

Improved energy budgeting process for mines using measurement and verification principles

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Thesis accepted in fulfilment of the requirements for the degree
*Doctor of Philosophy in Engineering in Development and
Management Engineering* at the North West University

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Graduation: June 2021

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ABSTRACT

Title: Improved energy budgeting process for mines using measurement and verification principles
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Degree: Doctor of Philosophy in Engineering in Development and Management Engineering
Keywords: Budgets, Measurement and Verification, Energy, Financial principles, Mines

Budgets are a common tool used to determine the future income and expenditure of a mine. The operating budgets (largely focussed on the energy consumption of the mine) are also used to measure the mine's performance. It is, therefore, crucial that this budget is a true representation of the expected energy performance for a financial year. The problem, however, is that the budgets are often drawn up by a financial resource of the mine who mainly focusses on financial aspects such as changes in inflation and electricity costs.

Unfortunately, little detailed attention is given to the operational changes affecting the budget. The financial resource easily assumes that the mine will operate as in the past. However, it is very common for the mine to operate otherwise due to the implementation of growth and savings projects, different time-of-use (TOU) profiles, and the type of days considered within each month. This was established by evaluating the budgeting structures of eight South African mines.

These changes influence a large section of the operating budget. Since these changes are not accurately accounted for, if at all, the budget becomes irrelevant early on in the assessment period. This affects both the cash-flow of the mine as well as the ruling of the mine's performance, if it is measured against the budget. These effects can have drastic consequences on the sustainability of the mine if not managed properly.

There is, therefore, a need to investigate and improve the methods used to develop the mine's budgets. Additional attention should be given to operational changes as well and not just the financial changes of the budget. Established measurement and verification (M&V) principles are known for their unique methods to address operational changes of energy-related events. The suggestion is, thus, to integrate these established M&V principles in the budgeting process to successfully accommodate for the operational changes.

To allow this integration, the M&V principles are altered into budgeting principles by developing parallels between the M&V and budgeting process. In order to develop these parallels, a critical analysis of eight South African mine budgets and 90 published budget-related literature references are conducted. The result of the critical analysis highlights the need for integration between these two fields

of interest and provides a relation between well-established M&V principles as an alternative solution to budgeting for mines.

With this knowledge and understanding, six new budget-related parallels were developed to integrate the two mentioned fields. These parallels are the *measurement boundary*, the *measurement resolution*, the *data quality*, the *routine adjustments*, the *development of the baseline* and finally, the *assurance of the baseline*. The new improved budgeting process was applied to the eight South African mines included in the critical analysis for validation.

The *measurement boundary* changed from the original whole facility budgeting to a zero-based budgeting approached where, instead of using monthly totals as in the original budgeting process, hourly profiles were created for each weekday-type (Sunday, Monday, maintenance days etc.). The *measurement resolution* changed from monthly totals to half-hourly resolutions to accommodate the TOU profiles of different components and to allow for changes between various types of days.

The *data quality* was scrutinized to ensure that the data used for budgeting was accurate and representative. The current *routine adjustments* were evaluated and improved, and several new routine adjustments were also included in the process. The budget was *developed* using only relevant parameters and ultimately reported on to provide *assurance* when approving the budget.

The application of the improved budgeting structure on a case study (one of the eight mines in the critical analysis) showed a 9.2 MW difference, which amounts to 5.6% of the total energy consumption, and which was noticed between the ‘old’ and the ‘new’ budgeting structure only by adapting these M&V-related parallels into the existing budgeting structures of the mines. This amounts to a cost difference of R19.4 million on the case study mine’s budget which is considered to be a significant impact.

Finally, the *validation and verification* of the new budgeting procedure proved that the new budgeting structure forecast the energy consumption for 2019 with less than 0.5% error (<R5 million difference) where the old budget forecast the cost to be R81.5 million less than the actual cost was. If the old budgeting structure was used, the mine could have insufficient cash-flow available and the ESMs could have been held responsible for not achieving the expected savings.

The new budgeting structure accurately forecast the energy consumptions and allowed the mine to evaluate the component’s hourly energy performance. This enabled the exact measuring of the ESMs’ performance which is a significant factor to consider from this research. These results confirm the need for the application of well-established M&V principles for combining energy- and cost-related uncertainties.

PUBLICATIONS

A publication related to this study is published in the 31st Annual South African Journal for Industrial Engineering (SAJIE) in November 2020. The publication is titled:

Improve mine energy budgeting process using measurement and verification principles

This publication addressed the need to adapt the current budgeting structures used by mines with M&V principles. The paper's main objective was to determine how the M&V principles can be adapted into the budgeting process. This publication is provided in Appendix C. The published research on this study gives surety that the impact of the research adds value to the engineering field.

ACKNOWLEDGEMENTS

I would firstly like to give a special thank you to TEMM International (Pty) Ltd for the bursary without which this study would not be possible. Furthermore, I want to formally thank Dr Andries Gous and Dr Johann van Rensburg for giving me the opportunity to work under your guidance. Thank you also to all the staff at Centre for Research and Continued Engineering Development Pretoria (CRCED), who created the ideal environment for working and learning.

On a personal note, I would like to thank God for making all things possible. Thank you to all my family and friends for understanding declined invitations. Finally, a special thank you to my husband, Dr Wiehan Pelser, for all of your love, support and the profound impact you have on my life. For you I quote Paulo Coelho's Alchemist: *"And, when you want something, all the universe conspires in helping you to achieve it."*

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LIST OF ABBREVIATIONS

Abbreviation	Description
AAE	Absolute Average Error
ASHRAE	American Society of Heating, Refrigeration and Air-Conditioning Engineers
BL	Baseline
CRCED	Centre of Research and Continued Engineering Development
CV (RMSE)	Coefficient of Variation of the Root-Mean-Square Error
EI	Energy intensity
ESM	Energy Saving Measure
FDR	Feeder
FP	Fridge plant
FY	Financial year / fiscal year
IPMVP	International Performance Measurement and Verification Protocol
INC	Incomer
ISO	International Organization for Standardization
JEC	Joint Evaluation Committee
KPMG	Klynveld Peat Marwick Goerdeler
kW	Kilowatt
kWh	Kilowatt-hour
LVL	Level
M&V	Measurement and Verification
MP	Meter panel
POD	Point of delivery
R ²	Coefficient of determination
SA	South Africa
SAJIE	South African Journal for Industrial Engineers

SANS	South African National Standard
TEMM	Technology and Engineering Management
TOU	Time of use

GLOSSARY

Accuracy	How well the measured outcome conforms to the true value.
Assessment period	Associated with the period used for the assessment of the performance.
Baseline period	The period that will be used as the reference point for the assessment period evaluation.
Budget	An estimation of revenue and expenses over a future period of time.
Commodity	A group of similar components, such as a group of compressors, a group of pumps or a group of fridge plants.
Completeness	Considering all the relevant effects in the same resolutions.
Component	Specific unit that consumes energy, such as a compressor, pump or fridge plant
Component isolation	Savings measurement approach defined in this document that determines energy, demand, and/or water savings for a specific system.
Confidence	The assurance that the final values are correct and accurate.
Conservativeness	Not overestimating but rather underestimating.
Demand	The average rate of energy flow over a specified period of time.
Error	The difference between the true or actual value and the value indicated by the measurement system.
Forecasted energy	Predicted energy for the assessment period. Typically calculated using modelling technique.
Interactive effects	Energy effects created by an energy conservation measure but not measured within the measurement boundary. Examples include the cooling energy savings and heating penalty that result when lighting energy use is reduced.
External effects	Effects of external events (such as production changes and temperature changes) on various components.

Measurement and verification (M&V)	Determination of actual savings achieved by one or more energy conservation measure(s).
Measurement boundary	Boundary drawn around equipment and/or systems to segregate those that are relevant to savings determination from those that are not.
Non-routine adjustments	Calculations used to account for changes in static factors within the measurement boundary since the baseline period.
Relevance	The quality or the state of being closely connected or appropriate.
Routine adjustments	Adjustments to account for changes in selected independent variables within the measurement boundary since the baseline period.
Time of use (TOU)	Pricing structures for some forms of energy, especially electricity, including different prices for different times of day and weekends.
Uncertainty	Range or resolution of doubt surrounding a measured or calculated value within which the true value is expected to fall within some degree of confidence.
Variance	A measure of the extent to which observed values differ from each other (i.e., variability or dispersion), found by averaging the squares of the individual deviations from the mean.
Zero-based budgeting	Building a budget from zero up, meaning that each individual unit gets accounted for individually and all is added up to obtain the final budget for the whole facility.

1. BACKGROUND AND LITERATURE

1.1 BUDGETING STRUCTURES OF SOUTH AFRICAN MINES

1.1.1 THE IMPORTANCE OF BUDGETS

Capital resources are the main driver of a company and are vital for the support of the operations, new initiatives and acquisitions [1], [2]. The available capital resources, along with the expenditure for forthcoming activities, are planned by using a budget. A budget allows for the planning of all financial interactions which is then used to guide the forecast for future occurrences [3].

Another important purpose of budgets is to plan and communicate financial goals [4]. Communication ensures that the responsible people are aware of the goals and can manage their operations accordingly. New initiatives are often the basis to achieve necessary growth and achieve the defined goals [5]. The assumptions made on the revenues and costs of initiatives usually have a varying impact on the outcome [3]. In many cases a budget is used to monitor and manage the performance of certain initiatives to gauge their success or failure within an assessment period [2], [6].

A mine's budget provides benchmarks that indicate if plans are succeeding [7]. Since the impact of new energy saving measures (ESMs) are unknown, budgets are oftentimes used as a level of measurement for these ESMs [8]. Budgets further provide feedback to managers as to their performance and incentivise them to take corrective actions when necessary [9].

Budgeting is, therefore, an essential function of mine operations [9]–[11]. The problem is that mine budgets often become obsolete early in the year, despite enormous effort spent in preparing them. A KPMG survey of finance professionals found that 56% of respondents agreed that at some point during the year, the budget ceased to be relevant [12]. *Using an irrelevant or ineffective budget leads to the mine managers, investors and engineers involved having unrealistic goals and expectations* [13].

Using the budget as a reference point for operational performances becomes impractical and, more often than not, it causes the mine to be over budget. The impact of being over budget could lead to insufficient funds being available to continue with the normal operations [14]. In worst cases, it can lead to the closure of mine sections or the whole mine. It is, therefore, essential to approach the budgeting process with caution and ensure that the budget is an accurate representation of what is expected [15].

1.1.2 TYPICAL BUDGETING STRUCTURES AND THEIR LIMITATIONS

Large companies develop three types of budgets which, when combined, give the Master Budget. These three types of budgets include the *Financial Budget*, the *Static Budget* and the *Operational Budget* [16]. The financial budget will include projections for items on the income statement, the balance sheet and the cash flow statement. These projections can include revenue, expenses, operating costs, sales and

capital expenditures. The static budget gives all the fixed expenses that are not expected to change in the upcoming fiscal year. These includes fixed manufacturing costs and fixed selling and administrative expenses, such as the rent of buildings [17]–[19].

Thirdly, an operational budget is developed. The operational budget includes the expenses and revenue generated from the day-to-day business operations of the company [19]. These day-to-day business operations in the mining environment mainly include the electricity consumption of the mine. More than 85% of a deep level mine's operational sources are obtained from electricity [19].

In most cases, the operating budget assumes that the energy consumption will be similar to the previous year [20], [21]. This means that the assumption is made that all components (in the mining environment this will be the fans, compressors, pumps, etc.) will behave similarly to the previous year. Adjustments are, however, made for inflation and energy cost increases (such as electricity, increases in fuel prices, etc.) [20]. In some instances, the budget further allows for the effect that production changes have on the energy consumption of the mine [19].

Figure 1-1 illustrates the three budgeting types which, combined, gives the Master Budget for a company [22].

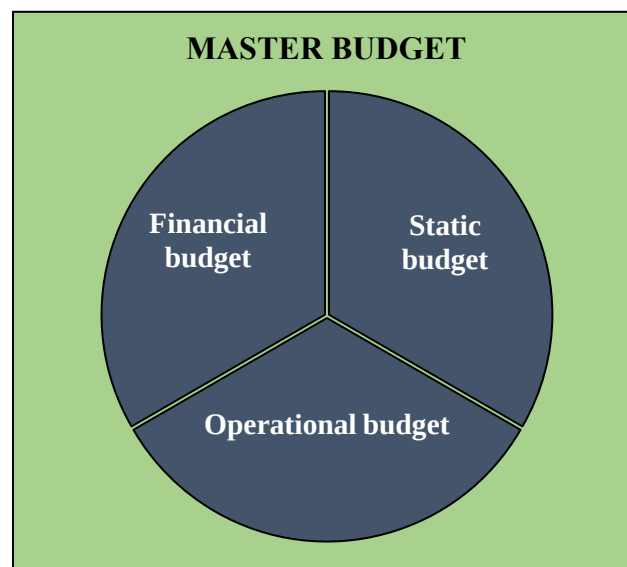


Figure 1-1: Subsections of the master budget

All three of these budgets are equally important and the inaccurate compilation of any one of these budgets can result in an obsolete Master Budget [22]. The budget for the next fiscal year is usually compiled by a competent financial resource of a facility. Having financial background, the financial resources gives adequate attention to the *financial budget* and the *static budget* due to the contributing factors being within the financial fields [23].

The operational budgets fall within the engineering fields and, when compiled by a financial resource, the specific details of energy-contributing factors can easily be neglected [24]. This particularly occurs

within the mining environment where the day-to-day operations can differ significantly due to the large number of existing and new variables [25].

These variables, such as the changes in temperatures or the depth of the mine, are essential variables which are often neglected when compiling the operational budget [26]. From literature, it is noted that the variables most often used when compiling the operational budget are [13], [22], [27]–[30]:

- a) Production changes (based on the forecasted production figures);
- b) Planned growth projects (such as shaft expenditure, increasing crew numbers, etc.).

Furthermore, these variables are usually estimated values or biased assumptions obtained from the shaft managers (person responsible for the specific shaft's operations) who aim to ensure that the budget is rather too large than too small. The inclusion of these biased and inaccurate adjustments can greatly affect the forecast energy consumptions for the whole mine [35], [39], [68].

In most cases, the purpose of the budget is to 1) plan for future consumptions and 2) use the budget as an energy management tool. If the operational budget is calculated accurately, the first purpose is met easily. However, to use the budget as an energy management tool, which implies that the budget should act as a target or reference point for the normal or planned energy consumption, can be more complicated.

The current budgeting structures used by mines were critically analysed and it was observed that it is common practice to develop the budget on a high boundary (whole facility). This means that the budget can be used to monitor the energy performance of the whole facility. However, should the energy increase/decrease unexpectedly, the change in energy cannot be allocated to a specific component (the reason for the change will be unknown). Therefore, developing budgets on a high boundary can limit the budget for energy management purposes.

The critical analyses on the eight mines that participated in the questionnaires also identified several other challenges with the operational budget used by mines. A summary list of the main challenges is provided:

- *The assumption is made that all physical conditions will be similar to the previous year (historical energy consumption). In the mining environment it is noted, however, that the energy consumptions vary year-on-year and should therefore not be used as is for future predictions.*
- *The budgets are developed for the whole facility (whole mine) and rarely provide a break-down per individual commodity. This limits the application of the budget for energy management purposes.*
- *The operational budget typically allows for adjustments on production, savings projects and growth projects. However, the energy consumption of a mine is influenced by multiple*

additional variables as well (such as temperature changes, the depth of the mine, weekday profiles and the TOU profiles).

- *The variables included in the budget (such as the production, savings and growth projects) are usually estimated or assumed values. Sometimes the effect is calculated but with outdated models which are proved to be insufficient and not reliable.*

Additional to the challenges faced with the current budgeting structures used by mines it is observed that mines develop budgets similarly [34], [55], [56]. However, there is a lack of a well-structured formal methodology used by these mines. This causes the mines to often neglect important factors (such as the changes associated with production or other variables) which can contribute to the obsolescence of the budgets.

It is proposed to use well-established principles and best practices as a solution to reduce the above-mentioned limitations in the budgeting process. In the next section, the applicability of Measurement and Verification (M&V) as such principles are evaluated. The application of these principles within the mine budgeting structures is also discussed.

1.2 M&V PRINCIPLES AS A SOLUTION TO BUDGETING

1.2.1 BACKGROUND ON M&V PRINCIPLES

Energy savings cannot be directly measured because savings represent the absence of energy [31]. Instead, savings are determined by comparing measured consumption before the implementation of an ESM and after the implementation of the ESM allowing for suitable adjustments for changes in conditions. The process of quantifying these savings delivered by an ESM is called M&V [32].

The M&V principles allows for a set-out plan to demonstrate how much energy the ESM has avoided which can then be translated to the cost that was saved [33]. Good M&V practice is based on six respectable fundamental principles: *accuracy*, *completeness*, *conservativeness*, *consistency*, *relevance* and *transparency* [34]. These fundamental principles are considered the foundation of preparing and maintaining energy-related savings. These principles and a short description of each are summarised in Table 1-1 [31]–[34].

Table 1-1: Well-established M&V principles

Principle		Contribution to M&V process
(A)	Relevance	M&V should include a notational measurement boundary around units (or commodities) to separate those that are relevant to the ESM from those that are not [35].
(B)	Consistency	M&V should be consistent in measurement resolutions of expected conditions, modes and independent variables [36].
(C)	Accuracy	The M&V process and all calculations involved need to be as accurate as possible which includes the evaluation of the data quality . This includes

Principle		Contribution to M&V process
		evaluating the data for any missing data, outliers or events that bias the dataset. The existence of these data errors should be recognized, their range of possible impacts should be presented and the data can be removed from the dataset when deemed as erroneous. [34].
(D)	Completeness	M&V needs to include all potential dependent variables that can affect the savings. These include the new and existing <i>routine adjustments</i> (expected changes in normal conditions) [35].
(E)	Conservativeness	M&V should be reasonable in estimating the energy savings. During the <i>baseline development</i> phase there should be focus on underestimating the savings to ensure that no accidental savings are claimed [37].
(F)	Transparency	M&V should be clearly explained and documented so that an outside party can review the process. The <i>assurance</i> of the M&V application process should be captured in supporting documents [37].

The principles in Table 1-1 provide the basis for assessing adherence to the M&V process. The aim of these principles is to eliminate differences in M&V practices, provide uniformity and enable the quantification of energy savings obtained from the ESMs [38]. It is essential that engineers or project managers use these principles to ensure that the savings obtained from the ESMs are correctly quantified [37]. Each one of these principles are stand-alone concepts which, when combined, provide a well-rounded application procedure. The effectiveness of the M&V application process is due to the reliance of these principles.

The **measurement boundary** (associated with principle A) ensures that the M&V process is *relevant* to the specific need of the evaluation. If the boundary is too small or too large, the calculated savings can be biased. The International Performance Measurement and Verification Protocol (IPMVP) is one of several standards used in South Africa to guide the M&V application. The IPMVP presents three M&V options that can be used when assessing the performance of an ESM. These options are:

- Option A (component isolation boundary)
- Option B (whole facility boundary)
- Option C (calibrated simulation on either an isolated or whole facility boundary)

The component isolation boundary is a single boundary drawn around the ESM specifically and focuses on the energy movement directly in and out of the boundary. The whole facility boundary focuses on the energy movement of the whole facility. The performance of a small ESM can, however, become lost in the noise (up and down movement of the day-to-day energy) of the operations when evaluated on such a high boundary.

The **measurement resolution** (associated with principle B) ensures that the M&V process is *consistent* by considering a significant time resolution for the evaluation. Most evaluations can be done on a low resolution (such as annually, quarterly and monthly) as long as there are no significant changes that

occurs more frequently. When changes, such as the energy consumed by the mine differing from a weekday to a weekend or the TOU profiles of equipment, are considered, higher resolutions (daily or half-hourly) should rather be used.

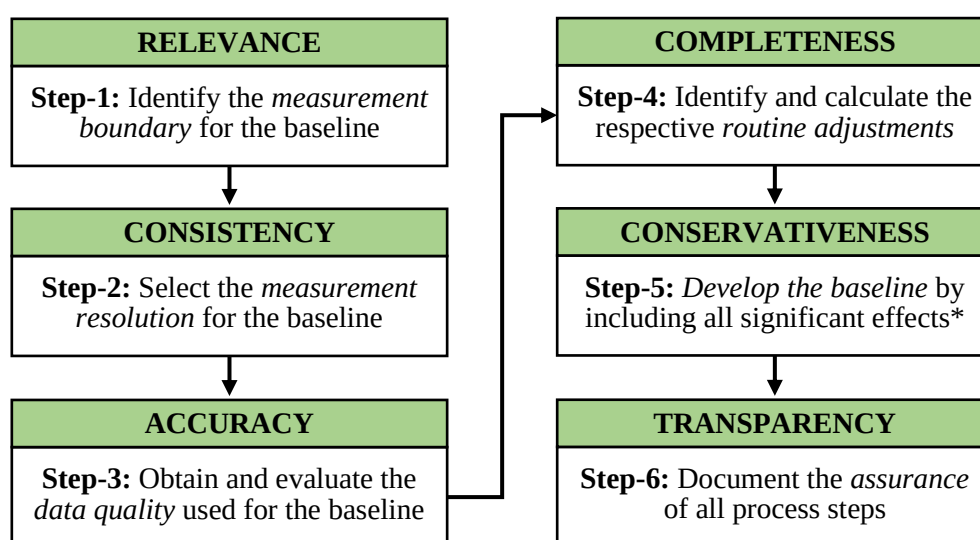
The **data quality** (associated with principle C) ensures that the data used when developing the baseline is as *accurate* as possible. This includes the evaluation of the dataset for any missing data or outliers (data obtained from faulty or incorrect meter readings). The data should also be evaluated for any unplanned events (non-routine adjustments) that occurred in the baseline data. These unplanned events can cause the energy consumption to be lower/higher than normal and should therefore not be seen as part of the normal energy consumption.

The **routine adjustments** (associated with principle D) ensures that the application process is *complete*. It is, therefore, important to ensure that 1) all the relevant parameters are considered and 2) the effect of these parameters is accurately quantified. This ensures that all of the potential changes expected or planned for the assessment period are adequately accounted for. Neglecting routine adjustments will ultimately provide an obsolete baseline.

The **baseline development** step (associated with principle E) ensures that the savings obtained from the evaluation are *conservative*. To allow for this, it is important to include all the significant effects (even the effects not anticipated, such as unplanned events/non-routine adjustments). This can easily be incorporated by including a variance factor to allow room for error on the baseline. Typically, these adjustments can be accurately accounted for in the assessment period and the respective changes are made to the baseline.

The **assurance** (associated with principle F) of the baseline is delivered in the *transparency* of the process. Including a reporting step, where all of the process steps are captured, ensures that a third party can independently evaluate the application process to provide assurance that the baseline is correct.

The combination of these principles provides a well-structured M&V application process. Figure 1-2 presents this M&V process, where each M&V principle is linked to a specific step in the M&V process.



**this also refers to the unplanned or non-routine adjustments in the assessment period*

Figure 1-2: General measurement and verification (M&V) structure

Figure 1-2 captures the M&V application process, along with the M&V principles linked to each step. This application process is a well-established process that can easily be used to quantify the ESM savings on any facility. In the next sub-section, the application process of the M&V principles in the mining environment is evaluated.

The aim is to identify how mines implement M&V plans (identify which M&V option is typically used, what factors are usually considered, and other application steps generally applied in mines). This section is vital for the ultimate comparison between how South African mines develop budgets and also how South African mines evaluate ESM performances using M&V principles.

1.2.2 M&V APPLICATIONS ON MINES

When the performance of an ESM implemented on a mining system is evaluated, an M&V plan is generally used to quantify the saving of the ESM. This section assesses the M&V application of twelve different ESM evaluations on South African mines. The twelve studies considered are obtained from published journal articles released between 2015 and 2020.

The application process discussed in Figure 1-2 were used to assess the M&V application of each of these twelve references. The performance of each reference is included in Table 1-2.

Table 1-2: M&V applications on mines

Reference	Measurement boundary	Measurement resolution	Data quality	Routine adjustments	Baseline development	Assurance
[13]	Whole facility	Monthly	Evaluated data for abnormality	Included effects of savings, growth and production	Estimated unplanned events and replaced with real effects	M&V plan submitted, and reports approved
[19]	Component isolation	Half-hourly	Evaluated data for abnormality	Included effects of savings, growth and production	Estimated unplanned events and replaced with real effects	M&V plan submitted, and reports approved
[31]	Component isolation	Daily	Evaluated data for abnormality	Included effects of production only	No estimation, only replaced with real effect	M&V plan submitted, and reports approved
[32]	Whole facility	Monthly	Evaluated data for abnormality	Included effects of production only	No estimation, only replaced with real effect	M&V plan submitted, and reports approved
[36]	Whole facility	Half-hourly	Evaluated data for abnormality	Included effects of production only	No estimation, only replaced with real effect	M&V plan submitted, and reports approved
[38]	Component isolation	Half-hourly	Evaluated data for abnormality	Included effects of production only	No estimation, only replaced with real effect	M&V plan submitted, and reports approved
[39]	Component isolation	Half-hourly	Evaluated data for abnormality	Included effects of production only	Estimated unplanned events and replaced with real effects	M&V plan submitted, and reports approved
[40]	Component isolation	Daily	Evaluated data for abnormality	Included effects of savings, growth and production	No estimation, only replaced with real effect	M&V plan submitted, and reports approved
[41]	Component isolation	Daily	Evaluated data for abnormality	Included effects of production only	No estimation, only replaced with real effect	M&V plan submitted, and reports approved
[42]	Component isolation	Half-hourly	Evaluated data for abnormality	Included effects of production only	No estimation, only replaced with real effect	M&V plan submitted, and reports approved
[43]	Component isolation	Annually	Evaluated data for abnormality	Included effects of savings, growth and production	No estimation, only replaced with real effect	M&V plan submitted, and reports approved
[44]	Component isolation	Monthly	Evaluated data for abnormality	Included effects of production only	Estimated unplanned events and replaced with real effects	M&V plan submitted, and reports approved

Table 1-2 shows that all twelve of the M&V applications on mines conformed to the same methodology. Nine of the twelve references considered a component isolation **measurement boundary** where only three of the references considered a whole facility evaluation. The reason for this is, when evaluating ESMs on a whole facility, the expected savings from the ESM should be at least 10% of the whole facility's energy consumption. Due to the small ESM evaluations, most of the mines developed baselines for the specific ESM boundary only. This allows for the accurate evaluation and monitoring of the energy performance of the ESM.

Four of the twelve references quantified the savings from the ESMs on a high **measurement resolution** (monthly or annually). The savings were evaluated on the low resolutions due to a combination of a lack of sufficient data in higher resolutions and also due to the project not requiring any small adjustments. Three references evaluated the ESM performance on daily resolutions and the remaining five references used half-hourly resolutions. The savings were calculated in higher resolutions to account for the changes in TOU profiles along with the different types of days.

The different types of days considered by the three references who developed baselines on daily resolutions were combined as:

- Weekdays
- On-Saturday
- Off-Saturday
- Sunday
- Christmas holiday
- Easter holiday
- Other public holidays
- Maintenance days

The energy consumption on each of these days can be significantly different due to the planned production outputs. A weekday (Monday to Friday) profile is usually very consistent. The number of active crews stays similar and no changes are expected. All of the other days typically have different energy consumption profiles. These types of days were also considered for each season or month due to the energy consumption that differs based on the season (mainly due to temperature changes).

All twelve the references evaluated the **data quality** before using the dataset to develop baselines. The data were evaluated for missing data and outliers. These data points were identified and addressed. If the datapoint was presumed as normal, it remained as part of the dataset but was removed if it could be proved to be an outlier. The data were also evaluated for unplanned events that occurred in the baseline period. These data were removed (in three of the cases) and replaced with the average of the normal operating conditions (in the remaining nine cases).

All twelve of the references also included **routine adjustments** into the evaluation process. Four of the twelve references included both the effect of savings/growth projects where the remaining eight references only included production changes. These changes were calculated using mathematical models such as regression models, power models and polynomial models. The most suitable applications were identified, and the effects of the events calculated.

During the **baseline development** step, half of the references included non-routine adjustment predictions in the baseline already. This involves adding a variance factor to the baseline that will ensure that the baseline has leverage for unplanned events. However, these non-routine adjustments were accurately quantified in the assessment period (after the unplanned event occurred) and the baseline was updated and adjusted accordingly.

The application process of all twelve of the references were well documented. The **assurance** of a well-documented report ensures that the process can be audited and validated by an independent resource. All twelve references presented structured M&V plans alongside pre-approved baseline reports.

All twelve of these references conformed to the presented M&V methodology and principles presented in Figure 1-2. The M&V applications delivered twelve baselines (one for each reference) and not one of these baselines became obsolete in the assessment period. Relevant and accurate results were obtained from this methodology.

1.3 CRITICAL ANALYSIS LINKING M&V PRINCIPLES TO BUDGETS

1.3.1 RESEARCH QUESTION

From the previous two sub-sections (Section 1.1 and Section 1.2), it is determined that energy budgets mainly focus on financial aspects and neglect detail on the operational changes observed, especially when applied on mines. This causes the energy budget to become obsolete when used to evaluate performance. The evaluation of ESM performance on mines using M&V principles continuously delivers reliable results. The M&V baseline seldom becomes obsolete when used to evaluate performance. From this background section the following research question is posed:

Can well-established M&V principles be used to improve the budgeting structure of mines?

In this sub-section, a critical analysis is applied to a wide range of references to test this research question.

1.3.2 CRITICAL ANALYSIS SET-UP

This section provides an analysis of the research question. For the analysis, a critical literature study was conducted to review whether the M&V principles are in any ways addressed or discussed in the budgeting process with specific focus on the energy budgets of South African mines. This includes an in-depth evaluation of existing literature to determine whether any research exists to address the research question. A conceptual analysis strategy is used to test the research question [45].

This strategy is based on a qualitative research method and consists of five steps: (1) **Research**; (2) **Examine**; (3) **Compare**; (4) **Conduct**; and (5) **Test** [44]. An overview of the strategy is presented in Figure 1-3.

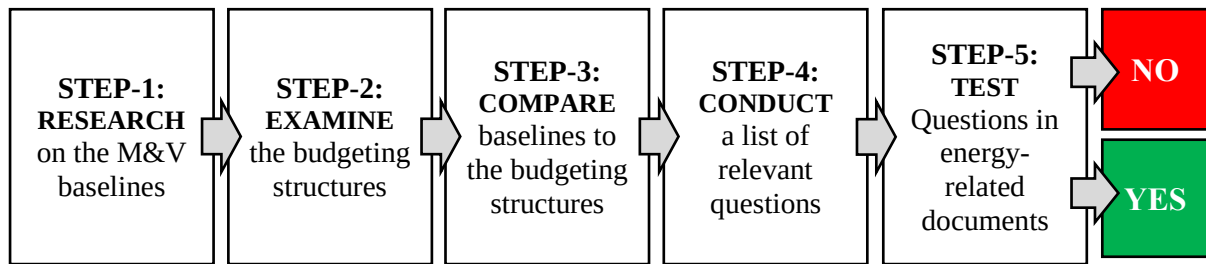


Figure 1-3: Critical analysis strategy

The strategy starts with the research of the M&V principles (Step-1) and the examination of the budgeting structures used by the literature references (Step-2). This information is then used to compare the M&V baselines and budgeting structures from literature (Step-3). A list of relevant questions is then compiled to test whether the M&V principles are used within the budgeting context (Step-4 and Step-5). The outcome of Step-5 indicates if the research question has been addressed by the existing literature. If the research question stays unaddressed (response on the questions in Step-5 is “no”) the need for this study is established, seeing as no existing research addresses the research question.

1.3.3 CRITICAL ANALYSIS APPLICATION

The critical analysis of this thesis is completed by considering 98 references, of which 8 of these references are from questionnaires conducted on South African mines. The remaining 90 references are peer-reviewed literature-based references. To simplify the critical analysis, the 98 references are sorted into three categories based on their application in industry. These categories are:

1. Energy budgeting structures used by South African mines (8 questionnaire references)
2. Energy budgeting structures used in other industries in South Africa (42 literature-based references)
3. Energy budgeting structures used by various industries across the globe (48 literature-based references)

The assessment of these three categories ensures that the critical analysis does not focus only on the budgeting structures in South African mines, but also on existing research in other industries and parts of the world that could potentially be adapted for this research. The critical analysis will evaluate whether any existing research can be used to address the research question. The five-step strategy presented in Figure 1-3 are applied to each of the three categories in the sub-sections below.

CATEGORY 1: BUDGETING STRUCTURES USED BY SOUTH AFRICAN MINES

Step-1: Research on the M&V baselines

The first step in the five-step strategy was already addressed in Section 1.2 by evaluating the M&V principles in detail. The main finding was that a general 12-step methodology is used when evaluating ESM findings (presented in Figure 1-2) and that this methodology complies with six M&V principles, namely: accuracy, completeness, conservativeness, consistency, relevance and transparency.

The same principles apply to all three categories that are discussed in the chapter: **1) budgeting structures in South African mines** (this section), 2) budgeting structures of other industries in South Africa and 3) budgeting structures from various industries across the globe.

Step-2: Examine the budgeting structures (of South African mines)

Step-2 is applied on the feedback obtained from questionnaires conducted on eight of South Africa's largest mineral mines. These eight mines operate under three of the major role-players in deep-level mining in South Africa which represents 87% of the deep-level mining shares in the country. The budgeting structures of these mines are therefore considered to be a representative sample. Limited research on the budgeting structures of South African mines encouraged the enactment of relevant questionnaires.

These questionnaires are key to the proposed solution to address the research question. This was done by using industrial engineering best practices to present a *formal standardised questionnaire* [45] which was distributed to the eight participating mines. These questionnaires included questions such as:

- i. *Does the mine compile operational budgets for the fiscal year?*
- ii. *Who is responsible for the development of the budgets?*
- iii. *Does the budget ever become obsolete within the assessment period?*
- iv. *What steps are considered when developing the budget?*

The completion of the questionnaires was handled independently, and no alterations were made to the responses. A copy of the original feedback of all eight of the mines that participated in the questionnaires can be obtained in Appendix A.

Both category 2 (budgeting structures on other industries in South Africa) and category 3 (internationally used budgeting structures) refer to 90 published literature references. The general steps followed by the South African mines in the questionnaires will be compared with these published literature references to validate the authenticity of the questionnaires.

The questionnaires were firstly evaluated to identify the general step-by-step approach used for developing the budgets. Figure 1-4 presents the step-by-step application process for each of the eight mines' budgets. It was found that the details of the approaches taken by these mines all have similar general steps, which were used to simplify the findings. These general steps are *inform*, *data*, *evaluate*, *develop*, *convert*, *validate*, and *approve*, all of which are addressed in more detail in the remainder of this discussion.

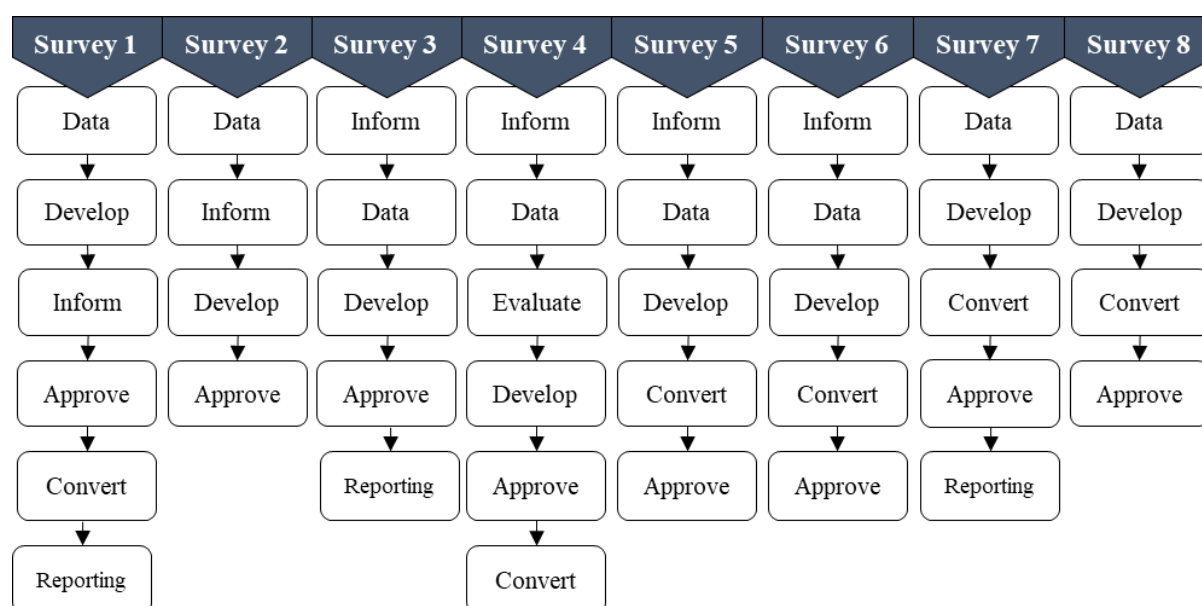


Figure 1-4: Summary of the existing budgeting structures

Each of the general steps are explained below:

Inform: Obtain background knowledge on the mine's historical performance. Identify historical events that had an impact on the energy consumption that should be considered when using the historical data. Furthermore, decisions are made on the boundaries that will be used for the budgets (whole facility, shaft-level, commodity-level, etc.) and what resolutions the budget should be in (monthly, daily, hourly, etc.).

Data: During this step, decisions are made on what types of data are required (energy consumptions, production figures, planned projects, etc.). Thereafter, the data is obtained from meters, servers or from responsible personnel.

Evaluate: The data that will be used for the budgets is evaluated to ensure that the data is complete (no missing data) and representable (no outliers). The effects of unplanned events (historical occurrences) are also considered to ensure that these effects do not bias the presumed normal operations of the mine.

Develop: During this step, the budget is created. Several different approaches to budget development can be presented. Most commonly, a linear model is presented where the budget is equal to the historical performance plus/minus the effect of expected changes.

Convert: This step involves converting between different units. Usually the budgets are developed in terms of energy (kWh) and converted to a cost budget (in Rands) at the final stages of the budgeting process. In some occurrences, the costing budget is initially developed (in Rands) and ultimately converted into an energy budget.

Report and approve: This step allows for the budgeting process to be documented for future use. The documentation step is considered an important step since it creates authenticity in the budgeting process. It also ensures that the process can be validated by an independent reference due to the transparency of the application steps. All mines need to have their energy budgets approved by mine managers before the energy budgets can be used. This is typically the final step in the process.

The summary above indicates that all eight mines that took part in the questionnaires developed their operational budgets similarly. These mines all used the same main steps to develop the budgets. The *inform* step (**Step-1**) addresses both the boundary and the resolution of the budget. Table 1-3 displays the eight mines' boundaries and resolutions used.

Table 1-3: Boundaries and resolutions considered for mine budgets

	(1) Boundary	(2) Resolution
Mine nr.1	Whole facility	Quarterly
Mine nr.2	Per shaft	Monthly
Mine nr.3	Per shaft	Monthly
Mine nr.4	Whole facility	Monthly
Mine nr. 5	Per shaft	Monthly
Mine nr.6	Per shaft	Monthly
Mine nr.7	Per shaft	Monthly
Mine nr.8	Per shaft	Monthly

From Table 1-3 it is seen that most of the mines developed energy budgets on a large boundary (whole facility or per shaft). None of these mines considered evaluating the energy budgets on a lower level such as per commodity or per component. This limits the use of the budget for energy management purposes since the individual components of the mine cannot be monitored independently [46]. All eight of the mines also developed budgets on a low resolution (quarterly or monthly). The limitation of developing energy budgets on such a low resolution is the negligence of TOU profiles which can significantly impact the forecasted costs [43], [47].

After the mines made decisions on the boundaries and the resolutions, the *data* (**Step-2**) that will be used for budgeting were obtained. From the questionnaires it was noted that most of the mines obtained energy data from a third-party server. The third-party server is typically a contracted company responsible for the measuring of all the energy data which includes ensuring that the data is complete

(no missing data) and that the meters extracting the data are calibrated. This brings surety to the accuracy of the energy data used for budgeting.

Production data is also typically used in the budgeting process and the production data is obtained from weight bridges on the mine. These weight bridges are usually calibrated since the production figures are an important parameter used daily by mine managers and investors. The problem with the production data is that the correlation with the energy is usually not established due to stockpiling of the production before weighing. This can cause the production data included in the energy budgets to bias the real prediction of the energy consumptions.

Evaluate (Step-3) the expected changes in the operations are furthermore common steps followed by all the mines in the questionnaires. The expected changes are occurrences that will increase or decrease the energy consumption of the operations. The expected changes considered by the eight mines are (1) changes in production, (2) savings projects and (3) growth projects. Most of the mines assume the effect of these changes with the exception of production. For the changes in production, an energy intensity (also known as the specific energy consumption) model is used to predict the energy based on what the forecasted production will be. Equation 1-1 and Equation 1-2 present the energy intensity model and the forecasted energy, respectively [48].

$$EI = \frac{Energy_{historic}}{Production_{historic}} \quad \text{Equation 1-1}$$

$$Energy_{forecasted} = EI \times Production_{forecast} \quad \text{Equation 1-2}$$

where:

EI	Energy intensity (in kWh/tonne)
Energy _(historic)	Historical energy consumption (in kWh)
Production _(historic)	Historical production (in tonnes)
Energy _(forecasted)	Forecasted energy (in kWh)
Production _(forecast)	Production forecast for the forecasted energy time period (in tonnes)

Energy intensity is one of the most widely used indicators of energy efficiency of a system. Yet its application in the mining industry can be misleading due to the weak correlation between energy consumed by a mine versus the production outputs of that mine [48], [49]. Figure 1-5 illustrates the energy versus production trends for the first four mines in the questionnaires (gold mines).

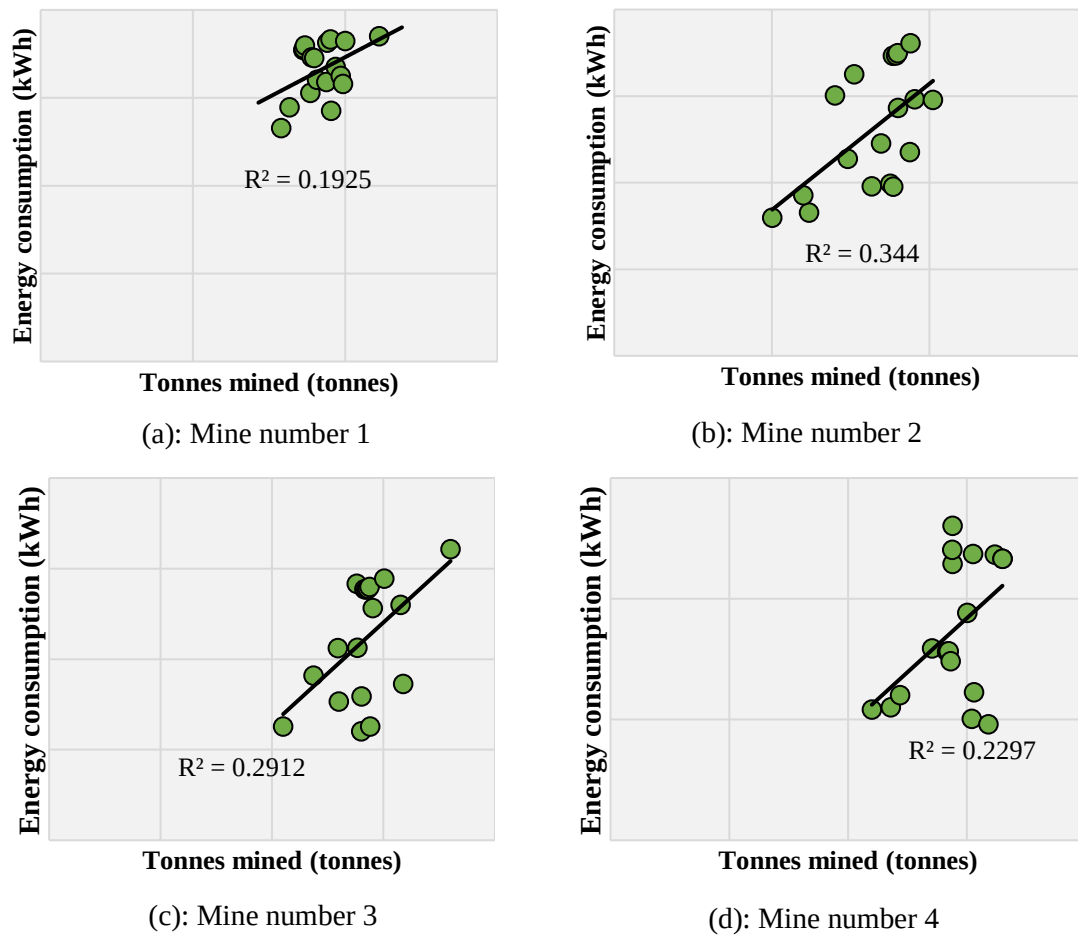


Figure 1-5: Energy and production of a gold mine

In Figure 1-5, the goodness of fit (how well the model fits the data [50]) is addressed by the R^2 statistic in the figures. The R^2 statistic indicates how close the data is to the fitted regression line. An R^2 value close to 1 (which indicates a 100% accurate fit of the data) is considered a perfect fit. An R^2 value between 0.75 and 1 is considered a good fit, and a value between 0.50 and 0.75 is considered an acceptable fit. R^2 values lower than 0.50 are not preferable [44], [50].

The linear correlation (presented by the R^2 in Figure 1-5) between energy consumption and tonnes mined on the gold mines is 27% on average between the four mines. Energy intensities rely on linear correlation between two parameters. A weak correlation can therefore impact the energy predictions negatively when using an energy intensity model.

Figure 1-6 illustrates the actual energy consumption for a 12-month period as well as the forecasted energy when using an energy intensity model. The CV(RMSE), the Coefficient of Variation of Root-Mean Squared Error, which is a percentage indication of the size of the difference between the actual and the forecasted values, is calculated and discussed by referring to Figure 1-6.

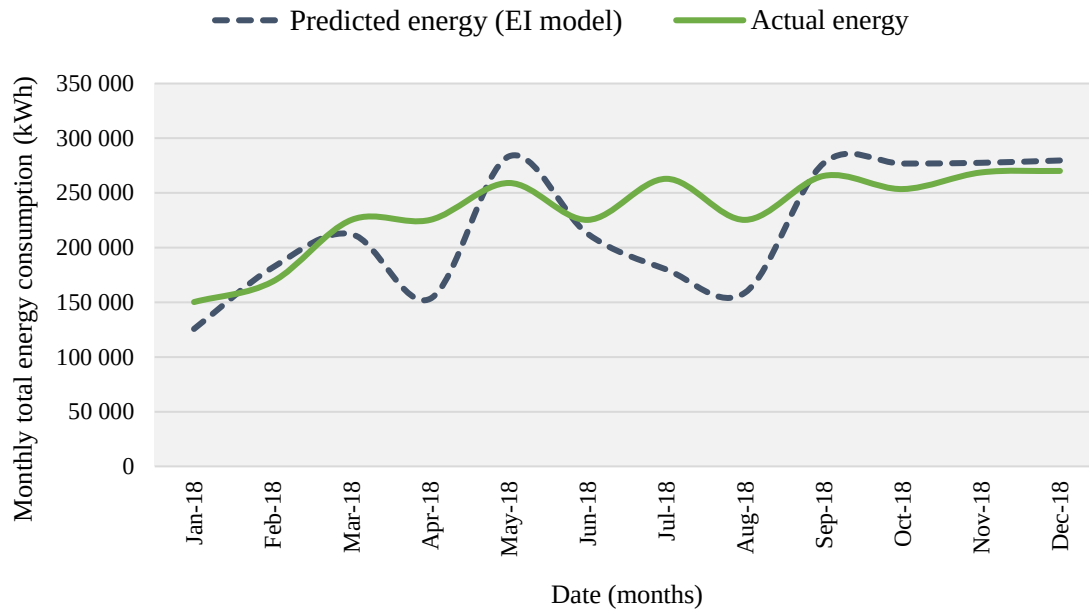


Figure 1-6: Forecast energy consumption of a gold mine

As per the ASHRAE Guideline, a CV(RMSE) of and below 25% indicates a good model fit with acceptable predictive capabilities. For the dataset given above, the CV(RMSE) was found to be 62%, implying that the model is not reliably predictive [51].

A similar situation is observed on the four platinum mines that participated in the questionnaires. The R^2 correlation between the production and the energy consumption is even lower than that noticed on the gold mines (average $R^2 = 0.22$). The even weaker correlation ensured that the CV(RMSE) noticed when comparing the actual energy for a 12-month period with that of the forecasted energy from the energy intensity model increased to 72%, implying that only 28% similarities are observed.

The weak linear correlations between production and energy prove to be a problem when creating energy budgets, especially when adjustments are required for expected increases/decreases in production. This study will, therefore, improve the correlation by evaluating non-linear models additionally for production modelling. Attention will also be given to the production drivers to see whether, by changing the drivers, better correlations can be obtained.

Additionally, evaluating the raw data prior to the modelling phase can also enhance the correlations. This study will therefore enhance the current evaluation-of-data step by also evaluating for missing data, outliers and removing unplanned events from the dataset. An outlier is an observation/data point that lies an abnormal distance from other values in a random sample from a population. Various approaches exist that can identify outliers in a set of data [3], [45].

When the data is obtained for the boundary and resolutions decided on, the energy budget is created in the *development* step (**Step-4**). All eight mines considered the same approach for creating the energy budget (as provided in Equation 1-3:

$$\text{Energy budget} = \text{Historical energy} \pm (\text{Savings \& Growth \& Production}) \quad \text{Equation 1-3}$$

Where:

Energy budget:	The forecasted energy consumption for the upcoming fiscal year (in kWh)
Historical energy:	The energy consumption of the previous fiscal year (in kWh)
Savings:	The energy effect of savings projects (usually a static assumed value in kWh)
Growth:	The energy effect of growth projects (usually a static assumed value in kWh)
Production:	The energy effect due to changes in production (as calculated using the energy intensity model in kWh)

Based on Equation 1-3 the energy budget is directly equivalent to the previous fiscal year's energy consumption plus/minus adjustments for savings, growth and production. This study will look at other relationships as well to ensure that the most conservative model is ultimately chosen as the energy budget.

The ultimate goal of the energy budget is to present the costing values so that the mine can ensure that adequate funding is available to proceed with planned operations. For this reason, the energy budget needs to be converted into a costing budget in the *converting step* (**Step-5**). Some of the mines in the questionnaires started the whole evaluation process with costing values (and therefore did not present an energy budget).

Creating a costing budget can be difficult since tariff changes and projects focussed on utilising varying energy costs (such as energy load shifting) should constantly be calculated. For this reason, it is desirable to create an energy budget and merely convert it into a costing budget in the final steps of the process, as most of the mines that participated in the questionnaires did. This conversion from energy to cost can still be complicated even when only doing it in the final stages of budgeting. The conversion methodology also differs depending on the resolutions used for budgeting. Creating budgets in half-hourly or hourly resolutions allows for the easy incorporation of the Eskom tariffs, since this is already available in hourly profiles (see Figure 1-7).

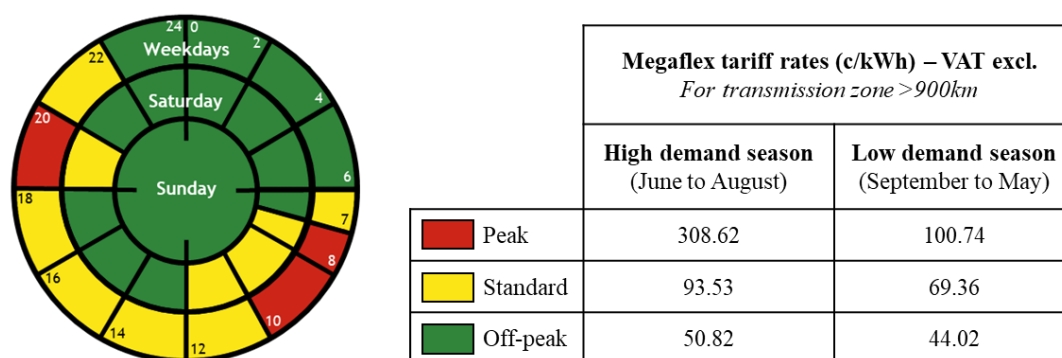


Figure 1-7: Eskom tariffs for 2019/2020

When converting an energy budget to a costing budget on low resolutions, such as monthly resolutions, a more complex method is considered. For the conversion the Eskom invoice per point of delivery (POD) is considered. All fixed charges (such as the administration charges and the distribution network capacity charges) are carried over as fixed values with increases allowed for inflation. The remainder of the Eskom invoice's costs are divided by the total energy consumption depicted on the Eskom invoice to obtain an average R/kWh ratio. This ratio can be adjusted to allow for the expected percentage Eskom tariff increases and finally be used to convert the total monthly energy consumption to a costing value. This is the method used by most of the mines in the questionnaires.

Throughout the budgeting process, it is important to document all steps and ensure that the application process complies with adequate *reporting* (**Step-6**). Three of the eight mines included reports on the energy budget process before submitting the energy budget for approval. Having adequate reports available on the budgeting process ensures that when the energy budget is finalised, the process can be audited. This enhances confidence in the accuracy of the energy budgets.

Finally, the budget is approved by upper management and sign-off in the final step, *approve* (forms part of **Step-6**). During this stage of the budgeting process, the final budget is presented to a board of representatives (mine managers, financial managers and engineers) to approve the budget. Thus, the general budgeting steps used by South African mines are presented in the flow diagram below (Figure 1-8).

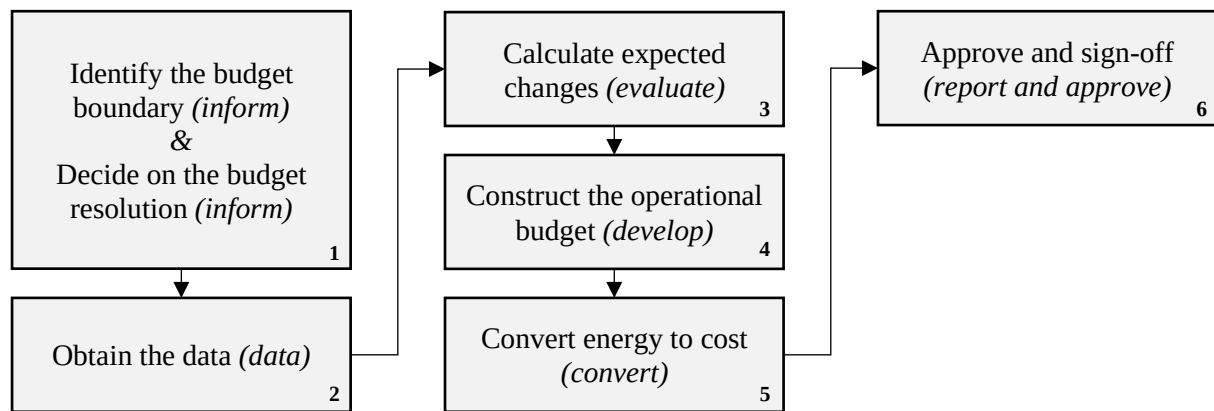


Figure 1-8: General budgeting structure

It is noted that the flow follows similar concepts used by the budgeting structures of the mines (*inform*, *data*, *evaluate*, *develop*, *convert* and *report and approve*). The budgeting structure presented in Figure 1-8 can now be compared to the M&V structure compiled in the first step of the five-step strategy (and presented in Figure 1-2).

Step-3: Compare the M&V baselines with the budgeting structures

The third step in the five-step strategy is to compare the budgeting structure (Figure 1-8) with the M&V structure (Figure 1-2). The aim of the comparison is to identify the limitations (shortcomings) in the budgeting structure and relate the limitations to the established M&V applications. The comparison between these two structures is presented in Table 1-4.

Table 1-4 compares the initial evaluation of both the M&V process and the budgeting structure on mines. The initial evaluation specifically addresses the aspects considered before the evaluation start, such as the layout of the mine. Thereafter, the comparison is based on each of the M&V and budgeting steps discussed in this chapter. The final column (furthest to the right) presents the limitations identified from the comparison.

Table 1-4: Comparison between budgeting and M&V structures

Budgeting structure used by mines	M&V applications used by mines	Limitations of the budgeting structure (compared with the M&V applications)
Initial evaluation: Additional evaluation is not required partially due to the person responsible for the budget having prior knowledge of the systems.	Initial evaluation: Before any set-up commences, the mine (specifically the ESM boundary) is evaluated to understand the systems [52].	No additional evaluation is done on the mine's system. However, this can be a limitation when systems change over time.
Selecting boundaries: The mine budgets are typically on <i>whole facility</i> level, as seen from the feedback of the questionnaires.	Selecting boundaries: The guideline for option B (<i>whole facility</i>) is that the savings should be at least 10% of the mine's energy performance [33], [36].	Mines are large systems. Any occurrence that takes place on the mine probably affects less than 10% of the whole facility's consumption [11]. The budgets (developed on a <i>whole facility</i>) therefore can result in the negligence of detailed effects.
Selecting resolutions: From the eight mines that participated in the questionnaires, seven of these mines created monthly total budgets using the previous year's corresponding months as a basis.	Selecting resolutions: The general guideline is to use the previous 12-months data (full cycle) to obtain the baseline data (considered to be representative conditions) [35].	The budgets (typically in monthly resolutions) neglect hourly operational changes and in some instances the effect of seasonal changes. The cumulative effects of this can be significant.
Obtaining data: Data is obtained from all relevant meters which is typically maintained and calibrated by independent bodies responsible for the energy reporting of the mine.	Obtaining data: Before the data is obtained, the meters are checked to ensure that they have been calibrated [36], [52].	The budgeting process gives adequate attention to the data. However, the M&V process goes into a bit more detail by evaluating the data further. Further evaluations are done to ensure that the data is representative of <i>normal</i> operations.
Evaluating data: The data obtained from the calibrated meters are compared with the Eskom invoices to ensure that the data is representable and correct.	Evaluating data: After the data is obtained, the data is evaluated using approved mathematical models [34]. Missing data and outliers are assessed and excluded from the dataset if needed [27].	
Adjustments: Adjustments are often made for production and planned growth projects. However, the impact of these adjustments is either estimated or calculated using models which sometimes presents large errors [55], [56].	Adjustments: Normal operations are evaluated, and adjustments are made for all relevant variables [26]. The impact is mathematically calculated with models presenting small errors [30], [51]. Few to no assumptions are made [51].	The budgeting structures does not include many adjustments. In most cases there is only adjusted for production and other events are easily neglected.

Budgeting structure used by mines	M&V applications used by mines	Limitations of the budgeting structure (compared with the M&V applications)
Development: The budget is calculated using a constant approach (the previous year's energy plus/minus expected changes).	Development: Several baselines are often developed, each using different modelling techniques [40]. The statistical impact of each model is then compared to ensure that the most appropriate model is used as the baseline [52].	The budgeting process assumes a linear profile and this assumption is not tested. The limitation is that there might be other, more suitable models to use with greater accuracy.
Reporting: Reporting is not a main criterion for budgets. The budgeting process typically involves the development of the budget and the sign-off on the final figures produced by the budget.	Reporting: The reporting of the M&V application process is an important step in the evaluation process. It also provides assurance that the final baseline approved and validated can be done on well-documented work [35].	The budgets are signed off based on the final figures produced by the budget. The lack of well-documented work can impact the approval of the final budgeting values.
Approval: The developed budget is approved and signed off by selected representatives and management.	Approval: After the baseline is tested and deemed as represented it is signed off by a panel of informed personnel, such as a Joint Evaluation Committee (JEC) [35], [53].	The sign-off process of the budget is not as strict, which results in the budget being finalised based on the susceptibility of the final values rather than the traceability of the development process.

The main limitations identified in the budgeting structures of South African mines from the comparison with M&V methods in the table above are summarised as:

- (A) **Budget boundary:** The budget is developed for the whole facility only and neglects the implementation of budgets for each individual component. This affects the energy management of the components.
- (B) **Budget resolution:** The budget is developed on a low resolution (monthly) which means that operational changes related to TOU profiles and specific type-of-day (weekday, public holiday, etc.) are neglected.
- (C) **Data quality:** The M&V process allows for additional data evaluations (such as the removal of outliers and unplanned events from the baseline dataset). The budgets only verify that the data is correct and does not remove irrelevant data before using it to predict future consumptions.
- (D) **Expected changes:** The budget allows for the changes associated with an increase/decrease in production and other planned projects (growth and savings). However, the impact of these changes is merely estimated and based on assumptions with no mathematical reasoning.
- (E) **Budget development:** The budget relies heavily on the assumption that the following year's energy performance will be directly related to this year's energy performance. No modelling techniques are considered to improve this assumption.
- (F) **Report and approve:** After the budget are developed, the budget figures get approved internally and signed off. The general budgeting structure does not consider the validation of the budgeting process before signing it off. Neglecting the assurance provided by accurate reporting of the budget and the budgeting process can affect the traceability of the process, especially when audited by a third party.

Each one of these limitations has an equal M&V step (parallel), which is presented in Table 1-5.

Table 1-5: Refined budgeting limitations with an M&V parallel

No.	Budgeting limitations	M&V parallel
(A)	Budget boundary	Measurement boundary
(B)	Budget resolution	Measurement resolution
(C)	Data quality	Data quality
(D)	Expected changes	Routine adjustments
(E)	Budget development	Baseline development
(F)	Report and approve	Assurance

Table 1-5 is essential to this study, as it links the qualitative characteristics of the M&V principles to the limitations identified in the budgeting structures used by mines. By incorporating the M&V parallels into the budgeting structure, the limitations will be improved, and the improved budgeting structure will contain all the M&V principles (accuracy, consistency, conservativeness, completeness, relevance and

transparency). This essentially indicates how M&V principles can be used to address the limitations of current budgeting methods used in the South African mining environment.

Before addressing the limitations in the budgeting structures by the M&V parallels, the budgeting structures should first be evaluated if the M&V principles are not already addressed as per Step-4 of the strategy). To evaluate this query several M&V principles-related questions are generated in the next step of the five-step strategy.

Step-4: Conduct relevant questions for critical analysis

The parallels present several questions as to whether the six M&V principles are applied when creating the budget. Six relevant questions are contained in Table 1-6. These questions are constructed based on the contribution of each of the principles to the M&V process (as discussed in Table 1-1 in Section 1.2). These questions also relate to the six M&V parallels listed in Table 1-5.

Table 1-6: M&V principles with relevant questions

Principle		Question
(A)	Relevance	<i>Is the budget relevant to the needs of the application?</i>
(B)	Consistency	<i>Is consistency applied throughout the application process?</i>
(C)	Accuracy	<i>Is the budget compiled using accurate data?</i>
(D)	Completeness	<i>Does the budget consider any expected changes?</i>
(E)	Conservativeness	<i>Is the budget representative of the expected performance?</i>
(F)	Transparency	<i>Is the budgeting process reported for assurance?</i>

The step-by-step approach to budgeting for each of the eight mines in the questionnaires is evaluated to see whether any of the questions in Table 1-6 were addressed. If a reference addressed all 6 of these M&V principles (answers yes to all six questions in Table 1-6) the research question will be successfully addressed. The answers to these questions are discussed in the next step of the strategy.

Step-5: Test the questions in budget-related documents

The final step in the five-step strategy is to test each of the budgeting structures of the South African mines against the questions generated in Step-4. If the question were answered, the test proves to be successful and the M&V principles were addressed in the budgeting structure. If the test proves to be unsuccessful the M&V principles were not addressed in the budgeting structure and proves the need to address the principles. Figure 1-9 illustrates the final step in the five-step strategy.

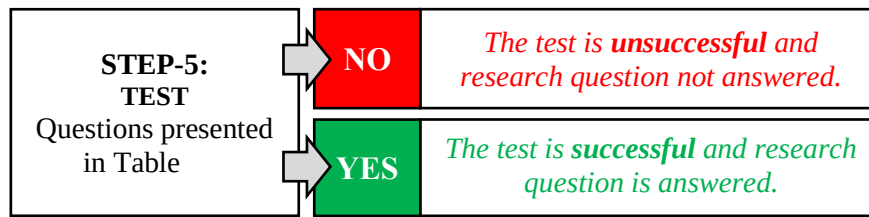


Figure 1-9: Application of the critical analysis strategy

Each of the questions generated in step-4 is provided below with the respective feedback from each questionnaire (on the eight South African mines), as presented in Appendix A.

(A) Is the budget relevant to the need of the application? (Testing for relevance)

The budget developed for the mine is considered relevant when it addresses the purpose of the budget. The aim of the budgets on mines is to plan for future consumption and to use the budget as a reference point for energy management [54]. To allow energy management the budget should consider smaller boundaries (as discussed in Section 1.1).

In order to successfully pass the strategy question (A), the mines that participated in the questionnaire should have considered boundaries relevant to their needs. From the critical analysis, it is seen that only one of the eight mines (mine number 6) developed its budget on a small boundary (commodity-level). This proves to be effective for energy management as all the commodities could successfully be evaluated during the performance assessment period.

The remainder of the mines that participated in the questionnaires all developed budgets on a large boundary (either for the whole mine or for each shaft on the mine: both are still considered as a whole-facility evaluation). This, however, is effective for evaluating the overall consumption of the mines, but it neglects the need for energy management.

Since all eight of these mines responded in the questionnaires that one of the main uses of the budgets is for energy management, it is considered that these mines (with the exception of mine number 6 which considered commodity-level budgets) developed irrelevant budgets and did not pass strategy question (A). Table 1-7 presents a matrix with the response of each mine's feedback obtained from the questionnaires on the strategy question.

Table 1-7: Responses to strategy question A (category 1)

Mine 1	Mine 2	Mine 3	Mine 4	Mine 5	Mine 6	Mine 7	Mine 8

A red block indicates that the mine did not pass the strategy question (answered “no” to strategy question A), where a green block indicates a pass on the strategy question (answered “yes” to strategy question A). The vast amount of *unsuccessful* feedback on strategy question A justifies the conclusion that, generally, South African mines do not develop budgets relevant to the need of the application.

(B) Is consistency applied throughout the application process? (Testing for consistency)

Consistency throughout the budgeting process ensures that the final product (the budget) is reliable. To ensure consistency in the budget, the data used for the budget should be uniform. This includes the resolutions considered when developing the budget [19], [50]. When multiple variables are included in the budgeting process, it is important to ensure that these resolutions are the same for all the variables.

To illustrate the concept of consistency in budgets, the development of a budget on monthly resolutions should be considered. The budget is probably created on monthly resolutions instead of annual totals to capture seasonal effects. But, if a savings project on refrigeration is theoretically calculated to save on average 2 MW power and is incorporated into the budget for each month as such, it can be reported as being inconsistent. This is because the energy savings achieved by this project might be dependent on the weather conditions, with more savings being achieved during certain seasons (depending on the details of the project). Ideally, the effect of this savings project should be calculated for each month individually to correspond with the resolutions of the budget and to also allow for seasonal changes.

Considering the example presented in the paragraph above, a mine will, therefore, pass the strategy question (B) if the resolutions for all variables included in the budgeting process are consistent. This question was applied to all eight of the mines that participated in the questionnaires and the responses are presented in Table 1-8.

Table 1-8: Responses to strategy question B (category 1)

Mine 1	Mine 2	Mine 3	Mine 4	Mine 5	Mine 6	Mine 7	Mine 8

A red block indicates that the mine did not pass the strategy question (answered no to question B). Since all of the mines answered no to strategy question B, it can be stated that, generally, South African mines do not apply consistency when developing budgets.

(C) Is the budget compiled using accurate data? (Testing for accuracy)

The accuracy of the data ultimately determines the reliability of the budget. If data accuracy levels are low, the budget will ultimately be unrealistic and unable to be used for energy management. It is, therefore, important to ensure that the data used for the budget is accurate.

For the data to be considered “accurate” it has to comply with the following criteria [51], [52]:

- 1) Data obtained from calibrated meters or servers (or else at least verified against a trusted reference such as the Eskom invoices or an alternative source of measurement);
- 2) Obtained data should be evaluated for completeness (no missing data points);
- 3) Historical data should be evaluated for abnormal events and the abnormal events should have been removed from the dataset; and

- 4) Data should be evaluated for outliers, and the outliers should be investigated and removed if required.

If the mines in the questionnaires addressed all four of the above-mentioned criteria, strategy question (C) will be successfully addressed. Table 1-9 presents the responses on the questionnaires of the eight mines' data accuracy tests.

Table 1-9: Responses to strategy question C (category 1)

Mine 1	Mine 2	Mine 3	Mine 4	Mine 5	Mine 6	Mine 7	Mine 8

Table 1-9 shows that seven of the eight mines did not comply with all four of the criteria listed (indicated by the red blocks in the table). It should be noted that all of the mines did, however, apply at least one of the criteria (criteria number 1 was most often applied). Since the mine should have complied with all four of the criteria, only one mine (mine 7) passed strategy question C (indicated with the green block in the table).

Mine 7 obtained data from calibrated meters and evaluated the data for completeness, outliers and unplanned events. An example of energy data from incomer meter 12 (INC-12) is illustrated in Figure 1-10. This specific incomer meter is chosen as it highlights inconsistency, outliers and unplanned events simultaneously. The data were evaluated in half-hourly resolutions and are presented as thus.

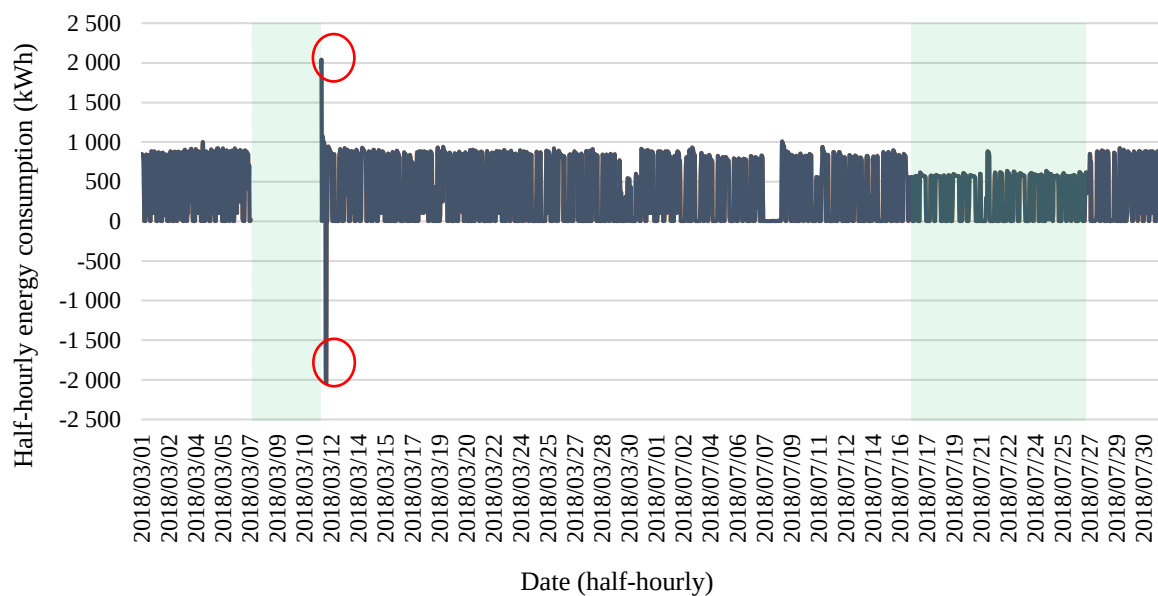


Figure 1-10: Daily actual energy consumption of INC12

The first highlighted section indicates data loss for several days. It was confirmed that the power meter was faulty and needed replacement. Due to the lack of data, the average consumption before this period was used to fill up the missing data. Immediately after the power meter was replaced, two data spikes

were observed (a positive and an equally negative spike). These two spikes are considered outliers and were removed due to the establishments that these spikes occurred as a result of the new meter's calibration.

Finally, a step change in the normal operation of the power meter was observed towards the end of the evaluation figure (indicated by the second highlighted block). This step change was established as the time period where a compressor fed by this incomer was switched off for maintenance and therefore the energy consumption was low. This data was also replaced with the average consumption before and after the maintenance period.

The vast amount of *unsuccessful* feedback on strategy question C leads to the conclusion that, generally, South African mines do not compile budgets using accurate data.

(D) Does the budget consider any expected changes? (Testing for completeness)

Energy savings are the difference between the energy that was used after an ESM was implemented and a baseline estimate of what would have been used without the ESM (referred to as the adjusted baseline). This is the case with budgeting as well. When predicting the energy consumption of the next year, assumptions are made on what will happen with the energy. It is, therefore, important to consider all outside effects on the energy consumption as well.

Typical factors to consider are variables such as the temperature or the increases/decreases in production outputs. These factors are bound to change year-on-year and affect the energy consumption of a mine. Anticipated changing factors are referred to as routine adjustments. Unexpected changes, such as the occurrence of a pandemic resulting in a national lockdown or strike action from a governing party or workers' union cannot be anticipated and the effect thereof can thus not be theoretically calculated beforehand. Such unexpected changes would (in M&V terms) justify non-routine adjustments (the effect of unplanned events).

When creating a budget, it is important to ensure that the budget allows for routine adjustments such as temperature and production changes. The eight mines that participated in the questionnaires were evaluated to see whether any of them included any routine adjustments. Table 1-10 displays the response matrix of the eight mines' responses to strategy question D.

Table 1-10: Responses to strategy question D (category 1)

Mine 1	Mine 2	Mine 3	Mine 4	Mine 5	Mine 6	Mine 7	Mine 8

Table 1-10 shows that all eight mines' budgeting structures consider the previous year's actual energy consumption, plus/minus expected changes. These expected changes are typically one or more of the following:

- Growth projects (expansions on the mines, increasing in crews, etc.),
- Savings projects (ESMs implemented to save energy), and/or
- Changes as a result of production increases/decreases.

It is noted that all of the mines consider at least one of the expected changes when developing a budget. It is further noted that half of the mines (four of the eight) considered only production when developing the energy budgets. For the savings and growth projects, the assumptions made on the effect of the projects are based on what the expected performance of the equipment involved in the project will be. An example of the implementation of a savings project on a pumping system is provided below.

Example: During the baseline period, Pump A and Pump B were running for 8 hours a day (Pump A = 25kW and Pump B = 35kW installed capacity). After evaluation it was found that by replacing Pump B with a smaller pump (also a 25kW pump), the required operational output will still be achieved, and the input power will be less. The savings associated with this project will thus be 10kW ($35\text{kW} - 25\text{kW} = 10\text{kW}$). This 10kW saving is then assumed to be in place as a static value each month.

By calculating the expected effects of projects in this manner the assumption is made that the total efficiency is possible and that the project will always deliver that saving.

For the expected changes in production, all of the models used an *energy intensity* model, as presented in Equation 1-1 and Equation 1-2. The use of an energy intensity model holds limitations and it is suggested to also consider other linear and non-linear models when evaluating the impact of changes in production. Non-linear models that historically proved to have good correlation with productions are the power model, the exponential model and the logarithmic model [57].

(E) Is the budget representative of the expected performance? (Testing for conservativeness)

When energy savings obtained from an ESM are calculated, several models are developed to compare the saving values with each other. A conservative model (a savings model that does not present the highest amount of savings) is usually identified as the approved model. This is to ensure that no unintended or accidental savings are claimed. When creating a budget, the purpose is to plan for the upcoming year's financial output to ensure that the facility has enough resources and capital expenditure available.

A conservative budget would, therefore, be a large enough budget that underestimates the effect of savings projects and overestimates the effect of growth projects, ultimately to ensure that the budget has a safety factor (but still be realistic and not over-estimate financial expenditure). Thus, to ensure that a conservative budget is used, the budgeting approach should allow for several budgets to be created and compared to identify the size of the safety factors required and to select the most appropriate option.

The eight mines that participated in the questionnaires are evaluated accordingly and the feedback of each mine's response on the strategy question D are presented in Table 1-11.

Table 1-11: Responses to strategy question E (category 1)

Mine 1	Mine 2	Mine 3	Mine 4	Mine 5	Mine 6	Mine 7	Mine 8

From Table 1-11 it is noted that none of the mines considered creating more than one budget to allow for the assessment of a conservative budget. The budgeting process followed by each of the eight mines was further evaluated with the aim of identifying the steps taken (or neglected) to ensure that the budget is conservative. A summary of the findings is listed:

- Mines 1, 3, 4 and 7 allowed for no alternative evaluations to include a confidence factor which will ensure conservativeness.
- Mine 2 underestimated all of the savings projects effects by 10% to ensure that if the ESMs do not perform as planned, some additional capital will be available.
- Mines 5 and 8 allowed for a confidence factor on the final budget (2.5% and 1.5% respectively). Both these mines thus increased their final budgets by a specific error percentage to allow for unexpected changes.
- Mine 6 included a historical variance factor into the budgeting process. This variance is the difference between the previous year's budget and actual consumption which is incorporated as an error percentage into the improved budgeting structure.

Ultimately, even though none of the mines created more than one budget to compare the conservativeness of the budgets, more than half of the mines that participated in the questionnaires incorporated some form of evaluation for conservativeness in their budgeting process.

(F) Is the budgeting process reported for assurance?

After the budget is created, it is important to ensure that the budgeting process is reported. The reporting of the process ensures that an independent person can evaluate and assess the process before agreeing/approving the process. This creates assurance that the budget is approved based on traceable documentations. The 8 mines that participated in the questionnaires were evaluated to see whether or not they validated their budgets before approving it. The feedback on this strategy question is presented in Table 1-12.

Table 1-12: Responses to strategy question F (category 1)

Mine 1	Mine 2	Mine 3	Mine 4	Mine 5	Mine 6	Mine 7	Mine 8

Table 1-12 shows that mines 1, 3 and 6 included a reporting step into the budgeting process. The traceability provided by the reporting of the process gives more confidence that the process steps followed by these mines are correct.

The critical analysis shows that none of the mining questionnaires addressed all six of the M&V principles (answered yes to all six relevant questions). The research question of this study is therefore not answered which emphasises the need to improve the current budgeting structures of the mines by implementing well-established M&V principles.

CATEGORY 2: BUDGETS USED BY OTHER INDUSTRIES IN SOUTH AFRICA

Step-1: Research on the M&V baselines

The first step of the five-step strategy is already discussed in Section 1.2 and is universal for all three categories: 1) budgeting structures in South African mines, 2) **budgeting structures of other industries in South Africa** and 3) budgeting structures from various industries across the globe. This step will, therefore, not be addressed again but will rely on the information already discussed in previous sections.

Step-2: Examine the budgeting structures (of other industries in South Africa)

For the evaluation of the budgeting structures on other industries in South Africa, 42 peer-reviewed literature-based references are considered. All of these references consider the development and/or the application of budgets on case study and were therefore included in this study. These 42 references are grouped into the following five clusters, each representing a different industry in South Africa:

- 1) Business (12 references) [58], [59], [68], [69], [60]–[67]
- 2) Medical (7 references) [70]–[76]
- 3) Education (8 references) [60]–[67]
- 4) Science (7 references) [85]–[91]
- 5) Agriculture (8 references) [92]–[99]

Figure 1-11 shows the distribution of the 42 references per research collection (publications in journal articles, theses, conference proceedings, reports and book sections). All the references are considered new to the research field as all the references were published post 2010. More than half of the references for other industries in South Africa are from published journal articles (22 of the 42 references) which are considered the most reliable type of research collections [42].

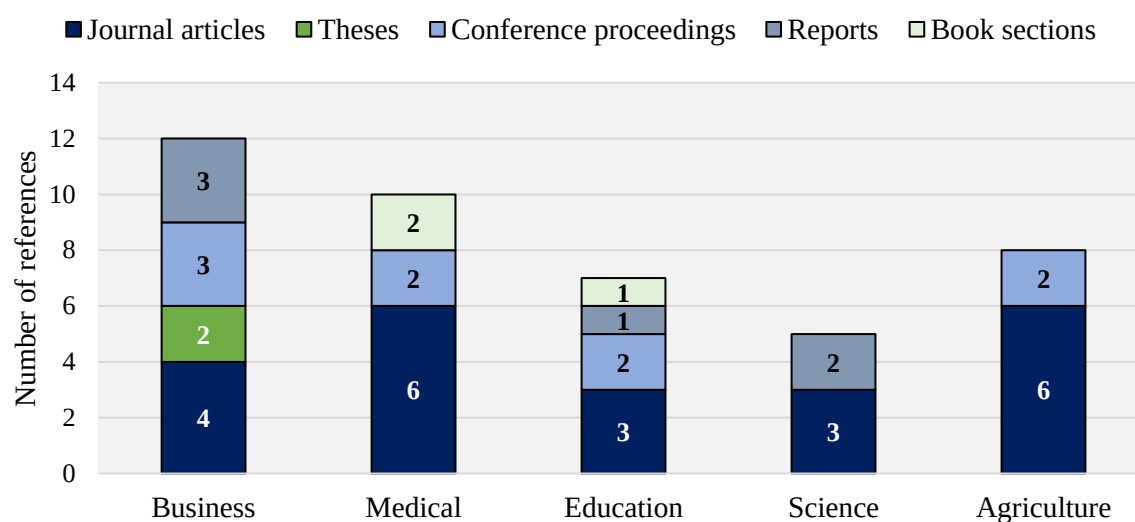


Figure 1-11: Distribution of Category 2 references

The general steps considered by the eight mines in the questionnaires are used to see whether or not the 42 literature-based studies on other South African industries addressed budgeting using similar steps to the eight mines in the questionnaires.

Figure 1-12 illustrates the number of similar steps (top section of the graph with the green dots) and the number of non-similar steps (bottom section with the red dots). Each group (Business, Medical, Education, Science, and Agriculture) is represented in the figure.

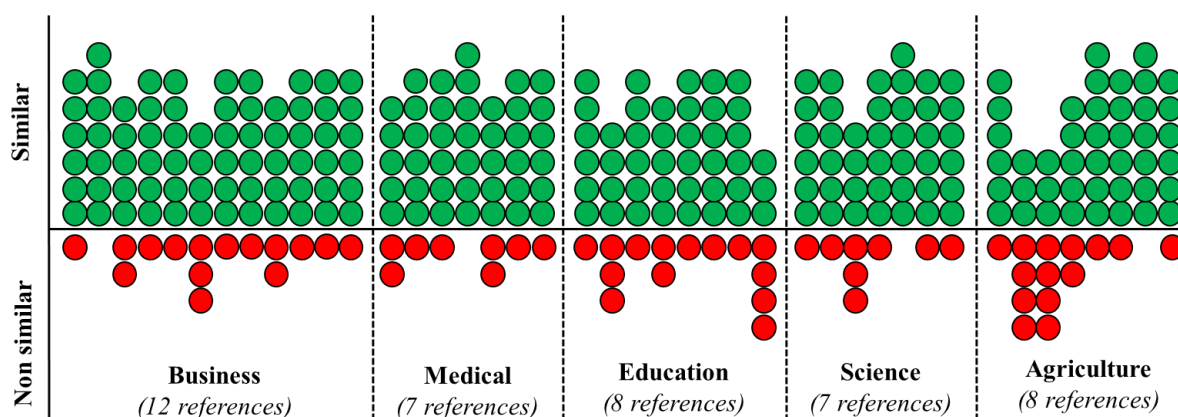


Figure 1-12: General budgeting structures used by Category 2

From Figure 1-12 it is clear that most of these groups followed steps that are similar to the mining industry in South Africa. The vast number of similar steps followed by these industries prove that the general steps followed by the mines in the questionnaires are universal budgeting steps and will, therefore, be used as the reference point for the steps followed when developing budgets.

Although most of the same steps were followed as the mines in the questionnaires, several other steps were considered as well. The different steps are discussed for each cluster and summarised:

- *Most of the studies neglected a validation step as discussed in category 1.*
- *Most of the medical references incorporated a clinical trial step, which was found to be irrelevant for application on mine budgets and not required for this study.*

Due to the vast number of similar steps (and the irrelevance of the other steps) used by the 42 references on other industries in South Africa and the mining industry in South Africa, the general budgeting structure is still considered to be that obtained from the questionnaires in the category 1 evaluation (as presented in Figure 1-8).

Step-3: Compare the M&V baselines to the budgeting structures

In Step-2 of the five-step strategy it was concluded that the general budgeting structure used by other industries in South Africa is similar to the budgeting structure used by South African mines (with the exception of industry-specific steps). The comparison between the M&V baselines and the budgeting structures on the 42 references in category 2 will, therefore, be similar to that already discussed in step-3 of the category 1 evaluation (refer to Table 1-4).

Step-4: Conduct relevant questions for critical analysis

Since the comparisons between the M&V structures and the budgeting structures of the 42 references in category 2 are similar, the relevant question conducted in Step-4 of the category 1 evaluation will also be considered for the category 2 evaluation (refer to Table 1-6).

Step-5: Test the questions in budget-related documents

The final step in the five-step strategy is to test each of the budgeting structures of the 42 references on other industries in South Africa against the questions generated in Step-4. The six relevant questions listed in Table 1-6 are addressed individually. Table 1-13 displays the response of each reference on these relevant questions.

In Table 1-13, if the questions were answered correctly the test proves to be successful and the M&V principle was addressed in the budgeting structure (indicated with a green block). If the test proves to be unsuccessful the M&V principle was not addressed in the budgeting structure and proves the need to address the principle (indicated with a red block).

Table 1-13: Responses to strategy questions A – F (category 2)

M&V principles	Business										Medical					Education					Science					Agriculture				
	(A)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	(B)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	(C)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	(D)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	(E)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	(F)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

References (x42)

Only the main findings of the responses to each question (questions A to F in Table 1-13) from the 42 references in category 2 are listed in this chapter. The full critical analysis for the category 2 references are presented in Appendix B.3.

- (A) **Relevance:** More than half of the references considered *small boundaries*. This contradicts what is observed for budgets in the mining industry. The reason for the difference is possibly due to the industries considered in this category being much smaller than the mining industry and could, therefore, easily apply a smaller boundary.
- (B) **Consistency:** The majority of the literature references, however, calculated certain aspects of the budget in different resolutions. These aspects were typically the adjustments incorporated into the budgets.
- (C) **Accuracy:** It is noted that less than 20% of the research studies mentioned the accuracy of the data used for budgeting.
- (D) **Completeness:** More than half of the literature references on other industries in South Africa considered expected changes during the budgeting process. Various other changes (other than those which the category 1 mines included) were considered. These changes are school holidays, rainy seasons, flu seasons, etc.
- (E) **Conservativeness:** During M&V applications, presenting multiple models is standard to identify the most suitable model. For budgeting purposes, this does not seem to be a standard as none of the 42 literature studies on other industries in South Africa considered any additional models either (as with the eight models in category 1).
- (F) **Transparency:** Only seven of the 42 references included a reporting step in the budgeting process. This influences the traceability of the budget should a third party need to approve the budget.

Table 1-13 shows that none of the 42 references in category 2 addressed all six of the M&V principles (answered yes to all six relevant questions). The research question of this study is therefore not answered which emphasises the need to improve the current budgeting structures by implementing well-established M&V principles.

CATEGORY 3: BUDGETING STRUCTURES USED GLOBALLY

Step-1: Research on the M&V baselines

The first step of the five-step strategy was previously discussed in Section 1.2 and is universal for all three categories: 1) budgeting structures in South African mines, 2) budgeting structures of other industries in South Africa and **3) budgeting structures from various industries across the globe.** This step will, therefore, not be addressed again but will rely on the information already discussed in previous sections.

Step-2: Examine the budgeting structures

The budgeting structure of 48 alternative references ([100], [101], [110]–[119], [102], [120]–[129], [103], [130]–[139], [104], [140]–[147], [105]–[109]) from various industries across the globe is evaluated. These 48 references are presented in Figure 1-13 which shows the distribution of the sources of the references. The references are divided into journal articles, theses, conference proceedings, reports and book sections.

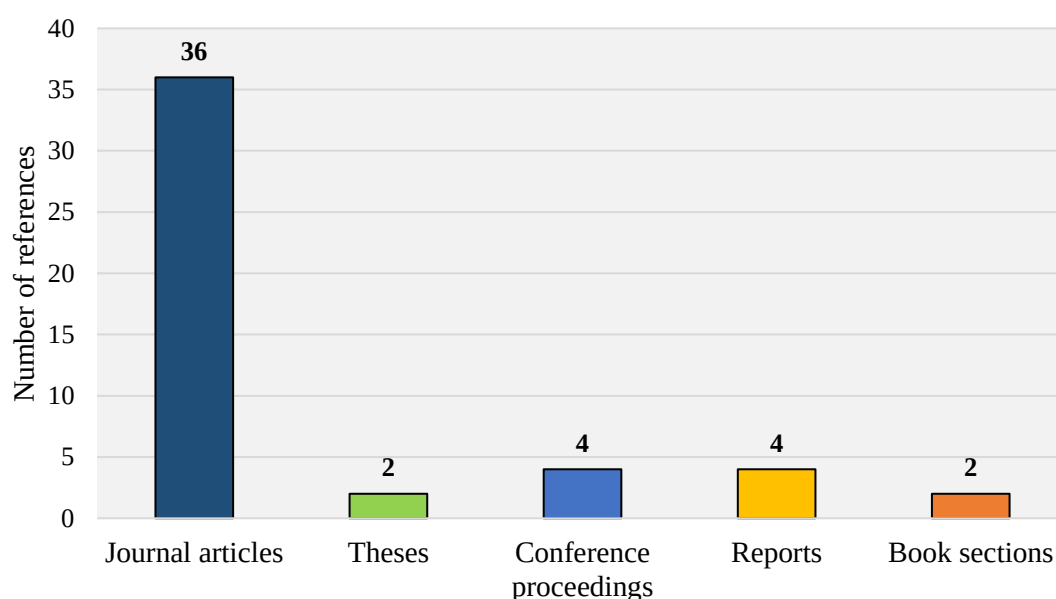


Figure 1-13: Distribution of the Category 3 references

All the references are considered new to the research field as all the references were published post 2010. More than 75% of the references (36 of the 48 references) are from published journal articles. The budgeting structures of each of these references are compared to the budgeting structure established by the eight mines that participated in the questionnaire (category 1).

Figure 1-14 illustrates the number of similar steps (top section of the graph with the green dots) and the number of non-similar steps (bottom section with the red dots).

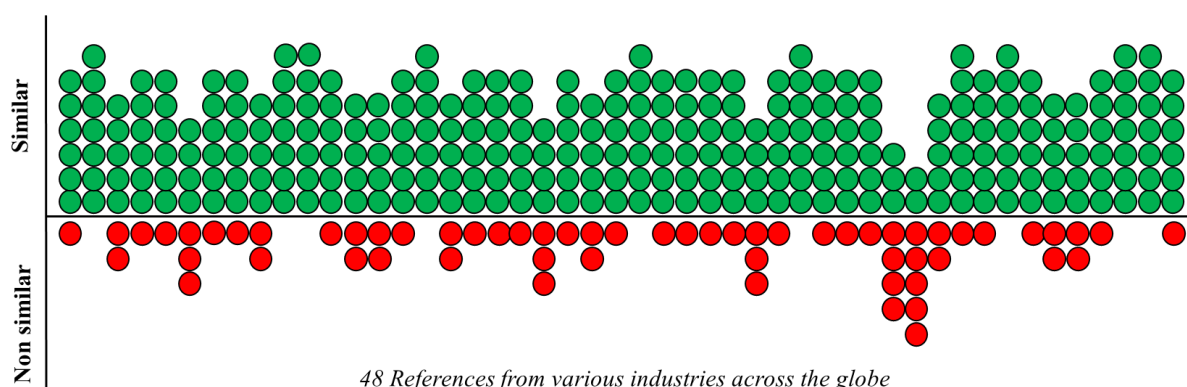


Figure 1-14: General budgeting structure used by Category 3

From Figure 1-14 it is clear that most of references followed similar steps to those in the mining industry in South Africa. The vast number of similar steps followed by these references proves that the general steps followed by the mines in the questionnaires are universal budgeting steps and will, therefore, be used as the reference point for the steps followed when developing budgets.

Step-3: Compare the M&V baselines to the budgeting structures

In Step-2 of the five-step strategy it was concluded that the general budgeting structure used globally is similar to the budgeting structure used by South African mines (with the exception of industry-specific steps). The comparison between the M&V baselines and the budgeting structures on the 48 references in category 3 will, therefore, be similar to that already discussed in step-3 of the category 1 evaluation (refer to Table 1-4).

Step-4: Conduct relevant questions for critical analysis

Since the comparison between the M&V structures and the budgeting structures of the 48 references in category 3 are exact, the relevant question conducted in Step-4 of the category 1 evaluation will also be considered for the category 3 evaluation (refer to Table 1-6).

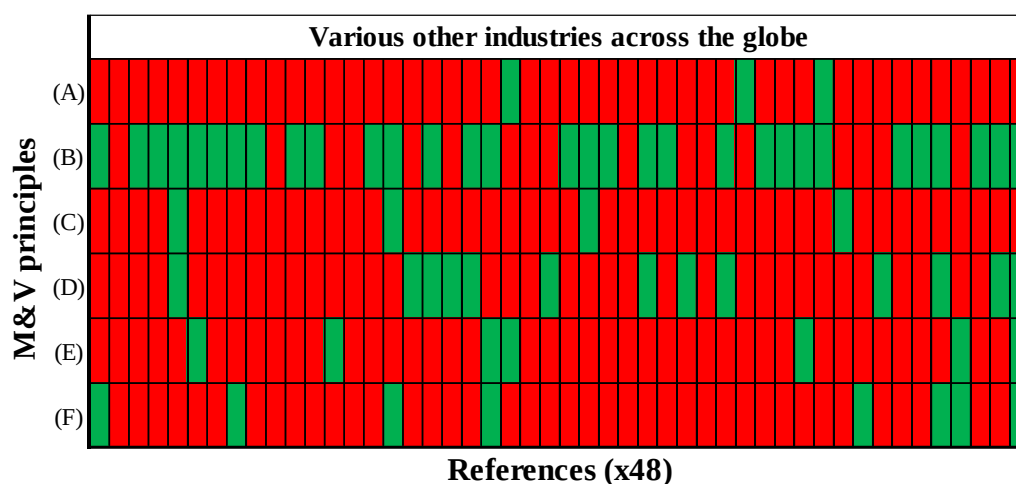
Step-5: Test the questions in budget-related documents

The final step in the five-step strategy is to test each of the budgeting structures of the 48 references on various industries globally against the questions generated in Step-4. The six relevant questions listed in Table 1-6 are addressed individually. Table 1-14 displays the response of each reference to these relevant questions.

In Table 1-14, if the questions were answered correctly the test proves to be successful and the M&V principle was addressed in the budgeting structure (indicated with a green block). If the test proves to

be unsuccessful the M&V principle was not addressed in the budgeting structure and proves the need to address the principle (indicated with a red block).

Table 1-14: Responses to strategy questions A – F (category 3)



Only the main findings of the responses to each question (questions A to F in Table 1-14) from the 48 references in category 3 are listed in this chapter. The full critical analysis for the category 3 references is presented in Appendix B.3.

- (A) **Relevance:** Almost none of the references considered *small boundaries*. This is contradictory to what is observed for budgets on the mining industry. The reason for the difference is possible due to the industries considered in this category being much smaller than the mining industry and could, therefore, easily apply a smaller boundary.
- (B) **Consistency:** The majority of the literature references, however, calculated certain aspects of the budget in different resolutions. These aspects were typically the adjustments incorporated into the budgets.
- (C) **Accuracy:** It is noted that less than 90% of the research studies (only 4 of the 37 references) mentioned the accuracy of the data used for budgeting.
- (D) **Completeness:** More than half of the literature references considered expected changes during the budgeting process. Various other changes (other than those which the category 1 mines included) were considered. These changes are school holidays, rainy seasons, flu seasons, etc.
- (E) **Conservativeness:** During M&V applications, presenting multiple models is standard practice to identify the most suitable model. For budgeting purposes, this does not seem to be a standard practice as none of the 48 literature studies on other industries in South Africa considered any additional models either (as with the eight models in category 1).
- (F) **Transparency:** Only eight of the 48 references included a reporting step in the budgeting process. This influences the traceability of the budget should a third party need to approve the budget.

Table 1-14 shows that none of the 48 references in category 3 addressed all six of the M&V principles (answered yes to all six relevant questions). The research question of this study is therefore not answered which emphasises the need to improve the current budgeting structures by implementing well-established M&V principles.

1.3.4 SUMMARY OF THE CRITICAL ANALYSIS ON THE THREE CATEGORIES

The core of the critical analysis was to identify whether any of the research studies (and questionnaire feedback) addressed any of the M&V principles. The hypothesis was that if a reference addressed all of the M&V principles, the budgeting structure of that reference would have addressed the research question of this study. However, from the feedback on the step-5 questions for each category it is noted that not one of the literature references applied all of the M&V principles.

Table 1-15 presents the final matrix (a summary of the responses in category 1, 2 and 3) for the critical analysis of this study.

Table 1-15: Critical analysis matrix for all 98 references

	Category 1	Category 2												Category 3											
(A)																									
(B)																									
(C)																									
(D)																									
(E)																									
(F)																									

References (x98)

The summary of the responses on the six M&V related questions presented in Table 1-15 shows that none of the 98 references (which includes the eight questionnaires of category 1) addressed all of the relevant questions. It is noted, however, that question B (*Is consistency applied throughout the application process?*) was widely addressed across all three reference categories. Question C (*Is the budget compiled using accurate data?*) was the question least addressed.

The lack of the application of M&V principles in the budgeting structures is therefore proved. This study will focus on addressing these principles accordingly, and fulfilling the limitations identified.

1.4 IMPORTANCE OF THE STUDY

1.4.1 NEED FOR THE STUDY

Budgets are used by mines as a guidance for energy consumptions and cost forecasting [148]. These budgets are, however, mainly focussed on the financial aspects of the mine (financial and static budgets)

and with little detail given to the operational changes depicted in the operational budget [6], [149]. This causes uncertainties in the Master Budget that will possibly affect the sustainability of the mine.

The study proposes that well-established M&V principles be used in the development of budgets to reduce the limitations. M&V principles are considered well-established structures that can be used to improve the existing budgeting structures. From the critical analysis, it was highlighted that none of the eight South African mine budgets evaluated in this study, and none of the other budgets on other industries across the globe included in the study, use these M&V principles when developing budgets. A need was, therefore, identified to:

Link the well-established M&V principles to the mine's budgeting structures to reduce limitations and decrease uncertainty by:

- 1. Adapting the boundaries used for the budget;**
- 2. Ensuring that consistent data resolutions are used;**
- 3. Evaluating all data for accuracy;**
- 4. Incorporating routine adjustments (planned events) into the budget;**
- 5. Including a variance factor in the budget that will ensure reserves for non-routine adjustments (unplanned events); and**
- 6. Reporting on the budget process before approval and sign-off of the budget.**

This need has a wide range of potential applications in different fields of operational budgeting. For this study, however, the effect will be evaluated by applying the principles to a case study (gold mine complex in the Gauteng region of South Africa).

1.4.2 RESEARCH OBJECTIVES

The main objective of this study is the application of well-established M&V principles on the operational budgets of a mine. This aims to assist mines to develop operational budgets that can be used for energy management as well. A few additional objectives are needed in the study to provide a functional application. These objectives are to:

- Research the budgeting structures used by mines to identify limitations.
- Research the M&V applications to understand the field of application.
- Develop parallels between the budgets and the M&V principles.
- Develop an improved budget structure for mines in South Africa.
- Validate the improved budgeting structure by application on a gold mine complex.
- Verify the improved budgeting structure by comparing the forecasted performance to the original budgeting structure.
- Estimate the value added by implementing this study.

These objectives will be addressed in Chapter 2 and Chapter 3 of this document. The successful adherence to these objectives will result in the novel contributions of this study.

1.4.3 NOVEL CONTRIBUTIONS

This chapter provided an overview of the limitations associated with mine budgets, along with the need to improve these budgets through adherence to well-established M&V principles. This thesis undertakes to provide several contributions to bridge this limitation with M&V principles by contributing to the following:

1. *Development of a structure to improve mine budgets in accordance with the developed parallels to support accurate budgeting;*
2. *Improving current methods used to predict the effect of savings, growth and production on energy consumption in budgets;*
3. *Critical analysis of budgets according to measurement and verification principles;*
4. *Development of unique parallels based on existing concepts (measurement and verification principles) for the application in a new field (budgets).*

Each of these contributions is discussed to promote the originality of the contribution within the engineering field. The discussion is led by five relevant questions:

1. What needs to be done?
2. How is it currently done?
3. Why is the current method insufficient?
4. How does this study solve the problem?
5. Why is this a novel contribution?

Each question is addressed per original contribution in the sub-sections below.

ORIGINAL CONTRIBUTION 1

Development of a structure to improve mine budgets in accordance with the developed parallels to support accurate budgeting.

What needs to be done?

Mines need to compile budgets for each financial year. These budgets should typically include all of the planned expenses and income for the assessment period. This includes the planned expenses of the mining operations (which consists mainly of the energy consumption of various components) along with the predicted production deliverables.

How is it currently done?

Budgets are typically compiled by a financial resource who focusses on the expected cost changes in the upcoming financial year. When the mine's operating budget is compiled, limited attention is given to the expected changes in the day-to-day operations of the mine. Changes in production outputs, temperatures and planned projects are often neglected.

This study evaluated 98 references related to development of budgets. Eight of these references were obtained from questionnaires on South African mines and the remaining 90 references were from peer-reviewed and published resources regarding the budgeting structures used by various other industries. It was found that all 98 of these references develop budgets in a similar manner.

A conclusion could, therefore, be made that budgets in general focus more on financial aspects and often neglect operational changes.

Why is the current method insufficient?

Due to the mining environment being so large, the negligence of the operational changes can have a significant impact on the final budgeting figures (expenses and revenues). This causes the budget to become obsolete early on in the assessment period. There is therefore a need to improve the existing structures to account for all of these operational changes on a mine when the budget is developed.

How does this study solve the problem?

M&V applications are used in the mining industry (and other industries) to quantify the impact of ESM performance. It was observed that the M&V application structure allows for the development of a baseline, which is to some extent similar to a budget. A baseline uses historical energy consumption data to predict future energy consumption data in the same way that a budget uses historical data to predict future occurrences.

However, it was also noticed that baselines are representative of the actual energy consumption that was predicted and rarely becomes obsolete in the assessment period. This is not observed for budgets. It was, therefore, suggested to include M&V principles into the budgeting process to enable the budgets to be as representative to the actual energy consumption as the baselines are.

The study ultimately developed six parallels between budgets and baselines in Chapter 2, phase 1 of the methodology. These six parallels were also based on the six well-established M&V principles (relevance, consistency, accuracy, completeness, conservativeness and transparency). The development of these parallels proved that M&V principles could be incorporated into the budgeting structure.

The second phase of the methodology (presented in Chapter 2) incorporated these parallels into the existing budgeting structure used by mines to present a new (improved) budgeting structure. In Chapter 3, this improved structure was applied to eight case studies (case study 1 was discussed in detail and the results of case study 2 to case study 8 were summarised).

The successful application of the improved structures on eight case studies proves that the methodology presented in Chapter 2 is functioning. Since the improved budgeting structure is new (improved version of the original structure), no structure or methodology exists for the specific application of M&V principles in the budgeting structures of mines. Additionally, no practical application exists for the integration of these multiple disciplines to a case study for verification and validation.

Why is this a novel contribution?

The proposed budgeting structure is a new and improved version of the original structure. There was no structure or methodology available for the specific application of M&V principles in the budgeting structures of mines. Additionally, no practical application existed for the integration of these multiple disciplines to a case study for verification and validation.

This study develops a generic budgeting structure based on the adaption of M&V principles in the existing budgeting structures. The structure consists of six systematic steps and ensures an M&V principle is addressed in each step. A discussion is provided for each step of the structure in the respective case studies to ensure the M&V principles are adhered to. This ensures the estimated results are accurate, complete, conservative, consistent, relevant and transparent.

A peer-reviewed conference proceeding paper presented at the 31st South African Institute for Industrial Engineering (SAIIE) conference held in Muldersdrift during October 2020 is related to this thesis. This paper was also published in the 31st Annual South African Journal for Industrial Engineering (SAJIE) in November 2020. This publication addressed the need to adapt the current budgeting structures used by mines with M&V principles. The paper's main objective was to determine how the M&V principles can be adapted into the budgeting process. This publication is provided in Appendix C.

The overall contribution of this study is to ultimately improve the budgeting structures of South African mines which can directly impact South Africa's economy. The published research on this study gives surety that the impact of the research adds value to the engineering field.

ORIGINAL CONTRIBUTION 2

Improving current methods used to predict the effect of savings, growth and production on energy consumption in budgets.

What needs to be done?

The effect of operational changes, associated with savings, growth projects and production changes on the budget needs to be quantified. Since the quantified effect will directly impact the budget, it is important to ensure that the effect is quantified correctly.

How is it currently done?

The quantification of these associated effects is easily overlooked. Most often, the effect of savings and growth projects are based on assumptions. The effect of production changes (along with other types of operational changes such as increases in the depth of the mine, temperatures or the number of employees) is usually quantified by an energy intensity model.

Why is the current method insufficient?

Energy intensity models assume that linear relationships exist between the dependent (energy) and independent (production) variables. This model implies that a change in production will have the same linear change in energy. This, however, is not always true.

How does this study solve the problem?

This study evaluated multiple other methods to predict the effect that production changes have on the energy consumption of a mine (refer to Chapter 1). Non-linear regression models, such as polynomial models, power models and logarithmic models are discussed amongst other to be a better fit for production changes on energy.

In Chapter 2, the new structure, therefore, suggests incorporating multiple models when evaluating the effect of production on the energy consumption. It is suggested to evaluate the performance of all of these models to ultimately identify the most suitable model for the forecast. By including this step in the new budgeting structure, the limitations of a linear model are removed.

In Chapter 3, multiple models were used to predict the effect of changes in production, planned growth and savings projects, depth of mine, temperature and the number of employees on energy consumption. It was seen that, by using non-linear regression models, the accuracy of the forecasts on a case study (Mine #1) could be improved as opposed to using an energy intensity model or merely an assumption of the effects.

Why is this a novel contribution?

The operational budget allows for changes in savings, growth and production. The effects of these changes, however, are estimated (for savings and growth) or calculated using outdated ineffective methods such as energy intensity models (for production). This causes the operational budget to be inaccurate and incomplete.

This study shows how multivariable regression models can be used instead, to accurately predict the effect of savings, growth, production and other relevant variables that affect the normal energy consumption of the mine. By including more accurate forecasts of these effects into the budget, the budgets will be improved, more reliable and practical for energy management purposes.

ORIGINAL CONTRIBUTION 3

Critical analysis of budgets according to measurement and verification principles

What needs to be done?

This study plans to incorporate existing M&V principles into the budgeting structure of mines. To allow for the incorporation of these principles, it is important to include a critical analysis on existing budgeting structures to assess whether these principles have been incorporated into budgeting structures (on the mining industry along with other industries).

How is it currently done?

There is currently no available literature that presents a critical analysis on budgets with focus on M&V principles. This study, therefore, highlights the need for the analysis.

Why is the current method insufficient?

A critical analysis is required, and no analysis is present (or could be obtained) from literature.

How does this study solve the problem?

This study evaluates 98 references to address six M&V-related questions. These questions are:

- (A) Is the budget relevant to the need of the application?*
- (B) Is consistency applied throughout the application process?*
- (C) Is the budget compiled using accurate data?*
- (D) Does the budget consider any expected changes?*
- (E) Is the budget representative of the expected performance?*
- (F) Is the budget process reported for assurance?*

If all of these questions are answered, it can be concluded that the references incorporated M&V principles into the budgeting structure. This study evaluated each of the 98 references with these six questions. Table 1.15 presents the feedback of each reference on the questions. A green block indicates that the reference included this in the budgeting structure, where a red block indicates that the question was not addressed.

Table 1.15: Critical literature analysis

(A)

(B)

(C)

(D)

(E)

(F)

References (x98)

Table 1.15 illustrates that none of the budget-related references included all of the M&V principles into the budget structures. This highlights the need for the study. The matrix presented in Table 1.15 also provides the critical analysis of budgets according to measurement and verification principles which proves the novelty to the mentioned fields.

Why is this a novel contribution?

The budgeting structures used by mines in South Africa are missing details, such as the accommodation of unplanned events, and focusses mostly on the financial aspects of the budget. Little to no attention is given to the operational changes of the mine. The consequences of the negligence of these changes from normal operations can be catastrophic and inflict permanent damage on the mine and its investors.

A need is, therefore, highlighted to analyse the current budgeting structures used by South African mines to determine requirements that can be used to mitigate these challenges and uncertainties. This study addressed this need by evaluating 8 of South Africa's largest mineral mines (which consist of 63 shafts) as well as 90 additional budget-related published documents in order to determine whether well-established M&V principles were in any form applied or addressed. The results from the critical analysis were used to formulate a clear and structured need for the study.

ORIGINAL CONTRIBUTION 4

Development of unique parallels based on existing concepts (measurement and verification principles) for the application in a new field (budgets).

What needs to be done?

To improve the current budgeting process, it is suggested to incorporate the well-established M&V principles into the budgeting structures of mines. To enable the incorporation of these principles into the mine's budgeting structures, parallels (analogies between the similarities) are required between budgets and M&V baselines.

How is it currently done?

No parallels between budgets and M&V baselines could be obtained from literature which emphasises the need to develop these parallels and to discuss the similarities / differences observed.

Why is the current method insufficient?

No parallels between budgets and M&V baselines could be obtained from literature which emphasises the need to develop these parallels and to discuss the similarities / differences observed.

How does this study solve the problem?

This study evaluated both the budget structures on mines (Section 1.1) and the M&V application process on mines (Section 1.2). In Section 1.4, a critical comparison between the two structures is provided in Table 1-4. This table also discusses the advantages and limitations of budgets and baselines. Chapter 2 then uses the comparison provided in Table 1-4 to develop parallels based on the similarities between the two fields. Six parallels are developed. These parallels are:

1. Measurement boundary
2. Measurement resolutions
3. Data quality
4. Routine adjustments
5. Baseline development
6. Assurance

The parallels are then incorporated into the budgeting structures to present a new, improved budgeting structure that can be used on mines. The new budgeting structure improved the budgets by an average of 5% (the equivalent of R18-5 million). This added accuracy of the budgets proves that the parallels created in Chapter 2 are correct and useable.

Why is this a novel contribution?

M&V principles are well established and used to create baselines for ESMs and performance assessments. From the critical analysis it was found that no budget-related documents clearly address all the M&V principles used when compiling a baseline. This is a problem, since mine budgets consist of limitations which can be improved by the application of M&V principles. This confirmed the need for an improved structure.

This study implements an improved structure by developing new parallels (i.e. practical associations) between the M&V principles and the budgeting structures used by mines. Each M&V principle was researched to create an equivalent to the budget-related features. These features were then converted to practically applied parallels to support relevance, consistency, accuracy, completeness, conservativeness and transparency.

1.5 OUTLINE OF DOCUMENT

This thesis consists of four individual chapters. These chapters cover the background and the literature review (Chapter 1), the methodology (Chapter 2), the application and results (Chapter 3) and the thesis conclusion (Chapter 4). Figure 1-15 presents an outline of the document.

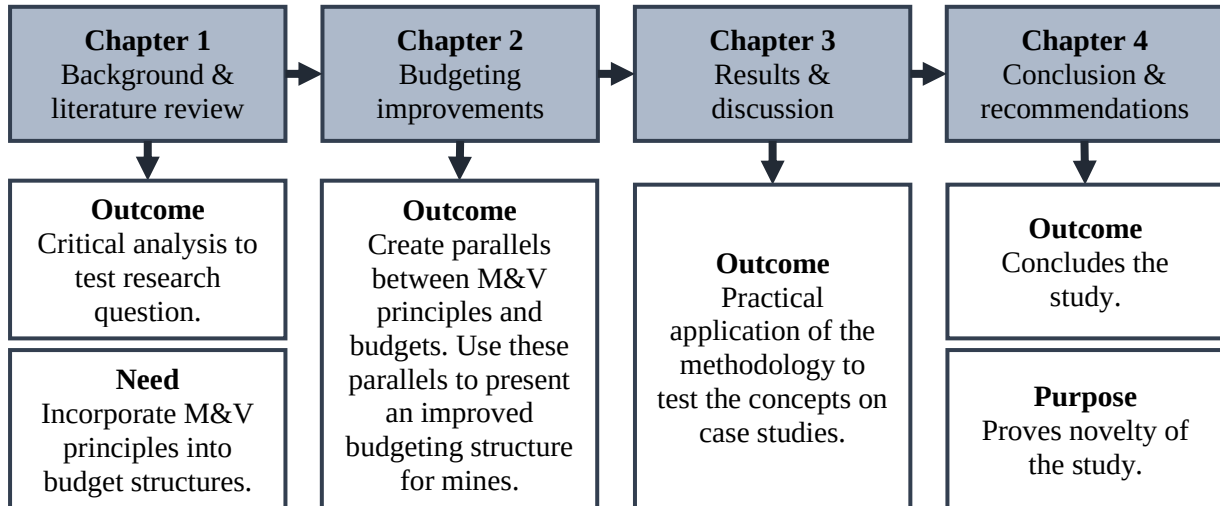


Figure 1-15: Outline of the document

The main focus of **Chapter 1** is to provide background to the study. This includes the discussion on how South African mines develop budgets. Special focus is given to the existing budgeting structure's limitations. This chapter further expands on the application of well-established M&V principles and how these principles account for the identified limitations.

This chapter also contains a critical literature review identifying the need to incorporate well-established M&V principles into the budgeting structures of mines. From the need, a few objectives are listed to assist with the application. The novel contributions of this study are also provided, which summarise the identified problems and suggested solutions.

Chapter 2 is defined as the methodology chapter, which contains all the relevant information and tools required for the application of M&V principles in mine budgets. This chapter firstly focusses on the parallels between the operational budgeting structure and the M&V principles. From the parallels six areas are identified (1) *measurement boundary*, (2) *measurement resolution*, (3) *data quality*, (4) *routine adjustments*, (5) *baseline development* and (6) *assurance*.

These six areas are addressed and an improved structure for mine budgeting is developed (a new budgeting structure). The new structure is also verified in Chapter 2 by evaluating the new structure to the research question used to evaluate the literature references against in Chapter 1. The new structure successfully answered the related questions which verifies the new structure for the use on mines.

Chapter 3 provides the validation of the improved budgeting structure on a gold mine complex case study. The successful application of the improved budgeting structure on the case study validates the

structure which is further authenticated by comparing the improved (new) budgeting results with the original (old) budgeting results. The application process and the results of the improved budgeting structure are also discussed on seven additional case studies.

The final chapter, **Chapter 4**, concludes the study by providing a summary of all the findings and how the stated objectives are met. Recommendations for future work is finally provided, which can assist in and contribute to additional studies in the field.

2 DEVELOPMENT OF AN IMPROVED BUDGETING STRUCTURE

2.1 PREAMBLE

Chapter 1 highlighted the limitations of the current budgeting structures used by South African mines. A need was identified to improve the current budgeting structures by incorporating well-established M&V principles into the structures. The objective of this chapter (Chapter 2) is, therefore 1) to assess whether the M&V principles can be used to improve the existing budgeting structures and 2) to incorporate these principles into the structures.

Ultimately, a new structure for budgeting should be delivered in this chapter that uses parallels (analogies) between the existing budgeting structures and the M&V principles. These parallels are based on the similarities between the two fields and should be created in such a manner to address the shortcomings identified in the budgets. These parallels are also a critical step for the development of the new budgeting structure (the methodology).

Chapter 2, therefore, consists of two phases. The first phase is the development of the parallels which are required to enable the development of the new structure (phase 2). Both these phases are briefly discussed below.

1. **Creating parallels (phase 1):** in chapter 1, six principles for M&V and budgeting structures were presented. In this phase of Chapter 2 these principles will be used to identify how the shortcomings in the budgeting structure can be addressed. Examples of the application of each parallel is discussed. These parallels will then be used to develop a new structure for budgets in the next phase.
2. **Develop an improved structure (phase 2):** the parallels created in the previous phase are now used to develop an improved budgeting structure (structure). A rigid methodology along with practical examples are presented in this phase to ultimately deliver a structure that improves the existing budgeting structure. This structure can be adapted to other industries and used to develop improved budgets.

It is important to note that phase 1 is not part of the methodology to create budgets but rather a critical step required to allow for the development of the new structure (the methodology) that can be used to create budgets. Figure 2-1 illustrates the two phases described above where each phase can be observed as a single entity.

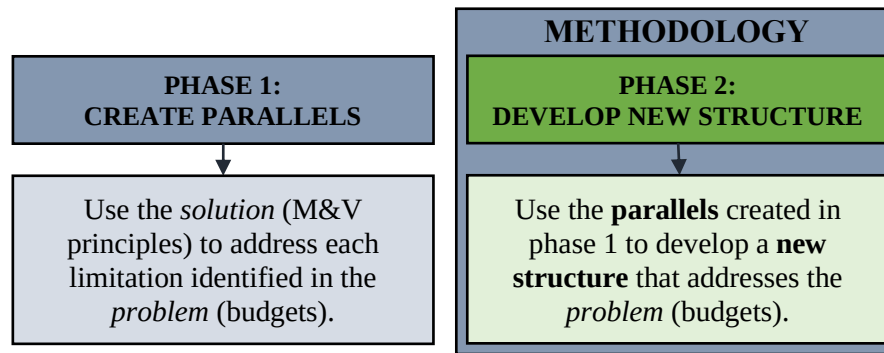


Figure 2-1: Outline of Chapter 2

In Figure 2-1 the *problem* refers to the budgeting structures currently used by mines in South Africa where the *solution* refers to the M&V principles that can be incorporated into the budgeting structures to improve the current budgets. It is also noted that phase 2 can only occur after phase 1 is successfully applied.

The methodology (phase 2) presented in Figure 2-1 is *authenticated* in Section 2.4 by assessing the new structure alongside the objectives set aside in Chapter 1. The critical analysis questions conducted on the relevant literature references are used to test whether the new structure applied M&V principles to the structure. This ultimately provides the foundation to *verify* and *validate* the developed structure by the application thereof on practical case studies (in Chapter 3).

2.2 PHASE 1: CREATE PARALLELS

2.2.1 DEVELOPMENT OF BUDGET-RELATED PRINCIPLES

This section presents the parallels between the *problem* and the *solution*, where the problem is the shortcomings in the mine budgeting structures discussed in Chapter 1 and the solution is the incorporation of the well-established M&V principles. The purpose of the parallels is to link the M&V principles to the identified shortcomings in the budgeting structure.

Ultimately, when a limitation identified in a budgeting step is addressed with an M&V principle the budgeting structure will be improved. Detailed parallels between the budgeting structures and the M&V principles are developed using a technique adapted from “*Application of accounting principles on energy-related reporting*” [42]. This is done to ensure that the well-established M&V principles can be reflected in budgets used by mines. The adapted methodology is presented in Figure 2-2.

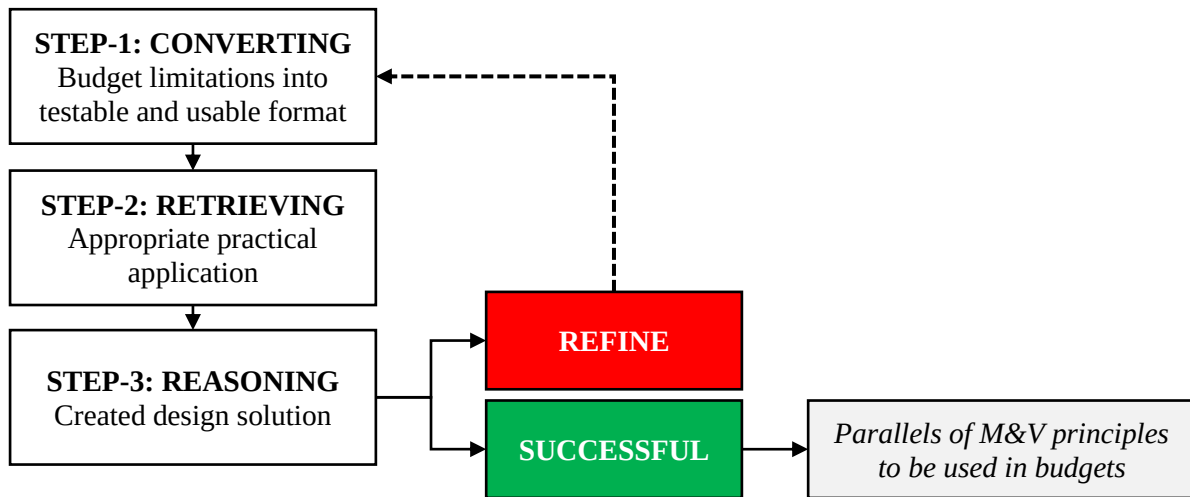


Figure 2-2: Parallel methodology

The adapted methodology presented in Figure 2-2 consists of three steps. These steps are:

- 1) **Converting** the limitations of the budgets into a testable and useful format by considering the M&V principles (create and describe the parallel).
- 2) **Retrieving** a practical application to test the developed parallels (case study based).
- 3) **Reasoning** whether the solution is viable or not.

If Step-3 in Figure 2-2 is unsuccessful, the solution should be refined, and a new parallel should be created (revert to Step-1). If Step-3 is considered successful, a relevant parallel is created, and the M&V solution can be adopted into the budgeting structure. A general discussion of each step is presented in the following paragraphs.

Step-1: During this step the limitations in the budgeting process are identified. The limitations are compared with a relevant M&V principle. The parallel is then created which addresses the budget-related limitations with the M&V principle (hypothesis).

Step-2: The hypothesis created in the first step is tested by applying it to a case study. The aim is to test whether the adapted principles will work or at least improve the existing structure.

Step-3: A decision is made on whether the parallel is successful or not. The decision is based on whether the parallel could successfully be applied to a budget-related example or not.

The above methodology is applied to the six budgeting limitations, as listed in Section 1.1. Each parallel is individually discussed according to the three steps illustrated in Figure 2-2. The outcome will be to establish how each of the budgeting limitations can be addressed by incorporating M&V principles.

2.2.2 PRACTICAL APPLICATION OF PARALLELS

PARALLEL 1: MEASUREMENT BOUNDARY

Step-1: Converting

Budgets are typically developed over a large boundary such as for the entire mine or for the whole shaft. This type of boundary is referred to as a whole facility boundary. The three M&V options provided in the IPMVP discusses two relevant boundaries, namely *component isolation* (which is synonymous with a small boundary) and *whole facility* (which is synonymous with a large boundary). It is common practice in M&V to firstly evaluate several factors, which include the availability of the data and the level of evaluation required, before deciding on the boundary.

It is noted, from previous M&V applications on mining facilities, that option A is usually used for evaluating an ESM, as discussed in Section 1.2. Using a component isolation boundary ensures that only the units directly effecting the components are considered. This is more ideal to evaluate the energy performance of an ESM. The energy consumption of the ESM is considered more specifically, as opposed to the energy consumption of the whole mine. This also allows for the energy management of each individual component as opposed to the energy management of the whole mine as a single entity.

Figure 2-3 illustrates how an M&V application compares with the budgeting's application when considering the measurement boundary. Typically, the budgeting structure considers high level boundaries where the M&V applications on mines typically consider isolated component boundaries.

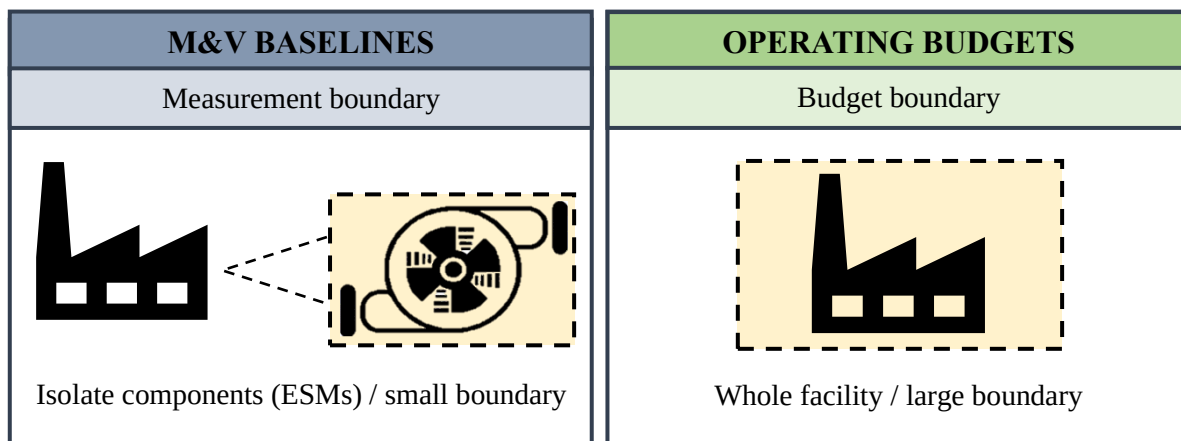


Figure 2-3: Measurement boundary parallel

When evaluating ESM performance (the energy performance of a component believed to deliver savings) on a whole facility level, the energy consumption of the ESM (or component) is recommended to be a minimum of 10% of the total facility's energy [52]. This is to ensure that the increase/decrease in energy due to the ESM can be quantified on such a high level. Due to a mine's complexity and large energy consumption needs, implementing ESMs larger than 10% of the facility's consumption is

improbable. This makes an isolated boundary a practical boundary to use when evaluating the performance of different components on a mine.

The first parallel between budgets and M&V applications will, therefore, be the boundary used when creating the budget/baseline. *The hypothesis of this parallel is that by creating budgets for smaller boundaries the energy movement of each component can be monitored which allows for the energy management of each component. It can furthermore be adjusted to permit for the final budget to be more relevant.*

The hypothesis is tested in the following step of the parallel methodology. The aim is to identify whether the isolation of each component in the budget will allow for the accurate evaluation of the energy movement. This includes the normal up and down movement of the operation's energy (also referred to as the *noise* of the operation, which is defined as the expected variance by the IPMVP [147]), allowing the *noise* that is seen in the energy usage to be directly linked to a specific component.

By developing a budget for each component (or at least for a smaller boundary than the entire mine or an entire shaft), measuring performance of projects will also be a more realistic task. This will also ensure that expected changes, such as the changes seen in production, are only allocated to the specific units that have a direct impact on production.

Step-2: Retrieving

The practical application of this parallel is done by comparing the evaluation of an ESM's performance on a typical mine using both a component isolation and a whole facility boundary for evaluation. By evaluating the performance of an ESM on both boundaries, a realistic view is provided of the level of detail included with both boundaries. The application will be demonstrated by means of an example.

Example on an isolated boundary (option A)

Suppose that Mine X implements an ESM on an underground dewatering pump. The normal energy consumption, also referred to as the baseline energy consumption associated with the period immediately before the ESM was implemented, of the dewatering pump is 31 600 kWh per day.

The ESM applied to the pump decreases the energy consumption of the pump to 28 100 kWh per day. A daily saving of 3 500 kWh is, therefore, achieved from the ESM on the pump. Figure 2-4 illustrates the energy consumption of the pump right before the implementation of the ESM and thereafter. The decrease in daily energy consumption is shown in Figure 2-4.

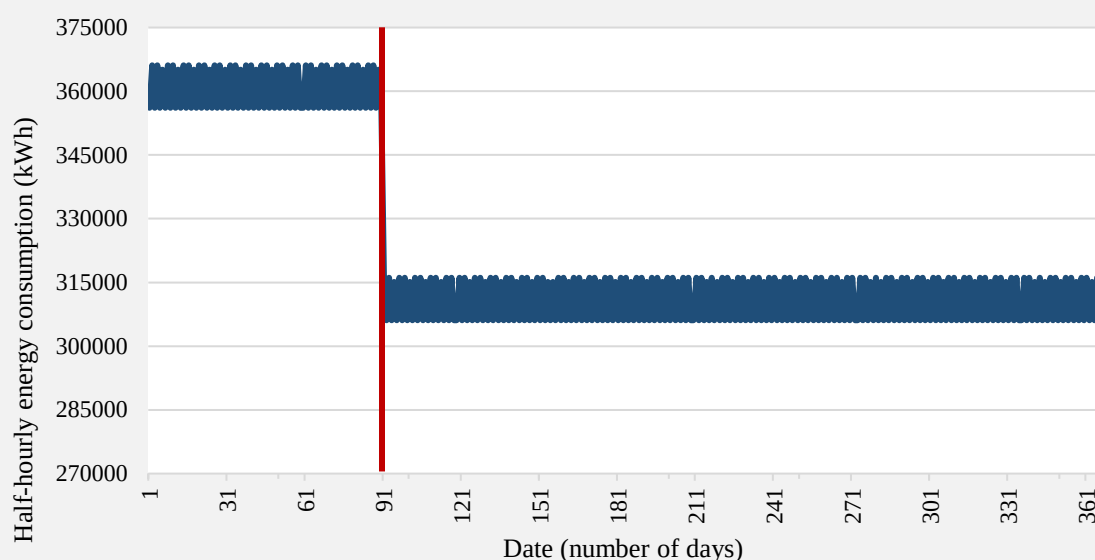


Figure 2-4: Energy consumption of a dewatering pump

The decrease in energy observed on day 91, as presented with the red line in Figure 2-4, indicates that the ESM achieved the planned savings. The advantages of evaluating the performance on a component isolation boundary (option A) ensures that all components on the mine can be monitored to ensure that the planned energy consumptions/savings are obtained (and also quantify the size of the savings).

The limitation of evaluating each individual component on the mine is that it can be a time-consuming exercise. However, the application process only needs to be done for one component and can thereafter be adapted for the various other components (given that the required metering is in place). The developed structure can then also be used *as is* for each new developed budget year-on-year. The energy management benefit obtained when evaluating each individual component is also a great advantage above developing a budget for the whole facility, as discussed in Appendix B.3.

Example on a whole facility boundary (option B)

It is assumed that Mine X consumes on average 196 523 000 kWh per day. The dewatering pump in Figure 2-4, therefore, consumes 0.16% of the total mine's energy consumption. Evaluating the energy saving on the whole facility of the mine will result in the performance of the pump getting lost in the noise of the operations of the mine. This becomes problematic when multiple pumps' performance is evaluated. Ultimately, this could mean that a larger percentage of the energy consumption will be inaccurately monitored.

Figure 2-5 illustrates the energy consumption of the mine with the installation of the ESM on the pump indicated with the red line.

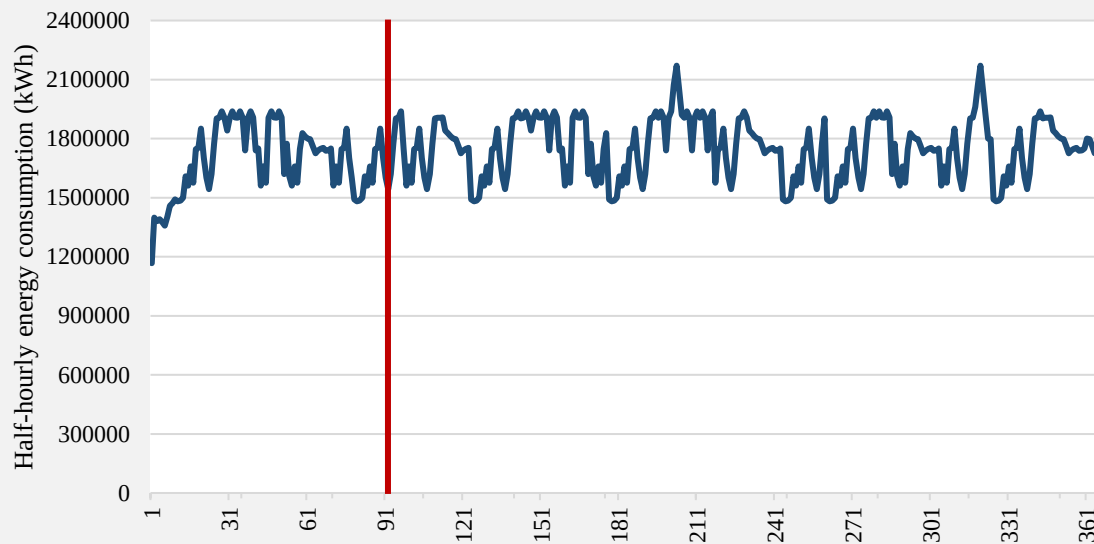


Figure 2-5: Energy consumption of the mine (whole facility)

From Figure 2-5 the performance of the single pump cannot be seen as clearly as in Figure 2-4. This can complicate the performance evaluation of the ESM. Ultimately, it is seen that the evaluation of the performance on a high-level boundary can indicate how the total mine is performing as opposed to how individual components are performing.

This can be problematic when used in a budget where the energy performance of the mine will be monitored for each component. The budget would, therefore, not be able to justify if ESMs occurred as planned. Increases in the energy consumption of the mine can also not be addressed to any component. Ultimately, the mine will be over (or under) budget without knowledge on the reasons associated for the savings (losses).

This, in turn, can influence future budgets when this historical energy consumption is used to plan for the next financial year. This example illustrated that the development of a budget on a whole facility is limited, which affects the energy management purposes of the budget and also the future planning of energy consumptions of the mine.

Step-3: Reasoning

The issue with creating budgets on a whole facility (for the whole mine as a single entity) was presented in the previous step. It was seen that, when evaluating the energy performance of single components, the expected increases/decreases can easily be observed. This allows for the energy management of the component and the quantification of the savings/losses.

It is further seen that when the mine is evaluated as a whole facility, small changes on individual components are not seen as clearly as when evaluating each component separately. This restricts the energy management of the individual components and the quantification of the savings/losses of that component. The adaption of the boundary (from a whole facility as with the current budgeting structures

to an isolated component boundary) will therefore address the first need for the study listed in Section 1.4.

Table 2-1 revisits the first need for the study and discusses how the parallel addressed the identified need for the study.

Table 2-1: First need for the study

Need for the study	Addressed by the parallel?
<i>Adapting the boundaries for the budget</i>	Yes. This parallel identified that the current boundary (whole facility) has limitations and a new boundary (isolated component) is suggested for the development of budgets for South African mines.

It can, therefore, be argued that the parallel is correct/successful, and that the application illustrates the effects of evaluating the budget on a component level as opposed to a whole facility level. This adaption of the boundary will allow the budget to be more representative of the energy consumption of various components which enables energy management and ultimately improves the forecasts of the budget.

PARALLEL 2: MEASUREMENT RESOLUTION

Step-1: Converting

From the questionnaires on the South African mines it was noted that budgets are typically created in either annually, quarterly or monthly resolutions which is considered a low resolution group [52]. This low-resolution budget acts as the overall reference point for the mine. However, when evaluating the performance of an ESM, using higher resolutions (such as weekly, daily and hourly profiles) is also considered. M&V methods allows for higher resolutions to ensure that the precise movement of energy can be evaluated.

The precise movement of energy is extremely important when the energy consumption shifts between different TOU periods. Consuming energy in off-peak TOU periods is less costly than consuming energy in peak TOU periods. Many ESMs on mines are specifically focused around the TOU profiles and are referred to as load shifting ESMs, as discussed in Section 1.2. It is important to capture these projects in the budget, because it has a large effect on the total consumption of the mine which will impact the budget significantly if neglected. The vast amount of load shifting that ESMs present on South African mines encourages the evaluation of the mine's energy performance on a higher resolution, such as half-hourly, instead of a low resolution (monthly or annually).

The critical analysis completed in Chapter 1 on budgeting structures (Section 1.1) and M&V applications on mines (Section 1.2) was used to compare the resolutions used by both fields. Figure 2-6 illustrates what data the M&V baselines used compared with what data the budgets used, both on the application of a mine.

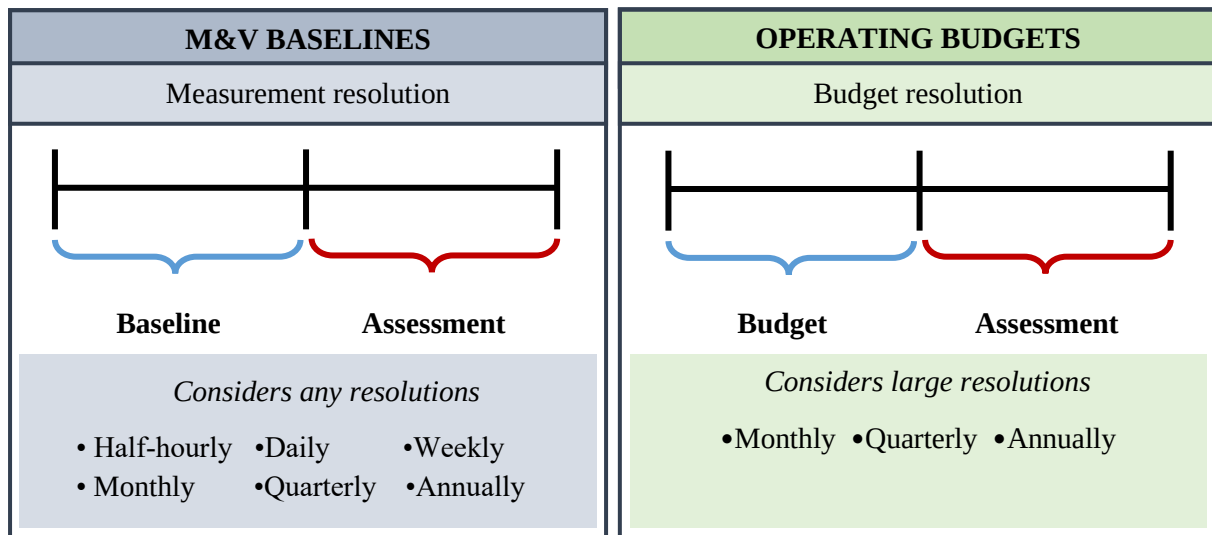


Figure 2-6: Measurement resolution parallel

The second parallel between budgets and M&V applications will, as depicted in Figure 2-6, be between in the resolution to be considered when creating the baseline/budget. *The hypothesis of this parallel is that by creating budgets in higher resolutions, the energy movement can be considered more precisely to allow for the evaluation of the impact of load shifting ESMs as well. Including the impact of load shifting ESMs is believed to increase the accuracy of the costing budget.*

The hypothesis is tested in the following step of the parallel methodology. The aim is to identify whether the forecasted costs calculated on a half-hourly profile will be more accurate compared with the costs calculated on a monthly resolution.

Step-2: Retrieving

The practical application of this parallel is done by comparing the energy costing budget as calculated using half-hourly resolution versus when calculated using only a month total resolution. The example will be illustrated on a one-month resolution only considering the energy consumption of a single compressor located on Shaft 1 of Mine X.

Example of the compressor ring budget as calculated in half-hourly resolutions

Figure 2-7 provides an example of a compressor's half-hourly energy consumption for a normal weekday in **January 2018** (the baseline) and **January 2019** (the assessment period). A normal weekday is considered a typical weekday (Monday to Friday) where the energy consumption does not change due to the occurrence of a public holiday or an unplanned event. The blue striped line represents the compressor baseline where the green solid line represents the compressor's actual energy consumption over a 24-hour period.

The baseline represents the previous year's actual energy consumption. Changes in operations occurred (due to the effect of ESMs) which affected the actual energy consumption. The change observed between the two normal weekday profiles can, therefore, be allocated to the effect of the ESM. The different coloured blocks (green, yellow and red) indicate the different TOU periods (off-peak, standard and peak) for a winter weekday profile. The Eskom time periods for summer and winter months are also discussed in Section 1.1.

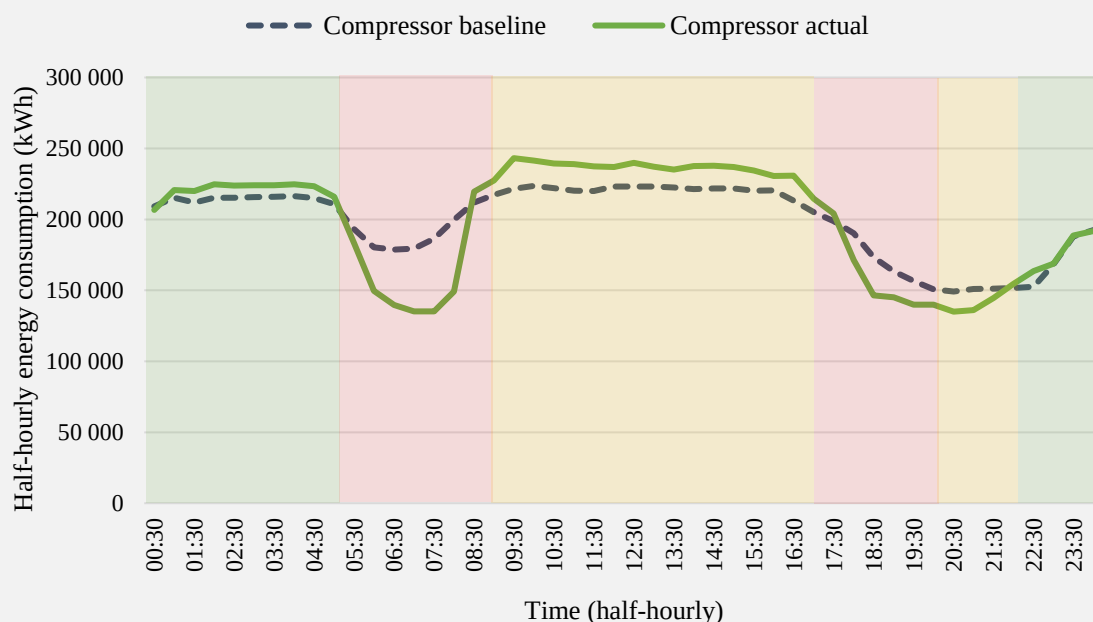


Figure 2-7: Average weekday profile for a compressor

From Figure 2-7 it is seen that during the off-peak and standard Eskom TOU periods (indicated by the transparent green and yellow blocks, respectively), the energy consumption is more than the baseline energy consumption. During the peak Eskom TOU periods, however, the actual energy consumption is much lower than the baseline energy consumption. Table 2-2 provides the total energy consumption and the associated energy cost for the peak, off-peak and standard TOU profiles, where the TOU Eskom costs are used for a Megaflex >600km line for winter month weekdays as listed:

Off-peak	R0.73 per unit of energy (kWh)
Standard	R1.22 per unit of energy (kWh)
Peak	R3.71 per unit of energy (kWh)

Table 2-2: Energy and cost savings on a compressor

TOU period	Energy baseline (kWh)	Energy actual (kWh)	Energy saving (kWh)	Cost baseline (R)	Cost actual (R)	Cost saving (R)
Off-peak	321 589	325 356	-3 767	R234 020	R236 761	-R2 741
Standard	407 004	423 303	-16 299	R594 126	R610 679	-R16 553
Peak	226 274	206 218	20 056	R652 337	R574 905	R77 432
Total	954 867	954 877	-10	R1 480 484	R1 422 346	R58 138

An average weekday cost saving of R58 138 is expected on the compressor ring in evaluation, as depicted in Table 2-2. The evaluation of the savings on a half-hourly resolution allowed for the allocation of the TOU savings. The same methodology applies for Saturday and Sunday profiles. If this is done over a one-month period, the estimated cost saving on the compressor in the example is calculated as over R1-million.

Example of the compressor ring budget as calculated in monthly resolution

The same compressor can be evaluated on a monthly resolution. The previous year's actual energy consumption and actual cost (plus increases in tariffs) are used for the baseline example. Figure 2-8 illustrates the energy consumption of the compressor for **January 2018** (which acts as the baseline month in this example) versus the energy consumption of the compressor for **January 2019** (which is the assessment period's actual energy in this example).

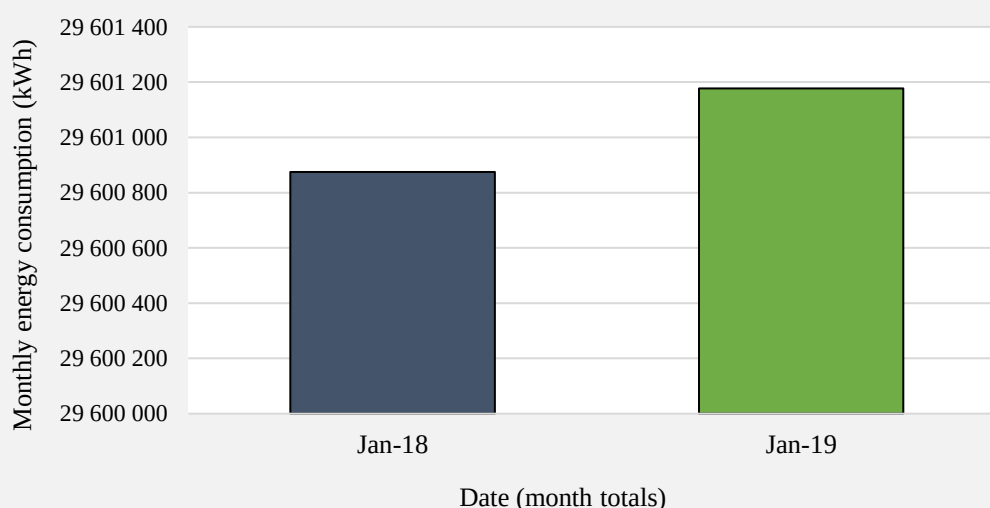


Figure 2-8: Monthly energy consumption on a compressor

If it is assumed that the production did not change from Jan-18 to Jan-19, and Figure 2-8 is used to evaluate the performance of the energy, it will immediately assume that the compressor underperformed in the assessment period (January 2019). The associated cost for the monthly energy consumption is calculated with the average January 2019 Eskom invoice's costing ratio (R/kWh) as

discussed in detail in Section 1.3. The R/kWh for R1.55 results in a cost saving of negative (-) R500 for January 2019. If the assumption is made that the mine has ten compressors, the overall effect on the budgets for compressors adds up to R5-million (in this example). Ultimately, the budget for January 2019 will be out by at least R5-million (on the compressors alone).

Step-3: Reasoning

Creating budgets on a low resolution, such as monthly totals, neglects the TOU impact on the cost savings. The first example illustrated that by including the TOU profiles, a R1-million cost saving was realised over a one-month period, even though the compressor consumed more energy in the assessment period compared with the baseline period. In the second example, the same compressor's savings, calculated on a monthly resolution, showed the same negative energy saving as in the first example, but furthermore, could not show any cost savings.

By creating budgets on a high resolution, such as half-hourly profiles, more detailed forecasts can be obtained which also allows for the correct quantification of the budgeting costs. The increase in resolutions of the budget (from monthly to half-hourly) therefore addresses the need for the study as listed in Section 1.4. Table 2-3 revisits the second need for the study and discusses how this parallel addresses the need.

Table 2-3: Second need for the study

Need for the study	Addressed by the parallel?
<i>Ensure that consistent and relevant data resolutions are used</i>	Yes. This parallel discussed how the low resolutions (monthly) budgets neglect small changes in operations, especially the changes associated with the TOU periods. It was seen, through the examples, that the negligence of these changes can have a significant effect on the final budget. This parallel therefore suggests considering higher resolutions (such as half-hourly resolutions) as opposed to small resolutions for the budget.

From this table, it can be concluded that the hypothesis of the second parallel is thus correct/successful, and the suggestion is to include the M&V's approach for resolution selection into the budgeting structures of mines.

PARALLEL 3: DATA QUALITY

Step-1: Converting

The data used for budgets or M&V baselines are ultimately used for perspective of what is happening on the mine. Using inaccurate data can cause the perception of what is happening on the mine to be incorrect. Since many significant decisions are based on the budgets/baselines, it is important to ensure that the data is accurate. The data used for mine budgets are usually obtained from calibrated meters and compared to Eskom invoices which gives the surety of the data. However, it is uncommon practice

for the mines to further evaluate the data for any abnormal activities, as observed in the critical analysis of the questionnaires on South African mines discussed in Section 1.1.

Abnormal activities include the occurrences of unplanned events, such as a national lockdown implemented due to a pandemic (as experienced world-wide in 2020) [150] or other, smaller but also significant events such as natural disasters (fires, floods, etc.) strike actions, fatalities, public holidays and unplanned maintenance on mine equipment [3]. These types of events greatly impact the *normal* energy consumption of the mine [41], [151].

When the energy savings of an ESM are calculated using an M&V approach, these types of events are usually eliminated/adjusted for in the baseline dataset. The baseline should, ultimately, be a true representation of what the expected normal conditions are. The adjustment for these unplanned events is therefore crucial in an M&V application. These adjustments are often neglected when budgets are developed since the previous year's actual data is used as is. This would cause the abnormal events to be factored into the budget, and effectively expecting the same abnormal event to occur in the assessment period. This would not be an accurate assumption, and such events should not be factored into the new budget.

The third parallel between budgets and M&V applications, is therefore based on the evaluation of the historical data to ensure that all unplanned events are accounted for. Figure 2-9 illustrates this parallel.

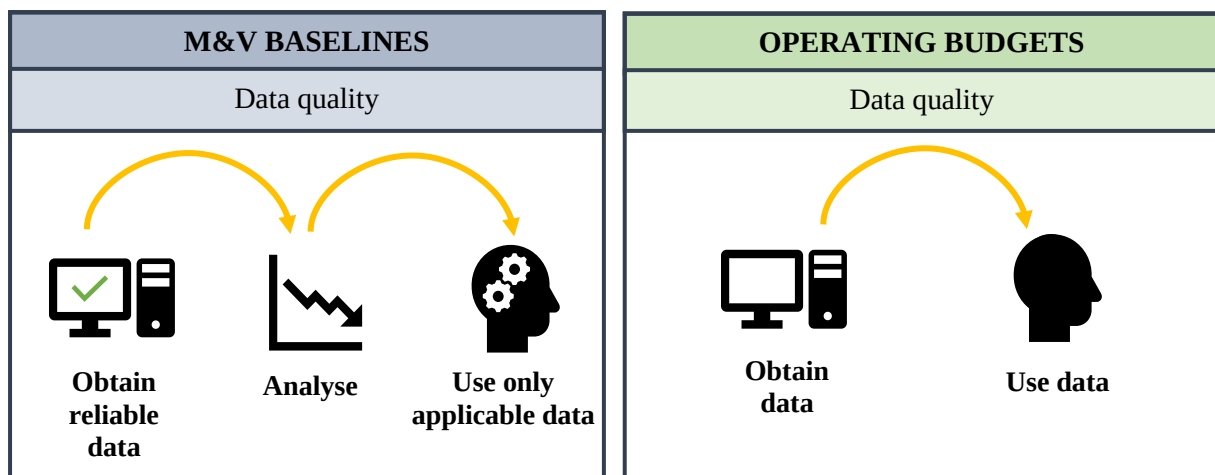


Figure 2-9: Data quality parallel

The aim of this parallel is to ensure that the data used for the budgets are evaluated and all abnormal activities are excluded from the dataset. *The hypothesis is thus, that by ensuring the data is a good representation of the normal activities on the mine, the final budget will also be a good forecast of the normal activities of the mine.* This hypothesis is tested in the next step of the parallel methodology.

Step-2: Retrieving

To test the hypothesis stated in the previous step of the parallel methodology, two budgets will be created for a specific shaft (on a large boundary for the purpose of this example). The budgets are created for a full 12-month period, where the previous twelve months' actual energy data is considered as the baseline dataset. During the baseline period the following three events occurred on Shaft A:

- 1) In month 2, a fire occurred on Shaft A which caused an increase in ventilation and a decrease in all other commodity activities.
- 2) In month 9 a fatality occurred which caused all operations to stop for a duration of three days.
- 3) In months 11 and 12, the shaft closed down and halted all production outputs due to a national strike action.

The daily energy usage for 2018 for Shaft A is illustrated in Figure 2-10, where the impact of all three of these events is noticeable (even on such a large boundary).

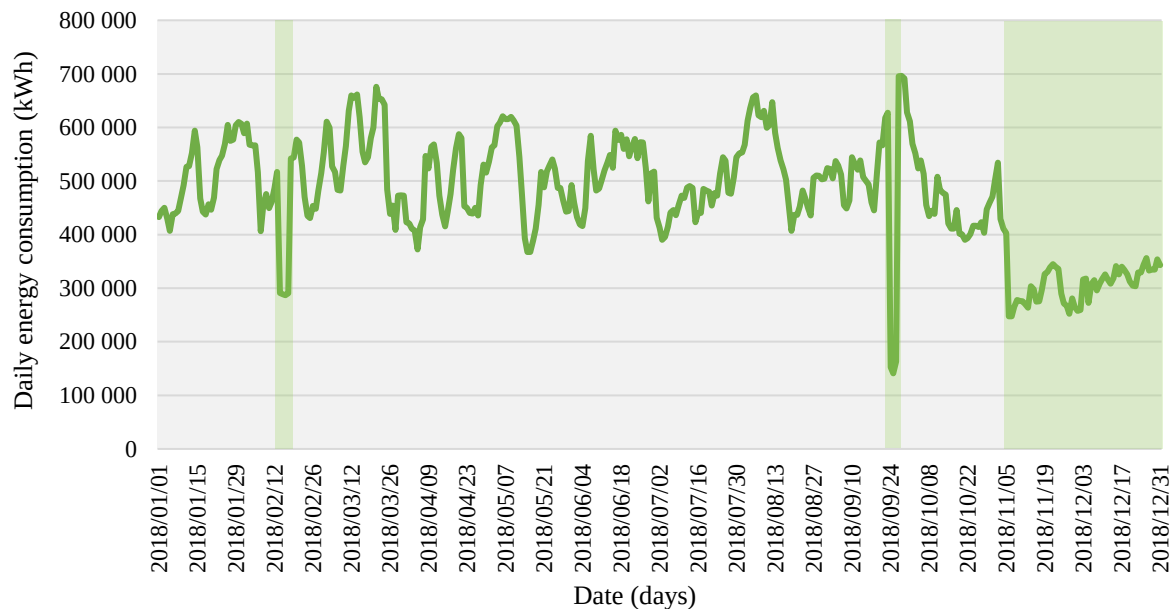


Figure 2-10: Daily energy consumption (including unplanned events)

The decreases in energy consumption due to the unplanned events that occurred in 2018 will result in the total energy consumption for each month to be less than what the actual energy would have been if these events did not take place. The influence of these events is depicted in the two examples below.

Example of Shaft A's budget on data that includes the unplanned events of 2018

The data as displayed in Figure 2-10 are used to calculate the total monthly energy consumption of Shaft A. The total monthly energy consumption of 2018 for Shaft A is used for the budget for 2019. It is assumed that there are no planned savings or growth projects for 2019 for Shaft A. The budget for Shaft A is thus equal to 2018's actual energy consumption, as depicted in Equation 2-1:

$$2019 \text{ Energy Budget (kWh)} = 2018 \text{ Actual Energy (kWh)}$$

Equation 2-1

The energy budget, as calculated using Equation 2-1, can now be used to assess the energy performance of Shaft A during the assessment period (2019). Figure 2-11 illustrates the 2019 Budget as well as the 2019 actual energy consumption.

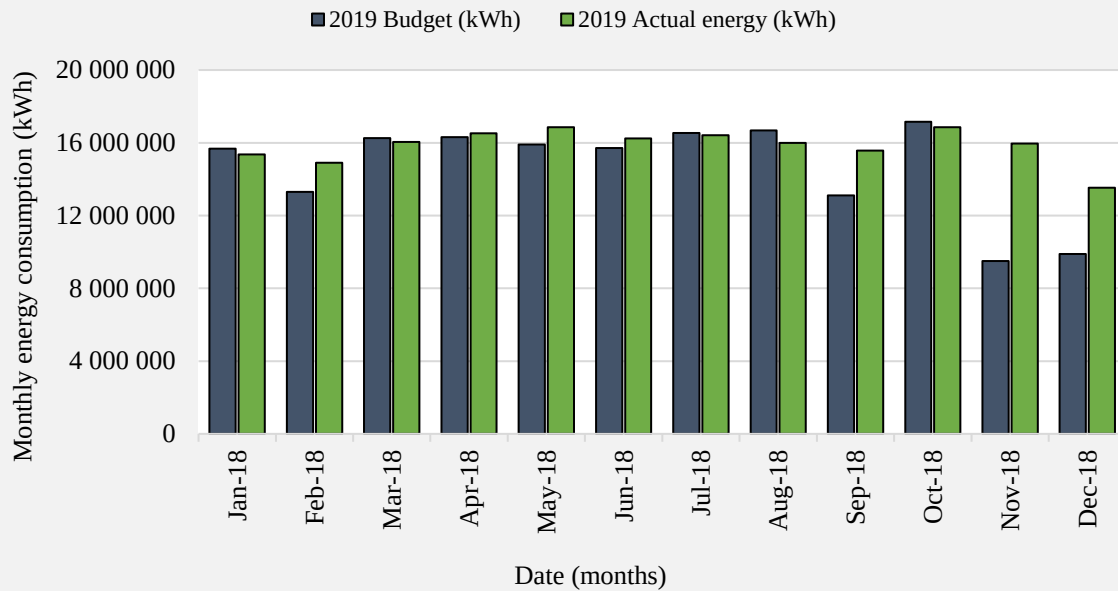


Figure 2-11: Monthly energy consumption (including unplanned events)

From Figure 2-11 it can be seen that during the months of the unplanned events (February, September, November and December) the actual energy consumption of 2019 exceeded the budgeted energy consumption. The inclusion of the unplanned events in the dataset ensured that the evaluation of the energy over these months is unfair and not a true representation of the real events.

Example of Shaft A's budget on data that exclude the unplanned events of 2018

A more realistic representation of the normal operations of Shaft A would be to exclude the effect of the unplanned events from the dataset before using the data to compile a budget. For the second example, the budget will be recreated, with the same methodology used in the above example (and presented by Equation 2-1), but the data will be evaluated, and the abnormal events removed before the budget is created.

To exclude the unplanned events from the dataset, the event itself is evaluated. For all three events it is assumed that directly before and directly after the event, the energy consumption was normal. Thus, the data is evaluated in half-hourly resolutions for each event and replaced with the corresponding half-hour's energy directly before and directly after the event. For Saturdays and Sundays, the previous and the next Saturday and Sunday averages are used.

Figure 2-12 illustrates the true energy consumption (with the solid green line) for 2018 during the fire in February 2018. The green striped line in Figure 2-12 represents the average energy consumption directly before and directly after the fire.

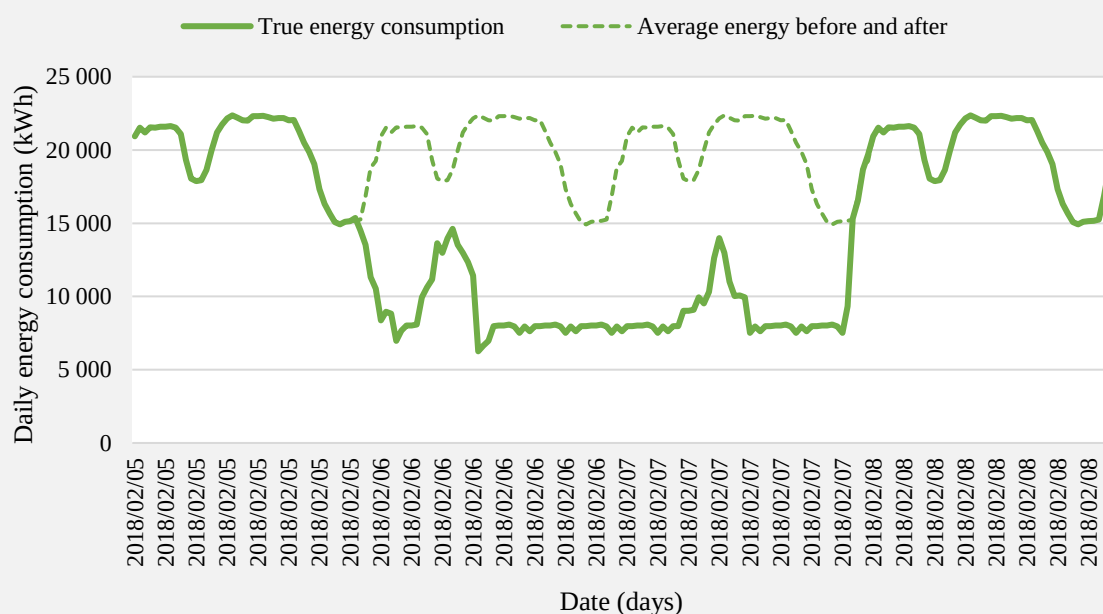


Figure 2-12: Daily energy consumption (excluding unplanned events)

For this example, instead of including the actual fire energy consumption (represented by the striped green line in Figure 2-12) the average consumption before and after the fire will be used to substitute the true energy consumption. Therefore, when calculating the total energy consumption on the mine for February 2018, the energy consumption will be 15.1 GWh instead of 13.9 GWh. This can be done for both the fatality and the strike events.

Figure 2-13 thus demonstrates the budget as calculated in the previous example (unplanned events not removed), the budget calculated in this example (where the effects of the fire, fatality and strike are removed), and the actual 2019 energy consumption.

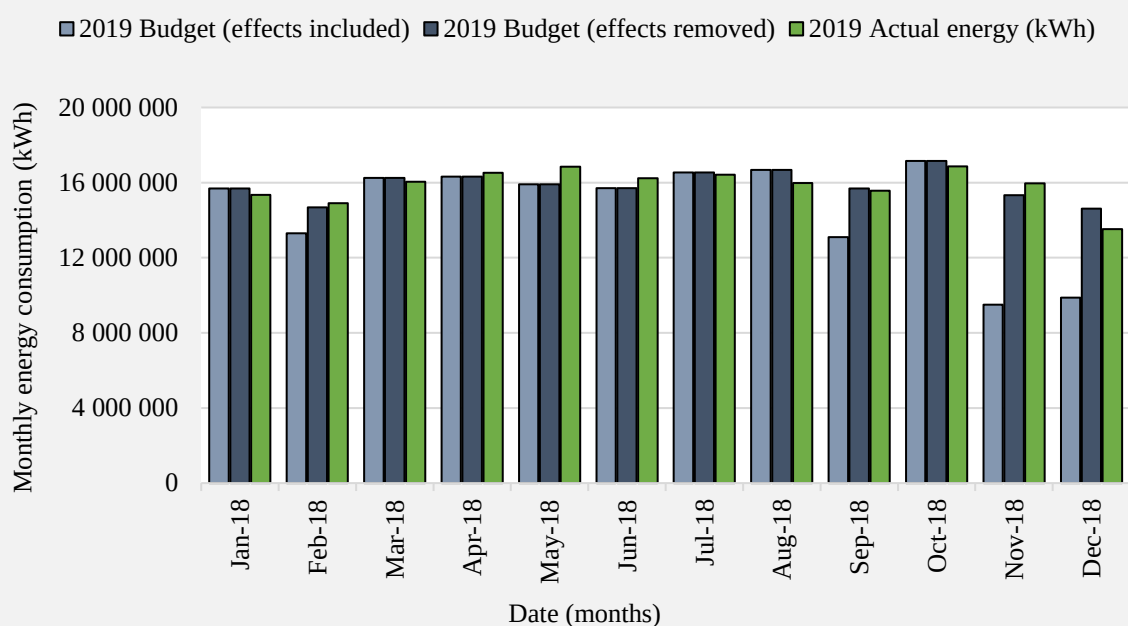


Figure 2-13: Monthly energy consumption (excluding unplanned events)

In Figure 2-13 the budget calculated with the data where the effects of the events are removed correlates much better with the actual 2019 data.

Step-3: Reasoning

By excluding the effects of unplanned events in the dataset used to create the budgets for 2019, a more accurate representation of the true events could be seen. This, along with the removal of outliers and missing data, therefore, addresses the third need for the study as listed in Section 1.4. Table 2-4 revisits this need for the study and discusses how this parallel addresses the need.

Table 2-4: Third need for the study

Need for the study	Addressed by the parallel?
Evaluating all data for accuracy	Yes. The current mine budgets evaluated the data for missing data and outliers, which already improves the accuracy of the dataset. However, M&V applications also consider the effect of unplanned events, such as a fire, in the baseline period. The example discussed how the accuracy of the forecasts of the budgets can be improved by including this additional step in the budgeting structure of mines.

From this table, it can be concluded that the hypothesis of the third parallel is, therefore, tested as true. It can, therefore, be assumed that the data used for budgets should first be evaluated to ensure that no unplanned events bias the normal operations of the mine. A method for adjusting for such events should then be used when compiling the budget.

PARALLEL 4: ROUTINE ADJUSTMENTS

Step-1: Converting

Routine adjustments are factors expected to change routinely during the assessment period such as weather or production. From the questionnaires completed by the eight South African mines (as discussed in Section 1.1) it was noted that production is the main routine adjustment taken into consideration, sometimes followed by savings¹ and growth projects. None of the mines that participated in the questionnaires considered any other effects. Furthermore, these effects are merely assumed or calculated using simple or outdated methods [19], [152].

For M&V applications, all possible effects on the ESM are monitored. This includes a vast number of variables, which are typically not included when creating budgets. These variables include temperature changes, changes in the number of active crews (employees) and the depth of mine. The effects of these variables are also mathematically calculated using viable modelling methods where the modelling parameters are similarly evaluated to ensure that the effects adjusted for are relevant. Figure 2-14 illustrates this fourth parallel between baselines and budgets.

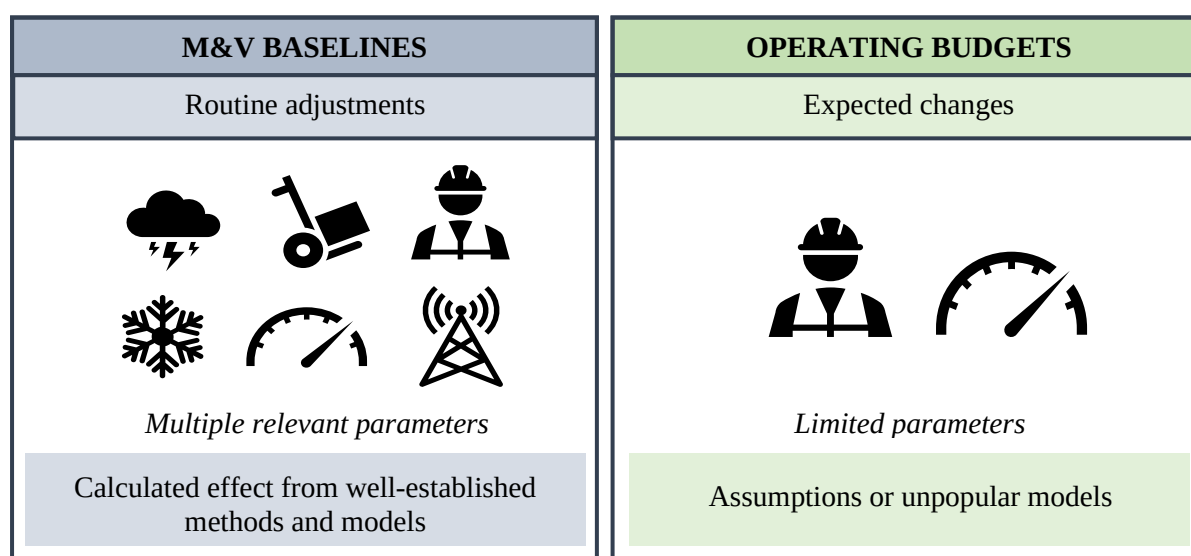


Figure 2-14: Routine adjustments parallel

The difference between the method of calculating the expected changes and the number of expected changes to consider highlights the fourth parallel (routine adjustments). *The hypothesis is that by accurately calculating the effect of expected changes (and including the most relevant and major expected changes) the budget will be more accurate.* This hypothesis is tested in the next step of the

¹ These savings projects refer to the planned savings projects for the upcoming financial year and should therefore be accounted for when creating budgets.

parallel methodology. The hypothesis is also broken up into two sections, the first to address the types of routine adjustments to consider, and the second, the methods used to quantify the effects.

Step-2: Retrieving

The hypothesis is tested a) by identifying the relevant variables (temperature, number of employees, production, etc.) to consider and b) by evaluating the methods used by M&V and by budgets to quantify the effect of these principles. The examples are discussed on the applications of compressors only. Similar principles will apply on the other commodities as well.

a) Relevant variables

The various relevant variables on mines are discussed in Section 1.3 (refer to Figure 1-5). It was shown that some of the variables have better correlations to the energy consumption of the mine. Correlations (R^2 -values) higher than 0.50 were considered a good enough correlation to include the variable in the forecasting of the energy for the mine.

Good enough correlations were observed between *production*, *number of employees* and the *depth of the mine* with the *energy consumption of compressors*. This section of the parallel description will, therefore, only assess the effect of one variable (production) to illustrate what the impact can be if the variable is included as opposed to the impact when the variable is neglected. Similar principles will apply to the remaining variables as well.

Example of how the budget can be impacted by including the effect of production changes

For this example, the historical energy consumption and production over a historic 12-month period (January 2018 to December 2018) are considered for the compressor commodity of Mine X. This data is then used within Equation 1-1 to calculate the energy intensity for the compressors. Thereafter, the energy intensity is used with the forecasted production figures for the assessment period (January 2019 to December 2019).

Figure 2-15 illustrates the total monthly energy consumption (in kWh) and the total monthly production (as the tonnes hoisted) for Mine X from January to December 2018. The red line in Figure 2-15 also shows the production forecast (the forecasted tonnes hoisted) for January to December 2019. The aim of the forecasted production line in this figure is to illustrate the expected change from 2018 to 2019 in production.

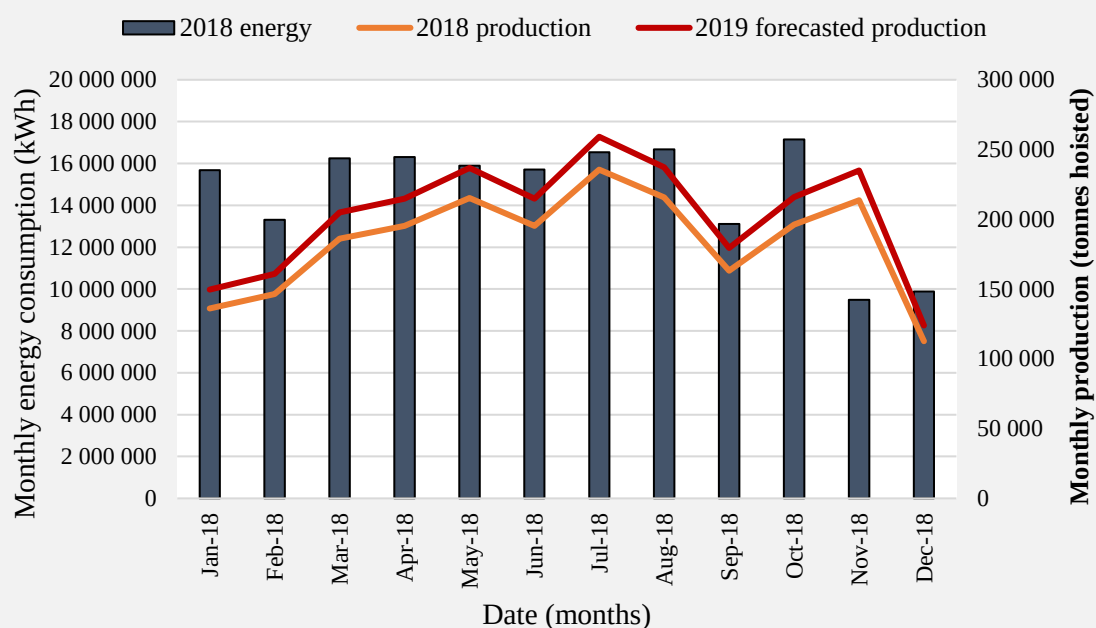


Figure 2-15: Monthly energy and production (2018 with 2019 forecasts)

Over the 12-month period (2018) the average monthly energy consumption was 14 667 750 kWh and the average monthly production was 184 138 tonnes hoisted. The specific energy consumption (energy intensity) for 2018 is therefore 79.6 kWh/t. This energy intensity figure can now be used with the production forecast figures for 2019 to estimate what the energy consumption for 2019 would be for Mine X. The forecast energy consumption for 2019 is illustrated in Figure 2-16, alongside the 2018 energy consumption.

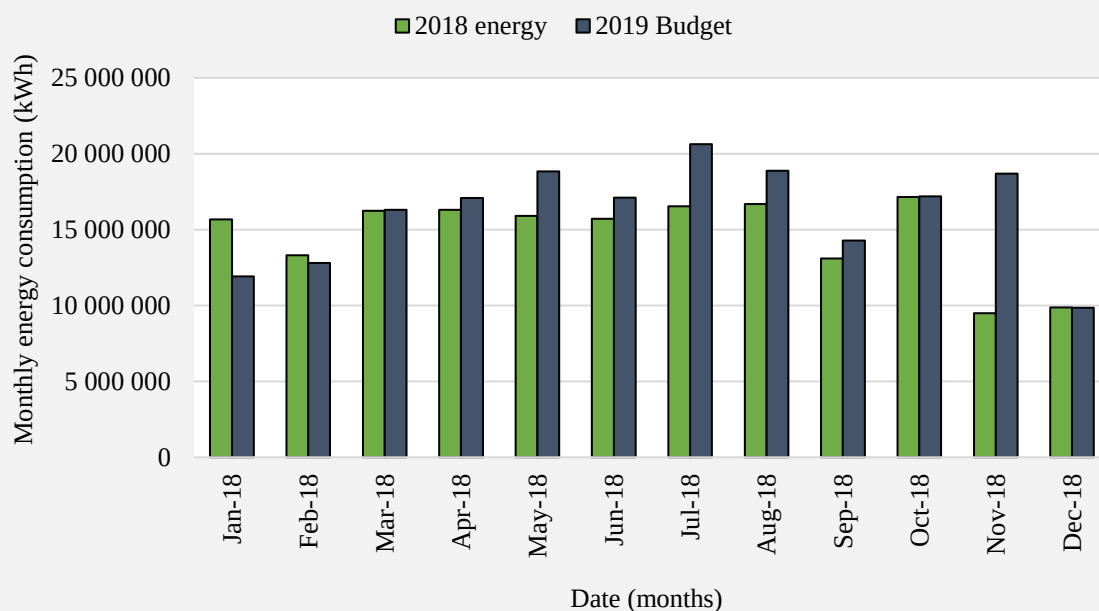


Figure 2-16: Forecast energy consumption (2019 budget)

From Figure 2-16, it is observed that the predicted energy consumption increased when compared with 2018's energy consumption. This is due to the change in production calculated with the energy intensity model. The total energy consumption of the compressor commodity increased by 6.3% from 2018 to 2019 due to changes in production.

Example of how the budget can be impacted by excluding the effect of production changes

If the production changes discussed in the example above were neglected, the 6.3% calculated change in the energy consumption of the compressors will be neglected. This will directly impact the compressor's budget by 6.3%. Since the compressors are one of the largest commodities on a mine (typically consumes about 30% of the total mine's energy) [32], a 6.3% change in energy observed by the compressors can result in a significant change on the whole budget of the mine.

The examples discussed above illustrated the importance of including all the relevant variables for each commodity when predicting the future energy consumption. The negligence of any of these variables can impact the energy consumption forecasts by the budgets significantly.

b) Quantification of relevant variables

After the relevant variables are identified, the effect of these variables needs to be quantified. Budgets typically use an energy intensity model (as applied in the example above as well). M&V applications on mines usually consider multiple other models alongside the energy intensity model to ultimately identify the most suitable model for the forecast.

To test the hypothesis, the effect of production will be calculated using an energy intensity model (first example and also applied in the examples above) and also by considering multiple other models typically considered in M&V practice (second example). To illustrate the relevance of a variable on the energy consumption, the effects of changes in production will be considered in an example. Similar principles will apply to other routine adjustment effects as well.

Example of how the current budgeting structures account for changes in production

The first example discussed above (under the category *relevant variables*) illustrated how an energy intensity model was used to predict the energy changes observed due to production. Figure 2-17 illustrates the predicted energy consumption for 2019 (with the energy intensity model), along with the actual 2019 energy consumption for the compressors.

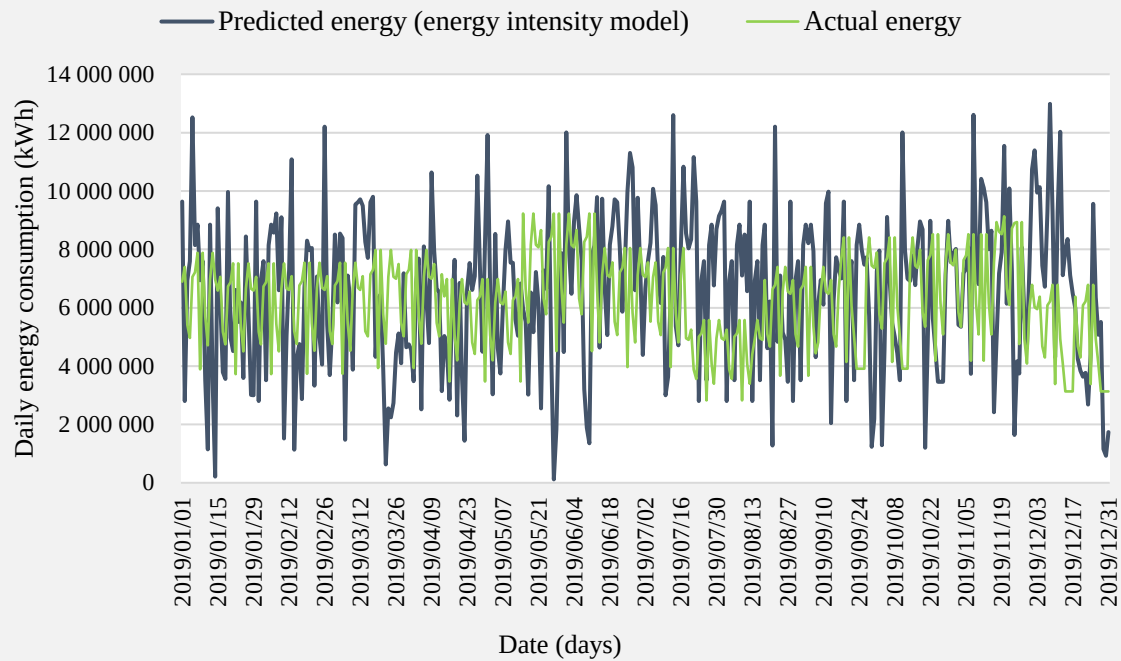


Figure 2-17: Actual and predicted energy per day

From Figure 2-17, it can be observed that an offset between the predicted and the actual energy consumption exists. The actual and forecasted values are compared and a 53% absolute average energy (AAE) are observed, with a R^2 and CV(RMSE) value of 0.16 and 42%, respectively. A CV(RMSE) percentage value smaller than 15% is desired [52], R^2 value higher than 0.75 [40] and an AAE percentage value lower than 5% [27] is desired. The calculations of these variables are discussed in Section 1.2 as well. Ultimately, it is observed that the forecast energy consumption is not considered a good enough forecast.

Example of how M&V applications account for changes in production

When the effect of routine adjustments is calculated for M&V applications, various options are considered before deciding on the final method to use. The aim is to identify the option that will be most fitting to the data by evaluating and comparing the CV(RMSE), R^2 and AAE values.

For this example, the same data will be used to evaluate the effect of the production changes from 2018 to 2019, but instead of assuming that energy intensity is the most suitable solution, various modelling techniques will be compared to identify the model that fits the data the best.

To illustrate this example, the following four models will be considered for evaluation:

- 1) Energy intensity;
- 2) Linear regression model;
- 3) Power model; and

4) Polynomial model.

The energy intensity model is already covered in the previous example, and the results will be used for this example. The linear regression model, the power model and the polynomial models are demonstrated.

$$\text{Linear regression} \quad y = mx + C \quad (2-6)$$

$$\text{Power:} \quad y = mx^C \quad (2-7)$$

$$\text{Polynomial (2nd degree):} \quad y = mx + mx^2 + C \quad (2-8)$$

where m and C are constant factors, y is the energy (in kWh) and x is the production (in tonnes hoisted). The historical energy and production values are used to create the models. Table 2-5 presents the R^2 and the average absolute error values obtained from all four the models considered for this evaluation.

Table 2-5: Modelling statistics

	Energy intensity	Linear regression	Power	Polynomial
CV(RMSE)	42%	12%	6%	13%
R^2	0.163	0.326	0.563	0.432
Absolute error	53%	18%	9%	11%

From Table 2-5 it is seen that the energy intensity model (used in the previous example) delivers to worst fitting to the data ($R^2 < 0.2$) with an absolute error of 53%. Considering the four models above, the energy intensity model would be the last model to be considered when predicting future energy consumptions. Taking this into consideration, using a power model to predict the energy consumption for 2019 would give much more accurate results.

Step-3: Reasoning

The examples above illustrated the importance of a) including all relevant variables and b) correctly quantifying the effect of these variables. It was noted that the current budgeting structures only adjust the budgets for production (and in some instances for savings and growth projects). However, neglecting the effect of other important variables can significantly impact the budget and it is therefore suggested to evaluate all the variables.

It was further observed that budgets typically quantify the effect of production changes using an energy intensity model. The examples above proved that other models might be more successful in predicting the effect of production changes on the energy consumption predicted by the budgets. The incorporation of these two steps (ensuring all relevant variables are included and ensuring the variables are correctly quantified), therefore addresses the fourth need for the study, as listed in Section 1.4.

Table 2-6 revisits this need for the study and discusses how this parallel addresses the need.

Table 2-6: Fourth need for the study

Need for the study	Addressed by the parallel?
<i>Incorporating routine adjustments (planned events) into the budget</i>	Yes. This parallel specifically addressed the differences between including and excluding relevant variables. It was also illustrated that the methods used for quantifying the effect of the variables can impact the budget.

From this table, it can be concluded that the hypothesis of the fourth parallel is, therefore, tested as true. It is suggested for the budgeting structures to first consider other modelling options to ensure that the adjustments included for production and other effects are correct, rather than just using an energy intensity model. It is also suggested to consider what other variables would affect the energy consumption, and to include this when determining a model that can be used for compiling a budget. This is discussed as part of the next parallel.

PARALLEL 5: BASELINE DEVELOPMENT

Step-1: Converting

From the questionnaires obtained from the eight mines in South African (discussed in Section 1.1), it was observed that budgets are developed whilst assuming a direct correlation² with the previous year's actual energy consumption. In some instances, adjustments are made for expected changes (addressed in the previous parallel), but overall, it is assumed that the budget will be directly equal to historical energy consumptions. This is also discussed in Section 1.1 and presented by Equation 1-2.

In the M&V applications on mines (discussed in Section 1.2), this assumption is not made when developing baselines. When baselines are created for M&V applications, a more complex approach is used. During the M&V process, all possible effects are also considered (and not necessarily assumed to have a linear correlation without testing this first) to ensure that the expected *variances* are adjusted for by means of non-routine adjustments.

Non-routine adjustments are associated with unplanned changes that occur in the assessment period. When evaluating the energy performance of an ESM on a baseline, the baseline can be adjusted in the assessment period to allow for unplanned events. This ultimately ensures that the baseline is representative of the true events occurring in the assessment period.

² Direct correlation relates to the budget being developed with the linear assumption that the budget is equal to the historical energy consumption, plus/minus the expected changes.

Adjusting the budget in the assessment period for unplanned events is, however, not possible. Budgets are typically developed, approved and signed off before the commencing of the assessment period. Thereafter, the budget cannot be altered. It is therefore important to ensure that the budget includes reserves³ for unplanned events. These reserves included in budgets can be considered the equivalent of the variances included in baselines.

For the fifth parallel, it is suggested that budgets adapt the M&V approach by considering a variance factor in the development phase. Figure 2-18 visually represent the additional steps included in the M&V process compared to the budgeting steps.

M&V BASELINES	OPERATING BUDGETS
Baseline development	Budget construction
$A + B + \text{variance \%} = C$	$A + B = C$

Figure 2-18: Baseline development parallel

From Figure 2-18 it is seen that the M&V process allows for variances, which are neglected in the budgeting process. *The hypothesis of the fifth parallel is that the budget is dependent on more variables than just routine adjustments, and that by including a variance factor for non-routine adjustments, the budget can be more accurate.* The hypothesis is tested in the examples below.

Step-2: Retrieving

To test the hypothesis of the fifth parallel, the occurrence and the impact of non-routine adjustments over a one-year period are evaluated.

An example on the identification and quantification of non-routine adjustments

In the examples discussed with the development of the third parallel (data quality) it was noted that three unplanned events happened on one single shaft. These events were a fire, a fatality and the production halt due to a national strike action. The example specifically illustrated the impact of the fire on Shaft A, where a large decrease in energy consumption was observed for a duration of two weeks.

³ Reserves for unplanned events can be observed as a safety factor that allows room for error on the budget. Since budgets are concerned with having sufficient funds available for the financial year, it is important to ensure that the budget has a reserve fund to guarantee that the mine will have enough funds available to continue normal operations even after an unplanned event occurs.

A similar evaluation on the impact of the fatality and the national strike action also showed a decrease in energy consumption for three days (for the fatality) and two months (for the strike). These three events ultimately impacted almost a fourth of the year's energy consumption of the shaft, making it significant to include the impact of unplanned events into the assessment period as well.

The impact of future unplanned events cannot be predicted, and it is therefore suggested to compare the previous year's actual energy consumption to the budgeted energy consumption. This difference (the variance) should then be used as the expected variance included in the budget that will allow for possible future unplanned events.

Step-3: Reasoning

From the example discussed above, it was seen that unplanned events influence the assessment period significantly. These events ensured that the mine was under-budget. The hypothesis is therefore tested as true and it can be concluded that non-routine adjustments have to be accounted for.

However, the effect of these events differs from event to event and it cannot always be predicted. The example above, therefore, also tested the variance between historical predicted consumption and actual energy consumption. The percentage difference between the actual and the budgets was used as a variance in the following year's budget. The example illustrated that this variance could, in most cases, account for the overall effect of unplanned events.

This parallel, therefore, addresses the fifth need for the study listed in Section 1.4. Table 2-7 revisits this need for the study and discusses how this parallel addresses the need.

Table 2-7: Fifth need for the study

Need for the study	Addressed by the parallel?
<i>Include a variance factor in the budget that will ensure reserves for non-routine adjustments (unplanned events).</i>	Yes. This parallel evaluated the effect of unplanned events on the actual energy consumption and it was found that these events can cause the operation to be over-/under budget. It was therefore suggested to allow for unplanned events in the budget by including a variance factor which is the difference between the actual and the predicted energy consumption of historical budget.

From this table, it can be concluded that the hypothesis of the fourth parallel is, therefore, tested as true. It is suggested for the budgeting structures to consider historical variances between the actual energy consumption and the predicted energy consumption (the budget).

PARALLEL 6: ASSURANCE

Step-1: Converting

In M&V applications, assurance of the baseline is obtained through the validation of a baseline. The validation of the baseline involves evaluating the quality of the forecasts to ensure credibility of the baseline. The main criteria considered in the validation process is the transparency of the forecasting capacity. The first step is to test the baseline on the data not used for modelling (not included in the baseline dataset). The purpose is to test whether the baseline is functional on *new* data. If the performance is acceptable, the baseline is validated and deemed feasible to use for ESM evaluations.

The current budgeting process does not provide any assurance of the budgeting process. From the questionnaires discussed in Section 1.1, once the budget is finalised, the mine managers approve the budget based on how susceptible they are for the financial impact displayed by the numbers. Figure 2-12 illustrates the difference between the M&V process for validation and the lack of a process on the budgeting side.

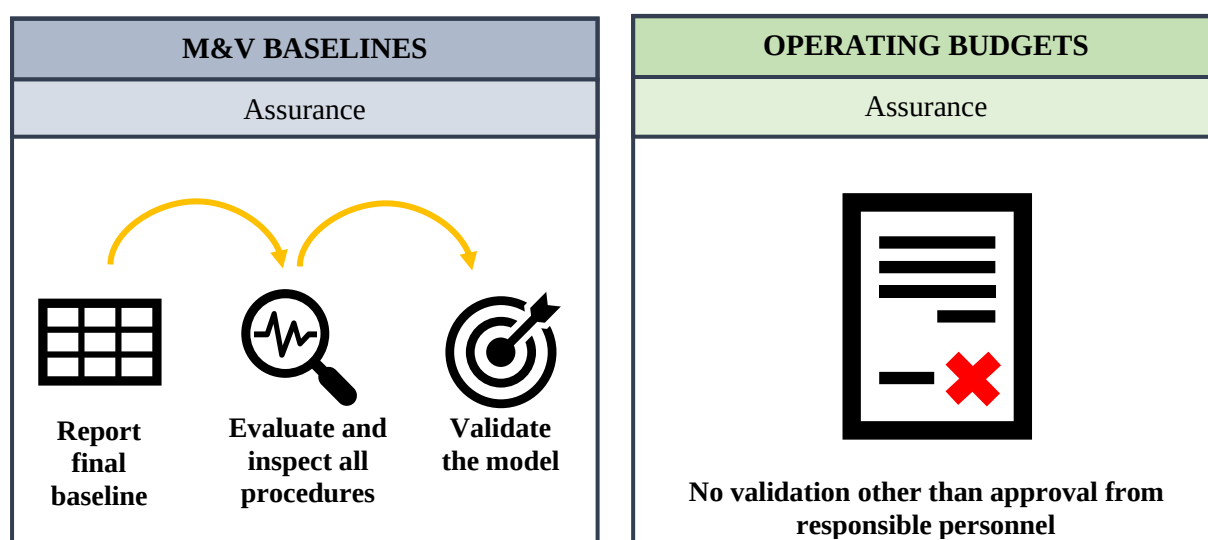


Figure 2-19: Assurance parallel

Considering the reporting step included in the M&V process, *the hypothesis is that by being transparent in all calculations and ensuring that the budgeting process is captured, more assurance and validity will exist in the final budget figures. The aim is to ensure that when the budget is being approved, not only the final figures are approved but the whole budgeting procedure is considered and signed off.* To test the hypothesis, the transparency of the M&V process along with the assurance it provides are discussed.

Step-2: Retrieving

This final step is included in the budgeting process to ensure that the process is captured and evaluated by the relevant personnel that need to approve the budget. M&V applications construct an M&V proposal which captures the listed relevant information:

- i. Background on the ESM;
- ii. Data used to quantify the ESM performance;
- iii. Assumptions made to create the baseline;
- iv. Modelling techniques; and
- v. Validation and assurance of the savings presented.

The aim of the M&V proposal is to ensure that the savings can be easily reproduced (calculation steps are traceable). Table 2-8 presents the M&V proposal layout prescribed by the South African National Standard 50010 (SANS50010) [153].

Table 2-8: M&V proposal

M&V PROPOSAL FOR AN ESM

1) Project description

State the M&V method and chapter from the Procedures Manual which will be followed. Describe the energy efficiency measure and how it will save energy. Include a description of any variables which affect energy consumption, such as outside temperature, time of day, etc.

2) Assumptions

State all substantive assumptions for the before and after retrofit energy consumption for the project (variances with temperature, the estimated annual hours of operation, etc.).

3) M&V activities

Describe all activities for measuring and verifying the energy consumption both before and after installation. This will include equipment surveys, baseline and post-installation metering. State how the baseline energy values will be adjusted by using post-installation parameters.

4) Calculations and adjustments

State how the energy savings for the ESM will be calculated, including any calculations for the baseline and post installation energy consumption. Show any adjustments to meet the minimum efficiency standards and all relevant equations.

5) Metering plan

Describe all metering activities including any sampling that will be employed to reduce the number of metering devices, the type of metering that will be employed (power, flow, etc.), the equipment that will be used, how the equipment will be calibrated, the specific equipment which will be metered and the length of time metering will be conducted.

6) Accuracy and quality assurance

Describe any accuracy requirements that will be met and all activities to assure that metered data is accurate over the term of the agreement.

7) Report to be prepared

Describe any reports that will be prepared and the format of all data that will be submitted to show energy savings on this ESM.

8) Schedule

State the schedule for performing all metering, analysis and reporting on this ESM.

9) Project budget

Provide an estimated budget to perform the M&V activities on this ESM. Include the cost of all metering equipment. Do not include normal ESM costs outside of measuring and verifying the energy savings.

The *M&V proposal* presented in Table 2-8 can be altered to specifically address the needs of a budget. The *budget proposal*, therefore, will be aimed to specifically address the following questions:

- i. What is the boundary of the budget?
- ii. In what resolution is the budget?
- iii. What data was included and was the data evaluated for missing data and outliers?
- iv. What routine adjustments were included and how were they accounted for?
- v. How was the budget developed?
- vi. Is the budget reliable?

The adaption of the M&V proposal into a budget proposal will enable the budgeting process to be more traceable and give assurance in the final values presented in the budget. This will also aid in the approval process of the budget by enabling the responsible personnel to have confidence in the signed-off values.

Step-3: Reasoning

Step-2 illustrated how the M&V applications ensure that the application process is transparent. Baseline reports are presented which include the step-by-step process followed to develop the baseline. All relevant material is presented. This document is delivered along with the saving calculations of the ESM, which is also documented in a formal report.

These reports ensure that any evaluator can trace and recreate all the values presented in the report. This delivers assurance that the methodology followed is correct. The budgeting process, however, neglects this step. The final figures are merely presented to the relevant engineers and financial managers of the mine who decide whether the budgeted values are within expected ranges. These values are then approved without the traceability of the values questioned.

This parallel focussed on the reporting included in the M&V process which ensures transparency of the process. This parallel, therefore, addresses the final need for the study listed in Section 1.4. Table 2-9 revisits this need for the study and discusses how this parallel addresses the need.

Table 2-9: Sixth need for the study

Need for the study	Addressed by the parallel?
<i>Report on the budgeting process before approval and sign-off of the budget</i>	Yes. This parallel discussed the reporting methods of M&V applications which ensures the transparency of the savings delivered. This parallel also evaluated the negligence of reporting (and transparency) in the current mine budgeting structures and suggested that the M&V reporting techniques are adapted in the budgeting process.

From this table, it can be concluded that the hypothesis of the sixth parallel is, therefore, tested as true. It is suggested that the budgeting process also includes a reporting step to ensure that the process is traceable. This will, ultimately, deliver assurance in the final approved budgeting values.

2.2.3 SUMMARY ON THE APPLICATION OF THE PARALLELS

These parallels create links between the well-established M&V principles and the budgeting structure. A new structure for budgets using these parallels is suggested as the solution for the limitations found in the current budgeting structures used by mines.

The refined parallels are 1) measurement boundary, 2) measurement resolution, 3) data availability and traceability, 4) routine adjustments, 5) baseline development and 6) validation. The six parallels are summarised along with the respective M&V principles in Table 2-10.

Table 2-10: Summary of budget-related parallels

M&V baseline	Operating budget	M&V principle addressed
Measurement boundary	Budget boundary	Relevance (principle A)
Measurement resolution	Budget resolution	Consistency (principle B)
Data quality	Data quality	Accuracy (principle C)
Routine adjustments	Unplanned events	Completeness (principle D)
Baseline development	Budget development	Conservativeness (principle E)
Validation	Validation	Transparency (principle F)

The development of this improved budgeting structure, along with the application of the M&V principles within the structure, is discussed in detail in phase 2 of this chapter.

2.3 PHASE 2: DEVELOP STRUCTURE

The parallels presented in Section 2.2 present a link between the M&V principles and the budgeting structures. The integration of these parallels into the existing budgeting structures used by mines will allow the mine budgeting process to comply with the six M&V principles (accuracy, consistency, conservativeness, completeness, relevance and transparency). This phase is concerned with the presentation of this improved structure for mine budgets.

2.3.1 PRACTICAL APPLICATION OF THE STRUCTURE

A general structure for budgeting was presented in Chapter 1, Figure 1-8. This structure is compiled from the general budgeting structures used by the eight South African mines that participated in the questionnaires presented in Appendix A. For the improved structure, the existing step-by-step processes are enhanced by the M&V related parallels created in Phase 1 of the methodology. The improved structure, therefore, still consists of the seven steps illustrated in Figure 2-20. The way in which each step was modified using the parallels, and the discussion of the application of each of these steps, are presented in detail in the following sub-sections.

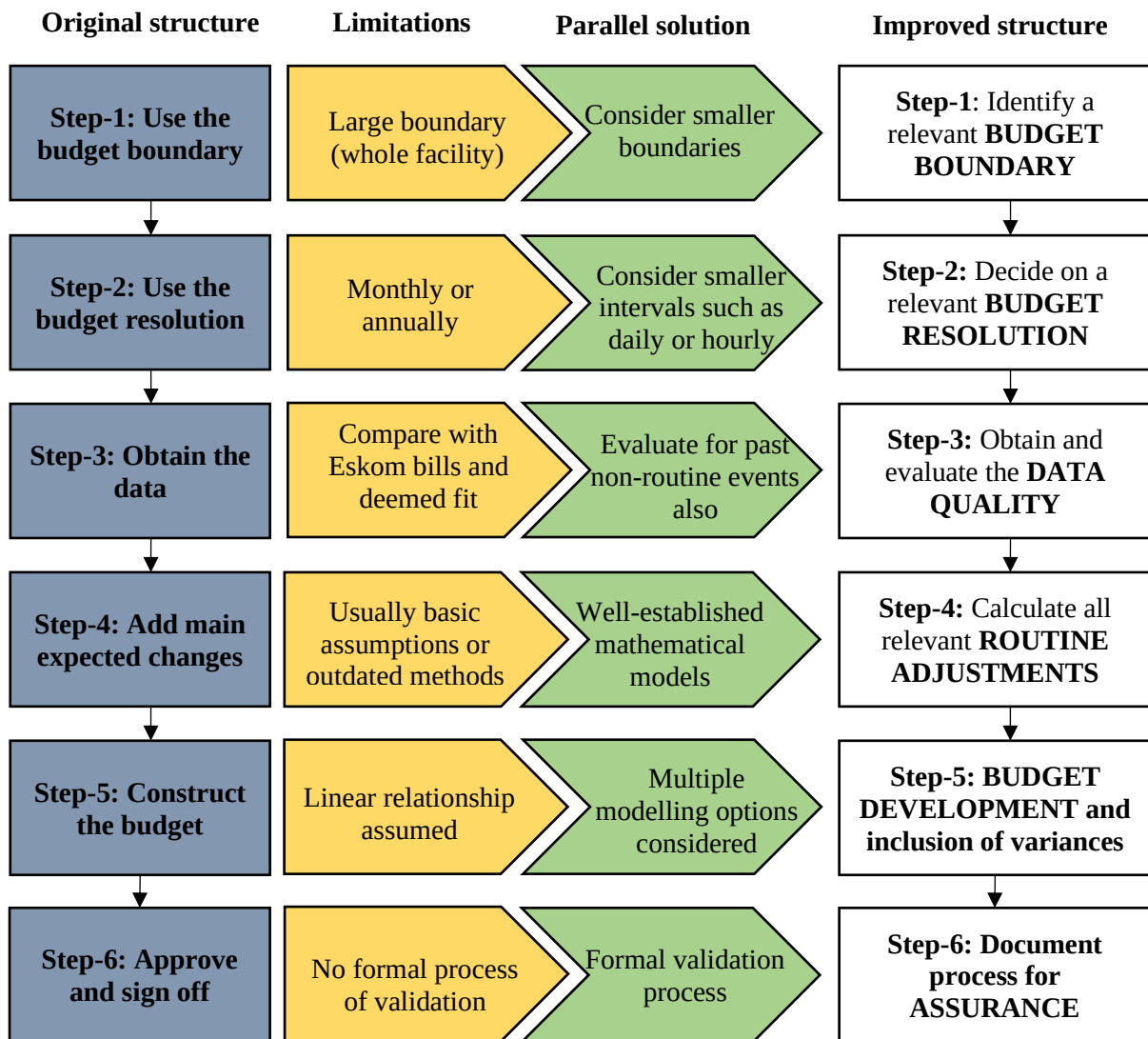


Figure 2-20: Configuring of the improved budgeting structure

Figure 2-20 presents the improved budgeting structure (the right column) where well-established M&V principles are included. It is important to note that the improved structure is still a budgeting structure and only included M&V principles that addressed the limitations in the current budgeting structures. This new structure, therefore, is not an M&V baseline structure, but an improved budgeting structure.

This new structure is applied to eight case studies in the sub-sections below. The application of each step is discussed individually.

STEP-1: BUDGET BOUNDARY

The first step of the developed structure is to identify the *budget boundary*. The original approach assumed that the whole facility should be used. However, the M&V options allow for either a component isolation or the whole facility. The first parallel created in phase 1 of the methodology (parallel 1: *measurement boundary*) tested the M&V application of boundary selection on the budgeting

process. The application was successful, and it was noted that the M&V approach for boundary selection can be adapted into the budgeting process.

M&V applications present two boundary options (component isolation and whole facility). For the budgeting structure it is suggested to evaluate the data and the purpose of the budget before deciding which of the two boundaries to use. The data evaluation includes:

- The purpose of the budget;
- The layout of the mine;
- Identification of the available energy meters;
- The design specification of the various components; and
- Accuracy of the energy meters.

The flow chart in Figure 2-21 presents the step-by-step process of deciding which boundary will be most suitable for creating a mine budget. The two boundary options are 1) *whole facility boundary* and 2) *component isolation boundary*. The main difference between the two boundaries is the purpose of the boundary.

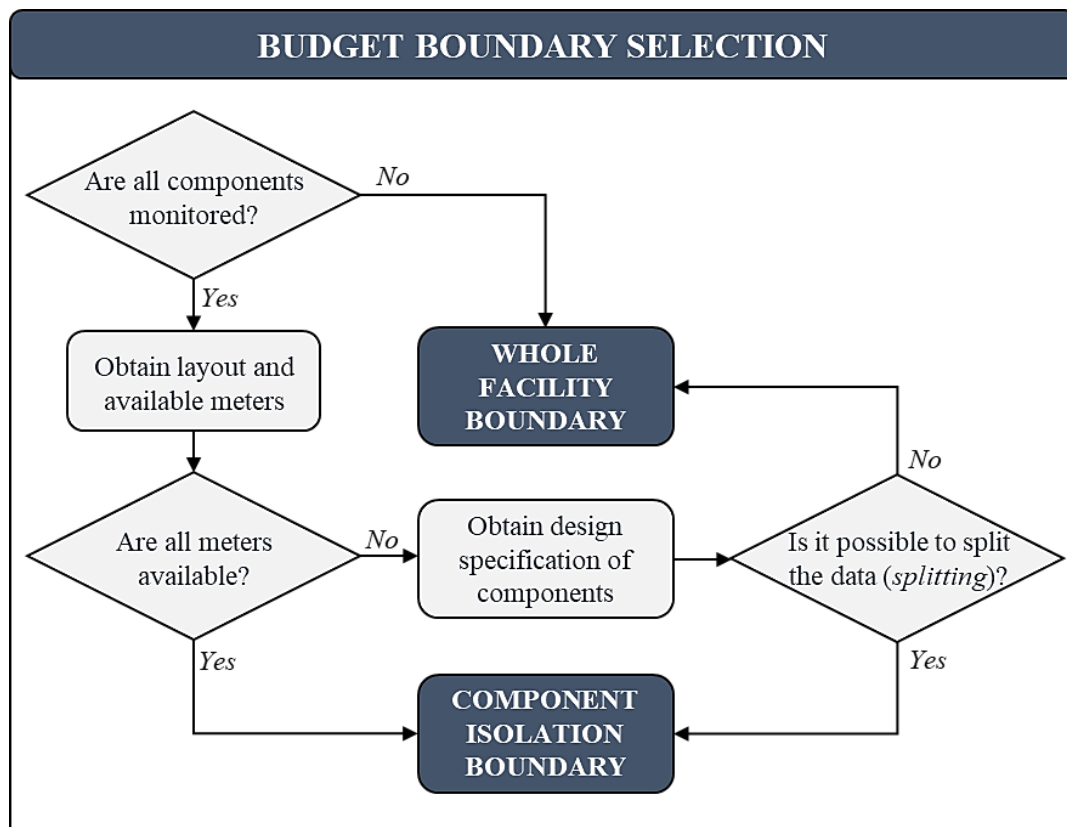


Figure 2-21: Identify the budget boundary

The flow chart presented in Figure 2-21 can be easily used to identify which boundary should be used for the budget evaluation. The first question presented (*Will each component be monitored?*) is concerned with the purpose of the budget and relies on the M&V concept where the evaluation of an

ESM smaller than 10% of the whole facility's energy consumption is recommended to not be monitored on a high level. This means that if the budget will be used for the energy management of each component, a whole facility boundary will not suffice.

The second element to consider is the data and information available on the individual components. The energy data is required for each individual component to create budgets for each of these components. In some instances, the energy data is available for most of the components but not for all of the components. In this case, it is suggested to use *splitting* to determine the energy consumption of these components. Splitting describes the process of creating split ratios for certain components while considering the energy consumption of the remaining components and the energy consumption of the whole facility. The splitting process is described in detail in Appendix D, and although it is not commonly acceptable for M&V purposes, it is often used by mines as part of their budget monitoring process.

If splitting is not possible due to insufficient energy data, a whole facility budget boundary should be considered, regardless of the purpose of the budget. Finally, it should be noted that developing a budget for each individual unit can be time consuming and there is a pay-off between desired accuracy of the budget and the amount of time and effort willing to be allocated to the budgeting process. This pay-off is discussed in detail in Appendix B.3.

STEP-2: BUDGET RESOLUTION

The second step in the developed structure is to decide on the *budget resolution*. During this step, decisions on the amount of data points to be included are considered. It is also important to consider the type of data that will be included in the budget. Typically, the budget is constructed using the previous 12-months' data to create quarterly or monthly budgets (the resolution is thus quarters or months). The M&V approach, however, suggests including much higher resolution, such as half-hourly data to ensure the inclusion of all small events and TOU profiles.

By using higher resolution, seasonal effects and various types of days (such as weekday versus weekends) can also be considered. This enables the changes in public holidays, weekdays and weekends to be budgeted for. Figure 2-22 presents a flow chart which can be used to identify which resolution (annually, quarterly, monthly, daily or half-hourly) to use when developing the budget. The resolution type is based on the type of data available and what the purpose of the budget is.

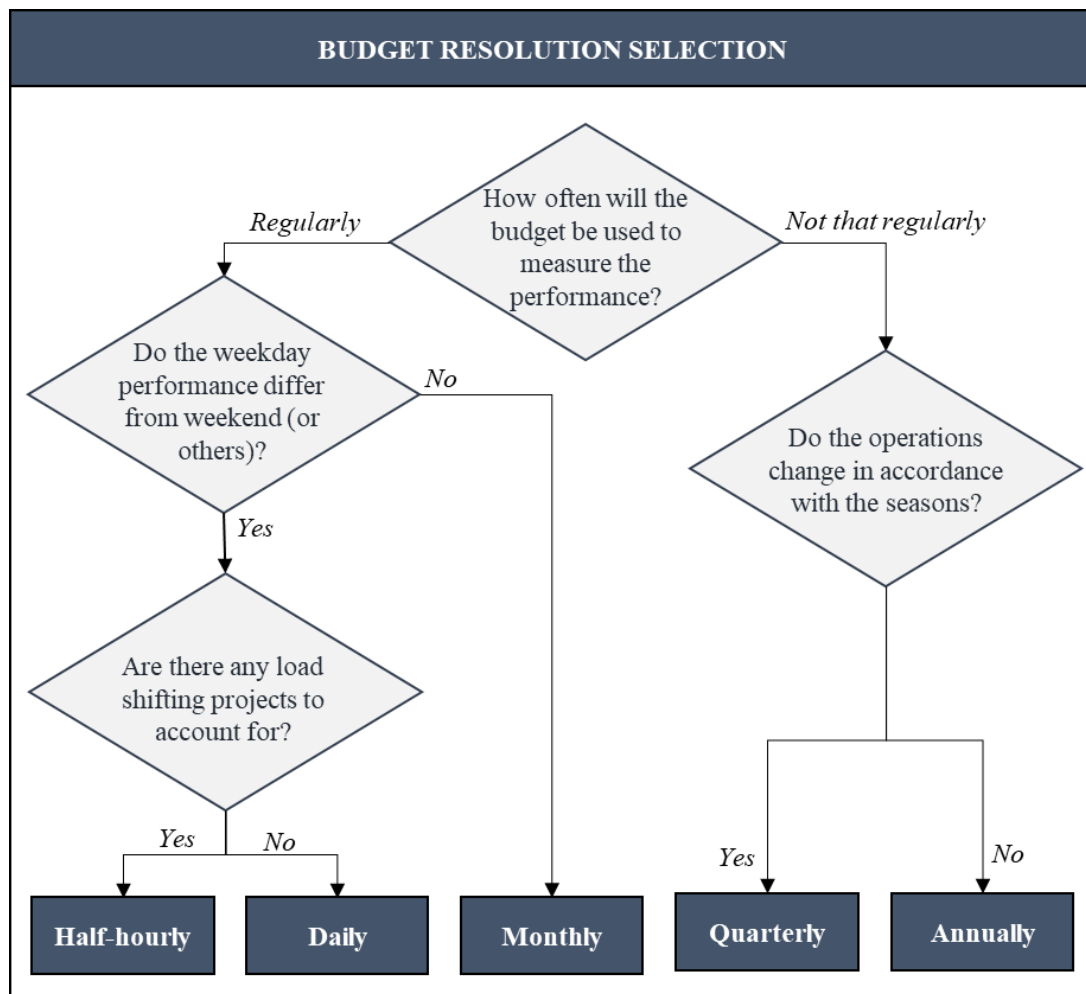


Figure 2-22: Identify the budget resolution

The measurement resolution parallel created in phase 1 of the methodology demonstrated that budgets can be developed on any of these resolutions and by including higher resolutions into the budget, the budget will be more versatile especially for energy management purposes. The flow diagram presented in Figure 2-22 above aims to help identify which resolution to use.

The first decision is made based on the purpose of the budget (“How often will the budget be used to measure the performance?”). If the purpose of the budget is to monitor the energy performance not regularly (for example, the budget will only be used to determine if the mine was under or over budget ultimately at the end of the financial year). Then a quarterly or annually budget is sufficient. Although, if large differences between winter and summer months are observed, quarterly budgets might be more preferable than annual budgets.

If the budgets will be used to measure the energy performance on more frequent resolutions, monthly, weekly or daily resolutions should be considered instead of quarterly and annual resolutions. This is to allow for proper energy management. If the energy consumption differs between the various types of days (weekday, Saturday, Sunday, Public Holidays, etc.), daily resolutions should be considered above

monthly resolutions. This will allow the budget to incorporate energy predictions for each type of day specifically.

Finally, if the performance of various projects affecting the TOU profiles (typically load shifting projects) will be monitored against the budget, a half-hourly profile should be considered above all else. This will ensure that the correct Eskom tariffs are accounted for.

STEP-3: DATA QUALITY

The third step of the structure is termed the *data quality* step and summarises data accuracy, data integrity, the relevance of the data and all the estimations or assumptions made within the calculations. Figure 2-23 illustrates the sublevel steps included within the third structure step. These sublevel steps are compiled from M&V approaches used on mines.

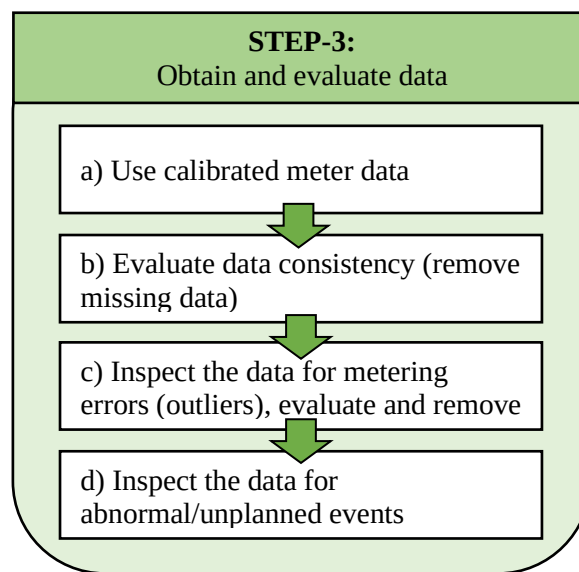


Figure 2-23: Addressing the data quality

Obtaining data from reliable sources already enhances the quality of the data that will be used when creating the budgets. This is why data should be obtained from calibrated meters (consider step *a* and step *b* in Figure 2-23). From the questionnaires on the eight South African mines, it was noticed that most of these mines obtain data from meters whose calibration status is unknown, but the data is compared with the Eskom invoices.

If the percentage difference between the Eskom invoice values and the metering data is small enough [153] the data should be representative and accurate. Since the Eskom invoices are based on calibrated and audited meters, it is an easy method that can be used to ensure that the data used (not obtained from calibrated meters) are accurate. Although this might not always be generally acceptable in terms of M&V principles, it is used on large facilities such as mines to reduce the cost of calibration. Alternatively, internal maintenance checks can be put in place to monitor the accuracy of meters if needed.

For the c) consistency and d) outliers well-established approaches are available. Typical measures of data consistency include statistics such as the range (i.e., the largest value minus the smallest value among a distribution of data), the variance (i.e., the sum of the squared deviations of each value in a distribution from the mean value in a distribution divided by the number of values in a distribution) and the standard deviation (i.e., the square root of the variance).

If one is evaluating the consistency of data drawn in a sample from a population, the standard error of the mean (i.e., the standard deviation of the sampled population divided by the square root of the sample size) is often examined. Finally, the consistency of data produced by instruments and tests is typically measured by estimating the reliability of obtained scores. Reliability estimates include test-retest coefficients.

To determine whether data contains possible outliers, 1) identify the point furthest from the mean of the data, 2) determine whether that point is further than $1.5 \times \text{IQR}$ (Interquartile Range) away from the mean, 3) if so, that point could be a potential outlier and should be investigated to determine whether it must be eliminated from the data resulting in a new set of data, 4) repeat these steps to determine if new data set contains an outlier until the dataset no longer contains outliers.

STEP-4: ROUTINE ADJUSTMENTS

The fourth parallel (*routine adjustments*) created in phase 1 of this chapter identified that multiple variables could affect the energy consumption and that the various units should be considered when creating the budget. The original budgeting structure considered production changes and in some instances the effect of growth- and savings projects. However, the effect of these variables is mostly based on assumptions or calculated using outdated methods, such as an energy intensity model for production.

For the improved budgeting structure, this step will be improved by 1) considering all relevant variables that could affect energy consumption and also by 2) improved methods for quantifying the associated effects. The application process for both steps is discussed in the subsections below.

(1) Considering all relevant events

From the parallels created it was noticed that there are several possible energy-governing factors/variables that could affect the energy consumption of the mine. These variables (also known as routine adjustments) should, therefore, be accounted for when creating the budgets. The first step is to identify which variables should be considered and this is typically done in the assessment period. This can be done by evaluating the performance of the isolated component used for the budget. For example, when a budget is developed for a compressor ring, the routine adjustments to consider can be determined by identifying all the independent variables (unplanned events) that will be affected by a change in the compressed air consumption.

(2) Improved methods for quantifying associated effects

The routine adjustments included in the original budgeting process of the mines rely on multiple assumptions or are calculated using outdated methods. The fifth parallel created in phase 1 of the methodology discussed the application of various other modelling techniques to include when quantifying the impact of routine adjustments instead of only using one. The proposal is, therefore, made to always develop at least two or more models to allow for the comparison of the statistical factors of the models. This will ensure that the model ultimately used has some creditability.

There are numerous types of models that can be considered. Models typically used in M&V applications are 1) linear regression model, 2) power model, 3) polynomial model and 4) logarithmic model [18], [37], [154]. The general formulas for each of these models are listed below:

Linear regression:	$y = mx + b$	<i>Equation 2-2</i>
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Power:	$y = ax^b$	<i>Equation 2-3</i>
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Polynomial:	$y = ax^3 + bx^2 + cx + d$	<i>Equation 2-4</i>
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Logarithmic:	$y = a^x$	<i>Equation 2-5</i>
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where y represents the energy consumption and x the dependent variable (production, employees, temperature, etc.). The remaining variables (a , b , c and d) all represent constant values which act as weights to the y and the x variables. These models are typically applied to the same dataset to identify which model is the most suitable and shows the best fit to the data. Three statistical factors that are recommended for consideration when evaluating these models are discussed briefly below [27], [37], [52], [155].

- i. **AAE:** the difference between the true or actual value and the value indicated by the measurement system. A *random* error is a general category for errors that can take values above or below the average value. A *systematic* error is a persistent error that does not occur by chance.
- ii. **RMSE:** a data-fitting method that minimizes the sum of squared residuals, a residual being the difference between an observed value and the fitted value provided by a model.
- iii. **Regression fit (R^2):** an indication of overall fit of the model to the data.

The most suitable model will thus comply best to all three (or the most) of these statistical factors.

STEP-5: BUDGET DEVELOPMENT

Step-5 of the improved structure is the step where the budget is developed. All the information and data obtained in the previous five steps are used in this step. Previously, the budget was assumed to be equal to the historical energy consumption plus/minus some adjustments. The improved budgeting structure

provides more detailed steps for developing the budget and does not rely so heavily on only the historical energy consumption.

The first part of the development step is to ensure that all of the routine adjustments are considered. This is already mainly covered in the previous step. This step, therefore, focusses on non-routine adjustments (unplanned events) as well. Non-routine adjustments are the adjustments associated with unplanned events such as the occurrence of a natural disaster or a national lockdown caused by a pandemic. Equation 2-6 demonstrates the improved structure's budget equation.

$$\text{Budget} = (\text{Historical Energy}) \pm (\text{Routine Adjustments}) \pm (\text{Non} \quad \text{Equation 2-6} \\ - \text{Routine Adjustments})$$

Since non-routine adjustments are unplanned events (and no proper planning can be done prior to the occurrence of the event), the non-routine adjustment term in Equation 2-6 is replaced with a variance factor. The variance factor is based on the historical differences between the budget and the actual consumptions which will give an indication of the typical *unplanned event* sizes. Equation 2-6 can, therefore, be presented as in Equation 2-7 as well:

$$\text{Budget} = (\text{Historical energy}) \pm (\text{Routine adjustments}) \pm (\text{Variances}) \quad \text{Equation 2-7}$$

A small variance indicates that the data points tend to be very close to the mean, and to each other. A high variance indicates that the data points are very spread out from the mean, and from one another. When developing the budget, this variance will allow for future unplanned events (non-routine adjustments) and, therefore, having a high variance will allow the budget to be more conservative, especially when an unplanned event occurs.

This variance can be determined by evaluating the historical energy performance against the budgets. The difference between the actual energy consumption and the budget will indicate the variance. Equation 2-8, therefore, captures the variance percentage that can be used in the budget.

$$\text{Variance} = (\text{Historical energy budget}) - (\text{Historical energy}) \quad \text{Equation 2-8}$$

It is suggested that multiple historical budgets and actual energy consumptions are considered when calculating the variance. It should also be noted that this variance allows for unplanned events and would therefore not necessarily be correct. The aim is, however, to expand the budget slightly to some extent to allow for abnormal and unexpected changes.

After the energy budget is developed, it can be converted into a cost budget by using the Eskom tariffs. It is suggested to allow for expected Eskom tariff increases when converting the energy budget into a costing budget. If the budget was developed in half-hourly resolutions, the conversion from energy to

cost will be straight forward (due to the Eskom tariff prices being available in half-hourly resolutions as well).

If the energy budget was developed in smaller resolutions (such as weekly or monthly), the conversion from energy to cost can be calculated by applying the following four steps:

- Step-1:** Obtain the historical energy and cost values for the desired budgeting resolution (as picked in Step-2 of the new structure methodology).
- Step-2:** Calculate the R/kWh conversion ratio for each resolution (e.g. if *monthly* resolutions are desired, use the historical cost for the specific *month* and divide it by the historical energy consumption for that *month*. Repeat this step for each *month*).
- Step-3:** Adapt the R/kWh conversion ratio obtained in the previous step with the expected Eskom tariff increases for each resolution.
- Step-4:** Apply this R/kWh conversion ratio to the energy budget in the resolutions used to calculate the R/kWh conversion ratio.

This four-step methodology to calculate the R/kWh conversion ratio should allow, to some extent, the TOU impact as well. This is due to the historical cost values being calculated over all Eskom tariffs simultaneously. However, this method does not allow for changes in TOU periods for the new budget being developed. The new budget would therefore assume that the TOU periods will be similar to the historical TOU periods. This is ideal if no changes in TOU periods are expected for the new assessment period.

STEP-6: ASSURANCE

The final step of the structure is the assurance step. During this step, the transparency of the budgeting structure should be captured in formal documentation to allow for the reproducibility of the budget and the auditing of the final budgeting values. Parallel 6 presented an **M&V proposal** which is altered in this step of the methodology to reproduce a **budget proposal**. The budget proposal considers most of the aspects of the M&V proposal, but the focus moves from quantifying savings to preparing a budget. The budget proposal specifically addresses the following questions:

- vii. What is the boundary of the budget?
- viii. In what resolution is the budget?
- ix. What data was included and was the data evaluated for missing data and outliers?
- x. What routine adjustments were included and how were they accounted for?
- xi. How was the budget developed?

By formally addressing each of these points, the budgeting process will be traceable which will provide assurance that the budgets are correct when being evaluated and approved by the financial department of the mine. A budget proposal is discussed in Table 2-11. This budget proposal is, in essence, a mere

summary of the steps followed to present a budget for the mine, a commodity or a component (depending on the boundary selection).

Table 2-11: Budget proposal

BUDGET REPORT FOR MINE / COMMODITY / COMPONENT

1) Budget description

Describe the boundary used (isolated component or whole facility) along with the resolution of the budget. Discuss why the boundary and resolutions are relevant as opposed to other boundaries/resolutions. This point is a summary of step-1 and step-2 of the new structure presented in Section 2.3.

2) Assumptions and data changes

Fully disclose all the data challenges experienced when developing the budget. Include all the data points identified as outliers and the reason why the points were removed. Finally elaborate on any assumptions made with regards to the data as well as the budgeting method. This point is a summary of step-3 of the new structure presented in Section 2.3.

3) Calculations and adjustments

State all the relevant variables (routine adjustments) and how they will be accounted for in the budget. Discuss the importance of these variables and the effect if these variables are excluded. This point is a summary of step-4 of the new structure presented in Section 2.3.

4) Budgeting plan

Describe how the budget will be calculated and what steps were taken to ensure that the budget is a true representation of the expected performance. This point is a summary of step-5 of the new structure presented in Section 2.3.

5) Accuracy and quality assurance

Describe any accuracy requirements that will be met and all activities to ensure that metered data is accurate over the term of the agreement. This point is a summary of the verification of the new structure that will be presented in the next section of this chapter, Section 2.4.

6) Reporting

Describe any reports that will be prepared and the format of all data that will be submitted to present the budget. This point is a summary of all the relevant information that needs to be evaluated by the responsible personnel before the budget is signed off.

The report presented above enables an independent reviewer to audit the budgeting process. It also gives confidence to the relevant personnel that the budget is correct before signing off on the budget.

Additional confidence can be added by quantifying the uncertainty of the new budget and the original budget. The uncertainty can be calculated using Equation 2-9:

$$Uncertainty (\%) = Q = \frac{\max - \min}{\max} \quad \text{Equation 2-9}$$

In Equation 2-2, the difference between the budget indicating the maximum result (max) and the budget indicating the minimum result (min) is firstly obtained. This difference is then divided by the maximum result to determine the associated uncertainty. Using multiple and different quantification options and determining the associated uncertainty provide assurance to the final answer [59]. If different calculation options provide similar results (i.e. lower value of Q in Equation 2-9), it will provide assurance that results are consistent, and vice versa [92] [94].

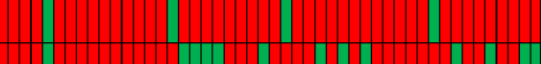
The measurement uncertainty in the M&V process results from instrumentation error due to poor measurement equipment calibration, data tracking errors, and human errors in data capturing [92]. Measurement uncertainty is unavoidable, although it can be mitigated with proper data handling protocols and the use of high-accuracy, calibrated metering equipment such as Class 1, Class 2, and Class 3 meters with specified error bands of $\pm 1.5\%$, $\pm 2.5\%$, and $\pm 4\%$, respectively [93]. Including these uncertainty analyses into the budgeting process will ensure accuracy.

2.3.2 SUMMARY ON THE APPLICATION OF THE STRUCTURE

A detailed discussion on the development of the structure for the application of the M&V principles in the budgeting structures of mines was discussed in this section. A six-step structure was developed using six parallels created between the budgeting and the M&V environments. The outcome of the section is an improved structure that can be applied to a mine when compiling the financial budget for the following year.

The next section focusses on the verification of the methodology by ensuring that the new structure (developed in phase 2) addresses the need for the study by incorporating the M&V principles. The critical analysis completed in Chapter 1, Section 1.3 addressed if (and how) 98 references incorporated the six M&V principles into the budgeting structure. Ultimately, the need to incorporate the M&V principles into the budgeting structure was highlighted when it was observed that none of these structures allowed for this incorporation, as presented in Table 2-12.

Table 2-12: Summary of the critical analysis on 98 references

	Category 1	Category 2	Category 3
(A)			
(B)			
(C)			
(D)			
(E)			
(F)			

References (x98)

This section of Chapter 2 will revisit each of the six questions used to assess the 98 references in Chapter 1, Section 1.3 to identify whether the new structure can successfully address all the questions (all blocks in Table 2-12 for this study should ultimately be green).

2.4 VERIFICATION OF THE NEW STRUCTURE

The main problem that led to the need for this study is the early obsolescence of mine operational budgets due to ineffective compilations of the budgets. In Section 1.3, a critical analysis was conducted to test the following question: “*Can well-established M&V principles be used to improve mines’ budgeting structures?*”. This research question was studied and tested by applying a critical analysis to a wide range of literature-based references.

The critical analysis involved the review of M&V principles (generated parallel questions) in the mine budgeting structures. By evaluating these questions against the mine budget structures used in South Africa, it was noted that the M&V principles are inconsistently applied and addressed, and that there is no research that clearly links these principles to budget structures.

The need for the study is, therefore, to address each of these principles in the budgeting structure of mines in South Africa. The methodology developed in Chapter 2 (phase 2), focussed on addressing each of the M&V principles and incorporating the principles into the budgeting structure. A new budgeting structure was presented that applied these principles. This new structure provides an essential part in presenting the impact of this study.

To validate the methodology (phase 2), it is, therefore, necessary to ensure the M&V principles are applied and addressed within the new structure. The successful application of the M&V principles into the structure would mean that the need for the study set out in Chapter 1 (Section 1.4) was addressed. The parallels created in phase 1 of this chapter already verified that the M&V principles **can be**

incorporated into the budgeting structures and that the successful incorporation of the principles will address the need for the study.

This section will, therefore, merely assess whether the M&V principles **are incorporated** in the new structure (phase 2). A discussion on the critical analysis questions and how they are addressed within the structure is presented:

(A) Relevance: Are all important parameters measured and reliable?

Since data is only obtained from calibrated meters, the data obtained is considered reliable, although checks are also put in place to ensure the compliance of the data. When selecting the boundary, the external effects of all the units are evaluated to ensure that all the data is included. *The first need-for-the-study, adapting the boundary of the budget, is therefore successfully addressed by this methodology.*

(B) Consistency: Are the resolution periods consistent for all sections of the budget?

When the budget resolution is selected in Step-2 of the structure, specific attention is given to the most effective resolution periods. From M&V it is suggested that a one-year (12 consecutive months) period would be most suitable, seeing as it accounts for all seasonal variations. This is also the suggested resolution for the budget. *The second need-for-the-study, ensuring that consistent data resolution is used, is therefore successfully addressed by this methodology.*

(C) Accuracy: Is there any mention of accuracy of the data used to develop the budgets?

In the third step of the structure, data is compiled from reliable references such as calibrated meters. The obtained data is further investigated for outliers or missing data. The outliers/missing data are addressed according to engineering best practices which gives confidence to the accuracy of the data used for the budget development. *The third need-for-the-study, evaluating all data for accuracy, is therefore successfully addressed by this methodology.*

(D) Completeness: Does the budget consider any effects of the expected changes?

The fourth step of the structure allows for routine adjustments. During this step specific attention is given to all planned changes in normal operations; this includes the effect of production, the planned effect of savings projects as well as the planned growth projects. This step further allows for the accurate calculations of these effects which contributes to question A in this list. *The fourth need-for-the-study, incorporating non-routine adjustments (unplanned events) into the budget, is therefore successfully addressed by this methodology.*

(E) Conservative: Is the budget conservative and does it underestimate savings effects?

During the budget development step (Step-5) several possible budget scenarios are presented, each calculated using a different model. The highest budget is the most probable one to be selected as the final budget. This is to allow for the budget to be conservative and not overestimate any effects of production, savings or growth. *The fifth need-for-the-study, including various models to enable the identification of the most suitable budget, is therefore successfully addressed by this methodology.*

(F) Transparency: Are all activities included and fully disclosed?

Before the budget's boundary is decided on, the whole facility is evaluated to identify the external effects of the different components. This ensures that all the important data is measured and included in the budgets. The budget is also created in such a way that it is easily traceable, and all calculations are transparent. *The final need-for-the-study, report on the budgeting structure before approval and sign-off, is therefore successfully addressed by this methodology.*

The summarised critical analysis results presented in Chapter 1 are adapted with the developed structure, which indicates that this method applies and addresses all the M&V principles consistently. The adapted version is presented in Table 2-13. The final column in Table 2-13 presents the improved structure which indicates that the structure is effectively validated.

Table 2-13: Adapted critical analysis from Chapter 1

Heatmap showing the relationship between M&V principles and References (x98). The y-axis lists M&V principles (A) through (F), and the x-axis lists References (x98). The heatmap cells are colored red or green, indicating the presence or absence of a principle in a reference.

From Table 2-13 it is seen that this study will address all six M&V principles into the budgeting structures of mines where none of the existing 98 budget-related references included all six of the principles. This is indicated by the final column in the table (all the blocks representing this study are

green). By adapting these six principles into the budgeting structures, the need for the study was successfully addressed and the new structure is verified.

2.5 CHAPTER CONCLUSION

The aim of this chapter was to test whether the well-established M&V principles presented in Chapter 1 can be used to improve the current mine budgeting structures. Practical parallels between the M&V principles and the mine budgeting structures were created (phase 1) based on a critical comparison between these two fields. These parallels were used to create an improved budgeting structure (phase 2). The core of the chapter lies within the final phase (develop an improved structure) where another methodology is displayed. This methodology is specifically aimed at creating the budget (Section 2.3). This improved budgeting structure is finally validated and verified to prove that it successfully addresses the need for the study.

The practical application of the structure developed in this chapter will be presented in the next chapter. This will indicate how the structure can be applied in practice, and what the results thereof would be. This serves as further verification of the developed methodology.

3 APPLICATION OF THE NEW STRUCTURE

3.1 PREAMBLE

As part of the development of the methodology in Chapter 2, six parallels between M&V applications on mines and the budgeting structures of mines were inspected. The significance of these parallels was used to develop a new structure to improve budgeting methods. The use of this new structure will enable mines to improve on their budgeting structures and to ensure that the improved budgeting structures comply with a set of principles used in M&V. The focus of Chapter 3 is, therefore, to apply this new (improved) budgeting structures on eight real-world case studies.

Firstly, a brief description of the selected case studies is presented to familiarise the reader with these facilities (Section 3.2). Thereafter, a detailed discussion of the application of the improved budgeting structure to one of the eight case studies is presented (Mine #1 is the selected case study). The step-by-step application process is discussed along with the results for Mine #1 (Section 3.3). Subsequently, the new structure is applied to the remaining seven case studies (Mine #2 to Mine #8) where only the results of the application are discussed (Section 3.3). The full application on these case studies is, however, presented in Appendix D. This serves as a further validation of the developed budgeting structure.

The chapter concludes with an overall validation of the improved budgeting structure (in Section 3.4) by comparing the performance of the original budgets and the improved budgets on the eight South African mines that participated in the questionnaires (which will serve as the eight case studies used in this chapter). Finally, the objectives of this study are revisited alongside the results of the application to assess whether the research objectives were achieved.

3.2 MOTIVATION FOR CASE STUDY SELECTION

Eight South African mines were selected as the case studies that will be discussed in this chapter. These eight South African mines are the same mines that participated in the questionnaires discussed in Section 1.3. The validation of the improved structure on all eight of these mines will ultimately prove that the existing budgeting structures were successfully enhanced.

This chapter presents the detailed application of the methodology on a single component (fridge plant referred to as FP1) on mine #1 as an example, which serves as case study 1. The other case studies are presented in Appendix D and focus on various other components of the eight mines that participated in the questionnaires.

Figure 3-1 presents a simple layout of Mine #1, for which the application of the methodology will be addressed in detail in Section 3.3. The POD is indicated with the green circle in Figure 3-1. The POD feeds the plant and each of the shafts, with the distribution of the POD energy indicated with the blue

incomer circles (INC). The shafts then feed their various components, which is measured by feeders (FDR) and indicated with the yellow circles.

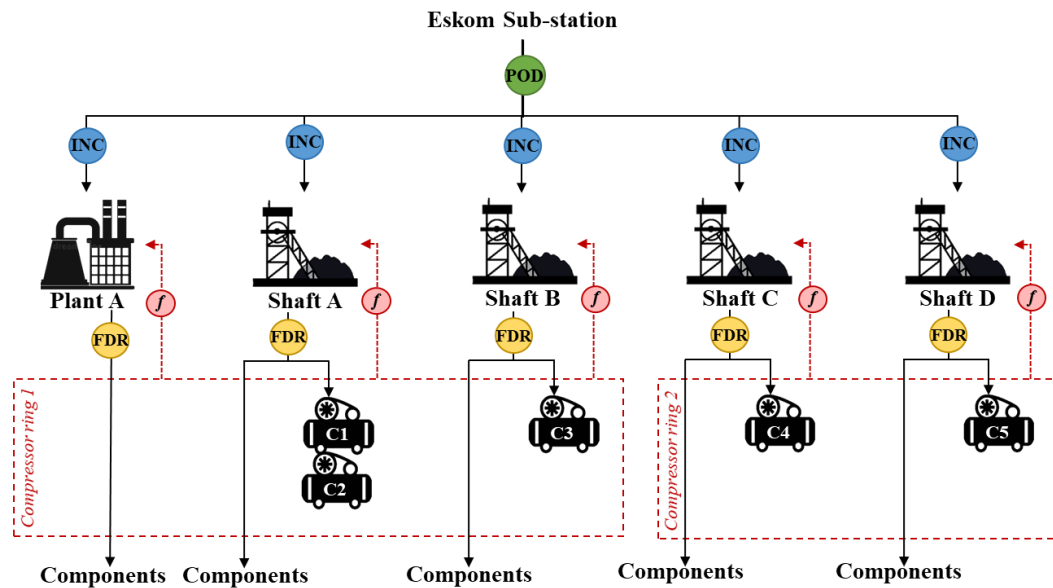


Figure 3-1: General layout of case study 1 (Mine #1)

It should be noted that each shaft has its own set of components, except for the compressors which are shared between the various shafts. Plant A, Shaft A and Shaft B share the compressed air delivered from three compressors: two of the compressors are situated at Shaft A and one of the compressors is situated at Shaft B. A similar situation is observed on the second compressor ring where Shaft C and Shaft D share the compressed air of two compressors. The compressed air consumption of each shaft (and the plant) is measured by a flow meter (the red circle).

The flow meter reading of each shaft is indicative of the amount of compressed air consumed by that shaft compared with the other shafts on the ring. These flow meter readings are then used to determine the amount of compressor energy that each shaft (or plant) required. The total compressor energy is divided between the shafts (and plant) on the respective rings using this split ratio calculated from the flow meters. This is to ensure that, for example, Shaft A is not made accountable for the cost of the energy used by the two compressors located on their premises, but rather only for the cost of the compressed air usage.

The general layouts for the remaining seven case studies (Mine #2 to Mine #8) are similar to the layout presented in Figure 3-1. These layouts are discussed in detail in Appendix E.

3.3 IMPLEMENTING THE DEVELOPED BUDGETING STRUCTURE

3.3.1 APPLICATION OF NEW STRUCTURE ON MINE #1

The detailed application of the developed budgeting structure is presented for the Fridge Plant (FP1) on 22 level (22 LVL) of Shaft A (which forms part of Mine #1). The same concept applied to the remainder of Mine #1, but the detailed steps are not presented in this discussion. A detailed electrical reticulation layout for Shaft A is presented in Figure 3-2, where FP1 on 22 LVL is indicated with a red box. FP1 consumes only electrical energy.

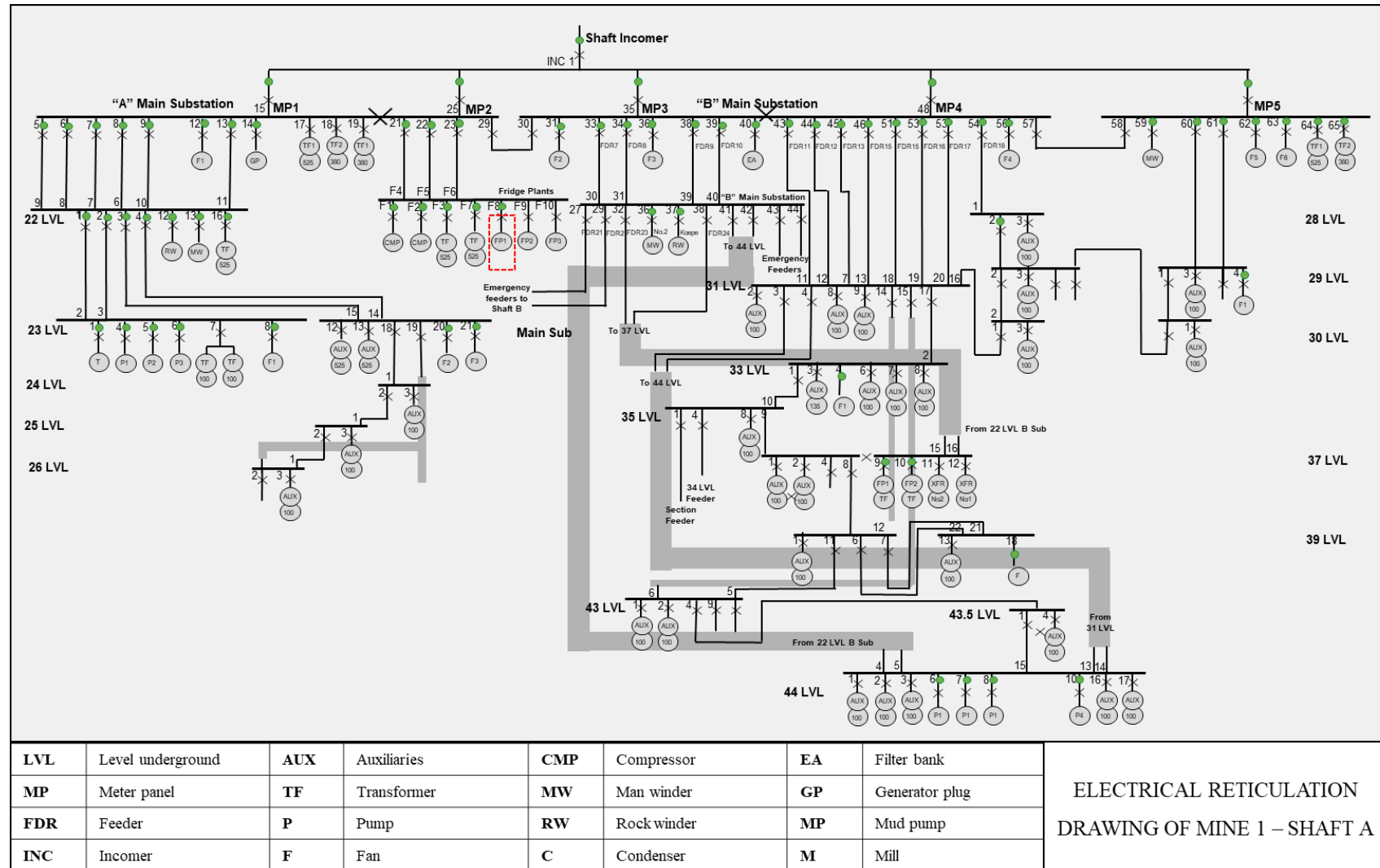


Figure 3-2: Electrical reticulation of case study 1 (Shaft A of Mine #1)

All the components of Shaft A are present in Figure 3-2. The green circles on the figure indicate energy meters which will be used for the development of the budget. The new budgeting structure allows for the development of an individual budget for each of the components in Figure 3-2. Due the vast number of components, the detailed application will only be presented for FP1, with the application for the remaining components presented in Appendix D.

The application process for case study 1 (the FP1 application on Mine #1) is demonstrated in the subsections below. In some of sections, reference is made to two additional fridge plants (FP2 and FP3) on Mine #1 in order to distinguish between the operational differences of these fridge plants to the case study fridge plant (FP1)

STEP-1: BUDGET BOUNDARY

From the newly developed budgeting structure, the first step in the budgeting process is to identify the boundary that will be used for development of the budget. The methodology discussed in Chapter 2 presented a flow chart that can be used to identify the ideal budget boundary. This flow chart presented in Figure 2-21 (Section 2.3) will be used for the application on the first case study (a fridge plant on a South African deep-level gold mine, referred to as Mine #1). Figure 3-3 presents the flow chart questions with the response to the questions for the application on Mine #1 highlighted in the green blocks and lines.

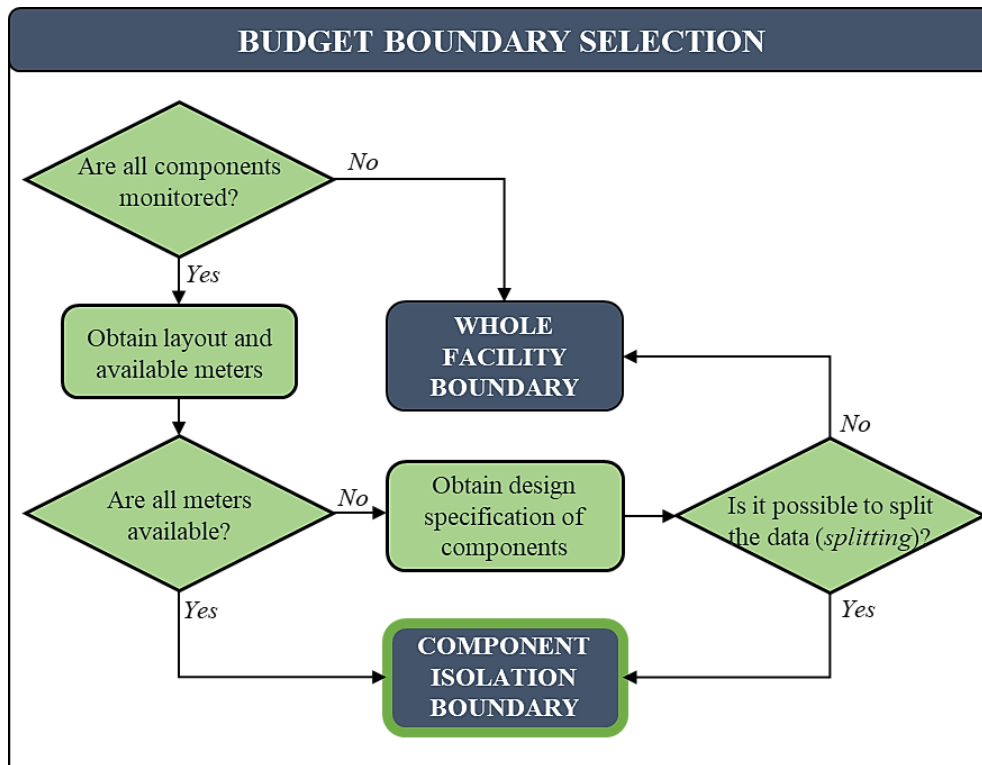


Figure 3-3: Selecting the boundary for case study 1 (Mine #1)

From the application of the methodology to determine the budget boundary, it is seen from Figure 3-3 that “Component Isolation” is recommended for use. The small boundary allows for the individual evaluation of each component. These individual evaluations are based on the energy meters allocated by each component.

It might be the case that some of the components do not have energy meters installed. The energy consumption of such components can then be determined by using a method such as developing a “splitfile”. This formed part of the decision-making process, as presented in the flow chart in Figure 3-3. A splitfile is the name given to the task where the energy that is available is divided between the components it is feeding, as discussed in Section 2.3 and Appendix D. This is done using the available information regarding the components. As an example, the basic application of a splitfile for two of the fridge plants located on 22 LVL (FP2 and FP3) is demonstrated below. Similar approaches can be used for other areas or components where energy meters are not directly available for components.

Creating the splitfile for fridge plant 2 (FP2) and fridge plant 3 (FP3) FP2 and FP3

Step-A: Identify the areas where meters are available

For this example, three fridge plants are considered (FP1, FP2 and FP3). All three of these fridge plants are fed from a single incomer (INC). Figure 3-4 represents the section of the layout (presented in Figure 3-2 – the electrical reticulation layout of Shaft A) where the fridge plants are located.

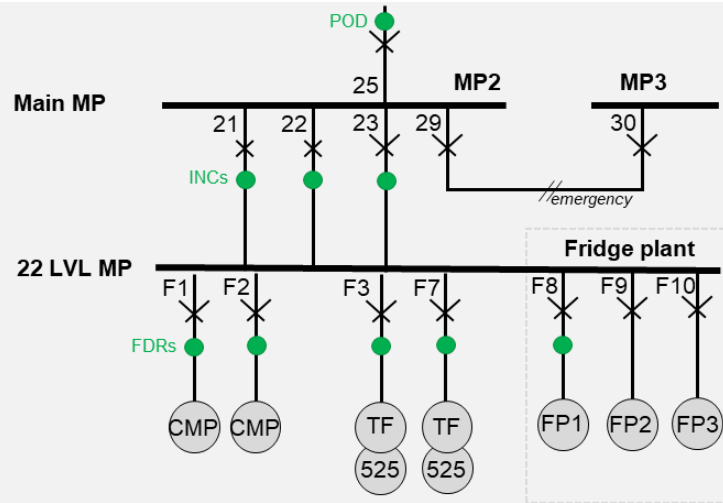


Figure 3-4: Condenser electrical reticulation subsection

This figure illustrates that the three fridge plants are located on the 22 LVL meter panel (MP). It is further observed that the 22 LVL MP is fed directly from three incomers (INCs) flowing from MP2. The green circles in the figure illustrate the areas where energy meters are available. It is observed that the energy of two of the three fridge plants is not measured.

Step-B: Energy balance

The first law of thermodynamics is referred to as the Conservation of Energy principle, meaning that energy can neither be created or destroyed [7]. The energy balance is therefore maintained within the system (control volume). This implies that the total energy flowing into the 22 LVL MP will be equivalent to the total energy flowing from the 22 LVL MP (sum of the INCs needs to be equal to the sum of the FDRs). Using this energy balance concept, the energy consumed by the two fridge plants can be calculated using Equation 3-1.

$$\sum E_{in} = \sum E_{out} \quad \text{Equation 3-1}$$

where E_{in} and E_{out} represents the energy into and the energy out of the system respectively. The application of this equation is applied to the fridge plants in Equation 3-2:

$$E_{21} + E_{22} + E_{23} = E_{CMP1} + E_{CMP2} + E_{TF} + E_{TF} + E_{FP1} + [E_{FP2} + E_{FP3}] \quad \text{Equation 3-2}$$

Raw data obtained for all of the available meters are substituted into Equation 3-2 and the total energy for the two fridge plants is calculated as 362 GWh. Since both these fridge plants are the same size (similar design specifications) it is assumed that both the fridge plants consume an equal part of this energy.

This application can be done in any interval (hourly, daily, etc.) and applies to all other components as well.

The splitfile allows for the allocation of energy to all the areas where energy meters are not available. Ultimately, the energy data for the whole shaft (presented in Figure 3-2) are available which enables the development of the budget on a component specific boundary.

STEP-2: BUDGET RESOLUTION

The second step in the improved structure created in Chapter 2 is to decide on the budget resolution. To help with the decision, a flow chart is presented which allows for the decision of the application on annually, quarterly, monthly, daily or half-hourly resolutions. Figure 3-5 represents the flow chart (Figure 2-22) created in Section 2.3 and includes the decisions of the application of the case study (highlighted in the green blocks and lines).

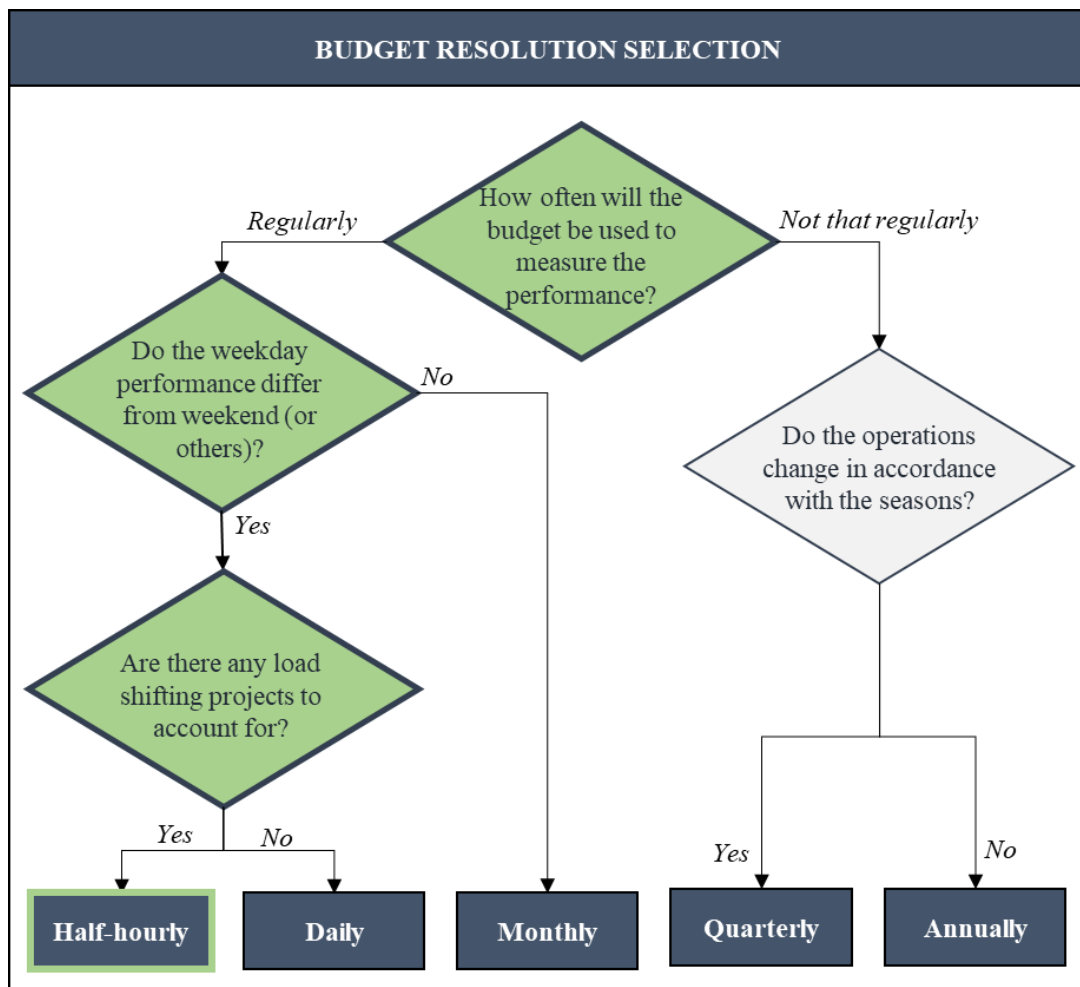


Figure 3-5: Choosing the budget resolution for case study 1 (Mine #1)

From Figure 3-5 it can be seen that the purpose of the case study budget is to monitor the performance of the mine (Question 1). Seasonal changes should also be considered (Question 2) due to the external effects of temperature on the energy consumption of the refrigeration systems of the mine. It is common practice that the energy consumption on mines differs between normal weekdays and other types of days (weekends, public holidays, maintenance days, etc.) and therefore this should also be considered

(Question 3). Finally, load shifting projects are implemented, especially on the compressors, which should also be considered (Question 4).

Considering the four questions addressed in the flow chart presented in Figure 3-5, the budget should be developed in half-hourly intervals to allow for proper energy management, changes in temperature, different types of work days and load shifting projects. These changes are considered for all variations of the *types of days* that are considered. Considering the various types of days is important due to the differences observed in operating hours (input) and the production (output) of the mine. The types of profiles that will be considered for this case study are:

- | | | |
|-------------------------|----------------------|--------------------------|
| 1. Normal weekdays | 4. Sunday | 7. Other public holidays |
| 2. Working Saturday | 5. Christmas holiday | 8. Maintenance days |
| 3. Non-working Saturday | 6. Easter holiday | |

These eight types of days are selected due to the observed changes in energy consumption and production outputs on the different days. Normal weekdays consider a typical Monday to Friday where all employees are present and normal operating hours are in place. A working Saturday profile is very similar to a normal weekday profile due to the mine being in full production, where a non-working Saturday represents a non-working day, which is similar to a Sunday.

The holidays (Christmas, Easter and the remaining holidays) also consume less energy and produce little to no production. These holidays should also be evaluated separately due to the duration of the holiday. In December, the decrease in energy consumption and production outputs is observed for a duration of two weeks. At Christmas, production is usually halted completely (no production). On Easter holidays the impact of the holiday is observed for only one week and in most instances, production is only reduced and not necessarily completely halted. The energy consumption and production changes are less drastic on the remaining holidays. On maintenance days, energy is consumed but no production is delivered.

STEP-3: DATA QUALITY

The purpose of this step is to ensure that the data used for the budgets are representative. From the methodology developed in Chapter 2 it was indicated that this step consists of four sub-steps, namely a) use calibrated meter data, b) evaluate the data consistency, c) inspect the data for errors/outliers and d) inspect the data for abnormal/unplanned events. The occurrence of any of these data mistakes can influence the final budget. The case study's data is evaluated for all four of these mistakes in the discussion below.

This step of the application process will only focus on the data errors observed on some of the components on Shaft A of Mine #1 as an example, rather than discussing all of the components in detail.

a) Use calibrated meter data

The data used for the evaluation is obtained from an outside technology company appointed by the mine to measure the energy data of the mine. This technology company ensures that all the meters are correct and that important meters are usually calibrated on time, and issues a calibration certificate for the various meters. This ensures that the meter data used for the budget is obtained from calibrated meters. This data was obtained from the technology company for the meters installed at Mine #1.

b) Evaluate the data consistency

Even though the data is obtained from calibrated meters, it is still possible for the data to have inconsistencies. To ensure that the dataset used for the budgets are complete, the data has to be evaluated for consistency. This is done by ensuring there is no missing data. Figure 3-6 presents the 2018 energy data in half-hourly intervals for Fan 1 located on meter panel 5 of Shaft 1 (presented in Figure 3-2). Fan 1 is fed by the feeder FDR 61.

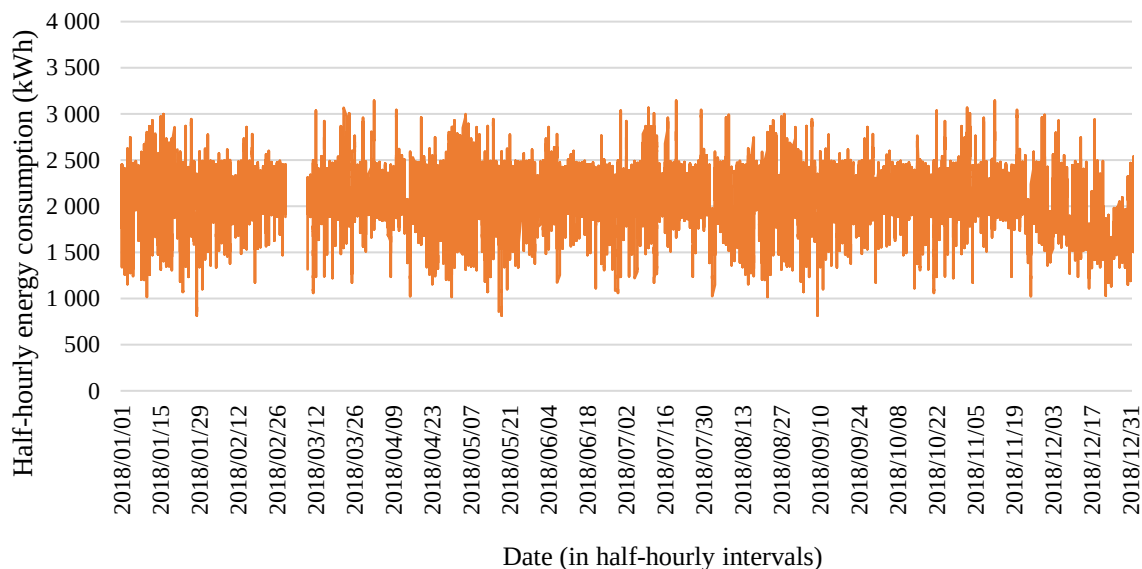


Figure 3-6: Energy for a fan in case study 1

Figure 3-6 shows that on the 5th and 6th of March 2018 there was no data recorded for Fan 1. When creating daily profiles this *missing data* can influence the profile as it will assume that the Fan consumed zero energy on these two days. To ensure that the missing data does not affect the actual normal profiles of the mines these two days should be addressed. Possible methods that can be used to address it are to either completely exclude the days from all further evaluations, or for the average energy consumption of the day before and the day after to be used as substitutions. For the case study, these two days will be excluded from further calculations.

All the other components' meter data were evaluated for missing data and were removed accordingly.

c) Inspect the data for metering errors

The energy consumption of all the components was evaluated for data errors. Data errors are events that occurred which indicate that there was a possible fault with the meters and as a result an abnormality (such as a spike in the data, for example) was observed. An example of this is that the evaluation on the case study indicated that several large spikes (negative values) were observed on the compressor located on MP4 (fed by FDR56). Figure 3-7 shows the half-hourly energy data for 2018 for this specific compressor.

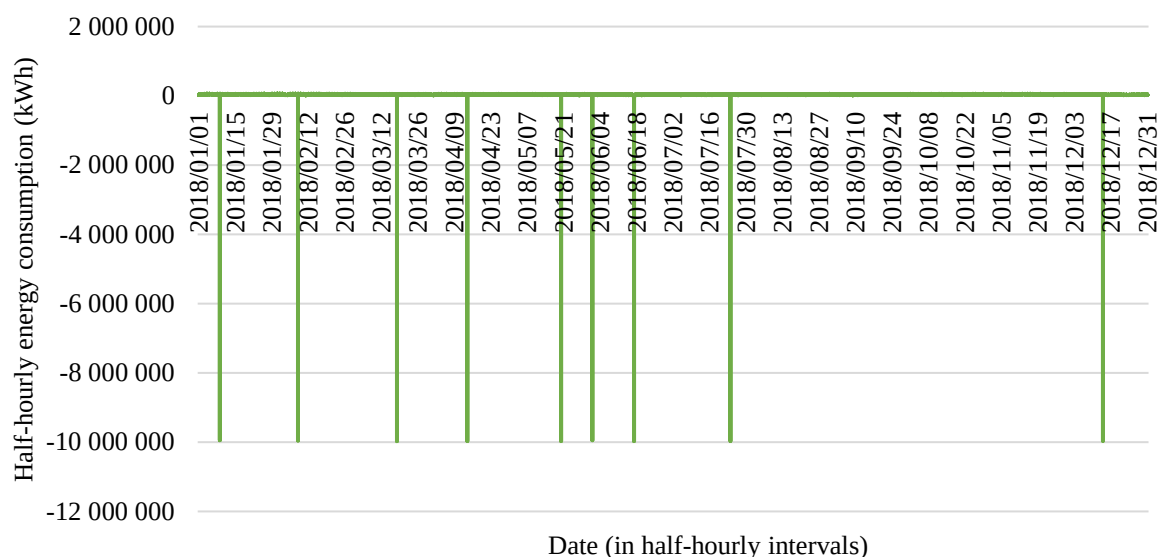


Figure 3-7: Energy for compressor in case study 1 (including errors)

Figure 3-7 shows that there were nine spikes (all of relatively the same size) observed on the compressor. It is also noted that all of these spikes are negative. Since the compressor cannot consume a negative amount of energy, this data can be seen as power meter mistakes and should be addressed in the dataset before being developing the budget. For the case study, this data was replaced with the average energy consumption directly before and directly after the events. The new (alternative) dataset, where the erroneous data was replaced, is presented in Figure 3-8.

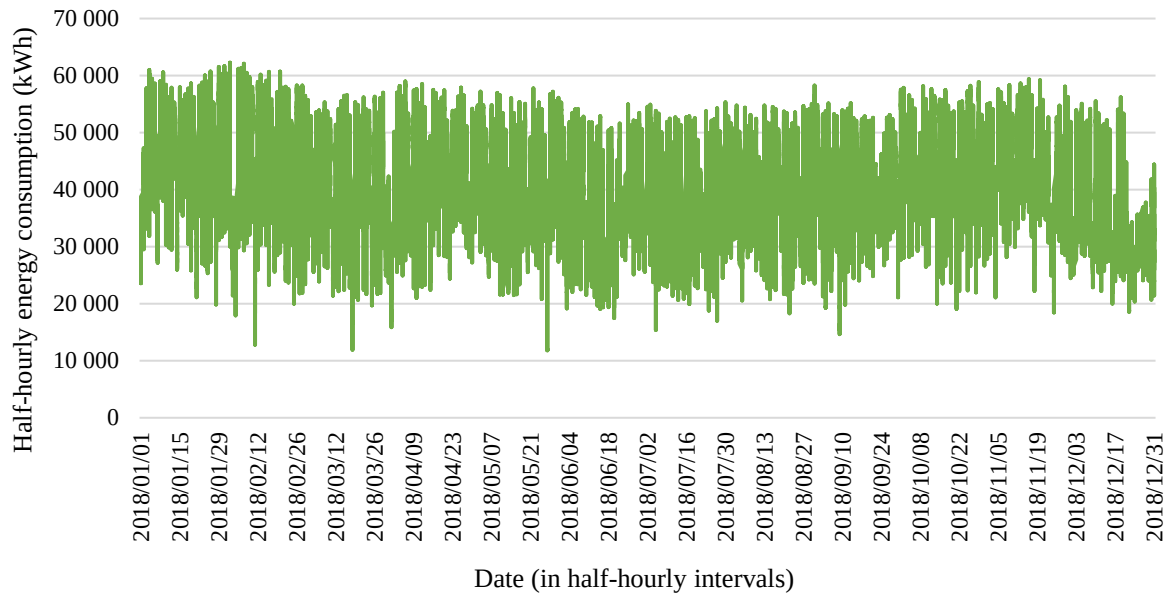


Figure 3-8: Energy for a compressor in case study 1 (excluding errors)

Figure 3-8 illustrates the normal consumption of the compressor on MP5 where the outliers are removed. A more accurate representation of the energy consumption is observed with no negative values that will possibly bias the energy profiles of the compressor.

d) Inspect the data for abnormal/unplanned events

Unplanned events in the baseline dataset can impact the energy predictions since the historical energy is frequently used as the basis for forecasting. For example, the historical energy data of the pumps are used to predict the future energy data for the same pump. If the historical energy data of the pumps are influenced by unplanned events, these unplanned events will therefore resurface in the future predictions for the pumps as well. This emphasises the need to ensure that all unplanned events that occurred in the baseline period are adjusted for.

Figure 3-9 illustrates the energy consumption for the four dewatering pumps at 44 LVL (as indicated on the electrical reticulation layout in Figure 3-2).

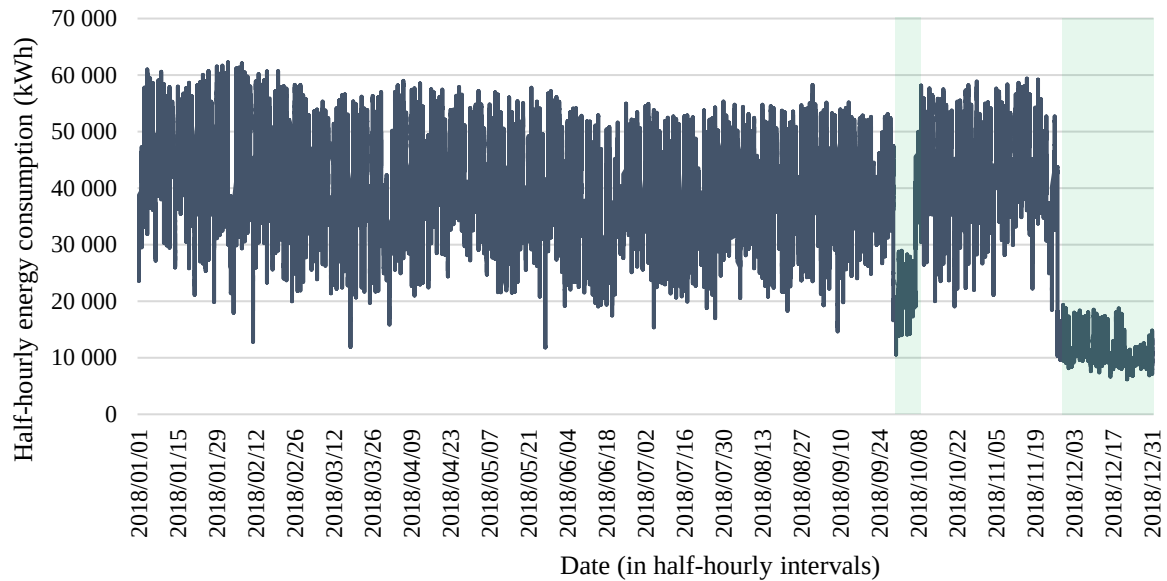


Figure 3-9: Pumping energy in case study 1 (including unplanned events)

Figure 3-9 shows two abnormal trends in the overall dataset. The first decrease is observed from 27 September 2018 until 7 October 2018. A second decrease is observed from 24 November 2018 for the remainder of the year. After an investigation of these two events, it was noted that the first decrease was due to a fatality that occurred on Shaft 1 which resulted in the closure of the shaft for 10 consecutive days. The timeline of the second decrease corresponds to the occurrence of a strike on this particular mine. The strike ensured that the mine could only operate essential components and no production outputs were delivered.

Both these events were unplanned and therefore should be excluded from the dataset before the budget can be developed. This data can either be removed completely or the change can be adjusted for. The adjustment can be calculated as the difference between the normal energy consumption before and after the occurrence of the event. Figure 3-10 presents the replacement of the decreases by the average of the normal consumption during these times.

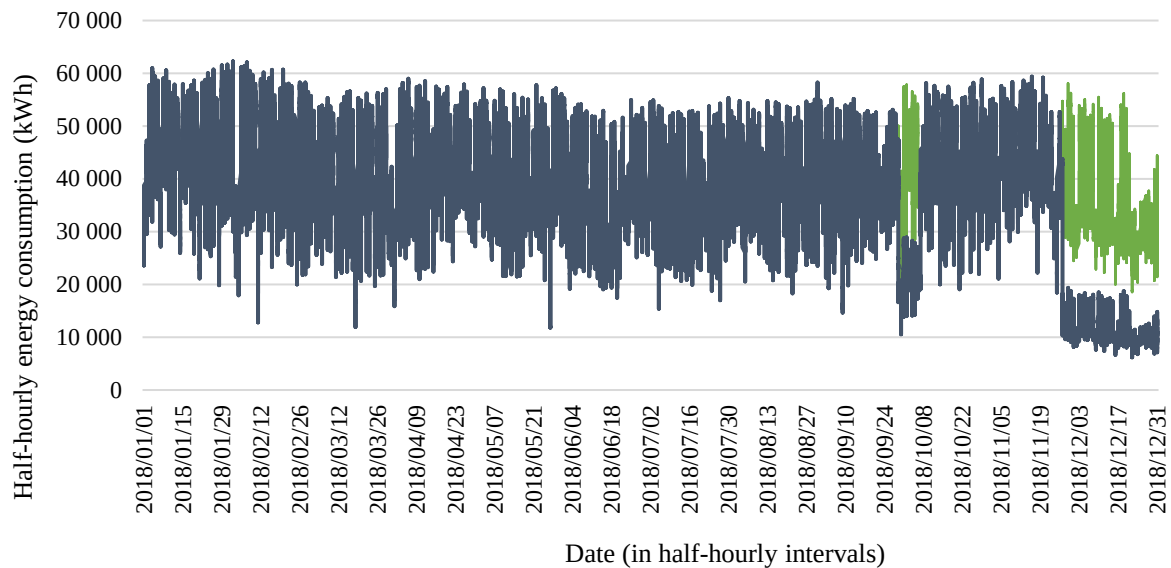


Figure 3-10: Pumping in case study 1 (unplanned events replaced)

The *new general* data (green graph in Figure 3-10) also shows a decrease at the end of December 2018. This decrease is specifically included to allow for the normal decrease in energy consumption observed due to the Christmas holidays. The decrease is calculated as the typical percentage decrease from the first part of December and the Christmas period (a 60% decrease was typically observed from previous years).

STEP-4: ROUTINE ADJUSTMENTS

Routine adjustments are the adjustments included in the budgets for all the planned changes. This includes changes for production, savings projects, growth projects, etc. It should be noted that there is a significant difference in the way that M&V adjusts a baseline for routine adjustments, and the way in which this is accounted for in budgeting. For M&V applications, routine adjustments are applied based on actual data of events that already occurred. However, in order to develop a budget, estimations of the variables for which routine adjustments should be made are required. For this reason, factors such as the expected production for a future period will need to be considered, for example.

This step of the methodology is broken up into two subsections a) considering all relevant variables (these variables are the planned operational changes such as an increase in the depth of the mine) and b) improved methods for quantifying the associated effects. This ensures that all the relevant variables are firstly considered to ensure that adjustments are made for all the variables that could affect the budget and then also the method of quantifying this effect. Each of the two subsections is addressed individually.

a) Consider all relevant variables

The first step is to identify which variables should be considered to develop the budget (the budget is developed for the assessment period 2019). This is done by evaluating all the external effects of the

individual components. The application will be illustrated on FP1, as an example. The energy consumption of FP1 is evaluated and compared with various factors that could potentially affect the energy consumption of this fridge plant. The factors that will be considered are:

- 1) *Changes in production*, since a reduction/increase in production is observed to slightly impact the amount of water required down the mine. This, in turn, effects the amount of cooling required for the water requirements.
- 2) *The energy consumption of FP1 and FP2*: this is to ensure that these fridge plants does not carry any of FP1's load and vice versa.
- 3) *The change in ambient temperature*, since colder temperatures would require the fridge plants to reduce the energy required for cooling.
- 4) *The number of employees*, since the cooling requirements can be different depending on the intensity of the workload (workload intensities differ between the various types of days which is determined by the number of employees present on the mine).
- 5) *The depth of the mine*, since the deeper the mine, the more cooled water will be required which will result in the fridge plants producing more cold-water outputs.

No changes in savings or growth projects are considered since there are no planned savings or growth projects allocated for 2019 on the fridge plant. The R^2 for each of the variables listed above are presented in Table 3-1 to identify which of the variables should be included in the evaluation and should be considered for routine adjustments.

Table 3-1: Correlation between FP1 and other variables

	R^2 value	Important? ($R^2 > 0.75$)
<i>Production</i>	0.7982	Yes
<i>Energy consumption of FP2</i>	0.6521	No
<i>Ambient temperature</i>	0.8532	Yes
<i>Number of employees</i>	0.4563	No
<i>Depth of mine</i>	0.0523	No

From

Table 3-1 it is noted that only production and ambient temperature have important/significant effects on the energy consumption of FP1. For example, Figure 3-11 presents the correlation between the energy consumption of FP1 and the production outputs of Shaft 1.

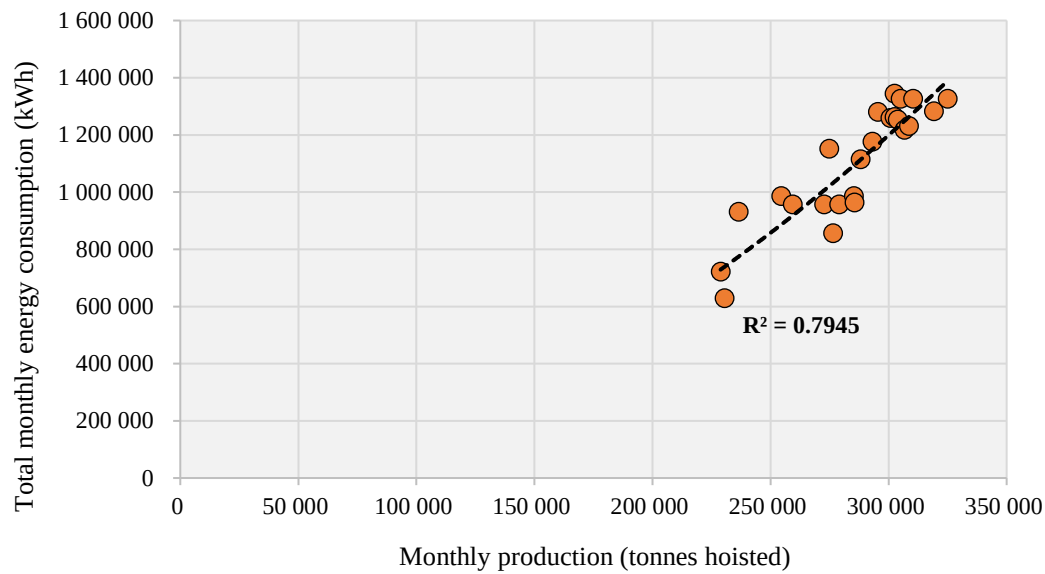


Figure 3-11: Fridge plant energy and production

The correlation between the energy consumption of FP1 and the total production of Shaft 1 is 79.82%. A R^2 value higher than 0.75 is considered significant. For this reason, changes in production should be accounted for when developing the budget for FP1. Similar relationship graphs were compiled for the remaining four variables.

The effects of both these variables (production and temperature) are calculated in the next subsection. A similar technique is applied to all the remaining components for Mine #1 as well.

b) Quantification of the relevant variables

Table 3-1 presented the correlations between FP1 and the various listed variables. From the R^2 values it was seen that only the correlations with production and the ambient temperature are significant. The effects of both these variables are evaluated in the discussion below.

Quantifying the effect of production on the energy consumption of FP1

To predict the effect that changes in production will have on the energy consumption of FP1, both the tonnes hoisted and the energy consumption data for FP1 are required. For this evaluation, weekly interval data will be considered to allow for stockpiling. Table 3-2 presents the weekly production and energy consumption for a duration of 3-months (1 June 2018 until 31 August 2018). These dates were chosen since no other operational changes were recorded that could potentially affect the energy consumption of FP1.

Table 3-2: Routine adjustment data for FP1

Week number	Date	Production (tonnes hoisted)	FP1 Total energy (kWh)
Week 1	1-Jun to 7-Jun	157 066	230 569
Week 2	8-Jun to 14-Jun	180 231	236 413
Week 3	15-Jun to 21-Jun	194 058	259 077
Week 4	22-Jun to 28-Jun	201 312	244 491
Week 5	29-Jun to 5-Jul	225 362	272 699
Week 6	6-Jul to 12-Jul	239 058	274 846
Week 7	13-Jul to 19-Jul	239 080	285 243
Week 8	20-Jul to 26-Jul	240 804	288 173
Week 9	27-Jul to 2-Aug	246 413	259 445
Week 10	3-Aug to 9-Aug	246 413	285 524
Week 11	10-Aug to 16-Aug	278 481	293 082
Week 12	17-Aug to 23-Aug	287 808	276 469
Week 13	24-Aug to 31-Aug	293 982	295 468

Four types of models are created for the dataset. These models are:

- i. Energy intensity model (Equation 1-1)
- ii. Linear regression model (Equation 2-2)
- iii. Power model (Equation 2-3)
- iv. 3rd degree polynomial model (Equation 2-4)

The actual energy and the forecasted energy for each of these models are presented in Figure 3-12.

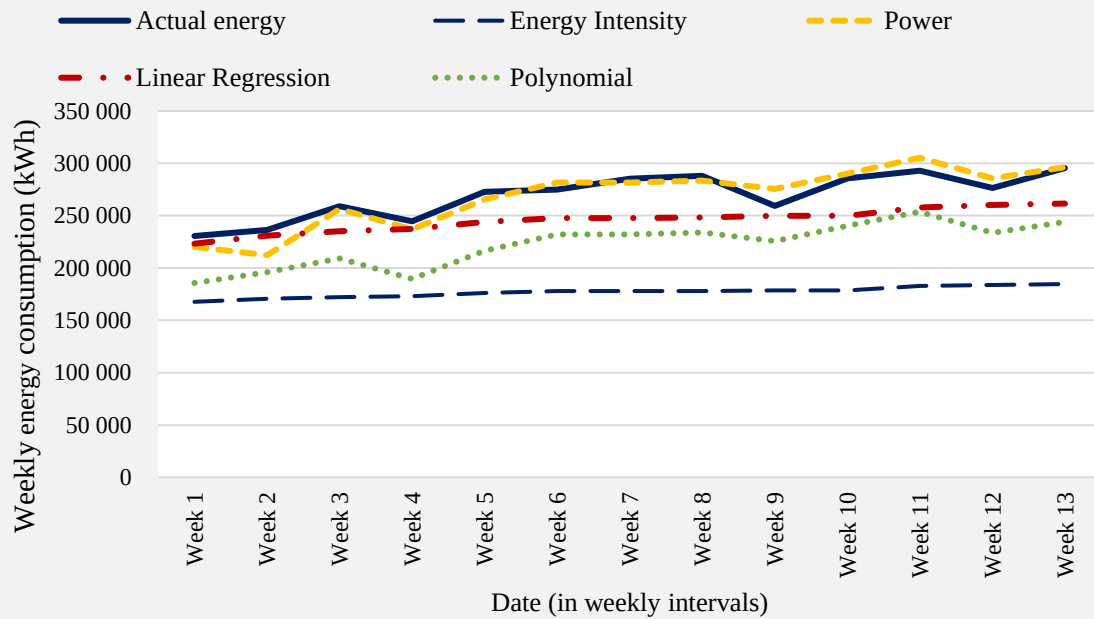


Figure 3-12: Model predictions for changes in production

From Figure 3-12, it can be observed that the power model's trend (yellow striped line) is very similar to the actual energy consumption of FP1 (solid blue line). The energy intensity model's forecast energy (striped blue line), however, shows the greatest difference to the actual energy consumption. The R^2 , CV(RMSE) and AAE% of each of the models are presented in Table 3-3. The R^2 , CV(RMSE) and AAE% are based on a validation sample dataset applied to the model (data not used within the modelling process).

Table 3-3: Production model validation results

	Energy intensity model	Power model	Linear regression model	Polynomial model
R^2	0.231	0.745	0.563	0.302
CV(RMSE)	30.22	8.23	12.44	5.22
AAE %	32.4%	2.31%	4.86%	8.31%

An R^2 value higher than 0.75, a CV(RMSE) smaller than 15% and an AAE% smaller than 5% was desired (the ranges of these variables are discussed in Section 1.2). From Table 3-3 it is evident that the power model produced the best fitting of the data and complies with all three of the set standards. The power model is presented in Equation 3-3.

$$Energy_{FP1} = 2.623(Production)^{0.125} \quad \text{Equation 3-3}$$

Equation 3-3 can now be used to predict the energy consumption for FP1 based on the planned production outputs. The difference between the calculated energy and the historical energy will, therefore, be the adjustment that will ultimately be included in the budget for FP1. Figure 3-13 illustrates how the changes in production are accounted for in the 2019 budget.

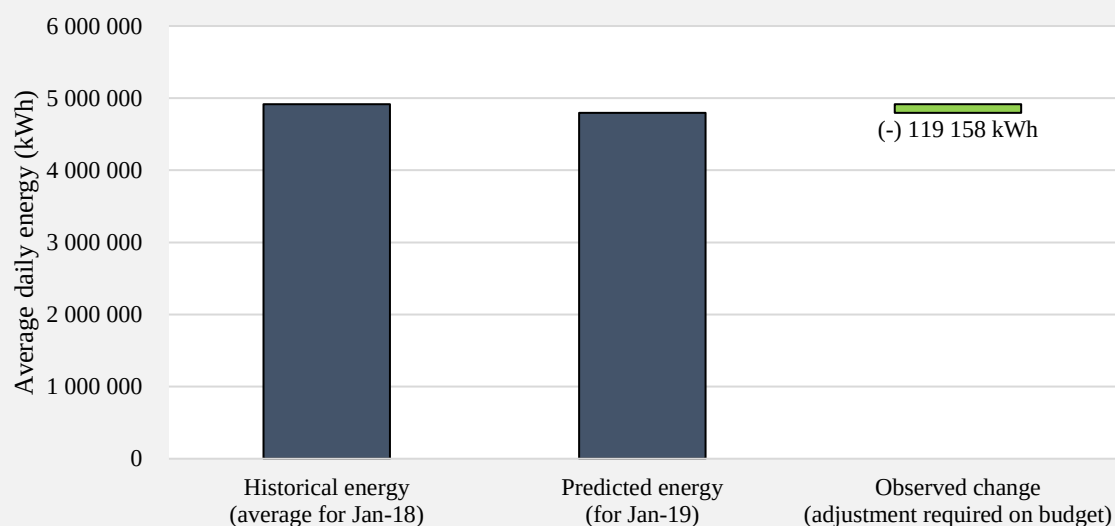


Figure 3-13: Daily energy adjustment required for production changes in January

Figure 3-13 illustrates the energy consumption for January 2018 along with the predicted energy consumption for January 2019 (based on the forecasted production figures). The difference between the historical energy consumption and the actual energy consumption (shown in the green bar in the figure) are used to account for the change in production in the 2019 budget.

Quantifying the effect of temperature on the energy consumption of FP1

The change in temperature is seen to have an effect on the energy consumption of FP1. However, future temperatures cannot necessarily be predicted, and the average seasonal temperatures are relatively constant from year to year [41]. Developing a model to predict the energy consumption based on temperatures would, therefore, not be possible. It is recommended to rather use representing historical energy when developing the budget.

For example, when developing the budget for a weekday in January 2019, rather use the historical average weekday energy of January 2019 as opposed to using the average energy consumption of the whole year (2018). This will ensure that the temperature observed in the basis month (January 2018) is representative of the temperatures in the assessment month of the budget (January 2019).

Figure 3-14 displays the daily changes in energy and temperature observed in 2018 (the base year).

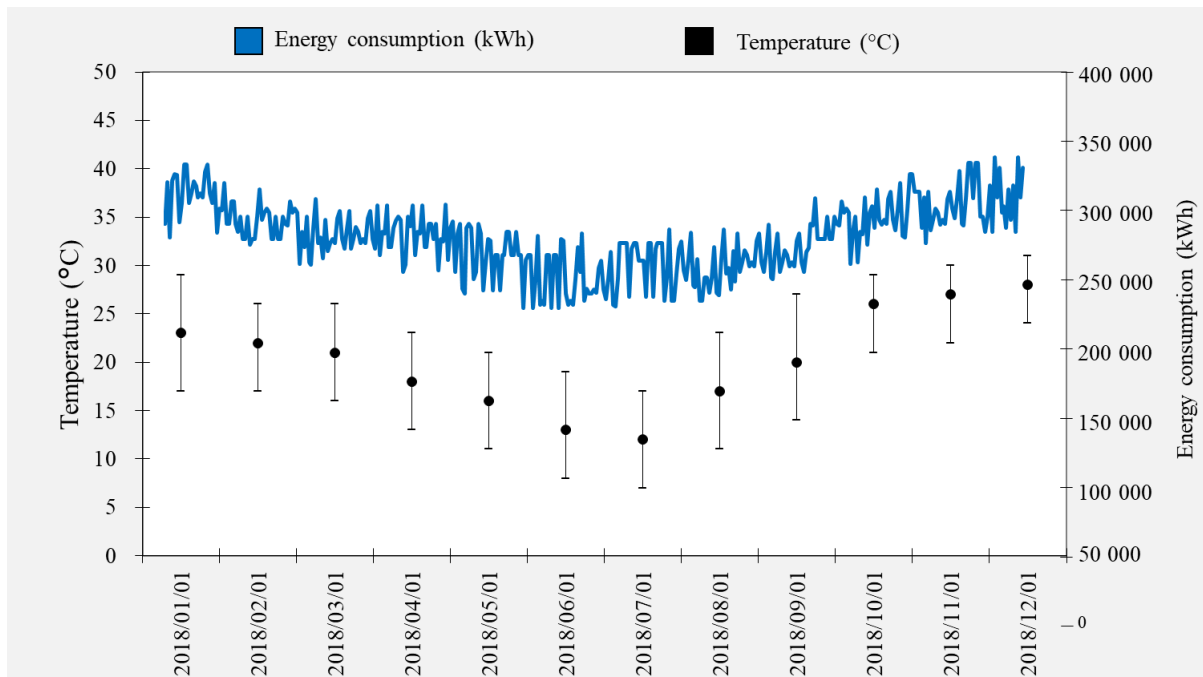


Figure 3-14: FP1 energy and ambient temperature for 2018

The black circles in Figure 3-14 illustrate the average ambient temperature for the month. The maximum and minimum temperatures are indicated with the stripes connected to the circles. The blue line in the figure illustrates the daily energy consumption of FP1 in kWh. From Figure 3-14 it is observed that the energy required by the fridge plant reduces as the temperature reduces, and vice versa.

Using for example the average of the whole year to predict a single month's energy consumption will ensure that the predicted energy will be too low in the summer months and too high in the winter months. It is therefore decided to narrow the effect of temperature down to individual months when developing the budget.

The improved structure allows for the development of several models. This, in turn, ensures that the most suitable model can be used to quantify the effect of the routine adjustment. These effects can now be incorporated into the budget development step (Step-5).

STEP-5: BUDGET DEVELOPMENT

The original budget of Mine #1 was developed by considering a simple direct relationship between the historical energy consumption and certain assumptions on the effect of planned projects and changes in production. The new budgeting structure will consider various other external effects (quantified effects and not merely assumptions) along with predictive modelling techniques. The developed energy budget will finally be converted into a costing budget by incorporating Eskom TOU profiles.

The budget *application* will be demonstrated on FP1 for Shaft A in detail as an example. The *results* of this step (Step-5 of the improved budgeting structure), however, will also be illustrated for the budget

for 1) the whole fridge plant commodity, 2) the total budget for Shaft A and 3) the total budget for Mine #1.

Application of Step-5 on a single component: FP1

The new budgeting formula (presented by Equation 2-7 in Section 2.3) was adapted to calculate the 2019 energy budget for FP1 and is presented by Equation 3-4.

$$\text{Budget}_{\text{FP}} = (\text{Historical Energy})_{\text{FP}} \pm (\text{Routine Adjustments})_{\text{FP}} \pm (\text{Variances})_{\text{FP}} \quad \text{Equation 3-4}$$

where:

$\text{Budget}_{\text{FP}}$	The 2019 budget for FP1; in kWh
$(\text{Historical Energy})_{\text{FP}}$	The 2018 actual energy consumption for FP1; in kWh
$(\text{Routine Adjustments})_{\text{FP}}$	The adjustments calculated in Step-4; in kWh
$(\text{Variance})_{\text{FP}}$	The variance calculated using Equation 2-8; in kWh

This formula is applied to each half-hour resolution for each type of day specified in Step-2 of the improved budgeting structure. Figure 3-15 illustrates the historical energy for FP1 for the average weekday in January 2018, alongside with the respective 2018 budget for FP1 for the same time period.

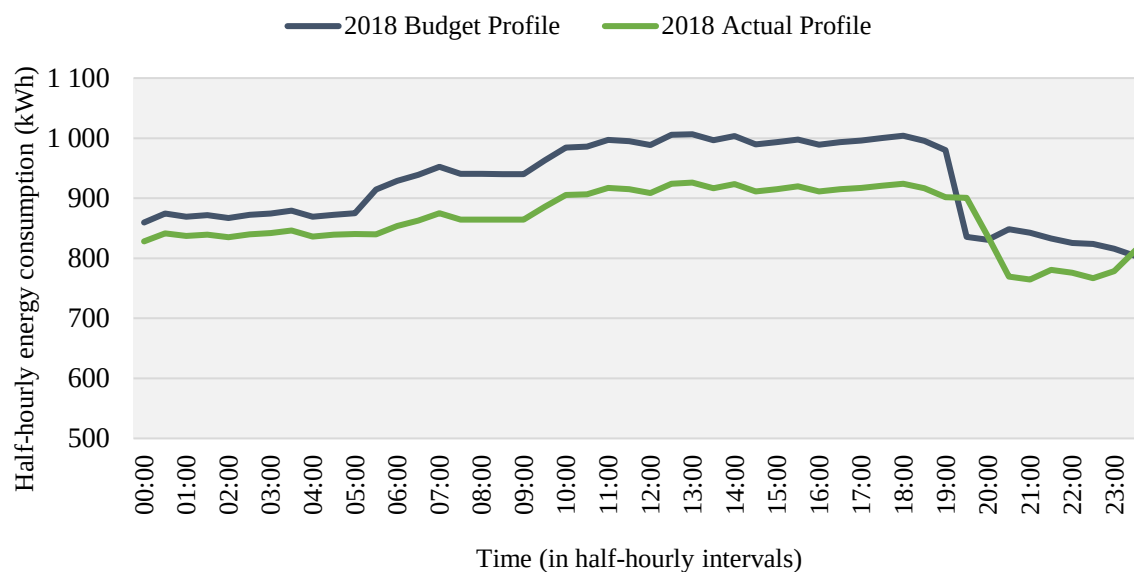


Figure 3-15: FP1 2018 budget and actual energy consumption

The total variance between the average weekday in January in the 2018 budget and that of the 2018 actual energy consumption is calculated as 2 824 kWh (6.4%). This indicates that the budget for FP1 for 2019 should include on average a 6.4% variance to allow for future unplanned events (non-routine adjustments).

The routine adjustments were identified as the effect of 1) production and 2) temperature in Step-4 of the new structure. The modelling of the production changes was observed to be 119 158 kWh for an

average day in January 2019. This adjustment was calculated using the forecasted production figures for Mine #1. To allow for the change in temperature, caution was taken to ensure that seasonal effects were included by using specific months for the basis of the budget predictions.

These values are used to calculate the half-hourly budget for FP1 for a weekday profile in January 2019. The result is presented in Figure 3-16, which also includes the 2018 Budget and Actuals (as presented in Figure 3-15).

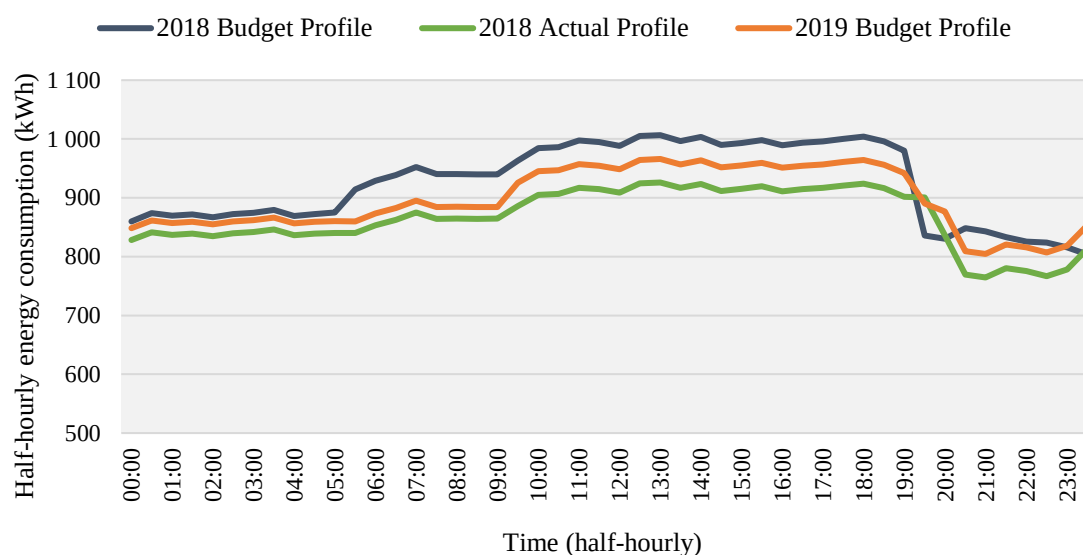


Figure 3-16: FP1 2018 Budget and actual energy with 2019 budget

Finally, the energy budget is converted into a costing budget using the Eskom TOU tariffs for 2018 (2019 Eskom tariffs would not be available yet since the budget is typically signed off before these tariffs are published). An expected tariff increase is applied to the 2018 tariffs that will be used to predict the 2019 tariffs. For the 2019 budget an expected tariff increase of 13% will be used. Table 3-4 presents the 2018 half-hourly Eskom tariffs for a weekday in January as well as the tariffs that will be used for the budget where the 13% increase is applied.

Table 3-4: Eskom TOU tariffs with expected increases for 2019

Time	2018 Eskom TOU tariff	2018 Eskom TOU tariff (plus expected increases)	Time	2018 Eskom TOU tariff	2018 Eskom TOU tariff (plus expected increases)
00:00	R0.73	R0.82	12:00	R1.22	R1.38
00:30	R0.73	R0.82	12:30	R1.22	R1.38
01:00	R0.73	R0.82	13:00	R1.22	R1.38
01:30	R0.73	R0.82	13:30	R1.22	R1.38
02:00	R0.73	R0.82	14:00	R1.22	R1.38
02:30	R0.73	R0.82	14:30	R1.22	R1.38
03:00	R0.73	R0.82	15:00	R1.22	R1.38
03:30	R0.73	R0.82	15:30	R1.22	R1.38
04:00	R0.73	R0.82	16:00	R1.22	R1.38

Time	2018 Eskom TOU tariff	2018 Eskom TOU tariff (plus expected increases)	Time	2018 Eskom TOU tariff	2018 Eskom TOU tariff (plus expected increases)
04:30	R0.73	R0.82	16:30	R1.22	R1.38
05:00	R0.73	R0.82	17:00	R3.71	R4.19
05:30	R0.73	R0.82	17:30	R3.71	R4.19
06:00	R3.71	R4.19	18:00	R3.71	R4.19
06:30	R3.71	R4.19	18:30	R3.71	R4.19
07:00	R3.71	R4.19	19:00	R1.22	R1.38
07:30	R3.71	R4.19	19:30	R1.22	R1.38
08:00	R3.71	R4.19	20:00	R1.22	R1.38
08:30	R3.71	R4.19	20:30	R1.22	R1.38
09:00	R1.22	R1.38	21:00	R1.22	R1.38
09:30	R1.22	R1.38	21:30	R1.22	R1.38
10:00	R1.22	R1.38	22:00	R0.73	R0.82
10:30	R1.22	R1.38	22:30	R0.73	R0.82
11:00	R1.22	R1.38	23:00	R0.73	R0.82
11:30	R1.22	R1.38	23:30	R0.73	R0.82

In Table 3-4, the green cells indicate the off-peak periods, the yellow cells indicate the standard periods and the red cells indicate the peak periods. These tariffs are used to calculate the 2019 cost budget for each half-hour for the weekday profile in January. Figure 3-17 illustrates both the energy and the cost budget for FP1.

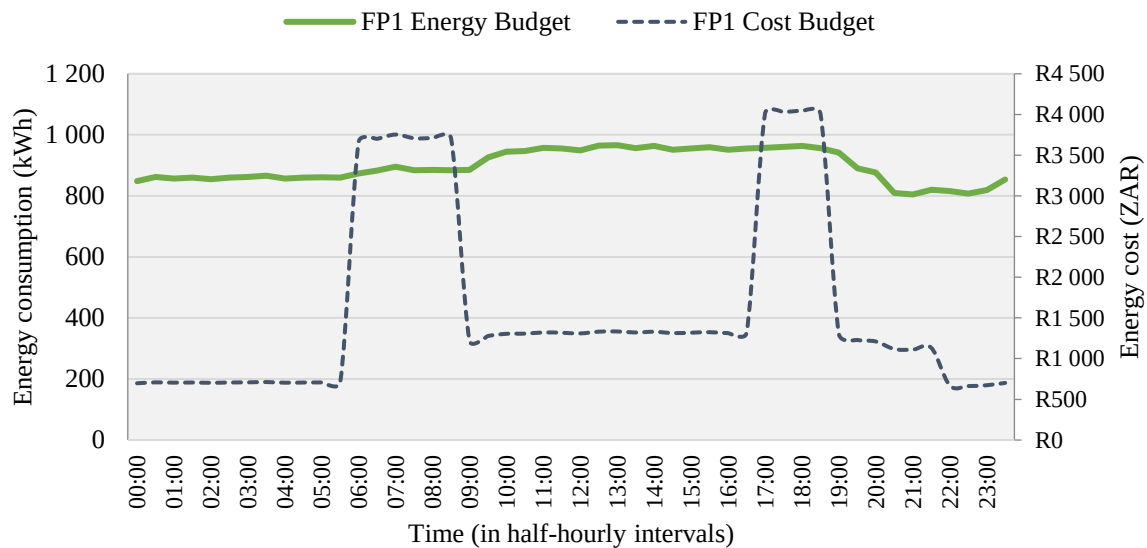


Figure 3-17: Average January 2019 weekday budgets for FP1

These steps are applied to remaining weekday-types as well (Saturday, Sunday, Public Holidays, etc.). Ultimately a total 2019 budget is compiled for FP1. The total energy budget and total costing budget for 2019 for FP1 is displayed in Figure 3-18 and Figure 3-19.

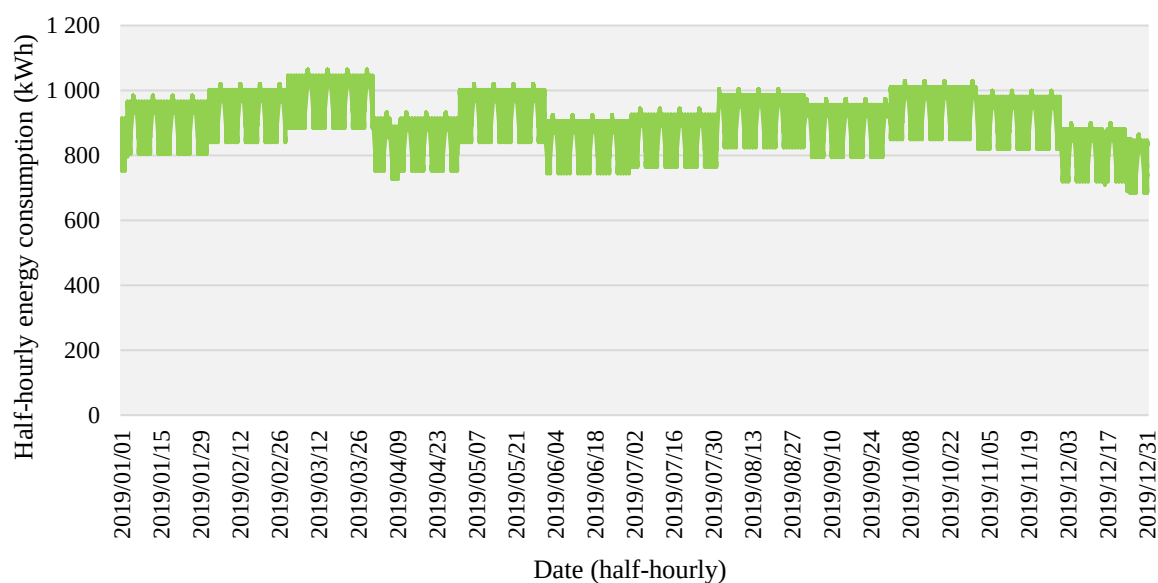


Figure 3-18: FP1 2019 half-hourly energy budget

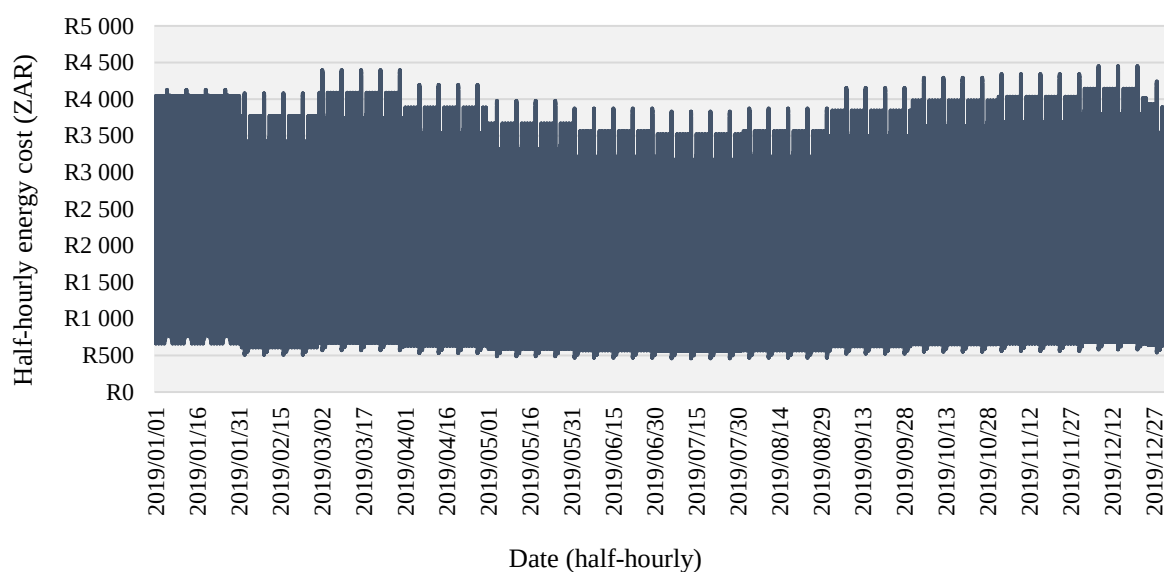


Figure 3-19: FP1 2019 half-hourly cost budget

The budget for FP1 allows for the half-hourly evaluation of the energy consumption on the budget. Figure 3-20 illustrates the budget for a day in June 2019 along with the actual energy consumption for the same day. At 06:30, the fridge plant started to consume almost 40% more than its expected energy consumption. The respective personnel could be notified immediately, and action was taken.

Two hours later (08:30) the fridge plant operated as normal again. This proves the added benefit of the budget and helps with the energy management of the components.

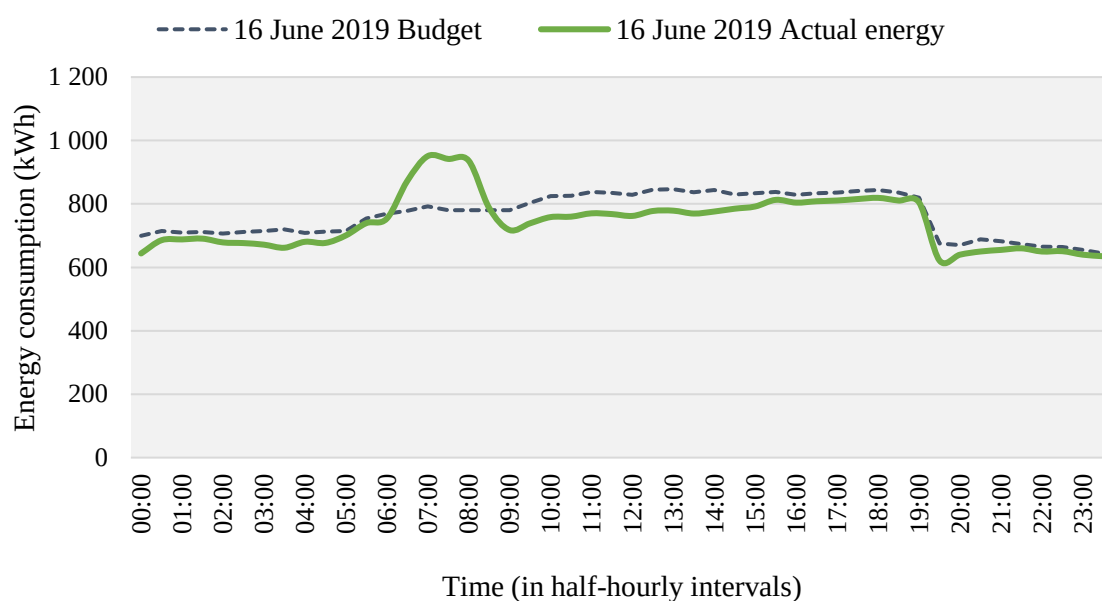


Figure 3-20: Specific day budget and actual comparison

Results of Step-5 on whole commodity: All the fridge plants for Shaft A

The above steps are applied to all the remaining fridge plants on Shaft A as well. The average weekday budget profile for January 2019 for the Refrigeration commodity is presented in Figure 3-21.

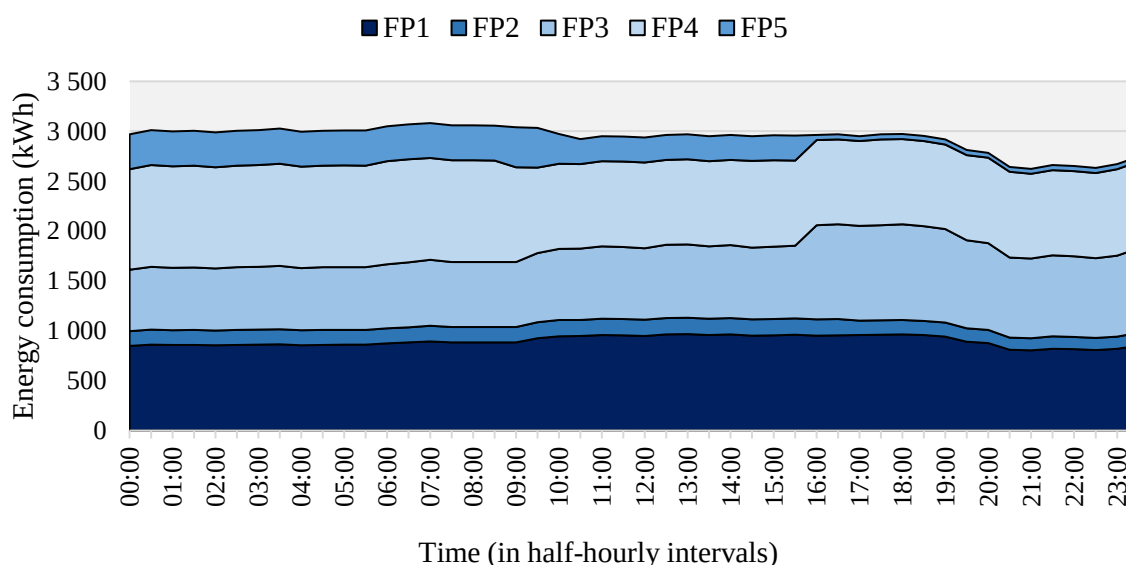


Figure 3-21: Refrigeration budget for an average weekday in January 2019

From Figure 3-21, the total energy consumption of each fridge plant can be observed, whilst monitoring the whole commodity. This means that when the refrigeration commodity goes over the budget, it can easily be identified which fridge plant increased in energy consumption. This makes the energy management of the fridge plants more user friendly.

The construction of the budget is shown in Figure 3-22 for the whole year (2019). The purpose is to compare the performance of the budget to the actual energy consumption of 2019. This figure further allows for the assessment of each fridge plant's performance. The original budgeting structure was only able to identify whether there were any savings or losses, where the new budgeting structure is able to address the source of the savings or losses as well.

Figure 3-22 indicates the number of non-routine adjustments included per fridge plant along with the variances from historical budgets. The first bar (2018 Actual Energy) indicates the actual energy consumption in 2018 where the different colour bars indicate the energy consumption of each fridge plant respectively. The 2019 budget (per fridge plant) can now be easily assessed against the actual energy consumption for 2019 (per fridge plant).

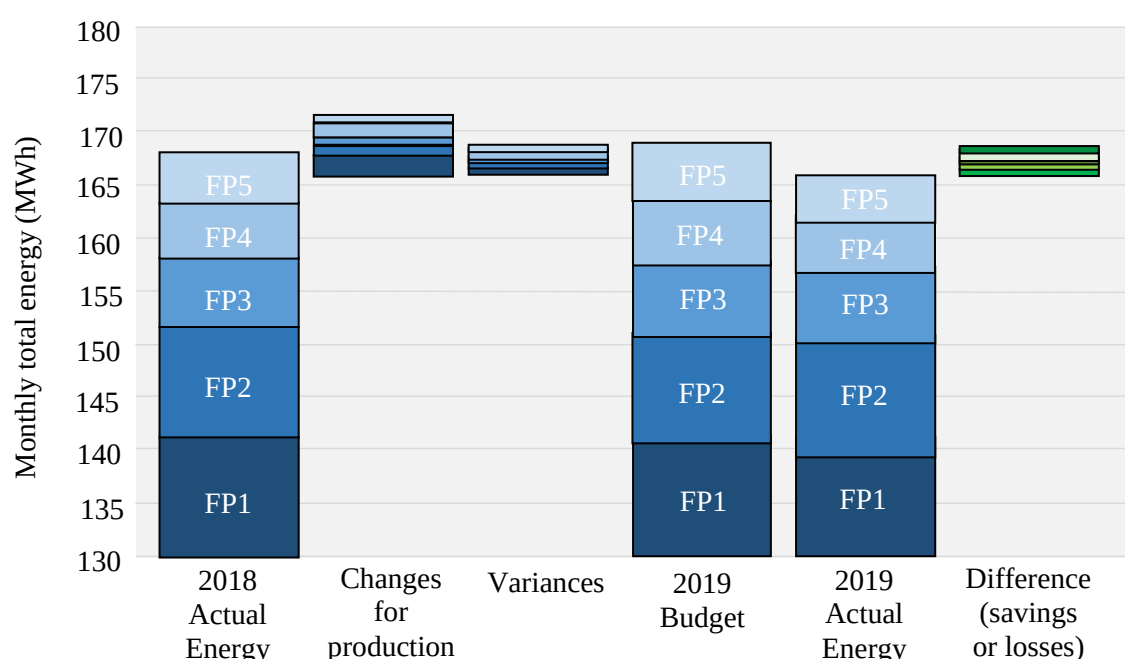


Figure 3-22: Annual break up for the Fridge Plant Budget

From Figure 3-22 it is observed that all of the fridge plants presented savings (the green bars at the far right of the figure). This figure ultimately proves that a budget could be successfully developed for the fridge plan commodity (the group of fridge plants).

Results of Step-5 for the total shaft: Shaft A

The above steps are applied to all the components of Shaft A to ultimately produce commodity energy consumption budget profiles, as presented in Figure 3-23, for all of the shaft's commodities. These commodity budgets for 2019 can be added together to obtain the shaft total budget for 2019. Figure 3-23 illustrates the budgeted energy consumption for a weekday in January 2019 for Shaft A.

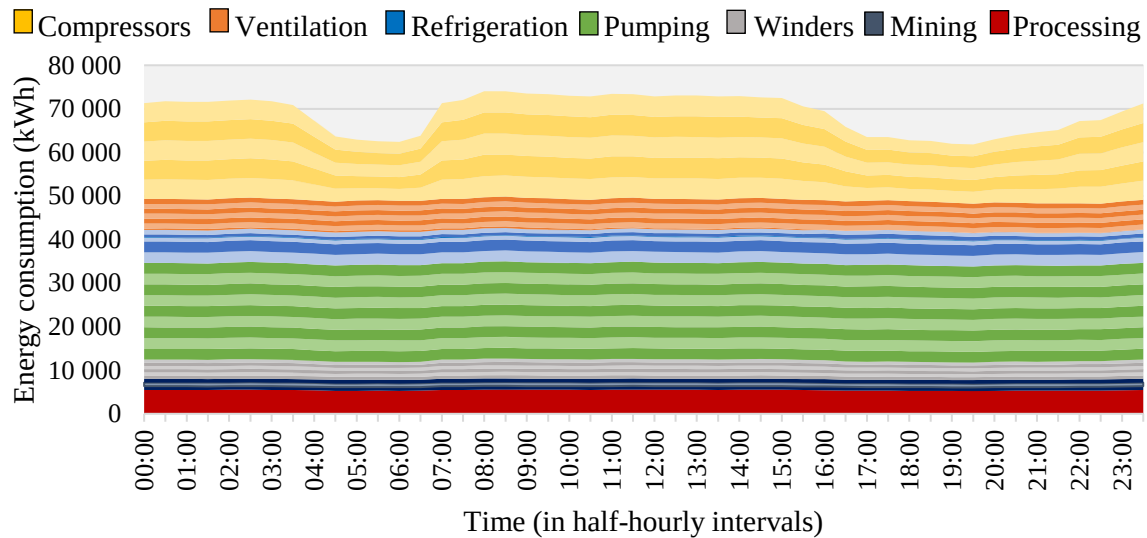


Figure 3-23: Shaft A budget for an average weekday in January 2019

From Figure 3-23, the total shaft's energy budget can be seen, along with the distribution of the budget between each commodity. Each shade of colour in Figure 3-23 represents a different component in that commodity. This can be further narrowed down by the distribution of each component as well. This allows for the energy management of the whole shaft in half-hourly resolutions.

Results of Step-5 for the total mine: Mine #1

All of the above steps were applied to each of the four shafts and the one plant that forms part of Mine #1. Figure 3-24 provides the budget for a weekday profile in January for the whole of Mine #1.

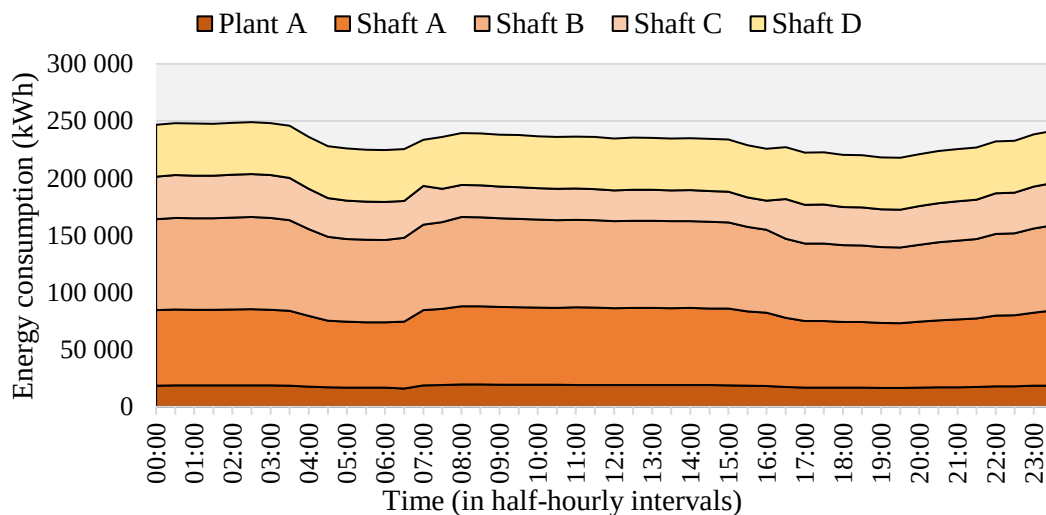


Figure 3-24: Mine #1 total budget for a weekday in January 2019

Figure 3-24 provides the total budget for the mine for a weekday. If required, it can also provide the breakdown of the budget for each shaft/plant, each commodity and each component. These daily budgets can be added together to obtain a monthly total budget for Mine #1. This in turn can be added together to obtain a total annual budget for Mine #1.

STEP-6: ASSURANCE

This step is included in the budgeting structure to give assurance to the person signing off on the budget that the budget is correctly calculated. The purpose of this step is, therefore, to capture the general steps followed and the results within a well-refined report. The key element of the report is to enable the traceability of the budgeting plan, much like what an M&V plan does for a baseline.

For the application of this step on case study 1 a *Budget Report* is compiled. This report is, in essence, a summary of the application process of the previous five steps discussed in this section. The purpose of this report is to allow an independent person to audit the budgeting process before approving the budget. The transparency of the budgeting process will ensure that the final approved budget is correct and gives creditability to the application thereof. The Budget Report is presented and briefly discussed below for the application of FP1 only.

BUDGET REPORT FOR FRIDGE PLANT 1 (FP1)

1) Budget description *(summary of step-1 and step-2 of the new framework)*

The budget is developed for the fridge plant specifically (isolated boundary) in half-hourly resolutions.

2) Assumptions and data changes *(summary of step-3 of the new framework)*

No missing data or outliers were identified on the fridge plant; therefore, no data points were removed. The only assumption made was that the average monthly ambient temperature of 2019 (the assessment period) will be similar to the average monthly ambient temperature of 2018 (the baseline period).

3) Calculations and adjustments *(summary of step-4 of the new framework)*

Correlations between changes in production and temperature were observed to impact the energy consumption of FP1. A power model was developed that accounts for the changes in production. For the changes in temperature the assumption was made that the average monthly temperatures from 2018 to 2019 remain similar. This assumption made it possible to develop power models (for production changes) for each specific month's half-hourly energy data; this ensures that the adjustment made for non-routine events includes both the changes in production and the changes in temperature.

4) Budgeting plan *(summary of step-5 of the new framework)*

The budget for FP1 was calculated by Equation 3-4 (refer to step-5 in Section 3.3). The historical variance between the budget and actual energy consumption was accounted for to allow for possible unplanned events in the assessment period.

5) Accuracy and quality assurance (summary of the verification of the new framework)

The methodology used to develop the budget for FP1 is verified in Section 2.4 which gives assurance that the budget is accurate.

6) Reporting (overall summary of the budget proposal)

The budget report presents a summary of the steps taken to develop the energy budget for FP1. These steps were verified, and the budget obtained for 2019 is representative of the historical energy consumption of FP1.

The purpose of the budget proposal presented above was to capture the general steps followed and the results within a well-refined report. The key element of the report is to enable the traceability of the budgeting plan, much like what an M&V plan does for a baseline. The budget proposal, therefore, gives a summary of how the results presented in this chapter achieve the objectives set out in Section 1.4.

3.3.2 RESULTS OF CASE STUDIES 2 TO 8

The application of the new budgeting structure on case study 2 to case study 8 is presented in Appendix E. This section of Chapter 3, therefore, only presents the results obtained from the application of the improved structure on the case studies. Only relevant results are discussed in this section. Table 3-5 presents the findings when the case studies were evaluated with the improved structure.

Table 3-5: Results for case studies 2 to 8

	Mine #2	Mine #3	Mine #4	Mine #5	Mine #6	Mine #7	Mine #8
Step-1: Boundary	Per component	Per component	Per component	Per component	Per component	Per component	Per component
Step-2: Resolution	Half-hourly	Half-hourly	Daily	Monthly	Daily	Half-hourly	Half-hourly
Step-3: Data quality	Data evaluated and correct	Data evaluated and correct	Data evaluated and correct	Data evaluated and correct	Data evaluated and correct	Data evaluated and correct	Data evaluated and correct
Step-4: Adjustments	Projects, production and seasons	Projects, production and seasons	Projects, production and seasons	Projects, production and seasons	Projects, production and seasons	Projects, production and seasons	Projects, production and seasons
Step-5: Budget	Included all relevant variables and variances	Included all relevant variables and variances	Included all relevant variables and variances	Included all relevant variables and variances	Included all relevant variables and variances	Included all relevant variables and variances	Included all relevant variables and variances

	Mine #2	Mine #3	Mine #4	Mine #5	Mine #6	Mine #7	Mine #8
Step-6: <i>Assurance</i>	<i>Reporting in place</i>	<i>Reporting in place</i>	<i>Reporting in place</i>	<i>Reporting in place</i>	<i>Reporting in place</i>	<i>Reporting in place</i>	<i>Reporting in place</i>

Table 3-5 shows that the improved budgeting structure could be applied successfully on all of the remaining mine case studies. An isolated component boundary was used for all remaining mines, similar to the application on Mine #1. An isolated boundary was used to enable the budgets to be used for energy management purposes as well.

All of the budgets were also created in half-hourly profiles to incorporate the TOU profiles for each type of day (weekday, Saturday, Sunday, Public Holidays, etc.). The budgets were all created in these high resolutions to ultimately enable the comparison of the performance of each original budget (which was created in monthly resolutions) with the high resolutions.

The data for all case studies were evaluated for missing data and outliers. Erroneous data entries were addressed accordingly and removed from the dataset. The abnormal events that occurred in the baseline period were also identified and removed. Ultimately, the models developed in Step-4 and Step-5 were based on quality datasets.

The routine adjustments were mainly identified as changes in production, expected planned and growth projects, changes in temperature and finally, changes in the number of crews. These changes were identified by evaluating the relationship that these variables had with the energy consumption. If a strong correlation ($R^2 > 0.75$) was observed, the relationship was established. Various models were then applied to the data to present the model with the smallest CV(RMSE).

Finally, the budgets were developed and included the required variances. The budgeting process was also documented in a formal budget proposal for assurance. The formal documentation of the budgeting procedure allows for assurance when the budget needs to be approved by a third party. The successful application of the new, improved structure verifies the methodology presented in Chapter 2. The monetary impact of the case studies is presented in the following section.

3.4 VALIDATION OF THESIS

3.4.1 CONFORMITY OF THE NEW STRUCTURE TO NEED FOR THE STUDY

Chapter 1 highlighted an important need to link well-established M&V principles to the current budgeting structures used by South African mines in order to prevent the mine budgets from becoming obsolete by:

- 1. Adapting the boundaries used for the budget;*
- 2. Ensuring that consistent data resolutions are used for all modelling purposes;*
- 3. Evaluating all data for accuracy;*
- 4. Incorporating non-routine adjustments into the budget;*
- 5. Including various models to enable the evaluation of the most suitable budget; and*
- 6. Validating the budget before approval and sign-off of the budget.*

In the following paragraphs it is highlighted how the newly developed structure conforms to the need for the study and how the research is used to decrease and/or manage the associated uncertainty of the current budgets.

1. Adapting the boundaries used for the budgets

The budget boundaries are selected in the first step of the improved structure. Two budget options are presented (individual components and whole facility). The original budgeting structures were developed on whole facility boundaries, but it was identified in Chapter 1 that there is a need to develop the budgets on smaller boundaries. The improved structure was therefore applied on eight case studies where all eight of the applications were developed using smaller boundaries (per individual component).

Developing the budget per individual component allowed for the improved energy management and evaluation of each component by improving the monitoring thereof. The energy trends for each component can be monitored to ensure that if the total performance of the mine is over/under the budget, the reason for the variance can be identified and allocated to a specific component. The original budgeting structure did not allow for this application. Therefore, by creating budgets for higher resolutions the need for this study could be accomplished.

2. Ensuring that consistent data resolutions are used for all modelling purposes

The second step of the improved developed structure allowed for the identification of the budget resolutions (monthly, daily, hourly, etc.). The original budgeting structure developed budgets in low resolution (annually, quarterly or monthly) and therefore neglected small operational changes and any changes that affected the TOU profiles of the components. Chapter 1, therefore, highlighted the need to evaluate budgets in higher resolutions (daily or half-hourly) to ensure that different types of days and TOU profiles could be accounted for.

All eight of the case studies were evaluated in half-hourly resolutions to allow for these small operational changes to be considered. The application of the new structure in half-hourly resolutions allowed for the successful evaluation of each individual component's energy performance on a daily resolution. This further helped to improve the energy management of the mine. The original budgeting structure did not allow for this application. Therefore, by creating the budgets in higher resolutions the need for this study could be accomplished.

3. *Evaluating all data for accuracy*

Chapter 1 highlighted the need to evaluate all the data used to develop the budgets. This is to ensure that accurate and representable data is used for the budgets. The original budgeting structure did not explicitly allow for a data evaluation step in the structure. The improved structure evaluates the data at the hand of four criteria:

- i. Obtain data from calibrated meters*
- ii. Evaluate the dataset for any missing data*
- iii. Evaluate the dataset for any outliers or erroneous data points*
- iv. Evaluate the data for unplanned events*

By including these four criteria into the data processing step of the improved structure the final budget should be more representative. This step therefore ensures that the need for this study is addressed.

4. *Incorporating non-routine adjustments into the budget*

The existing mine budgeting structures only account for expected projects and in some instances for expected changes in the production outputs of the mine. Chapter 1 highlighted the need to ensure that all the relevant parameters are considered, and the effect of these parameters is accurately calculated. The improved structure, therefore, addresses this need by evaluating the external effects of all the components and their surroundings to identify the adjustments to consider. Furthermore, multiple models are considered to predict the effect of the routine adjustments. The most suitable model per component is ultimately used to ensure the accurate quantification of the routine adjustments.

5. *Including various models to enable the evaluation of the most suitable budget*

Step-5 in the improved structure ensures that the budget created is the most suitable budget for the situation. This entails the inclusion of all relevant parameters (routine and non-routine adjustments) as well as the method used for calculating the budget. The need to improve the current approach, where the budget is equal to historical data plus/minus certain assumptions on the expected changes, is established in Chapter 1. In Chapter 3 this need is addressed by ensuring that the budget does not solely rely on historical data and assumptions but rather on representable energy data with adjustments made on calculated effects.

6. *Validating the budget before approval and sign-off the budget*

The original budgeting structure had no means of validating the budget before having it signed off. Chapter 1, therefore, established the need to first validate the budget before deeming it fit for use in the assessment period. The improved budgeting structure, however, includes a validation step where specific attention is given to the validation of the budget before it is signed off. The validation includes the quantification of the uncertainty of the budgets and the comparison of the improved and the original

budgeting structures. The incorporation of a validation step into the budgeting structure (with the improved structure) thus addresses this need identified in Section 1.4.

From this discussion the validation of the work is clear, since it addresses the uncertainty management requirements highlighted in the need for the study in Section 1.4. The newly developed budgeting structure was further validated by the application thereof on eight case studies.

3.4.2 QUANTIFYING THE SIGNIFICANCE OF THESIS

The benefit of this thesis is most apparent in the improvement of the budget predictions when using the improved budgeting structure as opposed to the original budgeting structure. A discussion and evaluation of the impact that the improved structure has on the budgeting of South African mines are, therefore, provided. This is presented as the quantified impact of the combined case studies in Table 3-6.

Table 3-6: Quantified effect of the improved structure on the eight case studies

Case study	Actual 2019 costing (as per Eskom Invoice)	Original budget		Improved structure	
		2019 Annual Whole Facility Cost Budget	Uncertainty range (% variance)	2019 Annual sum of Individual Component Cost Budgets	Uncertainty range (% variance)
Case study 1	R158 981 045	R171 051 733	7.6%	R158 381 235	0.4%
Case study 2	R166 043 595	R176 464 612	6.3%	R163 393 159	1.6%
Case study 3	R168 578 960	R181 205 824	7.5%	R167 783 170	0.5%
Case study 4	R168 850 448	R177 191 660	4.9%	R167 161 944	1.0%
Case study 5	R169 324 613	R186 387 876	10.1%	R172 581 367	1.9%
Case study 6	R170 969 787	R183 764 256	7.5%	R170 152 089	0.5%
Case study 7	R168 698 639	R157 479 986	6.7%	R164 041 652	2.8%
Case study 8	R171 968 226	R178 058 485	3.5%	R170 248 544	1.0%
Total impact	R1.33-billion	R1.41-billion	3.5% - 10.1%	R1.33-billion	0.4% - 2.8%

Table 3-6 indicates the overall quantified impact of this thesis as R81.5-million, as calculated by the difference of the original budget impact and the improved budget impact. The difference in results indicates uncertainty in the quantification of the result. From the arguments in Chapter 1, it is considered important to be transparent in any form of uncertainty. The uncertainty ranges were, therefore, calculated (application of Equation 2-9) and an overall uncertainty range of 0.4% to 2.8% is observed on the new improved structure compared with the uncertainty range of 3.5% to 10.1% on the original budget.

Extrapolation of uncertainty indicators to the total South African mining industry is additionally evaluated. The National Treasury of South Africa published the mineral mining resources budget for the 2019 fiscal year where the total expenditure estimates for 2019/2020 are R3.13-billion rand⁴. With an uncertainty range of 3.5% to 10.1% (as obtained with the original budgeting structure), the potential uncertainty on the mineral mining resources budget for South Africa equates to an average of R212-million.

The improved structure minimises the uncertainty to an average of 1.2% which equates to only R37.5-million. This means that the improved budgeting structure enables the South African mineral mine budget to improve its accuracy by an expected R174.5-million per annum. The extrapolation of these uncertainty indicators presents a significant potential of uncertainty management, while maintaining relevance, consistency, accuracy, completeness, conservativeness and transparency.

The improved accuracy of the new budgeting structure allows for mines to better plan for future expenses. Chapter 1 (Section 1.1) discussed the importance of accurate forecasting and the impact of inaccurate budgets on the life of mine. By improving the budgets of a mine, mines can ensure that enough capital resources are available and that the mine is sustainable.

3.5 CHAPTER CONCLUSION

This chapter presented the application of the newly developed structure (based on well-established M&V principles) on eight individual case studies, each corresponding to the eight mines that participated in the questionnaires of the study. The full application of the improved structure is demonstrated on case study 1 in Section 3.3, where the application on the remaining seven case studies is presented in Appendix E.

The combined impact of the eight case studies equates to R81.5-million, with a quantified uncertainty range of 0.4% to 2.8%. The results show that M&V-related parallels are relevant in analysing and describing each case study. Extrapolation of uncertainty indicators to the total South African mining industry budget showed that the uncertainty can potentially account for R174.5-million per annum.

With the application of this structure based on the well-established M&V principles, the concern of mine budgets becoming obsolete in the assessment period is reduced. Additionally, the improved structure allowed the budget to be developed in such a manner that it can be easily used for energy

⁴ The Estimates of National Expenditure e-publications for individual votes are available on www.treasury.gov.za. These publications provide more comprehensive coverage of vote specific information.

management purposes as well. This research, therefore, ensures that M&V principles could successfully be used to improve the current mine budget structures of South Africa.

4 THESIS CONCLUSION AND RECOMMENDATIONS

4.1 PREAMBLE

This final chapter presents a conclusion to the research providing a brief summary of the main findings. In order to provide a functional application of the study, objectives were stated in Chapter 1. A discussion is provided to assess how these objectives were met by the development of the methodology and application thereof on case studies, as presented in this document. Recommendations for future work are also discussed and the document is concluded in Section 4.5.

4.2 SUMMARY OF WORK

Budgets are a common tool used to determine the future income and expenditure of a mine. The budgets are also used as a reference point for a mine's performance. It is, therefore, crucial that the budget is a true representation of the expected occurrences. The problem, however, is that the budgets are often drawn up by a financial resource of the mine who focusses mainly on financial aspects such as changes in inflation and electricity costs. Unfortunately, detailed attention is not always given to the operational changes that have to be considered when developing the budget. It is likely that the financial resource will assume that the mine will operate as it did in the past without incorporating expected operational changes.

It is highly likely that the operations of a mine will differ year on year. This is due to the vast number of factors that could affect the operations of the mine, which includes the implementation of ESMs, TOU profiles, and the types of days considered within each month. This study proposed that the six M&V principles be incorporated into the budgeting structures of mines. These principles are *relevance*, *consistency*, *accuracy*, *completeness*, *conservativeness* and *transparency*. These M&V principles are well-established structures with a range of qualitative characteristics. The adaption and incorporation of these principles can, therefore, be used to the advantage of improving budgeting structures. This was demonstrated in the preceding chapters of this thesis.

Chapter 1 provided relevant background on the current budgeting structures used by South African mines and the associated limitations of these structures. These limitations were used to highlight the significant limitations of the current budgeting structures that are used. A solution to the problem was proposed through the investigation of relevant insights of the M&V application on ESMs on mines. The proposed solution entailed the adaption of well-established M&V principles into budgeting structures. A research question was formulated and tested, which highlighted that there exists a need to ***link the well-established M&V principles to the mine's budgeting structures to decrease uncertainty.***

The overall aim of Chapter 2 was to test whether existing M&V principles can be used to improve and extend the use of the operational budgets. The main objective of this chapter was to develop practical parallels that link budget-related principles and M&V principles. This demonstrated that there are parallels between these concepts that can be utilised to improve the existing budgeting structures. To realise the effect of these parallels by means of their practical application, a new structured framework from engineering best practices was developed. The new framework serves as a methodology for the practical application of these parallels on mine budgets.

Chapter 3 validated the use of the newly developed framework to test how these parallels can affect and improve the current budgeting structures by applying the developed structure on different case studies. These problems relate to the eight mines that participated in the questionnaires discussed in Chapter 1 and presented in Appendix A. The impact of the thesis was quantified as R81.5-million by implementing the methodology on the eight case studies.

4.3 MEETING THE REQUIRED OBJECTIVES

The main objective of this study is the application of well-established M&V principles on the current mine budgeting structures. This aims to assist mines to develop uniform and reliable operational budgets that can be used for both traditional budgeting outcomes and improved energy management. Supporting objectives were determined for the study to provide a functional application (defined in Section 1.4). The novel contributions of this study are additionally highlighted (bold) in the list of the objectives presented below:

- **Research the budgeting structures used by mines to identify limitations.**
- **Research the M&V applications to understand the field of application.**
- **Develop parallels between the budgets and the M&V principles.**
- **Develop a generic budget structure for mines in South Africa.**
- Validate the improved budgeting structure by application on a gold mine complex.
- Verify the improved budgeting structure by comparing the results to the original budgeting structure.
- Quantify the value added by implementing this study.

The more detailed discussions below support that the objectives were achieved. The first four objectives also present the novel contributions of this study. An additional contribution, not listed above, is the published article on this study discussed in Appendix C. Each of the objectives are briefly discussed.

Research the budgeting structures used by mines to identify limitations

The current budgeting structures used by South African mines were researched in the critical analysis (Section 1.3). From the evaluation, the advantages and limitations of the current structures were identified, along with the preferred applications. This critical review was based on the budget

application process used by the eight South African mines that participated in the research questionnaires presented in Appendix A. This objective is part of the first novel contribution of this study (refer to Section 1.4).

Research the budgeting structures used by mines to identify limitations

The application of M&V principles on all industries, with special focus on the mining industry, are discussed in Section 1.3. The application process published in the IPMVP are discussed along with the various M&V options' limitations and advantages. Each of the six M&V principles are further discussed in Appendix B.1. This objective is part of the second novel contribution of this study (refer to Section 1.4).

Develop parallels between the budgets and the M&V principles.

Six parallels are created between the existing M&V principles and the current mine budgeting structures. The development of the parallels formed part of phase 1 of the methodology. The development and the application of these parallels are discussed in Chapter 2 and Chapter 3, respectively. This objective is part of the third novel contribution of this study (refer to Section 1.4).

Develop a generic budget structure for mines in South Africa.

A generic structure for an improved budgeting structure is developed in phase 2 of the methodology (Chapter 2). This improved structure uses the parallels created between budgets and M&V applications on mines to adapt the existing budget structures. This objective is part of the fourth novel contribution of this study (refer to Section 1.4).

Validate the improved budgeting structure by application on a gold mine complex.

The new budgeting structure was validated by applying the structure on a gold mine complex. The successful application of the new structure on a case study validates the methodology used to develop the new budgeting structure and successfully addresses the objective of this study.

Verify the improved budgeting structure by comparing the results to the original budgeting structure.

A case study application proved that the improved budgeting structure could successfully improve the accuracy of the budgets by 8.6% which relates to a R6.8-million difference. Cumulatively, for all eight mines, the cost difference between the budgets amounted to R81.5-million.

Quantifying the value added by implementing this study.

This research is successfully validated in Section 3.7 by ensuring the developed structure conforms with the need for the study presented in Chapter 1. The monetary value added by this study can be quantified as the R81.5-million impact of the new budgeting structure on case study mines in South Africa.

The critical analysis is additionally validated with the presentation of the critical analysis at a peer-reviewed conference during October 2020. The findings of the paper were also published in the 31st Annual South African Industrial Journal for Engineering (SAIJE) in November 2020. This paper is available in Appendix C.

4.4 THESIS CONCLUSION

Budgets are used to gauge the financial targets of a company. A well-structured budget ensures that the company can easily monitor their targets and ensure sustainability by acting in a timely manner if needed. Another vital function of a budget is to plan and communicate financial goals. Communication ensures that the responsible engineers are aware of the goals and can manage their operations accordingly. New initiatives are often the basis for achieving necessary growth and for achieving the defined goals. The assumptions made on the revenues and costs of initiatives usually have a varying impact on the outcome. In many cases a budget will serve the purpose of tracking chosen initiatives to gauge their success or failure within a current year.

A mine's budget process lays out the coordination of the departments and sets the benchmarks to monitor whether plans are succeeding. Since the impact of new ESMs is unknown, budgets serve the purpose of tracking chosen initiatives to gauge their success or failure. Budgets further provide feedback to managers as to how their performance should incentivise them to take corrective actions when necessary. Budgeting is, therefore, an essential function of a mine. The problem is that mine budgets often become obsolete early in the year, despite the enormous effort spent in preparing them.

Measurement-and-verification (M&V) principles are known for their effectiveness when addressing operational changes. This study presents a novel approach where the M&V principles are altered into financial principles by developing analogies between the fields. A critical analysis on South African mines' budgets were conducted to create these parallels. To test the new parallels, a generic structure was developed from engineering best practices. The structure consists of six steps, namely:

- (1) Budget boundary:** Ensures that the boundary is representative to the purpose of the budget;
- (2) Budget resolution:** Ensures that the time-of-use profiles are accounted for;
- (3) Data quality:** Provides confidence in the data used for budgeting;
- (4) Routine adjustments:** Ensures adjustments are correctly accounted for;
- (5) Budget development:** Ensures all relevant factors are considered;
- (6) Assurance:** Ensures that the budgeting process is transparent.

The combined impact of the eight case studies equates to R81.5-million, with a quantified uncertainty range of 0.4% to 2.8%. This result shows that the M&V principles are relevant in analysing and

describing the case studies. With the application of this structure based on well-established M&V principles, the concern of the current mine budgeting structures is reduced. The application of this structure, therefore, ensures that the mines' budgets do not become obsolete.

4.5 RECOMMENDATIONS FOR FUTURE WORK

A few recommendations for further studies are listed below. These recommendations could support the need for further research to be conducted in this field of study.

Incorporating other well-established principles:

- | | |
|-----------------|--|
| Problem: | Measurement and verification (M&V) principles set out in the IPMVP were used to improve the quality of the current budgeting structures of mines. Many other well-established principles can also be used to improve the quality of the current budgeting structures of mines. |
| Recommendation: | Other principles (such as financial principles or energy reporting principles) can additionally be reviewed for a potential further improvement of the budgeting structures. |

Application of the improved structure on other industries:

- | | |
|-----------------|--|
| Problem: | The developed structure was only applied to mining case studies. |
| Recommendation: | Extend the application of the structure to other industries as well. |

Improve the quantification techniques of routine and non-routine adjustments:

- | | |
|-----------------|---|
| Problem: | All routine and non-routine adjustments are calculated using mathematical models in excel application software. |
| Recommendation: | Improve the quantification of these adjustments by considering machine learning techniques to identify and quantify the effect of routine and non-routine events. |

Simulate the budgets using advanced software techniques:

- | | |
|----------|---|
| Problem: | The improved budgeting structure requires time intensive work to develop a bottoms-up approach to the budget. |
|----------|---|

Recommendation: It is recommended that additional applications are incorporated using simulation software that will improve the time used to create the top-down budgets.

Use the budget as a benchmarking tool:

Problem: The new structure delivers the expected future performance of a specific component (or commodity).

Recommendation: The budget can be further used to create benchmarks to compare the various components (or commodities) of specific shafts with each other to ensure that the optimal conditions are met for the component (or commodity).

Ensure that the budget is flexible:

Problem: The new structure only considers the six M&V principles.

Recommendation: Other principles can also be considered, such as flexibility, to enable a more accurate representation of actual performance.

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APPENDIX A: MINE QUESTIONNAIRES

This Appendix contains supporting information to the critical literature review discussed in Chapter 1.

Appendix A.1: South African mine questionnaires

- The mine questionnaires completed by a representative of the mine. Eight questionnaires are presented. A short summary of the findings on the questionnaires is also discussed.

A.1 SOUTH AFRICAN MINE QUESTIONNAIRES

The questionnaires presented in this chapter were conducted on eight South African mineral mines (4 deep-level gold mines and 3 platinum mines). The eight questionnaires are available at the end of this Appendix. The following sub-sections discussed the feedback from the eight mines that partook in the questionnaires.

Figure A-1 presents the location of the eight mines that participated in the questionnaires (indicated with the red location icons). Four of the eight mines are located in the North-West province, two are located in the Gauteng province and the remaining two mines are located in the Free-State province. The purple dots in Figure A-1 indicates the gold mines in South Africa and the green triangles indicates the platinum mines in South Africa.

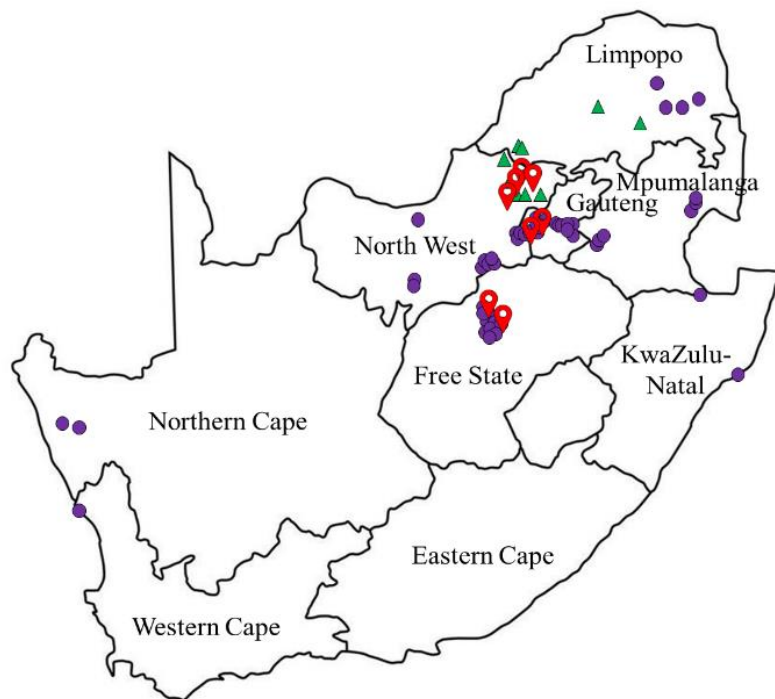


Figure A-1: Location of the mines that partook in the questionnaires

The spread of the mines that participated in the questionnaires indicates that most of the general regions are considered which is a representable sample for the evaluation included in this study. All eight the questionnaires are presented in this section of Appendix A.

MINE QUESTIONNAIRE 1

GENERAL BIUDGETING STRUCTURE OF A SOUTH AFRICAN MINE

All personal details are excluded from the questionnaires due to privacy agreements. This specific questionnaire will be referred to as the questionnaire of Mine 1.

Please score on a scale of 1 to 3, where 1 = "No", 2 = "Sometimes" and 3 = "Yes". A not applicable (NA) option is also provided should you feel the question is irrelevant to your conditions.

1. Please select the degree of approval for each of the following planning related options.

- | | | | | | |
|-----|--|-------------------------------------|-------------------------------------|-------------------------------------|----|
| 1.1 | Do you plan for future consumptions and costs? | 1 | ☒ | 3 | NA |
| 1.2 | Do you consider historical performances when planning? | 1 | 2 | ☒ | NA |
| 1.3 | Do the current planning methods prove to be sufficient? | 1 | ☒ | 3 | NA |
| 1.4 | Does the mine have a signed-off energy budget? | 1 | 2 | ☒ | NA |
| 1.5 | Is the energy budget reliable and recommendable as a form of planning? | ☒ | 2 | 3 | NA |

2. Please mark whether the following have incurred during the assessment period of your budget.

- | | | | | | |
|-----|--|-------------------------------------|-------------------------------------|-------------------------------------|----|
| 1.1 | Do you think that the budget can be used as a reference point? | ☒ | 2 | 3 | NA |
| 1.2 | Does the budget ever become obsolete within the assessment period? | 1 | 2 | ☒ | NA |
| 1.3 | Does poor planning can cause the budget to become obsolete? | 1 | 2 | ☒ | NA |
| 1.4 | Can the budget be used for energy management? | 1 | ☒ | 3 | NA |
| 1.5 | Are the current budgeting approach sufficient enough? | ☒ | 2 | 3 | NA |

3. Please select the degree of approval for the following budgeting structure related options.

- | | | | | | |
|-----|--|-------------------------------------|-------------------------------------|---|----|
| 1.1 | Is the accuracy of the budgeting data assessed ? | ☒ | 2 | 3 | NA |
| 1.2 | Are all activities included in the budget (is the budget complete)? | 1 | ☒ | 3 | NA |
| 1.3 | Are the budgets conservative? | ☒ | 2 | 3 | NA |
| 1.4 | Is the method consistent (no changes made halfway through)? | ☒ | 2 | 3 | NA |
| 1.5 | Are all the data measured (or are some of the parameters assumed)? | ☒ | 2 | 3 | NA |
| 1.6 | Is the budgeting process transparent (are all activities fully disclosed)? | ☒ | 2 | 3 | NA |

4. Please complete this section with regards to the general steps taken to create the budget:**General:**

Who creates the budget? Financial resource / Engineering resource / Other: _____

What, in your opinion, is the purpose of the budget? To account for growth

How long does the budget typically take to compile? 6 months → 1 year

Data used for budgeting:

What data do you include? Actual data of previous year

Where do you obtain the data? Monthly report sent from mine

Is the data reliable (and how do you determine this)? Yes, matched to Eskom bill

Expected changes in operations:

Do you consider the effect of operational changes, such as changes in production? No

What changes in operation (if any) do you consider _____

How do you quantify these changes? _____

Do you adjust for unplanned events (such as a Strike action) during the assessment period? Yes

If so, how do you quantify these adjustments? Either measured values as actual budget

If not, why not? _____

Budget structure:

In what intervals do you develop the budget? Monthly / Daily / Half-hourly / Other: _____

What is the budget boundary? Whole facility / Per Shaft / Per Commodity / Other: _____

Is the budget validated before being signed off? Yes

If so, how do you validate the budget? consensus amongst engineering managers

Briefly explain the step-by-step approach used to develop the budget:

Jan - Jul : Actual of previous + growth - savings

Aug - Nov : Forecasted consumption + growth - savings

Dec : % of forecasted consumption

Forecast : varies mostly = AVERAGE (Jan-Jul)

THANK YOU FOR PARTICIPATING IN THIS RESEARCH SURVEY.

MINE QUESTIONNAIRE 2

GENERAL BUDGETING STRUCTURE OF A SOUTH AFRICAN MINE

All personal details are excluded from the questionnaires due to privacy agreements. This specific questionnaire will be referred to as the questionnaire of Mine 2.

Please score on a scale of 1 to 3, where 1 = "No", 2 = "Sometimes" and 3 = "Yes". A not applicable (NA) option is also provided should you feel the question is irrelevant to your conditions.

1. Please select the degree of approval for each of the following planning related options.

- | | | | | |
|--|---|-------------------------------------|-------------------------------------|----|
| 1.1 Do you plan for future consumptions and costs? | 1 | ☒ | 3 | NA |
| 1.2 Do you consider historical performances when planning? | 1 | 2 | ☒ | NA |
| 1.3 Do the current planning methods prove to be sufficient? | 1 | 2 | ☒ | NA |
| 1.4 Does the mine have a signed-off energy budget? | 1 | 2 | ☒ | NA |
| 1.5 Is the energy budget reliable and recommendable as a form of planning? | 1 | 2 | ☒ | NA |

2. Please mark whether the following have incurred during the assessment period of your budget.

- | | | | | |
|--|-------------------------------------|-------------------------------------|-------------------------------------|----|
| 1.1 Do you think that the budget can be used as a reference point? | 1 | ☒ | 3 | NA |
| 1.2 Does the budget ever become obsolete within the assessment period? | 1 | ☒ | 3 | NA |
| 1.3 Does poor planning can cause the budget to become obsolete? | 1 | 2 | ☒ | NA |
| 1.4 Can the budget be used for energy management? | 1 | 2 | ☒ | NA |
| 1.5 Are the current budgeting approach sufficient enough? | ☒ | 2 | 3 | NA |

3. Please select the degree of approval for the following budgeting structure related options.

- | | | | | |
|--|-------------------------------------|-------------------------------------|-------------------------------------|----|
| 1.1 Is the accuracy of the budgeting data assessed? | 1 | 2 | ☒ | NA |
| 1.2 Are all activities included in the budget (is the budget complete)? | 1 | ☒ | 3 | NA |
| 1.3 Are the budgets conservative? | 1 | 2 | ☒ | NA |
| 1.4 Is the method consistent (no changes made halfway through)? | 1 | ☒ | 3 | NA |
| 1.5 Are all the data measured (or are some of the parameters assumed)? | ☒ | 2 | 3 | NA |
| 1.6 Is the budgeting process transparent (are all activities fully disclosed)? | 1 | 2 | ☒ | NA |

4. Please complete this section with regards to the general steps taken to create the budget:**General:**

Who creates the budget? Financial resource / Engineering resource / Other: _____

What, in your opinion, is the purpose of the budget? Management as well as planning

How long does the budget typically take to compile? 2-3 months

Data used for budgeting:

What data do you include? Historical utility, ton, cost data

Where do you obtain the data? Billing sheets & mine system

Is the data reliable (and how do you determine this)? Yes, same data compared to eskom accounts

Expected changes in operations:

Do you consider the effect of operational changes, such as changes in production? Yes

What changes in operation (if any) do you consider Production changes waiting to include employee changes

How do you quantify these changes? _____

Do you adjust for unplanned events (such as a Strike action) during the assessment period? No

If so, how do you quantify these adjustments? _____

If not, why not? _____

Budget structure:

In what intervals do you develop the budget? Monthly / Daily / Half-hourly / Other: _____

What is the budget boundary? Whole facility / Per Shaft / Per Commodity / Other: _____

Is the budget validated before being signed off? Yes

If so, how do you validate the budget? Compared to historical data

Briefly explain the step-by-step approach used to develop the budget:

Historical data is obtained, models for utilities as function of production are fit (different models). Best model is chosen and used to "predict" utilities based on production. Cost calculated as weighted average Eskom tariff & increases are applied

THANK YOU FOR PARTICIPATING IN THIS RESEARCH SURVEY.

MINE QUESTIONNAIRE 3

GENERAL BIUDGETING STRUCTURE OF A SOUTH AFRICAN MINE

All personal details are excluded from the questionnaires due to privacy agreements. This specific questionnaire will be referred to as the questionnaire of Mine 3.

Please score on a scale of 1 to 3, where 1 = "No", 2 = "Sometimes" and 3 = "Yes". A not applicable (NA) option is also provided should you feel the question is irrelevant to your conditions.

1. Please select the degree of approval for each of the following planning related options.

- | | | | | |
|--|------------------------------------|------------------------------------|------------------------------------|----|
| 1.1 Do you plan for future consumptions and costs? | 1 | 2 | ☒ 3 | NA |
| 1.2 Do you consider historical performances when planning? | 1 | ☒ 2 | 3 | NA |
| 1.3 Do the current planning methods prove to be sufficient? | ☒ 1 | 2 | 3 | NA |
| 1.4 Does the mine have a signed-off energy budget? | 1 | 2 | ☒ 3 | NA |
| 1.5 Is the energy budget reliable and recommendable as a form of planning? | ☒ 1 | 2 | 3 | NA |

2. Please mark whether the following have incurred during the assessment period of your budget.

- | | | | | |
|--|------------------------------------|------------------------------------|------------------------------------|----|
| 1.1 Do you think that the budget can be used as a reference point? | ☒ 1 | 2 | 3 | NA |
| 1.2 Does the budget ever become obsolete within the assessment period? | 1 | 2 | ☒ 3 | NA |
| 1.3 Does poor planning can cause the budget to become obsolete? | 1 | 2 | ☒ 3 | NA |
| 1.4 Can the budget be used for energy management? | 1 | ☒ 2 | 3 | NA |
| 1.5 Are the current budgeting approach sufficient enough? | ☒ 1 | 2 | 3 | NA |

3. Please select the degree of approval for the following budgeting structure related options.

- | | | | | |
|--|------------------------------------|---|------------------------------------|----|
| 1.1 Is the accuracy of the budgeting data assessed ? | ☒ 1 | 2 | 3 | NA |
| 1.2 Are all activities included in the budget (is the budget complete)? | ☒ 1 | 2 | 3 | NA |
| 1.3 Are the budgets conservative? | ☒ 1 | 2 | 3 | NA |
| 1.4 Is the method consistent (no changes made halfway through)? | ☒ 1 | 2 | 3 | NA |
| 1.5 Are all the data measured (or are some of the parameters assumed)? | 1 | 2 | ☒ 3 | NA |
| 1.6 Is the budgeting process transparent (are all activities fully disclosed)? | 1 | 2 | ☒ 3 | NA |

4. Please complete this section with regards to the general steps taken to create the budget:

General:

Who creates the budget? Financial resource / Engineering resource / Other: _____

What, in your opinion, is the purpose of the budget? To have a financial reference point

How long does the budget typically take to compile? ± 1 month

Data used for budgeting:

What data do you include? Financial data and Energy data

Where do you obtain the data? Eskom bills

Is the data reliable (and how do you determine this)? Yes, Eskom bills are verified

Expected changes in operations:

Do you consider the effect of operational changes, such as changes in production? NO

What changes in operation (if any) do you consider None

How do you quantify these changes? -

Do you adjust for unplanned events (such as a Strike action) during the assessment period? NO

If so, how do you quantify these adjustments? -

If not, why not? As it is officially signed-off

Budget structure:

In what intervals do you develop the budget? Monthly / Daily / Half-hourly / Other: Annually

What is the budget boundary? Whole facility / Per Shaft / Per Commodity / Other: _____

Is the budget validated before being signed off? NO

If so, how do you validate the budget? -

Briefly explain the step-by-step approach used to develop the budget:

An average of the previous year's energy and costs
are used

THANK YOU FOR PARTICIPATING IN THIS RESEARCH SURVEY.

MINE QUESTIONNAIRE 4

GENERAL BIUDGETING STRUCTURE OF A SOUTH AFRICAN MINE

All personal details are excluded from the questionnaires due to privacy agreements. This specific questionnaire will be referred to as the questionnaire of Mine 4.

Please score on a scale of 1 to 3, where 1 = "No", 2 = "Sometimes" and 3 = "Yes". A not applicable (NA) option is also provided should you feel the question is irrelevant to your conditions.

1. Please select the degree of approval for each of the following planning related options.

- | | | | | |
|--|---|----------|----------|----|
| 1.1 Do you plan for future consumptions and costs? | 1 | <u>2</u> | 3 | NA |
| 1.2 Do you consider historical performances when planning? | 1 | 2 | <u>3</u> | NA |
| 1.3 Do the current planning methods prove to be sufficient? | 1 | 2 | <u>3</u> | NA |
| 1.4 Does the mine have a signed-off energy budget? | 1 | 2 | <u>3</u> | NA |
| 1.5 Is the energy budget reliable and recommendable as a form of planning? | 1 | 2 | <u>3</u> | NA |

2. Please mark whether the following have incurred during the assessment period of your budget.

- | | | | | |
|--|----------|----------|----------|----|
| 1.1 Do you think that the budget can be used as a reference point? | 1 | <u>2</u> | 3 | NA |
| 1.2 Does the budget ever become obsolete within the assessment period? | 1 | <u>2</u> | 3 | NA |
| 1.3 Does poor planning can cause the budget to become obsolete? | 1 | 2 | <u>3</u> | NA |
| 1.4 Can the budget be used for energy management? | 1 | 2 | <u>3</u> | NA |
| 1.5 Are the current budgeting approach sufficient enough? | <u>1</u> | 2 | 3 | NA |

3. Please select the degree of approval for the following budgeting structure related options.

- | | | | | |
|--|----------|----------|----------|----|
| 1.1 Is the accuracy of the budgeting data assessed ? | 1 | 2 | <u>3</u> | NA |
| 1.2 Are all activities included in the budget (is the budget complete)? | 1 | <u>2</u> | 3 | NA |
| 1.3 Are the budgets conservative? | 1 | 2 | <u>3</u> | NA |
| 1.4 Is the method consistent (no changes made halfway through)? | 1 | <u>2</u> | 3 | NA |
| 1.5 Are all the data measured (or are some of the parameters assumed)? | <u>1</u> | 2 | 3 | NA |
| 1.6 Is the budgeting process transparent (are all activities fully disclosed)? | 1 | 2 | <u>3</u> | NA |

4. Please complete this section with regards to the general steps taken to create the budget:**General:**

Who creates the budget? Financial resource / Engineering resource / Other: _____

What, in your opinion, is the purpose of the budget? Management and Planning

How long does the budget typically take to compile? 2-3 months

Data used for budgeting:

What data do you include? Historical utility, tonnes, costing data

Where do you obtain the data? Billing sheets and mine systems

Is the data reliable (and how do you determine this)? Some what, the data is usually compared to Eskom Bills

Expected changes in operations:

Do you consider the effect of operational changes, such as changes in production? Yes

What changes in operation (if any) do you consider Production

How do you quantify these changes? Modelling techniques (Energy Intensity)

Do you adjust for unplanned events (such as a Strike action) during the assessment period? No

If so, how do you quantify these adjustments? —

If not, why not? —

Budget structure:

In what intervals do you develop the budget? Monthly / Daily / Half-hourly / Other: —

What is the budget boundary? Whole facility Per Shaft / Per Commodity / Other: —

Is the budget validated before being signed off? Yes

If so, how do you validate the budget? Compared to historical data

Briefly explain the step-by-step approach used to develop the budget:

Historical data is obtained, models for utilities as function of production are fit. Model used to predict utilities based on production. Cost calculated as weighted averages from Eskom tariffs and increases are applied.

THANK YOU FOR PARTICIPATING IN THIS RESEARCH SURVEY.

MINE QUESTIONNAIRE 5

GENERAL BIUDGETING STRUCTURE OF A SOUTH AFRICAN MINE

All personal details are excluded from the questionnaires due to privacy agreements. This specific questionnaire will be referred to as the questionnaire of Mine 5.

Please score on a scale of 1 to 3, where 1 = "No", 2 = "Sometimes" and 3 = "Yes". A not applicable (NA) option is also provided should you feel the question is irrelevant to your conditions.

1. Please select the degree of approval for each of the following planning related options.

- | | | | | |
|--|----------------------------------|----------------------------------|----------------------------------|----|
| 1.1 Do you plan for future consumptions and costs? | 1 | ☒ | 3 | NA |
| 1.2 Do you consider historical performances when planning? | 1 | 2 | ☒ | NA |
| 1.3 Do the current planning methods prove to be sufficient? | 1 | ☒ | 3 | NA |
| 1.4 Does the mine have a signed-off energy budget? | 1 | 2 | ☒ | NA |
| 1.5 Is the energy budget reliable and recommendable as a form of planning? | ☒ | 2 | 3 | NA |

2. Please mark whether the following have incurred during the assessment period of your budget.

- | | | | | |
|--|----------------------------------|----------------------------------|----------------------------------|----|
| 1.1 Do you think that the budget can be used as a reference point? | ☒ | 2 | 3 | NA |
| 1.2 Does the budget ever become obsolete within the assessment period? | 1 | 2 | ☒ | NA |
| 1.3 Does poor planning can cause the budget to become obsolete? | 1 | 2 | ☒ | NA |
| 1.4 Can the budget be used for energy management? | 1 | ☒ | 3 | NA |
| 1.5 Are the current budgeting approach sufficient enough? | ☒ | 2 | 3 | NA |

3. Please select the degree of approval for the following budgeting structure related options.

- | | | | | |
|--|----------------------------------|----------------------------------|---|----|
| 1.1 Is the accuracy of the budgeting data assessed ? | ☒ | 2 | 3 | NA |
| 1.2 Are all activities included in the budget (is the budget complete)? | 1 | ☒ | 3 | NA |
| 1.3 Are the budgets conservative? | ☒ | 2 | 3 | NA |
| 1.4 Is the method consistent (no changes made halfway through)? | ☒ | 2 | 3 | NA |
| 1.5 Are all the data measured (or are some of the parameters assumed)? | ☒ | 2 | 3 | NA |
| 1.6 Is the budgeting process transparent (are all activities fully disclosed)? | ☒ | 2 | 3 | NA |

4. Please complete this section with regards to the general steps taken to create the budget:

General:

Who creates the budget? Financial ~~resource~~ / Engineering resource / Other: _____

What, in your opinion, is the purpose of the budget? Energy management

How long does the budget typically take to compile? ± 6 months

Data used for budgeting:

What data do you include? Actual data from previous year

Where do you obtain the data? Monthly reports from shaft engineers

Is the data reliable (and how do you determine this)? Sometimes. Errors are present some of the months. Usually matched to Eskom bills

Expected changes in operations:

Do you consider the effect of operational changes, such as changes in production? Yes

What changes in operation (if any) do you consider Growth projects (expansions)

How do you quantify these changes? -

Do you adjust for unplanned events (such as a Strike action) during the assessment period? No

If so, how do you quantify these adjustments? -

If not, why not? -

Budget structure:

In what intervals do you develop the budget? ~~Monthly~~ / Daily / Half-hourly / Other: _____

What is the budget boundary? Whole facility / Per ~~Shift~~ / Per Commodity / Other: _____

Is the budget validated before being signed off? Yes

If so, how do you validate the budget? Consensus among managers

Briefly explain the step-by-step approach used to develop the budget:

January to July : Actual of previous years energy

August to November: Forecasted consumptions (based on the average of January to July)

December: 1/2 of forecasted consumption of November
↳ average of January to July

THANK YOU FOR PARTICIPATING IN THIS RESEARCH SURVEY.

MINE QUESTIONNAIRE 6

GENERAL BIUDGETING STRUCTURE OF A SOUTH AFRICAN MINE

All personal details are excluded from the questionnaires due to privacy agreements. This specific questionnaire will be referred to as the questionnaire of Mine # 6.

Please score on a scale of 1 to 3, where 1 = "No", 2 = "Sometimes" and 3 = "Yes". A not applicable (NA) option is also provided should you feel the question is irrelevant to your conditions.

1. Please select the degree of approval for each of the following planning related options.

- | | | | | |
|--|---|-------------------------------------|-------------------------------------|----|
| 1.1 Do you plan for future consumptions and costs? | 1 | 2 | ☒ | NA |
| 1.2 Do you consider historical performances when planning? | 1 | 2 | ☒ | NA |
| 1.3 Do the current planning methods prove to be sufficient? | 1 | ☒ | 3 | NA |
| 1.4 Does the mine have a signed-off energy budget? | 1 | 2 | ☒ | NA |
| 1.5 Is the energy budget reliable and recommendable as a form of planning? | 1 | ☒ | 3 | NA |

2. Please mark whether the following have incurred during the assessment period of your budget.

- | | | | | |
|--|-------------------------------------|-------------------------------------|-------------------------------------|----|
| 1.1 Do you think that the budget can be used as a reference point? | 1 | ☒ | 3 | NA |
| 1.2 Does the budget ever become obsolete within the assessment period? | 1 | 2 | ☒ | NA |
| 1.3 Does poor planning can cause the budget to become obsolete? | 1 | ☒ | 3 | NA |
| 1.4 Can the budget be used for energy management? | 1 | ☒ | 3 | NA |
| 1.5 Are the current budgeting approach sufficient enough? | ☒ | 2 | 3 | NA |

3. Please select the degree of approval for the following budgeting structure related options.

- | | | | | |
|--|-------------------------------------|-------------------------------------|---|----|
| 1.1 Is the accuracy of the budgeting data assessed? | ☒ | 2 | 3 | NA |
| 1.2 Are all activities included in the budget (is the budget complete)? | 1 | ☒ | 3 | NA |
| 1.3 Are the budgets conservative? | ☒ | 2 | 3 | NA |
| 1.4 Is the method consistent (no changes made halfway through)? | ☒ | 2 | 3 | NA |
| 1.5 Are all the data measured (or are some of the parameters assumed)? | ☒ | 2 | 3 | NA |
| 1.6 Is the budgeting process transparent (are all activities fully disclosed)? | ☒ | 2 | 3 | NA |

4. Please complete this section with regards to the general steps taken to create the budget:**General:**

Who creates the budget? Financial ☒ resource / Engineering resource / Other: _____

What, in your opinion, is the purpose of the budget? management

How long does the budget typically take to compile? 3 months

Data used for budgeting:

What data do you include? energy from Eskom invoices

Where do you obtain the data? Eskom invoices

Is the data reliable (and how do you determine this)? Yes

Expected changes in operations:

Do you consider the effect of operational changes, such as changes in production? No

What changes in operation (if any) do you consider -

How do you quantify these changes? -

Do you adjust for unplanned events (such as a Strike action) during the assessment period? No

If so, how do you quantify these adjustments? -

If not, why not? Budgets are already signed off so can't change it

Budget structure:

In what intervals do you develop the budget? Monthly / Daily / Half-hourly / Other: -

What is the budget boundary? Whole facility / Per ~~Shift~~ / Per Commodity / Other: -

Is the budget validated before being signed off? No, only approved by managers

If so, how do you validate the budget? -

Briefly explain the step-by-step approach used to develop the budget:

- Get previous 12 months Eskom Bills
- Assume next 12 months will be similar to previous 12 months
- Adjust for Eskom tariffs
- Sometimes adjust for large anticipated events or changes
- Present budget to managers for approval

THANK YOU FOR PARTICIPATING IN THIS RESEARCH SURVEY.

MINE QUESTIONNAIRE 7

GENERAL BUDGETING STRUCTURE OF A SOUTH AFRICAN MINE

All personal details are excluded from the questionnaires due to privacy agreements. This specific questionnaire will be referred to as the questionnaire of Mine 7.

Please score on a scale of 1 to 3, where 1 = "No", 2 = "Sometimes" and 3 = "Yes". A not applicable (NA) option is also provided should you feel the question is irrelevant to your conditions.

1. Please select the degree of approval for each of the following planning related options.

- | | | | | |
|--|---|---|----------|----|
| 1.1 Do you plan for future consumptions and costs? | 1 | 2 | <u>3</u> | NA |
| 1.2 Do you consider historical performances when planning? | 1 | 2 | <u>3</u> | NA |
| 1.3 Do the current planning methods prove to be sufficient? | 1 | 2 | <u>3</u> | NA |
| 1.4 Does the mine have a signed-off energy budget? | 1 | 2 | <u>3</u> | NA |
| 1.5 Is the energy budget reliable and recommendable as a form of planning? | 1 | 2 | <u>3</u> | NA |

2. Please mark whether the following have incurred during the assessment period of your budget.

- | | | | | |
|--|---|----------|----------|----|
| 1.1 Do you think that the budget can be used as a reference point? | 1 | 2 | <u>3</u> | NA |
| 1.2 Does the budget ever become obsolete within the assessment period? | 1 | <u>2</u> | 3 | NA |
| 1.3 Does poor planning can cause the budget to become obsolete? | 1 | 2 | <u>3</u> | NA |
| 1.4 Can the budget be used for energy management? | 1 | 2 | <u>3</u> | NA |
| 1.5 Are the current budgeting approach sufficient enough? | 1 | 2 | <u>3</u> | NA |

3. Please select the degree of approval for the following budgeting structure related options.

- | | | | | |
|--|----------|----------|----------|----|
| 1.1 Is the accuracy of the budgeting data assessed? | 1 | 2 | <u>3</u> | NA |
| 1.2 Are all activities included in the budget (is the budget complete)? | 1 | 2 | <u>3</u> | NA |
| 1.3 Are the budgets conservative? | 1 | <u>2</u> | 3 | NA |
| 1.4 Is the method consistent (no changes made halfway through)? | 1 | 2 | <u>3</u> | NA |
| 1.5 Are all the data measured (or are some of the parameters assumed)? | <u>1</u> | 2 | 3 | NA |
| 1.6 Is the budgeting process transparent (are all activities fully disclosed)? | 1 | 2 | <u>3</u> | NA |

4. Please complete this section with regards to the general steps taken to create the budget:**General:**

Who creates the budget? Financial resource / Engineering resource Other: _____

What, in your opinion, is the purpose of the budget? Planning next year's expenses

How long does the budget typically take to compile? ± 1 month

Data used for budgeting:

What data do you include? Energy and Production

Where do you obtain the data? Eskom Bills & weighbridges

Is the data reliable (and how do you determine this)? Yes

Expected changes in operations:

Do you consider the effect of operational changes, such as changes in production? Yes

What changes in operation (if any) do you consider Production, savings, growth

How do you quantify these changes? Models / Predictions

Do you adjust for unplanned events (such as a Strike action) during the assessment period? No

If so, how do you quantify these adjustments? -

If not, why not? _____

Budget structure:

In what intervals do you develop the budget? Monthly / Daily / Half-hourly / Other: _____

What is the budget boundary? Whole facility / Per Shift / Per Commodity / Other: _____

Is the budget validated before being signed off? Yes

If so, how do you validate the budget? Budget compared to historical data and actuals in a 3-month "window" to test if the

Briefly explain the step-by-step approach used to develop the budget: Budget works

Obtain historical energy and production data, evaluate the data to see if all is correct. Predict future consumption by assuming that future consumption will be equal to historical consumption. Adjust for Production changes (with Energy Intensity model) and growth & savings (from assumed values). Final Budget gets tested on real data (for 1st 3 months) before approval

THANK YOU FOR PARTICIPATING IN THIS RESEARCH SURVEY.

MINE QUESTIONNAIRE 8

GENERAL BIUDGETING STRUCTURE OF A SOUTH AFRICAN MINE

All personal details are excluded from the questionnaires due to privacy agreements. This specific questionnaire will be referred to as the questionnaire of Mine 8.

Please score on a scale of 1 to 3, where 1 = "No", 2 = "Sometimes" and 3 = "Yes". A not applicable (NA) option is also provided should you feel the question is irrelevant to your conditions.

1. Please select the degree of approval for each of the following planning related options.

- | | | | | |
|--|---|------------------------------------|------------------------------------|----|
| 1.1 Do you plan for future consumptions and costs? | 1 | 2 | ☒ 3 | NA |
| 1.2 Do you consider historical performances when planning? | 1 | 2 | ☒ 3 | NA |
| 1.3 Do the current planning methods prove to be sufficient? | 1 | ☒ 2 | 3 | NA |
| 1.4 Does the mine have a signed-off energy budget? | 1 | 2 | ☒ 3 | NA |
| 1.5 Is the energy budget reliable and recommendable as a form of planning? | 1 | 2 | ☒ 3 | NA |

2. Please mark whether the following have incurred during the assessment period of your budget.

- | | | | | |
|--|------------------------------------|------------------------------------|------------------------------------|----|
| 1.1 Do you think that the budget can be used as a reference point? | 1 | 2 | ☒ 3 | NA |
| 1.2 Does the budget ever become obsolete within the assessment period? | 1 | ☒ 2 | 3 | NA |
| 1.3 Does poor planning can cause the budget to become obsolete? | 1 | 2 | ☒ 3 | NA |
| 1.4 Can the budget be used for energy management? | 1 | ☒ 2 | 3 | NA |
| 1.5 Are the current budgeting approach sufficient enough? | ☒ 1 | 2 | 3 | NA |

3. Please select the degree of approval for the following budgeting structure related options.

- | | | | | |
|--|------------------------------------|------------------------------------|------------------------------------|----|
| 1.1 Is the accuracy of the budgeting data assessed? | ☒ 1 | 2 | 3 | NA |
| 1.2 Are all activities included in the budget (is the budget complete)? | ☒ 1 | 2 | 3 | NA |
| 1.3 Are the budgets conservative? | 1 | ☒ 2 | 3 | NA |
| 1.4 Is the method consistent (no changes made halfway through)? | 1 | ☒ 2 | 3 | NA |
| 1.5 Are all the data measured (or are some of the parameters assumed)? | ☒ 1 | 2 | 3 | NA |
| 1.6 Is the budgeting process transparent (are all activities fully disclosed)? | 1 | 2 | ☒ 3 | NA |

4. Please complete this section with regards to the general steps taken to create the budget:**General:**

Who creates the budget? Financial resource / Engineering resource / Other: _____

What, in your opinion, is the purpose of the budget? Energy management

How long does the budget typically take to compile? 2 months

Data used for budgeting:

What data do you include? Eskom bills

Where do you obtain the data? Eskom

Is the data reliable (and how do you determine this)? Yes

Expected changes in operations:

Do you consider the effect of operational changes, such as changes in production? No

What changes in operation (if any) do you consider -

How do you quantify these changes? -

Do you adjust for unplanned events (such as a Strike action) during the assessment period? No

If so, how do you quantify these adjustments? -

If not, why not? -

Budget structure:

In what intervals do you develop the budget? Monthly / Daily / Half-hourly / Other: -

What is the budget boundary? Whole facility / Per Shaft / Per Commodity / Other: -

Is the budget validated before being signed off? Yes

If so, how do you validate the budget? Approved by multiple people

Briefly explain the step-by-step approach used to develop the budget:

Budget = Historical Eskom bill ± Eskom tariff changes

THANK YOU FOR PARTICIPATING IN THIS RESEARCH SURVEY.

APPENDIX B: SUPPLEMENTARY BACKGROUND

This Appendix contains supporting information to the background (Chapter 1) of this study and is broken up into four sections.

Appendix B.1: M&V applications on mines

- Detailed discussion on the evaluation of ESM performance on mines using M&V application principles.

Appendix B.2: Critical analysis results (category 2 and category 3)

- Detailed discussion on the steps followed in the critical analysis of the literature (on other industries) on the current budgeting structures.

Appendix B.3: Measurement boundary

- Detailed discussion on differences between evaluating a budget on a small boundary versus a large boundary. A critical comparison is presented to address the question: *“Is the additional effort required to develop budgets on smaller boundaries worth it?”*

Appendix B.4: External effects on mines

- Detailed discussion on effects that 1) production, 2) temperature, 3) depth of mine and 4) the number of employees have on each of the mine’s commodity energy consumption.

B.1 M&V APPLICATIONS ON MINES

When the performance of an ESM implemented on a mining system is evaluated, a M&V plan is generally used to quantify the saving of the ESM. This section assesses the M&V application of twelve different ESM evaluations on South African mines. The twelve studies considered are obtained from published journal articles released between 2015 and 2020. Figure B.1-1 illustrates the distribution of the references used in the critical analysis between five mine commodities (compressors, fans, pumps, fridge plants and the remainder).

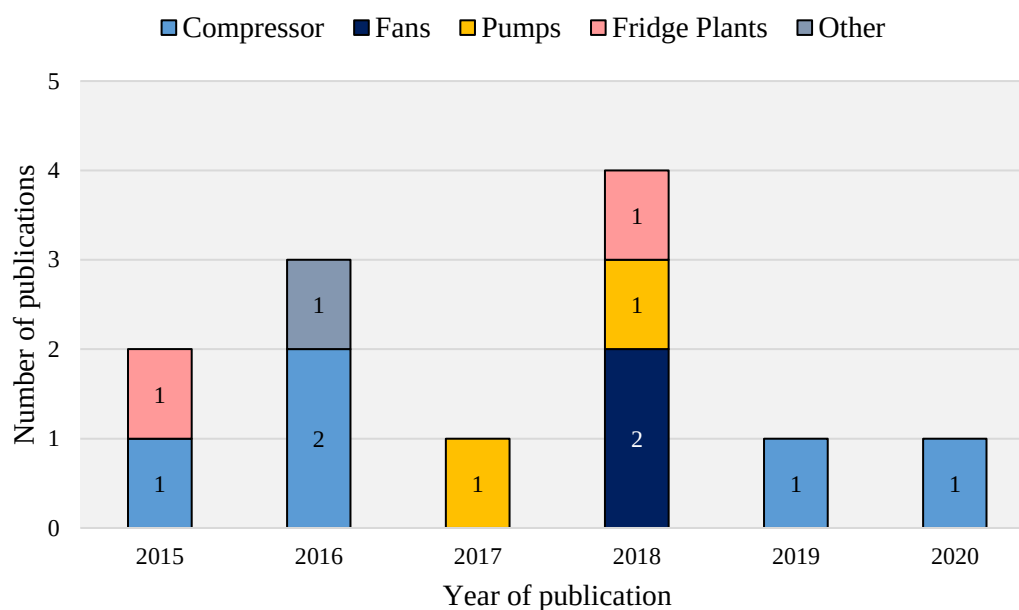
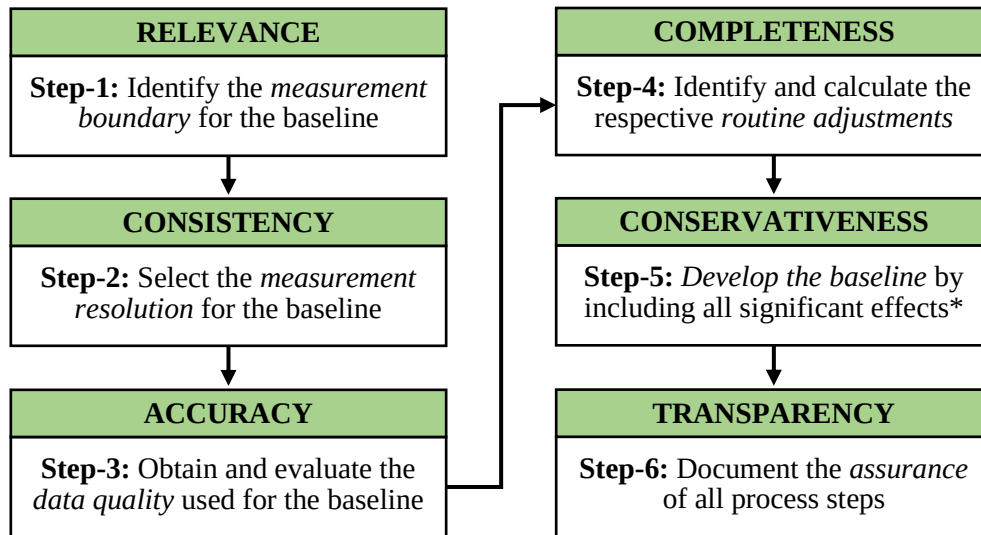


Figure B.1-1: Distribution of the M&V references

The M&V application of each references is discussed at the hand of the six M&V principles and the general M&V layout discussed in Chapter 1. The layout is presented again in Figure B.1-2 and discussed in the section thereafter.



**this also refers to the unplanned or non-routine adjustments in the assessment period*

Figure B.1-2: General measurement and verification (M&V) structure

Figure B.1-2 captures the M&V application process, along with the M&V principles linked to each step. This application process is a well-established process that can easily be used to quantify the ESM savings on any facility. In the next sub-section, the application process of the M&V principles in the mining environment is evaluated.

For the critical analysis of the twelve references, each of the steps presented in Figure B.1-2 will be addressed per reference in the sections below.

Step-1: Relevance

The first step in the M&V application process is to identify a **measurement boundary** for the ESM evaluation. Three boundaries for the evaluation of ESM performances are presented by the IPMVP. These boundaries are (1) Retrofit isolation, (2) Whole facility and (3) Calibrated simulation. Each of these boundaries consists of different advantages and limitations, which is also discussed in Appendix B.3.

When deciding on the boundary for an ESM the following should be considered.

- How big is the expected impact of the ESM performance compared to the whole facility's energy consumption?
- What energy parameters are available?
- Can the ESM be isolated?
- Are there multiple external effects on the performance parameters of the ESM? *(also refer to Appendix B.4 for an evaluation of the external effects present on a mine).*

Table B.1-1 displays the results of the twelve literature references on the question: “*What measurement boundary was used*” and also whether it was **relevant** for its application. Option A refers to an isolated component boundary and Option B refers to a whole facility boundary. Typically, a green block will indicate that the boundary was relevant for its application where a red block indicates the opposite.

Table B.1-1: Critical analysis on M&V application for **relevance**

Reference question	Compressors					Fans		Fridge Plants		Pumps		Other
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]
(A) What measurement boundary was used?	A	A	B	A	A	B	B	A	A	A	A	A

Table B.1-1 illustrates that nine of the twelve references considered a component isolation measurement boundary where only three of the references considered a whole facility evaluation. The reason for this is, when evaluating ESMs on a whole facility, the expected savings from the ESM should be at least 10% of the whole facility’s energy consumption.

Due to the small ESM evaluations, most of the mines developed baselines for the specific ESM boundary only. This allows for the accurate evaluation and monitoring of the energy performance of the ESM. The three mines who evaluated the ESM performance on a low resolution, all evaluated expected savings with a total effect of 10% and higher on the whole facility’s energy consumption, making the boundary still relevant to the purpose of its application.

The overall finding from the first step of the M&V application on mines is that the boundary used for the ESM evaluation is relevant to its application. This proves that the M&V application process include the M&V principle *relevance*.

Step-2: Consistency

The second step in the M&V application process is to identify a **measurement resolution** for the ESM evaluation. The measurement resolution is decided on based on each specific ESM’s conditions. If an ESM implemented is concerning a TOU profile change, such as when cost is managed by optimising the use of the components in a less expensive time period, half-hourly profiles should be considered. If the ESM specifically only achieve savings on a weekday, daily profile should be considered to allow for the weekends (and other types of days) to be excluded from the evaluation.

The twelve M&V literature references were evaluation to assess which measurement resolution was considered. The results are displayed in Table B.1-2. Typically, a green block will indicate that the measurement resolution was consistent for its application where a red block indicates the opposite.

Table B.1-2: Critical analysis on M&V application for **consistency**

Reference question	Compressors					Fans		Fridge Plants		Pumps		Other
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]
(B) What measurement resolution was used?	Half-hour	Month	Half-hour	Half-hour	Annual	Half-hour	Half-hour	Month	Half-hour	Half-hour	Daily	Half-hour

Four of the twelve references quantified the savings from the ESMs on a low measurement resolution (monthly or annually). The savings were evaluated on the low resolutions due to a combination of a lack of sufficient data in higher resolutions and also due to the project not requiring any small adjustments. Three references evaluated the ESM performance on daily resolutions and the remaining five references used half-hourly resolutions. The savings were calculated in higher resolutions to account for the changes in TOU profiles along with the different type of days.

The different type of days considered by the three references who developed baselines on daily resolutions were combined as:

- Weekdays
- On-Saturday
- Off-Saturday
- Sunday
- Christmas holiday
- Easter holiday
- Other public holidays
- Maintenance days

The energy consumption on each of these days can be significantly different due to the planned production outputs. A weekday (Monday to Friday) profile is usually very consistent. The number of active crews stays similar and no changes are expected. All of the other days typically have different energy consumption profiles. These types of days were also considered for each season or month due to the energy consumption that differs based on the season (mainly due to temperature changes).

Step-3: Accuracy

The third step in the M&V application process is to identify a test the **data quality** used for developing the baseline. When evaluating the data quality, specific attention is given to 1) missing data, 2) outliers and 3) effect of historical events (unplanned events). The twelve literature references were evaluated to address whether these references included these evaluations within the M&V process. The results are displayed in Table B.1-3. Typically, a green block will indicate that the data was accurate since the above-mentioned quality points were addressed.

Table B.1-3: Critical analysis on M&V application for **accuracy**

Reference question	Compressors					Fans		Fridge Plants		Pumps		Other
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]
(C) Was the data evaluated for accuracy?												

All twelve the references evaluated the **data quality** before using the dataset to develop baselines. The data were evaluated for missing data and outliers. These data points were identified and addressed. If the datapoint was presumed as normal, it remained as part of the dataset but were removed if it could be proved to be an outlier. The data were also evaluated for unplanned events that occurred in the baseline period. These data were removed (in three of the cases) and replaced with the average of the normal operating conditions (in the remaining nine cases).

Step-4: Completeness

The fourth step in the M&V application process is to identify all the relevant **routine adjustments** and the accurate quantification thereof. Routine adjustments are changes that occur routinely and can usually expected. In the mining environment this typically includes the changes associated with increases/decreases in production output and the effect that seasonal changes (temperature) has on the normal energy consumption.

The effect of these changes can be calculated by evaluating the historical change in energy that occurred for the routine adjustments. The normal energy before and after the routine adjustment can also be considered for the adjustments. These datasets can be used in regression models to predict the effect of the routine adjustments. Typical models that is used in M&V applications are:

- Power model
- Polynomial models
- Linear regression model
- Intensity model

These models are fitted to the datasets and the CV(RMSE), the R^2 and the AAE values are compared. The model with the most suitable variables is usually used to predict the effect of the routine adjustment. The twelve M&V references were evaluated to identify whether routine adjustments were addressed and included within the evaluation of the ESM effect. The results are illustrated in Table B.1-4. Typically, a green block will indicate that routine adjustments were included and accurately quantified.

Table B.1-4: Critical analysis on M&V application for **completeness**

Reference question	Compressors					Fans		Fridge Plants		Pumps		Other
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]
(D) Were all the relevant routine adjustments considered and correctly quantified?												

All twelve the references also included ***routine adjustments*** into the evaluation process. Four of the twelve references included both the effect of savings/growth projects where the remaining eight references only included production changes. These changes were calculated using mathematical models such as regression models, power models and polynomial models. The most suitable applications were identified, and the effects of the events calculated.

Step-5: Conservativeness

The fifth step in the M&V application process is to ***develop the baseline***. This step is concerned about what variables are included when developing the baseline. It is important to ensure that the baseline is developed in an accurate and conservative matter such as to ensure that savings are not inflated (over-estimated). The twelve literature references were evaluated to ensure that conservative savings were calculated, and the results are presented in Table B.1-5.

Table B.1-5: Critical analysis on M&V application for **conservativeness**

Reference question	Compressors					Fans		Fridge Plants		Pumps		Other
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]
(E) Is the savings conservative?												

During the ***baseline development*** step, half of the references included non-routine adjustment predictions in the baseline already. This involves adding a variance factor to the baseline that will ensure that the baseline has leverage for unplanned events. However, these non-routine adjustments were accurately quantified in the assessment period (after the unplanned event occurred) and the baseline was updated and adjusted accordingly.

Step-6: Transparency

The final step in the M&V application process is the reporting of the process and all findings to give ***assurance*** that the baseline and savings quantified is correct. The twelve M&V literature references

were evaluated to see whether the savings. The results are presented in Table B.1-6, where a green block indicates that the M&V process was traceable through reporting and validation of the savings.

*Table B.1-6: Critical analysis on M&V application for **conservativeness***

Reference question	Compressors					Fans		Fridge Plants		Pumps		Other
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]
(F) Is the M&V process transparent?												

The application process of all twelve the references were well documented. The **assurance** of a well-documented report ensures that the process can be audited and validated by an independent resource. All twelve references presented structured M&V plans alongside pre-approved baseline reports.

Summary of the critical analysis on the M&V applications on mines

All twelve these references conformed to the presented M&V methodology and principles. The M&V applications delivered twelve baselines (one for each reference) and not one of these baselines became obsolete in the assessment period. Relevant and accurate results were obtained from this methodology as presented in Table B.1-7.

Table B.1-7: Critical analysis on M&V application

Reference question	Compressors					Fans		Fridge Plants		Pumps		Other
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]
(A)												
(B)												
(C)												
(D)												
(E)												
(F)												

B.2 CRITICAL ANALYSIS ON BUDGETS

This section of Appendix B continues the critical analysis of the category 2 and category 3 references. In Chapter 1 (Section 1.4) the critical analysis is applied in full on the category 1 references (mine questionnaires) and only a summary is presented for the category 2 and category three references. Table B.2-1 presents the groups and the references included in each category.

Table B.2-1: Category 2 and 3 references

Category 2 references (South Africa)	Category 3 references (International)
Business (12 references) [58], [59], [68], [69], [60]–[67]	International (48 references) [100], [101], [110]–[119], [102], [120]–[129], [103], [130]–[139], [104], [140]–[147], [105]–[109]
Medical (7 references) [70]–[76]	
Education (8 references) [60]–[67]	
Science (7 references) [85]–[91]	
Agriculture (8 references) [92]–[99]	

A total of 90 references are listed in Table B.2-1 of which 42 are located in South Africa and the remaining are from industries across the globe. These references were identified specifically for their application, discussion and/or development of budget techniques discussed. Figure B.2-1 illustrates the distribution of the 90 references where it can be seen that most of the references are in the time period of 2010 to 2020.

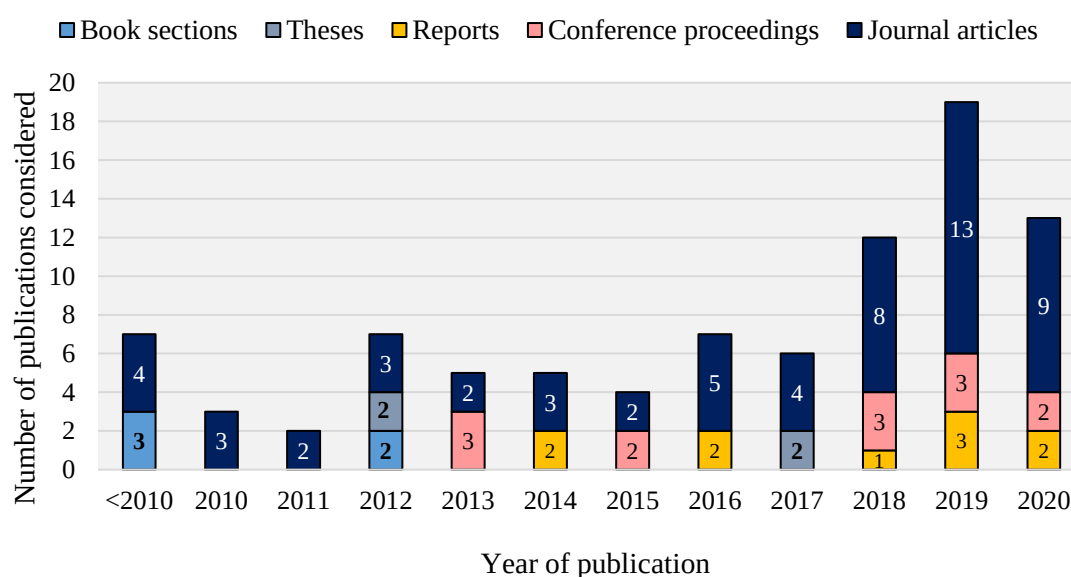


Figure B.2-1: Distribution of the 90 references

Figure B.2-1 shows that most of the references (almost 60%) are obtained from published journal articles, which are considered the most reliable references due to the critical reviewing process it has undergone before publishing. The remaining of the references were obtained from book sections, theses, reports and conference proceedings, all of which are peer-reviewed and also considered reliable references. This gives creditability to the research included in this thesis.

The six M&V related questions generated in Section 1.4 will be used to test the research question on each of these 90 references above. These six M&V related questions are listed again:

- (A) *Is the budget relevant to the need of the application? (Testing for relevance)*
- (B) *Is consistency applied throughout the application process? (Testing for consistency)*
- (C) *Is the budget compiled using accurate data? (Testing for accuracy)*
- (D) *Does the budget consider any expected changes? (Testing for completeness)*
- (E) *Is the budget representative of the expected performance? (Testing for conservativeness)*
- (F) *Is the budgeting process valid? (Testing for transparency)*

To answer these questions, the five-step strategy that consists of the (1) **Research**; (2) **Examine**; (3) **Compare**; (4) **Conduct**; and (5) **Test** [44] will be used. This strategy is discussed in Chapter 1. An overview of the strategy is presented in Figure B.2-2.

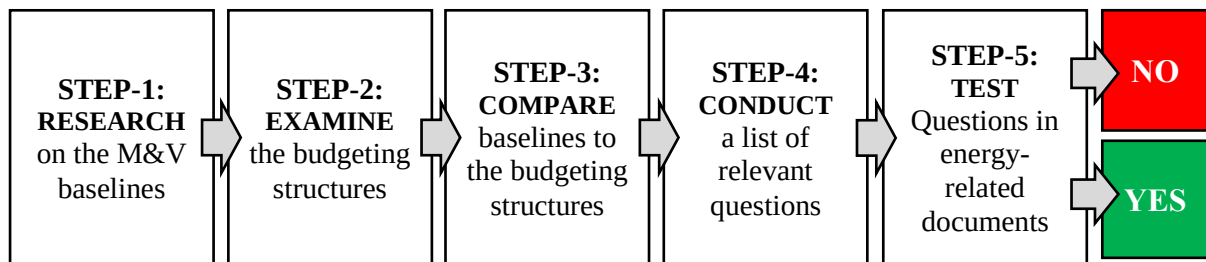


Figure B.2-2: Critical analysis strategy

The application of this strategy is discussed individually for the category 1 and the category 2 references in the sub-sections below.

CATEGORY 2: BUDGETS USED BY OTHER INDUSTRIES IN SOUTH AFRICA

Step-1: Research on the M&V baselines

The first step of the five-step strategy was already discussed in Section 1.13 and is universal for all three categories (budgeting structures in South African mines, budgeting structures of other industries in South Africa and international budgeting structures). This step will, therefore, not be addressed again but will rely on the information already discussed in previous sections.

Step-2: Examine the budgeting structures (of other industries in South Africa)

For the evaluation of the budgeting structures on other industries in South Africa, 42 peer-reviewed literature-based references are considered. These references all discussed either how the budgets were developed or how the budgets were applied on case studies. These 42 references are grouped into five clusters, each representing a different industry in South Africa. These five clusters are: 1) Business, 2) Medical, 3) Education, 4) Science and 5) Agriculture.

The general steps considered by the eight mines in the questionnaires are used to see whether or not the 42 literature-based studies on other South African industries addressed budgeting using similar steps to the eight mines in the questionnaires.

Figure B.2-3 illustrates the number of similar steps (top section of the graph with the green dots) and the number of non-similar steps (bottom section with the red dots). Each group (Business, Medical, Education, Science, and Agriculture) are representative in the figure.

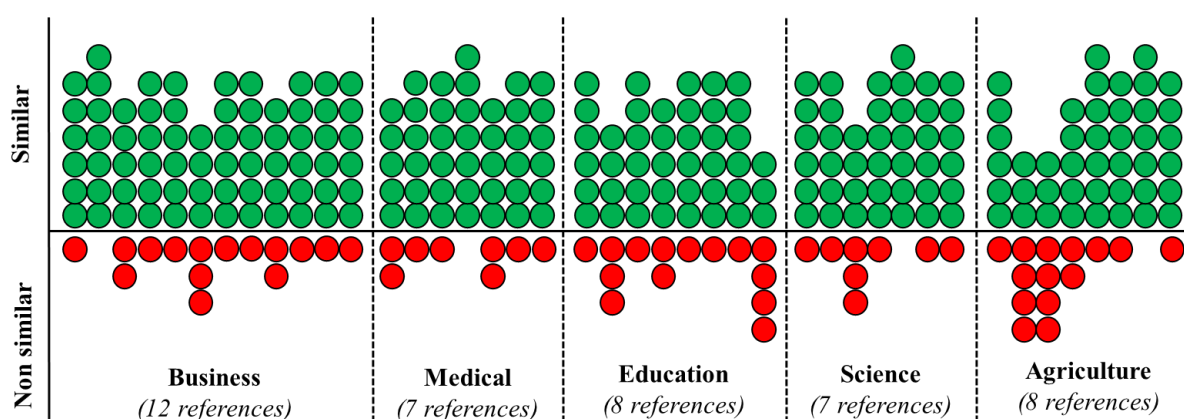


Figure B.2-3 General budgeting steps by the 42 references on other industries in South Africa

From Figure B.2-3 it is clear that most of these groups followed similar steps than that of the mining industry in South Africa. The vast number of similar steps followed by these industries prove that the general steps followed by the mines in the questionnaires are universal budgeting steps and will, therefore, be used as the reference point for the steps followed when developing budgets.

Although most of the same steps were followed as the mines in the questionnaires, several other steps were considered as well. The different steps are discussed for each cluster and summarised:

- Most of the studies neglected a validation step as discussed in category 1.
- Most of the medical references incorporated a clinical trial step, which was found to be irrelevant for the application on mine budgets and not required for this study.

Due to the vast number of similar steps (and the irrelevance of the other steps) used by the 42 references on other industries in South Africa and the mining industry in South Africa, the general budgeting structure are still considered to be that obtained from the questionnaires in the Category 1 evaluation.

Step-3: Compare the M&V baselines to the budgeting structures

In Step-2 of the five-step strategy it was concluded that the general budgeting structure used by other industries in South Africa is similar to the budgeting structure used by South African mines (with the exception of industry-specific steps).

The comparison between the M&V baselines and the budgeting structures on the 42 references in category 2 will, therefore, be similar to that already discussed in step-3 of the category 1 evaluation (refer to Table 1-4)

Step-4: Conduct relevant questions for critical analysis

Since the comparison between the M&V structures and the budgeting structures of the 42 references in category 2 are similar, the relevant question conducted in Step-4 of the category 1 evaluation will also be considered for the category 2 evaluation (refer to The parallels present several questions as to whether the six M&V principles are applied when creating the budget. Six relevant questions are contained in Table 1-6. These questions are constructed based on the contribution of each of the principles to the M&V process (as discussed in Table 1-1 in Section 1.2). These questions also relate to the six M&V parallels listed in Table 1-5.

Table 1-6).

Step-5: Test the questions in budget-related documents

The final step in the five-step strategy is to test each of the budgeting structures of the 42 references on other industries in South Africa against the questions generated in Step-4. If the question were answered the test proves to be successful and the M&V principle was addressed in the budgeting structure. If the test proves to be unsuccessful the M&V principle was not addressed in the budgeting structure and proves the need to address the principle.

Each of the questions generated in Step-4 is provided below with the respective performance of each literature references (on the 42 references in other industries of South Africa).

(A) Is the budget relevant to the need of the application? (Testing for relevance)

All of the budgets created within the literature references were created for specific goals. Identifying whether or not a reference's boundary is relevant or not, is therefore, complicated and open to personal interpretation. For the critical evaluation, the performance on the strategy question is based on whether or not a whole facility or an isolation boundary were chosen.

Table B.2-2 provides the feedback for each reference's result on strategy question A. A red block indicates that the budget was developed on a high-level (whole facility) and a green block indicates that an isolation boundary was chosen. A red block, therefore, does not necessarily indicate that the budget is irrelevant but that the budget could have been in more detail (by adapting an isolated boundary).

Table B.2-2: Results of strategy question A (category 2)

[illegible]

It is noted that almost 50% of the 42 literature references considered smaller boundaries compared to what the mines in the questionnaires considered. The reason for this is possibly due to the difference in the size of the industries. A mine is relatively larger than a typical business, hospital or school and can, therefore, be more complicated to create smaller boundary budgets compared to the other industries.

(B) Is consistency applied throughout the application process? (Testing for consistency)

Consistency throughout the budgeting process ensures that the final product (the budget) is reliable. To ensure consistency in the budget, the data used for the budget should be uniform. This includes the resolutions considered when developing the budget [156]. When multiple variables are included in the budgeting process, it is important to ensure that these resolutions are similar for all the variables.

The 42 literature references were evaluated to identify the consistency of the resolutions used for budgeting. Some of the budgets considered consistent resolutions. The majority of the literature references, however, calculated certain aspects of the budget in different resolutions. These aspects were typically the adjustments incorporated into the budgets. Table B.2-3 demonstrates the result of each literature reference's feedback on strategy question B.

Table B.2-3: Results of strategy question B (category 2)

Business										Medical					Education					Science					Agriculture																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																				
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The inconsistent resolutions may result in an inconsistent budget. It is, therefore, recommended to ensure that all resolutions are considered when creating a budget and it is important to ensure that the resolutions are consistent, especially for seasonal effects.

(C) *Is the budget compiled using accurate data? (Testing for accuracy)*

The accuracy of the data ultimately determines the reliability of the budget. If data accuracy levels are low, the budget will ultimately be unrealistic and unable to be used for any energy management. It is, therefore, important to ensure that the data used for the budget is accurate.

For the data to be considered “accurate” it has to comply to the following for criteria [27], [31], [34], [52], [157]:

- 1) Data obtained from calibrated meters or servers (or else at least verified against a trusted reference such as the Eskom invoices);
- 2) Obtained data should be evaluated for completeness (no missing data points);
- 3) Historical data should be evaluated for abnormal events and the abnormal events should have been removed from the dataset, and
- 4) Data should be evaluated for outliers, the outliers should be investigated and removed if required.

Table B.2-4 presents the feedback for each literature reference’s feedback on strategy question C.

Table B.2-4: Results of strategy question C (category 2)

Business	Medical	Education	Science	Agriculture
				

It is noted that less than 20% of the research studies mentioned the accuracy of the data used for budgeting. The vast amount of *unsuccessful* feedback on strategy question C enables for the reaction that, generally, these references does not compile budgets using accurate data.

(D) Does the budget consider any expected changes? (Testing for completeness)

Considering expected changes when developing a budget proves to be a popular step in the budgeting process. More than half of the literature references on other industries in South Africa considered expected changes during the budgeting process. The feedback on question B for each of the literature references are presented in Table B.2-5.

Table B.2-5: Results of strategy question D (category 2)

Business	Medical	Education	Science	Agriculture
				

The type of changes considered for the other industries in South Africa varies. The popular changes are temperature and number of people present (employees).

(E) Is the budget representative of the expected performance? (Testing for conservativeness)

When energy savings obtained from an ESM is calculated, several models are developed to compare the saving values to each other. As a rule-of-thumb, the most conservative (the savings model presenting the least amount of savings) are identified as the approved model. This is to ensure that no unintended or accidental savings are claimed. When creating a budget, the purpose is to plan for the upcoming year’s financial output to ensure that the facility has enough resources and capital expenditure available.

A conservative budget would, therefore, be a large enough budget that underestimate the effect of savings projects and overestimate the effect of growth projects, ultimately to ensure that the budget has a safety factor. Thus, to ensure that the most conservative budget is used, the budgeting approach should also allow for several budgets to be created and compared to identify the size of the safety factors.

During M&V applications, presenting multiple models are standard to identify the most suitable model. For budgeting purposes, this does not seem to be a standard as none of the 42 literature studies on other industries in South Africa considered any additional models either (as with the eight models in category 1). Table B.2-6 presents the feedback on strategy question E for category 2.

Table B.2-6: Results of strategy question E (category 2)

Business	Medical	Education	Science	Agriculture

(F) Is the budgeting process valid? (Testing for transparency)

During the critical analysis of most of the budgeting structures presented by the literature references, uncertainty was addressed to some of the aspects included in the process as well as on how some of the calculations were done. This impacted the transparency of the budgeting process.

After the budget is created, it is important to ensure that the budget is correct before approving the budget. Validating the budget ensures that the process is transparent and reliable. The eight mines that participated in the questionnaires were evaluated to see whether or not they validated their budgets before approving it. The feedback on this strategy question are presented in Table B.2-8.

Table B.2-7: Results of strategy question F (category 2)

Business	Medical	Education	Science	Agriculture

Summary of the Category 2 critical analysis results

From the critical analysis on the 42 references in category 2 (budgeting structures used by other industries in South Africa), the following observations were made:

- The overall budgeting structure is similar to that used by the mining industry in South Africa (Figure B.2-2 shows that most of the references had at least 50% or higher similarities with the mine's budget structures).
- The routine adjustments accounted for was different than what the mines accounted for. This is expected since it is on other industries.
- It seems like the medical industry gave the most attention to the data quality. This can be because of the data obtained being obviously faulty.

- Generally, smaller boundaries were also considered compared to the high boundaries that mines use. This can be due to the facility (in each category) being smaller compared to a mine which makes the development of budgets on smaller boundaries easier.
- It is also noted that the budgets were mainly developed on monthly resolutions.

These observations ultimately show that none of these references included all six of the M&V principles (relevance, consistency, accuracy, completeness, conservativeness and transparency) in the budgeting structures. The need for the study, which is to incorporate these principles into the budgeting structures, are therefore established.

CATEGORY 3: BUDGETING STRUCTURES USED GLOBALLY

Step-1: Research on the M&V baselines

The first step of the five-step strategy is already discussed in Section 1.13 and is universal for all three categories (budgeting structures in South African mines, budgeting structures of other industries in South Africa and international budgeting structures). This step will, therefore, not be addressed again but will rely on the information already discussed in previous sections.

Step-2: Examine the budgeting structures

The budgeting structure of 48 alternative references from various industries across the globe is evaluated. All the references are considered new to the research field as all the references were published post 2010. More than 75% of the references (36 of the 48 references) are from published Journal Articles. The budgeting structures of each of these references are compared to the budgeting structure established by the eight mines that participated in the questionnaire (category 1). Figure B.2-4 illustrates whether these 48 references followed similar or different steps compared to the established structure in category 1.

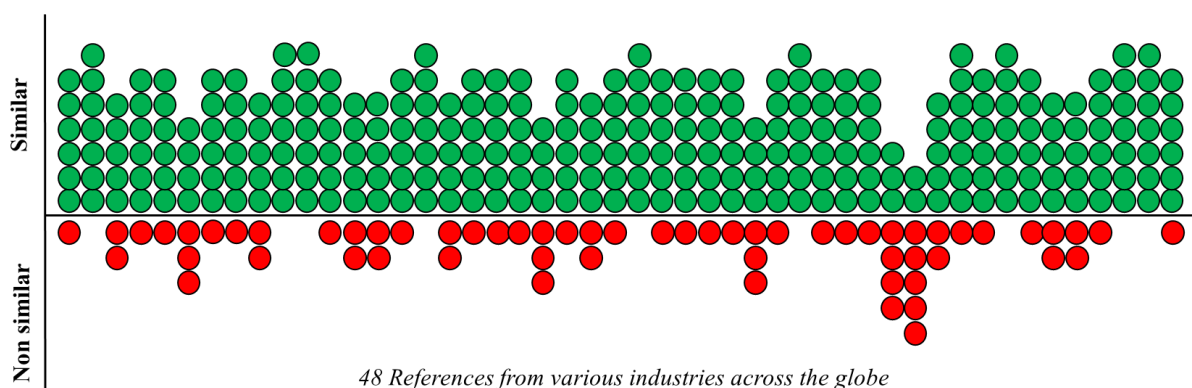


Figure B.2-4: General budgeting steps by the 48 references across the globe

From Figure B.2-4 it is clear that most of references followed similar steps than that of the mining industry in South Africa. The vast number of similar steps followed by these references proves that the

general steps followed by the mines in the questionnaires are universal budgeting steps and will, therefore, be used as the reference point for the steps followed when developing budgets.

Step-3: Compare the M&V baselines to the budgeting structures

In Step-2 of the five-step strategy it was concluded that the general budgeting structure used globally is similar to the budgeting structure used by South African mines (with the exception of industry-specific steps). The comparison between the M&V baselines and the budgeting structures on the 48 references in category 3 will, therefore, be similar to that already discussed in step-3 of the category 1 evaluation (refer to Table 1-4).

Step-4: Conduct relevant questions for critical analysis

Since the comparison between the M&V structures and the budgeting structures of the 48 references in category 3 are exact, the relevant question conducted in Step-4 of the category 1 evaluation will also be considered for the category 3 evaluation (refer to The parallels present several questions as to whether the six M&V principles are applied when creating the budget. Six relevant questions are contained in Table 1-6. These questions are constructed based on the contribution of each of the principles to the M&V process (as discussed in Table 1-1 in Section 1.2). These questions also relate to the six M&V parallels listed in Table 1-5.

Table 1-6).

Step-5: Test the questions in budget-related documents

The final step in the five-step strategy is to test each of the budgeting structures of the 48 global references against the questions generated in Step-4. If the question were answered the test proves to be successful and the M&V principle were addressed in the budgeting structure. If the test proves to be unsuccessful the M&V principle were not addressed in the budgeting structure and proves the need to address the principle. Figure B.2-5 illustrates the final step in the five-step strategy.

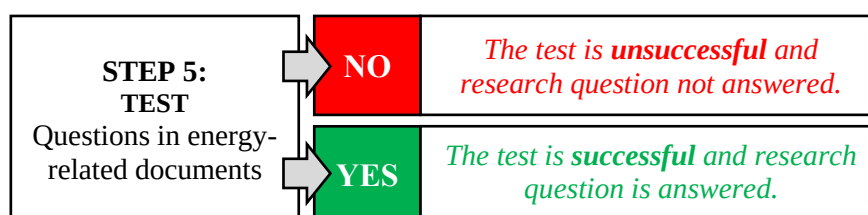


Figure B.2-5: Step five of the five-step strategy

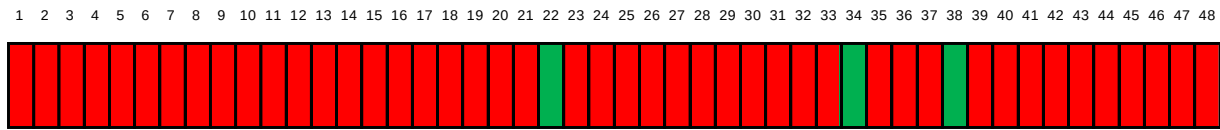
Each of the questions generated in Step-4 is provided below with the respective performance of each questionnaire results (on the 48 global references) discussed.

(A) *Is the budget relevant to the need of the application? (Testing for relevance)*

Most of the references used relevant boundaries to the case study discussed. It should also be noted that most of these budgets were developed for specific scenarios (such as for the educational department of

a primary school) which allows for the boundary to be identified easily. Table B.2-8 provides the feedback for each literature study's result on question E.

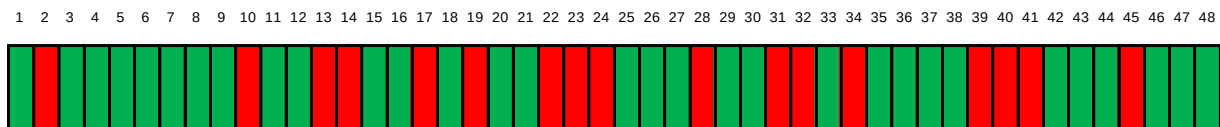
Table B.2-8: Results of strategy question A (category 3)



(B) Is consistency applied throughout the application process? (Testing for consistency)

Some of the budgets considered consistent resolutions. The majority of the literature references, however, calculated certain aspects of the budget in different resolutions. These aspects were typically the adjustments incorporated into the budgets. Table B.2-9 demonstrates the feedback of each literature's references on question D.

Table B.2-9: Results of strategy question B (category 3)



(C) Is the budget compiled using accurate data? (Testing for accuracy)

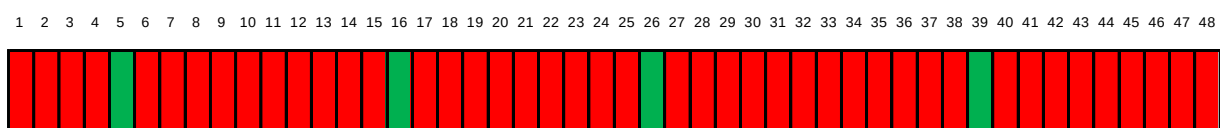
The accuracy of the data ultimately determines the reliability of the budget. If data accuracy levels are low, the budget will ultimately be unrealistic and unable to be used for any energy management. It is, therefore, important to ensure that the data used for the budget is accurate.

For the data to be considered “accurate” it has to comply to the following for criteria [34], [52], [53], [155], [157]:

- 1) Data obtained from calibrated meters or servers; and
- 2) Obtained data should be evaluated for completeness (no missing data points); and
- 3) Historical data should be evaluated for abnormal events and the abnormal events should have been removed from the dataset, and
- 4) Data should be evaluated for outliers, the outliers should be investigated and removed if required.

If the 48 references addressed all four the above-mentioned criteria, strategy question C will be successfully addressed. Table B.2-10 presents the results of the eight mines data accuracy tests.

Table B.2-10: Results of strategy question C (category 3)

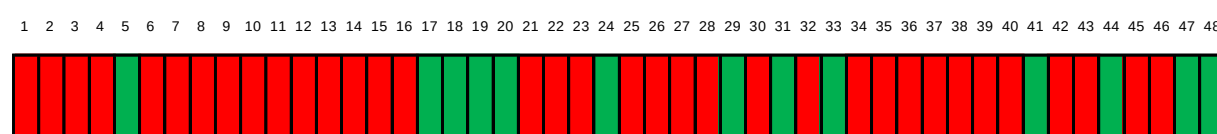


It is noted that only three of the 48 research studies mentioned the accuracy of the data used for budgeting. Most of the remaining research studies only included one or at most two of the listed accuracy checks.

(D) Does the budget consider any expected changes? (Testing for completeness)

Considering expected changes when developing a budget proves to be a popular step in the budgeting process. More than half of the literature references on other industries in South Africa considered expected changes during the budgeting process. The feedback on question B for each of the literature references are presented in Table B.2-12.

Table B.2-11: Results of strategy question D (category 3)

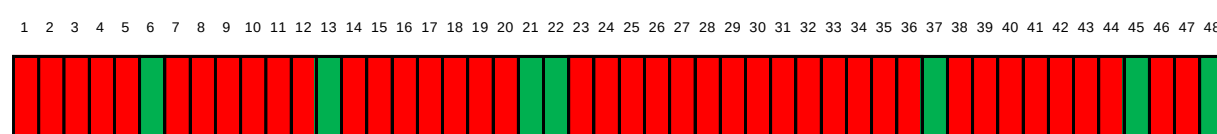


The popular changes, other than employees, temperature and production.

(E) Is the budget representative of the expected performance? (Testing for conservativeness)

During M&V applications, presenting multiple models are standard to identify the most suitable model. For budgeting purposes, this does not seem to be a standard as none of the 42 literature studies on other industries in South Africa considered any additional models either (as with the eight models in category 1). Table B.2-12 presents the performance of each literature references in category 3 on question C.

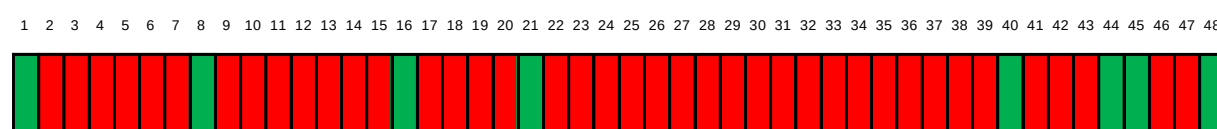
Table B.2-12: Results of strategy question E (category 3)



(F) Is the budgeting process valid? (Testing for transparency)

During the critical analysis of most of the budgeting structures presented by the literature references, uncertainty was addressed to some of the aspects included in the process as well as on how some of the calculations were done. This impacted the transparency of the budgeting process. Table B.2-13 provides the feedback for each literature study's result on question F.

Table B.2-13: Results of strategy question F (category 3)



After the budget is created, it is important to ensure that the budget is correct before approving the budget. Validating the budget ensures that the process is transparent and reliable.

Summary of the Category 3 critical analysis results

From the critical analysis on the 48 references in category 3 (budgeting structures used internationally by various industries); the following observations were made:

- *The overall budgeting structure is similar to that used by the mining industry in South Africa (Figure B.2-4 shows that most of the references had at least 60% or higher similarities with the mine's budget structures).*
- *The routine adjustments accounted for was different than what the mines accounted for. This is expected since it is on other industries.*
- *Generally, smaller boundaries were also considered compared to the high boundaries that mines use. This can be due to the facility (in each category) being smaller compared to a mine which makes the development of budgets on smaller boundaries easier.*
- *It is also noted that the budgets were mainly developed on monthly resolutions.*

These observations ultimately show that none of these references included all six of the M&V principles (relevance, consistency, accuracy, completeness, conservativeness and transparency) in the budgeting structures. The need for the study, which is to incorporate these principles into the budgeting structures, are therefore established.

Critical analysis conclusion

The core of the critical analysis was to identify whether any of the research studies (and questionnaire feedback) addressed any of the M&V principles. The hypothesis was that if a reference addressed all of the M&V principles, the budgeting structure of that reference would have addressed the research question of this study. However, from the feedback on the step-5 questions for each category it is noted that not one of the literature references applied all of the M&V principles.

Table B.2-14 presents the final matrix (a summary of the responses in category 1, 2 and 3) for the critical analysis of this study.

Table B.2-14: Critical analysis matrix for all 98 references

	Category 1	Category 2	Category 3
(A)	Red	Red	Red
(B)	Red	Red	Red
(C)	Red	Red	Red
(D)	Red	Red	Red
(E)	Red	Red	Red
(F)	Red	Red	Red

The summary of the responses on the six M&V related questions presented in Table B.2-14 shows that none of the 98 references (which includes the eight questionnaires of category 1) addressed all of the relevant questions. It is noted, however, that question B (*Is consistency applied throughout the application process?*) were widely addressed across all three reference categories. Question C (*Is the budget compiled using accurate data?*) was the question least addressed.

The lack of the application of M&V principles in the budgeting structures are therefore proved. This study will focus on addressing these principles accordingly, and fulfilling the limitations identified.

B.3 MEASUREMENT BOUNDARIES

Three boundaries for the evaluation of ESM performances are presented by the IPMVP. These boundaries are (1) Retrofit isolation, (2) Whole facility and (3) Calibrated simulation. Each of these boundaries consists of different advantages and limitations, which is presented in Table B.3-1.

Table B.3-1: M&V option descriptions

	Option A: Retrofit Isolation	Option B: Whole facility	Option C: Calibrated simulation
Description:	Savings are determined by isolating the ESM and only includes energy streams directly impacting the ESM.	Savings are determined by measuring the whole facility's energy consumption to evaluate the performance of the ESM(s).	Savings are determined through simulation of the energy use of individual components or the whole facility.
Preferred application :	This option is chosen if the performance of the ESM and its effected area is of concern only and can be easily isolated. It can also be used where interactive effects can be measured and excluded.	This option works best when there are many ESMs present and the interactive effects between the ESMs are substantial. The expected savings of the ESMs should be large enough to be noticed on a high level (recommended that savings should be more than 10% of the energy consumption).	Where there are many different types of ESMs present and needs to be monitored individually. Also, applicable where the ESMs involve diffuse activities which cannot easily be isolated from the rest of the facility. Where energy data is not available or correct.
Limitations:	Installing new meters can be costly and if multiple ESMs need to be evaluated multiple baselines will be required which could be time consuming to compile. Using this option becomes excessively complex if isolation of the ESM cannot commence. If this is the case, option B should be considered instead.	If the total expected savings are less than 10% of the whole facility energy consumption, the savings can be argued to be noise.	Requires accurate models and calibrated meters to measure data. Simulation analysis needs to be conducted by trained personnel who are experienced with the software and calibration techniques. Baseline or assessment energy data is not available / correct.

When evaluating a large facility, such as mine, any of these three options can be used, depending on what the desired outcome is. To evaluate the performance of a specific ESM, retrofit isolation will probably be the best approach. When the goal is to evaluate the performance on a high level (measure the performance of all the components), whole facility will be more suitable.

Calibrated simulations can also be used in either of the situations, especially if adequate data is lacking. However, developing simulations is a complex approach and in many instances, the thought pattern of a calibrated simulation cannot easily be traced. This makes it really difficult for a mine to implement a calibrated simulation and are hardly ever considered as the option to used.

Creating budgets for individual components delivers the benefit of energy management on the components. This option is therefore always desirable, however, on a large facility (such as a mine) developing budgets on a component level can be very time consuming to the vast number of components present. This, however, presents the following question:

“Is the extra work required to develop an operational budget for each component worth the effort when comparing to a shaft level or whole facility budget?”

The *hypothesis* is that by creating the budget in more detail a more accurate budget can be presented. The hypothesis is tested by creating baselines (using M&V procedures) on a case study. Two M&V baselines will be created for a single shaft on Mine A. The first baseline will be created on a whole facility level (Option A) and the second baseline will be created per component (Option B). Ultimately, the accuracy of these two baselines will be compared.

To address the *question* the time used to create each of the baselines will be compared to the difference in accuracy. If the percentage difference in accuracy is higher than the percentage difference in the time used to create the baselines, the question will hold true. If the question holds false it will be assumed that the additional effort required to create baselines for each component (Option A) is not worth the effort since the change in accuracy is not that significant.

Finally, the assumption will be valid that if the question holds true or false on M&V baselines, it will hold the same for mine budgets. The following assumptions are made to simplify the application process:

- a) The data is already evaluated and consists of no outliers or missing data
- b) No changes in production is expected (previous year’s production = current year’s production)
- c) No savings or growth projects occurred (no expected adjustments required)
- d) Linear model is used

CREATING A BASELINE USING OPTION A (RETROFIT ISOLATION)

The electrical reticulation of the shaft that will be considered for the hypothesis testing are presented in Figure B.3-1. On this figure, the incomers (INC) into “A” Main substation and “B” Main substation is denoted with the numbers 1 and 2. These two INC energy readings will be the main focus of the whole facility evaluation. The remainder of the feeders (FDR) are connected to components (fans, compressors, winders, etc) or other meter panels usually named after the underground level that it is located on. The FDR readings will be the main focus of the isolated component boundary evaluation.

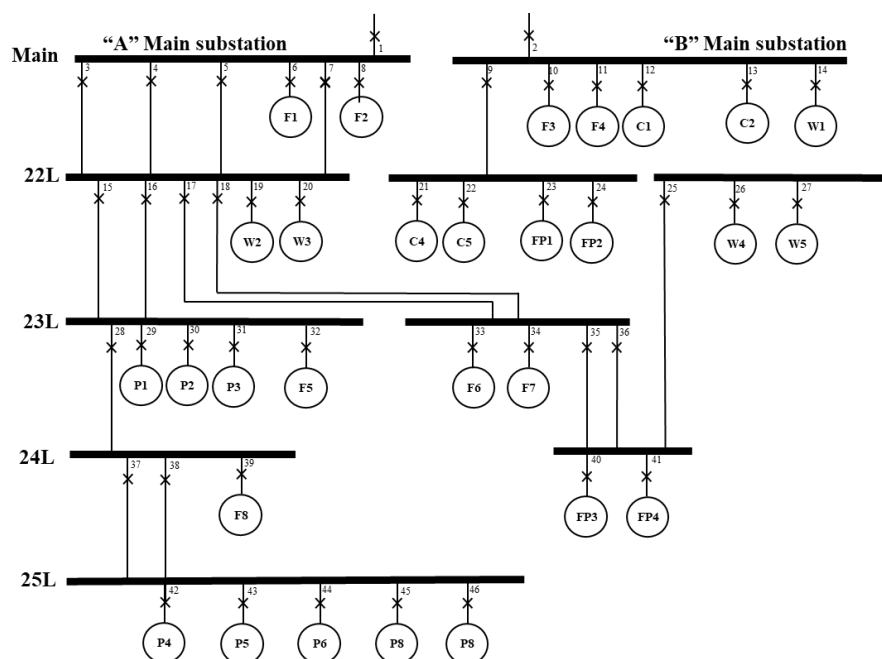


Figure B.3-1: Shaft X electrical layout

The components illustrated on Figure B.3-1 are listed in Table B.3-1 along with the level it is located on and the average monthly kWh consumption. The assumption is made that all of the meters are calibrated, and the data quality was already evaluated to ensure that the values presented in Table B.3-1 are correct.

Table B.3-1: Component descriptions for isolated boundary

Level	Component	Consumption (kWh)
Main level	Ventilation fan (F1)	588 504
Main level	Ventilation fan (F2)	1 488
Main level	Ventilation fan (F3)	593 712
Main level	Ventilation fan (F4)	0
Main level	Compressor (C1)	2 495 376
Main level	Compressor (C2)	2 856 960
Main level	Man winder (W1)	46 128
22 level (22L)	Rock winder (W2)	1 654 656
22 level (22L)	Man winder (W3)	11 160
22 level (22L)	Compressor (C3)	2 351 362
22 level (22L)	Compressor (C4)	2 533 621
22 level (22L)	Fridge plant (FP1)	1 523 612
22 level (22L)	Fridge plant (FP2)	1 236 223
22 level (22L)	Man winder (W5)	157 728

Level	Component	Consumption (kWh)
22 level (22L)	Rock winder (W6)	148 800
23 level (23L)	Pump (P1)	1 523 621
23 level (23L)	Pump (P2)	856 263
23 level (23L)	Pump (P3)	1 232 597
23 level (23L)	Ventilation fan (F5)	362 552
23 level (23L)	Ventilation fan (F6)	596 566
23 level (23L)	Ventilation fan (F7)	562 821
24 level (24L)	Fridge plant (FP3)	0
24 level (24L)	Fridge plant (FP4)	1 623 322
24 level (24L)	Ventilation fan (F8)	384 648
25 level (25L)	Pump (P4)	90 024
25 level (25L)	Pump (P5)	0
25 level (25L)	Pump (P6)	1 121 952
25 level (25L)	Pump (P7)	1 281 912
25 level (25L)	Pump (P8)	0
Total consumption (sum of all individual consumptions)		6 594 028

A baseline is developed for each of these components considering the previous 12-month's energy data. The energy data is obtained from each component in daily resolutions. Production outputs for the same 12-month period is obtained in monthly resolutions. Table B.3-2 contains a list of all the planned growth and savings projects, along with all of the existing growth and savings projects.

Table B.3-2: Planned and existing projects

Growth projects		Saving projects	
Component	Planned effect	Component	Planned effect
New projects			
-	-	Compressor (C1)	250 000 kWh
-	-	Compressor (C2)	250 000 kWh
-	-	Pump (P7)	100 000 kWh
Existing projects			
Fridge Plant (FP2)	350'000	-	-

The budget for each component will be calculated using Equation B.3-1:

$$\text{Budget} = \text{Historical energy} \pm \text{Adjustments} \pm \text{Variances} \quad \text{Equation B.3-1}$$

Where the *historical energy* is the previous year's corresponding month's energy consumption, the *adjustments* is the adjustments due to the planned and existing savings projects presented in

Table B.3-2. The *variance* is the difference between the previous year's budget and the previous year's actual energy consumption, which will be assumed as 5% for the purpose of this application.

The following external effects will be evaluated on each component. It is possible that the external effects for each component varies and it should therefore be individually calculated per components. Four external effects will be evaluated on the energy consumption of each component. These external effects are:

- 1) Changes in production
- 2) Changes in temperature
- 3) Changes in the depth of the mine
- 4) Changes in the number of employee's present

Each one of the external effects are discussed in more detail in Appendix A.4. The effects were calculated using a linear regression model and the R^2 of these models were used to predict if a correlation was noticed. Typically, a R^2 greater than 0.75 are considered a good correlation [19], but for this evaluation, R^2 values greater than 0.50 will also be considered a good-enough correlation.

The above-mentioned data was used to develop individual baselines for each component present on Shaft X. Table B.3-3 presents the application process along with the average monthly predicted energy consumption. The table also shows the actual energy consumption and the percentage difference from what was predicted by the budget and the actual energy. The final row in Table B.3-3 presents the budget for the whole of Shaft X, which is the sum of all of the individual budgets.

Table B.3-3: Application and performance of component isolated budgets

Component	External effects considered	Budgeted energy consumption (kWh)	Actual energy consumption (kWh)	Percentage difference (error)
Ventilation fan (F1)	Employees Depth of mine	589 681	588 504	0.20%
Ventilation fan (F2)	Employees Depth of mine	1 490	1 488	0.15%
Ventilation fan (F3)	Employees Depth of mine	595 612	593 712	0.32%
Ventilation fan (F4)	Employees Depth of mine	0	0	0.00%
Compressor (C1)	Production	2 526 069	2495376	1.23%
Compressor (C2)	Production	2 908 957	2856960	1.82%
Man winder (W1)	Employees Depth of mine	46 599	46 128	1.02%

Component	External effects considered	Budgeted energy consumption (kWh)	Actual energy consumption (kWh)	Percentage difference (error)
Rock winder (W2)	Employees Depth of mine Production	1 663 922	1 654 656	0.56%
Man winder (W3)	Employees Depth of mine	11 266	11 160	0.95%
Compressor (C3)	Production	2 356 300	2 351 362	0.21%
Compressor (C4)	Production	2 580 493	2 533 621	1.85%
Fridge plant (FP1)	Temperature Depth of mine	1 557 589	1 523 612	2.23%
Fridge plant (FP2)	Temperature Depth of mine	1 255 078	1 236 223	1.53%
Man winder (W5)	Employees Depth of mine	159 069	157 728	0.85%
Rock winder (W6)	Employees Depth of mine Production	148 979	148 800	0.12%
Pump (P1)	Depth of mine Production	1 557 598	1 523 621	2.23%
Pump (P2)	Depth of mine Production	874 416	856 263	2.12%
Pump (P3)	Depth of mine Production	1 272 163	1 232 597	3.21%
Ventilation fan (F5)	Employees Depth of mine	371 833	362 552	2.56%
Ventilation fan (F6)	Employees Depth of mine	604 441	596 566	1.32%
Ventilation fan (F7)	Employees Depth of mine	565 691	562 821	0.51%
Fridge plant (FP3)	Temperature Depth of mine	0	0	0.00%
Fridge plant (FP4)	Temperature Depth of mine	1 696 858	1 623 322	4.53%
Ventilation fan (F8)	Employees Depth of mine	404 688	384 648	5.21%
Pump (P4)	Depth of mine Production	92 014	90 024	2.21%
Pump (P5)	Depth of mine Production	0	0	0.00%
Pump (P6)	Depth of mine Production	1 147 981	1 121 952	2.32%

Component	External effects considered	Budgeted energy consumption (kWh)	Actual energy consumption (kWh)	Percentage difference (error)
Pump (P7)	Depth of mine Production	1 315 498	1 281 912	2.62%
Pump (P8)	Depth of mine Production	0	0	0.00%
Total Shaft X:		26 304 284	25 835 608	1.78%

The evaluation on Shaft X gave a total percentage difference between the actual and the predicted values of 1.78%. Additional time and effort were required for identifying the external effects on each component, but it was also noted that the same components, typically have the same external effect. The assumption can therefore be made that all of the components in a specific commodity will react similar to a change in any of the above-mentioned external effect.

The advantage of the component specific budget is that each individual component can now be evaluated as a single entity. Which allows for proper energy management of each unit as opposed to that of the whole facility.

CREATING A BASELINE USING OPTION B (WHOLE FACILITY)

When creating a baseline on a whole facility level, little to no attention is given to the individual components. The whole mine is seen as a “black box” and focus is only on the energy lines into this black box. Figure B.3-2 illustrates the black box with the two incomers (marked with the number “1” and the number “2”).

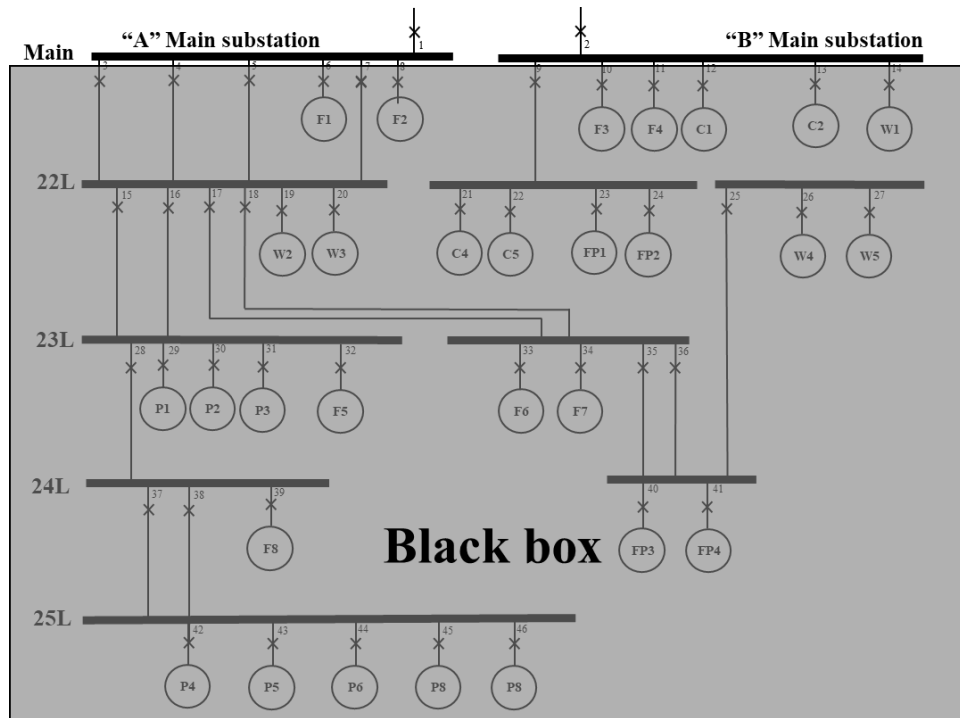


Figure B.3-2: Black box layout for Shaft X

The average monthly consumption (in kWh) for Shaft X are provided in Table B.3-4.

Table B.3-4: Component description for whole facility evaluation

Level	Component	Consumption (kWh)
Main level	Incomer 1	3 940 714
Main level	Incomer 2	2 653 231
Total consumption (sum of two incomers)		6 593 945

Less than 1% difference is noted between the INCs (presented in Table B.3-4) and the FDRs (presented in Table B.3-2). This provides confidence that the data used for the evaluation is correct. Exactly the same methodology is used to develop the budget on a whole facility level. Similar assumptions are made as well. The only large difference considered is changes in production. Other changes are not considered due to the weak correlation between the whole mine's energy consumption and the other external effects considered.

Table B.3-5 provides a summary of the results of the budget on a whole facility. The table also shows the actual energy consumption and the percentage difference from what was predicted by the budget and the actual energy. The final row in Table B.3-5 presents the budget for the whole of Shaft X, which is the sum of all of the individual budgets.

Table B.3-5: Application and performance of whole facility budgets

Component	External effects considered	Budgeted energy consumption (kWh)	Actual energy consumption (kWh)	Percentage difference (error)
Ventilation fan (F1)	Production	4 186 220	3 940 714	6.23%
Ventilation fan (F2)	Production	2 852 223	2 653 231	7.50%
Total Shaft X:		7 038 443	6 593 945	6.87%

A 6.87% difference is observed when evaluating the budget on a whole facility level. The reason for the large variance is expected as a result of the negligence of the external effects such as temperature and the number of employees present on the mine.

COMPARING THE TWO OPTIONS

A brief application process for creating budgets on 1) an isolated component boundary and 2) a whole facility boundary is discussed above. The performance of the budgets against actual energy data was also discussed and the average percentage difference were provided. It was noted that the budgets created on an isolated component boundary gave a 1.78% difference, where the budget on a whole facility level gave a 6.87% error. This is a total percentage difference of more than 5%, which is equivalent to R9.8 million rand on average.

Above the added accuracy that the isolated component budgets provide, developing budgets on smaller boundaries allows for the energy management of the individual components as well. This can be very beneficial for the evaluation of specific ESM performance. Ultimately, the increased accuracy and the energy management benefit of the isolated component evaluation needs to address the concern of whether *the extra time required to develop component specific budgets are worth the effort*.

The most time-consuming exercise in developing the budget is identifying the external effects on the components (or whole facility). This has to be done multiple times for the component specific budgets due to the vast number of components presents, and only once for the whole facility evaluation. However, it was seen that the external effects on similar components are the same (e.g. the external effects are the same for all the pumps). This means that the number of evaluations for an isolated boundary can decreased from the number of components to the number of commodities (in this example it can be decreased from 52 to 6).

Ultimately, this will mean that the evaluation of the external effects will only take six times longer than the evaluation on the whole facility. For the whole facility, the external effects can be assumed to take up a forth of the time used to develop the total budget. Considering that this forth of the total time should increase six times when the budget is developed on a isolated component (to allow for the six external

event evaluations), the total time used to develop the budget on isolated components will increase with just over 50%. Figure B.3-3 illustrate the effect of the increase in time.

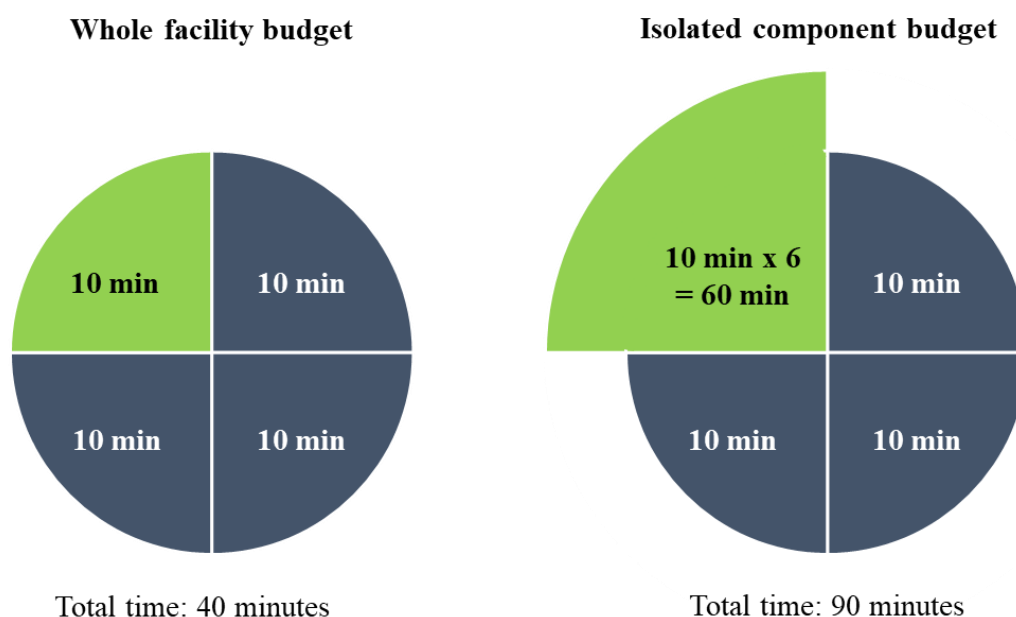


Figure B.3-3: Additional time illustration on the fourth of the process

From Figure B.3-3 it can, therefore, be assumed that the amount of time required to develop budgets on an isolated component is about double the time it will require to develop the budgets on a whole facility level. From the eight mines that participated in the questionnaires (discussed in Chapter 1 and Appendix A) it was noted that the average time used to compile budgets are about 1 month.

Developing budgets on an isolated component boundary will therefore take about 2 months. If the assumption is made that an engineer, with an exaggerated average salary of R250'000 per month develops the budget, it will mean that it will cost the mine R250'000 to have a budget that is 5% more accurate which is the equivalent of R9.8 million. The salary of the engineer, therefore, only makes up about 3% of the added accuracy provided by the component isolated budget.

The energy management benefit of an isolated component budget can have further possible savings when used to monitor and adjust the energy increases where necessary. **Overall, it was proved that the extra time required to develop component specific budgets are worth the effort.**

B.4 EXTERNAL EFFECTS

The interactive effects on a mine refers to the effect that changes on independent variables, such as production, temperature, depth of mine or the number of employees, has on dependent variables, such as the energy consumption of the various commodities on the mine. To verify the existence of these interactive effects, eight case studies are evaluated. These eight case studies are the eight mines that participated in the questionnaires (discussed in Appendix A.1). The aim of the evaluation is to identify which independent variable (production, temperature, mine depth and/or employees) effects which dependent variable (energy consumption of each commodity).

For the evaluation on the case studies, energy data for each commodity (mining, hoisting, pumping, compressors, ventilation, refrigeration and processing) are obtained in weekly resolutions along with the independent variables (production, temperatures, depth of mine and number of employees). This data is obtained for the duration of 24-months. The evaluation per independent variable is discussed in the sub- sections below. Table B.4-1 gives a summary of the correlations found to be relevant for each external event. The green block with the “yes” indicates that a correlation exist between the dependent and the independent variable.

Table B.4-1: External effects on mine commodities

Commodity	Production	Temperature	Mine depth	Employees
Mining	Yes			
Hoisting	Yes		Yes	Yes
Pumping	Yes	Yes		
Compressors	Yes			
Ventilation			Yes	Yes
Refrigeration		Yes	Yes	
Processing	Yes			

The data presented in Figure B.4-1 was evaluated independently to give assurance for the correlations observed. The sub-sections below address each of the external effects with the aim to identify correlations and prove the correlations presented in Table B.4-1.

EXTERNAL EFFECTS OF PRODUCTION

To determine whether Production has an effect on a commodity the relationship between production and each commodity’s energy consumption is evaluated over a 24-month period (in weekly resolutions) for all eight case studies. For illustration purposes, Figure B.4-1 only illustrates the correlation of each commodity’s energy with changes in production.

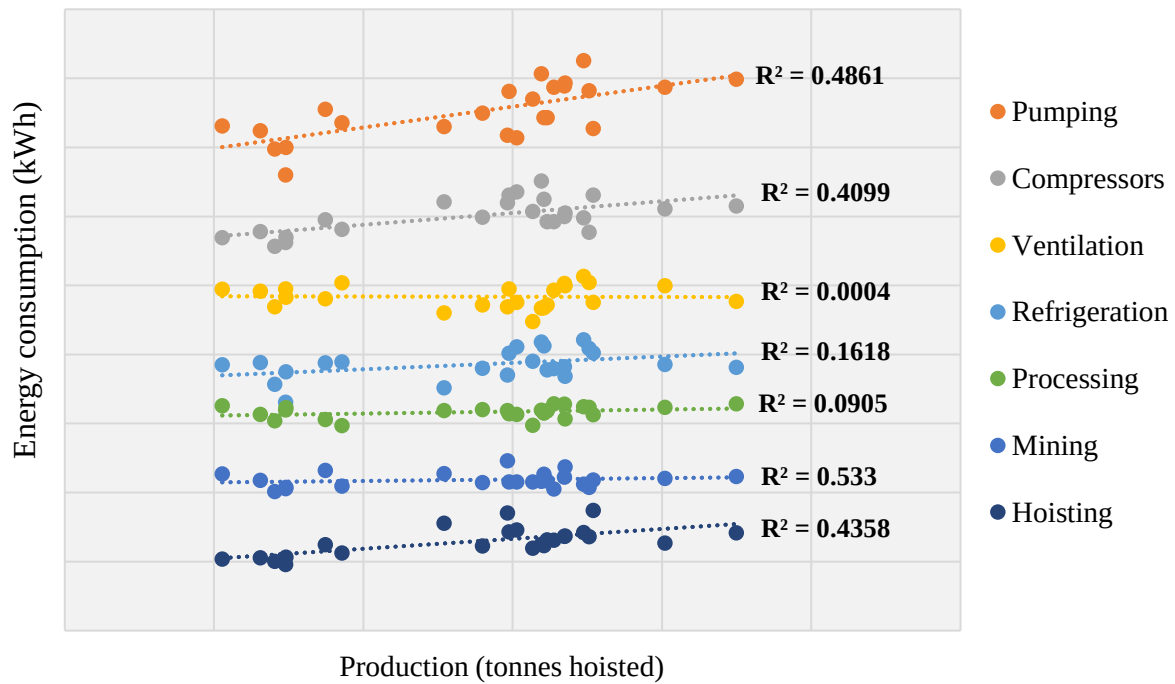


Figure B.4-1: Correlation between commodity energy and production

Figure B.4-1 shows the correlations between the various commodity's energy consumption and respective changes in production outputs for the mine. A strong correlation is associated with an R^2 value higher than 0.75 [19]. To ensure that all effects are accounted for, R^2 values higher than 0.50 will also be considered as a good-enough correlation to include the changes in forecasting. Figure B.4-1, therefore, illustrates that the following commodities need to be adjusted for expected changes in production:

- i. Mining ($R^2 = 0.533$)
- ii. Hoisting ($R^2 = 0.635$)
- iii. Pumping ($R^2 = 0.586$)
- iv. Compressors ($R^2 = 0.509$)

This implies that when the energy consumption is forecasted for any of these commodities listed above, production should be accounted for. The R^2 values for the remaining seven case studies is presented in Table B.4-2, where an R^2 value higher than 0.5 are assumed to be a good-enough correlation to include in forecasting. The final column in the table provides the average correlation percentage between all eight the case studies.

Table B.4-2: Regression fit between the commodity energy and production

	Case study 2	Case study 3	Case study 4	Case study 5	Case study 6	Case study 7	Case study 8	Average (%)
Mining	0.562	0.495	0.623	0.821	0.532	0.612	0.502	59%
Hoisting	0.652	0.752	0.521	0.503	0.603	0.552	0.532	59%
Pumping	0.531	0.496	0.531	0.652	0.701	0.563	0.598	58%
Compressors	0.503	0.498	0.523	0.523	0.519	0.521	0.571	52%
Ventilation	0.021	0.130	0.506	0.125	0.126	0.318	0.215	21%
Refrigeration	0.213	0.125	0.211	0.231	0.152	0.095	0.142	17%
Processing	0.052	0.123	0.123	0.213	0.062	0.102	0.028	10%

The correlations observed in Table B.4-2 is similar to what is observed on the first case studies. That changes in production should be considered for mining, hoisting, pumping and compressors. Some of the mines showed stronger correlations than others and some mines had additional correlations (case study 3 showed a correlation between ventilation and production as well).

It can, therefore, be concluded that it is feasible to evaluate each mine's commodity relationship with production before assuming that the only affected areas will be mining, hoisting, pumping and compressors. However, it can also be assumed that there is a definitive relationship between production and these four commodities since all of the case studies showed existing correlations.

Weak correlations between production and processing is observed due to the stockpiling of the ore before sending it to the processing plants. Ore typically get stockpiled for several weeks before it is sent to the processing plant and therefore, considering the energy consumed by the processing plants and the production outputs delivered by the mine might not show a correlation.

Ultimately, the external effects of production are established and the production-related content in Table B.4-1 is proved correct.

EXTERNAL EFFECTS OF TEMPERATURE

External effects of temperature should be easily observed during the transition from winter months to summer months. Correlations between the two parameters are expected to be visible on refrigeration especially. Refrigeration is used to cool down the water that enters the mine shafts, during the winter months, the refrigeration requirements would, therefore, be less due to the already-cold environment.

To investigate the relationship, the temperatures for one case study is illustrated along with the energy consumption for the case study in Figure B.4-2.

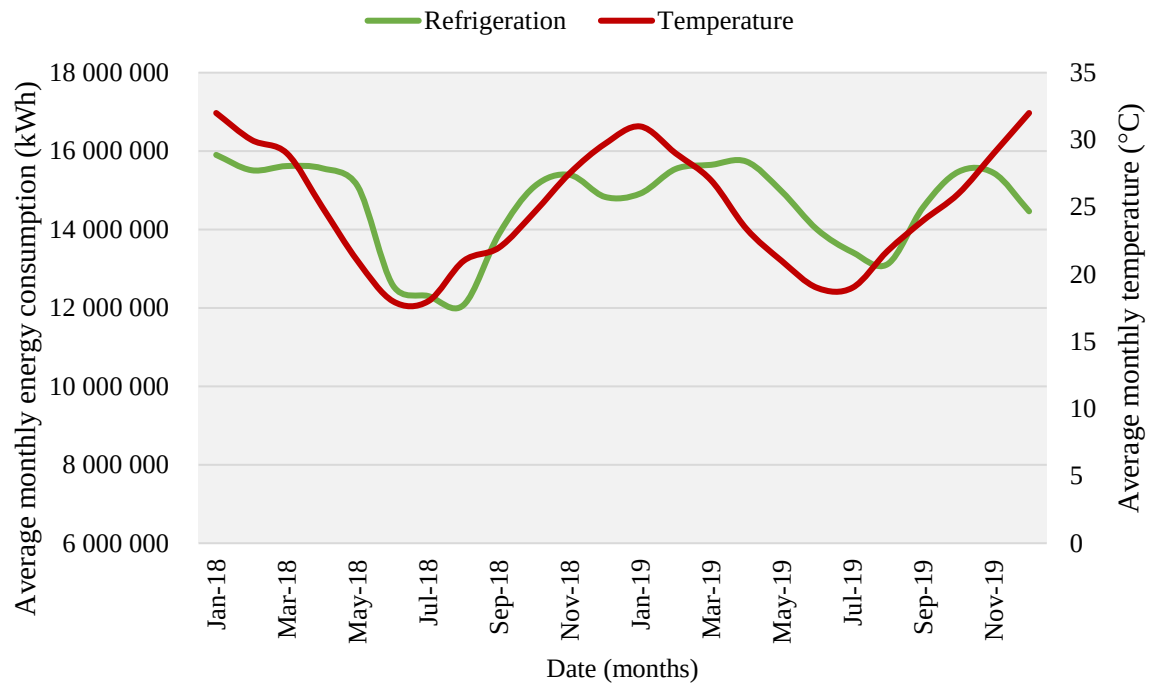


Figure B.4-2: Correlation between refrigeration energy and temperature

Figure B.4-2 illustrates that the energy consumption of the fridge plant (refrigeration commodity) decreases when the energy decreases. This can be assumed to be because of the outside temperature being lower in the winter months compared to the summer months which results in less refrigeration power required to cool down the water.

The correlation between temperature and each of the other remaining commodities are presented in Figure B.4-3, where R^2 provides the correlations and correlations higher than 0.50 are assumed to be good-enough to include in the evaluation of the forecasts.

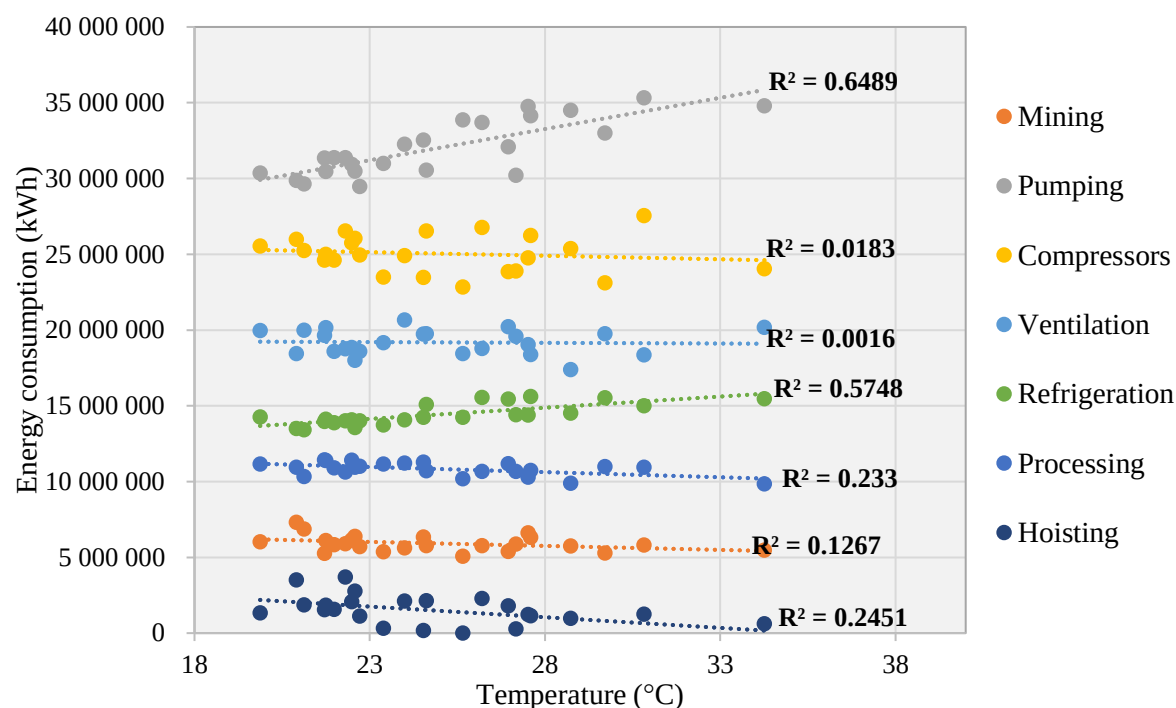


Figure B.4-3: Correlation between commodity energy and production

Figure B.4-3 illustrates the correlation between the commodity's energy consumption and changes in temperature. The expected correlation between temperature and refrigeration energy is observed ($R^2 = 0.575$). A good-enough correlation is also observed between temperature changes and pumping energy on the mine in the case study. Table B.4-3 provides the R^2 values for the remaining case studies, where similar correlations are observed between refrigeration and pumping with temperature.

Table B.4-3: Regression fit between the commodity energy and temperature

	Case study 2	Case study 3	Case study 4	Case study 5	Case study 6	Case study 7	Case study 8	Average (%)
Mining	0.213	0.213	0.213	0.123	0.042	0.021	0.052	13%
Hoisting	0.221	0.213	0.231	0.163	0.382	0.123	0.191	22%
Pumping	0.425	0.321	0.562	0.462	0.621	0.521	0.563	50%
Compressors	0.362	0.421	0.321	0.222	0.360	0.213	0.322	32%
Ventilation	0.321	0.123	0.285	0.164	0.339	0.132	0.154	22%
Refrigeration	0.596	0.623	0.652	0.521	0.652	0.705	0.512	61%
Processing	0.023	0.032	0.029	0.102	0.095	0.032	0.122	6%

Table B.4-3 confirms the relationship between temperature and refrigeration and on temperature. This relationship therefore proves that the temperature-related context in Table B.4-1 is correct.

INTERACTIVE EFFECTS OF THE DEPTH OF MINE

Increasing the depths of mines allows for the extraction of more valuable minerals without the complications of opening a new mine. Mines, therefore, tend to mine deeper and deeper each year. The

average gold mine extends to depth at a rate of 10 to 25 meters per year [158] where platinum mines extend only at a rate of 5 to 8 meters per year [158].

To evaluate the effect of extended depths on a mine, the correlation between the depths of the mine of one case study are evaluated against three commodities. All commodities are not included in the figure due to the randomness of the regression fit which influence the visibility of the remaining fits. The main effects were observed on hoisting, refrigeration and ventilation. Figure B.4-4 presents a linear correlation for these three variables.

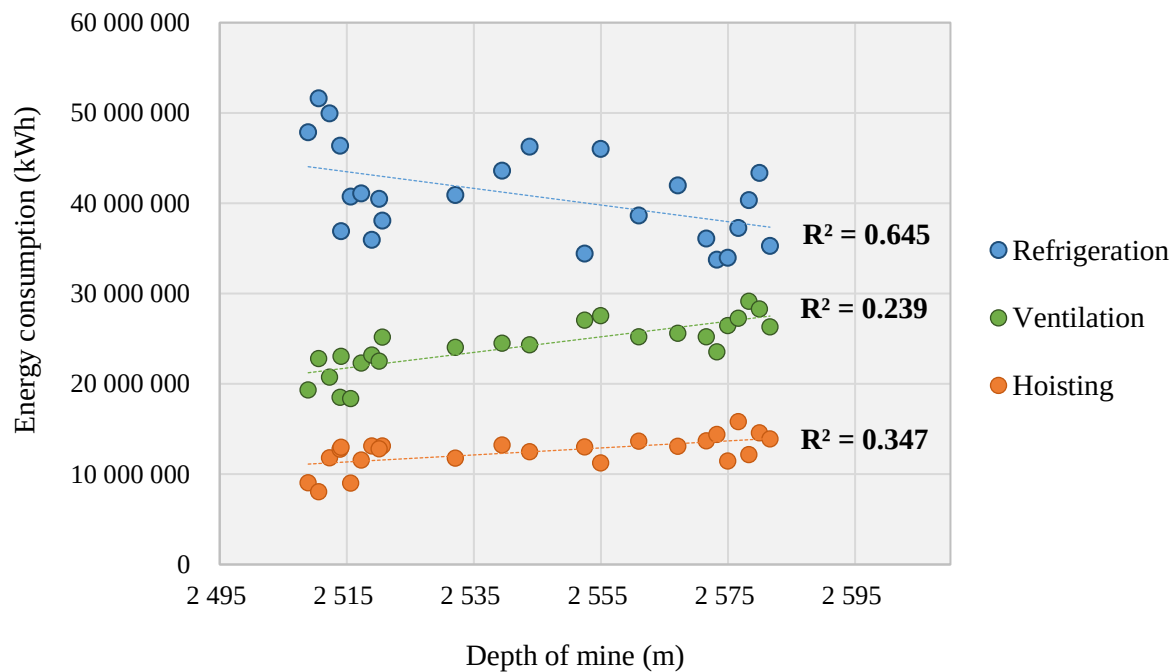


Figure B.4-4 Correlation between commodity energy and depth of mine

Figure B.4-4 shows that a change in the depth of the mine has an effect on the energy in hoisting, ventilation and refrigeration for this specific case study. Table B.4-4 presents the correlation for the other case studies, where similar correlations are observed between refrigeration and pumping with hoisting.

Table B.4-4 Regression fit between the commodity energy and depth of mine

	Case study 2	Case study 3	Case study 4	Case study 5	Case study 6	Case study 7	Case study 8	Average (%)
Mining	0.213	0.213	0.213	0.123	0.042	0.021	0.052	13%
Hoisting	0.503	0.498	0.523	0.523	0.519	0.521	0.571	52%
Pumping	0.425	0.321	0.562	0.462	0.621	0.521	0.563	50%
Compressors	0.362	0.421	0.321	0.222	0.360	0.213	0.322	32%
Ventilation	0.321	0.123	0.285	0.164	0.339	0.132	0.154	22%
Refrigeration	0.596	0.623	0.652	0.521	0.652	0.705	0.512	61%
Processing	0.023	0.032	0.029	0.102	0.095	0.032	0.122	6%

Table B.4-4 shows that refrigeration has the strongest relationship (61% on average) on the other case studies as well. A weaker relationship is observed on hoisting and ventilation (52% and 50% on average, respectively). The application of the correlation factors therefore establishes a strong relationship between the depth of mine and refrigeration. However, the weak correlation between the depth of mine and hoisting and ventilation will also be considered for this study. These relationships prove that the depth-of-mine-related context in Table B.4-1 is correct.

INTERACTIVE EFFECTS OF THE NUMBER OF EMPLOYEES

To evaluate the effect of changes in the number of employees, the correlation between the number of employees (or crews) present on a mine is evaluated against the energy consumption per commodity for that mine. External effects are observed between the commodities hoisting and ventilation on the number of employees, which is expected.

More crews going underground will result in more hoisting energy consumption due to the cage (the unit transporting employees underground and back up) operating more often. The relationship is established especially on the days where no crews / limited people are going underground (such as on public holidays). The same is true for the ventilation energy consumption. The purpose of the ventilation is to supply the mine with air. If there are no crews, limited ventilation is required.

The correlation between the eight case study mine's energy consumption per commodity is presented against the number of crews in Table B.4-5.

Table B.4-5: Regression fit between the commodity energy and number of crews

	Case study 1	Case study 2	Case study 3	Case study 4	Case study 5	Case study 6	Case study 7	Case study 8	Average (%)
Mining	0.213	0.213	0.213	0.213	0.123	0.042	0.021	0.052	13%
Hoisting	0.503	0.503	0.498	0.523	0.523	0.519	0.521	0.571	52%
Pumping	0.213	0.213	0.213	0.123	0.242	0.021	0.052	0.563	20%
Compressors	0.362	0.362	0.421	0.321	0.252	0.369	0.213	0.322	32%
Ventilation	0.521	0.496	0.623	0.752	0.521	0.752	0.705	0.817	67%
Refrigeration	0.021	0.024	0.57	0.101	0.068	0.199	0.352	0.059	20%
Processing	0.123	0.023	0.132	0.231	0.102	0.295	0.032	0.122	13%

The relationship between ventilation and hoisting with the number of employees are shown as 52% and 67%, respectively. It can, therefore, be assumed that when the forecasts for these two commodities are made that the changes in the number of employees should be considered. The correlations observed in Table B.4-5 confirm the number of employees related context in Table B.4-1.

APPENDIX C: PUBLICATION

This Appendix discusses the related publication on this research study.

Appendix C.1: Published paper

- Related publication based on this research study

C.1 PUBLISHED PAPER ON RELATED RESEARCH

A peer-reviewed conference proceeding paper presented at the 31st South African Institute for Industrial Engineering (SAIIE) conference held in Muldersdrift during October 2020 is related to this thesis. This publication addressed the need to adapt the current budgeting structures used by mines with M&V principles. The paper's main objective was to determine how the M&V principles can be adapted into the budgeting process.

The paper was additionally upgraded to a journal article and is published in the South African Industrial Journal for Engineering (SAIJE) in November 2020.

The paper is presented below.

IMPROVE MINE ENERGY BUDGETING PROCESS USING MEASUREMENT AND VERIFICATION PRINCIPLES

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This work has been supported by TEMM International (Pty) Ltd.

ABSTRACT

Budgets are used to predict and measure the mine's performance. Problems arise when the budget is developed by financial resources with little focus on operational changes. The implementation of energy-saving-measures (ESMs), number of workdays or time-of-use (TOU) profiles are often neglected making the budget obsolete.

Measurement-and-verification (M&V) principles are known for their effectiveness when addressing operational changes. This paper presents a novel approach where the M&V principles are altered into financial principles by developing analogies between the fields. A critical analysis on South African mines budgets were conducted to create these analogies.

The result of the analysis highlights the need for the integration and provides a relation between well-established M&V principles as an alternative solution to budgeting. The solution was applied to a gold mine complex in South Africa. The new budget could account for an additional R26.2-million (16.8%) compared to the original budget by successfully incorporating the M&V principles.

1. BACKGROUND

Budgets are a common tool used to determine the revenue and expenses of a mine [1]. It is further used to measure the mine's performance [2]. It is, therefore, vital that the budget is complete, accurate and transparent [3]. A problem arises when budgets are drawn up by financial resources that only focus on the financial aspects of the budget. Little to no attention is given to the operational changes occurring on a day-to-day basis throughout the mine [4].

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Financial resources easily assume that the mine will operate as in the past (normal operation) [5]. The implementation of energy saving measures (ESMs), different time-of-use (TOU) profiles and the number of working days versus weekends during a month ensures large changes in the normal operation of the mine [3]. These operational changes have a large impact on the budget since it acts as the basis for the budget [5].

Neglection of the operational changes causes the budget to become obsolete within the first few months of the assessment period [6]. The assessment period is the time period for which the budget was developed for. This effects the cash-flow of the mine since the operational changes now cannot be funded properly. Furthermore, it effects how the mine's performance is assessed since it is measured against the budget. These effects have drastic consequences and can negatively impact the mine and its operations [7].

There is, therefore, a need to better incorporate operational changes into mining budgets. Specific attention should be given to both the operational- and financial-related changes and uncertainties. Established Measurement and Verification (M&V) principles are known for their unique ability to address such changes and uncertainties in normal operation. This study thus focusses on the integration of the M&V principles into the budgets to improve the operational forecasting of the mine and to allow for better financial planning.

2. BUDGETING AND MONITORING OF MINE ENERGY SYSTEMS

The aim of this section is to identify and evaluate the current budgeting structures that are used by South African mines. A survey of 63 South African mineral mine shafts was conducted to evaluate their budgeting structures. These 63 shafts operate under 3 of the major role-players in deep-level mining in the country. They represent 87% of the deep-level mining shares in South Africa and are therefore considered to be a representative sample.

Budgeting in its most traditional form is used for financial management purposes [8]. It is concerned with top-down planning for financial performance, built on organisational hierarchies, and intended as a measure of control over operational expenditures [9]. Figure 2-1 illustrates the general steps used by South African mines when developing their budgets. These general steps are compiled out of the budgeting steps followed by the 63 shafts that participated in the survey.

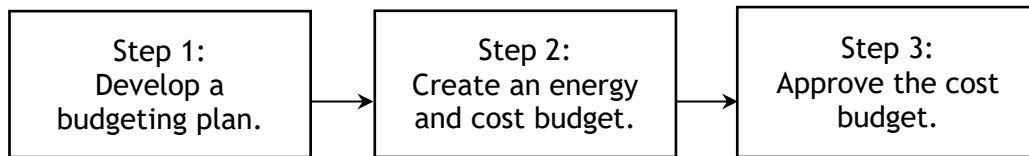


Figure 2-1: Existing budgeting structure used by mines for forecasting and assessments

STEP 1: DEVELOP A BUDGETING PLAN

Before the budget can be developed, planning must commence [8]. Budget planning involves the number of details desired within the budget, the purpose of the budget, and the uses of the budget [9]. The South African mining complexes that took part in the survey all considered the following aspects before developing the budget:

a) Measurement boundary

The budget boundary is the set of components to be considered within the budget [9]. The budget can be developed for the whole facility or only portions thereof. A typical mine layout consists of business units broken down into shafts and plants, each consisting of a number of commodities (pumping systems, compressor houses, etc.) [10].

The survey done in this study showed that the budgets were compiled on business-unit level with the exception of 3 mines who develop their budgets on shaft-level. None of the mines consider budgeting on commodity levels due to the magnitude of data and associated errors which will be time-consuming to convert into a reliable format to be used within the budget.

b) Measurement period and budget intervals

The measurement period represents the historical data that will be included within the budget calculations [10]. The measurement period should be representative of the normal operations of the mine and should not include abnormal events such as industrial actions [11]. The survey showed that the typical period used for budgeting by South African mines typical period is the previous 12 months.

The budgeting intervals are the number of intervals the budget will be composed for [10]. Typical intervals within South African mines are either monthly or quarterly. This means that the final budget will be developed to show monthly or quarterly expected total consumptions. Annual budgets are not considered due to seasonal changes.

c) Data availability

After deciding on the boundary and the measurement intervals, the data can be compiled for the decided boundary in the measurement intervals. The typical data gathered by the South African mines are:

- Monthly total consumptions for each shaft, plant and business unit;

- Monthly total production data (tons hoisted for shafts and tons treated for plants);
- Existing growth and savings projects; and
- Planned growth and savings projects.

d) Adjustments

Routine adjustments are occurrences that are expected to change and need to be accounted for [11]. The most common routine adjustments are changes in weather and production. The survey showed that South African mines account for production changes within the budgeting structure by including production forecasts. The energy associated with changes in production are calculated using energy-intensity models. No additional routine adjustments are typically considered or regularly evaluated.

e) Utility costing

The energy budgets developed for a mine needs to be converted into financial budgets. This conversion requires an energy-to-cost ratio usually depicted in R/kWh. This ratio can be obtained by identifying the TOU and comparing it to the Eskom TOU tariffs [12].

STEP 2: CREATE THE BUDGET

The budget should be an accurate representation of what is expected of future consumption. Equation 2-1 and Equation 2-2 demonstrates how the energy and cost budget is conventionally calculated.

$$\text{Energy Budget} = \text{Historical energy} \pm \text{Production} + \text{Growth} - \text{Saving} \quad (2-1)$$

$$\text{Cost Budget} = \text{Energy Budget} \times \text{Cost Ratio} + \text{Load shifting effects} \quad (2-2)$$

The variables in both equations are:

Historical energy: Energy for the boundary in the desired intervals; in kWh

Production: Energy changes due to production changes; in kWh

Growth: Projects that increases energy consumption; in kWh.

Savings: Projects planned by the engineers to reduce energy; in kWh.

Cost ratio: The ratio as obtained from Eskom tariffs; in R/kWh

Load shifting: Savings project but with only a cost effect; in R

Load shifting is introduced in this step to ensure that all cost effects are accounted for. Load shifting accounts for energy saving initiatives where certain mine components operates in other TOU periods. No energy savings are obtained, but the cost of the energy can be decreased by using the energy in another TOU period. Excluding load shifting projects from the budget will, therefore, not affect the energy budget but will have an effect on the costing budget.

STEP 3: APPROVE AND SIGN-OFF THE BUDGET

The developed budget is shared with auditors and mine managers for approval. Once approval is obtained, the budget is signed-off and no further changes are made to the budget. Approval (or comments) are provided on the judgement of the relevant person, and not according to a set up criteria.

The existing budgeting structure discussed in this section proves to hold limitations to its application. The negligence of accurate operational changes within the budget causes the budget to become obsolete early on into the assessment period. This article suggests incorporating established measurement and verification principles into the budgeting process.

3. MEASUREMENT AND VERIFICATION PRINCIPLES

A literature survey was conducted on 15 recently published documents on budgeting structures (from 2015 to 2020) [4-19]. The aim of the literature survey was to identify whether M&V principles have been used in the budgeting structures previously. Of these 25 documents, only 11 considered one or two of these principles, but none considered all of the M&V principles. The inclusion of all of the M&V principles within the budgeting structures is thus a novel approach.

M&V principles are used to evaluate the ESM performance before (baseline) and after (post-installation) implementation [12]. Equation 3-1 shows the general equation used to determine the savings of the ESMs. Adjustments are included to allow for unplanned changes (such as increases in temperature or number of employees) [12,13].

$$\text{Savings} = (\text{Baseline Energy} - \text{Post Installation Energy}) \pm \text{Adjustments} \quad (3-1)$$

The variables in both equations are:

Savings: Calculated savings; in kWh

Baseline energy: Forecasted energy consumption; in kWh

Post installation energy: Actual energy consumption; in kWh

Adjustments: Expected or unplanned changes; in kWh

The baseline and performance assessment energy can be determined using one of three M&V options, labelled options A (Retrofit Isolation), B (Whole Facility), and C (Calibrated Simulation) [14]. The main steps used by these approaches to determine the energy savings are shown in Figure 3-1.

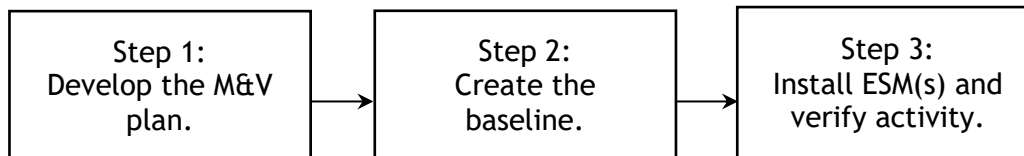


Figure 3-1: Existing M&V structure used to calculate ESM(s) savings

STEP 1: DEVELOP THE M&V PLAN

The M&V plan demonstrates how the savings will be calculated and included based on the following sections: (a) measurement boundary; (b) measurement period; (c) data availability and quality; and (c) routine and non-routine adjustments [13].

a) *Measurement boundary*

Savings may be determined for an entire facility or a portion of it, depending upon the ESM characteristics and the purpose of the reporting. The purpose of the reporting determines the M&V option that will be used.

- If the purpose of reporting is to verify the savings from equipment affected by the savings program, a measurement boundary should be drawn around that equipment and measurement requirements for the equipment within the boundary can then be determined (*option A*) [12-14].
- If the purpose of reporting is to verify and/or help manage total facility energy performance, the meters measuring the supply of energy to the total facility can be used to assess performance and savings. The measurement boundary in this case encompasses the whole facility (*option B*) [12-14].
- If the baseline or reporting period data are unreliable or unavailable, energy data from a calibrated simulation program can take the place of the missing data, for either part or all of the facility. The measurement boundary can be drawn accordingly (*option C*) [12-14].

b) *Measurement period and baseline intervals*

The measurement period represents the historical data period that will be used to develop the baseline. The baseline intervals are the frequency of the intervals included in the baseline and includes, but are not limited to, half-hourly, daily, weekly and monthly intervals [15]. M&V principles specifies that care should be taken when selecting the period and intervals as it should [16]:

- Represent normal operating cycles;
- Include only time periods for which fixed variable energy-governing facts are known about the facility; and
- Coincide with the period immediately before commitment to undertake the ESM.

c) Data availability and quality

The required data sets include:

- Energy carrier data (historical energy data in the case of application on a mine)
- Energy driver data (production data in the case of application on a mine)

The energy carrier and driver data undergo multiple data quality tests to ensure accuracy, completeness, consistency and reliability [16-18].

d) Adjustments

Routine adjustments are factors expected to change routinely during the assessment period such as weather or production. Non-routine adjustments are unplanned events such as strike actions. The effect of both these adjustments are considered and accounted for in the baseline [19].

STEP 2: DEVELOP THE BASELINE

The baseline is created using a set of guidelines, such as the guidelines stipulated in the International Performance Measurement and Verification Protocol (IPMVP) [19] which guides the three M&V options. Engineering estimates or mathematical modelling are used to assess the significance of the parameters included in the baseline modelling. Models usually contain several sets of regression parameters each valid over a defined range of conditions. In most instances several regression models are considered for difference usage periods [20].

STEP 3: INSTALL ESM(S) AND CONSTRUCT VERIFICATION ACTIVITIES

After the baseline is completed and approved, the ESM is implemented and tested. The performance assessment starts after the successful implementation of the project. Operational verification consists of a set of activities that help to ensure that the ESM is installed, commissioned and performing its intended function [19,20]. Operational verification serves as a low-cost initial step for assessing savings potential or verifying performance over time and should be included in the M&V plan and precede other post installation saving verification activities [21].

4. CRITICAL COMPARISON BETWEEN BUDGETING STRUCTURES AND M&V APPLICATIONS

Mine managers use the budgets to compare the actual performance of the mine against all of the projects. Research shows that the budgeting structures are effective for cash flow

planning but not the most effective way to measure performance of ESMs against [22]. Engineers use M&V principles to develop baselines for all ESMs. The savings obtained when compared to the baseline are rarely seen on the budget. This raises the question of whether the budgets are correctly developed.

The M&V research shows that similar steps are taken when compiling baselines as used for compiling budgets. However, project-specific M&V plans are much more comprehensive and, as a result, more accurate than budgets [23]. This section identifies the gaps in the budgeting steps which can be addressed by the M&V principles. When the gaps in the budget are addressed by M&V principles, the budget will reflect similar accuracies and completeness observed in the project-specific baselines.

Table 4-1 presents a critical comparison between the budgeting structure used by South African mines and the M&V principles. The final column in Table 4-1 addresses the gaps noticed in the budgeting process.

Table 4-1: Critical comparison between budgets and M&V

	Budgeting structure	M&V principles	Gaps identified in the Budgeting process
Basis	Basic structure of the budget is high level (large boundary with large intervals of data). The application process is easy and does not require a lot of time and effort.	Basic structure of the baseline contains detailed steps with small boundaries and small intervals. The process is very thorough and can be time consuming but delivers accurate results.	Boundaries and intervals of the budget are too large compared to what is used for the baseline (the project performance is sensitive to the interactive effects of other systems on the mine). There is a playoff between the amount of time used to create the budget and the accuracy of the results.
Step 1	Develop the budgeting plan: The budget plan consists of four main steps which boils down to which data to be used. No	Develop the M&V plan: The M&V plan consists of four main steps, which critically considers the data to be used. A lot of	The data included in the budget are obtained from energy meters with no added attention given to ensure data is accurate

	Budgeting structure	M&V principles	Gaps identified in the Budgeting process
	accuracy tests are done on the data to ensure that only high-quality data is being used. Routine adjustments for production are included.	effort goes into ensuring that the data is accurate, complete, consistent, representative, and reliable. Routine and non-routine adjustments are considered (specific to the relevant boundary).	and complete as is the case of baselines. The budget only considers adjustments for productions and not routine and non-routine adjustments relevant to the specific project as the M&V baselines does.
Step 2	Create the budget: Budget is created with the data obtained in Step 1. The energy budget is then converted into a cost budget using Eskom tariff ratios and TOU.	Create the baseline: Baseline is created with data obtained in Step 1. More detail into baseline due to higher intervals. Different baseline modelling options are considered.	Budgeting procedure is straightforward where the baseline considers various modelling options. The baseline has more detailed steps and analyses. The baseline considers the characteristics of the specific ESM.
Step 3	Approve the budget: Budget is approved by financial personnel who compares cost figures to expected figures. This is the main basis used to validate the budget.	Install ESM(s) and verify activity: ESM is installed, and multiple tests are conducted to ensure the ESM is running as planned and that the baseline is still representative. The conditions of the baseline and performance assessment periods are compared, and adjustments are made to account for any changes. The interactive effects of the specific project are	Budget is approved by Financial personnel who only evaluate the cost budget. The M&V principles include multiple checks to ensure that the baseline is really correct. The M&V principles adjust the baseline to the conditions of the performance assessment using routine and non-routine adjustments. The interactive effects of the

	Budgeting structure	M&V principles	Gaps identified in the Budgeting process
		also considered and addressed accordingly.	ESM on other boundaries (and vice versa) are considered.

Table 4-1 shows that there are gaps within each step of the budgeting process. The gaps are mainly due to (a) the level of evaluation; (b) method of modelling; and (c) accuracy tests. The budgeting approach is therefore adjusted to represent the M&V approach with the aim to increase the budget's accuracy and allow the budget to be used for energy management principles.

The identified gaps will be addressed specifically as:

a) The level of evaluation

The high-level boundary limits the usage of the budget. To enable the budget to be used for energy management purposes more detail needs to be included. The boundary should therefore shift from whole facility to component level. This will ensure that each of the commodity performances will be considered. However, due to the vast number of components available, this can be challenging and time-consuming to include all commodities.

A solution to this is to combine the components into commodity totals, for example; all the individual pumps will be added to give the total “pumping” commodity. The best practice will be to develop the baseline on shaft level and then to sub-divide the shaft totals to each commodity. By doing this, no extra budgets are developed (saves time and resources) and the budget can still be used for energy management due to the inclusion of all the commodities.

The budget will also be compiled using higher resolution data (such as using half-hourly intervals instead of monthly totals). This will allow for better TOU allocations to improve the overall accuracy of the budget. Problematic areas will also be easier to identify by including more resolutions.

b) Method of modelling

The budget is calculated using Equations 2-1 and 2-2 which is a linear equation. The M&V baselines are calculated using a variation of models such as regression models or simulation models, specifically developed for the characteristics of the commodity or ESM. The trend

between energy drivers and energy carriers are evaluated before deciding what modelling technique to use.

The new budgeting structure will therefore include the assessment of the input and output trends before applying a modelling technique. This step will address the type of adjustments required to the historical data to ensure that the budget is representative enough. This allows for the consideration of changes expected in the performance assessment period when compiling the budget.

c) Test for accuracy and consistency

The model's accuracy will be determined using target shuffling, which is a method particularly useful for indenting false positives. This method also tests if two events or variables occurring together are perceived to have a cause-and-effect relationship, as opposed to a coincidental one [22].

The bootstrap sampling method will be used to test the model's consistency. This method tests a model's performance on certain subsets of data over and over again to provide an estimate of accuracy. To do this a random sample of the data is divided into three subsets: training, testing and validation. The model is built on the data in the training subset, and then evaluated on the testing subset data [22].

The modifications are made to the existing structure to include the fulfilment of the three gaps identified. The new budgeting process is demonstrated in Figure 4-1, additional detail is given to indicate the M&V enhanced areas.

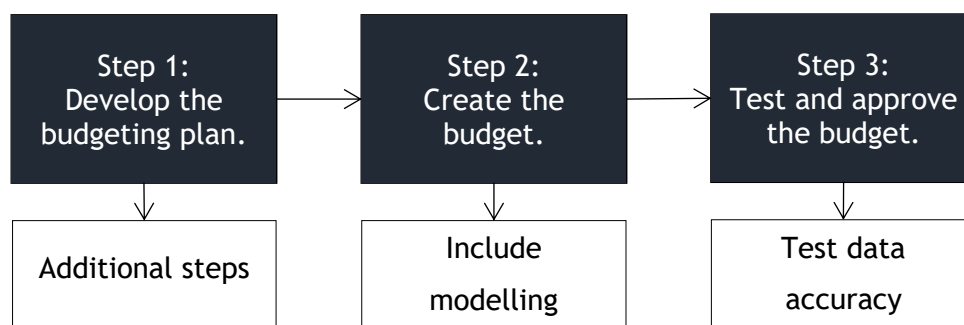


Figure 4-1: New budgeting structure for mines

5. PRACTICAL APPLICATION AND RESULTS

5.1 Case Study Background

The newly developed budgeting structure is applied to a South African gold mine complex. The gold mine consists of 5 production shafts each feeding a number of components (pumps,

compressors, fridge plants, etc.) One of the shafts also feeds a processing plant. The results of the application are only displayed for Shaft 1 for simplicity reasons.

5.2 Practical Application of The New Budgeting Structure

STEP 1: DEVELOP THE BUDGETING PLAN

a) Measurement boundary

The measurement boundary used for the budget is each individual shaft. All energy going into the shaft will be used as the energy driver. Budgets for the commodities and the plants will be sub-divided out of the shaft budgets. The division will be based on the historical average percentage consumption of the commodity compared to the shaft's total consumption.

b) Measurement period and baseline intervals

The measurement period intervals are chosen as half-hourly. The previous 12-months half-hourly data per shaft is thus used to calculate budgets.

c) Data availability and quality

The energy data is obtained from calibrated meters in half-hourly intervals. The data is tested for abnormalities as shown in Figure 5-1 where the 2018 half-hourly energy for Shaft 1 is displayed. The red lines show the inter-quartile lines (IQL) used to identify the abnormalities. These values are addressed and were all removed from the dataset.

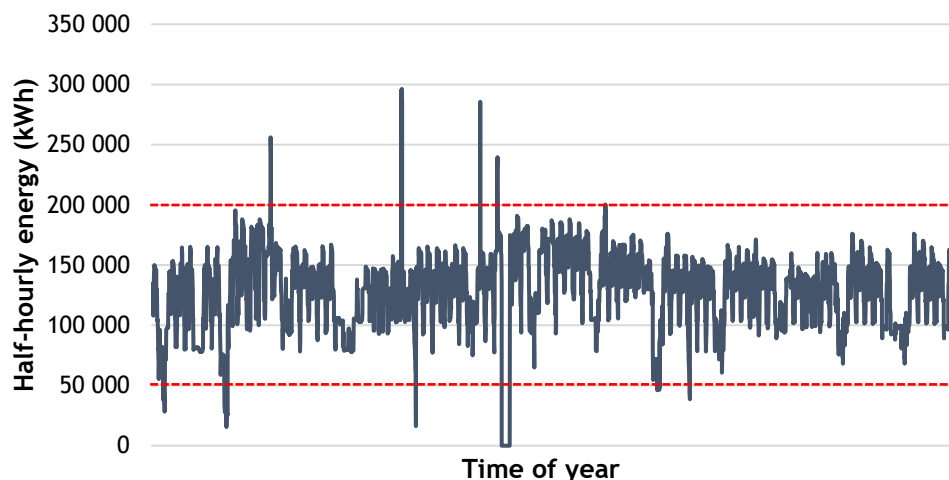


Figure 5-1: 2018 half-hourly energy consumption for case study mine

A similar approach is taken to clean the production data. The production data is obtained as “daily tons hoisted” for 2018.

The growth and savings projects for Shaft 1 were obtained from the project approval plans for 2018. Shaft 1 had no growth projects planned and 2 savings projects, a pumping project (expected savings of 1.5 MW) and a compressed air project (expected savings of 3 MW).

d) Adjustments

The only adjustments considered will be routine adjustments for production changes. The 2018 production data (abnormalities already removed) are used to forecast the 2019 production. The mine expects to produce 8.0% more due to new developments on Shaft 2 and Shaft 3. Since Shaft 3's production is being hoisted at Shaft 1, the increase in planned production affects Shaft 1 as well.

The expected energy increase associated with the 2.8% production increase is calculated using the linear production model presented in Equation 4-1.

$$Energy = m(Production) + C \quad (4-1)$$

where m and C are variables obtained using the 2018 energy and production data in a LINEST function in Microsoft Excel. The model is tested on a sampling dataset and presented an error of 1.3% which is acceptable for production modelling [23].

STEP 2: CREATE THE BUDGET

The budget is created using the original budgeting equation as presented in Equation 2-1. The difference, however, is that the budget is now developed for half-hourly intervals. This means that the daily total production is converted into half-hourly portions by taking the energy profile into consideration. The same is done for the Savings projects. Figure 4-3 illustrates the typical weekday profile for a summer month for Shaft 1's actual 2018 energy and the 2019 budget.

A similar approach is done for a Saturday and Sunday profiles for both the Summer and Winter months.

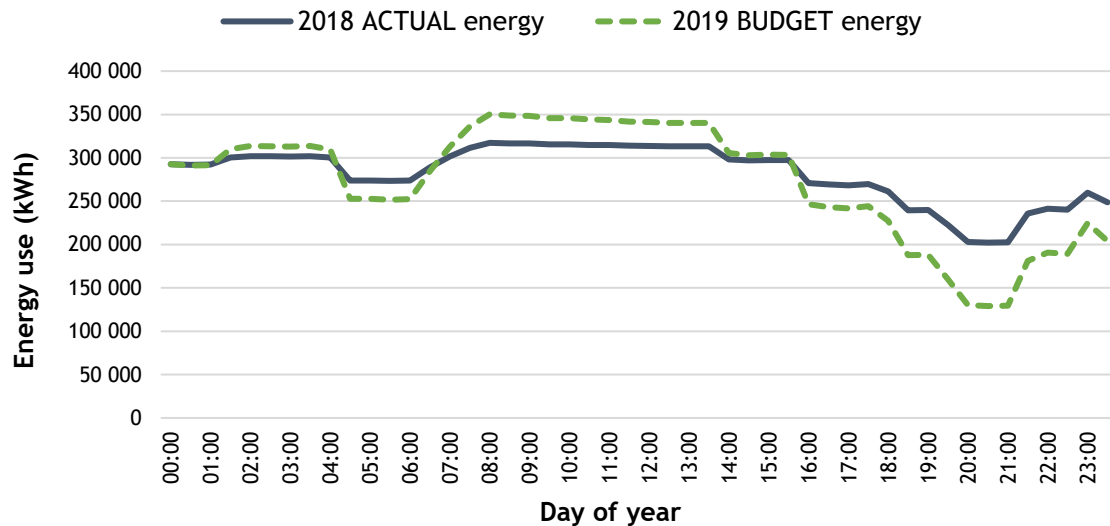


Figure 5-2: Summer Weekday Budget profile for Shaft 1

The commodity breakdowns are also created. Figure 4-6 illustrates how the Summer Weekday Profile for Shaft 1 is divided between the commodities using the percentage subdivisions.

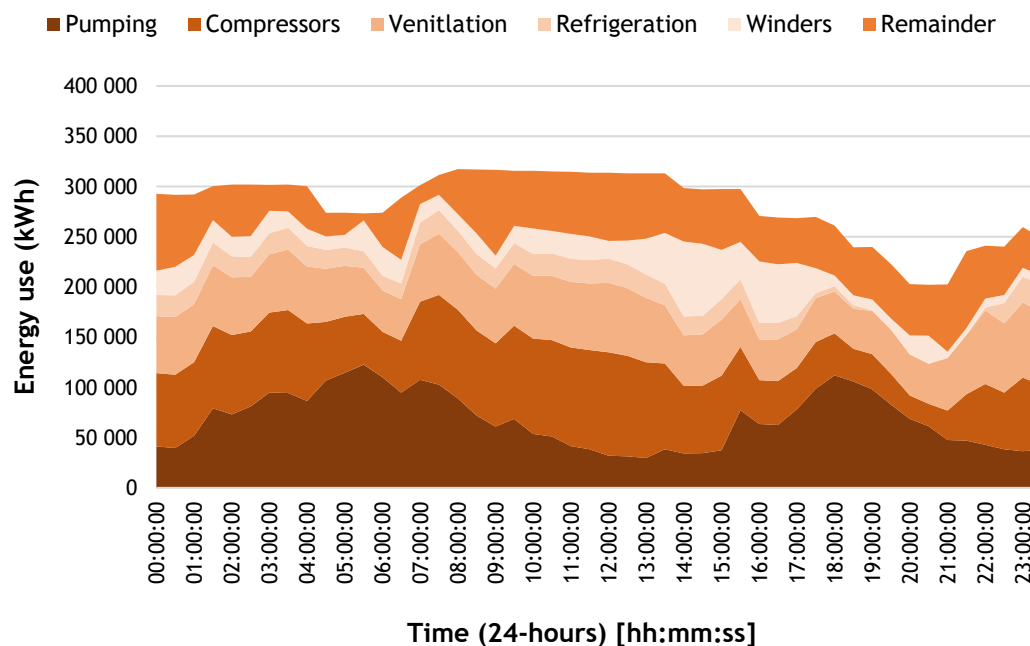
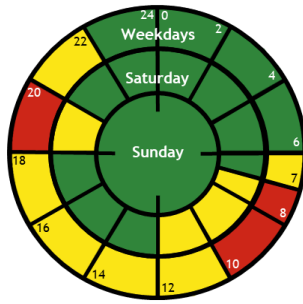


Figure 5-3: Summer Weekday Budget Profile for Shaft 1's commodities

The half-hourly profiles of the budget enable easy application of Eskom's TOU to convert the energy budget into a cost budget. The Eskom tariffs as approved by NERSA and presented in Figure 4-4 are used to calculate the Cost Budget.

Table 5-1: Megaflex tariffs for 2020/21 for transmission zone >900 km



		High demand season (Jun. to Aug.)	Low demand season (Sep. to May)
Peak		308.62	100.74
Standard		95.53	69.39
Off-peak		50.82	44.02

Step 3: Test and approve the budget

The newly developed budget's accuracy and completeness are tested to ensure that the budget can be used effectively. The accuracy was tested using the target shuffling method and an accuracy of 99.5% were obtained. The completeness of the budget was tested using the bootstrap method where a 100% completeness of the budget was observed.

5.3 Verification of The New Budgeting Structure

The original budgeting structure was used to develop a budget for the mining complex discussed in the case study. The purpose is to compare the application of the original budget to the application of the new budget. The original budget is developed for monthly total energy consumptions per shafts. The new budget is developed half-hourly and added up to the monthly total to compare together on Figure 4-5.

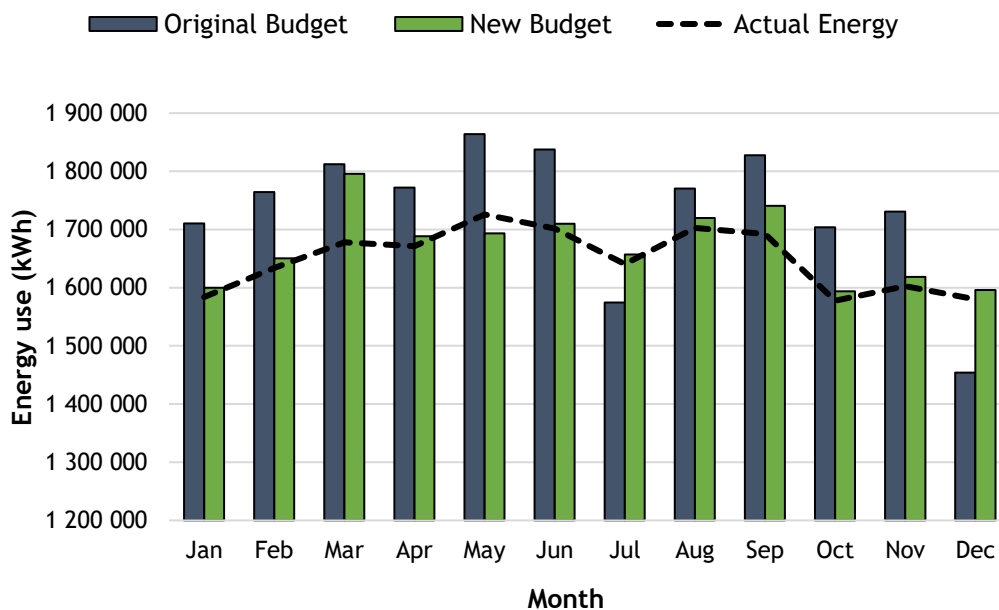


Figure 5-4: Old budget, new budget and actual consumption comparison

The old budget predicted the energy consumption for Shaft 1 with an accuracy of 15.2% where the new budget predicted the energy consumption within a 3.4% accuracy. The 3.4% error could be addressed as the Compressed Air project on Shaft 1 which started 22 days later than planned.

5.4 Discussion

The newly developed budget enabled the user to address commodity performances which the original budgeting structure did not allow as it was only developed on Shaft level. A simple adjustment to the structure thus enabled the budget to be used for energy management purposes as well.

The new budget was validated by successfully applying it to a South African gold mine complex. The new budgeting structure was verified by comparing its accuracy to the existing budgeting results. The new budget had a 6.4% improvement. Which resulted in a R8.8-mil difference in the cost forecasts. These improvements are noted for Shaft A only. When adapting these changes to the budgeting structure of the whole mine, a 16.8% improvement is noted. This results in a R26.2-million difference in the cost forecast of the mine.

6. CONCLUSION AND RECOMMENDATIONS

South Africa's mining industry is suffering due to higher-than-inflation increases in electricity costs. To reduce their dependence on electricity sources energy management is applied. Unfortunately, the financial budgets of the mine are being used as the reference point. Due to the high level of detail on the budget, effective energy management is limited. This is the reason that mines struggle to see the effect of their ESMs on the budgets.

This article addressed the problem by incorporating M&V principles into the budgeting structure. This was done by developing analogies between the M&V principles and the Budgeting process followed by South African mines. M&V principles are known for their reliability and accuracy and are believed to improve the budgeting structure to be more representative and enable energy management. This new structure was developed and applied to a gold mine complex in South Africa.

The new budgeting structure improved the accuracy of a South African gold mine complex budget with 16.8%. This resulted in a R26.2-million difference between the original budget versus the new budget. Effective energy management could also be applied by using the new budgeting structure due to the visibility of commodity performances. This confirms the

value of incorporating M&V principles when constructing financial budgets. The developed methodology was proven to be viable, and the application thereof results in more accurate budgeting methods. It is recommended that the new structure should be adapted and applied to other industries for future studies.

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APPENDIX D: DEVELOPMENT OF SPLITFILE

This Appendix contains supporting information to the understanding and the development of the splitfile. Only one section is included in this Appendix.

Appendix D.1: Splitfile

- The development process (methodology) of the splitfile is discussed in this Appendix.

D.1 DEVELOPING A SPLITFILE

When a budget is developed on an isolated component boundary, the energy data is required for each individual component. In some cases, the energy data is available for most of the components but not all of the components. When this happens, splitting can be applied to use the available data and predict the unavailable data using split ratios. The application of the splitting process is explained at the hand of a case study (specifically on Mine #1) in this section of Appendix D.

Figure D.1-1 presents a section of Mine #2's layout. Two meter panels are observed, along with electrical lines flowing to a number of components. The various green circles indicate available energy meters.

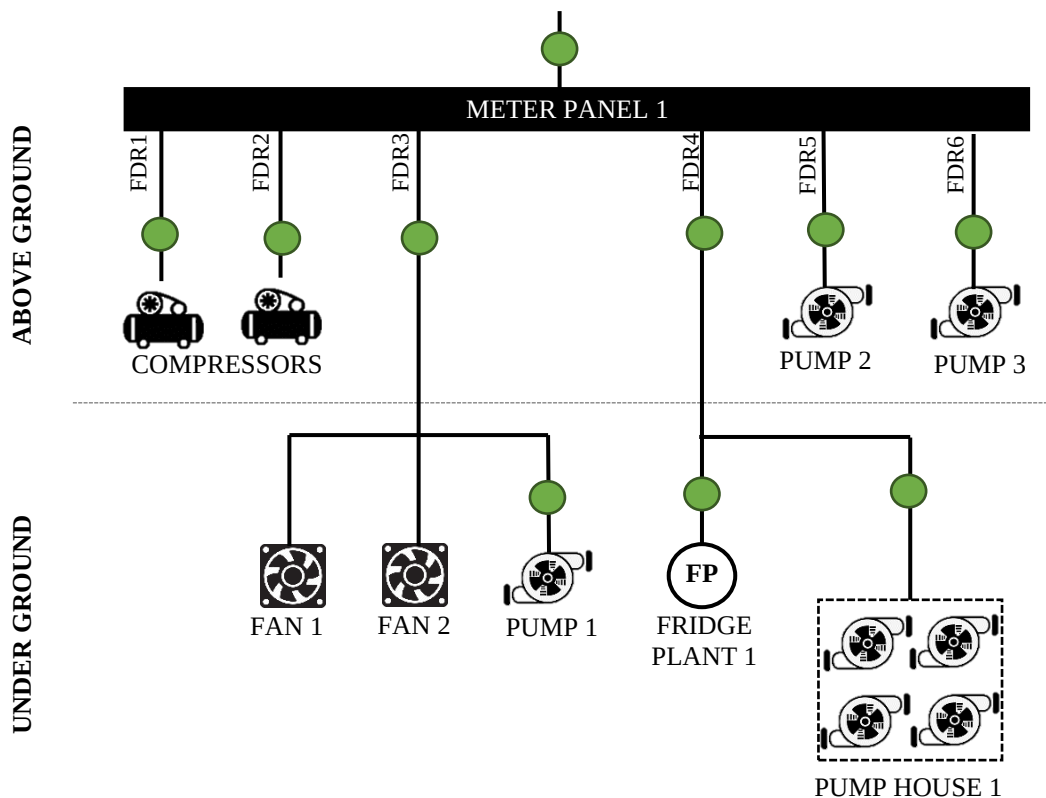


Figure D.1-1 Section of Mine #2's layout

It is noted on Figure D.1-1 that the total energy into meter panel 1 is measured. The energy flowing directly out of meter panel 1 is also measured. An energy balance over meter panel 1 will result in a small error, if all meters are accurate. It is further observed that some of the feeders (indicated with FDR on Figure D.1-1) feeds multiple components. When FDR3 is considered it is observed that the total energy consumed by the feeder is available, along with the energy consumed of the pump (PUMP 1). The fans, however, do not have available energy meters.

When developing a budget for FAN 1 and FAN 2, an energy balance can be drawn over the components and FDR3. Equation D.1-1 presents the energy balance formula for this example.

$$E_{FDR3} = E_{FAN1} + E_{FAN2} + E_{PUMP1} \quad \text{Equation D.1-1}$$

Where the E in Equation D.1-1 represents the energy consumption of the specific components (or feeder line). The two unknown energy consumption values (E_{FAN1} and E_{FAN2}) can thus be calculated as the difference between the energy of the feeder and the energy of the pump. This balance can be applied in half-hourly resolutions (if desired) to calculate the energy consumption of the fans.

The energy balance formula, however, only allows for the total energy consumption of both fans. This can be broken down by considering the design specifications of both fans. For this example, both the fans are similar in size (250-kW fans), and the assumption is therefore made that each of these fans consume an equal amount of the energy allocated to the fans with the energy balance.

By evaluating the components as such, ratios can be allocated to all the components where energy meters are unavailable. The limitation of this process, however, is that when one of the existing meters are not calibrated and give inaccurate results, not only will that component's budget be incorrect, but all of the components relying on that meter will also be affected. It is therefore important to ensure that all the meters are always calibrated and correct.

APPENDIX E: APPLICATION OF THE STRUCTURE (CASE STUDY RESULTS)

This Appendix contains supporting information to the critical literature review discussed in Chapter 1.

Appendix E.1: Case study 2 to 8 results and discussion

- Supplementary detail and information regarding the application of the new structure on case studies 2 to 8 (Section 3.2.3)

E.1 CASE STUDY 2 TO 8 RESULTS AND DISCUSSION

The application process discussed in Chapter 3 was applied to one case study (mine #1). The results of the application of the methodology on the remaining seven case studies were only summarised in Table 3-5. The application process on these case studies are discussed in more details within this Appendix.

For the application on the remaining case studies, the new structure will be discussed step-by-step along with the application and results obtained for each case study. Detailed examples will be provided for relevant scenarios. The sub-sections below contain this discussion for each step in the new structure.

Step-1: Budget boundary

The first step in the budgeting process is to identify the boundary that will be used for the budget. The methodology discussed in Chapter 2 presented a flow chart that can be used to identify the ideal budget boundary. This flow diagram was used to identify the boundaries for each of the remaining case studies. Table E.2-1 provides the boundaries selected for each case study, along with a short description as to why the specific boundary was chosen.

Table E.2-1: Case study boundaries

Case study	Boundary	Discussion
Mine #2	Isolated component	The purpose for each of these mine's budgets is to ultimately use the budgets for energy management purposes as well as for financial planning.
Mine #3	Isolated component	
Mine #4	Isolated component	
Mine #5	Isolated component	
Mine #6	Isolated component	
Mine #7	Isolated component	
Mine #8	Isolated component	

Table E.2-1 shows that all the remaining case studies are evaluated on an isolated component boundary as oppose to a whole facility boundary. The reason for why an isolated boundary is preferred is the added benefit of energy management it delivers to the budget. As discussed in Appendix B.3, developing a budget on an isolated boundary, can increase the budget's accuracy (with an estimated 5%). This additional accuracy is also appealing to the isolated boundary option for budgets.

The available data was also evaluated, and all the mines will be able to develop a budget for each component due to the availability of most meters and the application of a splitfile (as discussed in Appendix D)

Step-2: Budget resolution

The second step in the improved structure created in Chapter 2 is to decide on the budget resolution. To help with the decision, a flow chart was presented which allows for the decision of the application on annually, quarterly, monthly, daily or half-hourly resolutions. Table E.2-2 presents the budget intervals decided on for each of the case study mines, along with a short description as to why the boundary was decided on.

Table E.2-2: Case study resolution

Case study	Boundary	Discussion
Mine #2	Half-hourly	TOU profiles need to be included.
Mine #3	Half-hourly	TOU profiles need to be included.
Mine #4	Daily	No TOU effects but various types of days should be considered.
Mine #5	Monthly	Month-on-month performances are similar but seasonal changes need to be considered.
Mine #6	Daily	No TOU effects but various types of days should be considered.
Mine #7	Half-hourly	TOU profiles need to be included.
Mine #8	Half-hourly	TOU profiles need to be included.

Most of the budgets (Mine #2, #3, #7 and #8) were also created in half-hourly profiles to incorporate the TOU profiles for each type of day (weekday, Saturday, Sunday and Public Holidays). The budgets were created in these resolutions to ultimately enable the comparison of the performance of each original budget (which were created in monthly resolutions) with the high resolutions.

The budgets created in other resolutions (daily and monthly) did not plan to change any TOU operations and, therefore, did not need to develop the budgets in half-hourly. Changes in the type of days (weekdays, weekends, public holidays, etc.), however, were considered for the daily resolution budgets and seasonal effects were considered for the monthly budgets.

Step-3: Data quality

The purpose of this step is to ensure that the data used for the budgets are representative. Chapter 2 indicated that this step consists of four sub-steps, a) use calibrated meter data, b) evaluate the data consistency, c) inspect the data for errors/outliers and d) inspect the data for abnormal/unplanned events. The occurrence of any of these data mistakes can influence the final budget. The case study's data are evaluated for all four of these mistakes in the subsections below.

The sections below highlight some of the main data discrepancies seen on the remaining seven case studies.

a) Use calibrated meter data

All seven remaining mines used calibrated meter data to obtain the energy data used for the budgets. To further ensure the accuracy of the data, the energy data was compared to the total Eskom Bill. All seven mines showed errors of less than 1% when the whole facility's energy meters were compared to the total mine's Eskom Bill.

b) Evaluate the data consistency

Even though the data is obtained from calibrated meters, it is still possible that the data can have inconsistencies. To ensure that the dataset used for the budgets are complete the data has to be evaluated for consistency. This is done by ensuring there are no missing data. Mine #4 and Mine #5 both had large data gaps (missing data).

For these mines, the reason for why the data gaps were observed were evaluated and it was found, in both instances, that the meters were damaged for a duration of several hours. This missing data was replaced with the average energy consumption readings of the meters for a 24-hour period before and after the meter started missing readings.

c) Inspect the data for metering errors

The energy consumption of all the components were evaluated for data errors. Data errors are events that occurred which indicates that there was fault with the meters and as a result a spike in the data was observed. The evaluation on the case studies indicated that several large spikes were observed on the various components. These spikes were evaluated and addressed accordingly.

d) Inspect the data for abnormal/unplanned events

Unplanned events in the baseline dataset can impact the energy predictions since the historical energy is frequently used as the basis for forecasting. The historical energy data was, therefore, evaluated and all unplanned events were removed from the historical energy data before the data was used to develop any of the case study's budgets.

Step-4: Routine adjustments

Routine adjustments are the adjustments included in the budgets for all the planned changes. This includes changes for production, savings projects, growth projects, etc. This step of the methodology is broken up into two subsections a) considering all relevant events and b) improved methods for quantifying the associated effects. This ensures that all the relevant events are firstly considered to ensure that adjustments are made for all the events that could affect the budget and then also the method of quantifying this effect. Each of the two subsections are addressed individually.

a) Consider all relevant events

The first step is to identify which events should be considered and this is typically done in the assessment period. This is done by evaluating all the external effects of the individual components. This type of evaluation is done for all of the case studies with the main external effects to be considered for each commodity presented in Table E.2-3.

Table E.2-3: External effects to consider for case studies

Commodity	Production	Temperature	Mine depth	Employees
Mining	Yes			
Hoisting	Yes		Yes	Yes
Pumping	Yes	Yes		
Compressors	Yes			
Ventilation			Yes	Yes
Refrigeration		Yes	Yes	
Processing	Yes			

Table E.2-3 illustrates the external effects of production, temperature, depth of mine and number of employees on the mine for each commodity. The evaluation process for these external events are discussed in detail in Appendix B.4.

b) Quantification of the relevant events

The effect of these events is quantified by developing regression models for the energy consumption per commodity and the respective external effects that need to be considered. A Power Model generally showed the best correlations between the external effects and the commodity energy consumptions and predicted the effects within a 5% expected accuracy.

Step-5: Budget development

The original budget was developed by considering a simple linear relationship between the historical energy consumption and certain assumptions on the effect of planned projects and changes in production. The new budgeting structure will consider various other external effects (quantified effects and not assumptions) along with non-linear modelling techniques. The developed energy budget will finally be converted into a costing budget by incorporating Eskom TOU profiles for the mines where half-hourly profiles were considered.

The new budgeting formula (presented by Equation 2-2 in Chapter 2) was adapted to calculate the 2019 energy budget for a single component and is presented by Equation .

$$\text{Budget}_x = (\text{Historical Energy})_x \pm (\text{Routine Adjustments})_x \pm (\text{Variances})_x \quad \text{Equation E.2-1}$$

Where:

Budget_x	The 2019 budget for component x; in kWh
$(\text{Historical Energy})_x$	The 2018 actual energy consumption for component x; in kWh
$(\text{Routine Adjustments})_x$	The adjustments calculated in step 4 for component x; in kWh
$(\text{Variance})_x$	The variance calculated using Equation E.2-1; in kWh

This formula is applied to each resolution as depicted in Table E.2-2 for each mine's case study. Budgets are developed and ultimately delivered for each component. The process is revisited several times to ensure that budgets are presented for each component. Ultimately, the component budgets are compiled to present the budgets for the whole facility.

Step-6: Assurance

This step in the budgeting process ensures that the final budget procedure is documented to provide assurance to the application process. All seven remaining mine case study's budgeting process were presented in a formal budgeting report and presented for final approval.

Summary of the application on the mine case studies

Table E.2-4 presents the findings when the case studies were evaluated with the improved structure.

Table E.2-4: Results for case studies 2 to 8

	Mine #2	Mine #3	Mine #4	Mine #5	Mine #6	Mine #7	Mine #8
Step 1: <i>Boundary</i>	<i>Per component</i>	<i>Per component</i>	<i>Per component</i>	<i>Per component</i>	<i>Per component</i>	<i>Per component</i>	<i>Per component</i>
Step 2: <i>Resolution</i>	<i>Half-hourly</i>	<i>Half-hourly</i>	<i>Daily</i>	<i>Monthly</i>	<i>Daily</i>	<i>Half-hourly</i>	<i>Half-hourly</i>
Step 3: <i>Data quality</i>	<i>Data evaluated and correct</i>	<i>Data evaluated and correct</i>	<i>Data evaluated and correct</i>	<i>Data evaluated and correct</i>	<i>Data evaluated and correct</i>	<i>Data evaluated and correct</i>	<i>Data evaluated and correct</i>
Step 4: <i>Adjustments</i>	<i>Projects, production and seasons</i>	<i>Projects, production and seasons</i>	<i>Projects, production and seasons</i>	<i>Projects, production and seasons</i>	<i>Projects, production and seasons</i>	<i>Projects, production and seasons</i>	<i>Projects, production and seasons</i>
Step 5: <i>Budget</i>	<i>Power model</i>	<i>Linear regression</i>	<i>Linear regression</i>	<i>Power model</i>	<i>Power model</i>	<i>Power model</i>	<i>Power model</i>
Step 6: <i>Assurance</i>	<i>Reporting in place</i>	<i>Reporting in place</i>	<i>Reporting in place</i>	<i>Reporting in place</i>	<i>Reporting in place</i>	<i>Reporting in place</i>	<i>Reporting in place</i>

Table E.2-4 shows that the improved budgeting structure could be applied successfully on all of the remaining mine case studies. An isolated component boundary was used for all remaining mines, similar to the application on Mine #1. An isolated boundary was used to enable the budgets to be used for energy management purposes as well.

Most of the budgets were also created in half-hourly profiles to incorporate the TOU profiles for each type of day (weekday, Saturday, Sunday and Public Holidays). These budgets were created in these resolutions to ultimately enable the comparison of the performance of each original budget (which were created in monthly resolutions) with the high resolutions.

The remaining budgets did not plan any TOU changes for the assessment period and therefore developed budgets on daily or monthly resolutions (to still account for changes in the type of day and seasonal effects). These budgets are still considered to be consistent and relevant to the need for its application.

The data were all evaluated for missing data and outliers. These erroneous data were addressed accordingly and removed from the dataset. The abnormal events that occurred in the baseline period was also identified and removed. Ultimately, the models developed in Step-4 and Step-5 was based on quality datasets.

The routine adjustments were mainly identified as changes in production, expected planned and growth projects, changes in temperature and finally, changes in the number of crews. These changes were identified by evaluating the relationship that these variables had on the energy consumption. If a strong correlation ($R^2 > 0.75$) was observed, the relationship was established. Various models were then applied to the data to present the model with the smallest CV(RMSE).

Finally, the budgets were developed and included the required variances. The budgeting process was also documented in a formal budget report for assurance. The formal documentation of the budgeting procedure allows for assurance when the budget needs to be approved by a third party. The successful application of the new, improved structure verifies the methodology presented in Chapter 2.