of the auxiliary system intensities have been reduced to three specific energy efficiency initiatives. The initiatives were identified through comparison of the high-production, low-consumption and average power profiles. These potential initiatives are:

- Permanently stopping one compressor.
- Implementing control to ensure only one tails transfer pump operates.
- Implementing control to ensure only one deslime cyclone overflow pump operates.

Before implementation, these potential initiatives must be evaluated against the feasibility criteria developed in Section 2.5. The goal of this evaluation is to eliminate infeasible initiatives. However, before continuing with the evaluation, an understanding of the current system operation is

required. From this understanding, the proposed system operation as well as the requirements for such operation can be developed. This process is summarised in Table 17 below. As before, understanding of the current system is achieved through a plant walkthrough as well as through discussion with plant personnel.

Table 17: Requirements for TTP energy efficiency initiative implementation

Initiative	Current operation	Proposed operation	Requirements for implementation
Permanently stop one compressor	Two 200 kW compressors operate in a duty and standby configuration. The duty compressor starts up automatically according to a pressure set point.	The standby compressor should only operate when the duty compressor fails.	Lower the compressed air demand by isolating unused sections of the plant. This will ensure that the standby compressor is not started unnecessarily.
Operate one tails transfer pump	Two 90 kW pumps drain the tails sump. These pumps are configured to deliver low flow, high pressure.	Reconfigure the pumps to high flow, low pressure. This will ensure that only one pump is needed to control the tails sump level.	Replace the current tails pumps with high flow, low pressure pumps.
Operate one cyclone overflow pump	Two 250 kW pumps drain a sump leading to the final thickener. The pumps are automatically started and stopped according to the sump level.	If the same control strategy is kept in place, installing a larger sump will attenuate plant disturbances thus only one pump will be required to maintain the sump level and flow to the final thickener at acceptable values.	Replace current sump with a larger sump.

With the knowledge of the current and proposed operations, as well as the requirements for the implementation thereof, the potential initiatives can be evaluated against the feasibility criteria developed in Section 2.5. If all the criteria are satisfied, the initiative can be considered feasible and should be implemented. The evaluation of the potential initiatives is provided in Table 18.

Table 18: Evaluation of proposed TTP initiatives against feasibility criteria

Criteria	Initiative		
	Isolating unused plant sections	Replacing pumps	Replacing sump
1: Suitable payback	No capital is required for the initiative.	Pumps from unused plant sections will be repurposed. Therefore, no capital is required for the initiative.	A new sump will be required. Payback period > 1 year.
2: Minimal plant disturbance	Implementing the initiative requires isolation of the unused plant sections. This can be done during the plant shut. Additional downtime is not required.	Implementing the initiative requires replacing the pumps. This can be done during the plant shut. Additional downtime is not required.	Implementing the initiative requires replacing the sump. This will cause significant disturbance to the plant as all lines must be flushed. This will only be possible during an extended shut.
3: Operational feasibility	The control strategy remains unchanged.	The pumps will operate in a typical duty and standby configuration.	The pumps will operate in a typical duty and standby configuration. The larger sump will attenuate plant disturbances whilst keeping process parameters at acceptable levels.
4: Uncompromised production	Plant production will be unaffected by the initiative.	Plant production will be unaffected by the initiative.	Plant production will be unaffected by the initiative.
Feasible	Yes	Yes	No

Table 18 shows that the isolating of unused plant sections and replacing the tails pumps initiatives are feasible. As such, these initiatives were implemented on the TTP, the results of which are summarised in Table 19 below. Conversely, Table 18 shows that the sump replacement initiative does not satisfy all the criteria. As such, the initiative is infeasible and so was not implemented.

In Table 19 the cost and consumption savings achieved by implementing the initiatives were calculated according to the measurement and verification methodology provided in Section 2.6. Sample calculations for one day are shown in Table 29 and Table 30 of Appendix C for the compressor and pump initiatives respectively.

Table 19: Cost and consumption savings from TTP initiative implementation

Initiative	Implementation duration	Cost and consumption saving	Estimated yearly cost and consumption saving
Isolating unused plant sections	2 months (winter TOU months).	R350 000 0.23 GWh	R1.6 million 1.40 GWh
Replacing pumps	At the time of writing, this initiative was still in the process of being implemented by site personnel.		R370 000 0.26 GWh

The total estimated yearly cost and consumption savings achieved at the TTP by the implementation of the energy efficiency initiatives summarised in Table 19 are R1.97 million and 1.66 GWh, respectively. These initiatives were identified through the application of the methodology developed in Chapter 2.

3.3.3 Smelter converter plant

The final plant to which the methodology was applied was a smelter converter plant. As with the TTP, the application of the methodology to this plant shows the general applicability of the method to all platinum processing plants.

In the first two real-life case studies, all the detail of the application of the methodology was shown, after which the results from the application were presented. To avoid repetition, the full methodology will not be shown for the smelter converter plant case study. Instead, results obtained from the application of the methodology will be discussed.

In a smelter converter plant, matte, containing nickel, copper, cobalt, iron, sulphur, and PGMs, is converted. In the conversion process, air is blown into the matte to remove the iron and sulphur as iron sulphide (FeS) as well as sulphur as sulphur dioxide (SO₂). This process takes place until the desired iron content is achieved and typically lasts for a few hours. The product of the conversion process, known as converter matte, is then further refined at a base metal refinery (BMR) [37].

Unlike Concentrator A and the TTP discussed above, the smelter converter plant auxiliary loads are mostly variable loads, as shown in the plant 120-hour load variability diagram provided in Figure 46.

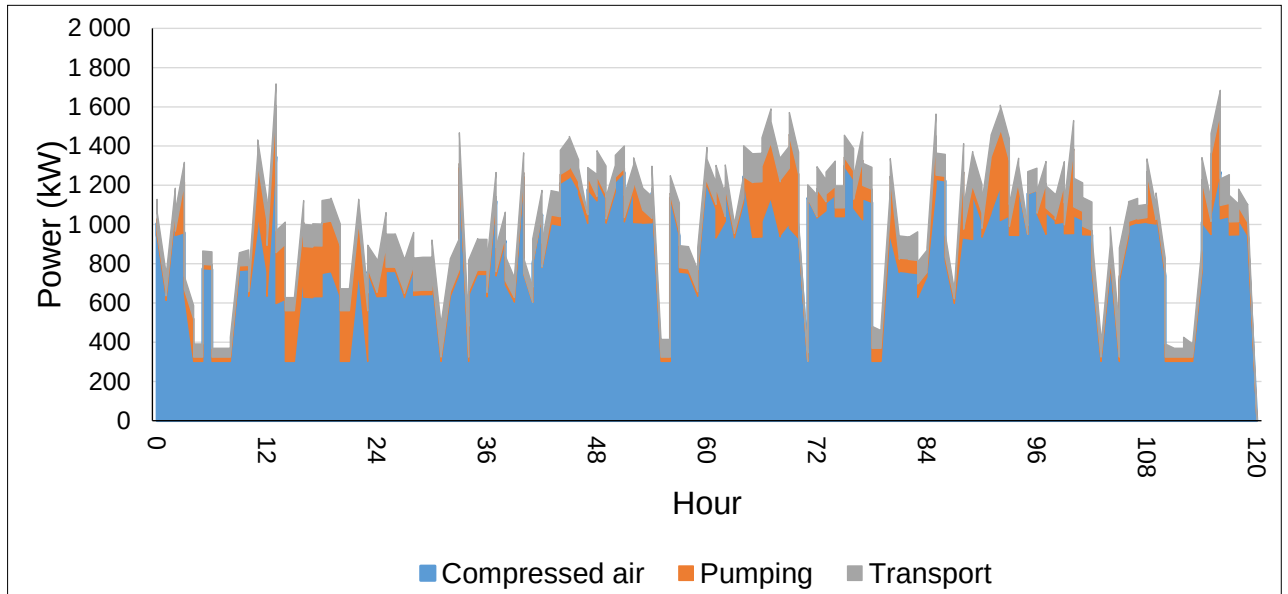


Figure 46: Smelter converter plant 120-hour load variability diagram

From the figure it can be seen that the three auxiliary system loads, namely compressed air, pumping, and transport, vary significantly over the measurement period. The load variability is confirmed by the LFs provided in Table 20, in which the greatest LF is that of the transport system.

Table 20: Smelter converter plant auxiliary system load factors

Auxiliary system	LF (%)	Load type
Compressed air	62	Variable
Pumping transport	19	Variable
Transport	67	Variable

This indicates that the smelter converter plant is a batch process. Despite this, load management opportunities were not implemented on the plant. This is because implementing such opportunities on the plant would violate all of the load shift criteria, as discussed in Table 21 below. As such, energy efficiency initiatives were instead investigated using the developed intensity analysis method.

Table 21: Evaluation of load shift criteria for smelter converter plant

Criteria	Comment	Does the system meet criteria
Uncompromised production	The converter plant is a process step in the smelting process. Parts of these processes, which are both upstream and downstream of the converting process, operate continuously and so cannot be stopped during peak tariff periods.	No
Storage capacity	Although the plant processes matte in batches, there is no storage capacity as the plant receives matte directly from the smelter. If the matte were stored, it would cool and solidify.	No
Increased production in optimal TOU periods	The converter plant has a maximum design capacity and so cannot increase its throughput during optimal tariff periods.	No

The results of the compressed air intensity analysis are represented as an intensity plot in Figure 47 below and as a time-dependent intensity plot in Figure 60 of Appendix D. In Figure 47, two areas have been labelled, namely area 1 and 2.

Area 1 represents days in which production was lower than normal and as such represent outlier data points. Area 2 represents days in which production targets were either met or exceeded. It should be noted that, as the converting process is a batch process, there is still large production variation within area 2.

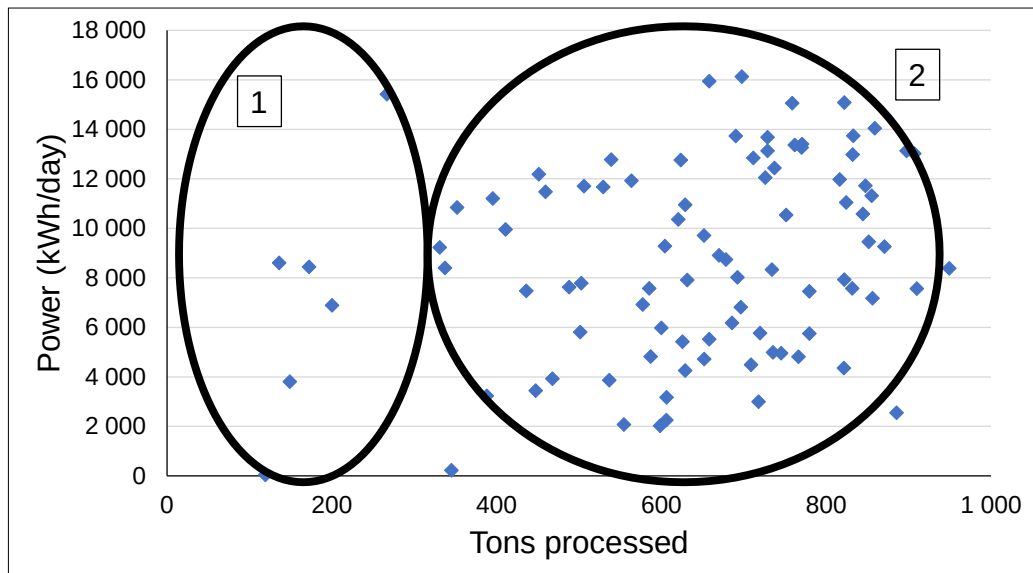


Figure 47: Smelter converter plant compressed air system intensity plot

The large production variance observed in area 2 is accompanied by a similar large variation in power consumption. It is however noted that, regardless of the mass of matte processed in area 2, there is a baseload of approximately 2 000 kWh per day that must operate.

Despite this, area 2 also shows that the energy consumed to process the same mass of matte varies across the entire range of tons processed. This is indicative of weak energy management and means that, for a given production, different equipment is operated, or the same equipment is operated for varying time periods. As such, there may be potential to implement energy efficiency initiatives to ensure that unnecessary equipment is not operated.

These findings are confirmed by the time-dependent intensity plot shown in Figure 60 of Appendix D. In the plot, there is a sustained period from day 43 – 46 in which the system intensity was at least one standard deviation lower than the measurement period average intensity. This observation confirms that, to meet the same production target, different equipment is operated, or the same equipment is operated for varying durations.

These results show that there is scope to implement an energy efficiency initiative on the smelter converter plant compressed air system. This initiative will ensure equipment is not operated unnecessarily, thus resulting in electricity and cost savings. However, before such an initiative can be implemented, it is necessary to identify the equipment causing the increased electricity consumption for a given production. As before, this identification is achieved by comparing the average weekday power profile to a day in which production was met with lower-than-average electricity consumption, referred to as the high-production, low-consumption day. This comparison is shown for the smelter converter plant compressed air system in Figure 48.

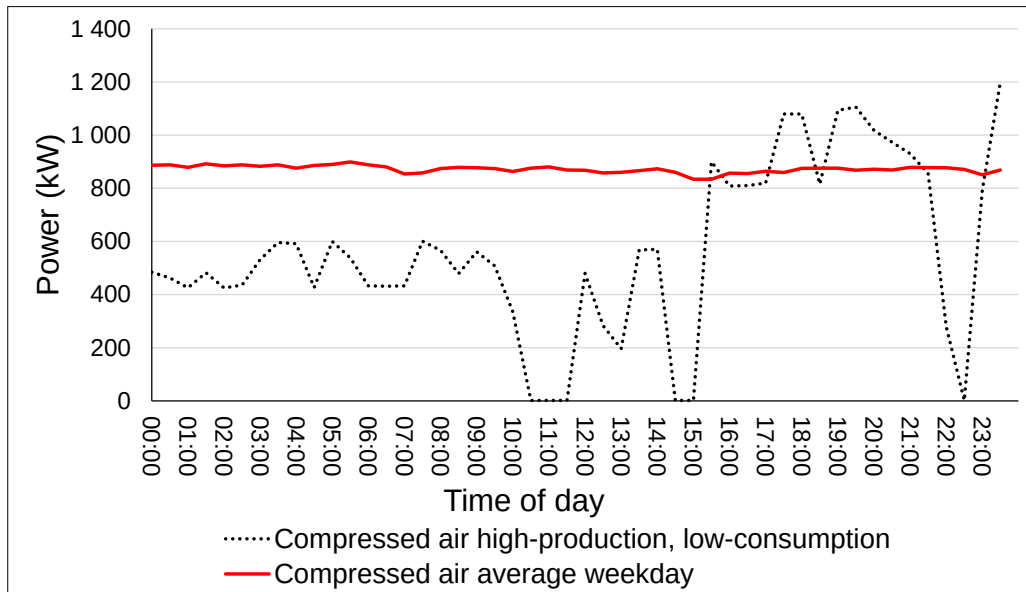


Figure 48: High-production, low-consumption and average weekday power comparisons for converter compressed air system

From analysis of the individual motors which make up the profiles shown in Figure 48, the motors running unnecessarily have been identified. The results of this are summarised in Table 22.

Table 22: Unnecessary motors running identified by comparison of high-production, low-consumption day to average day

System	Average weekday	High-production, low-consumption day	Potential energy efficiency initiative from comparison
Compressed air	Two 650 kW blowers operated continuously throughout the day.	Blowers were only operated when the converter process was running.	Implement control to only operate blowers when required.

Table 22 shows that a cost and energy saving can be achieved through optimisation of the converter plant compressed air system. This can be achieved by only operating the blowers as required. Before being implemented, this initiative must be evaluated against the feasibility criteria developed in Section 2.5 to determine if the initiative is indeed feasible. This evaluation is provided in Table 23.

Table 23: Evaluation of proposed smelter converter plant initiative against feasibility criteria

Criteria	Only operating blowers when required
1: Suitable payback	No capital is required for the initiative.
2: Minimal plant disturbance	The initiative can be implemented with no disturbance to the plant operation.
3: Operational feasibility	The initiative will require control room operators to stop the blowers when the converter plant is not processing matte and to start the blowers when required. The operation is simple and does not require additional control instrumentation.
4: Uncompromised production	Plant production will be unaffected by the initiative.
Feasible	Yes

Table 23 shows that stopping the converter plant blowers when matte is not being processed is feasible. As such, the initiative was implemented on the plant. The electricity and cost savings achieved by the initiative implementation are shown in Table 24 below. In the table, the savings achieved were calculated according to the measurement and verification methodology provided in Section 2.6. Sample calculations for one day are shown in Table 31 of Appendix D.

Table 24: Cost and consumption savings from smelter converter plant initiative implementation

Initiative	Implementation duration	Cost and consumption saving	Estimated yearly cost and consumption saving
Only operating blowers when required	6 months (summer and winter TOU months)	R1.3 million 1.25 GWh	R2.8 million 2.5 GWh

The total estimated yearly cost and consumption savings achieved at the smelter converter plant through the implementation of the energy efficiency initiative are R2.8 million and 2.5 GWh, respectively. This initiative was identified through the application of the methodology developed in Chapter 2.

3.4 Extrapolation of case study results

In the three case studies evaluated it was shown that obtaining electricity cost and consumption savings on platinum processing plant auxiliary systems is feasible. On average, it was seen that estimated consumption savings of 1.87 GWh could be achieved per plant. This equates to an average energy reduction across the three plants of 4.37%.

These results indicate that similar electricity cost and consumption saving opportunities exist on other South African platinum processing plants, which consume approximately 1 800 GWh annually. If this average energy reduction of 4.37% is extrapolated to all South African platinum processing plants, potential yearly electricity savings of up to 79 GWh could be achieved [17, 83]. This equates to an estimated yearly cost saving of more than R80 million.

3.5 Conclusion

In this chapter, the developed methodology in Chapter 2 was validated by applying it to three real-world case studies. Furthermore, to show the general applicability of the methodology, the method was applied to three different types of platinum processing plants, namely a concentrator, tailings treatment plant, and smelter converter plant.

The results show that, when a platinum mining operation consists of multiple platinum plants, benchmarking of plant auxiliary systems can be used to identify the plant with the greatest auxiliary system energy intensity. This plant can then be prioritised for investigation through the baseline and intensity analysis methods developed in this study.

The application of these methods to the three case studies resulted in five energy efficiency initiatives with estimated annual electricity and cost savings of 5.44 GWh and R6.23 million being identified and implemented. These initiatives were implemented without causing any disruptions to the plants and did not affect product quality.

The application of the methodology also resulted in the identification of potential load management initiatives. These initiatives were, however, infeasible on the specific plants investigated as not all the load management criteria were met. Despite this, there remains potential to implement load management initiatives on platinum processing plant auxiliary systems and, when investigating a new plant, the methodology to identify such initiatives should be followed.

If these results obtained in this chapter were to be extrapolated to all South African platinum processing plants, estimated yearly cost and energy savings of R80 million and 79 GWh could be achieved.

CHAPTER 4: CONCLUSION

4.1 Review of research objectives

The South African mining industry contributes significantly to the South African economy. The industry directly employed over 450 000 people in 2020. This, however, represents a 12% decrease over 12 years in the number of permanent employees in the industry. One of the causes for this decrease in employment is the closure of unprofitable mining operations.

Mining operations are price takers and so cannot increase profitability by increasing their mineral prices. Instead, mines must reduce their operational costs. Electricity is one such operational cost in which savings potential has been identified and can account for up to 12% of a mining operation's total expenditure.

On a typical platinum mining operation, platinum processing plants typically consume 19% of the total power used by the mine. Despite this high consumption, little focus has been placed on obtaining electrical cost and consumption savings on platinum processing plants. This is due to the perception that such savings cannot be achieved due to the inability to load shift large milling and smelting equipment, as well as the constant operating nature of the plants.

However, from a literature review, it was observed that, in other industries, electrical consumption and cost savings were obtained by optimising plant auxiliary systems. As auxiliary systems contribute significantly to the power consumption of platinum processing plants, it was concluded that there may be scope to implement electrical cost and consumption saving measures on platinum processing plant auxiliary systems.

Thus, a need was recognised to develop a methodology to identify electrical cost and consumption saving initiatives on platinum processing plant auxiliary systems. To meet this need, this study aimed to develop, implement, and verify a methodology to:

1. Benchmark and prioritise platinum processing plant auxiliary systems for further investigation.
2. Identify load management opportunities on platinum processing plant auxiliary systems.
3. Identify energy efficiency opportunities on platinum processing plant auxiliary systems.

4.2 Summary of findings

To meet objective 1 of this study, a benchmarking methodology was developed to benchmark the energy intensity of only the platinum plant auxiliary systems. This benchmarking methodology was applied to a platinum mining operation that consists of four active platinum concentrators.

The methodology was successful in identifying the concentrator with the greatest auxiliary system energy intensity. This concentrator was then prioritised for further investigation.

The value of the developed methodology was evident when the results were compared with benchmarking results in which the entire concentrators' energy intensities were benchmarked. When benchmarked in this way, the plant with the greatest energy intensity did not have the greatest auxiliary system energy intensity. Thus, if the developed benchmarking methodology was not followed, the plant with the greatest auxiliary system energy intensity may not have been prioritised for further investigation.

To meet objective 2 an auxiliary system baseline analysis method was developed. The method aimed to identify load management opportunities of platinum plant auxiliary systems through the identification and evaluation of plant variable loads.

Similarly, an intensity analysis method was developed to meet objective 3. The aim of the intensity analysis method was to identify platinum plant auxiliary loads suited to energy efficiency initiatives by comparison of daily production against daily energy usage.

The initiatives identified through the baseline analysis and intensity analysis methods were then evaluated against a set of feasibility criteria. The criteria, which are listed below, were developed to ensure that all initiatives identified through the application of the developed methodologies are indeed feasible. Thus, only initiatives which met all four of the criteria listed below were implemented.

1. The initiative should have a suitable payback period.
2. The initiative should be tested and implemented with minimal disturbance to the plant operation.
3. The initiative should be feasible from an operations perspective. Complicated control requiring large amounts of instrumentation should be avoided.
4. The initiative should not compromise plant production or quality.

To verify the validity of the baseline analysis and intensity analysis methods, the methodologies were applied to three real-world platinum processing plants. One of the plants to which the methodologies were applied was the platinum concentrator identified through the application of the benchmarking methodology. Furthermore, to show the general applicability of the methodologies to all platinum processing plants, the methodologies were also applied to a tailings treatment plant and a smelter converter plant.

Two load management initiatives were identified across the three platinum processing plants. These initiatives, which include a conveyor load shift at the concentrator and a pumping load shift at the tailing treatment plant, were not implemented. This is because, if implemented on the specific plant, the initiatives would violate one or more of the feasibility criteria listed above. Despite this, the methodology was successful in identifying opportunities to evaluate against the criteria and so, when evaluating new platinum processing plants, the baseline analysis method should still be followed.

Application of the intensity analysis methodology resulted in initiative identification and implementation on all the plants investigated. The estimated annual cost and consumption savings achieved by the initiatives as well as a brief description of the initiatives are provided in Table 25 below.

Table 25: Summary of implemented energy efficiency initiatives

Plant	Initiative	Annual cost saving	Annual consumption saving
Concentrator A	Lower the standby compressor set point.	R960 000	0.84 GWh
	Programme level control to automatically start and stop the pumps.	R500 000	0.44 GWh
Tailings treatment plant	Isolating unused plant sections.	R1.6 million	1.4 GWh
	Replacing pumps.	R370 000	0.26 GWh
Smelter converter plant	Only operating blowers when required.	R2.8 million	2.5 GWh

Thus, application of the intensity analysis methodology resulted in the implementation of initiatives with a combined annual electrical cost and consumption saving of R6.23 million and 5.44 GWh, respectively.

The application of the methodologies developed in this study show that electrical cost and consumption savings can be achieved through optimisation of platinum plant auxiliary systems.

The methodologies were developed to be generic to all South African platinum processing plants. This generic applicability was demonstrated by the application of the methodologies to three different types of processing plants. Thus, this methodology can be applied to identify feasible auxiliary system load management and energy efficiency initiatives on any South African platinum processing plant. It is estimated that, if similar results were to be obtained through the application of the methodology to all South African platinum processing plants, estimated yearly cost and energy savings of R80 million and 79 GWh could be achieved.

4.3 Recommendations for future work

Due to scope and time restrictions, several areas of investigation could not be fully covered in this study. It is recommended that the following areas be considered for future work:

- This study focussed on obtaining electrical cost and consumption savings through load management and energy efficiency initiatives. These initiatives were implemented if they provided a suitable payback period and were feasible according to the feasibility criteria. In order to further motivate the implementation of such initiatives, it is recommended that additional cost saving models and incentives be considered. Models and incentives to be considered may include demand reduction, clean development mechanism and carbon tax rebates.
- Due to the reasons listed in Chapter 2, simulation techniques were not used to identify electrical cost and consumption saving opportunities on platinum plant auxiliary systems. It is, however, recommended that simulation techniques be used to further assess the feasibility of such initiatives. In particular, dynamic simulations can be used to further evaluate the feasibility of load management opportunities on plant transport and pumping systems.
- This study did not take into account the effect of stopping and starting equipment on the achievable cost savings. Load management initiatives would result in an increase in stop-start cycles which in turn would increase equipment wear and thus decrease savings. Conversely, energy efficiency initiatives would result in some equipment being permanently stopped, thus introducing more redundancy into the system, and decreasing maintenance costs. These effects on cost savings should be considered in future works.

- There is scope to expand the study to include gold and other mineral processing plants in which the load management of large equipment is not feasible due to the constant operating nature of the plants. It is therefore recommended that, in future works, the platinum processing plant specific method be modified to be applicable to all mineral processing plants. Furthermore, the scope of the study should be expanded to include other energy sources as well as processing plants outside of South Africa.
- As mentioned in the above recommendation, the methodology should be modified to be applicable to all mineral processing plants. It should, however, be noted that the benchmarking technique developed in this study can already be generically applied to all mineral processing plants simply by distinguishing the plant auxiliary systems. Thus, it is recommended that further studies be done on using the benchmarking methodology developed in this study to identify facilities for further investigation in other mineral processing industries.
- In the case studies used in this study, load management initiatives were identified but not implemented as they violated one or more of the feasibility criteria. More case studies should be conducted in which load management initiatives on platinum plant auxiliary systems are implemented.
- The methodology developed in Chapter 2 and implemented in Chapter 3 is time and resource intensive. After application of the methodology on several case studies, it may be possible that certain trends emerge. For example, on the three plants considered in this study, the compressed air systems on all three plants presented savings opportunities. Thus, it may be possible in future works to reduce some of the time and labour required to identify electrical cost and consumption saving opportunities by focussing only on plant sections which have historically shown savings potential.

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APPENDIX A: MEGAFLEX TARIFF

Table 26: Eskom Megaflex tariff active energy charge³

Eskom Megaflex tariff, non-local authority		Active energy charge (c/kWh) VAT (15%) included					
		High demand season (June – August)			Low demand season (September – May)		
Transmission zone	Voltage	Peak	Standard	Off-peak	Peak	Standard	Off-peak
≤ 300 km	< 500 V	417.14	126.91	69.30	136.60	94.25	60.09
	≥ 500 V & <66 kV	410.60	124.38	67.55	133.92	92.20	58.49
	≥ 66 kV & ≤ 132 kV	397.59	120.44	65.41	129.71	89.25	56.65
	> 132 kV	374.72	113.51	61.65	122.27	84.12	53.38
> 300 km & ≤ 600 km	< 500 V	420.54	127.42	69.18	137.20	94.46	59.93
	≥ 500 V & <66 kV	414.69	125.61	68.22	135.30	93.10	59.06
	≥ 66 kV & ≤ 132 kV	401.50	121.61	66.02	130.96	90.14	57.19
	> 132 kV	378.48	114.67	62.23	123.44	84.95	53.88
> 600 km & ≤ 900 km	< 500 V	424.73	128.66	69.84	138.55	95.37	60.48
	≥ 500 V & <66 kV	418.86	126.90	68.91	136.63	94.05	59.66
	≥ 66 kV & ≤ 132 kV	405.59	122.88	66.71	132.30	91.07	57.78
	> 132 kV	382.28	115.79	62.92	124.69	85.81	54.45
> 900 km	< 500 V	429.01	130.01	70.56	139.96	96.31	61.12
	≥ 500 V & <66 kV	423.03	128.13	69.55	137.97	94.94	60.25
	≥ 66 kV & ≤ 132 kV	409.66	124.09	67.38	133.62	91.989	58.35
	> 132 kV	386.01	116.98	63.56	125.99	86.76	55.06

³ Adapted from Eskom Enterprises “Tariffs and Charges Booklet 2020/2021.” [Online]. Available: https://www.eskom.co.za/CustomerCare/TariffsAndCharges/Pages/Tariffs_And_Charges.aspx [Accessed 14 March 2021].

APPENDIX B: CONCENTRATOR A ADDITIONAL RESULTS

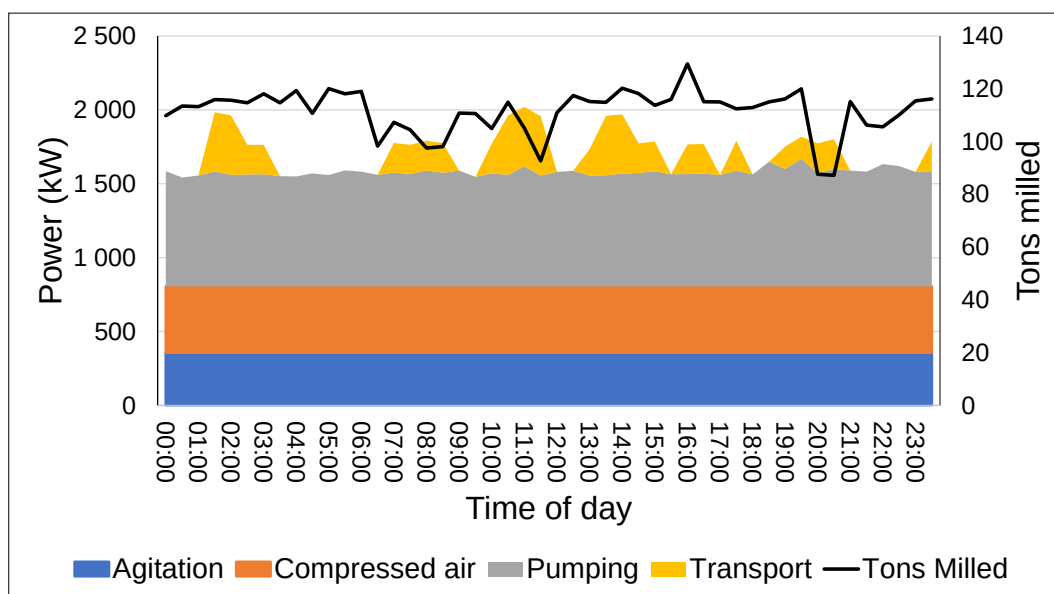


Figure 49: Concentrator A average Saturday auxiliary system profiles

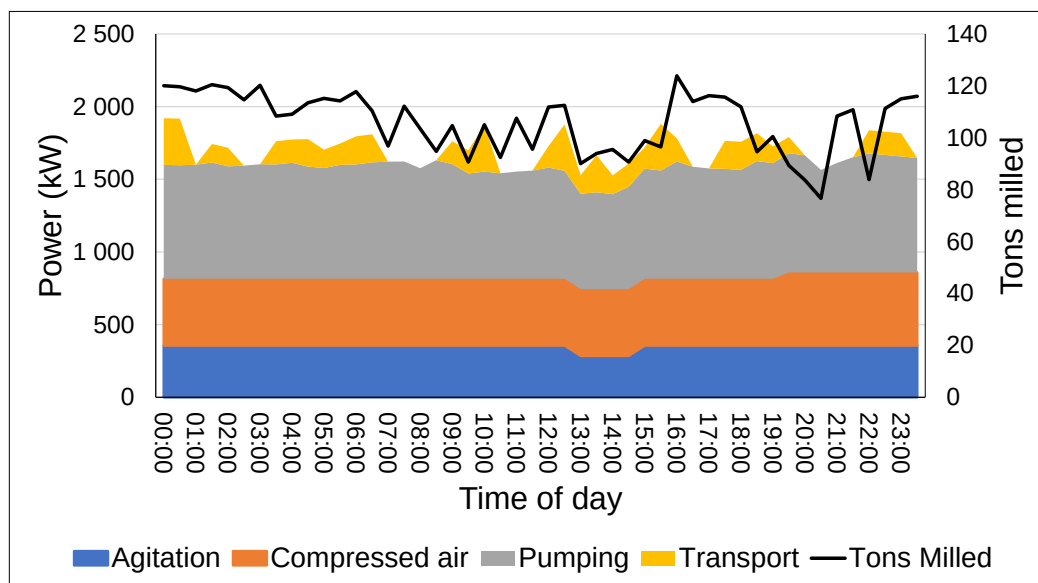


Figure 50: Concentrator A average Sunday auxiliary system profiles

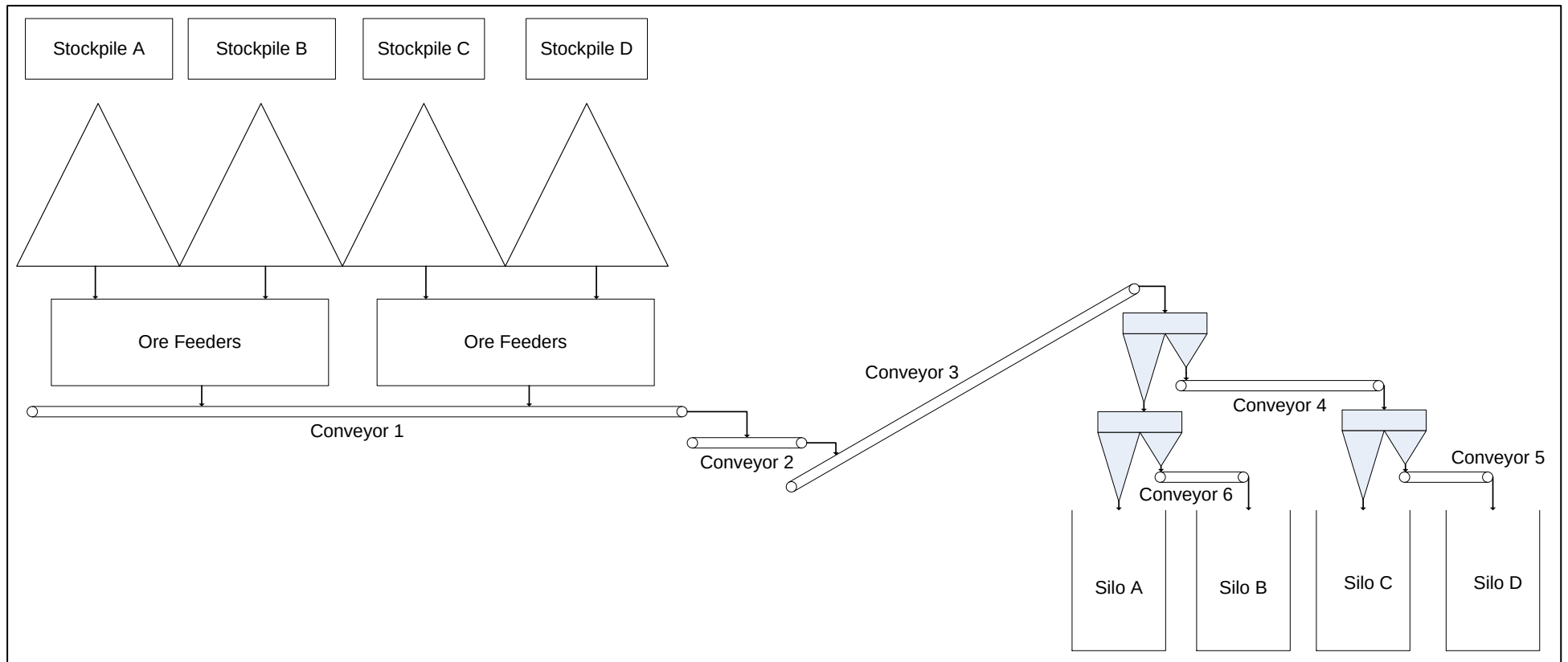


Figure 51: Schematic of Concentrator A transport system

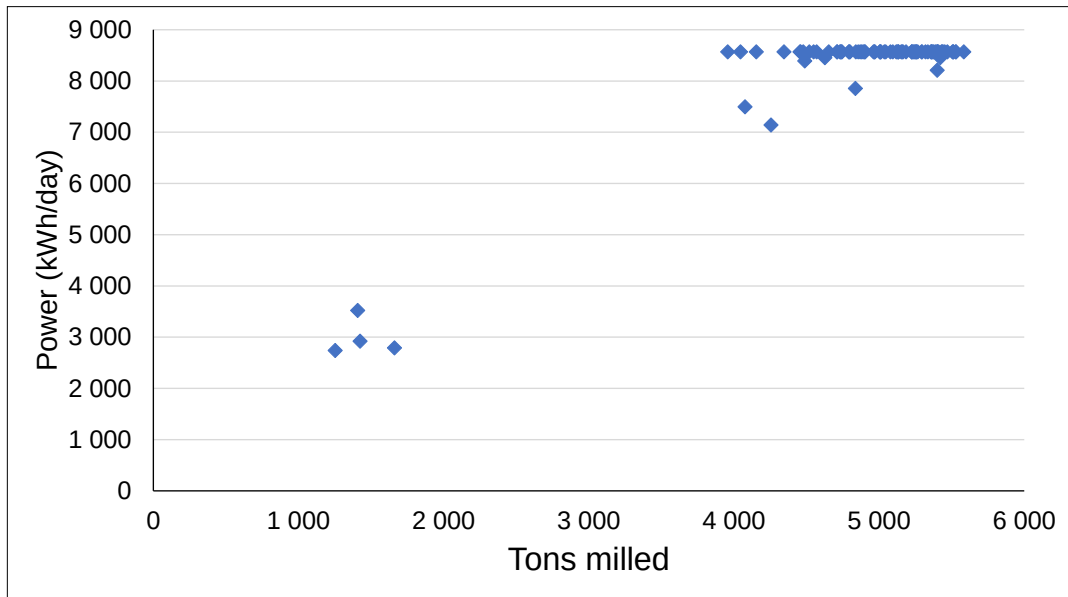


Figure 52: Concentrator A agitation system intensity plot

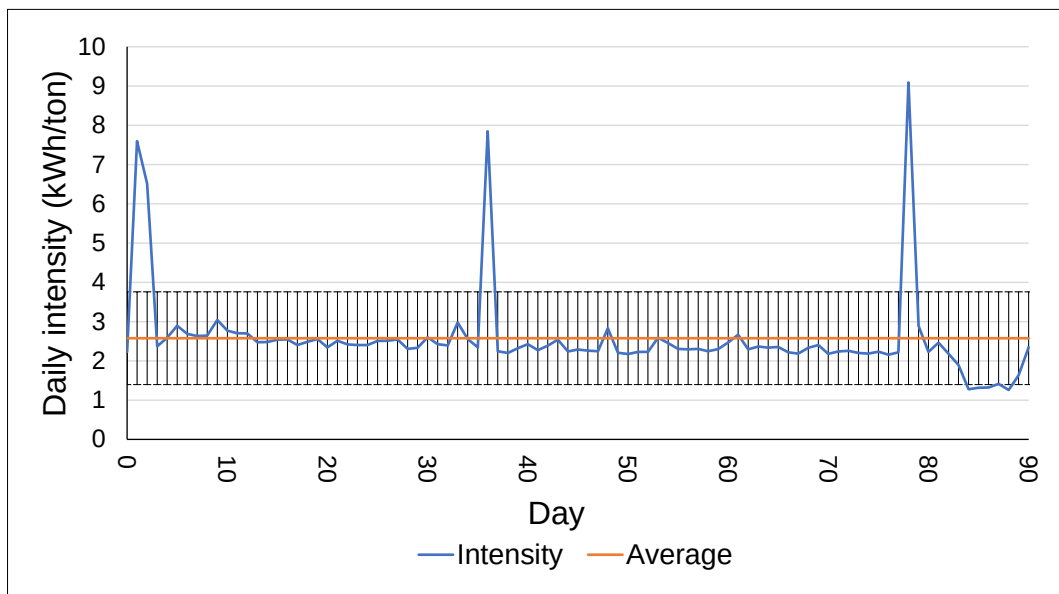


Figure 53: Concentrator A compressed air system time-dependent intensity plot with outliers

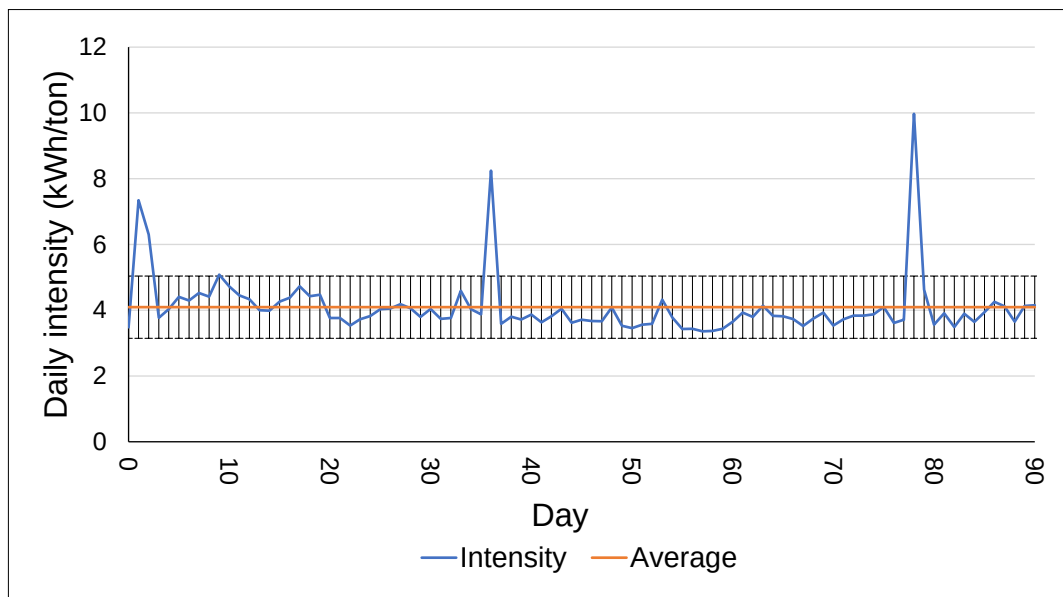


Figure 54: Concentrator A pumping system time-dependent intensity plot with outliers

Table 27: Single day cost and consumption saving sample calculation for Concentrator A lower standby compressor set point initiative

Time	Baseline power profile (kW)	Measured power profile (kW)	kW savings	TOU Tariff (R/kWh)	Cost saving (R)	Consumption saving (kWh)
00:30	97.3	0	97.3	0.65	31.6	48.6
01:00	97.2	0	97.2	0.65	31.5	48.6
01:30	97.2	0	97.2	0.65	31.5	48.6
02:00	97.2	0	97.2	0.65	31.5	48.6
02:30	97.2	0	97.2	0.65	31.5	48.6
03:00	97.2	0	97.2	0.65	31.5	48.6
03:30	97.2	0	97.2	0.65	31.5	48.6
04:00	97.2	0	97.2	0.65	31.5	48.6
04:30	97.5	0	97.5	0.65	31.6	48.8
05:00	97.5	0	97.5	0.65	31.6	48.8
05:30	97.5	0	97.5	0.65	31.6	48.8
06:00	97.5	0	97.5	0.65	31.6	48.8
06:30	97.5	0	97.5	0.94	45.9	48.8
07:00	97.5	0	97.5	0.94	45.9	48.8
07:30	97.5	0	97.5	1.30	63.6	48.8
08:00	97.5	0	97.5	1.30	63.6	48.8
08:30	97.2	0	97.2	1.30	63.4	48.6
09:00	96.6	0	96.6	1.30	63.0	48.3
09:30	97.2	0	97.2	1.30	63.4	48.6
10:00	97.2	0	97.2	1.30	63.4	48.6
10:30	97.1	0	97.1	0.94	45.7	48.6
11:00	96.9	0	96.9	0.94	45.6	48.4
11:30	96.9	0	96.9	0.94	45.6	48.4
12:00	96.8	0	96.8	0.94	45.6	48.4
12:30	96.5	0	96.5	0.94	45.5	48.3

13:00	96.6	0	96.6	0.94	45.5	48.3
13:30	96.9	0	96.9	0.94	45.6	48.4
14:00	96.6	0	96.6	0.94	45.5	48.3
14:30	97.5	0	97.5	0.94	45.9	48.7
15:00	97.2	0	97.2	0.94	45.8	48.6
15:30	96.9	0	96.9	0.94	45.6	48.4
16:00	97.2	0	97.2	0.94	45.8	48.6
16:30	97.2	0	97.2	0.94	45.8	48.6
17:00	96.9	0	96.9	0.94	45.6	48.4
17:30	96.9	0	96.9	0.94	45.6	48.4
18:00	97.2	0	97.2	0.94	45.8	48.6
18:30	97.2	0	97.2	1.30	63.4	48.6
19:00	97.2	0	97.2	1.30	63.4	48.6
19:30	97.5	0	97.5	1.30	63.6	48.8
20:00	97.5	0	97.5	1.30	63.6	48.8
20:30	97.8	0	97.8	0.94	46.1	48.9
21:00	97.5	0	97.5	0.94	45.9	48.8
21:30	97.5	0	97.5	0.94	45.9	48.8
22:00	97.5	0	97.5	0.94	45.9	48.8
22:30	97.5	0	97.5	0.65	31.6	48.8
23:00	97.5	0	97.5	0.65	31.6	48.8
23:30	97.5	0	97.5	0.65	31.6	48.8
00:00	97.2	0	97.2	0.65	31.5	48.6
Daily total					2146.0	2333.2

Table 28: Single day cost and consumption saving sample calculation for Concentrator A level control initiative

Time	Baseline power profile (kW)	Predicted power profile (kW)	Predicted kW savings	TOU Tariff (R/kWh)	Predicted cost saving (R)	Predicted consumption saving (kWh)
00:30	96.0	43.6	52.4	0.65	17.0	26.2
01:00	97.0	29.0	68.0	0.65	22.1	34.0
01:30	97.0	0.0	97.0	0.65	31.5	48.5
02:00	97.0	29.0	68.0	0.65	22.1	34.0
02:30	97.0	29.0	68.0	0.65	22.1	34.0
03:00	96.0	0.0	96.0	0.65	31.2	48.0
03:30	97.0	29.0	68.0	0.65	22.1	34.0
04:00	97.0	29.0	68.0	0.65	22.1	34.0
04:30	97.0	0.0	97.0	0.65	31.5	48.5
05:00	97.0	14.5	82.5	0.65	26.8	41.2
05:30	97.0	43.6	53.4	0.65	17.4	26.7
06:00	97.0	72.6	24.4	0.65	7.9	12.2
06:30	96.0	43.6	52.4	0.94	24.6	26.2
07:00	97.0	14.5	82.5	0.94	38.8	41.2
07:30	98.0	43.6	54.4	1.30	35.4	27.2
08:00	96.0	43.6	52.4	1.30	34.1	26.2
08:30	94.0	29.0	65.0	1.30	42.2	32.5
09:00	92.0	0.0	92.0	1.30	59.8	46.0
09:30	92.0	29.0	63.0	1.30	40.9	31.5
10:00	92.0	0.0	92.0	1.30	59.8	46.0

10:30	92.0	29.0	63.0	0.94	29.6	31.5
11:00	92.0	29.0	63.0	0.94	29.6	31.5
11:30	93.0	29.0	64.0	0.94	30.1	32.0
12:00	91.0	29.0	62.0	0.94	29.1	31.0
12:30	92.0	0.0	92.0	0.94	43.2	46.0
13:00	91.0	29.0	62.0	0.94	29.1	31.0
13:30	92.0	0.0	92.0	0.94	43.2	46.0
14:00	91.0	0.0	91.0	0.94	42.8	45.5
14:30	91.0	0.0	91.0	0.94	42.8	45.5
15:00	91.0	0.0	91.0	0.94	42.8	45.5
15:30	91.0	29.0	62.0	0.94	29.1	31.0
16:00	93.0	0.0	93.0	0.94	43.7	46.5
16:30	93.0	0.0	93.0	0.94	43.7	46.5
17:00	93.0	29.0	64.0	0.94	30.1	32.0
17:30	93.0	0.0	93.0	0.94	43.7	46.5
18:00	93.0	29.0	64.0	0.94	30.1	32.0
18:30	94.0	29.0	65.0	1.30	42.2	32.5
19:00	93.0	29.0	64.0	1.30	41.6	32.0
19:30	93.0	43.6	49.4	1.30	32.1	24.7
20:00	92.0	43.6	48.4	1.30	31.5	24.2
20:30	94.0	77.9	16.1	0.94	7.6	8.1
21:00	95.0	77.9	17.1	0.94	8.0	8.6
21:30	95.0	0.0	95.0	0.94	44.7	47.5
22:00	94.0	58.1	35.9	0.94	16.9	18.0
22:30	95.0	58.1	36.9	0.65	12.0	18.5
23:00	95.0	38.9	56.1	0.65	18.2	28.0
23:30	95.0	9.9	85.1	0.65	27.7	42.6
00:00	96.0	38.9	57.1	0.65	18.5	28.5
Daily total					1493.1	1631.0

APPENDIX C: TTP ADDITIONAL RESULTS

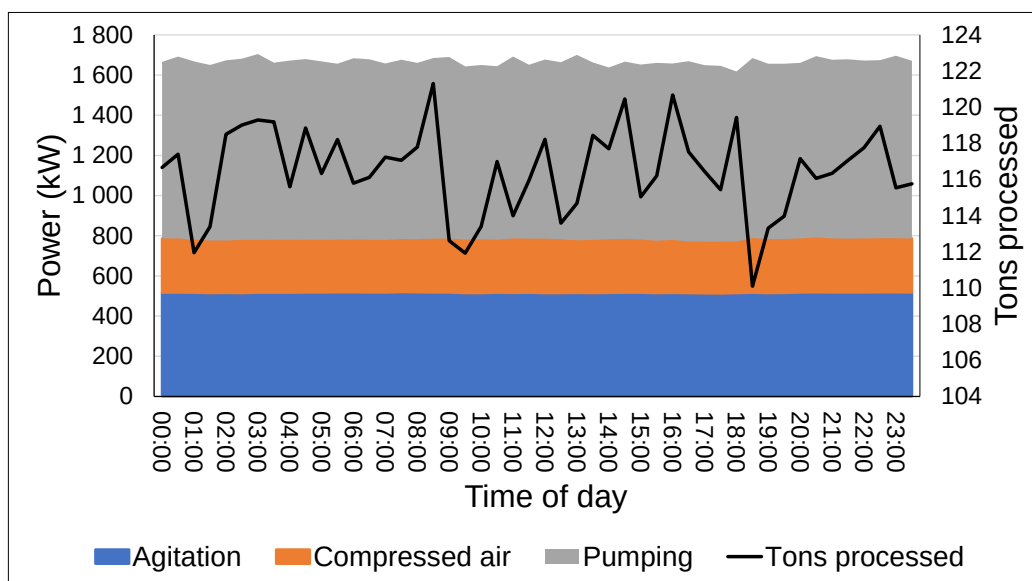


Figure 55: TTP average Saturday auxiliary system profiles

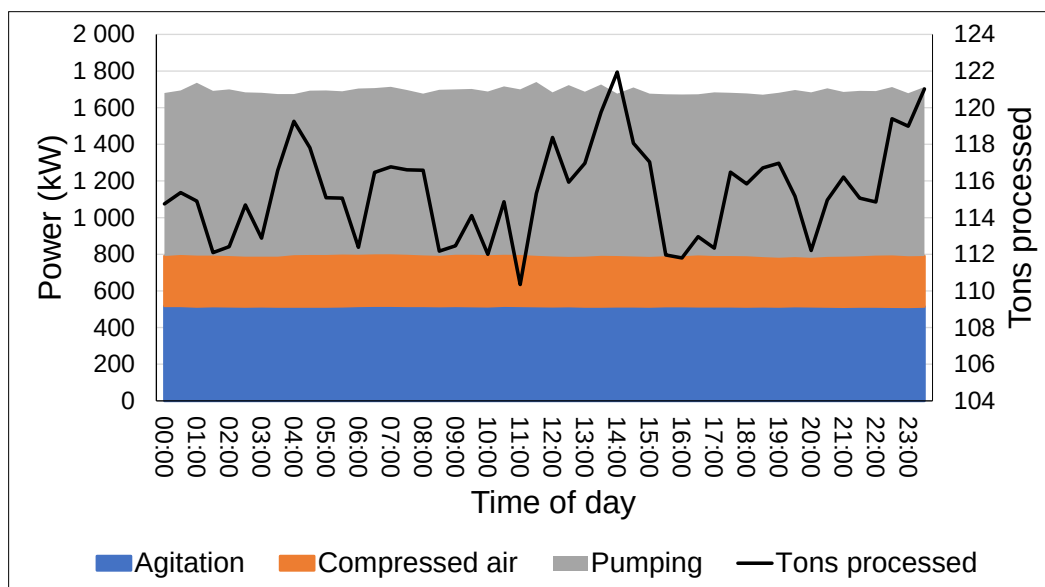


Figure 56: TTP average Sunday auxiliary system profiles

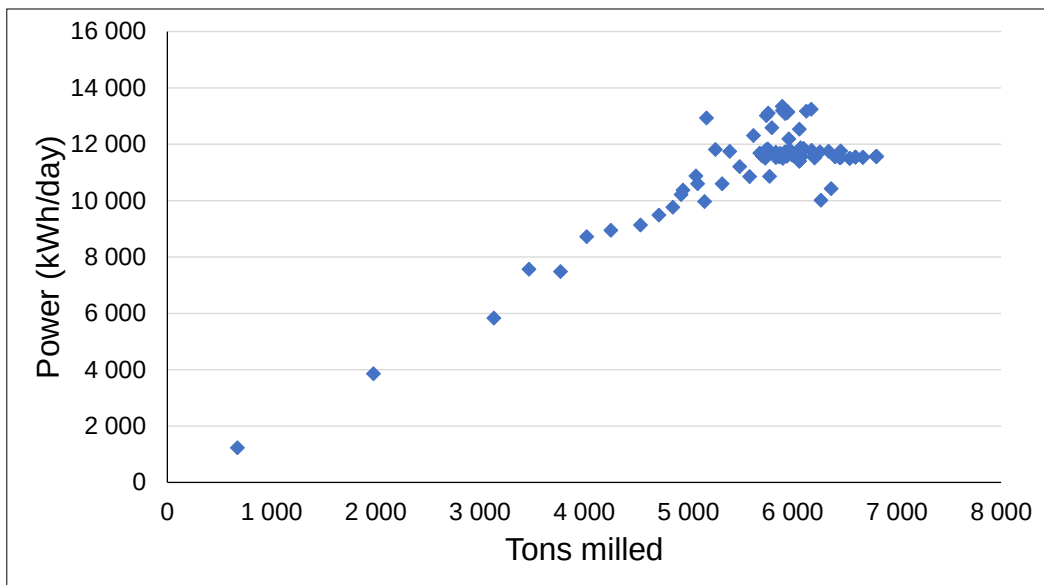


Figure 57: TTP agitation system intensity plot

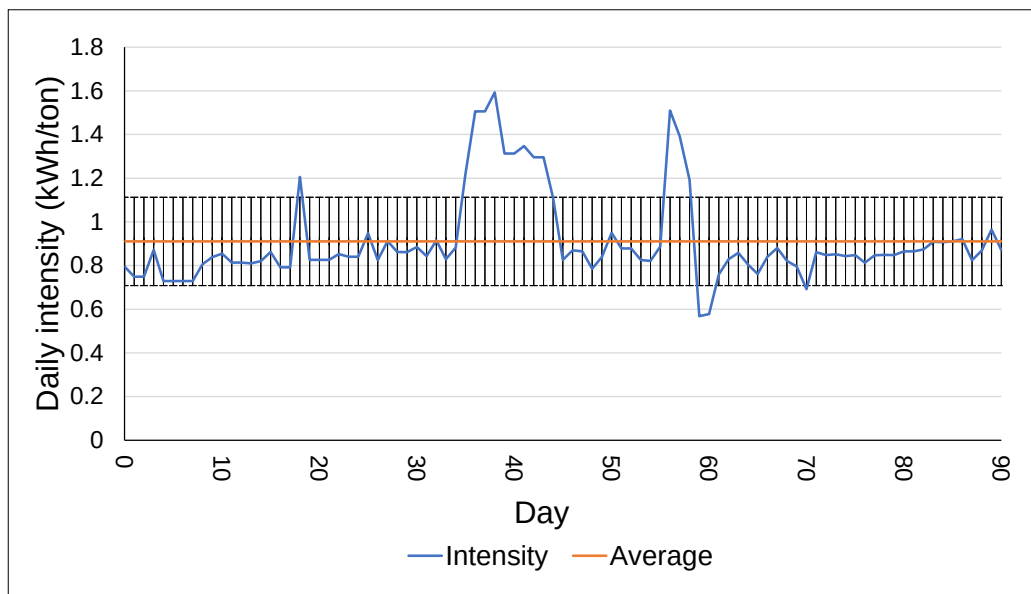


Figure 58: TTP compressed air system time-dependent intensity plot with outliers

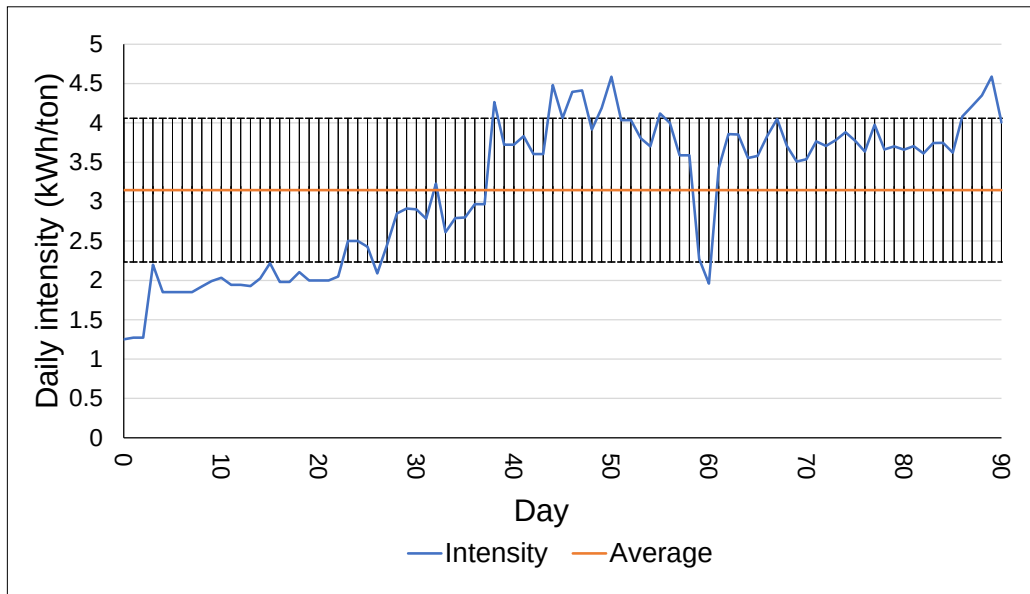


Figure 59: TTP pumping system time-dependent intensity plot with outliers

Table 29: Single day cost and consumption saving sample calculation for TTP isolate unused plant sections initiative

Time	Baseline power profile (kW)	Measured power profile (kW)	kW savings	TOU Tariff (R/kWh)	Cost saving (R)	Consumption saving (kWh)
00:30	189.0	0	189.0	0.82	77.1	94.5
01:00	196.0	0	196.0	0.82	79.9	98.0
01:30	196.0	0	196.0	0.82	79.9	98.0
02:00	196.0	0	196.0	0.82	79.9	98.0
02:30	196.0	0	196.0	0.82	79.9	98.0
03:00	196.0	0	196.0	0.82	79.9	98.0
03:30	189.0	0	189.0	0.82	77.1	94.5
04:00	189.0	0	189.0	0.82	77.1	94.5
04:30	189.0	0	189.0	0.82	77.1	94.5
05:00	189.0	0	189.0	0.82	77.1	94.5
05:30	182.0	0	182.0	0.82	74.2	91.0
06:00	182.0	0	182.0	0.82	74.2	91.0
06:30	182.0	0	182.0	4.14	376.7	91.0
07:00	182.0	0	182.0	4.14	376.7	91.0
07:30	189.0	0	189.0	4.14	391.1	94.5
08:00	189.0	0	189.0	4.14	391.1	94.5
08:30	178.0	0	178.0	4.14	368.4	89.0
09:00	175.0	0	175.0	4.14	362.2	87.5
09:30	175.0	0	175.0	1.37	119.5	87.5
10:00	161.0	0	161.0	1.37	110.0	80.5
10:30	157.0	0	157.0	1.37	107.2	78.5
11:00	157.0	0	157.0	1.37	107.2	78.5
11:30	164.0	0	164.0	1.37	112.0	82.0
12:00	164.0	0	164.0	1.37	112.0	82.0
12:30	164.0	0	164.0	1.37	112.0	82.0

13:00	157.0	0	157.0	1.37	107.2	78.5
13:30	157.0	0	157.0	1.37	107.2	78.5
14:00	171.0	0	171.0	1.37	116.8	85.5
14:30	175.0	0	175.0	1.37	119.5	87.5
15:00	175.0	0	175.0	1.37	119.5	87.5
15:30	175.0	0	175.0	1.37	119.5	87.5
16:00	178.0	0	178.0	1.37	121.6	89.0
16:30	182.0	0	182.0	1.37	124.3	91.0
17:00	182.0	0	182.0	1.37	124.3	91.0
17:30	182.0	0	182.0	4.14	376.7	91.0
18:00	185.0	0	185.0	4.14	382.9	92.5
18:30	185.0	0	185.0	4.14	382.9	92.5
19:00	185.0	0	185.0	4.14	382.9	92.5
19:30	185.0	0	185.0	1.37	126.4	92.5
20:00	185.0	0	185.0	1.37	126.4	92.5
20:30	185.0	0	185.0	1.37	126.4	92.5
21:00	185.0	0	185.0	1.37	126.4	92.5
21:30	185.0	0	185.0	1.37	126.4	92.5
22:00	185.0	0	185.0	1.37	126.4	92.5
22:30	185.0	0	185.0	0.82	75.4	92.5
23:00	182.0	0	182.0	0.82	74.2	91.0
23:30	182.0	0	182.0	0.82	74.2	91.0
00:00	189.0	0	189.0	0.82	77.1	94.5
Daily total					7624.1	4331.5

Table 30: Single day cost and consumption saving sample calculation for TTP replace pumps initiative

Time	Baseline power profile (kW)	Predicted power profile (kW)	Predicted kW savings	TOU Tariff (R/kWh)	Predicted cost saving (R)	Predicted consumption saving (kWh)
00:30	97.6	54.0	43.6	0.82	17.9	21.8
01:00	97.2	54.0	43.2	0.82	17.7	21.6
01:30	97.2	54.0	43.2	0.82	17.7	21.6
02:00	98.1	54.0	44.1	0.82	18.1	22.1
02:30	98.1	54.0	44.1	0.82	18.1	22.1
03:00	97.8	54.0	43.8	0.82	18.0	21.9
03:30	97.2	54.0	43.2	0.82	17.7	21.6
04:00	97.5	54.0	43.5	0.82	17.8	21.8
04:30	97.5	54.0	43.5	0.82	17.8	21.8
05:00	97.2	54.0	43.2	0.82	17.7	21.6
05:30	97.5	54.0	43.5	0.82	17.8	21.8
06:00	96.6	54.0	42.6	0.82	17.5	21.3
06:30	96.9	54.0	42.9	4.14	88.8	21.5
07:00	97.2	54.0	43.2	4.14	89.4	21.6
07:30	96.9	54.0	42.9	4.14	88.8	21.5
08:00	96.6	54.0	42.6	4.14	88.2	21.3
08:30	95.4	54.0	41.4	4.14	85.7	20.7
09:00	95.4	54.0	41.4	4.14	85.7	20.7
09:30	93.9	54.0	39.9	1.37	27.3	20.0
10:00	94.2	54.0	40.2	1.37	27.5	20.1

10:30	95.7	54.0	41.7	1.37	28.6	20.9
11:00	96.0	54.0	42.0	1.37	28.8	21.0
11:30	96.0	54.0	42.0	1.37	28.8	21.0
12:00	95.7	54.0	41.7	1.37	28.6	20.9
12:30	96.0	54.0	42.0	1.37	28.8	21.0
13:00	95.4	54.0	41.4	1.37	28.4	20.7
13:30	96.0	54.0	42.0	1.37	28.8	21.0
14:00	95.7	54.0	41.7	1.37	28.6	20.9
14:30	94.8	54.0	40.8	1.37	27.9	20.4
15:00	95.4	54.0	41.4	1.37	28.4	20.7
15:30	94.8	54.0	40.8	1.37	27.9	20.4
16:00	95.1	54.0	41.1	1.37	28.2	20.6
16:30	93.6	54.0	39.6	1.37	27.1	19.8
17:00	93.9	54.0	39.9	1.37	27.3	20.0
17:30	93.9	54.0	39.9	4.14	82.6	20.0
18:00	93.9	54.0	39.9	4.14	82.6	20.0
18:30	94.2	54.0	40.2	4.14	83.2	20.1
19:00	93.9	54.0	39.9	4.14	82.6	20.0
19:30	95.1	54.0	41.1	1.37	28.2	20.6
20:00	95.1	54.0	41.1	1.37	28.2	20.6
20:30	95.1	54.0	41.1	1.37	28.2	20.6
21:00	95.7	54.0	41.7	1.37	28.6	20.9
21:30	96.0	54.0	42.0	1.37	28.8	21.0
22:00	96.6	54.0	42.6	1.37	29.2	21.3
22:30	96.0	54.0	42.0	0.82	17.2	21.0
23:00	96.0	54.0	42.0	0.82	17.2	21.0
23:30	96.3	54.0	42.3	0.82	17.3	21.2
00:00	97.2	54.0	43.2	0.82	17.7	21.6
Daily total					1762.7	1006.5

APPENDIX D: SMELTER CONVERTER PLANT ADDITIONAL RESULTS

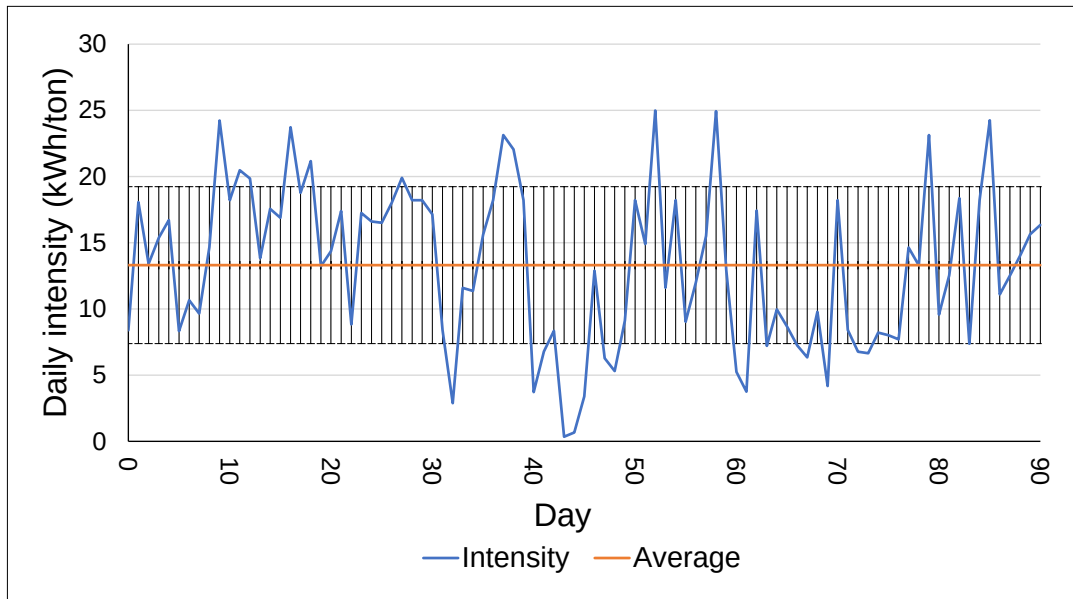


Figure 60: Smelter converter plant compressed air system time-dependent intensity plot

Table 31: Single day cost and consumption saving sample calculation for smelter converter plant blower optimisation

Time	Baseline power profile (kW)	Measured power profile (kW)	kW savings	TOU Tariff (R/kWh)	Cost saving (R)	Consumption saving (kWh)
00:30	887.0	1132.0	-245.0	0.82	-99.9	-122.5
01:00	888.0	1123.5	-235.5	0.82	-96.0	-117.8
01:30	879.0	837.2	41.8	0.82	17.1	20.9
02:00	892.0	1109.3	-217.3	0.82	-88.6	-108.6
02:30	884.0	1107.2	-223.2	0.82	-91.0	-111.6
03:00	888.0	927.7	-39.7	0.82	-16.2	-19.9
03:30	883.0	844.4	38.6	0.82	15.8	19.3
04:00	888.0	850.6	37.4	0.82	15.2	18.7
04:30	876.0	281.8	594.2	0.82	242.3	297.1
05:00	886.0	2.0	884.0	0.82	360.5	442.0
05:30	890.0	2.0	888.0	0.82	362.1	444.0
06:00	899.0	2.0	897.0	0.82	365.8	448.5
06:30	888.0	2.0	886.0	4.14	1833.7	443.0
07:00	880.0	2.0	878.0	4.14	1817.1	439.0
07:30	854.0	2.0	852.0	4.14	1763.3	426.0
08:00	858.0	1.9	856.1	4.14	1771.7	428.0
08:30	874.0	1.8	872.2	4.14	1805.0	436.1
09:00	879.0	1.9	877.1	4.14	1815.2	438.5
09:30	877.0	2.0	875.0	1.37	597.7	437.5
10:00	874.0	149.8	724.2	1.37	494.7	362.1
10:30	863.0	520.8	342.2	1.37	233.8	171.1
11:00	876.0	520.2	355.8	1.37	243.0	177.9

11:30	880.0	521.4	358.6	1.37	245.0	179.3
12:00	869.0	304.4	564.6	1.37	385.6	282.3
12:30	868.0	2.0	866.0	1.37	591.5	433.0
13:00	858.0	512.7	345.3	1.37	235.9	172.7
13:30	860.0	512.9	347.1	1.37	237.1	173.5
14:00	866.0	340.0	526.0	1.37	359.3	263.0
14:30	873.0	298.8	574.2	1.37	392.2	287.1
15:00	860.0	2.0	858.0	1.37	586.1	429.0
15:30	834.0	193.7	640.3	1.37	437.4	320.2
16:00	834.0	550.4	283.6	1.37	193.7	141.8
16:30	857.0	500.3	356.7	1.37	243.6	178.3
17:00	855.0	418.2	436.8	1.37	298.3	218.4
17:30	864.0	507.6	356.4	4.14	737.7	178.2
18:00	859.0	560.5	298.5	4.14	617.8	149.3
18:30	875.0	509.3	365.7	4.14	756.9	182.9
19:00	876.0	478.2	397.8	4.14	823.3	198.9
19:30	876.0	437.5	438.5	1.37	299.5	219.3
20:00	868.0	489.2	378.8	1.37	258.7	189.4
20:30	872.0	436.7	435.3	1.37	297.4	217.7
21:00	869.0	435.8	433.2	1.37	295.9	216.6
21:30	879.0	433.8	445.2	1.37	304.1	222.6
22:00	878.0	584.8	293.2	1.37	200.3	146.6
22:30	877.0	566.4	310.6	0.82	126.7	155.3
23:00	871.0	432.7	438.3	0.82	178.7	219.1
23:30	851.0	543.9	307.1	0.82	125.2	153.5
00:00	869.0	493.3	375.7	0.82	153.2	187.8
Daily total					22743.1	10685.3