

CHAPTER 4

Proposed Energy Model and Conclusion

4.1 MINE ENERGY MODEL ANALYSIS

Chapter 3 indicated that between the Monte Carlo and Regression statistical models, only 13% accuracy was achieved on the recent histories of actual energy used against monthly model predictions from 2012, not considering the differences in the 22-year outlook prediction. This in comparison to the mine energy departments 6% error for the same period and requires an investigation as to the principles of establishing their energy model. For management this is a key component in decision-making when considering the average energy cost (R) from the energy units (kWh) as predictions by the models are in the region of R 800 million annually (shown by figure 3.17). An increase in error percentage from any statistical model for mine energy forecasting will lower the NPV of the project and could possibly be the deciding factor on whether or not to proceed with such a project. The models when calculated based on the error percentages from chapter 3 have an average of R 80 million annual cost error and from equation 9 reduces the NPV of the project due to energy cost by R 643 million. This is not just important during project energy cost evaluations but also for current LOM energy forecasts. The net effect from errors in energy forecasting is:

- Reduces the annual capital availability for other mining related projects due to the high OPEX contribution of energy. Implicating that an R 80 million error allocation from the model would reduce capital availability by the same amount that could have been utilized elsewhere.
- Reduces the overall NPV of the specific business unit or project.
- Increases the required rate of return for investors due the uncertainty and cost band of the energy cost outlook.

As investors seek certainty on returns, energy related risks in deep level mining due to the unpredictability or high error percentages that cause uncertainty could be offset if proven that the outlook is within acceptable limits. It is assumed that the mine energy departments 6% error percentage on the energy unit outlook is within the acceptable limit based on general uncertainty in future forecasting and will be further investigated as to the reason for the increased accuracy and also the lowest NPV reduction cost model for the same tonnage profile.

4.1.1 Input variables for the mine energy model

In chapter 3 the investigation of the input variables proved that tonnes and year are statistically relevant to a deep mine energy model. Also in the work done by Deloitte in their model called for the establishment of a base load profile per utility process that accounts towards the majority of stable load in the energy model. The concept was proven in chapter 3 with table 3.2 when the coefficient of determination R^2 increased with the removal of the base load per process in comparison between tonnes and energy usage. Thus implicating that the traditional tonnage and year profiles are sufficient for energy forecasting with base loads as determined from historical data are removed. The base load is calculated from non-production related days and was the minimum required load to sustain the working conditions underground without any mining activities. The base load percentages are captured in figure 4.1 and show the high contribution of environmental conditioning processes like Ventilation, Refrigeration and Mining. Mining load as mentioned in chapter 3 has a 97% base condition due to the ventilation fans and pumps that are used on the level and is therefore also classified under environmental conditioning. It is also shown that the physical transportation of ore in Rock Hoisting has the lowest base condition; this is expected when considering that ore in principle should only be transported when delivered from the mining activity unless significant silos exist for transport management in the vertical shaft.

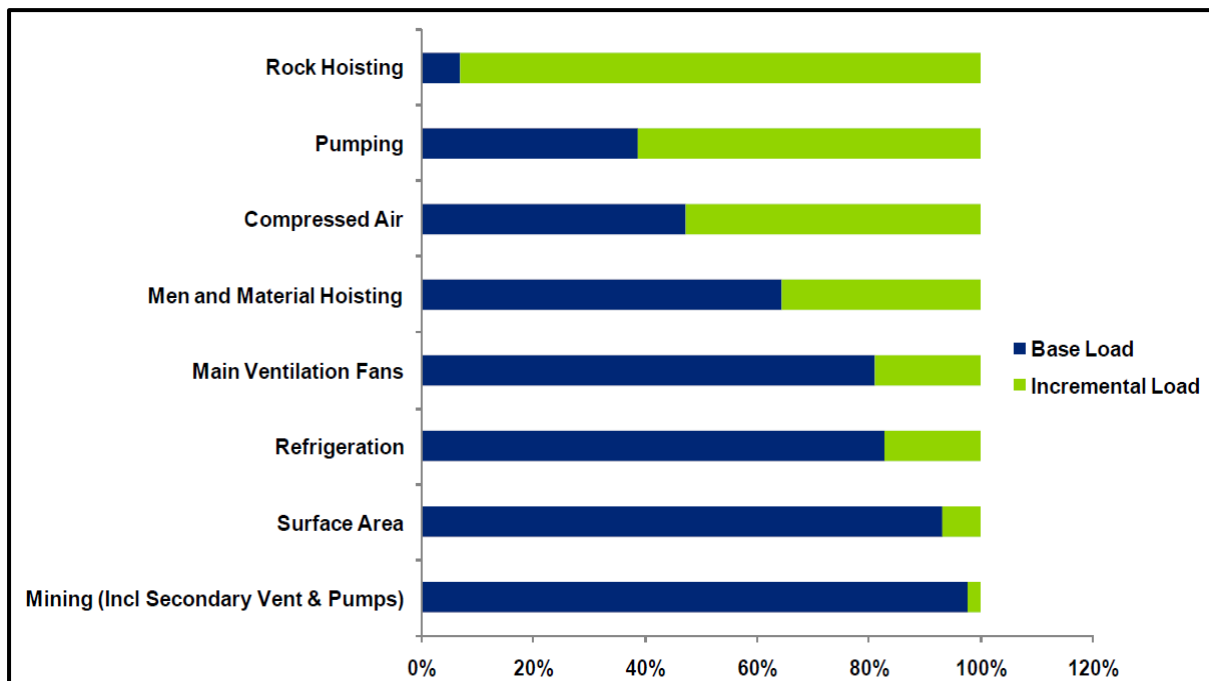


Figure 4.1: Base load analysis results.

Between the Monte Carlo and Regression analysis the latter had the best initial comparison with the actual values from a percentage error of 13% but then had the highest energy unit

outlook over LOM and subsequent associated energy cost. The effect resulted in the highest reduction on the NPV at almost R 1 billion more than the average with an annual average of R 100 million. The model as was mentioned in chapter 2 has a high error when extrapolating outside the relevant data range for the period 2002 to 2012.

When analysing the mine energy departments' model it was found that the variables and principles for energy forecasting encapsulates the fundamental methodology of both the Monte Carlo and Regression models. When investigating the key components that are used for input it was found that it:

- Includes a base load adjustment per utility process.
- Considers the tonnes on the variable load calculation.
- Considers the days in the prediction period over the LOM for production in years.

This shows that the model in itself is not new to what is currently available and relevant in statistical methodologies but rather is adjusted towards the mining requirements so uses key components to enable energy forecasting within the deep level mining environment. Increased accuracy must therefore be found from the additional input criteria for each utility process that includes:

- Base load adjustment from new equipment.
- Efficiency improvement or deterioration per utility process.
- Seasonality adjustment on environmental processes.

A better understanding is gained when referring back to the mining utility processes as was discussed in chapter 3. Within all the mentioned utility processes there exists constant change and the model is required to adapt to the changes for increased accuracy as was shown by the 6% variance to actual values. Mines are constantly developing into new resources to gain access to ore reserves and depleted sites are closed down. It's therefore required that the model somehow accounts for this adjustment in base load along with new equipment that requires input energy for operation.

Base load adjustment for new equipment: The working environment within a mine is constantly changing and so does the equipment that goes along with it. As mining takes place the geographical area and location of required equipment changes so that some equipment remains in place like fans and or pumps and some equipment are removed like winches. The idea behind the additional and removed equipment comes from the constant requirement to satisfy the environmental conditions as set out by the Mine Health and Safety Act (No. 29 of 1996) (SA, 1996) along with the Minerals Act (No. 50 of 1991) (SA, 1991). In order to transfer air and water it is common knowledge that base infrastructure remains in

place and only additional load is added, this process remains fairly constant until such time that the working area is depleted of ore reserves and the mining activity stops. This result in winches that are removed or stopped from operating and therefore reduces the energy requirements of a working place. However Ventilation, Refrigeration, Pumping and Compressed air are part of an integrated circuit and is therefore not just stopped as the mining activity at a specific point is stopped. Typically the mining activity will progress further from the available infrastructure due the mining methods that leads to an efficiency improvement or deterioration per utility process.

Efficiency improvement or deterioration per utility process: Technology is constantly improving and with it comes the option when installing new equipment to improve the component efficiency. Therefore it is possible to install new and more efficient equipment if funding permits. However as older equipment is operated within the mining environment it will deteriorate and ultimately increase the energy requirement in order to provide the same level of service (For example: A pump impeller deteriorates over time due to rock particles in water so an increased amount of energy is required to provide the same output flow condition). This again comes back to the available funding and the allowed expenditure on maintenance and operating costs. Figure 4.2 gives an illustration of the deteriorating efficiency from the deep mine to support the comments made. The work done by Robbins (2013) mentioned that some equipment like Refrigeration Plants require less energy when operated from surface during the colder winter ambient temperatures that affect the environmental processes underground. For the model it's therefore required that it includes the seasonality adjustment on environmental processes.

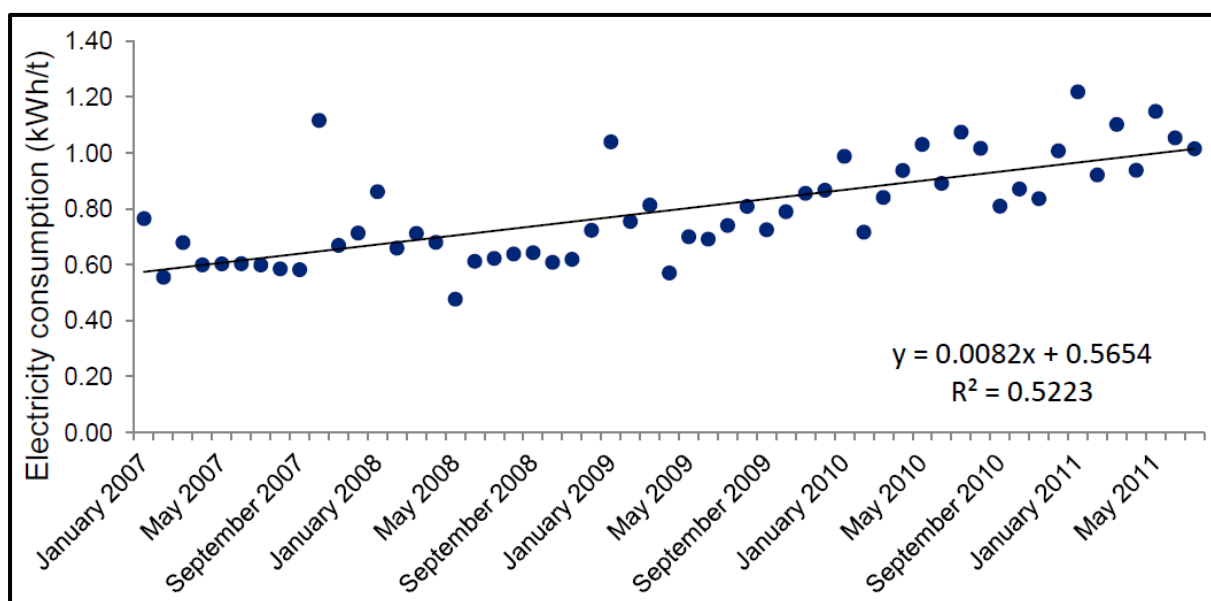


Figure 4.2: Deteriorating efficiency profile.

Seasonality adjustment on environmental processes: One of the selected input variables from chapter 3 was ambient temperatures and their effect on the energy consumption profiles of the selected mine. It was shown in table 3.1 that it had no collinearity with other input variables but that the profile remained fairly constant over the historical data. Neither the Monte Carlo nor Regression analysis could capture this variable, its importance is now emphasised for environmental processes with specific regards to Refrigeration.

4.1.2 Mine Energy Model, merger of the Monte Carlo and Regression analysis

Starting then with the regression analysis it was shown in its fundamental equation (1) that the energy required (y_i) is a function of a constant value (β_0) that captures the base condition which exists not only at process level but compiles towards a total mine base condition as discussed. A variable portion (β_1) or now also known as the variable load when multiplied with the associated contribution from variable tonnes (X) provides the generic model for development as from equation 9 within the regression framework. This enables us with a simplistic starting point to build towards in the Monte Carlo analysis, where the year contribution based on a variable detection method to ensure data integrity within the iteration process is captured.

$$y_i = \beta_0 + \beta_1 X + \varepsilon_i \quad (9)$$

Meticulously using this process to work through all the utility processes that contribute towards the mining energy requirements therefore provides a Monte Carlo equation as discussed in chapter 2 with iteration as shown in figure 4.3. The equation incorporates the expected LOM and the associated year thereof to provide the model with a newly introduced input variable (Y). Depending on the process usage and the statistical importance of both variables within the utility processes the year function is applied as shown in equation 10 along with figure 4.4.

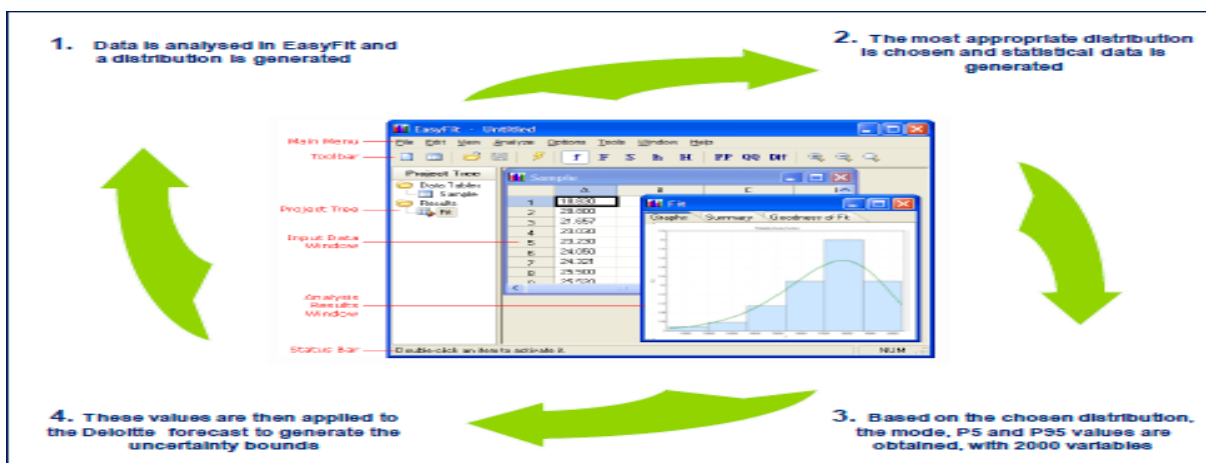


Figure 4.3: Iteration process within the Monte Carlo Analysis.

COMPRESSED AIR	$E = 31.327 \cdot T + 54732000$
MP UNDERGROUND LOAD SUB	$E = [0.093(Y - 2006) + 0.000] \cdot T + 93187000$
MP UNDERGROUND LOAD MAIN #	$E = 0.342 \cdot T + 33509000$
MAIN VENTILATION FANS	$E = 6.499 \cdot T + 63482000$
MP UNDERGROUND SERVICE WINDER	$E = [0.023(Y - 2006) + 0.028] \cdot T + 322350$
MP WEST MAN WINDER	$E = 0.725 \cdot T + 2541300$
MP UNDERGROUND MAN WINDERS	$E = 0.426 \cdot T + 1490600$
MP SERVICE WINDER	$E = 0.527 \cdot T + 1880500$
MP EAST MAN WINDER	$E = 0.734 \cdot T + 2796500$
SURFACE AREA	$E = 0.448 \cdot T + 11964000$
REFRIGERATION	$E = 9.999 \cdot T + 93462000$
MP UNDERGROUND ROCK WINDERS	$E = 5.185 \cdot T + 866330$
MP EAST ROCK WINDER	$E = 6.532 \cdot T + 1005000$
MP WEST ROCK WINDER	$E = [0.279(Y - 2006) + 1.111] \cdot T + 678560$
PUMPING	$E = [1.202(Y - 2006) + 74.472] \cdot T + 65957000$
TOTAL	$E = [138.154 + (1.598 \cdot (Y - 2006))] \cdot T + 427874140$

Figure 4.4: Monte Carlo equations for each utility process and its sub components.

$$y_i = \beta_0 + \beta_1 X + (Y - BY)X + \varepsilon_i \quad (10)$$

The Monte Carlo iteration process indicates that the year (Y) as determined in the LOM profile must be calculated with a base year (BY) and then subtracted (Y-BY) to add a single variable for addition or reduction towards the variable load. This simply makes a small adjustment for the utility processes that have smaller base conditions and therefore larger impact with tonnage changes. When calculated the total outlook is purely the sum of the collective utility processes and then mathematically manipulated so to capture both the year and tonnage outlook shown by the equations in figure 4.4. To this point we have therefore satisfied the first 3 input requirements also found in the model components mentioned in section 4.1.1. The model at the time of the Deloitte study was for the particular year and the LOM outlook so it is assumed that it would get a base adjustment in the following year.

Going forward towards the mine energy model it is found that in-depth detail is required in each of the utility processes in order to adjust them for the remaining criteria on base loads, efficiency and seasonality. We therefore conclude on equation 11, which shows how this adjustment is captured per utility process. Important from the mine energy model is that it

remains within the utility process and therefore is not summated toward a total mine single equation but rather each utility process is calculated based on the tonnage and year outlook and then the total values for energy contributes towards the summated total.

$$y_i = \beta_0 \left(\frac{\text{Production Days}}{\text{Calendar Days}} \right) (\text{Seasonal Adj}) + (\beta_1 X + (Y - BY)X) \left(\frac{\text{Production Days}}{\text{Calendar Days}} \right) + \text{New Energy Equipment} - \text{Energy Efficiency Projects} \quad (11)$$

- Base Load

From equation 11 it is shown that the base loads are annually calculated and adjusted according to the actual production days expected within the month. It's required as mine planning and production days change annually so to determine the specific day of work and then also for holidays. This value is then multiplied with the seasonal adjustment factor. As was mentioned, the utility process refrigeration requires substantially lower energy during the colder winter months to operate if the units are located on surface. This also has a direct effect on the pumping and possibly the ventilation requirements. The base adjustment provides a monthly expected energy total that is associated with the sustainability of working environments underground with no associated production.

- Variable Load

Variable load is basically carried forward in the model evolution from its regression and Monte Carlo analysis. The only new addition comes from adjustment requirements in production and calendar day as was done for the base load conditions. The model looks at the forecasted tonnage profile and the associated kWh/tonne adjustment, with the inclusion of the LOM year value and the reduction towards the base year provides the actual energy expected for actual production purposes.

- New Energy Equipment

The report discusses all the constant changes that take place within the mining environment as resources are mined out and additional equipment is required. To cater for this adjustment, the energy equipment section is added that looks at the load requirement of new and additional equipment (kW) and then multiplies it with the expected running hours (h) to provide the energy (kWh) that must be added. This when carried out at utility process level also indicates the rate of change for the specific utility and could if needed be used as a benchmark indicator. The benchmark indicator shows the rate of growth for the utility process and depending on the mining area along with the expected production should be able to provide management with clear benchmarks as to the productivity of energy usage over associated tonnes generated.

- Energy Efficiency Projects

Efficiency projects as the name describes are the improvement of the process efficiency to reducing the energy (kWh) to still deliver the same production profile or utility service level. As mining and operational costs are associated with energy increase this is an effective area for capital investment to reduce OPEX. Efficiency in equation 11 reduces the total energy requirement and is calculated on the same principles as new equipment mentioned previously.

The process to this point to establish the mine energy model is meaningless if it cannot be proven to be applicable within the mining environment. Shown again in figure 4.5 is a comparison of the evaluated models and the accuracy with historical actuals available to date. The best fit of all the models comes from the mine energy model with a 6% deviation from the historical actuals. This is expected from the model evolution and the best practice selection carried out on the regression and Monte Carlo models. The Deloitte and mine energy department models have indicated that the best method for prediction is in monthly forecasts to allow for different input variables that ultimately affect the accuracy of prediction. The assumption is made that a 6% error is sufficient for investor purposes and given the complexities that exist within the mining environment and mentioned in this report with regards to units price outlooks (c/kWh) and the energy required (kWh) at utility process level would not be drastically improved.

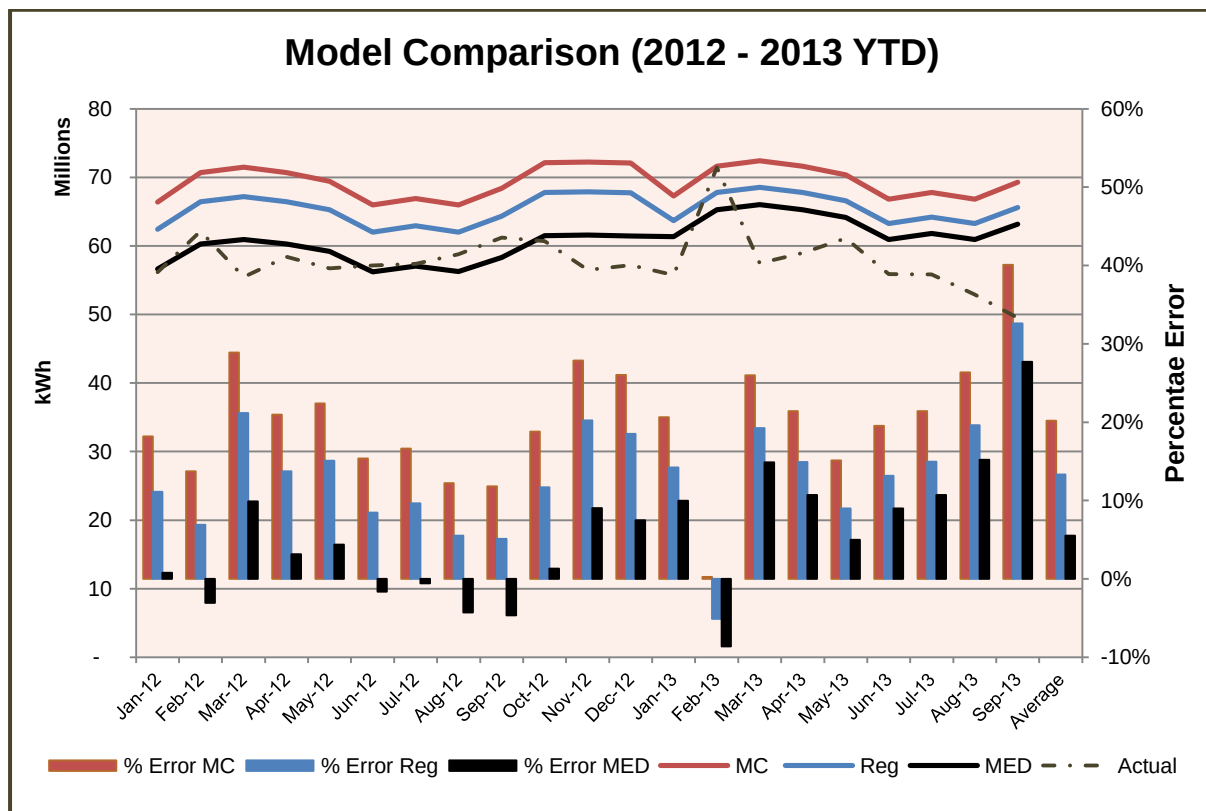


Figure 4.5: Model comparison to actual kWh along with percentage error to actual.

4.1.3 NPV Impact

When considering the amount of variables that influence each utility process and the fact that they are all summated towards a total energy requirement for the mine or project it is hard to imagine that statistical models will greatly improve in accuracy for deep level mining application going forward. Also the cost uncertainty that lies within the unit cost as government and industry arm wrestle to ensure the security of supply that is affordable within the country might have several investor risk concerns. The mine energy model is assumed and seems to be a good guideline or representative of what the expected energy requirements are going forward for deep level mining application on conventional mining techniques. The NPV impact of energy for any mine or new project is substantial as shown by figure 4.6. At current levels the contribution towards OPEX is at 20% and not considering the escalated impact that carbon tax will add a conservative outlook for deep level mining keeps it at an average of 15% over LOM profiles.

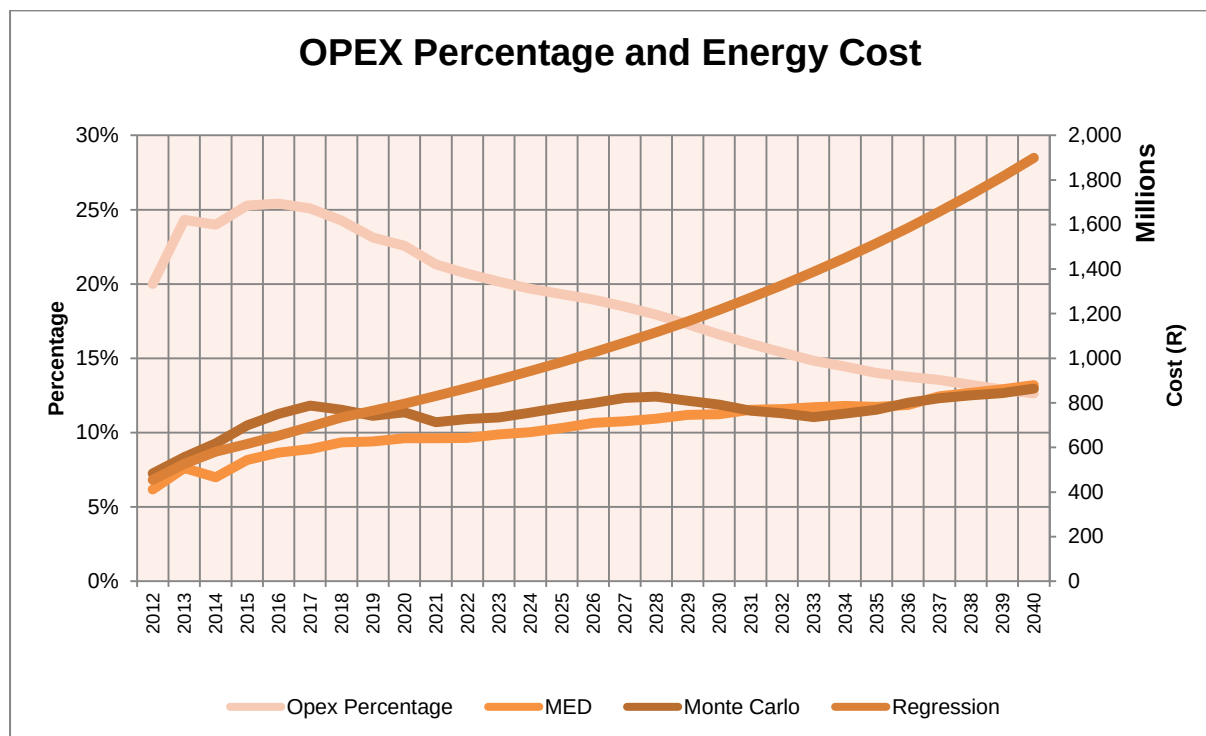


Figure 4.6: NPV calculations of the energy models.

To this point no mention was made of the sustainability impacts of energy and the carbon emissions associated along with it. Chapter 1 alluded to the carbon emissions factor of Eskom as they are globally one of the worst emitters at 1.02 kg/kWh. This will place companies with substantial mining assets in South Africa under considerable pressure to reduce energy requirements by increasing efficiency or offsets with renewable energy sources. So energy usage and predictions in general will always play a critical role in the mining environment within South Africa.

4.2 Conclusion

The study set out to illustrate the application of statistical models in deep level mining applications and to what extent they are able to predict future energy profiles or requirements. Chapter 1 gave a contextual framework of mining in general within South Africa and the challenges facing the industry. It was shown that mining historically and even now plays a substantial role within the economy. There was mention made that the dependency on the industry is 11 for every 1 person meaning that everybody working at a mine in South Africa has 11 people making direct and indirect living from the mine's expenditure. It is an industry faced with significant challenges when considering the unemployment and the growth requirements from government and the commodity price challenges that have increased investor expectations from the associated risk profiles.

Chapter 2 gave an overview of energy in general and the increasing contribution experienced within industry on OPEX. As unit price increases far exceeded CPI levels along with the revenue income stream principle from Eskom the industry has had not only to face this challenge but new legislation as South Africa transitions towards a greener economy. In-line with global trends the country is in the process of promulgating legislation that will see industry benchmarks for efficiency improvements and carbon tax. Shown in the chapter is that Eskom as a utility has not been keeping their maintenance of the operating fleet updated and therefore place a significant security of supply issue on the table. In 2008 this snowballed and nationwide load-shedding took place costing the industry huge amounts of money. With that having passed the events that took place at Marikana again shocked the industry and with employees demanding increased wages to sustain their way of life. At that point labour contributed towards the largest OPEX cost within industry but more worrying was the growth as mentioned coming from energy.

The cost of energy is determined by the actual unit cost of energy and then the amount of units consumed. To align with the National Energy Efficiency Strategy (NEES) along with its implementation protocol the National Energy Efficiency Action Plan (NEEAP) work done by mining companies in collaboration with the Energy Intensive User Group (EIUG) set out to show what an affordable price path should be for industrial energy consumers. Eskom as mentioned works on a revenue price principle and this requires the larger users to fund the new government build program. A top down and bottom approach was used to indicate what industry thinks the unit price should look like going forward. The National Energy Regulator of South Africa (NERSA) approved a 8% annual increase for the Multi Year Price Determination (MYPD - 3), but according to Eskom's financial statements wont enable them to achieve the required credit ratings from agencies like Moody's and Standard and Poor that therefore requires the increase to be further investigated. Based on the pricing models

by industry a price cone was made available and indicated in figure 3.16 to illustrate the high variance in possible unit costs. This could then be used in later chapters to show based on NPV calculations what the energy cost should look like.

Unit consumption investigation research on statistical models for energy forecasting within the mining industry indicated that for that the historical low unit price and its notable insignificant impact on OPEX never required accurate forecasting to be done and thus a lack of available information resulted. AngloGold Ashanti (AGA), however, approached Deloitte in 2011 to conclude a study for such a statistical model to forecast energy loads on one of its operations. The model selected for the project was the Monte Carlo analysis and the rationale made sense as research indicated that it had common uses in energy forecasting at utility level. For the purpose of evaluation a second methodology in a regression model was selected as it is well-known within the statistical fraternity and should be able to provide high level comparison to the Monte Carlo model. Basic principles of both these models were investigated to provide the reader with an overview of the fundamental principles and what assumptions are associated with any such model.

Investigations into the working principles of a typical deep level mine showed that the utility processes that make up the energy consumption consist mainly of seven separate functions:

- Pumping
- Refrigeration
- Compressed Air
- Ventilation
- Winders
- Surface Load
- Mining

The environmental conditioning of the underground area as required by the Mine Health and Safety Act (No. 29 of 1996) (SA, 1996) along with the Minerals Act (No. 50 of 1991) (SA, 1991) contributes towards about 83% of energy usage. When comparing production related energy usage and non-production usage that is energy consumed when there is actual drilling of the rock and weekends or holidays it was found that there exists a substantial base load condition within the deep level mining industry. This load is required to sustain the underground working environment as increased mining depth requires additional environmental conditioning like cooling due to increased Virgin Rock Temperatures (VRT's). Investigations into the variables that influence the energy requirement of a typical deep level mine indicated that via a process of statistical elimination tonnes broken and year are the best variables applicable in a mine energy model. Mines plan on a tonnage profile over the

Life of Mine (LOM) so the variables were known for the given evaluation and were therefore used in both the Monte Carlo Analysis that worked on tonnes and Regression Analysis that worked on years. The models were carried out to 2040 and then compared to the mine energy departments' model for evaluation with current actuals as measured on a monthly basis. The best fit on current actuals came from the mine energy departments' model with the lowest error percentage at 6% with the Monte Carlo at 20% and the Regression model at 11%. This when calculated along with the unit price path for different scenarios gave and discounted would provide the Net Present Value (NPV) reduction that each model has coming from energy. A financial analysis with the Capital Asset Pricing Model (CAPM) and the Security Market Line (SML) indicated that the required rate of return that investors of AGA shares have is 11.92%. Using this value the NPV analysis showed that the mine energy model has the best or lowest NPV impact and that the regression model was totally out of line with expectations.

Chapter 4 therefore investigated the fundamentals of the mine energy model and found that essentially it was an evolution of the regression model with the design principles of the Monte Carlo analysis included. The only difference was that additional real-time energy information like annual base load adjustments at utility level along with efficiency and seasonality adjustments increased the model accuracy. When considering the reduced impact on NPV and the current accuracy of the model it is therefore concluded that to some extent mine energy forecast models based on statistical principles could be developed. The consistency and relevance is however questionable when considering as with any statistical model the interpolation of models between data points. In chapter 3 the statement was made that interpolation provides a much more accurate answer than extrapolation.

Investors that provide funding for large capital projects require a higher return as the associated risk with their money increases. The models discussed in this research all work on an extrapolation principle and if they are satisfied with a 6% error then there is significance for the work done. This statement is made as no clear evidence of any similar or applicable statistical model could be found in research that pertains to deep level mining.

Mining has been taking place since the 18th century shallow ore resources are depleted and most mining houses would therefore look towards deeper deposits. The research indicates that to some extent there exist opportunity and some rationale in predicting energy requirements for deep level mining applications. Especially when considering the legislative and operational cost implications for the mining houses within the South African economy and with the requirements from government to ensure sustainable work and job creation from an industry that significantly contributes towards the Gross Domestic Product (GDP).

4.3 Requirements for future work

Throughout the report it was mentioned that the study is looking at a deep level mine within the South African context and that a limited amount of published info exists. This means that the study was focussed on a very specific niche market and sector within mining and the economy. There does however exist other mining methods like board and pillar mining found in the coal mines and then open pit operations with associated underground mining activities. Outside the borders of the country climatic conditions will differ and methodologies towards ore extraction so should be considered. It is therefore the recommendation that the following could be further investigated to look at not only the relevance but application of statistical models in mine energy forecasting:

- Further studies on the mentioned methods as only limited data was available for comparison at the time on historical trends.
- Determination of the extrapolation error percentages in mine energy statistical methods.
- Variable assumptions based on other mine planning parameters besides tonnage and year.
- Statistical models other than the ones used for this study.
- Unit cost outlook predictions based on statistical models.
- Cost impact of energy within the South African mining industry.
- Financial assessment and indicators of energy within the South African mining industry.
- Investor requirements within the South African mining industry.
- International perspective on the above mention points outside and applicable to the mining industry.

The focus of the study was limited to the South African context and the mining environment with current promulgated policies. As legislative requirements and economic pressures on the industries increase management would require investor relations and internal toolsets to understand the implications of transitioning towards greener economies and increasing energy focus. This would not only assist with better project or asset evaluations but provide insight into investment opportunities that could potentially offset future costs and provide investor confidence that ultimately reduces the required return on invested capital projects.

4.4 Limitations of the Study

As mentioned the study was focussed on the proposed project at a deep level mine within AngloGold Ashanti. It therefore focussed only on one specific business unit, and within

mining no single business unit is similar. Also the study only focussed on conventional stoping as a mining method that only captures a small percentage of all the mining methods in South Africa. Going further, the study looked at a South African mine and not what exists in similar or different methods internationally.

It is therefore concluded that the research must be considered as a first of a kind within the industry and could be expanded to the following areas:

4.5 Future studies from work

- Modelling of other conventional mines based on the same methodology and statistical models for comparison on results for outlook energy usage.
 - Modelling of other mining methods based on the same methodology mentioned in the previous point.
 - Open pit along with board and pillar mining methods as done in the Coal environment.
 - Investor confidence in South African mining industry due to concerns as was mentioned in the report.
 - Required returns and applicable financial models that determine or encapsulates the investor requirements for mining in South Africa.
-