Demand Side Management opportunities for a typical South African cement plant

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ABSTRACT

The South African electrical system is under threat of supply shortage. This is because, in the last decade, the maximum electrical demand has been encroaching on the net maximum capacity and the reserve storage margin has become smaller. Eskom, the country's electricity utility, has implemented a demand side management (DSM) programme in an attempt to alleviate the threat. Investigations into demand side reductions have been encouraged by the utility in sectors with high electricity consumption, such as the cement industry. As part of the non-metallic minerals sector, it is responsible for 5% of the electrical consumption for the mining and industrial division of the country. It has also been estimated that by 2020 the sector will be ranked as fifth for energy savings potential. Therefore, there may be opportunities to reduce the power demand of cement plants thus assisting Eskom in reducing the country's electrical consumption. This can be done by implementing DSM programmes, such as energy efficiency and load management. This dissertation investigates the global opportunities for energy efficiency in cement plants and determines their feasibility for the South African cement industry. It also investigates the potential of a load-shifting scheme to reduce evening peak loads and save electrical costs. To evaluate DSM potential for an undisclosed South African cement plant, historical data on electrical consumption was used in a simulation programme which the author wrote. This was done to determine a possible load-shifting scheme which could be implemented to save costs and reduce peak-period demand. A pilot study was performed to evaluate how shifting the load of raw and cement mills would affect the production and electrical costs of the plant. Results showed that, although in theory there is good opportunity for cost savings, it is highly dependent on the reliability of the mills and the change in production demand. Therefore, load-shifting schemes have to be highly adaptable on a daily basis to shift load when possible.

PREFACE AND ACKNOWLEDGEMENTS

It is my hope that this dissertation motivates energy efficiency in the South African and global cement industry. Whoever wishes to increase their knowledge, continue research in the topic or implement the strategies, I wish you the best of success.

I would firstly like to thank my mom and dad, Essie and Dave, who have encouraged me and stood by me my entire life. Your support has made me believe I can achieve anything I put my mind and heart into.

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LIST OF SYMBOLS

Symbol	*Description*	*Unit*
Q	Energy consumption	kWh
S	Energy consumption ratio	
W	Tariff weighted average	R
w	Tariff	R
C	Cost savings	R
Subscript		
1	Peak period	
2	Off-peak	
3	Standard	

LIST OF ABBREVIATIONS

Acronym	
	Phrase
AC	Alternating current
AUC	Area under the curve
capex	Capital expenditure
CFL	Compact fluorescent lamp
CO_2	Carbon dioxide
DC	Direct current
DSM	Demand Side Management
ECO	Energy conservation opportunity
ESCO	Energy service company
GHG	Green house gases
ICEE	Industrial and Commercial Energy Efficiency
ICLM	Industrial and Commercial Load Management
INEP	Integrated National Electrification Programme
IRP	Integrated Resource Planning
M&V	Measurement and Verification
MDGs	Millennium Development Goals
O&M	Observation and maintenance
OH	Operating hours
opex	Operation expenditure
PCP	Power Conservation Programme
SCADA	Supervisory control and data acquisition
VFD	Variable frequency drive
VSD	Variable speed drive
VSK	Vertical shaft kiln
	Name
CM1	Cement mill 1
CM2	Cement mill 2
RM3	Raw mill 3
RM4	Raw mill 4

GLOSSARY

Object	*Description*
Cement	Cement is a bonding agent which hardens and binds building materials
Chalk	A soft, white, powdery limestone consisting of fossil shells
Clay	A natural earthy material that is plastic when wet
Concrete	A stone-like material used for various structural purposes, made by mixing cement and various aggregate
ESCO contract scope	The areas of focus during an ECSO investigation into DSM opportunities
Fly ash	Fine particles of ash of a solid fuel carried out of the flue of a furnace with the waste gases produced during combustion
Grout	A fine plaster used as a finishing coat
Mortar	Used as a bonding agent between bricks and stones
Prehomogenising pile	A stock pile where materials are mixed to an even consistency
Shale	A dark fine-grained rock formed by compression of successive layers of clay-rich sediment
Slag	A mixture of shale, clay, coal dust, and other mineral waste produced during coal mining
Stucco	Used in decorative mouldings on buildings

Chapter 1

Introduction to Study

1.1. Background: Electrical energy situation

It is said that the prime mover for economic growth and development of a country is its energy consumption (Alam, et al., 1991). Regarding this, the total energy used per capita is a measure for the standard of living or quality of life achieved in all communities (Sheffield, 1998). It has therefore been encouraged in modern society to consume available energy without constraint to achieve the highest quality of life.

As one looks at the global usage of non-renewable energy and the implications on the ecology, it is evident that present energy utilisation rates cannot be sustained without future consequences. This chapter investigates opportunities of energy saving programmes in South African industry to participate in lowering global energy consumption.

Global electricity usage trends

In terms of end use, electricity is the most efficient form of energy (Kim and Starr, 2000). It provides a means in achieving many of the basic needs of humans. With the natural progression of technology and the instinct to reproduce, people are forced to produce and consume an increasing amount of electricity to meet these needs.

The world population has increased considerably since the discovery of electricity in the 18th century. With an increase from 700 million in 1750 to 6.8 billion in 2009, and a projected estimate of 9.4 billion people by 2050, it is clear that humans are fast reaching alarming numbers (Matt, 2010).

This growing population along with the improvement of information technology, biotechnology, advanced manufacturing and other technologies will result in growth of global electrical demand (Kim and Starr, 2000). If the demand is to be supplied by renewable sources, it would allow for a sustainable future. Currently, however, it is projected that only 10% of required electricity by 2020 will be generated by renewable sources (Bozon et al., 2007).

Figure 1.1 illustrates the projected world net electricity generation by fuel. Renewable energy has seen an increase in development and application in recent years with a total of 30% of electrical generation investments made into renewable sources in 2009 (Bozon et al., 2007). Although this is promising for a sustainable future, the majority of the increase in demand is supported by non-renewable sources.

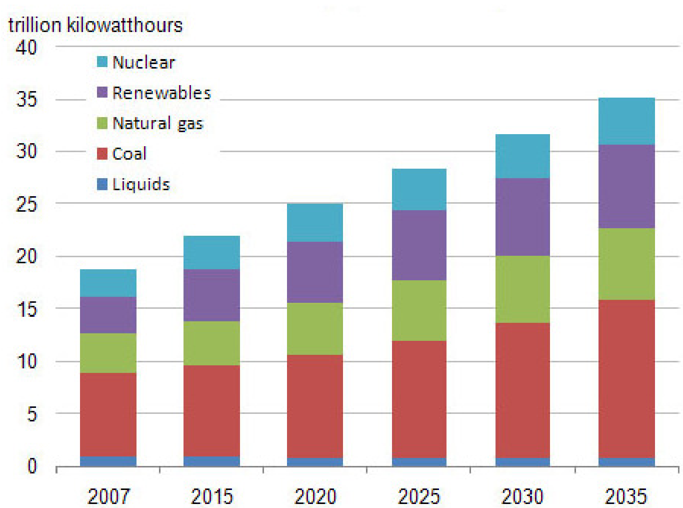

Figure 1.1-World net electricity generation by fuel; 1 trillion kilowatthours = 1×10^9 kWh (EIA, 2010)

Not only will the unprecedented consumption of these resources result in their eventual depletion, but the burning of fuel contributes considerably to the emission of green house gases (GHG) and ecological problems (IEA, 2009).

Carbon dioxide (CO_2) is among the greenhouse gases which cause global warming. Since the beginning of the industrial revolution, the burning of fossil fuels for energy has substantially increased the amount of CO_2 in the atmosphere. Energy production is responsible for 65% of global CO_2 emissions and is considered as a prime culprit in the global warming crisis (IEA, 2009).

With a dilemma between sustaining development, providing basic needs, and ecological degradation, there is a great need for improving the manner in which energy is created and used. This relies strongly on the strategies of both the consumer and the provider.

South African electricity situation

Eskom is the state-owned utility that provides South Africa with grid-electricity. It produces approximately 95% of electricity used in South Africa and 45% of electricity used in Africa through the Southern African Power Pool (Eskom, 2009).

In 2009 Eskom had a nominal generation capacity of 44 193 MW making it the largest producer of electricity in Africa and among the top seven utilities in the world in terms of generation capacity. Eskom was also among the top nine utilities in terms of electrical sales (Eskom, 2009).

Through the Integrated National Electrification Programme (INEP) of the Department of Minerals and Energy, Eskom has been committed to the electrification of households, clinics, and schools of previously disadvantaged communities. Since the beginning of the programme, approximately 4.9 million households, 163 clinics and 4957 schools have been electrified (DME, 2009).

As a result of such programmes, as well as the country's economic growth, South Africa's electrical demand has increased considerably in the last decade. Figure 1.2 illustrates this growth in comparison to maximum electrical generation capacity. As can be seen, the maximum demand has been encroaching on the net maximum capacity, while reserve storage margin has become smaller.

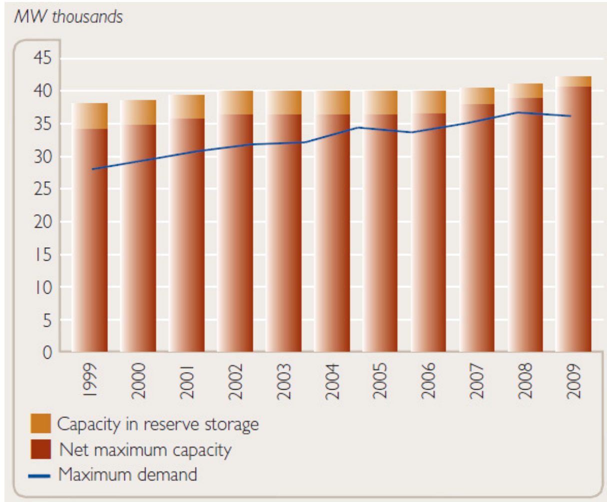

Figure 1.2-Generation plant capacity and maximum demand (Eskom, 2009)

In 2008 the consequence of operating a power system with a limited reserve margin was realised when Eskom was forced to introduce load shedding. This is the systematic interruption of electrical supply to different locations to reduce total demand. The electricity shortage was rotated between locations to ensure that not only a few areas bore the brunt of the impact. If the trend line in Figure 1.2 continues without intervention, electrical demand would begin to exceed maximum capacity and would result in a power system failure.

Many supply-side initiatives have been introduced by Eskom to assist in avoiding this under capacity in the future. Several of these measures, such as the re-commissioning of power stations, will possibly become operational only in 2012 (Eskom, 2009). Until then, a reduction in demand on the system needs to be achieved. A number of recovery and purchasing programmes have been undertaken to increase capacity and reduce the demand in the short term.

Eskom's new build and recovery programmes

Under the new build and recovery programme, Eskom aims to increase its supply-side capacity. This includes co-generation, the building of two open-cycle gas turbines and the reopening of three power stations that were "mothballed" in the 1990's (Eskom, 2009).

Co-generation is the encouragement of third parties to generate electricity for sale to the national grid. This includes the Pilot National Co-generators Programme and the Medium-Term Power Purchase Programme (Eskom, 2009). These resort under a power purchase agreement and cater for a wide variety of technologies and contribution sizes starting from 5 MW up to a total of 3000 MW (Eskom, 2009). Since the recommissioning of the mothballed power stations started in 2005, an additional capacity of 4,454 MW has been achieved, while the open-cycle gas turbines provide an additional 150 MW each (Eskom, 2009). All of these contributed significantly to the alleviation of the 2008 electricity shortage.

In response to immense electricity challenges experienced in January 2008, Eskom established a short term Stability and Recovery Programme (Eskom, 2009). This was divided into three phases; phase 1, was to stabilise the supply demand for electricity; phase 2 involves re-establishing an adequate reserve margin by managing demand; and phase 3 involves the plan to establish a sustained load reduction through the Power Conservation Programme (PCP) (Eskom, 2009).

Phases 1 and 2 of the recovery programme saw the introduction of load shedding. The impact of the limited supply caused a shift in electrical energy saving behaviour of South Africans. In promotion of this shift, national power alerts, such as shown in Figure 1.3, were aired on national television. This provided awareness among consumers and assisted in the recovery of the Eskom power system between January 2008 and October 2008 (Eskom, 2009).

Figure 1.3-National power alert (Eskom, 2009)

Phase 3 involved the introduction of Demand Side Management (DSM) in order to establish a sustainable reduction in load. This will be discussed in the following section.

Demand Side Management (DSM)

DSM is the programme by which Eskom aims to modify the electrical demand profile of the country. Through a comprehensive implementation of available electricity and supervision of customer use, it aims to reduce large "peaks" and "dips" in the electricity flow.

The typical daily demand profile for 2008 can be seen in Figure 1.4. The profile illustrates the large peaks and dips in concern for DSM. In times of peak electricity usage, between 19:00 and 21:00, Eskom needs the capacity to generate enough electricity to meet the needs of the consumers. However, when the peaks reduce, the load on some power stations have to be reduced dramatically before it has to be increased for the next peak. This is a complex control issue and an unwise utilisation of resources.

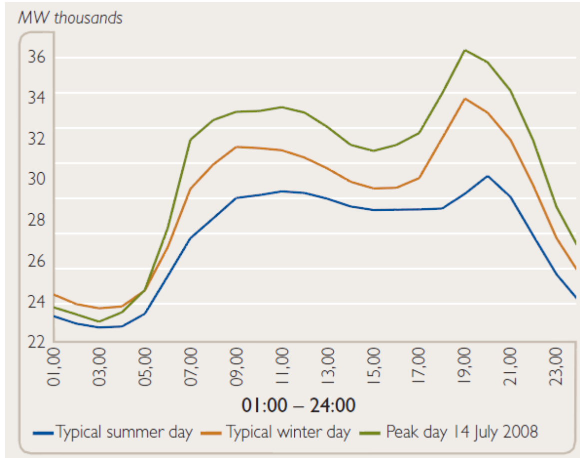

Figure 1.4-Electricity demand patterns, 14 July 2008 (Eskom, 2009)

Therefore, DSM aims to install energy-efficient technologies to reduce and alter the demand profile. In the short term, DSM provides a measure to reduce the severity of the peaks and reduce costs of expensive peaking plants. In the long run, it is an alternative to future extensive supply-side investments. DSM aims to achieve a reduction in peak demand of 3000 MW by March 2011 and a further 5000 MW by March 2026 (Eskom, 2009).

To achieve DSM objectives, attention is paid to the different sectors of the electricity market. The pie graph in Figure 1.5 illustrates the percentages of electricity usage per sector for 2008 (DME, 2008). The main contributors are the residential, commercial, mining and industrial sectors of South Africa and are therefore areas of focus.

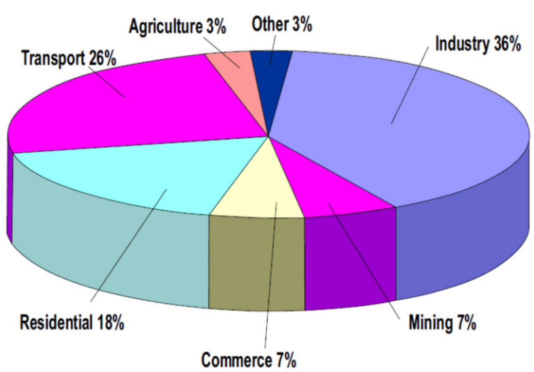

Figure 1.5 - Sectorial percentage market share on electricity in 2008 (DME, 2009)

The sensitivity of the market to the residential sector became evident when a 2% drop in demand was experienced in 2008 in reponse to the national power alert initiative (Eskom, 2009). Due to the increased awareness, it was possible to promote the installation of energy saving equipment in all sectors. It is speculated that many DSM initiatives have been initiating a culture of energy saving throughout South Africa.

Since implementation in 2003, the programme has exceeded performance targets. Figure 1.6 shows the cumulative performance and the improvement in demand savings in the last five years. The success of the initiative is further illustrated in Figure 1.2 as the maximum demand in 2009 was lower than that of 2008. This is also validated by the fact that no load shedding has been performed since May 2008 (Eskom, 2009).

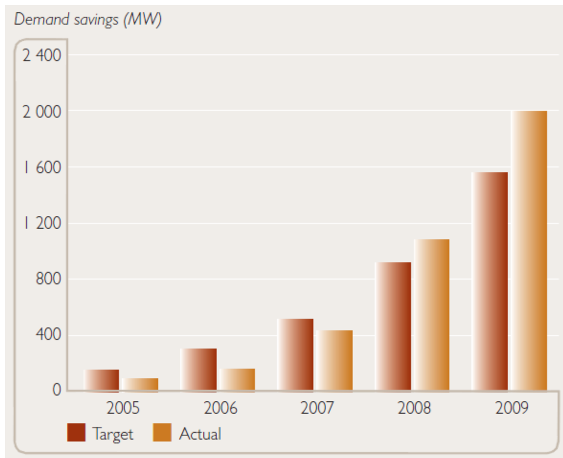

Figure 1.6 - DSM performance 2005 to 2009 (Eskom, 2009)

Given the success of DSM, it is logical to promote continued progression. Therefore Eskom provides incentives in the implementation of energy efficiency and energy saving strategies.

DSM motivation

An important incentive for Eskom is to fulfill its constitutional obligations to deliver socio-economic rights. This can be measured within the Millennium Development Goals (MDGs) (UN, 2008). One of the MDGs success indicators for delivering these rights is to achieve effective and equitable delivery of public services. This includes basic needs such as electricity.

Another indicator of the MDGs is to ensure environmental sustainablility (UN, 2008). Ninety per cent of electricity in South Africa is generated from coal, the most carbon-intensive of all fossil fuels (Tyler, et al., 2009). For every kWh of electricity generated, South Africa produces, on average, 0.843 kg of CO_2 (IEA, 2009). As a result, the electricity and heating sector contributes to 64% of carbon dioxide emissions in the country and currently contributes 1.2% to the total global CO_2

emissions (IEA, 2009). By reducing the demand for electricity and making provision for future efficiency, Eskom can reduce its carbon footprint in global industry.

Consumers experience the same incentive for preserving the environment. With increased awareness of global warming and green house gases, an increasing number of people are changing their lifestyles to save energy. This natural incentive for people will motivate and promote the energy efficiency that Eskom strives for.

In addition to global ecological preservation, financial incentives play a strong role in initiating energy efficiency. Increases above inflation were needed, by Eskom, to fund capacity expansion. As a result, the cost of electricity increased by 31.3% in 2009 and a further 24.8% in April 2010 (Lourens and Seria, 2010). This enormous increase made electricity a much more expensive commodity for South African consumers in comparison to previous years.

In addition to the overall increase, Eskom charges different tariffs at different times of the day to better reflect the costs of electricity generation for its larger customers. This is because additional peak-time generators are required during high consumption periods and are expensive to run, such as the open cycle gas turbines which operate on diesel fuel. The tariffs are higher during these times of peak demand and are further increased during winter periods when the demand is higher in general.

In response to the increase in cost, consumers are trying to use electricity more wisely to save money. This goes in hand with avoiding the prospect of load-shedding. After the 2008 load-shedding programme, South Africans were made aware of the consequences of reckless energy use, and as load-shedding is still a prospect until 2013, consumers are motivated into saving electricity to avoid further disruption by load-shedding.

As the attitudes of South Africans are directed towards electricity savings, the method by which they achieve it can be through DSM initiative programmes. Some of these are discussed in the following sections.

DSM initiatives in the residential sector

In many countries, an area highlighted to have significant potential for electrical savings is the domestic/residential sector (Clinch, 2001).

To reduce consumption in the residential sector, Eskom implemented a mass roll out of 19 million compact fluorescent lamps (CFL). This entailed the free exchange of incandescent light bulbs for CFL across the country, as they typically use five times less electricity. The programme contributed to 389.9 MW of savings in 2008 and implementation continued until May 2010 (Eskom, 2009).

In other DSM programmes aimed at the residential sector, Eskom encourages the spread of the energy burden to other sources of energy. Many campaigns and competitions have been run to promote the use of solar water heaters and liquid petroleum gas for cooking. Other initiatives included the implementation of efficient shower heads and smart electricity meters.

Due to the increased awareness of South Africans, business opportunities improved for companies that provide solutions to consumers looking to implement energy savings projects. Such corporations are known as energy service companies (ESCOs).

Energy service companies and their project scopes

ESCOs employ a form of outsourcing to design and implement energy savings projects for a broad range of comprehensive energy solutions. They can provide a cost effective route to overcome barriers in energy efficiency and DSM.

The ESCO analyses the consumer's property, creates an energy efficiency solution, installs the required equipment and maintains the system until the end of the contract or payback period. The risk of the project is transferred from the consumer to the ESCO while they reduce operating costs. This results in the production of valuable private energy saving projects in large industrial and commercial consumers (Eskom, 2009).

The scope of the ESCO contract is defined by what the customer requires in terms of technologies and systems. An illustration of such requirements can be seen in Figure 1.7. An ESCO can be involved in total energy management from the import of energy to the final end use, or only subsections of the system, such as a supply contract on the delivered energy or a performance contract on the energy service (Sorrell, 2007). This would determine to what degree savings are achievable and also the payback period of the contract.

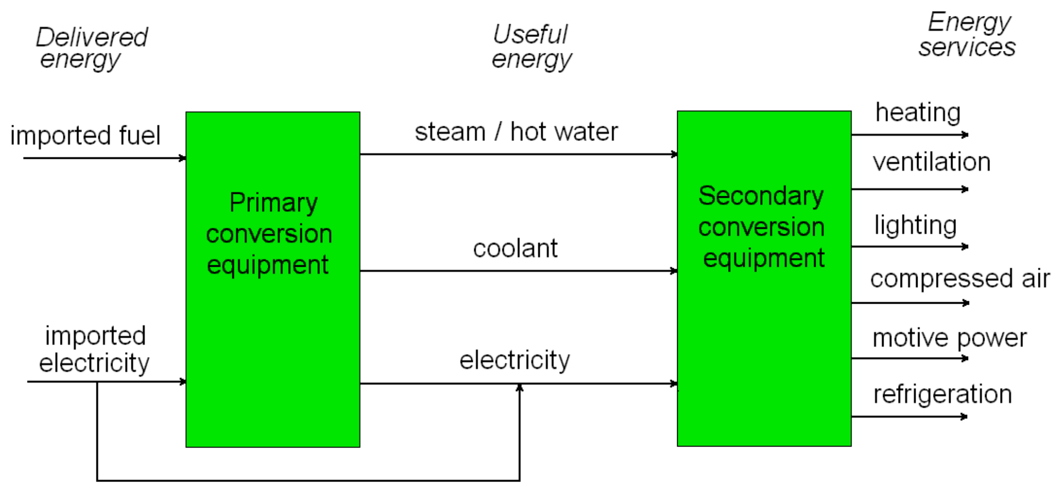

Figure 1.7-Scope of an energy service company. Adapted from Sorrell (2007)

DSM initiatives in industrial, commercial and mining sectors

The selling of DSM projects to consumers in the business sector may be difficult to achieve for ESCOs. This is because there is a low return on investment in terms of monthly electrical bill savings (Eskom, 2004a). Therefore, Eskom established the Industrial and Commercial Energy Efficiency (ICEE) and Load Management (ICLM) initiatives. These ensure that participants receive benefits from the installation of energy efficient technology and load management systems (Eskom, 2004b).

Energy efficiency aims at using less energy to achieve the same outcome as previously, thereby reducing overall electrical consumption. Load management projects help to reduce only peak time usage by either load-shifting or peak clipping. These spread the consumer electrical baseline more evenly over the daily demand profile or improve utilisation of cheaper off-peak tariffs (Orans, et al., 2010). Projects such as these are funded 100% by Eskom (Eskom, 2004b).

Eskom has agreed to fund, either partially or fully, the equipment that leads directly to energy reduction. This depends on the type of savings achieved. DSM is about saving MW's through load-shifting and MWh's through energy efficiency. This is the only deliverable for ESCOs and therefore the equipment that is installed is the means to achieve the saving targets (Eskom, 2004a).

Energy efficiency projects help to reduce the entire baseline of the consumer. Fifty per cent of the capital expenditure (capex) must be paid by the client benefiting from the equipment. Eskom covers the remaining capex, as well as 100% of operation expenditure (opex) and measurement and verification (M&V) costs (Eskom, 2004b).

After the installation of the equipment, the client assumes ownership of all assets and the ESCO is responsible for the maintenance of the project to ensure sustainability until the end of the useful life time of the project (Eskom, 2004b).

Through these DSM initiatives, Eskom can reduce the rate of increase in the carbon footprint due to South African electrical consumption. An improved generation capacity can then be projected. As a result DSM projects should be promoted and conducted for economical and ecological sustainability for both the country and the globe.

1.2. Motivation for this study

South Africa has large reserves of minerals which are found to be a primary source of energy and trade. For example, the country has 3.7% of the total world coal resources for 2010 (BP, 2010). In 2003 South Africa was the fifth largest coal producing country in the world, and was the fourth largest coal exporter (WCI, 2009). The industry is therefore dominated by large-scale minerals extraction and processing.

The energy intensive nature of this minerals extraction and processing results in large quantities of energy being used per unit of value produced. For this reason, a significant fraction of production costs is taken up by energy purchases. By reducing energy costs, industries are able to increase their profit and the financial incentives for conducting a DSM project are made apparent.

South African energy saving case study

To provide an example of the possible energy efficiency opportunities and their significant savings, the following case study is presented.

The Energy Research Institute of the University of Cape Town was approached by a non-disclosed South African manufacturing company to conduct an energy assessment. The assessment comprised of energy conservation opportunities (ECO) and their respective savings and payback periods (Fawkes, 2005). A summary of the assessment can be seen in Table 1.1.

Results showed that approximately R10.7 million could be saved per annum, amounting to 25% of total energy costs with a short payback period of the capital required of 0.82 years (Fawkes, 2005). This illustrates that there is enormous opportunity for energy savings should one consider an appropriate industry.

Table 1.1 - Energy conservation opportunities, with associated savings, implementation costs and payback periods (Fawkes, 2005)

Eco	*Description*	*Potential savings (R/year)*	*Implementation cost (R)*	*Payback period (years)*
1	Repair compressed air leaks and faulty blow-down valves to achieve 10% leakage targets	1 262 000	60 000	0.04
2	Avoid and discourage misuse of compressed air	263 189	30 000	0.11
3	Switch off compressors and maintain cooling towers during non-production time	268 075	0	0
4	Install suitable power factor correction equipment	516 690	1 007 500	2
5	Use waste heat to heat phosphate bath	190 000	300 000	1.58
6	Install high-efficiency lighting	179 803	628 198	3.4
7	Turn off bay lights during non-production hours	446 190	0	0
8	Install direct acting electric heaters to air replacement plants	4 355 536	4 000 000	0.92
9	Make use of heat pump heat recovery between air replacement plant exhaust and supply air streams	3 187 385	2 750 000	0.87
	Total	10 668 868	8 775 698	0.82

Determining the value of a DSM investigation

When an ESCO is approached to conduct an energy cost savings investigation, there is a need to establish whether the DSM project is worth the investment. Company features, such as market share, flexibility of production lines, ease of implementation, and others can be used to determine the potential of DSM interventions. Howells (2006) conducted a study to develop a ranking for industrial sectors according to these features. For the present study, the author was approached by a South African cement production company to conduct an energy cost savings investigation.

The classification of cement production resorts in the class of non-metallic minerals processing, along with brick making and others. Figure 1.8 illustrates the portions of electrical consumption in the industrial and mining sectors for 2003. As can be seen, non-metallic minerals processing holds a 5% share, and as a result is ranked as seventh for overall electrical consumption (Howells, 2006).

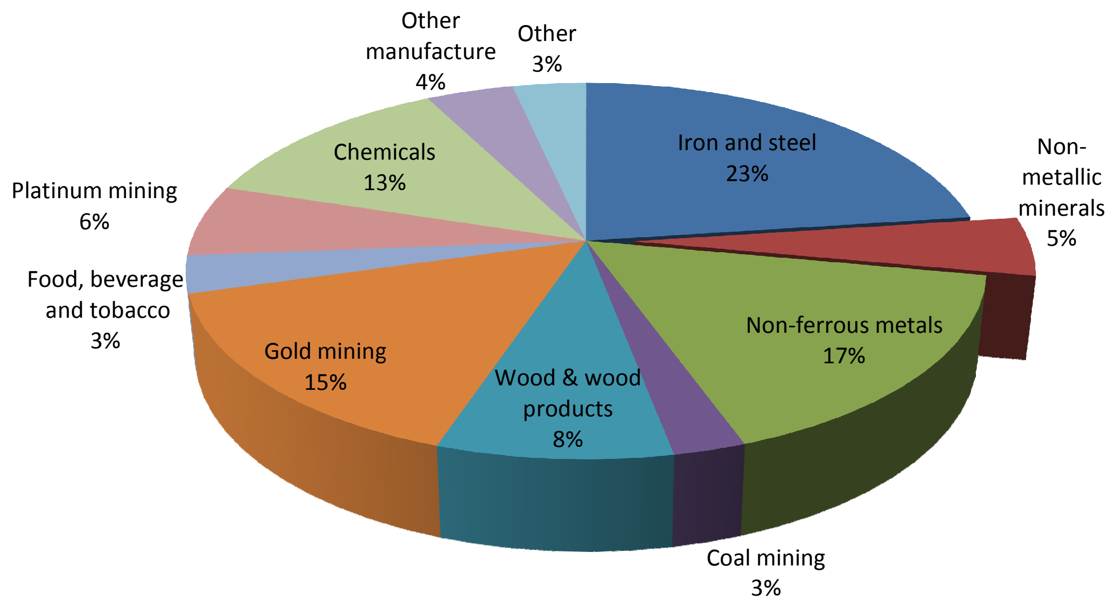

Figure 1.8 - Sectoral electricity consumption for 2003 (Adapted from: Howells, 2006)

Energy efficiency and load-shifting projects can have a lifetime of many years. As a result, the projected electrical consumption trend should also be considered in determining the validity of an investigation. In Howells' study, the non-metallic minerals sector was ranked 5th for growth in electrical demand with a 204% increase by 2020 relative to the 2003 total consumption of 12 017 GWh (Howells, 2006).

It is further possible to split the electrical consumption of each sector into percentages of their end-use. Table 1.2 provides information on typical percentages for the non-metallic minerals sector and, for a comparison, the two largest energy use sectors (namely non-ferrous metals, and iron and steel). As can be seen, the non-metallic sector is dominated by machine driven and compressed air processes. These are two of the top three ranked end-users for potential DSM savings, along with variable speed drives (Howells, 2006).

Table 1.2-Percentage usage of electricity by industrial sector (Adapted from: Howells, 2006)

	Non- metallic minerals (%)	*Iron and steel (%)*	*Non- ferrous metals (%)*
Process heating	8	39	1
Process cooling and refrigeration	0	1	0
Compressed air	14	8	0
Machine drive processes	72	40	2
Electrochemical process	0	2	95
Heating, ventilation and air-conditioning	3	3	1
Facility lighting	3	4	1
Other	0	2	0

Due to these indicators and others in Howells's study, the non-metallic minerals sector was classified as 8^{th} for DSM energy saving potential in 2003 and estimated as 5^{th} for 2020 (Howells, 2006). This shows that cement production belongs to a sector of industry that is worth investigating. To determine to what extent savings can be achieved, a closer inspection of cement plant energy consumption needs to be conducted.

Cement plant energy consumption

Cement plants can vary significantly in electrical consumption as they are influenced by plant capacity and function. This is because some plants are commissioned for completing only portions of the cement making process while others perform the entire production process from raw materials to cement.

South African cement plants can consume in the order of hundreds of megawatt hours per year with baselines ranging from 55 MWh to 194 MWh per year (Ottermann, 2010). In a typical cement plant, electricity accounts for 13% of all energy inputs but is responsible for almost 50% of the total energy costs (NRC, 2009). Cement companies can spend substantial amounts on electricity purchase and could benefit significantly from electrical cost reductions.

Overview of cement plant DSM opportunity

As stated previously, two methods of DSM cost savings can be used in the South African industry; energy efficiency and load management. By referring to the typical electrical end-use for a cement plant presented in Table 1.2, it is possible to establish general areas of focus for these methods to be applied.

As noted, the major portion of the electrical demand is taken by machine driven processes. In cement plants these are commonly involved in driving fans, crushers, mills, conveyors, compressors and turning kilns. This indicates, that should it be possible to implement a DSM programme to this one area of focus, it would provide great savings to the total electrical consumption of a plant.

Currently, electric motors and their associated systems account for 60% of South African electricity consumption (Eskom, 2008b). As this is recognised by Eskom, an Energy Efficient Motors Programme was initiated to create awareness of the impact motors can have on national electricity savings. Following this initiative it may be advantageous to investigate the improvement of energy efficiency of machine driven processes in the plant.

When considering this possibility, constraints have been presented by Hughes (2006) at an energy conference. He proposed that opportunity for improving motor efficiency in the cement industry is limited due to the specialised nature of the motors and the extremely dusty environment in which they operate. It is worthy to consider these perspectives and conduct further investigations into a particular cement plant to establish the limitations.

To determine whether the load management method of savings is possible, it is necessary to consider the basic processes of a cement plant. One needs to understand flow rates of materials, limitations of equipment, minimum production rates, quality constraints and many other aspects. This is to determine whether the production process provides flexibility during operating hours in which to apply load-shifting. For example: as in many non-metallic materials processing, the kiln is the slowest process of the cement making procedure. Therefore, there is a possibility to shift the electric motors' load before and after the kiln into periods with lower electrical tariffs, should the productivity of the kiln allow this. This would reduce peak time energy purchase and therefore reduce costs.

An investigation into these possibilities needs to be conducted to establish the availability for load management in the production and opportunity for energy efficiency of electric motors. Again referring to the end-use breakdown, other DSM opportunities may be found in compressed air management; heating processes; heating, ventilation, air conditioning; and lighting control. All of these could reduce electrical consumption of a plant should it be economically viable. These opportunities should be investigated to determine their validity and potential savings.

1.3. Objectives of the study

The primary objective for this study is to establish DSM opportunities within a typical South African cement plant. Specifically, energy efficiency opportunities relevant to the country's cement industry will be investigated. The work will focus on load-shifting in an attempt to reduce peak-time consumption and energy costs.

1.4. Scope of the study

Energy efficiency options in the cement industry will be investigated and the validity for the South African industry will be examined. The emphasis of the work will however be on energy management in the form of load-shifting.

To determine a viable load-shifting scheme, the study will optimise operating hours in typical cement plant mills. This is to reduce the amount of electricity consumption during Eskom's peak period while maintaining production rates and standard time consumption.

1.5. Layout of dissertation

Chapter 1 provides a background to the study. This includes an overview of the global and national electricity consumption problems and the environmental impact and, motivation and opportunities behind conducting DSM initiatives in the cement production industry.

Chapter 2 investigates the state-of-the-art in energy efficiency and cost saving opportunities at cement plants. Comparisons are made to establish viable options for typical South African cement plants.

Chapter 3 investigates the operation of a typical cement plant. Historical data on production is used in simulations to determine load-shifting options for the plant.

Chapter 4 provides results of a pilot study conducted on a plant with the load-shifting scheme developed in Chapter 3.

Chapter 5 concludes the study with recommendations for viable DSM opportunities for a typical South African cement plant.

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Chapter 2

Energy efficiency and load-shifting opportunities in the cement industry

2.1. South African cement production plants

To determine the opportunities in DSM savings within a cement plant, the cement making process needs to be understood. This chapter provides an overview of the cement making process in South Africa, including a description of equipment and the management skills involved.

The local industry will be compared with the global industry to establish where South Africa ranks within the growing international trend of energy savings and ecological impact reduction. By researching successful case studies of energy efficiency and load-shifting, both nationally and internationally, it can be determined whether similar projects can be applied to the cement plant under investigation.

Portland cement

Cement is a bonding agent which hardens and binds building materials. It is usually a fine grey powder and when mixed with water or other hydraulic material undergoes a chemical reaction. Over time the mixture "dries out" and hardens. Depending on the type of cement, the conditions under which the chemical reactions take place, can differ.

There are two types of cement: hydraulic, which is able to set under wet conditions, and non-hydraulic, which needs to remain dry in order to harden. An example of the hydraulic type is Portland cement and its various blends. The South African cement industry, which is currently accountable for 0.57% of the World's cement production, produces only Portland cement. It is commonly used around the globe for its general use in concrete, mortars, stucco and grout (Tatum, 2010).

Portland cement consists primarily of limestone and other additives. Depending on the purity of the limestone, secondary raw materials such as clay, chalk, shale, sand, iron ore and others may be added to meet production standards (Hassaan, 2001).

Wet or dry processes are used for the production of Portland cement depending on characteristics and availability of the raw materials used in the manufacture. Only the dry process is used in South Africa.

Dry process cement production

Figure 2.1 illustrates the basic process taken during the dry production of Portland cement, and will be briefly discussed.

Obtaining raw materials

Limestone is obtained from a mine or quarry usually situated close to the cement mill. It is then transported to a crusher where is it crushed to smaller segments approximately 50mm in size. If secondary raw material is needed, it is mixed together in a prehomogenising pile. To produce a good quality product and to maintain efficient combustion conditions in the kiln, it is crucial that the raw meal is completely homogenised.

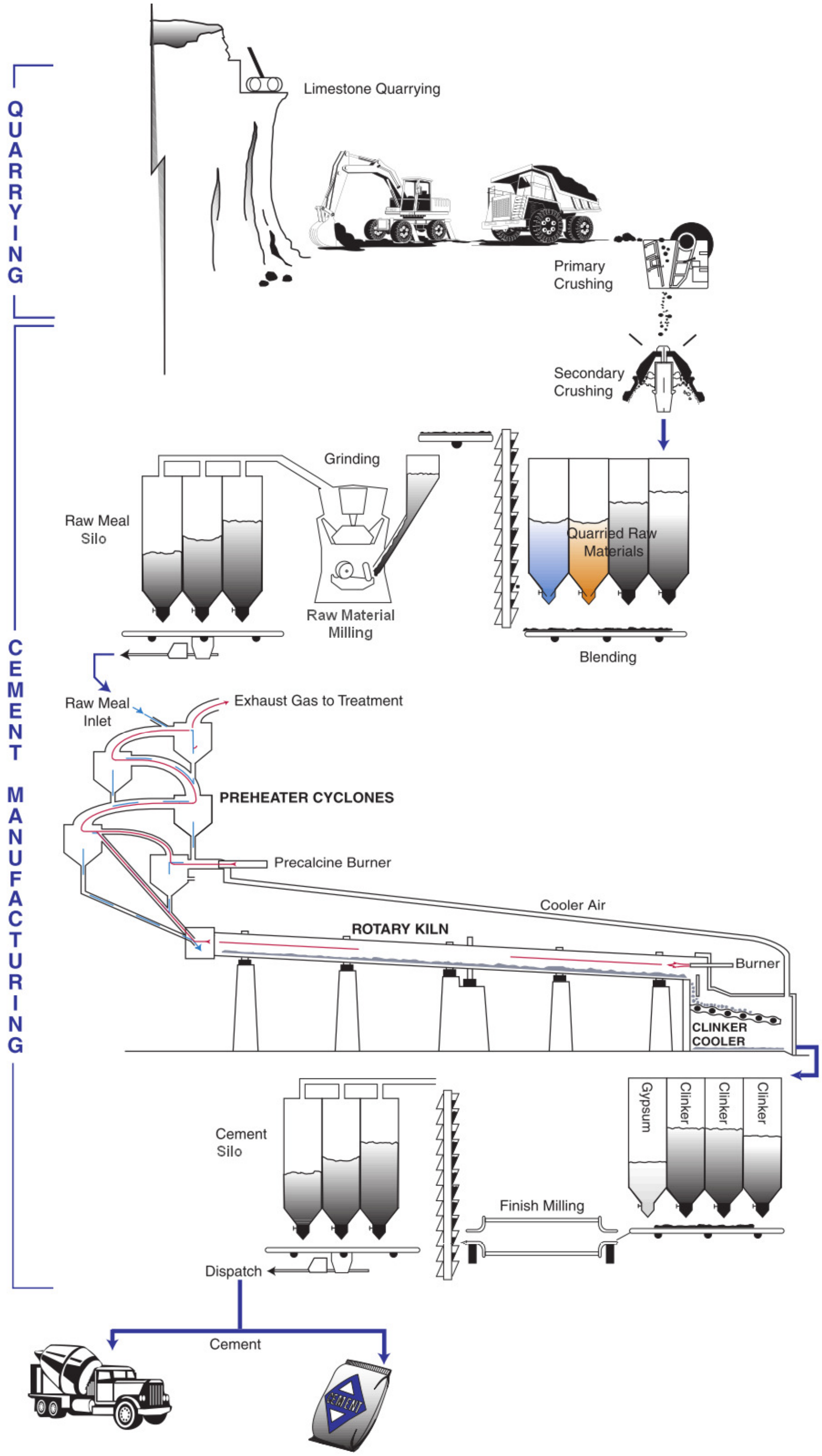


Figure 2.1 - Dry Process Cement Production. Adapted from Choate (2003)

Raw mill and silo

The raw materials are then ground together in a raw mill. This is to reduce particle size into a fine powder and form what is known as the raw meal. Four different types of mills may be used in this stage, which varies from one cement production company to the next. There are ball mills, consisting of a rotating horizontal cylinder partly filled with steel balls (NSI, 2010), vertical roller mills, using vertical spindles on a rotary table (Alstom, 2010), hammer mills, which implement a shaft mounted with hammers in a rotary drum (MS,2010), and high-pressure roll presses, which crushes material between two rollers (ALF-Cemind, 2010). Figure 2.2 illustrate these mills.

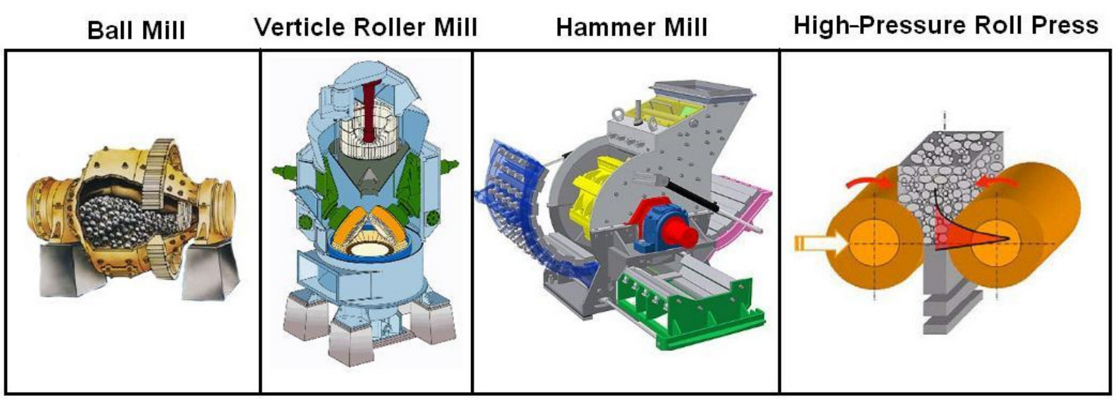


Figure 2.2 - Types of mills. Adapted from NSI (2010), Alstom (2010) MS (2010) and ALF-Cemind (2007)

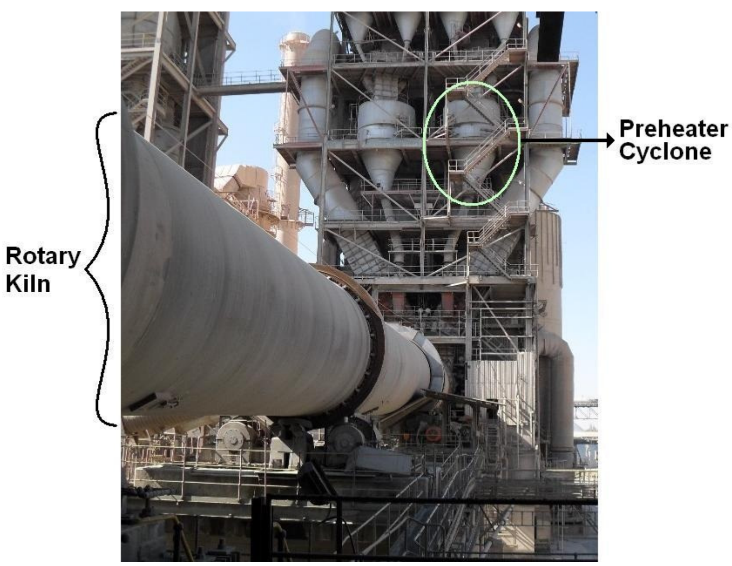
The material entering the mills may contain moisture and can form an undesirable mud as it is crushed. To avoid this, hot air is blown through the mill from either a furnace or as waste gases from the clinker kiln. This ensures that the raw meal created is in a dust-like composition.

Once a minimum particle size is reached it is possible for raw meal to pass through a particle size separator or classifier. Classifiers separate the finely ground particles from the coarse particles. The large particles are then recycled back to the mill. This can be achieved by, for example, blowing the lighter dust particles through a series of screens. It may also be separated and collected by an electrostatic precipitator, a device highly effective in filtration by means of an applied electrostatic charge (Q-filter, 2010). The raw meal is then stored in a silo where it is monitored to stay within a specified capacity level in the silo. It is then fed into the kiln.

Preheating

The exhaust of hot gases from the kiln can be used to preheat the raw meal. This is to evaporate any moisture that might have remained after the milling, or, that may have been absorbed from the atmosphere during storage. It is also used for the beginning process of sintering the raw meal. The material can be heated from 70°C to 800°C where de-carbonation can begin. This is where the limestone releases carbon dioxide in the process of forming clinker, the main compound of cement before it is ground (Wansbrough, 2008).

During this stage it is common to use gas-suspension cyclones. The hot air is drawn through a series of cyclones which create a vortex of air and raw meal. Due to centrifugal forces, the material is spun outwards and is separated from the air which travels upward to the atmospheric exhaust. During this spinning of gases and material, a great amount of heat transfer is achieved and the material is preheated before entering the kiln (Kolip, 2010). Figures 2.3 and 2.4 illustrate preheater cyclones in a production line followed by a rotary kiln.



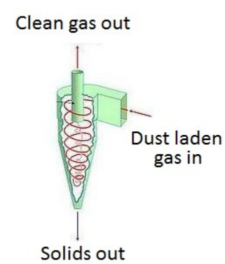


Figure 2.4 – Preheater cyclone (Wiki, 2010)

Figure 2.3 – Preheater cyclones and rotary kiln (at a typical South African cement plant)

Kiln, cooler and clinker silo

The kiln is a steel-plated cylinder lined with fire brick. A flame is emitted at one end while the raw meal is fed through the other. The kiln is mounted slightly angled to the horizontal and is made to slowly rotate about its longitudinal axis. The raw meal gradually moves down the kiln and begins to sinter (Wansbrough, 2008). Figure 2.5 shows a typical rotary kiln and its separate zones involved in the sintering process.

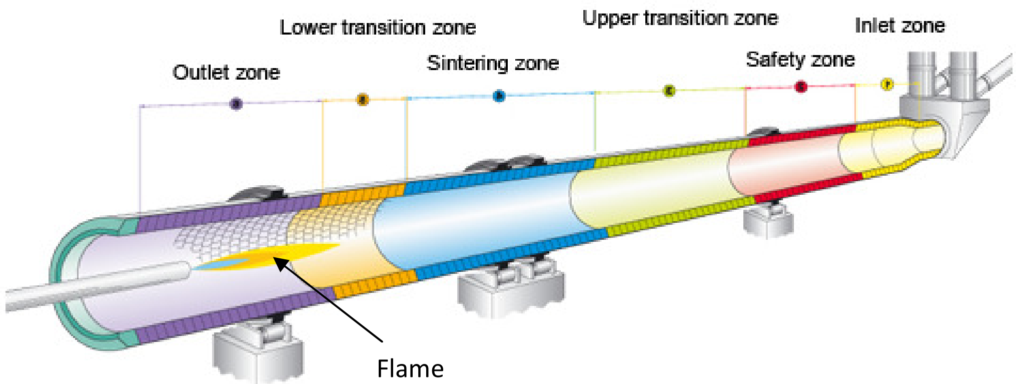


Figure 2.5 - Typical rotary kiln. Adapted from LWB (2008)

By burning specific fuels, the flame reaches temperatures as high as 1400°C (Sadeghian, 2009). Coal is the most widely used fuel in the cement industry. Fuels preparation is most often performed on-site by the crushing, grinding and drying of coal. This pulverised coal is injected through a nozzle and spontaneously ignites in the high temperatures. Another form of fuel is the burning of vehicle tyres and other waste that is fed into the kiln with conveyors.

When the material reaches the maximum temperature while rolling down the zones, chemical reactions take place between the partially decarbonised limestone and the secondary material. This now-fused material partially melts at the elevated temperature and aggregates to form nodules of sintered clinker, usually 3 to 25 mm in diameter (Wansbrough, 2008). A photograph of clinker can be seen in Figure 2.6.

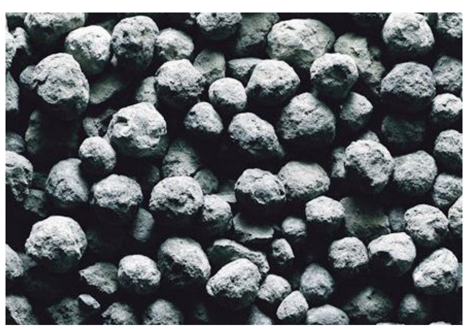


Figure 2.6- Clinker (Sheen, 2010)

When the nodules reach the end of the kiln after sintering is complete, they then fall into the coolers. For quality purposes the clinker needs to be cooled as quickly as possible. Different types of coolers have been used since mass production of cement began, such as air based rotary coolers and the satellite coolers that are attached to the kiln. As a result they need no extra drive and are therefore advantageous over stationary coolers. Due to their lower rate of cooling, however, they have been replaced by grate coolers (UNIDO, 1994).

A grate cooler houses perforated plates that are able to slide back and forth. This shuffles the clinker to the end of the cooler while air is blown through the perforated holes. The temperature of the clinker is reduced to 100°C before it is transported to a silo to be stored (UNIDO, 1994).

The sintering process in the kiln is usually the slowest stage of manufacture. Often the capacity of the kiln can determine the capacity of the plant. As a result, the kiln typically runs 24 hours, 7 days a week, and the levels of clinker are closely monitored in the silo.

Cement/finishing mill

The clinker is transported from the silo and combined with a small quantity of gypsum and fly ash. This is a material that retards the setting time of the cement. Quantities of gypsum and fly ash can determine the characteristics of the cement and can qualify different grades (Kavas, et al., 2005). In this final stage, the mixture is then ground together often using ball mills. As the mill drum rotates, steel balls cascade onto the clinker and gypsum. Usually different sized steel balls are used in succession and as the material passes through different chambers it is reduced gradually. This crushes and mixes the material into the fine grey powder known as cement (UNIDO, 1994).

Cement silos and packaging

Once the particles are fine enough to pass product standards they are removed and stored in cement silos. They are then packaged into cement bags or loaded for bulk transport in trucks or trains. The cement mill is directly related to the production rate of the cement plant and is therefore integral to the success of the plant.

To help maintain and control the processes around the plant, a supervisory control and data acquisition (SCADA) system can be used to monitor performance. Examples of information that could be captured by the system would be the flow rates of materials, motor power consumption, operating hours, kiln temperature, level of silos and others.

To evaluate where energy efficiency and load-shedding can be applied during the production process, one should comprehend processes which have a large demand for electricity.

2.2. Electrical consumption by department

Figure 2.7 illustrates the share of the electrical consumption by cement process departments. There are three dominant departments which make up 95% of the consumption (UNIDO, 1994). These are the finishing process, the clinker burning process and the raw material process. The finishing process largely comprises of the final grinding of the clinker and requires large electrical motors to run the cement mill. The power consumed by the mills depends on the surface area of the material and the fineness of the final product. It also depends strongly on the hardness of the material and the amount of additives required (BNL, 2005). This results in the use of the significant portion of electrical consumption by department, shown in Figure 2.7.

The clinker burning process requires not only large amounts of fuel to reach high temperatures in the kiln, but also the movement of large volumes of air. To ensure heat is transferred through the kiln and the preheater, electric motors are used to drive fans which create the movement of air and heat. Further to this, electric motors are also required for the slow rotation of the kiln.

The third department, the raw material process, requires the milling and drying of the raw material. This includes electric motors to drive the mills and the fans for grinding and heat transfer. Depending on the plant processes, it may also include motors responsible for running the limestone crushers.

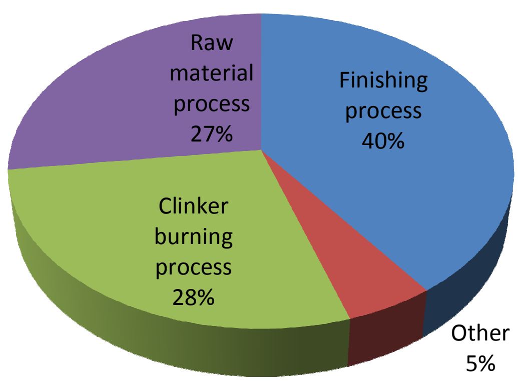


Figure 2.7- Ratio of electrical consumption by department (UNIDO, 1994)

2.3. Potential for energy efficiency

As an ESCO, one needs to establish a list of energy efficiency opportunities for the particular industry under investigation. To do this, the overall potential for the entire industry must be considered to determine which are applicable to a particular plant. Therefore a broad overview of opportunities for the dry cement making process will be considered.

Overall potential classification

Energy efficiency opportunities can be classified into three general categories (KEMA, 2005). These are listed below and brief examples for the cement industry are given:

1. High-efficiency equipment/processes - These involve modifications of major processes or equipment that are industry-specific and highly specialised. For a cement plant, some measures include: conversion of ball mills to roller mills for grinding, efficient materials transport systems, high-efficiency classifiers, conversion to more efficient kilns such as vertical precalciner kilns, variable speed drives (VSDs) for fans and other variable load drives, and improvements in compressed air system used to transport and mix material.
2. Controls - These present opportunities for improving process controls involved in, for example, clinker production and finish grinding, as well as operation of compressed air systems, and the shifting of electrical load.
3. Observation and maintenance (O&M) - O&M energy efficiency includes projects such as motor belt replacement, motor and bearing lubrication, fan blade cleaning, fan wheel balancing, and compressed air system maintenance.

Energy efficiency opportunities in the cement industry

For the first category, high-efficiency equipment/processes, Table 2.1 presents a list of plausible energy efficiency opportunities. These are established by a combination of case studies conducted for the cement industry worldwide (Hasanbeigi, et al., 2010a, b; Worrell, et al., 2000, 2008a, b; Price, et al., 2009; Choate, 2003). It includes the values of electricity savings potential and CO_2 reduction potential for two case studies in particular, Shandong Province, China (Hasanbeigi, et al., 2010b), and Thailand (Hasanbeigi, et al., 2010a).

The table lists opportunities for both major and minor changes in equipment and processes for a plant. For example, it includes the complete replacement of large machinery with higher efficiency models as well as the upgrade of subsystems. At a later stage, the relevance of each opportunity to the specific plant/s under investigation will be established.

Table 2.1- Electrical Efficiency Opportunities

Electricity-Saving Technologies and Measures	Electricity Saving Potential (GWh)	CO_2 Emission Reduction Potential (kt CO_2)	References*
Motors			
Adjustable Speed Drives	147.85	151.99	2, 5
High-efficiency motors	52.97	54.45	2, 5, 7
Efficient kiln drives	6.38	6.56	2, 3, 4
Variable Frequency Drive (VFD) in cooler fan of grate cooler	1.83	1.88	2, 5, 7
Variable Frequency Drive in raw mill vent fan	6.12	6.29	2, 5, 7
Adjustable speed drive for kiln fan	26.68	27.43	2, 5, 7
Installation of Variable Frequency Drive and replacement of coal mill bag dust collector's fan	1.53	1.57	2, 5, 7
Fans			
Replacement of preheater fan with high-efficiency fan	4.97	5.11	2, 5, 7
High efficiency fan for raw mill vent fan with inverter	7.23	7.44	2, 5, 7
Replacement of cement mill vent fan with high-efficiency fan	1.37	1.41	2, 5, 7
Fuel Preparation			
Efficient coal separator for fuel preparation	2.2	2.26	2, 5
Efficient roller mills for coal grinding	17.18	17.66	2, 3, 4, 5
Blending			
Raw meal blending system			3, 4, 6, 7
Grinding			
High-efficiency roller mill for raw material grinding	160.54	165.04	2, 3, 4, 6, 7
High-efficiency classifiers for raw mill	24.4	25.09	2, 7
Energy management and process control in finish grinding	34.98	35.96	2, 5, 6, 7
Improved finish grinding media for ball mills	11.72	12.04	2, 3, 4, 5, 6, 7
Replacing a ball mill with vertical roller mill	68.46	70.38	2, 5
High pressure roller press as pre-grinding to ball mill	181.2	186.27	2, 5, 7
High-efficiency classifiers for finish grinding	51.10	52.53	2, 3, 4, 5, 7
Preheating			
Low pressure drop cyclone for suspension preheater	39.32	40.42	2, 5, 7
Transport			
Efficient mechanical transport system for raw material preparation	8.51	8.75	2, 3, 4, 7
Bucket elevator for raw meal transport from raw mill to homogenising silos	2.3	1.2	1 , 7
Bucket elevators for kiln feed	1.2	0.6	1, 7
Power Generation			
Low-temperature waste heat recovery power generation	56.06	57.63	2, 5, 6
Preventable Maintenance	13.3	29.0	1, 3, 4, 7

* 1-(Hasanbeigi, et al., 2010a) 2-(Hasanbeigi, et al., 2010b) 3-(Worrell, et al., 2008a) 4-(Worrell, et al., 2008b) 5-(Price, et al., 2009) 6-(Choate, 2003) 7-(Worrell, et al., 2000)

To form an improved perspective of how these opportunities are applied in the cement making process, they can be considered at each dominant department as discussed previously. This will be considered along with opportunities from the other energy efficiency categories: O&M and controls.

Raw material process

1. Use of roller mills - It is customary to use ball mills for the grinding of the raw meal. These can be replaced by high-efficiency roller mills, ball mills combined with high-pressure roller presses, or vertical roller mills, to save energy without compromising quality. An additional advantage of the inline vertical roller mills is that they can combine raw material drying with the grinding process by using large quantities of low-grade waste heat from the kilns or clinker coolers (Worrell, et al., 2008a).
2. Raw meal process control – A problem exists with vertical roller mills tripping as a result of elevated vibration. Operation at high throughput makes manual vibration control difficult and the mill can trip. When it does so, it cannot be re-started until the motor windings cool down. A multivariable controller can manage total feed while maintaining a production target and keep within a safe range for trip-level vibration (Worrell, et al., 2008a).
3. Raw meal blending (homogenising) systems - To blend the raw meal, most plants use compressed air or use mechanical systems to agitate the powdered meal. A reduction in electrical consumption can be found by converting to gravity-type homogenising silos. In these silos, material funnels down one of many discharge points, where it is mixed in an inverted cone. Table 2.2 lists the relative electrical consumption of the types of blenders showing the large difference in demand (Fujimoto, 1993).

Table 2.2 - Comparison of homogenising systems (Fujimoto, 1993)

Homogenising system	kWh/ton of raw meal
Mechanical system	2.00 - 2.50
Air fluidised system	1.00 - 1.50
Gravity - inverted cone	0.25 - 0.50
Gravity - multi outlet	0.10 - 0.13

4. Efficient transport systems - Transport systems are required to convey powdered materials such as kiln feed, kiln dust, and finished cement throughout the plant. These materials are usually transported by means of either pneumatic or mechanical conveyors. Conversion to mechanical conveyors is cost-effective when replacement of conveyor systems is needed to increase reliability and reduce downtime (Worrell, et al., 2008a).
5. High-efficiency classifiers/separators - A recent development in efficient grinding technologies is the use of high-efficiency classifiers or separators. Standard classifiers may have a low separation efficiency, which leads to the recycling of fine particles, and results in extra power use in the grinding mill. High-efficiency classifiers can be used in both the raw materials mill and in the finish grinding mill (Worrell, et al., 2008a).

Clinker burning process

1. Adjustable speed drive for kiln fan - Adjustable or VSD for the kiln fan can result in reduced electrical use and reduced maintenance costs (Worrell, et al., 2008a).
2. Efficient kiln drives - A substantial amount of power is used to rotate the kiln. High efficiencies can be achieved using a single pinion drive with an air clutch and a synchronous motor (Regitz, 1996). Also, the use of alternating current (AC) motors is advocated to replace the traditionally used direct current (DC) drive. The AC motor system can result in 1.5% higher efficiencies (Holland, 2001).
3. Other energy-efficiency technologies and measures have great potential for overall energy savings. However, they do not have a direct influence on electricity demand. These include kiln combustion system improvements, reciprocating grate coolers, optimising heat recovery and upgrading the clinker cooler, seal replacement, low-temperature waste heat recovery for power generation, high-temperature waste heat recovery for power generation, multi-stage preheater/precalciner kiln and low pressure drop cyclones for suspension pre-heaters (Worrell, et al., 2008a).

Finishing process (Worrell, et al., 2008a)

1. Process control and management - Improved systems control can be implemented to monitor and maintain the flow in the cement mills and classifiers. This results in achieving a stable and high quality product while avoiding unnecessary electricity consumption.
2. Advanced grinding concepts - Energy efficiency is relatively low for ball mills in finish grinding. Several new mill concepts exist that can significantly reduce power consumption in the finish mill, including roller presses, roller mills, and roller presses used for pre-grinding in combination with ball mills. Roller mills employ a mix of compression and shearing to pressurise the material, where ball mills adopt specific feed charge and particle size. Both improve the grinding efficiency dramatically (Touil, et al., 2006). Today, high-pressure roller presses are most often used to expand the capacity of existing grinding mills, and are found especially in countries with high electricity costs or with poor power supply (Worrell, et al., 2008a).
3. Improved grinding media - Improved wear resistant materials can be installed for grinding media, especially in ball mills. Grinding media are usually selected according to the wear characteristics of the material as there is potential for reducing wear as well as energy consumption by increasing the ball charge distribution and surface hardness of grinding media (Choate, 2003).

4. High-efficiency classifiers - A recent development in efficient grinding technologies is the use of high-efficiency classifiers or separators which have great impact on improving product quality and reducing electricity consumption (Worrell, et al., 2008a).

Plant Wide Measures

1. Preventative maintenance - Preventative maintenance includes the training of personnel to be attentive to energy consumption and- efficiency. While many processes in cement production are primarily automated, there are still opportunities, requiring minimal training of employees, to increase energy savings.
2. High-efficiency motors and drives - Motors and drives are used throughout a cement plant to rotate the kiln, run fans, transport materials and grinding. In a typical cement plant, there can be 500-700 electric motors in operation, ranging from a few kW to MW-size (Vleuten, 1994). By improving control strategies, installing variable speed drives or high-efficiency motors, the power consumption of an entire plant can be reduced.
3. Compressed air systems - Compressed air systems are used for many different operations in the plant, for example in mixing and transporting material, dust collector filters, packaging and others. Total energy consumption by compressed air systems is relatively small in comparison to drive systems; however, it can amount to an unnecessary expense if the systems runs continuously and end-users are offline. In addition, compressed air is an expensive commodity for its poor efficiency; therefore management and maintenance systems can be implemented to minimise unnecessary expenses (Worrell, et al., 2008a).
4. Lighting – Energy efficiency in lighting can cost-effectively reduce energy consumption even though energy used for lighting in the cement industry is relatively low.

2.4. Priorities and barriers in DSM initiatives

Although there are great opportunities for energy efficiency and energy cost savings, one may ask why a cement company in particular might engage in the projects listed above. How important is energy efficiency to cement companies and what prevents them from embarking on such projects? By answering these questions, it would be possible to eliminate any inapplicable projects at a later stage.

By employing ESCOs, companies are looking to improve company performance. By taking on such measures, a cement plant can avoid future unnecessary costs, as well as governmental constraints. For example, vertical shaft kilns (VSK) have a poorer efficiency than rotary kilns and may contribute to unnecessary energy consumption (Cho, et al., 2007). In an attempt to enforce energy efficiency of the country's cement plants, an official Chinese government policy was adopted in 2006 to phase out VSK and completely replace them with more modern kilns (Hasanbeigi, et al., 2010b). However, in 2010 nearly 40% of China's cement plants still use VSK and the Chinese energy efficiency level compared to the global benchmark is relatively low (Hasanbeigi, et al., 2010b).

As a result, cement output in China became restricted in several provinces as they adopted electricity-use controls on cement producers from September to the end of December 2010. This is to fulfil their energy-saving goal of reducing energy consumption per gross domestic profit unit by 20% before the end of 2010. Because of this, some provinces, such as Guangxi, had to cut cement production by at least 50% and raise prices of cement by up to 30% (CC, 2010).

This would be detrimental to business and public relations. If more of the cement plants were able to adopt the energy efficiency opportunities discussed previously, energy consumption may have been lowered and such constraints may have been avoided.

In other cases, initiating electricity cost savings can be beneficial during economic recessions or market declines. For example, a boom in South African cement sales was experienced in 2007 as government invested in large infrastructure projects such as highways, the Gautrain, electricity plants and dams (Lourens, 2007). This is in addition to the preparations undertaken for the South African Fifa World Cup 2010, such as the construction of stadiums and airports (Mokopanele, 2010). Since then, however, due to the completion of many of the projects, the cement industries in South Africa have experienced a significant decline in sales (BD, 2010). The reduction in sales between January 2007and October 2010 is illustrated in Figure 2.8.

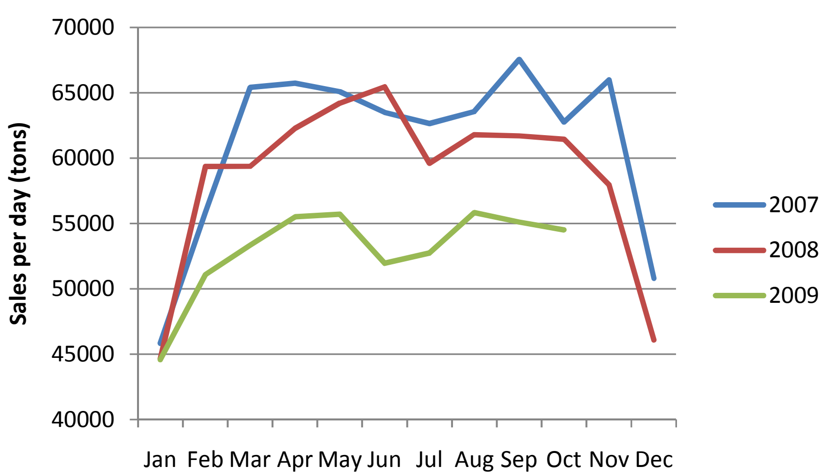


Figure 2.8- Monthly average daily sales of Portland cement in South Africa and neighbouring countries (CNCI, 2009)

The lower cement sales and higher electricity tariffs would most likely result in a desire for cement companies to maintain a competitive edge within the industry by increasing efficiency and reduce production costs. For these companies, participating in DSM projects becomes increasingly attractive.

Influential factors

When looking at the key factors to business success, many companies agree that these include: environmental regulations, market conditions, and energy costs (Worrell, et al., 2005). Internationally however, when rating key factors to company success, identifying and implementing cost saving measures falls low on the priority list, as can be seen Table 2.3.

Table 2.3 - Rated business factors (0=unimportant, 5=very important), (Worrell, et al., 2005)

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

With cost savings having such a low priority in key business factors, it would be extremely difficult to initiate any energy efficiency or power management programmes if there is a high level of deterrents. Considering this, there are several reasons why a company would avoid or be unenthusiastic about initiating any energy efficiency programmes. These include (Worrell, et al., 2005):

1. Limited capital - Energy-efficiency improvements in the cement industry involve large capital investments. Limited capital availability will be key factor in limiting increases in energy efficiency.
2. Production concerns - A high priority in cement making is keeping equipment operating and avoiding production disruptions. Therefore any activity that changes the present successful production processes will be accepted with difficulty. Additionally, some equipment may be

damaged from recurring stoppages, such as stresses in the ceramic insulation of the kiln during shutdown.

3. Limited staff time - implementing energy efficiency may require additional staff and staff time. This will not be a priority over keeping production running.
4. Information - Information on energy-efficiency improvements is readily available. However it may be time consuming to focus on the information and to make decisions.
5. Reliability concerns - Maintaining production is a high priority, therefore, cement making companies may be concerned about the reliability of all new equipment.
6. Inconvenience - if staff time is limited, smaller energy-efficiency projects are not pursued because they “are not worth the trouble.”

There may also be deterrents against a company working with an ESCO. These are (Worrell, et al., 2005):

1. Short programme period - It can take three to five years for customers to develop and implement a project. The time period may interfere with other plant plans or operations.
2. Limited incentives - many of the cement plant projects cost hundreds of millions of Rand. Projects saving a few million Rand may not provide enough incentive.
3. M&V (measurement and verification) requirements - many M&V requirements have favoured equipment change outs, where pre and post equipment efficiencies are easy to measure. Projects that require more “holistic” measurement, and which affect energy use of an entire system, are harder to justify savings and thus have limited acceptance.
4. Program administration: The collaboration with Eskom may deter companies from participation in DSM projects as the protocol is time consuming and a burden on customer staff.

The above adversely affect the validity of energy efficiency opportunities. They can determine whether taking on an endeavour would be feasible. An evaluation process can help to establish which opportunities are feasible.

2.5. Evaluating validity of opportunities

Three steps can be taken to evaluate the validity of an energy efficiency project. The steps can be classified as follows: intuitive screening, preliminary screening, and an integrated approach (Boake, 2003).

Intuitive screening: this is a basic evaluation of the cost-effectiveness of a programme. Straightforward calculations are done for benchmark comparisons, such as the cost of equipment compared against the marginal capacity costs saved from an "average" programme.

Preliminary screening: the expected cost savings of the DSM programmes are calculated and compared to the supply-side alternatives. The supply-side alternatives would be considered as the least expensive option to generate additional energy at various times of the day and year, and the least expensive option needed if the load were to grow. Should the savings outweigh the alternatives, then the programme can progress to the next evaluation step.

Integrated approach: This is called the Integrated Resource Planning (IRP) approach where new energy resource alternatives are considered in comparison to new generating capacity, power purchase, cogeneration, energy conservation and efficiency, renewable energy sources and heating/cooling applications to provide a consumer with reliable electricity at the lowest possible cost.

Using these steps, it is possible to reject energy efficiency projects which will not greatly benefit a plant overall. An ESCO can use such an evaluation process to establish a scope for any endeavours taken at a plant.

2.6. Scope of ESCO contracts for the cement industry

After intuitive screening, it is possible to determine the preliminary energy efficiency options in the cement industry. Thereafter, an ESCO contract scope, such as discussed in Chapter 1, can be determined.

For example, the efficiency in fuel preparation and power generation would resort under a supply contract, and would cover the scope represented in Figure 2.9. Another example would be for the performance contract regime, shown in Figure 2.10. This is where there is an investigation into electricity efficiencies, such as replacing ball mills with vertical roller mills, kiln waste gas heat recovery and replacing pneumatic transport systems with bucket elevators.

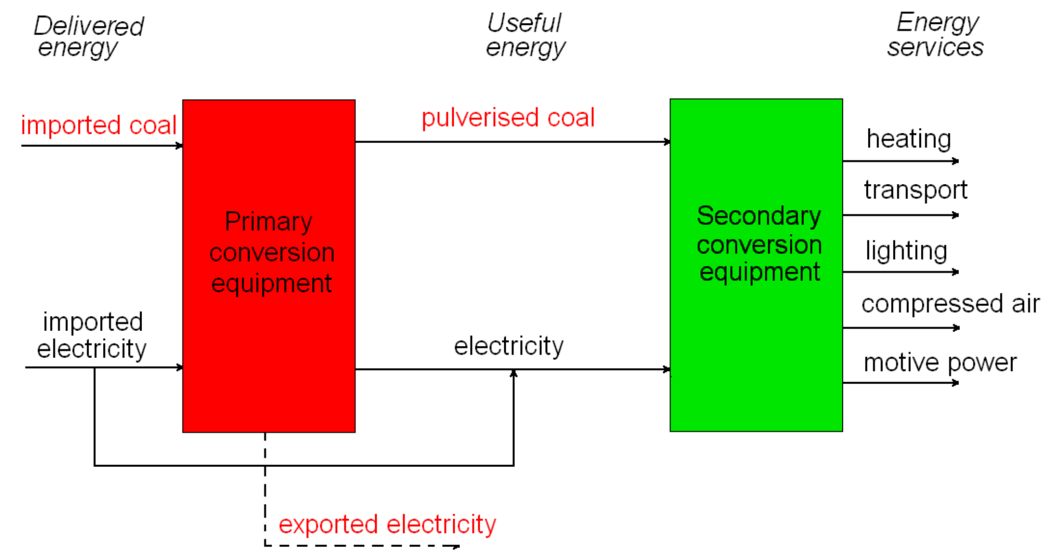


Figure 2.9- ESCO supply contract for the cement industry. Red indicates the covered scope of the contract. Adapted from Sorrell (2010)

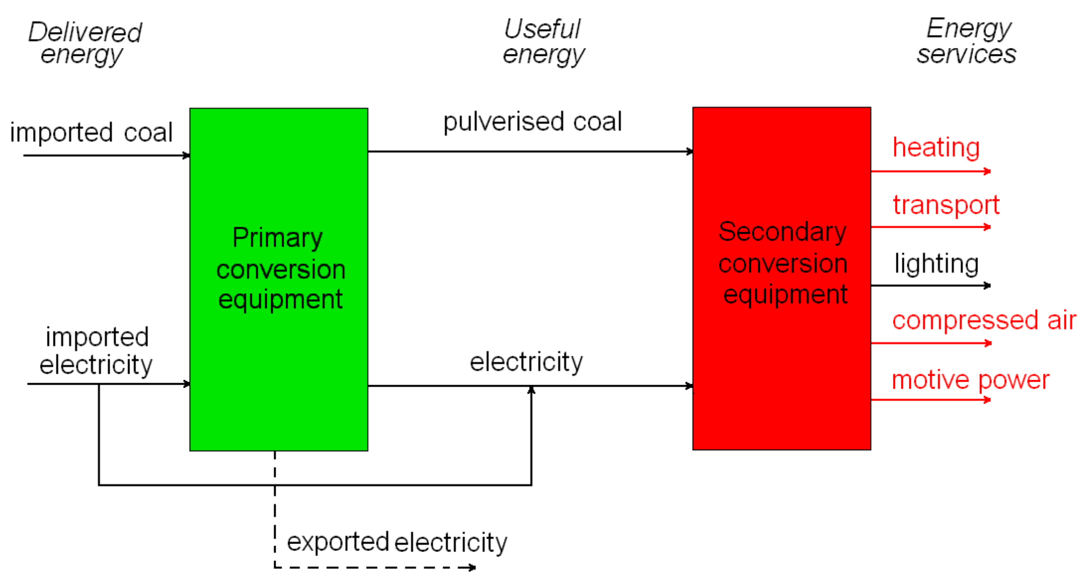


Figure 2.10 - DSM performance contract for the cement industry. Red indicates the covered scope of the contract. Adapted from Sorrell (2010)

To create such an ESCO contract scope for a specific plant, an evaluation of energy efficiency and load-shifting opportunities should be conducted. These provide an area of focus for a further investigation into cost saving possibilities.

2.7. Conclusion

Studies show that there are several opportunities for energy efficiency within the cement industry. The potentially positive impact on cement plants has been recognised in international plants, and in some cases it has been implemented.

Such programmes are beneficial to companies as they reduce production costs and therefore improve company performance. This can be advantageous when experiencing negative present affairs such as a reduction in sales, economic recessions and electrical power constraints.

To realise energy efficiency and load-shifting programmes, it is necessary to overcome their barriers and deterrents. This will help determine which opportunities are viable for a specific plant.

It is probable that such savings can be reaped for the typical South African cement plant. The following chapter uses this chapter's discussion and techniques to determine a feasible scope for the plant under investigation. The plant is evaluated by considering the installed equipment, production rates, plant layout, material flow, equipment reliability, planned maintenance and other factors.

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Chapter 3

Evaluation and simulation of a typical South African cement plant

3.1. The cement plant under investigation

This chapter provides information on the cement plant under investigation. A completed questionnaire and SCADA data from production lines are used to determine feasible energy efficiency opportunities for the plant. As the particular plant represents a typical cement plant in South Africa, the same procedure can be applied across the country to determine the energy saving possibilities.

As confidentiality of the plant will be respected, the name and location of the plant will remain anonymous. It will therefore be referred to as the "plant under investigation" for the remainder of the study.

Plant information

The questionnaire, found in Appendix A, requested information on the layout and equipment of the plant under investigation. The plant has three production lines; however, with the reduction in cement sales, only two of the production lines are in operation at present.

Table 3.1 provides information on the equipment used on the plant, while Figure 3.1 illustrates the layout of these production lines. The clinker production lines run in parallel and are joined at the clinker silo. Thereafter, clinker and fly ash are fed into two adjacent cement mills.

Table 3.1- Specification of the cement plant under investigation

Equipment	Description
Raw mill	2 x ball mill Dried by kiln waste gases
Transport of raw meal	Compressed air / pneumatics
Raw meal particle separator	Electrostatic particle separator
Preheater	Low-pressure drop cyclones
Kiln	Rotary kiln with grate cooler, one kiln has fan VSD
Cement mill	2 x ball mill with a roller press crusher
Cement particle separator	High-efficiency dynamic classifier

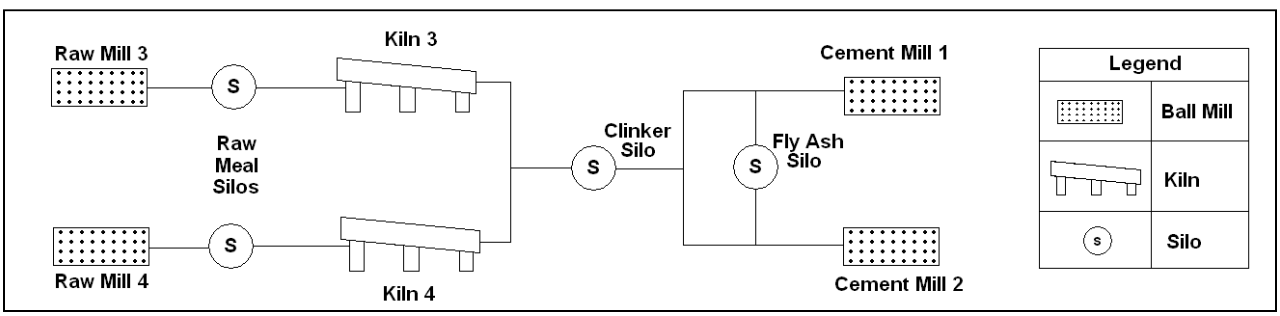

Figure 3.1 - Plant layout

Energy efficiency opportunities

With this basic knowledge of the plant, energy efficiency opportunities become immediately apparent, such as the replacement of the ball mills with vertical roller mills. Table 3.2 lists the benchmark opportunities discussed in Chapter 2 to compare with the cement plant under investigation. It provides results from an intuitive screening of each option and an example of a deterrent if the option is declared as unfeasible.

Table 3.2 - Feasibility of energy efficiency opportunities for the plant under investigation, green shade represents feasible options.

Electricity-Saving Technologies and Measures	Intuitive screening	Motive
Motors		
Adjustable speed drives	Feasible	Low inconvenience with replacement of small motors, wide scope
High-efficiency motors	Not feasible	Highly specialised, limited capital
Efficient kiln drives	Not feasible	Production concerns
Variable frequency drive (VFD) in cooler fan of grate cooler	Done	
Variable frequency drive in raw mill vent fan	Feasible	Low inconvenience, improved control
Adjustable speed drive for kiln fan	Done	
Installation of Variable Frequency Drive and replacement of coal mill bag dust collector's fan	Not feasible	Upgrade in coal mill will result in a shutdown of production
Fans		
Replacement of preheater fan with high efficiency fan	Done	
High efficiency fan for raw mill vent fan with inverter	Feasible	Low inconvenience, lower capex
Replacement of cement mill vent fan with high-efficiency fan	Feasible	Low inconvenience, lower capex
Fuel Preparation		
Efficient coal separator for fuel preparation	Not feasible	Upgrade in coal mill will result in a shutdown of production
Efficient roller mills for coal grinding	Done	
Blending		
Gravity type raw meal blending system	Done	
Grinding		
High-efficiency roller mill for raw material grinding	Not feasible	Limited capital
High-efficiency classifiers for raw mill	Done	
Energy management and process control in finish grinding	Feasible	Low inconvenience, lower capex
Improved finish grinding media for ball mills	Done	
Replacing a ball mill with vertical roller mill	Not feasible	Limited capital
High pressure roller press as pre-grinding to ball mill	Done	
High-efficiency classifiers for finish grinding	Done	
Preheating		
Low pressure drop cyclone for suspension preheater	Done	
Transport		
Efficient mechanical transport system for raw material preparation	Done	
Bucket elevator for raw meal transport from raw mill to homogenising silos	Not Feasible	Limited capital, Production concerns
Bucket elevators for kiln feed	Not Feasible	Limited capital, Production concerns
Power Generation		
Low-temperature waste heat recovery power generation	Not Feasible	Limited capital
Preventative Maintenance		

As can be seen, the plant under investigation has already implemented 11 out of 16 of the energy efficiency opportunities listed in the study. This indicates that this particular plant is energy savings conscious and could most likely benchmark against the case study cement plants used to compile the energy efficiency opportunity list in Chapter 2.

Several of the options were declared "not feasible" due to their high costs or to the disturbance in production caused during implementation. The feasible options should be investigated for further energy efficiency improvements in the plant. An ESCO contract block diagram can be used to illustrate such an investigation as done in Chapter 1 and 2. This is illustrated in Figure 3.2.

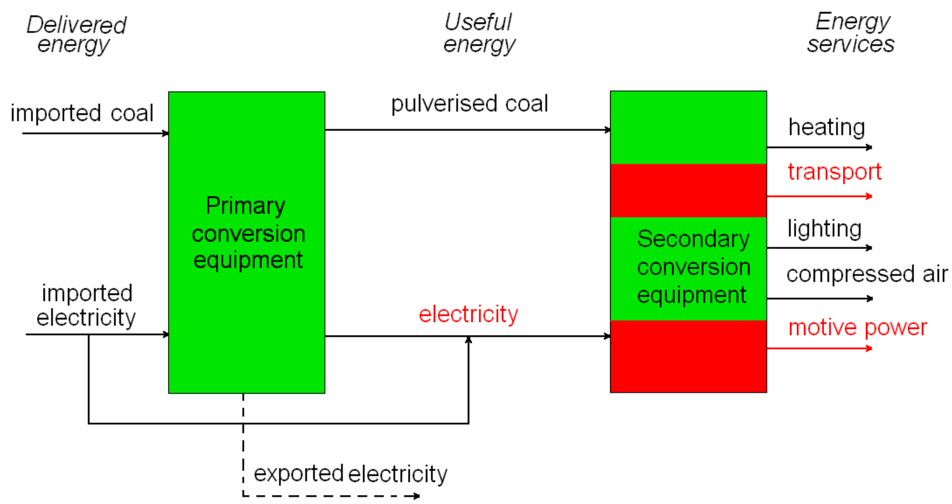

Figure 3.2 - DSM performance contract for the cement plant under investigation. Red indicates the covered scope of the contract. Adapted from Sorrell (2010)

Figure 3.2 is derived from the feasible energy efficiency options listed in Table 3.2. Installing variable speed drives would improve the energy efficiency of the cement plant's motive power; the high-efficiency fans would improve transport; and the energy management and process controls would improve the energy logistics of the useful energy. An investigation into such a contract however falls outside the scope of the present study.

Load-shifting opportunities

This study will, however, perform detailed investigations into the possibilities of load-shifting for the plant under investigation. This is because such an energy management scheme can be implemented without requiring large-scale equipment replacement or capital expenditure, therefore avoiding two deterrents of energy efficiency. The opportunities can also be readily evaluated by studying historical data and then modified for a specific plant.

There is a significant potential in realising electrical cost savings by implementing energy management, as proven in a benchmarking study of Canadian cement plants (NRC, 2009). Four of the five plants that were rated highest in energy management potential were also ranked the highest in cost savings and energy efficiencies initiatives. Although the energy management had no impact on changing their energy efficiency rating, the plants benefited greatly from such a programme and were able to improve cost savings.

As mentioned in Chapter 1, the load-shifting opportunities can be found in the layout of the plant and the flow rates of the equipment. The flow rates of the raw mills, cement mills and kilns are listed in Table 3.3. These were determined by averaging a daily record of the equipment performance over a period of three months, 1 May to 31 July 2010. The record can be found in Appendix B.

Table 3.3 - Plant flow rates

	Flow rate t/h
Raw mill 3	240
Raw mill 4	150
Kiln 3	120
Kiln 4	80
Cement mill 1	130
Cement mill 2	180

As can be seen in the table, the rates of the mills are much higher than those of the kilns. Therefore, the kiln, which operates 24 hours a day, determines the maximum production rate of the plant. It is possible to use the silos as a buffer to store enough material while shifting the load of the mills. The mill motors can be shut down and started up again within minutes, allowing for a dynamic operating plan (Paulus and Borggrefe, 2011). The load shifting scheme will adapt a plan to shut down the mills in a manner which will help the plant benefit the most from a reduction in electrical costs. This is as opposed to the standard practise of shutting them down only once the silos have reached their maximum capacities.

The number of hours for shutdown may be limited however, as production is dependent on upstream and downstream processes. The raw meal silo will have to be filled to a level where it can provide a continuous feed into the kiln while the raw mill is turned off. The clinker silo can be allowed to fill with clinker while the cement mills are also not running. The mills can then be operated during off-peak periods to replenish the raw material and extract clinker. Relying on storage capacities may bring production near to its technical limits (Paulus and Borggrefe, 2011); however the downtime can be planned to keep silo levels within their minimum and maximum capacities. This will allow shutdown during the peak period of the day to minimise the use during this period.

The load-shifting scheme does not contribute towards energy efficiency. This is because the total electrical usage for the day remains the same. Although less electricity is used during peak periods, more is used during off-peak periods, thereby giving the associated name of load-shift. This scheme uses the different tariffs charged by Eskom to achieve energy cost savings.

The scope of the load-shifting investigation does not include the coal mills of the plant. Although the coal mills have a higher flow rate than is required by the kiln, and a hopper is available as a material buffer, it is preferred not to shut down the coal mills. This is because hot waste gases from the kiln are drawn through the coal mill to, first, dry out the coal, and second, heat up the pulverised coal that flows into the kiln for combustion. As the air is circulated, it draws with it large amounts of coal dust from the mill which form part of the coal volume that is ignited. If the coal mill is stopped, then less coal dust is used and the coal hopper feed has to increase, and storage levels are depleted at a higher rate. Because of this, cement plant managers prefer not to load-shift coal mills (Human, 2010).

In addition to this, a concern is raised about controlling the temperature of the cement mills during load-shifting programmes. If milling temperature is too low, a change in chemical processes can cause the cement to gain properties of "flash set" - an irreversible stiffening of cement mix (Maltese, et al., 2007). Therefore, when shutting down the mill during peak periods, the mill may cool to an undesirable temperature and affect the quality of the cement. The setting quality of the cement can be accommodated. However, the extra inconvenience results in managers of cement plants to be less inclined to take part in cement mill load-shifting (Human, 2010). Regardless, an investigation into cement mill load-shifting opportunities will be included in the study.

3.2. Baselines

A power consumption baseline is used to calculate how equipment is operated over a 24-hour period. Average electrical consumption per hour can be plotted to establish a usage profile. This provides insight into how often a motor is used and for what period of time.

If the profile shows the motor operates on average almost constantly for 24 hours, there will be no opportunity to load-shift. However, if the motor is operated moderately and evenly throughout the day, there is good potential to load-shift.

Only the baselines for the mill motors are determined as they are being investigated for load-shifting. Although the kiln utilises electrical motors to rotate, these will not be investigated as the kiln operates 24-hrs a day and cannot be shut down during peak periods.

Therefore to gain such insight, data on each mill motor was obtained for a period of three months, from 1 May to 31 July 2010. The month of May resorts under Eskom’s “summer tariff”, where June and July are in the “winter tariff” period. By including both seasons, a level of conservatism with respect to the seasonal change is maintained for the study.

The DSM programme is only concerned with the demand profile during weekdays. Therefore, weekends and public holidays were removed from the data collection to create the mill motor baselines.

In cement production, the breakdown of upstream or downstream equipment could subsequently result in the shutdown of a mill. Stoppage records for each mill for the time period were examined to eliminate data which could unrealistically lower the electrical load profile of a motor. For example, if a raw mill was shut down for a prolonged period of time due to the stoppage of the kiln, data would not reflect the standard usage of that mill. Therefore the days of non-production were excluded.

After removal of this data, the number of days with viable data for each mill is shown in Table 3.4. The type of data used to create the baselines is also listed in Table 3.4, as well as the mill motor operating capacities.

As a result of different SCADA systems available for the study, the type of data used for raw mill 3 is different from the other mills. Although the different types of data do not affect the accuracy of the baselines, it does determine the method in which they are developed.

Table 3.4- Mill motor data and operating capacity

Motor	Number of days (1 May – 31 July 2010)	Data type	Operating capacity (MW)
Raw mill 3	46	Stoppage records	4
Raw mill 4	55	Power consumption	3.2
Cement mill 1	47	Power consumption	3.5
Cement mill 2	47	Power consumption	3.8

The method for obtaining a baseline from power consumption data is to average the hourly values obtained from the SCADA records. The hourly average of power usage over a 24-hour profile produces the magnitude and profile of the baseline. This method was used for determining baselines for raw mill 4 (RM4), cement mill 1 (CM1) and cement mill 2 (CM2).

The baseline for raw mill 3 (RM3) was calculated using the method of stoppage records. By averaging the number of times the mill was operated during each hour, a percentage usage throughout the day is calculated. If the percentages are multiplied by the operating capacity of the motor, a power consumption baseline is produced.

Figures 3.3a to 3.3d provide the baselines of the four mill motors. Take note of the profiles of the power consumption baselines. Because the profiles show no deviation greater than 30% during the peak periods, it is evident that no load-shifting scheme has been implemented.

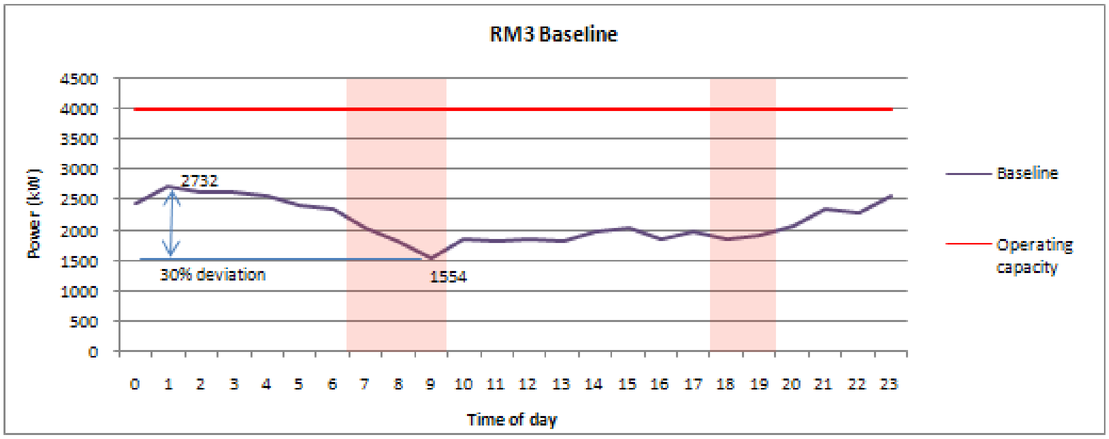

Figure 3.3a – Raw mill 3 baseline, 1 May – 31 July 2010, shaded area represents peak period, 3 data labels represent maximum value, minimum value and percentage deviation of baseline

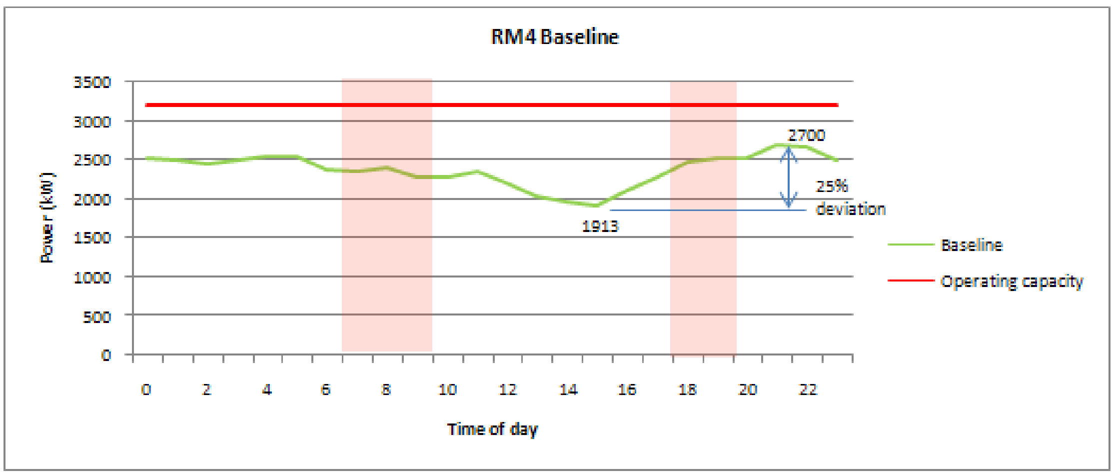

Figure 3.3b – Raw mill 4 baseline

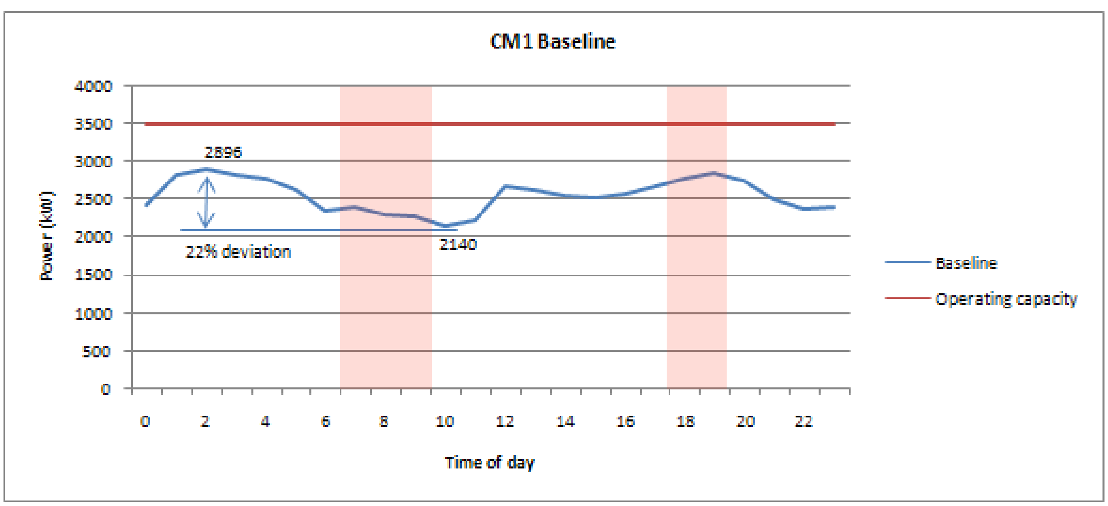

Figure 3.3c – Cement mill 1 baseline

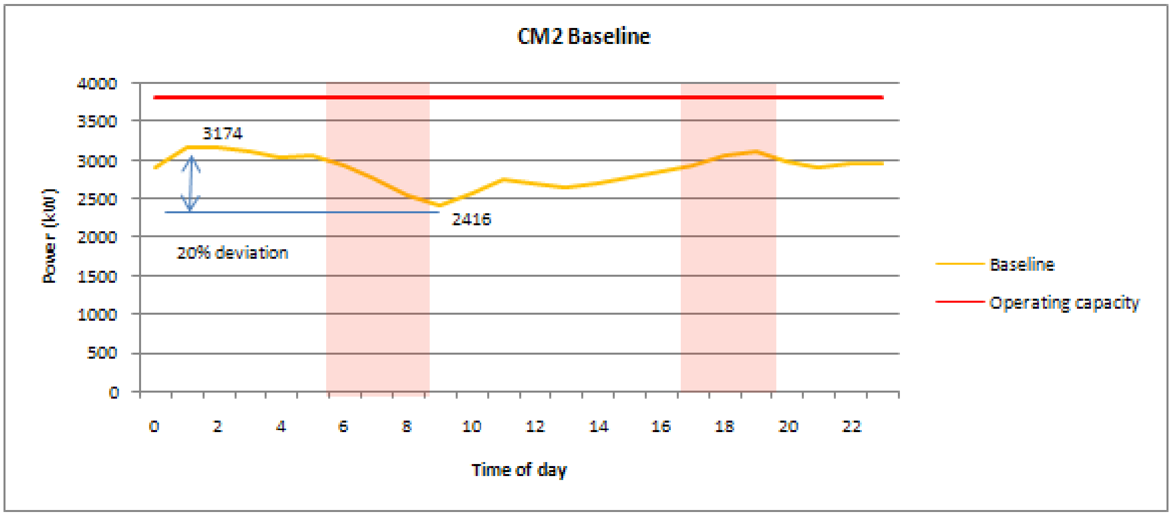

Figure 3.3d – Cement mill 2 baseline

The baselines show that there is opportunity for improvements in the operating strategy of the mills. No effort was previously made to shift load during the evening peak period between 18:00 and 20:00 nor during the morning peak between 07:00 and 10:00. The production during this time can most likely be shifted to off-peak periods between 22:00 and 5:00. This will be investigated further.

The baselines further show that on average RM3, RM4, CM1 and CM2 are used 72%, 80%, 76% and 68% of the time, respectively. This again gives good indication that there is opportunity for a load-shifting regime.

It is possible to use the historical baseline of a motor to establish a new “optimised” profile that involves a load-shifting schedule. This would show how the consumption could change. To do this, however, the number of hours that are available for load-shifting must first be determined.

3.3. Load-shifting functions

The main variable in a load-shifting scheme is the amount of hours that can be shifted. The factors that influence the operation of the mills are used to calculate how many hours are available. These are:

1. Plant layout
2. Flow rates
3. Silo capacity
4. Planned maintenance
5. Motor operating capacity
6. Percentage use of fly ash

7. Equipment reliability (incident hours)
8. Regulations of DSM load-shifting
9. Weekend operating hours

A simulation can be used to determine how many hours are available for the load-shifting of equipment feeding into or out of a silo. Flow rates, percentage fly ash and reliability are factors that are variable. The simulation can be used in different scenarios to calculate how many load-shifting hours are available as the factors change.

Silo Simulation

The number of hours load-shifted, directly affects the operating hours (*OH*) of equipment preceding and following the silo. *OH* is the dominant variable that influences the change in silo level. This is because it determines the amount of material flowing into and out of the silo. The changes in silo level may be calculated by multiplying the flow rates of equipment with the operating hours of the day as can be seen in Equation 1:

$-$ *Eq. 1*

The major constraint for the simulation is that the silo level has to stay within the capacity range for a specified duration of time. The range is defined as the array between maximum silo capacity and minimum silo capacity, as illustrated in Figure 3.4.

The simulation calculates available shut-down time of equipment for 31 days. The load-shifting hours are determined for either the inflow material or the outflow material depending on which silo is being simulated; either the raw meal silo or the clinker silo. The simulations for the silos differ slightly and will therefore be discussed separately.

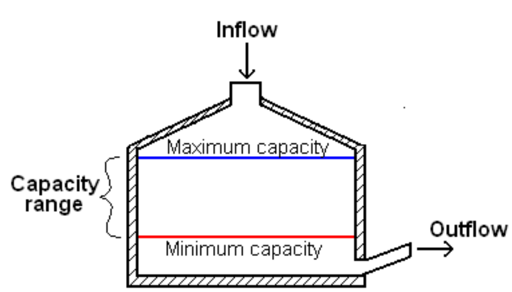

Figure 3.4 - Silo Specifications

Raw Meal Silo

Figure 3.5 illustrates the equipment involved in the raw meal silo simulation. Since the kiln needs to operate 24 hours a day, load-shifting is only calculated for the raw mill in the raw meal silo simulation. This determines how much material is fed into the silo. Therefore the simulation needs to calculate how many hours are available for load-shifting without the raw meal silo reducing beyond minimum capacity.

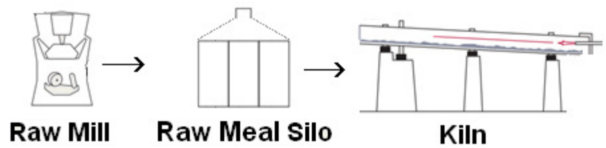

Figure 3.5 - Raw meal silo

To do this, the following information needs to be obtained: operating hours of equipment, flow rates, actual silo level, planned maintenance, and equipment reliability.

The simulation begins by using data from SCADA readings from three sources: 1) the silo, 2) the raw mill and 3) the kiln.

1) The silo SCADA provides the actual silo level. This gives a starting point from which to run the simulation of changing silo level.
2) The raw mill SCADA provides a) the inflow rate of material into the silo and b) the recent reliability factor for the mill.
    a. The flow rate value is calculated by averaging the flow rate readings for the previous week. This considers the recent performance of the mill.
    b. The reliability factor of the mill is expressed as average daily incident hours over the last month.
3) The SCADA data from the mill would also provide a) outflow rate and b) average incident hours.
    a. The flow rate out of the silo is again calculated from the average readings for the previous week. The values averaged may be either the rate of material fed into the kiln, or the rate at which clinker is produced by the kiln while taking into consideration the percentage weight-loss during the sintering process.
    b. Incident hours will again express the reliability of the kiln. However, it is acceptable to assume the kiln incident hours are equal to zero. This is because the kiln usually operates 24-hours a day if the production line is functioning.

The simulation takes into account the reliability factor of the mills by subtracting incident hours from the daily *OH*. The incident hours are dependent on the reliability of not only the mills, but also the auxiliary equipment and the equipment of upstream and downstream processes. The incident hours used in the daily *OH* calculation differ on a daily basis. This is because the simulation programme randomly generates numbers per day that are within a range around the historical average.

The range is determined from the standard deviation of the historical incident hours. For the plant under investigation, a range of 30% was used. This is because the standard deviation of the incident hours in the historic data equals to 27% and was rounded up for conservatism. The chances of the simulation providing unrealistic results are reduced by influencing the daily *OH* with changing incident hours. Then the probability of the silo level leaving the capacity range can be calculated.

OH is further affected by planned stoppages for the maintenance of equipment. Planned maintenance occurs on a regular basis and can be put into the simulation as an unchanging characteristic.

Maintenance is performed for a certain amount of hours, on a specific day of the week, for a number of times during the month. The simulation keeps track of time and date to consider planned stoppages in the future. The *OH* on a day of maintenance would be calculated as 24 hours minus the incident hours, load-shifting and maintenance hours as seen in Equation 2.

$$OH = 24 - incident\ hours - maintenance\ hours - load\ shifting \qquad Eq.2$$

The simulation can vary the load-shifting hours of the raw mill to alter the OH. This will result in predicting how silo levels will change as incident hours vary. Because of the large increments between full-load-shifting hours, the change in the simulation from one amount to another is significant. It can therefore be easily seen if the mill load can be shifted for, for instance, two or three hours. This is while taking into consideration the present production and performance. The maximum available load-shifting hours are later used for calculating an optimised baseline.

Figure 3.6 provides a flow diagram of the factors involved in the simulation as discussed above. Table 3.5 and Figure 3.7 show the salient calculations of the simulation and the resulting silo level graph for a period of a month. Appendix C provides a further description of the simulation.

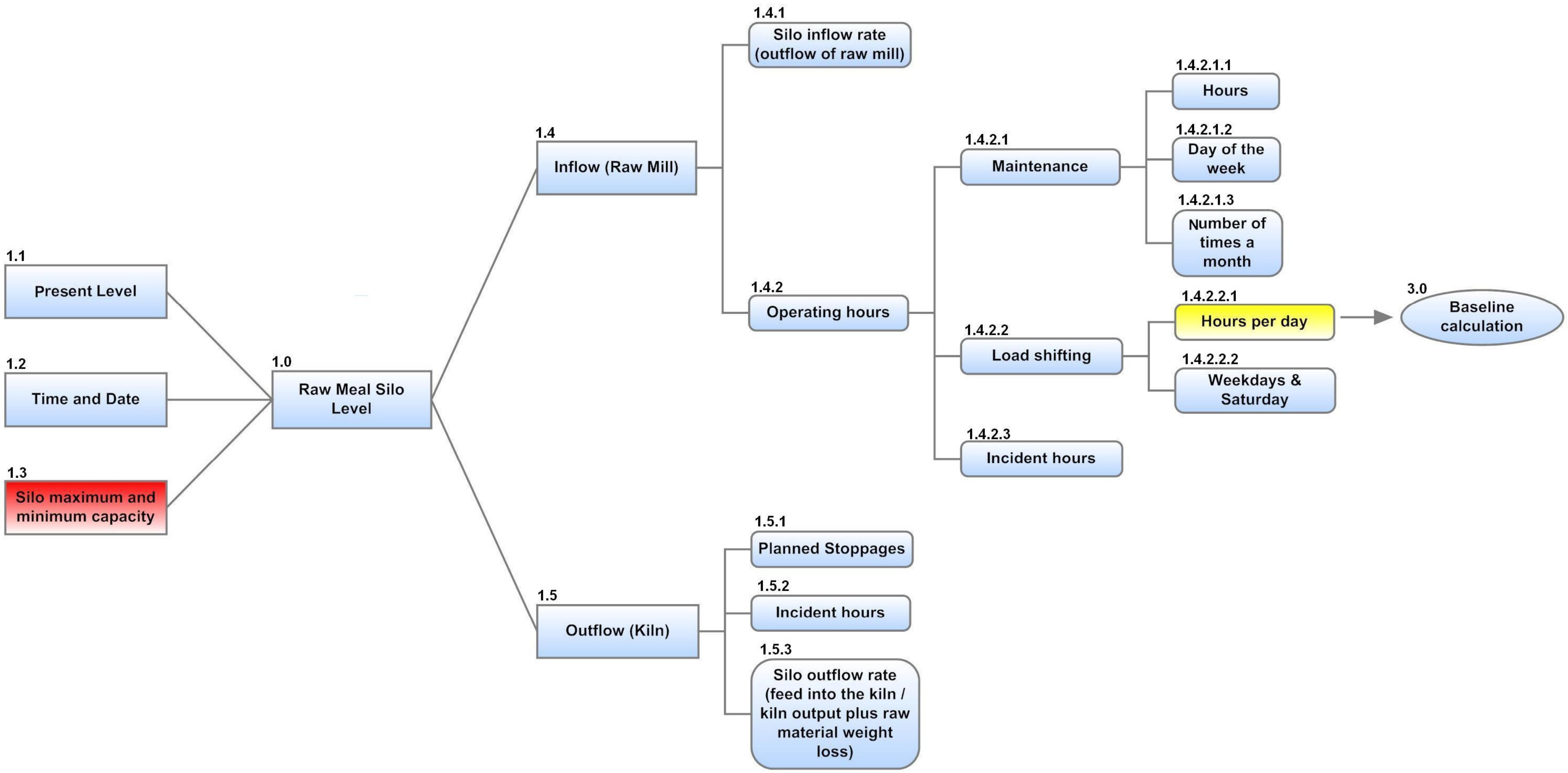

Figure 3.6 – Influential factors of the raw meal silo simulation. Red shaded boxes represent the main constraint for the simulation, yellow shaded boxes represent the main variable.

Table 3.5 - Raw meal silo simulation calculations

Silo	(t)
Max capacity	16000
Starting level (%)	80
Min level	10000

Flow rate	(t/h)
RM3 output (t/h)	235
Kiln3 input (t/h)	120

Load-shift (h)	6
Weekend OH	20
Incident (h)	
Raw mill 3	Kiln 3
5.6	1.23

	Raw Mill 3					Kiln 3		Silo (t)
Day	Incident (h)	Maintenance (h)	Load-shift (h)	OH (h)	Output (t)	OH (h)	Output (t)	
start								12000
1	6.04		6	11.96	2811	21.67	2600	12210
2	6.87		6	11.13	2616	24.00	2880	11947
3	5.54		6	12.46	2929	24.00	2880	11995
4	4.50		6	13.50	3172	21.76	2612	12555
5	5.04		6	12.96	3045	24.00	2880	12720
6	4.12		0	15.88	3731	24.00	2880	13572
7	7.24		0	12.76	2998	22.64	2717	13853
1	5.35		6	12.65	2974	22.33	2679	14148
2	6.67	9	6	2.33	547	21.16	2540	12155
3	4.85		6	13.15	3089	24.00	2880	12365
4	7.77		6	10.23	2404	24.00	2880	11888
5	6.26		6	11.74	2759	22.14	2657	11990
6	5.55		0	14.45	3396	19.66	2359	13027
7	7.90		0	12.10	2843	22.04	2645	13225
1	4.80		6	13.20	3101	24.00	2880	13446
2	6.04		6	11.96	2810	24.00	2880	13376
3	5.59		6	12.41	2916	20.55	2466	13826
4	6.86		6	11.14	2617	24.00	2880	13563
5	6.35		6	11.65	2737	24.00	2880	13420
6	5.99		0	14.01	3292	24.00	2880	13832
7	7.29		0	12.71	2986	23.37	2805	14014
1	5.31		6	12.69	2981	19.03	2284	14711
2	4.91	9	6	4.09	962	21.40	2568	13105
3	7.48		6	10.52	2472	20.12	2414	13163
4	4.57		6	13.43	3156	24.00	2880	13439
5	7.03		6	10.97	2577	21.64	2597	13419
6	6.09		0	13.91	3268	23.98	2877	13810
7	4.56		0	15.44	3629	24.00	2880	14559
1	5.10		6	12.90	3031	21.18	2541	15049
2	7.01		6	10.99	2584	20.30	2436	15197
3	5.86		6	12.14	2852	24.00	2880	15169

Incident hours – Randomly generated numbers between 30% brackets of average incident hours of the mill

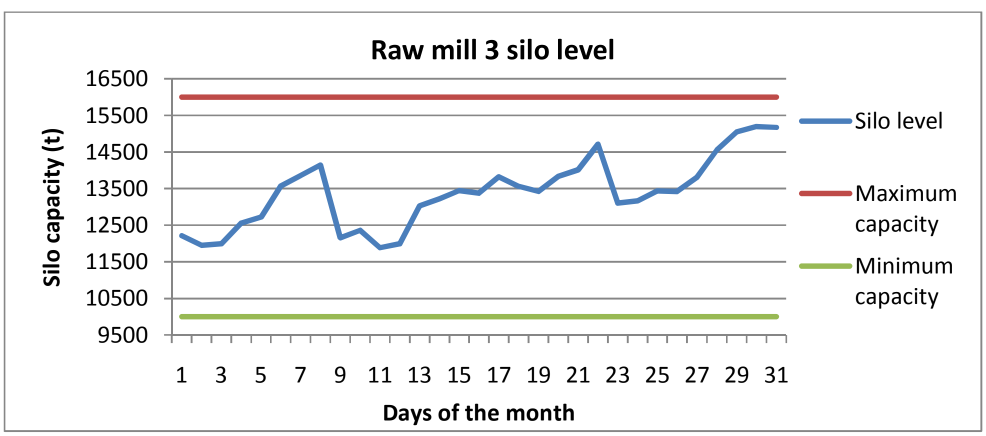

Figure 3.7- Change in raw meal silo level

As can be seen in Figure 3.7 and Table 3.5, the level is not adversely affected by 6 hours of load-shifting with that particular set of randomly generated incident hours per day. If the simulation is run a number of times, the probability of an adverse effect can be calculated. The simulation is run one hundred times, with different generated incident hours, and the number of times the silo level ends with a higher value than at the start, is recorded. This gives the probability of a positive effect on the silo levels. With 6 hours of load-shifting done on RM3, the probability of a positive effect was 73%. The calculations can be found in Appendix D. If the number of load-shifting hours is increased to 7, the probability of a positive effect drops to 38%. This indicates that no more than 6 hours of load-shifting are available for raw mill 3 without a high probability of a cumulative adverse effect on silo levels.

When subjecting raw mill 4 to the same simulation, it is calculated that 4 hours of load-shifting are possible with a 92% chance of positive effect.

Clinker silo simulation

The clinker silo simulation is similar to that of the raw meal silo simulation. One difference is that the clinker simulation determines the change of flow rate *out* of the silo. The cement mills receive clinker from the silo, as illustrated in Figure 3.8, and are therefore required to lower the silo level sufficiently to avoid overflowing.

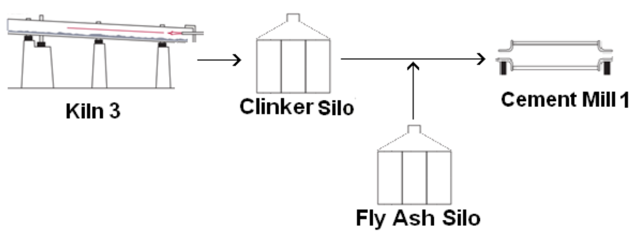

Figure 3.8- Clinker silo

Another difference to the simulation would be the changing amount of fly ash added to the cement mill. Depending on the type/brand of cement being produced, the percentage of fly ash milled with the clinker will change. This can also change from company to company in South Africa and with other additives, such as slag (Potgieter-Vermaak, et al., 2007).

The flow rate of the mill does not change with the percentage fly ash; it does influence the outflow of clinker from the silo. To take this into account the outflow rate used in the simulation is reduced by the percentage of fly ash used. For example if 15% fly ash is added, the flow rate is reduced by 15%.

The plant under investigation produces three blends of cement ranging from 15% to 40% fly ash additive. This becomes a second variable in the simulation. Figure 3.9 provides the flow diagram for the simulation and functions.

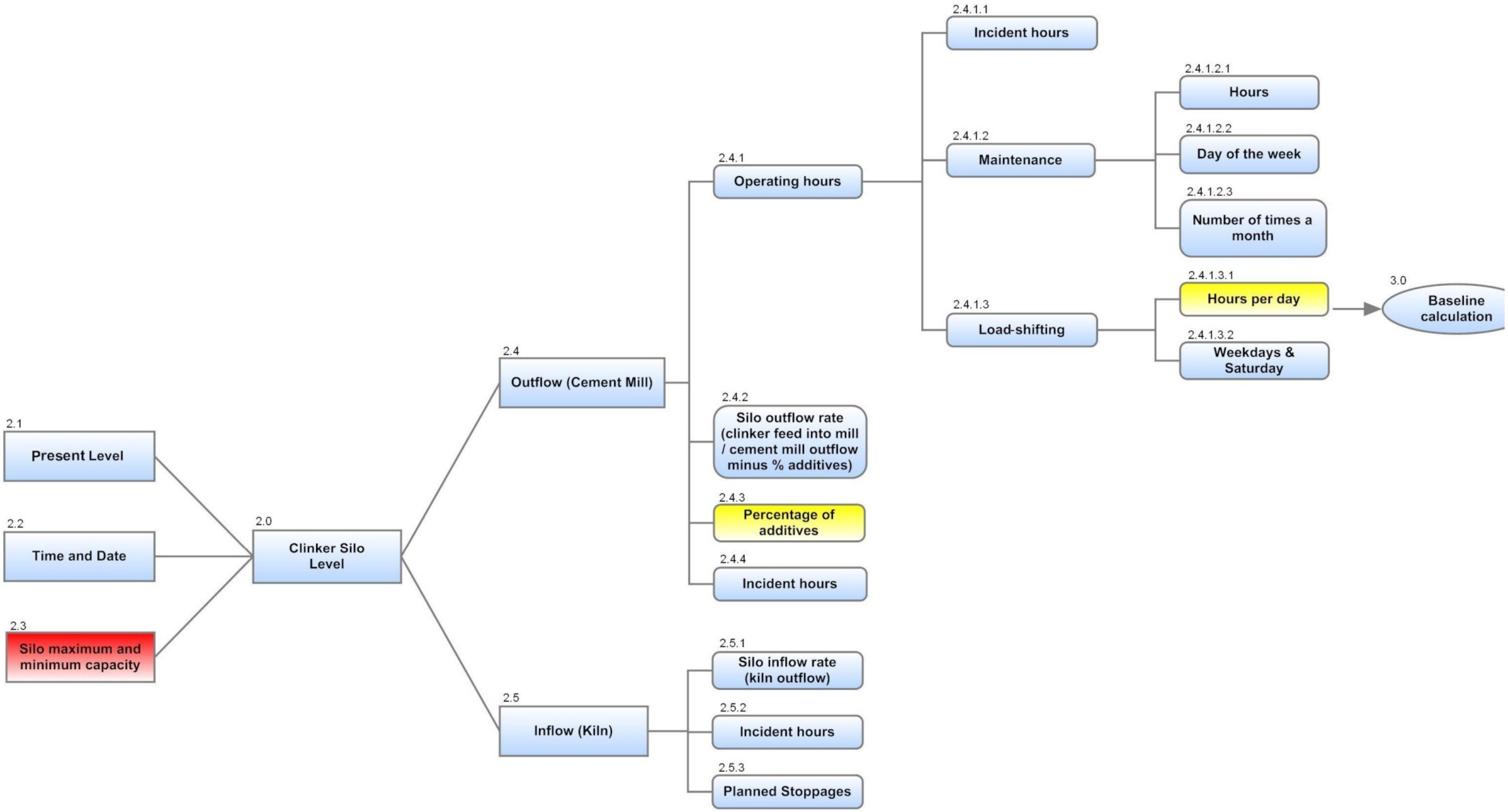

Figure 3.9- Influential factors of the clinker silo simulation. Red shaded boxes represent the main constraint for the simulation, yellow shaded boxes represent the main variable.

Silo simulation results

The simulations results are found in Table 3.6 and include the information required for the calculations. The values used were determined from the three months of SCADA data and daily reports provided by the plant under investigation. The summary can be found in Appendix B.

Table 3.6 - Silo simulation factor values and results

<table>
<tr><th></th><th colspan="2">Neighbouring silo capacity (t)</th><th colspan="3">maintenance</th><th colspan="2">operating hours</th><th></th><th></th><th></th></tr>
<tr><th></th><th>Max</th><th>Min</th><th>hours</th><th>day</th><th>per month</th><th>Saturday</th><th>Sunday</th><th>Incident hours</th><th>% fly ash</th><th>shifting hours</th></tr>
<tr><td>Raw Mill 3</td><td>16000</td><td>10000</td><td>9</td><td>Tue</td><td>2</td><td>20</td><td>20</td><td>5.6</td><td></td><td>6</td></tr>
<tr><td>Raw Mill 4</td><td>3500</td><td>700</td><td>9</td><td>Tue</td><td>2</td><td>20</td><td>20</td><td>6.0</td><td></td><td>4</td></tr>
<tr><td>Kiln 3</td><td></td><td></td><td></td><td></td><td></td><td>24</td><td>24</td><td>1.23</td><td></td><td></td></tr>
<tr><td>Kiln 4</td><td></td><td></td><td></td><td></td><td></td><td>24</td><td>24</td><td>2.07</td><td></td><td></td></tr>
<tr><td rowspan="4">Cement Mill 1+2</td><td rowspan="4">16000</td><td rowspan="4">9600</td><td rowspan="4">9</td><td rowspan="4">Wed</td><td rowspan="4">2</td><td rowspan="4">20</td><td rowspan="4">20</td><td rowspan="4">3.3</td><td>15</td><td>3</td></tr>
<tr><td>20</td><td>2</td></tr>
<tr><td>25</td><td>1</td></tr>
<tr><td>30</td><td>0</td></tr>
</table>

Because cement mills 1 and 2 both extract clinker from the same silo, it is necessary to combine their flow rates and consider them as a unit. The cement mills load shift are found to have a linear relationship with percentage fly ash usage and range from three hours each, to one hour each.

As stated, the different brands of cement produced have a 40% to 15% fly ash additive. Should only the 40% fly ash brand be produced, it is not possible to load-shift. However with both mills producing different brands of cement at different rates, it is possible to have an average percentage fly ash between 30% and 15%, the possible load-shifting range.

If 25% fly ash is used, it is recommended for convenience to load-shift one cement mill for two hours rather than both for only one hour.

3.4. Optimised baseline

Once the available load-shifting hours are known, it is then necessary to determine whether the mill motors would be able to achieve the load-shift and how it would affect the baselines.

These available hours may be restricted by DSM load-shifting regulations. The original baseline of the mills may not increase during Eskom's standard time. Therefore, the load-shifting hours have to be taken up entirely during off-peak periods. This is limited by the operating capacity of the mill motors, as it is sometimes not possible to maintain production solely during the off-peak periods.

The degree to which the available hours are limited can be determined by optimising baseline profiles to remain below operating capacity.

Another simulation is used to determine the best possible load-shifting strategy without exceeding motor installed capacity or raising the standard time usage. The simulation calculates an updated baseline for the preceding 31 day range. This is to determine how performance compares to the original baseline.

If the standard time values of the updated baseline are not above the original values, load may be shifted from peak periods. If not, an amount of load-shifting would also have to occur during standard time for the following days to lower the baseline.

The new baseline must have the same total area under the curve (AUC). This is because the AUC indicates how often the mill motors are run and therefore, the production of the mill. If the AUC is lowered, the production will be adversely affected.

The new baseline consists of the original baseline with two changes:

1) A number of peak period hours are equated to zero. These are the load-shifted hours. The maximum number of hours is calculated by the previous silo simulations;
2) The off-peak usage is increased to insure the AUC is not reduced during the load-shifting scheme.

If the off-peak values are higher than the operating capacity of the mill motors, then the baseline is not achievable and less load-shifting hours need to be implemented. The new off-peak power consumption should be marginally, say 2%, lower than the operating capacity of the motors to allow for unplanned breakages. With a 2% margin, an extra 14.4 hours of unplanned breakages can occur during off-peak periods without affecting production.

With the above logic an optimised baseline is developed. Figure 3.10 provides the flow diagram for the optimised baseline simulation.

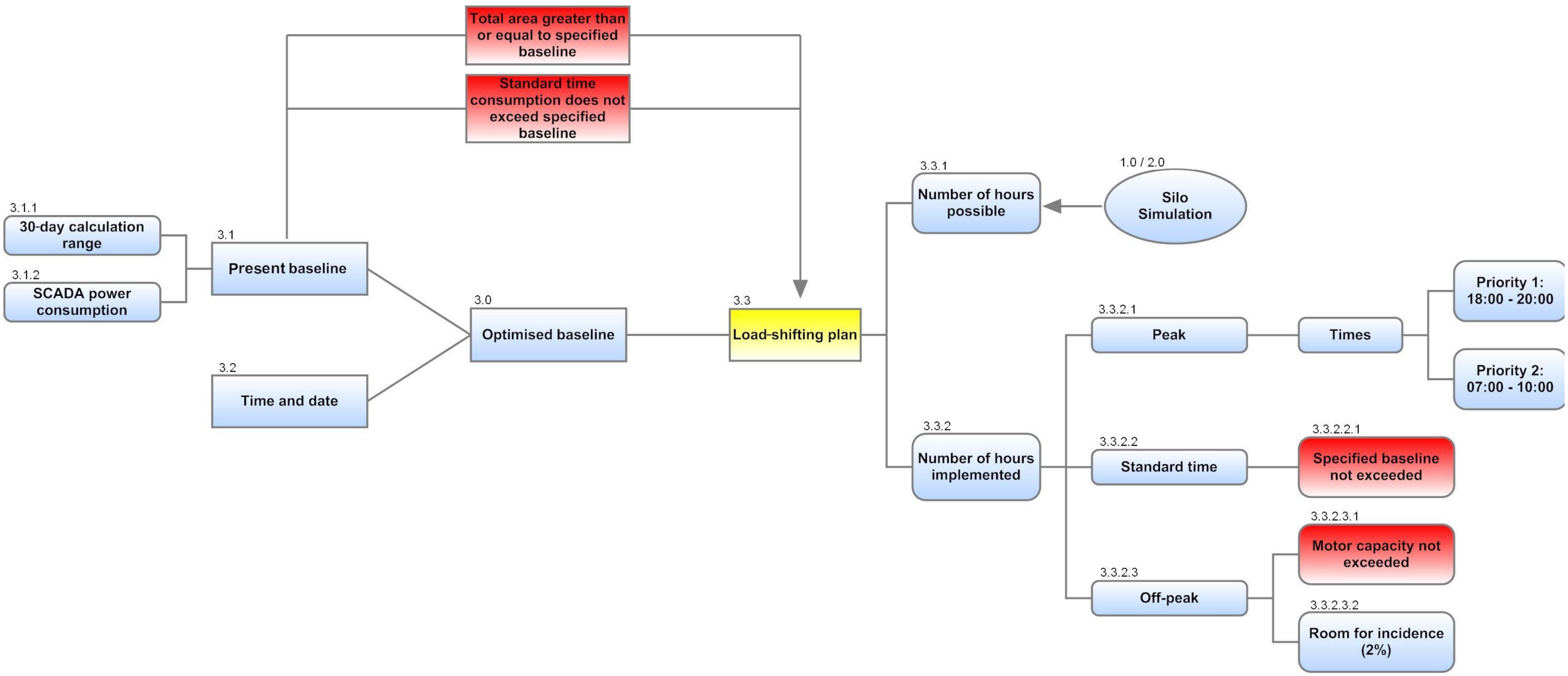

Figure 3.10 – Optimised baseline simulation. Red shaded boxes represent the main constraint for the simulation, yellow shaded boxes represent the main variable and black shaded boxes show tariff times periods.

Figures 3.11a to 3.11c present the achievable load-shifting profiles for the mills calculated by the baseline simulation.

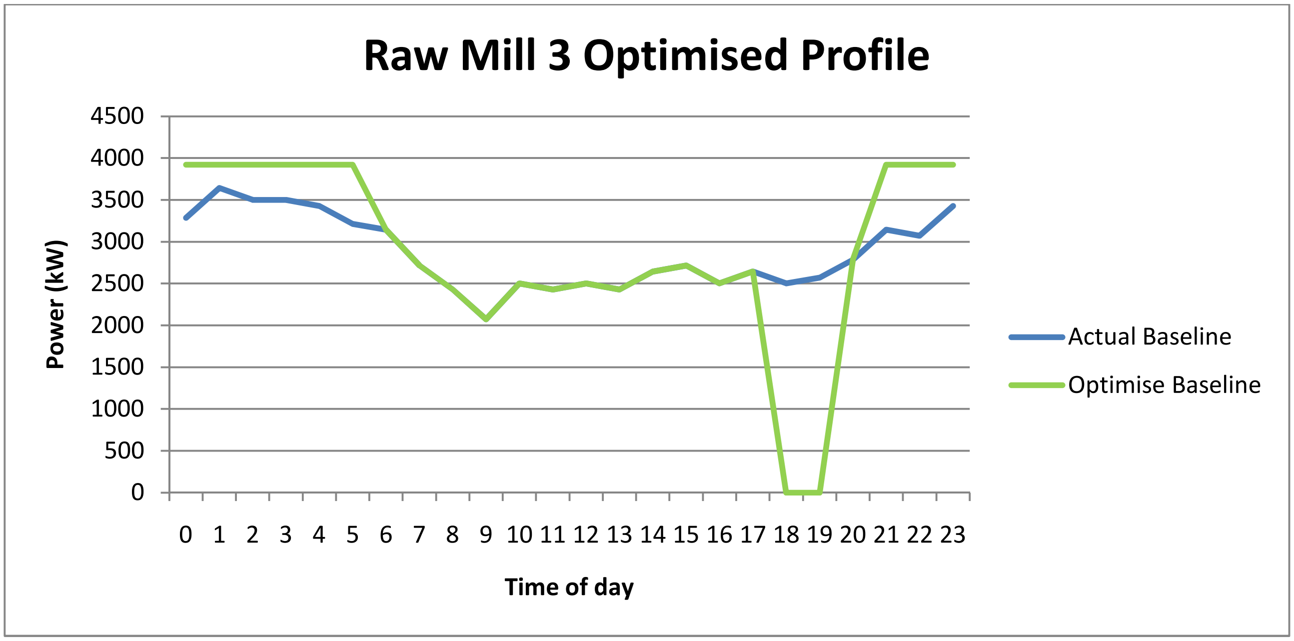

Figure 3.11a - Raw mill 3 optimised profile

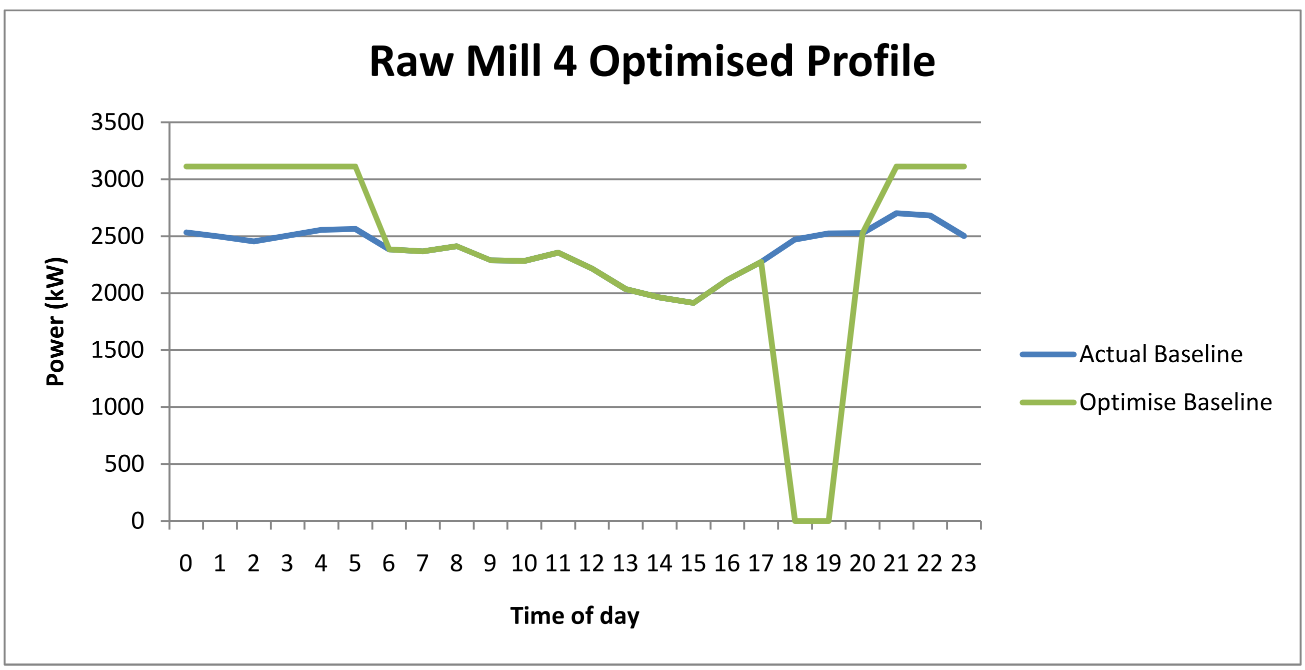

Figure 3.11b - Raw mill 4 optimised profile

The profiles of raw mills 3 and 4 illustrate how only two hours of load-shifting are possible without changing standard time usage or exceeding the operating capacity of 4 MW. The areas under the curve for both baselines are equal, indicating that production is not affected. The extra hours available for load-shifting will likely be taken up by unplanned stoppages due to overfull silo levels during standard and off-peak periods. This can also be implemented during morning peak periods but have to be planned on a daily basis with respect to actual baseline, occurring incidents and silo levels of that day.

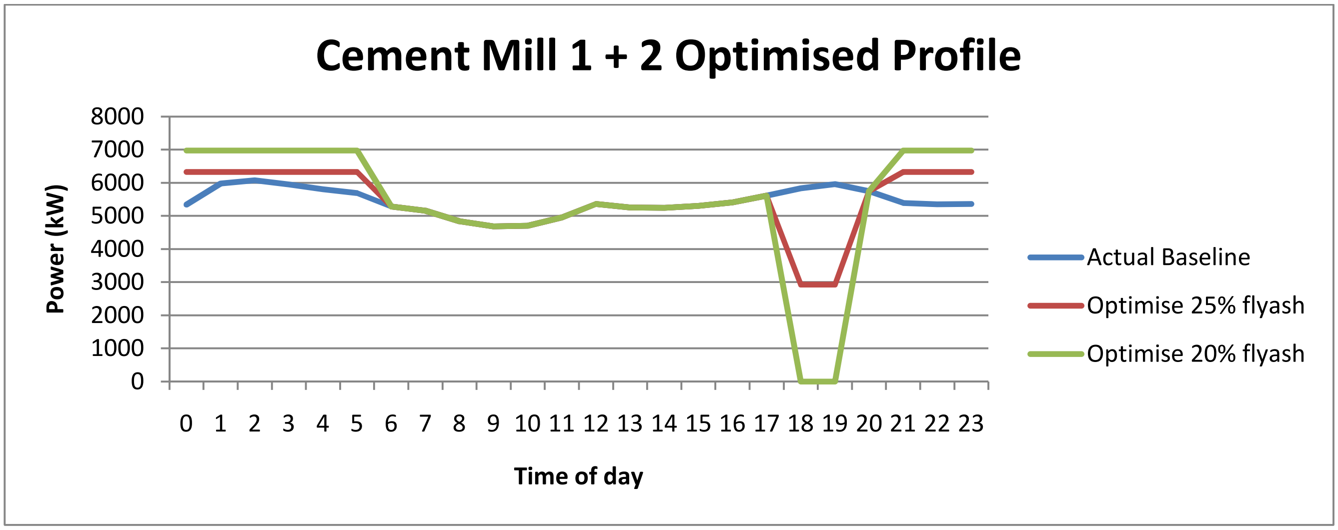

Figure 3.11c – Cement mill 1+2 optimised profile

The cement mill profiles are also affected by operating capacity of the motors and DSM regulations. Should only one brand of cement be milled at 15% fly ash additive, the full three hours of load-shifting would not be achievable. The off-peak capacity would be too high for the motors.

Therefore, the profile shows that the only options for the load-shifting of the cement mills are achievable if 20% - 25% of fly ash is used on average. Twenty per cent fly ash use allows for 2 hours of load shift for both mills, whereas the higher per cent fly ash usage only allows one mill to be load-shifted for 2 hours. This is why the evening peak period still has 3 MW of electrical consumption with the use of 25% fly ash.

3.5. Savings potential

It is now possible to determine the savings potential of such a load-shifting scheme. Table 3.7 lists the present Eskom tariffs for weekdays and weekends in summer and in winter. These are the marginal costs that will be used in the cost savings calculation. Table 3.8 provides the hourly power consumption values used in the baseline profiles.

Table 3.7 - Eskom electrical tariffs May 2010 - May 2011, the green shade represents the cheaper off-peak period, the yellow is the standard time and red is the peak period (Eskom, 2010)

	2010-06-01	Winter	2010-08-31	2010-09-01	Summer	2011-05-31
Hour	Weekday (c/kWh)	Saturday (c/kWh)	Sunday (c/kWh)	Weekday (c/kWh)	Saturday (c/kWh)	Sunday (c/kWh)
0	19.29	19.29	19.29	16.61	16.61	16.61
1	19.29	19.29	19.29	16.61	16.61	16.61
2	19.29	19.29	19.29	16.61	16.61	16.61
3	19.29	19.29	19.29	16.61	16.61	16.61
4	19.29	19.29	19.29	16.61	16.61	16.61
5	19.29	19.29	19.29	16.61	16.61	16.61
6	36.05	19.29	19.29	23.74	16.61	16.61
7	138.58	36.05	19.29	38.73	23.74	16.61
8	138.58	36.05	19.29	38.73	23.74	16.61
9	138.58	36.05	19.29	38.73	23.74	16.61
10	36.05	36.05	19.29	23.74	23.74	16.61
11	36.05	36.05	19.29	23.74	23.74	16.61
12	36.05	19.29	19.29	23.74	16.61	16.61
13	36.05	19.29	19.29	23.74	16.61	16.61
14	36.05	19.29	19.29	23.74	16.61	16.61
15	36.05	19.29	19.29	23.74	16.61	16.61
16	36.05	19.29	19.29	23.74	16.61	16.61
17	36.05	19.29	19.29	23.74	16.61	16.61
18	138.58	36.05	19.29	38.73	23.74	16.61
19	138.58	36.05	19.29	38.73	23.74	16.61
20	36.05	19.29	19.29	23.74	16.61	16.61
21	36.05	36.05	19.29	23.74	16.61	16.61
22	19.29	36.05	19.29	16.61	16.61	16.61
23	19.29	19.29	19.29	16.61	16.61	16.61

Table 3.8- Mill power consumption data, the green shade represents the cheaper off-peak period, the yellow is the standard time and red is the peak period

Week day hours	Raw mill 3		Raw mill 4		Cement mill 1+2		
	Original Baseline (kWh)	Optimise Baseline (kWh)	Original Baseline (kWh)	Optimise Baseline (kWh)	Original Baseline (kWh)	Optimise Baseline 25% fly ash (kWh)	Optimise Baseline 20% fly ash (kWh)
0	3286	3921	2533	3110	5336	6321	6970
1	3643	3921	2495	3110	5982	6321	6970
2	3500	3921	2455	3110	6071	6321	6970
3	3500	3921	2506	3110	5951	6321	6970
4	3429	3921	2556	3110	5800	6321	6970
5	3214	3921	2564	3110	5690	6321	6970
6	3143	3143	2384	2384	5285	5285	5285
7	2714	2714	2366	2366	5154	5154	5154
8	2429	2429	2412	2412	4842	4842	4842
9	2071	2071	2287	2287	4679	4679	4679
10	2500	2500	2283	2283	4703	4703	4703
11	2429	2429	2354	2354	4956	4956	4956
12	2500	2500	2214	2214	5361	5361	5361
13	2429	2429	2036	2036	5252	5252	5252
14	2643	2643	1961	1961	5245	5245	5245
15	2714	2714	1914	1914	5300	5300	5300
16	2500	2500	2117	2117	5411	5411	5411
17	2643	2643	2274	2274	5608	5608	5608
18	2500	0	2470	0	5833	2920	0
19	2571	0	2523	0	5962	2920	0
20	2786	2786	2527	2527	5749	5749	5749
21	3143	3921	2701	3110	5391	6321	6970
22	3071	3921	2682	3110	5351	6321	6970
23	3429	3921	2502	3110	5359	6321	6970

The savings gained from such a load-shifting scheme is summarised in Table 3.9.

Table 3.9 – Theoretical savings obtained by the load-shifting scheme

	Savings per weekday		Savings per Saturday	
	Winter	Summer	Winter	Summer
RM3	R 5,919	R 1,066	R 577	R 361
RM4	R 5,886	R 1,075	R 696	R 355
CM1	R 6,575	R 1,189	R 670	R 401
CM2	R 7,232	R 1,308	R 772	R 441
days in 2010:	66	195	13	39

	Yearly savings	Original yearly cost
RM3	R 620,033	R 6,670,640
RM4	R 620,923	R 5,785,710
CM1	R 690,195	R 6,173,033
CM2	R 759,599	R 6,928,949

	Plant savings for one year:	fractional savings of yearly cost without load-shifting
Average total fly ash 30%, CM not shut down:	**R 1,240,955.52**	0.05
Average total fly ash 25%, shut down CM1:	**R 1,931,150.48**	0.08
Average total fly ash 25%, shut down CM2:	**R 2,000,554.02**	0.08
Average total fly ash 20%, shut down CM 1 + 2:	**R 2,690,748.98**	0.11

The theoretical results show that significant savings can be achieved with the present reliability and production of the plant.

Orans (2010) suggests a manner of calculating energy efficiency and load-shift cost savings using a weighted average of the tariffs to take into account the significance of reducing the peak period. The weighted average tariff charges are often used by plants to gain a general perspective of electrical costs. This therefore will represent the savings for the generalised method.

Consider cases of the power consumption during the peak period (Q1 kWh), off-peak period (Q2 kWh) and standard (Q3 kWh). The ratios of consumption during peak period (S1) and off-peak periods (S2) are determined by Orans (2010):

$$Q = Q1 + Q2 + Q3 \qquad Eq.3$$

$$S1 = \frac{Q1}{Q} \qquad Eq.4$$

$$S2 = \frac{Q2}{Q} \qquad Eq.5$$

$$Weighted\ average\ of\ tariffs;\ W = S1w1 + S2w2 + (1 - S1 - S2)w3 \qquad Eq.6$$

where *w1, w2,* and *w3* are the tariffs during peak, off-peak and standard time, respectively.

If the weighted average tariff is used to calculate the cost savings due to load-shifting (C), it would be equal to the total power consumption multiplied by the change in weighted average marginal costs:

$$C = Q \times \Delta W \qquad Eq.7$$

The results of the weighted cost savings are shown in Table 3.10.

Table 3.10 - Savings gained by the load-shifting scheme with averaged tariffs

		Savings per weekday		Savings per Saturday	
		Winter	Summer	Winter	Summer
	RM3	R 6,050	R 1,122	R 850	R 362
	RM4	R 5,956	R 1,105	R 837	R 356
CM 1+2	0.25 fly ash	R 7,105	R 1,318	R 998	R 425
	0.2 fly ash	R 14,072	R 2,609	R 1,977	R 841

		Yearly savings per mill
	RM3	R 643,258.00
	RM4	R 633,336.00
CM 1+2	0.25 fly ash	R 755,489.00
	0.2 fly ash	R 1,496,007.00

	Plant savings for one year with weighted average
Average total fly ash 30%, CM not shut down:	**R 1,276,594**
Average total fly ash 25%, shut down CM1:	**R 2,032,083**
Average total fly ash 20%, shut down CM 1 + 2:	**R 2,772,601**

Using the averaged tariffs, the yearly electrical costs savings are still substantial. This shows that the DSM endeavour is worth pursuing.

The difference between savings calculated with a direct method and the averaged method is 1.5%-3%. The marginal change gives indication that, should an ESCO present a savings value to a company using the common practice of weighted average values, it could be used as a valid description.

Theoretical results

By implementing the three load-shifting strategies, the project has a potential to reduce a total of 16 MW to 22 MW of electrical consumption during peak periods every day. This would lower yearly electrical costs by R1.2 to R2.6 million depending on percentage of fly ash additive and which cement mill is load-shifted.

The ESCO contractual scope of the load-shifting scheme would be classified under the performance contract discussed in Chapter 2. By utilising different time-of-use pricing, this would be a form of energy logistics for a power performance contract (Sirchis, 1989). This can be illustrated as shown in Figure 3.12.

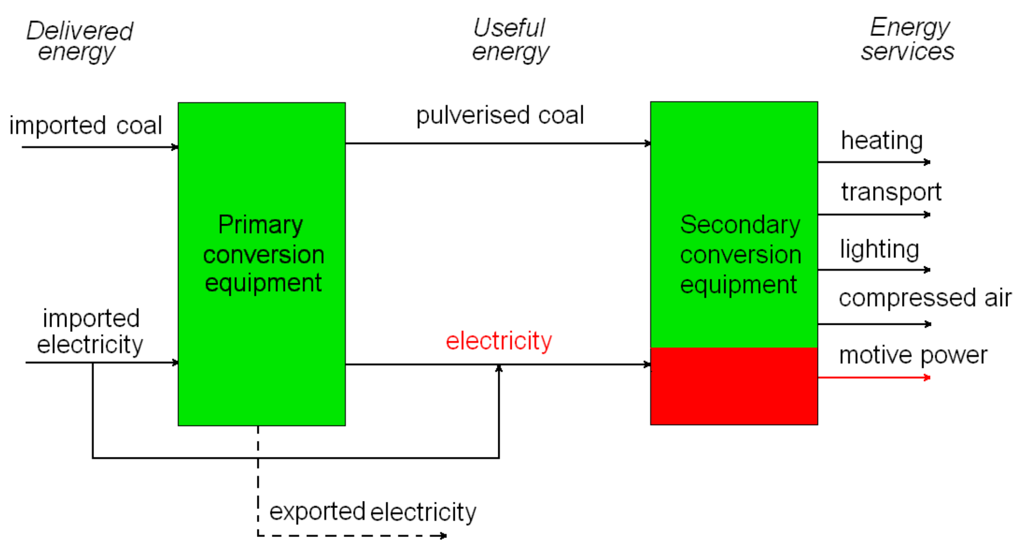

Figure 3.12 - DSM power performance contract for cement plant mill motors. Red indicates the covered scope of the contract. Adapted from Sorrell (2010)

The load-shifting scheme of the mill motors does not improve the motive power energy efficiency of the plant. It does however improve the logistics of the useful energy that is used in the motive power, hence, resulting in the ESCO contract block diagram shown in Figure 3.12.

3.6. Pilot study

A pilot study can be performed on the plant to verify whether the load-shifting scheme can achieve the predicted cost savings. The cement plant under investigation currently has an integrated operating and monitoring system. The load-shifting strategy can be implemented by using this system.

If all the influential factors discussed show that load-shifting is possible, the mills can be turned off during peak periods and used more regularly during off-peak periods for a number of hours. The SCADA system used to supply the plant data will again be used to record how the load-shifting affects the production and power consumption. Using this data, the verification of the simulation model can be achieved.

3.7. Conclusion

The investigation shows that there is great potential for reducing peak time usage for both the raw mills and cement mills in the plant. The strategy is dynamic in that it can be chosen to be implemented if conditions are appropriate. It can also be increased to the morning peak periods should there be a lower level of incident hours.

The daily calculation of the baseline and adjustment to the load-shifting strategy will allow production to continue while adhering to the DSM regulations. This will result in a flexible load-shifting project which has the potential for substantial electrical cost savings.

3.8. References

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Chapter 4

Pilot study

4.1. Pilot study

A pilot study is a small-scale preliminary trial to check the feasibility of theoretical results or to improve the design of research. For this study, such a trial was performed in the cement plant under investigation.

This provides an indication of whether load-shifting can be implemented in a typical South African cement plant and to what extent it affects production and power consumption.

Aim of the pilot study

The aim of the pilot study is to attempt to put into practice the theoretical load-shifting scheme outlined in Chapter 3. This is to determine the validity of the theory and how the production of the plant is altered with the change in mill operation.

Assumptions and contingencies

Assumptions are made regarding the reliability of the information obtained from the cement plant. This includes the completed questionnaire information and hourly data from the SCADA system.

The pilot study is expected to conform to the strategy determined in Chapter 3, which uses the information obtained from the plant. If incorrect data was provided, the pilot study will not perform as expected.

The contingency towards this assumption, however, is that the same system is used in the pilot study as was used to gather the data for the theoretical study. If any calibration inaccuracies are present in the SCADA system, they will affect the results in the same manner as the historical data. It is necessary to consider this when interpreting the pilot study results.

Method

The pilot study was performed over a period of five days, Monday 18 – Friday 22 October 2010. The DSM strategies of the silo and baseline simulations were followed.

A simplified breakdown of the approach or load-shifting parameters is given below and in Figure 4.1.

- Operate all four mills primarily between 21:00 - 06:00.
- If silo levels are acceptable for load-shifting for a minimum period of two hours there must be no operation between 18:00 - 20:00.
- Hours between 06:00 - 18:00 may act as a secondary operation time slot.
- If silo levels are acceptable for further load-shifting, the mills may be turned off from 07:00 into standard time. It is necessary, however, to ensure that the mills will be able to shut down between the evening peak period.

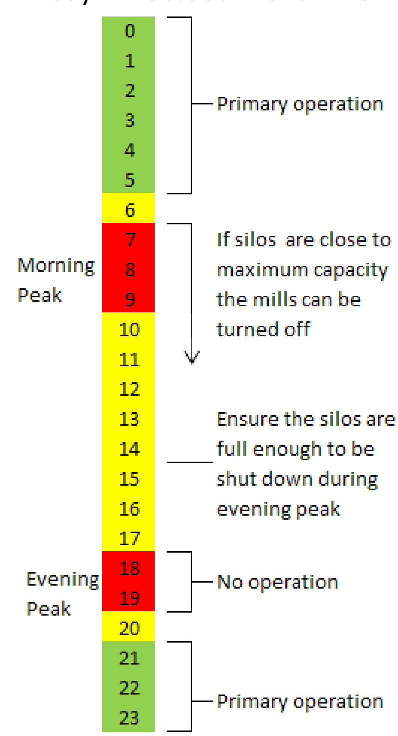


Figure 4.1 - Load-shifting parameters

Required information

The hourly power consumption recorded by the SCADA system will be used to determine the baselines of the mills during the pilot study period. These will be compared to the May to July baselines determined in Chapter 3.

Shift reports will be used to determine why a mill operated or did not operate over the five days of the pilot study. This is to understand the resulting baselines from the SCADA data.

4.2. Power consumption and baselines of the mills during the pilot study

Table 4.1 shows how the mills were operated during the morning and evening peak periods of the day.

- Raw mill 3 was successfully load-shifted during the evening peak period for four days and partially for the fifth.
- Raw mill 4 was only load-shifted in the morning for three of the five days
- Cement mill 1 was shut down once partially and once fully in the morning
- Cement mill 2 did not shut down at all

	Morning peak load-shifting 7h30 -10h00				Evening peak load-shifting 18h00 -20h00			
Date	Cement Mill 1	Cement Mill 2	Raw Mill 3	Raw Mill 4	Cement Mill 1	Cement Mill 2	Raw Mill 3	Raw Mill 4
18-Oct	Mill did not shut down	Mill did not shut down	Mill did not shut down	Mill shutdown full-time	Mill did not shut down	Mill did not shut down	Mill shutdown full-time	Mill did not shut down
19-Oct	Mill did not shut down	Mill did not shut down	Mill did not shut down	Mill shutdown full-time	Mill did not shut down	Mill did not shut down	Mill shutdown full-time	Mill did not shut down
20-Oct	Mill shutdown part-time	Mill did not shut down	Mill did not shut down	Mill did not shut down	Mill did not shut down	Mill did not shut down	Mill shutdown full-time	Mill did not shut down
21-Oct	Mill shutdown full-time	Mill did not shut down	Mill did not shut down	Mill did not shut down	Mill did not shut down	Mill did not shut down	Mill shutdown full-time	Mill did not shut down
22-Oct	Mill did not shut down	Mill did not shut down	Mill did not shut down	Mill shutdown full-time	Mill did not shut down	Mill did not shut down	Mill shutdown part-time	Mill did not shut down

Mill did not shut down (red)
Mill shutdown part-time (yellow)
Mill shutdown full-time (green)

Table 4.1 - Operation of the mills during the pilot study

As can be seen, only one mill was able to load-shift in the evening peak period as required by the pilot study. To understand why the plant was not able to shift load in the desired manner, the shift reports provide insight. Each mill will be discussed individually, reasons for non-compliance will be explained and the results of the pilot study will be investigated.

Cement mill 1

SCADA data were used to develop Figure 4.2. The figure presents the power consumption, and therefore the operation, of cement mill 1 during the pilot study. The light red shaded area represents the evening peak periods when the mill should have been shut down and electrical consumption equal to zero. The graph also provides indication as to when and why incident hours occurred.

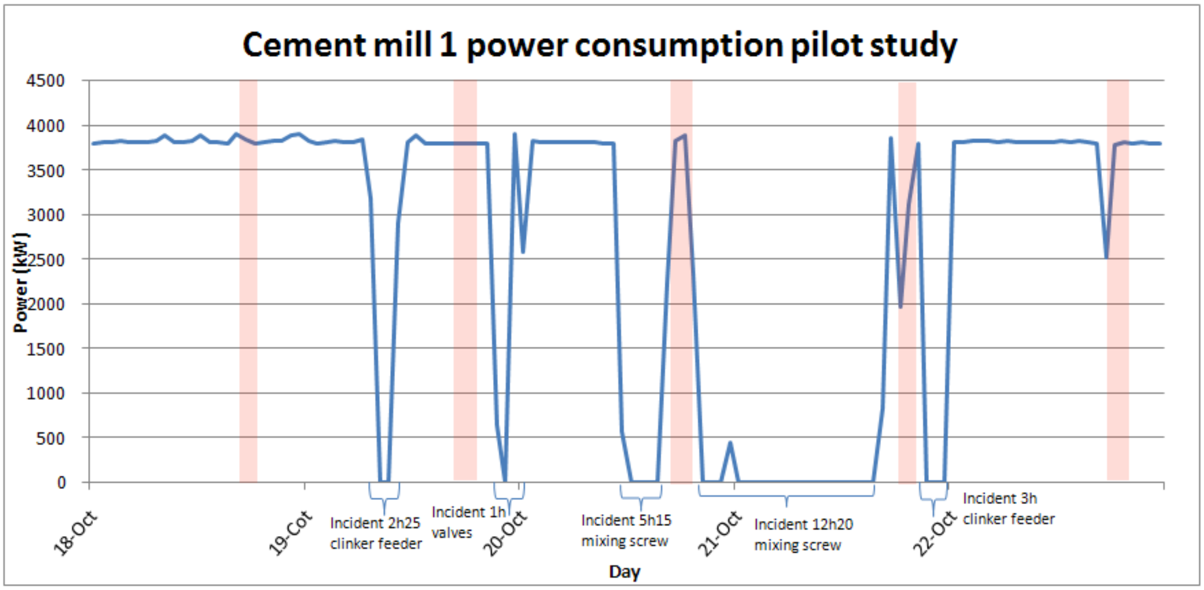


Figure 4.2 - CM1 power consumption pilot study

As can be seen in the graph, cement mill 1 did not once shut down during the evening peak period. At the time of the pilot study, the plant production manager increased production of the cement mills. As a result they were not allowed to be shut down for load-shifting so as to meet the raised production demand.

However, cement mill 1 had a total of 23.75 incident hours during the week and as a result produced the baseline shown in Figure 4.3. Fewer incident hours were experienced during the evening peak period and as a result were used to make up for the unscheduled, lost production time. Coincidentally, this caused a very high electrical usage during the peak period which is completely opposite to what was sought in the pilot study. Because of this, it is most likely that the cost to operate the mill is higher than that experienced during the investigation. This will be addressed later in the chapter.

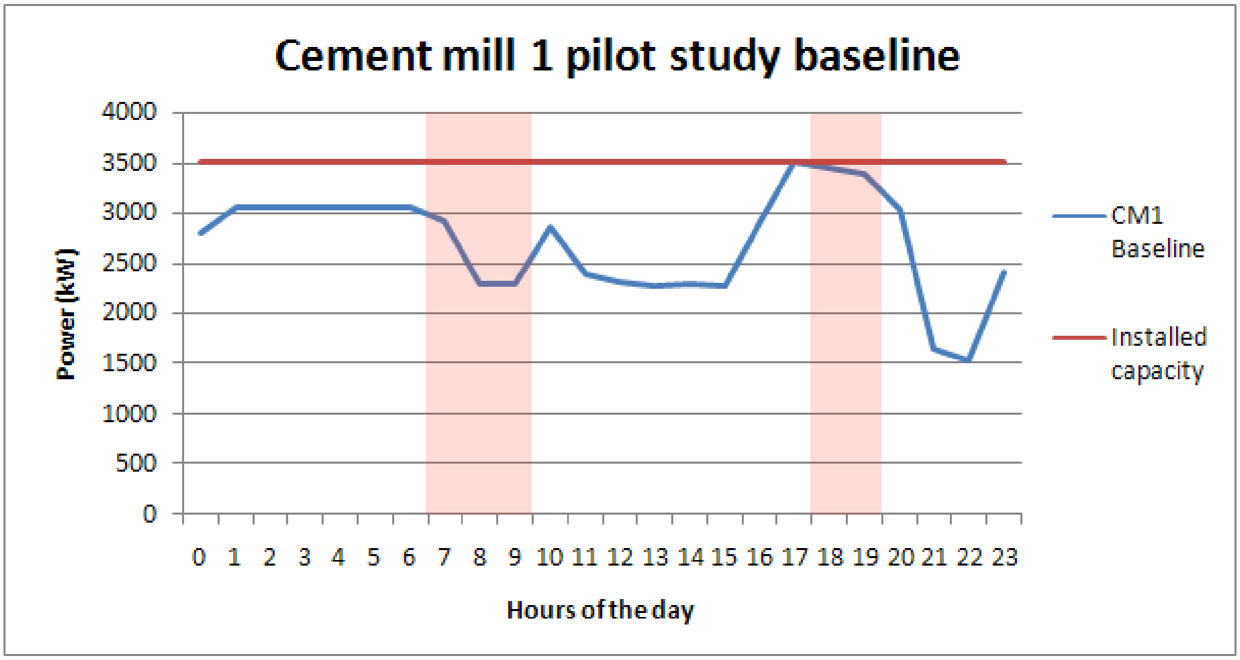


Figure 4.3 - CM1 pilot study baseline

Cement mill 2

The unexpected increase in cement production demands mentioned previously also required cement mill 2 to be operated continuously. As this cement mill has improved reliability compared to cement mill 1, it ran uninterruptedly for five days. This produced the power consumption profile and baseline shown in Figures 4.4 and 4.5.

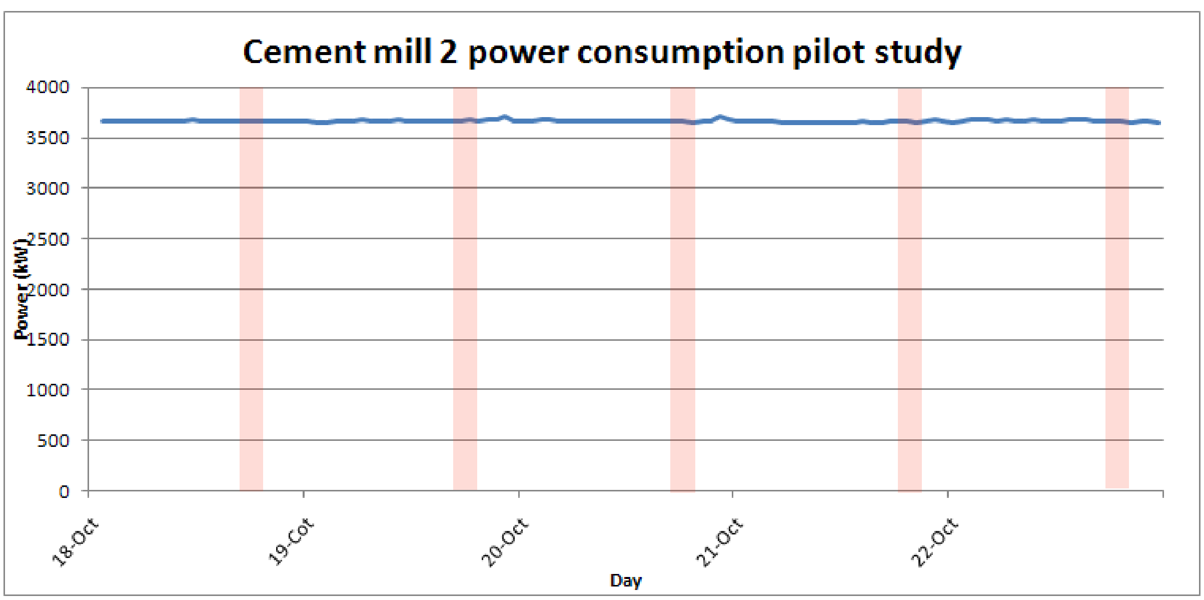


Figure 4.4 - CM2 power consumption pilot study

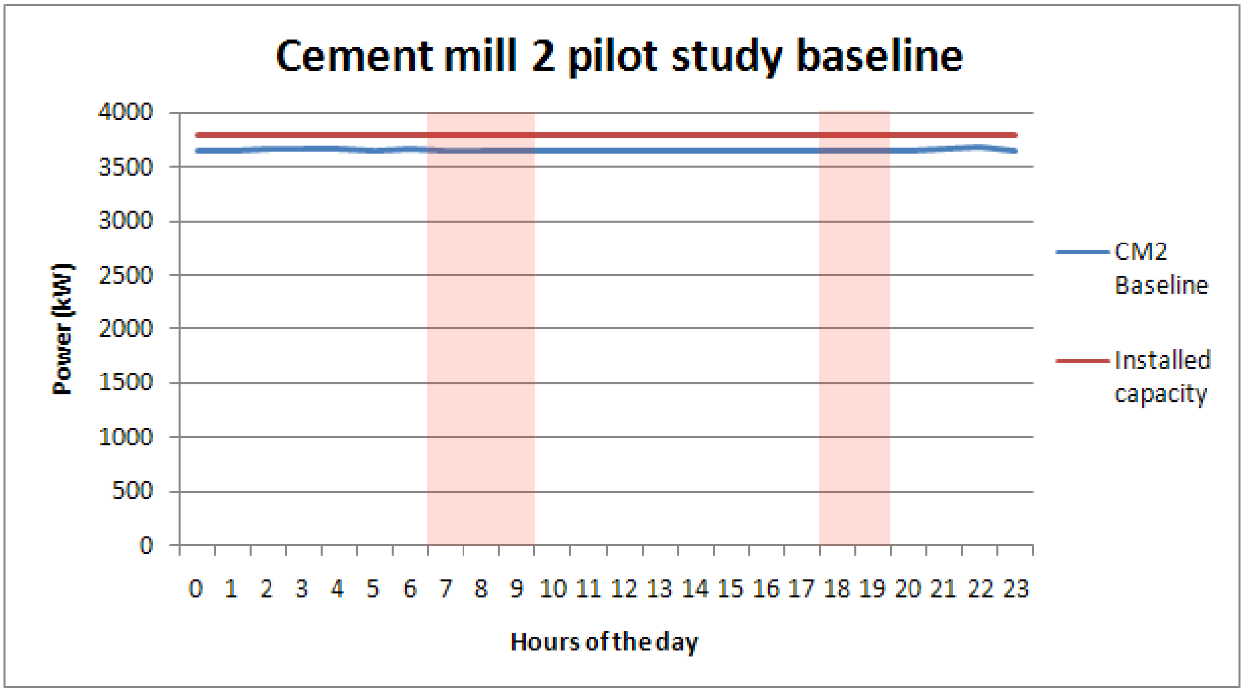


Figure 4.5 - CM2 pilot study baseline

If the demand on the cement mills remains high, such as experienced during the pilot study, there is no availability for load-shifting, and therefore no opportunity for electrical cost savings.

Raw mill 4

The pilot study power consumption profile for raw mill 4 is shown in Figure 4.6. Again, this mill experienced no load-shifting during the evening peak period. At the start of the pilot study, the raw meal silo levels were at a high enough capacity to allow for load-shifting during both the morning and evening peak periods. However, this was not sustainable, as the raw meal reclaimer failed during the afternoon standard time period. This caused the feed of raw meal into the mill to stop and it therefore had to be shut down. After experiencing three additional incident hours, the raw meal silo levels were too low to permit load-shifting during the evening peak period.

A similar experience occurred on the second day of the pilot study. Thereafter, the production manager decided not to load-shift raw mill 3 for the remainder of the pilot study. This was decided due to the low reliability of the mill and auxiliary equipment. The manager also stated that if load-shifting is planned for the future, it should be made for the morning peak periods. This is to enable maintenance to be performed on the mill during daylight hours.

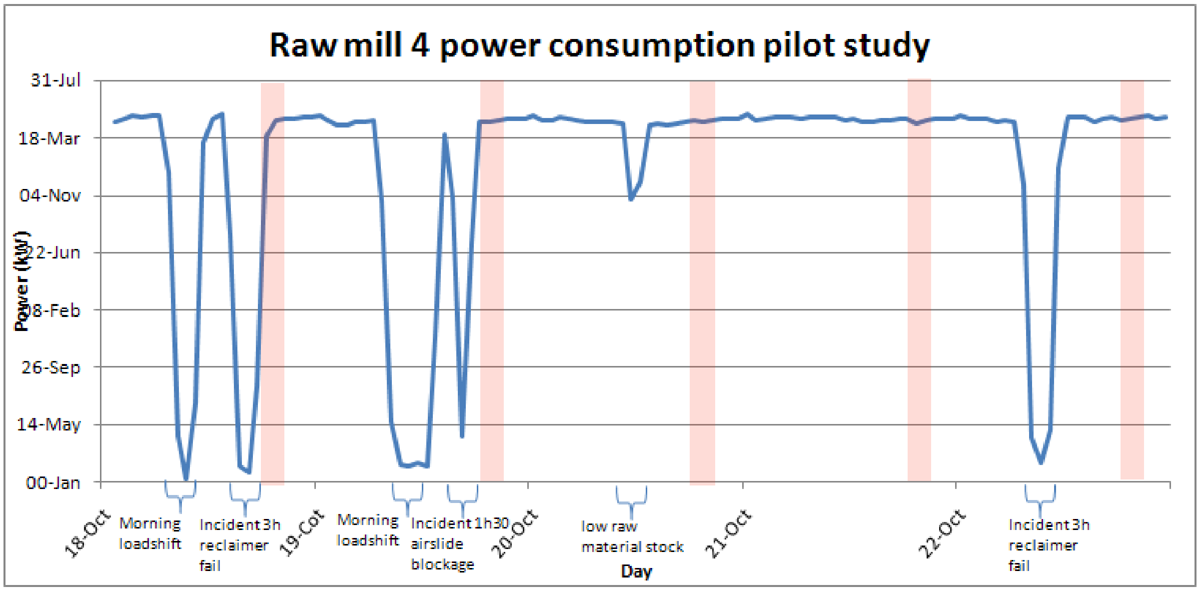


Figure 4.6 - RM4 power consumption pilot study

The baseline of raw mill 4 produced during the pilot study can be seen in Figure 4.7. It shows that although there was a 58% reduction in consumption for a portion of the morning peak period, there was none in the evening. This again does not meet the objectives of the load-shifting scheme. With the high level of unreliability of the mill, it is difficult to achieve planned load-shifting and cost savings.

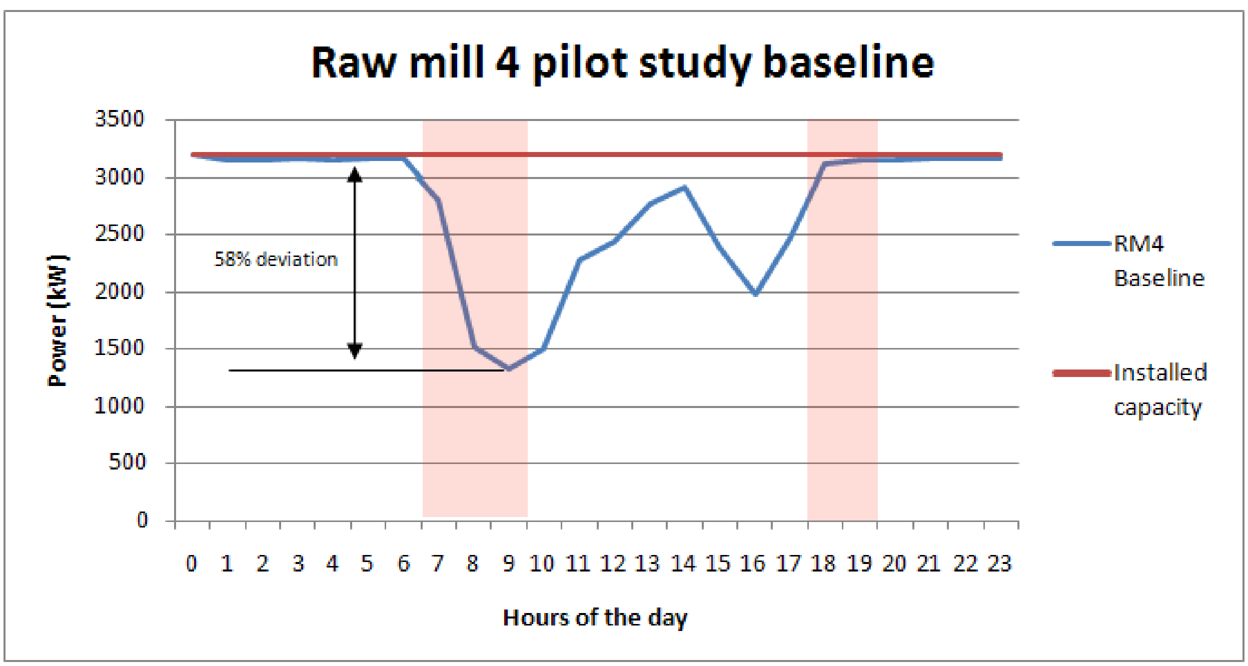


Figure 4.7 - RM4 pilot study baseline

Raw mill 3

Figure 4.8 presents the power consumption of raw mill 3 during the pilot study. The raw mill was successfully shifted in the evening peak period for all five days of the pilot study. The last day was however shifted for only one of the two evening peak period hours.

The figure further illustrates that there were 9 hours of scheduled maintenance and an additional 8.3 incident hours during the week. Despite this, the load-shifting was able to take place. The load-shifting goals were therefore achieved.

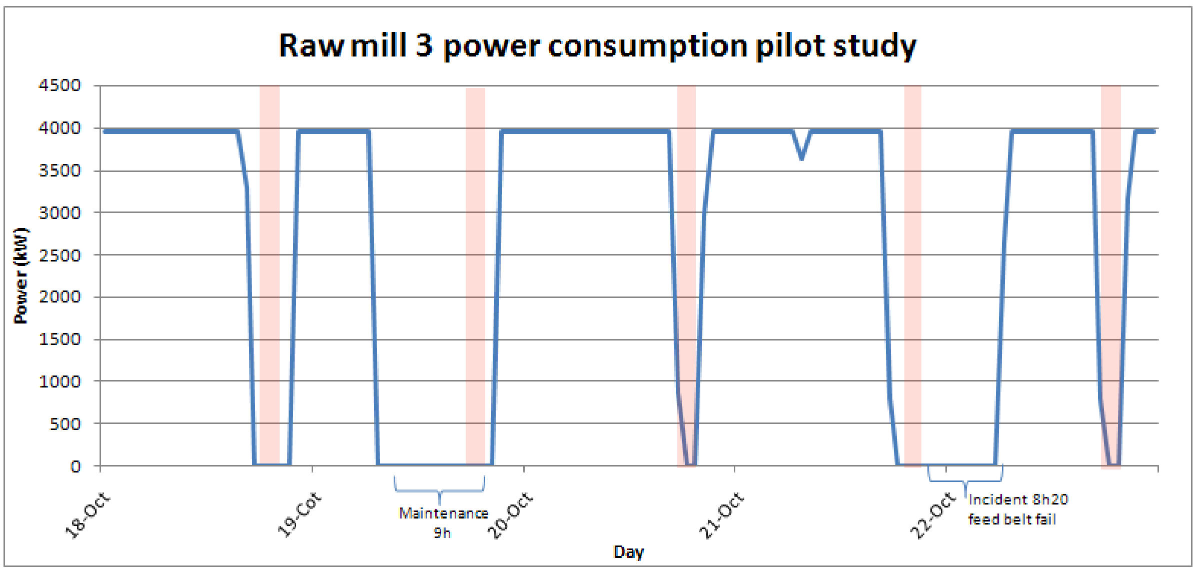


Figure 4.8 - RM3 power consumption pilot study

The baseline of raw mill 3 can be seen in Figure 4.9. The substantial reduction in evening peak period consumption is what was anticipated to be achieved in the pilot study.

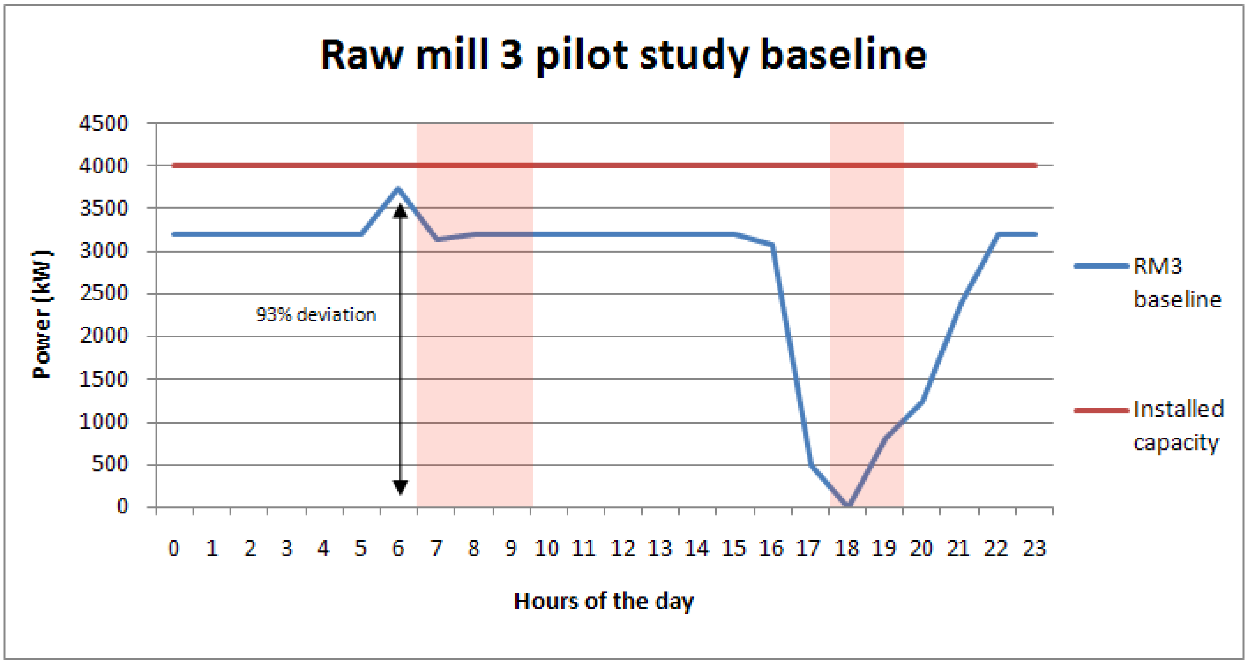


Figure 4.9 - RM3 pilot study baseline

4.3. Performance of the silo simulation

Figure 4.10 provides a comparison of the actual silo levels during the pilot study against the levels generated by silo simulation. The operating hours from Figure 4.8 were used in the simulation to create the change in level for every hour. The simulation has an average error of 3.5%. This deviation may be due to the changing flow rates of the equipment. The simulation uses the average flow rate values obtained from the 3 months of historical SCADA data. Raw mill 3 has a flow rate standard deviation of 15% and kiln 3 of 11%. The actual fluctuation of flow rates experienced would most likely bring about the differences that are seen in Figure 4.10. With a 3.5% error the simulation would be able to provide acceptable information into the changing levels of the silos over a monthly period.

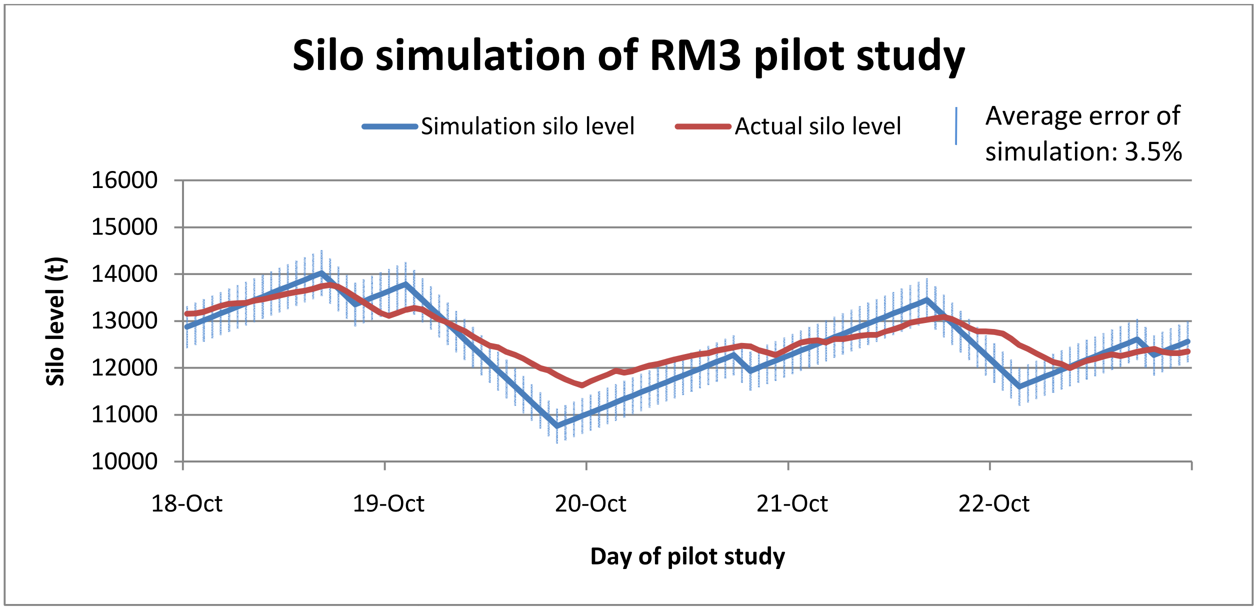


Figure 4.10 - Simulation comparison

Now that the performance of the mills during the pilot study is known, two questions must be answered. How does this affect the electrical costs and why did only one mill achieve the primary objective of the load-shifting scheme?

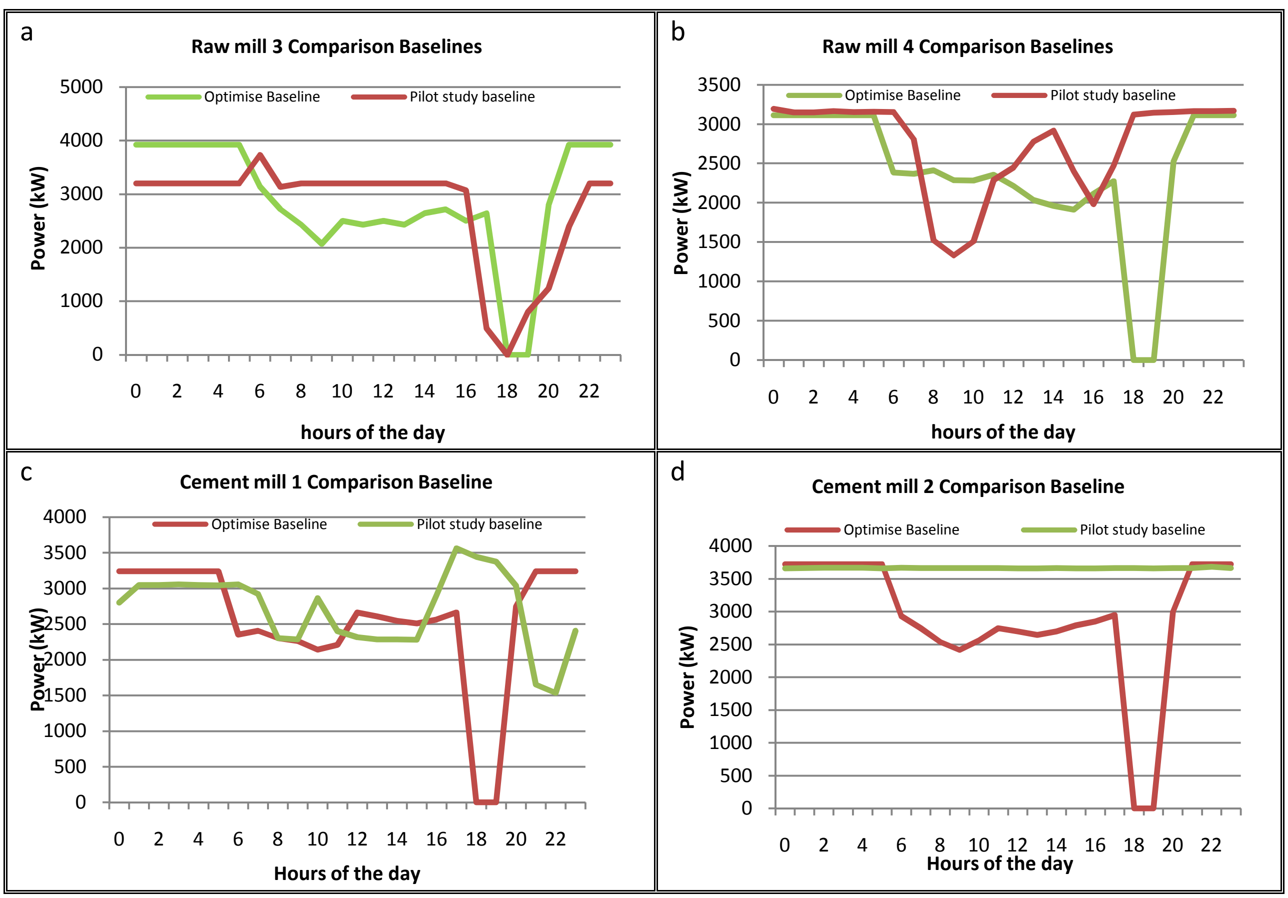
4.4. Change in cost

Table 4.2 lists the hourly average power consumption of the mills during the pilot study. The values were determined with the same method used in Chapter 3 for the initial investigation. The pilot study baselines used in the previous section were created using these values and will be compared to the baselines and costing of the initial investigation.

Figures 4.11a to 4.11e show the optimised baselines of the mills in comparison to the baselines achieved in the pilot study. The two baselines for each mill are considerably different from each other. Not only are the profiles dissimilar but total areas under the curve are also different. This is a clear indication that the average production of the mills over the pilot study were not the same as the three-month period of the investigation. This will be considered when analysing change in electrical cost.

Table 4.2 - Pilot study power consumption, the green shade represents the cheaper off-peak period, the yellow is the standard time and red is the peak period

Hour	RM3 (kW)	RM4 (kW)	CM1 (kW)	CM2 (kW)
0	3200	3194	2803	3663
1	3200	3148	3047	3665
2	3200	3148	3049	3671
3	3200	3164	3056	3669
4	3200	3152	3048	3669
5	3200	3158	3044	3661
6	3733	3154	3058	3670
7	3133	2809	2923	3665
8	3200	1523	2302	3664
9	3200	1330	2285	3665
10	3200	1512	2866	3663
11	3200	2290	2400	3664
12	3200	2449	2318	3662
13	3200	2777	2283	3661
14	3200	2918	2285	3666
15	3200	2400	2280	3663
16	3067	1980	2911	3663
17	493	2473	3564	3665
18	0	3120	3443	3664
19	800	3142	3374	3662
20	1240	3154	3041	3665
21	2400	3165	1654	3668
22	3200	3164	1536	3687
23	3200	3168	2407	3667



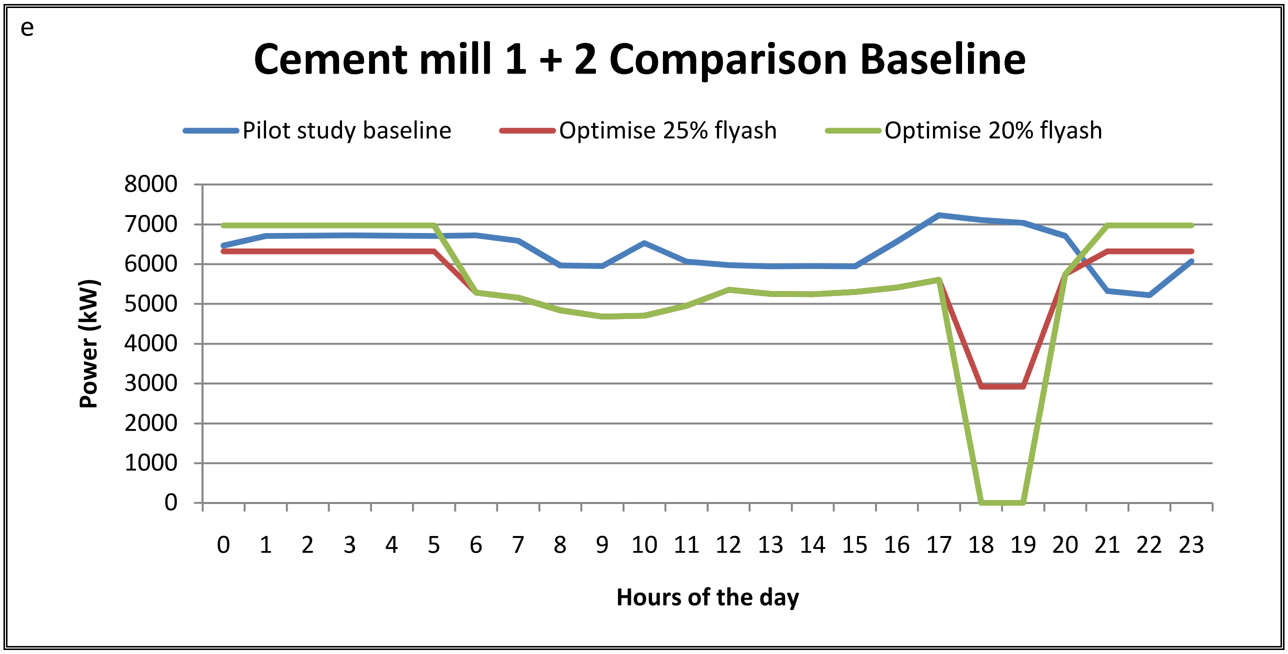


Figure 4.11a to 4.11e - Caparison baselines

The Eskom tariffs stated in Chapter 3 and the hourly power consumption values in Table 4.3 are used to calculate electrical costs for the pilot study. Table 4.3 lists the yearly cost of the mills if they were to operate in the same manner throughout the entire year as they did during the pilot study. It also lists the total yearly costs calculated for the original baseline in Chapter 3.

	RM3	RM4	CM1	CM2
Yearly total	R 6,275,032	R 6,382,796	R 6,665,085	R 8,933,275
Original yearly total	R 6,670,640	R 5,785,710	R 6,173,033	R 6,928,949
Percentage change	6	-10	-8	-29

Table 4.3 – Pilot study yearly costs

As can be seen, raw mill 3 is the only mill to have improved on electrical cost savings. Both cement mills and raw mill 4 had a higher electrical cost than before. Could this be solely as a result of incident hours interrupting the load-shifting scheme, or largely as a result of higher production output? This will be investigated.

Table 4.4 provides the total power consumption of the mills during the pilot study and during the investigation. This is used, as before, as an indication of production rate.

Table 4.4 - Difference in area under the curve

	RM3	RM4	CM1	CM2
Original	68789	57119	61152	69115
Pilot study	66067	65493	64911	87983
Percentage change	4	-15	-6	-27

A pattern can be seen in the change in production. Raw mill 3, the only mill to save money, had a lower production value, and the mills that cost more, had a higher production value. This would lead to a conclusion that the load-shifting and incident hours had little effect on electrical cost, and production rate is responsible for the change in expenses.

To eliminate this influence, each pilot study baseline is either reduced or increased every hour by an equal increment to establish a similar production rate as the original. In other words, the baselines are either shifted up or down so that the area under the curve correlates with the original baseline.

Table 4.5 lists the savings achieved by the mills if the profiles of the baselines during the pilot study remain the same but the magnitude is altered to match the areas under the curve with the original.

Table 4.5 - Shifted pilot study yearly costs

	RM3	RM4	CM1	CM2
Power consumption increment (kW)	+ 113	-349	-157	-786
New yearly total	R 6,551,489	R 5,532,478	R 6,283,324	R 7,017,241
Original yearly total	R 6,670,640	R 5,785,710	R 6,173,033	R 6,928,949
Savings	R 119,151	R 253,223	-R 101,291	-R 88,292
Percentage change	2	4	-2	-1

Results show that raw mill 3 and 4 achieve a reduction in yearly electrical costs by 2 and 4 per cent respectively. This is as a direct result of load-shifting of the electrical peak periods of the day. Both raw mills shifted a total of 9 hours off the peak periods. Because the tariffs of the morning peak and evening peak are the same, it does not make a difference to cost savings whether the hours are shifted in the morning or the evening.

The 2% savings differences between the raw mills are as a result of raw mill 4 experiencing all additional shutdown hours during the standard time. Raw mill 3, however, had additional shutdown hours during standard and off-peak periods, and therefore used more of the higher standard time tariff to meet the same production rate.

Cement mill 1 experienced a significant increase in electrical cost. This is as a result of lower consumption during off-peak periods and higher during peak periods. As discussed previously, this was caused by unpredictable incident hours. Although the mill pilot study achieved the exact opposite of what was sought for, it does however help validate the study of electrical savings. This is because the mill proved that if one could achieve the opposite of the study and *increase* electrical cost by shifting *into* peak periods, then one could also *decrease* cost by shifting *away from* peak periods.

The same applies to cement mill 2. Because the pilot study baseline was shifted to correlate to the production rates, it resulted in less consumption during off-peak periods and higher consumption during peak and standard periods. The shift is illustrated in Figure 4.12. The blue bars represent lower consumption during the hour than previously stipulated in the load-shifting scheme, and the red block represent the higher consumption. The total areas are equal to each other but because the tariffs are higher from 06:00 – 21:00, the pilot study mill operation resulted in higher electrical expenses.

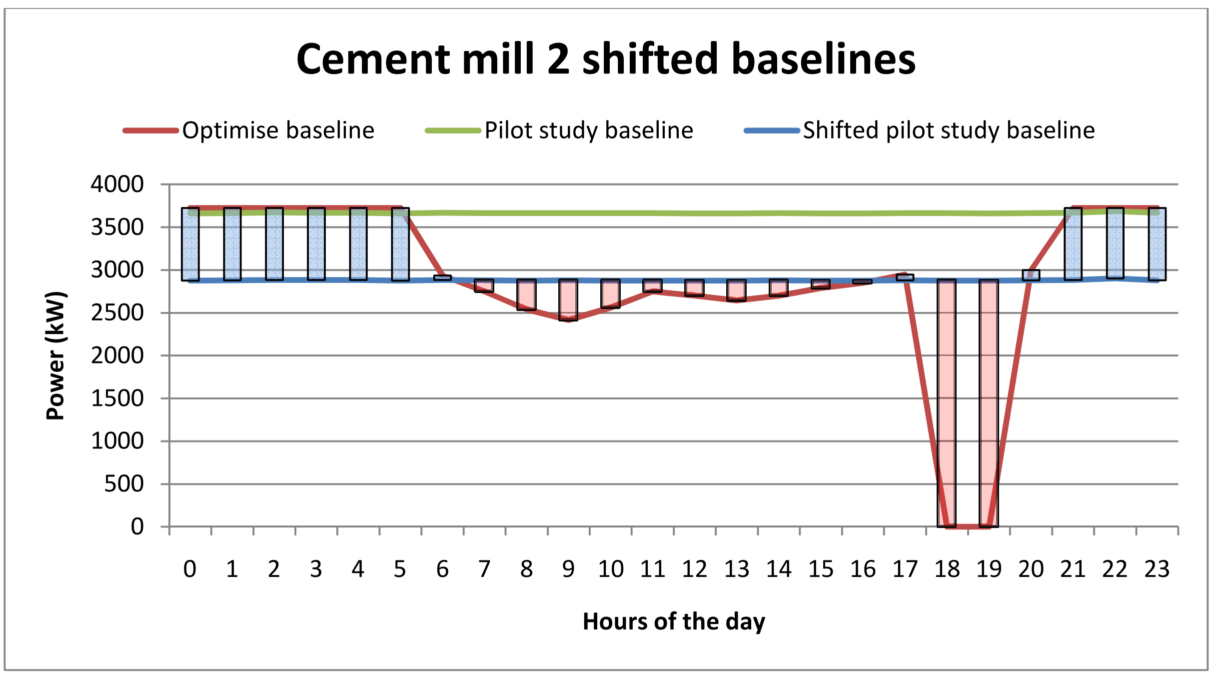


Figure 4.12 - CM2 shifted baseline

4.5. Change in peak period consumption

As stated previously, the objective of a load-shifting scheme for the cement plant would be to reduce the electricity costs. This is however, not Eskom's goal. The utility is interested in *how* the peak period demand is reduced.

Table 4.6 lists the reduction in power consumption during the morning and evening peak periods for each mill during the pilot study. These values are calculated after the baseline was shifted to make their production equal.

Table 4.6 - Pilot study power consumption reduction

	RM3 (kW)	*RM4 (kW)*	*CM1 (kW)*	*CM2 (kW)*	Grand total (kW)
Evening	-4045	572	886	-424	-3012
Morning	2658	-2450	69	931	1208
Total	-1388	-1878	955	507	-1804

The pilot study produced an overall reduction in peak period consumption by 1.8 MW. This is solely due to the evening load-shift of RM3 and CM2 and the morning shift of RM4. The remaining periods produced a rise in demand.

The priority time slot for Eskom is during the evening peak period from 18:00 – 20:00. This is when the country's electrical peak is the highest and threatens the power supply system. With this in mind, the load-shifting pilot study was a success as the plant's evening peak demand decreased by 3 MW.

4.6. Additional pilot study

It was decided to attempt an additional load-shifting pilot study on raw mill 4. This was done after maintenance had been performed on the reclaimer and reliability had been improved.

Figure 4.13 shows the baseline of the additional pilot study, which was performed from 1-5 November 2010. This is compared to the optimised baseline for the mill determined in Chapter 3. As can be seen the profile has a much improved correlation to the optimised baseline than before, as shown in Figure 4.14. No additional hours had been used during the standard time and a reduction in evening peak period was successful. The objective of the load-shifting scheme was achieved. This was done through two partial shifts and one full shift during the evening peak period, and one full morning shift. This is with an additional eight hours of maintenance during standard time.

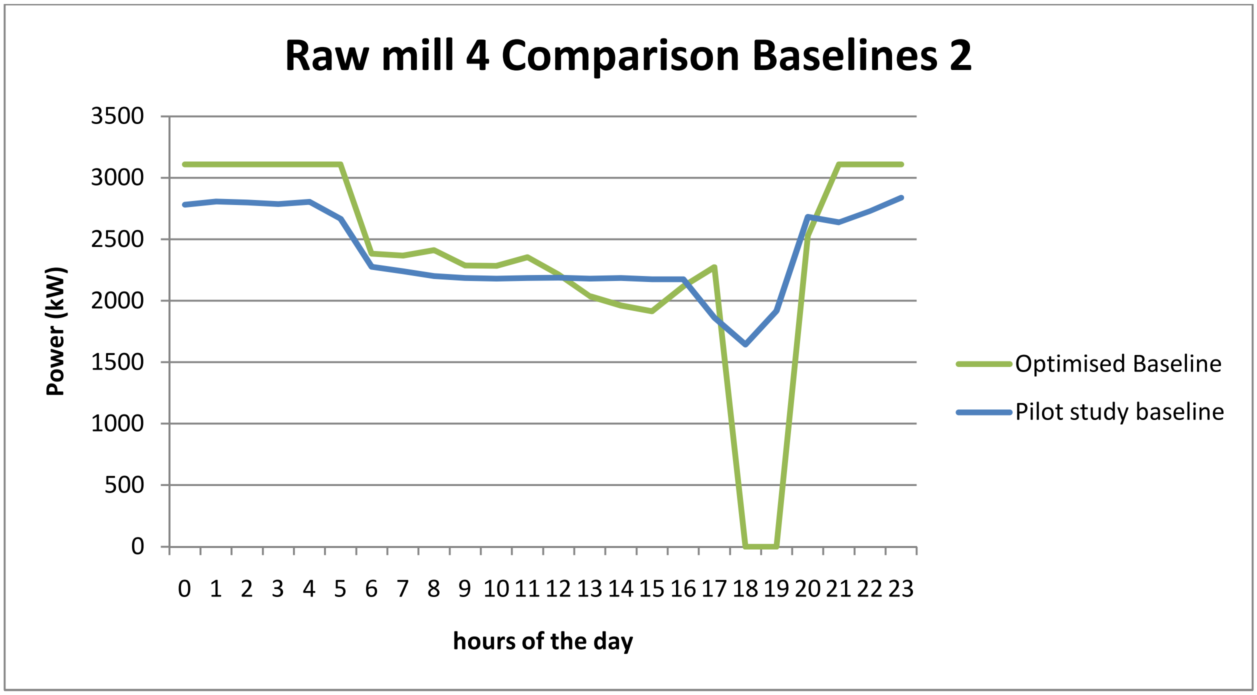


Figure 4.13 - Comparison baseline of additional pilot study on RM4

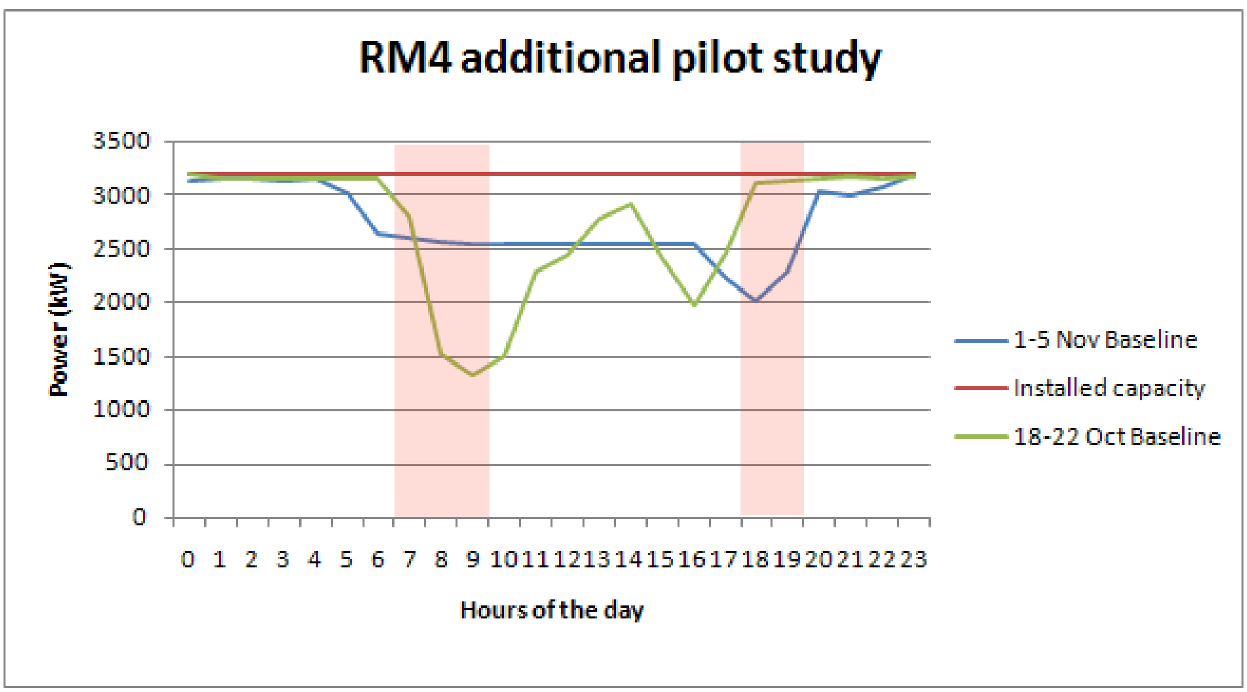


Figure 4.14 - Additional pilot study baseline

Although the baseline profile changes significantly between the pilot studies, it was found that the savings and reduction in peak period consumption were not significantly different. This is shown in Table 4.7. Both cases reduced the peak period consumption by 1.8 MW and had 4% savings on yearly electrical costs. The fundamental difference between them, however, is that the first pilot study increased the consumption in the evening peak periods, whereas the second reduced it. The former performance would therefore better suit Eskom's primary goal of reducing the evening peak consumption.

Table 4.7 – Results of additional pilot study

	1-5 Nov	*18-22 Oct*
	Electrical costs	
Pilot study	R 5,545,757	R 5,532,478
Original	R 5,785,710	R 5,785,710
Savings	R 239,953	R 253,232
Fractional change	0.041	0.044

	1-5 Nov	*18-22 Oct*
	Power consumption (kW)	
Evening	-1434	572
Morning	-438	-2450
Total	-1872	-1878

The additional pilot study confirms that savings are achievable if the reliability of the mill and auxiliary equipment will allow it. The different ways in which the savings were achieved is that the second pilot study was in a planned manner, and the first was a coincidence of incident hours. Regardless, savings are achievable by shifting in the morning or evening peak periods.

4.7. Conclusion

The pilot study produced significantly different results to those expected in Chapter 3. First, the total cost reduction was R183, 000 out of a possible R2.6 million and second, the reduction in peak period demand was 1.8 MW out of a possible 16 MW.

This may be due to the fact that the load-shifting theory relied on a distribution of incident hours over an extended period of time, particularly 3 months. The pilot study was not, however, conducted over such a period of time. Because it only ran over one work week, the occurrences of incident hours and change in daily production rate had a greater influence on the baseline than the original investigation. Despite this, the pilot study produced some insightful results.

The low reliability of raw mill 4 and cement mill 1 would undoubtedly disrupt a load-shifting scheme. During the pilot study the unplanned stoppages resulted in the need to utilise peak periods for production. In the case of the cement mills, it resulted in an increase in electrical costs compared to those calculated with the original baseline. This does not however provide grounds to dismiss savings opportunities. They are unfortunately highly dependent on a daily adaption based on incident hours and silo levels. The mills, although unreliable, are still capable of load-shifting and energy savings. This was shown in the additional pilot study performed on raw mill 4.

Further to this, the increase in production demand on the cement mills resulted in a planned cancellation of the load-shifting scheme. If a change in cement production demand requires an increase in production, and material silos can support it, then the cement mills will not be shut down. During this time, there is no opportunity for energy cost savings. Should demand be reduced the cement mills may be able to shift load. This was not the case, however, during the pilot study.

Raw mill 3 produced promising results. The evening peak period shutdowns reduced the anticipated yearly electrical costs by 2% and reduced demand by 1.88 MW. The mill was still able to achieve the load-shifting scheme with an additional 8.3 hours of incidents and scheduled maintenance.

The pilot study, therefore, provided three cases:

- Successful load-shifting
- Unsuccessful load-shifting due to incident hours
- Unsuccessful load-shifting due to raised production demand

In conclusion, the pilot study was successful in providing insight into how load-shifting may affect, or be affected, by plant operation and equipment reliability.

Chapter 5

Conclusion

5.1. Revision of the research goal

South Africa is under threat of electricity shortages in the near future, and Eskom hopes to reduce the demand to avoid future implications, such as rolling blackouts. After performing a literature survey on global energy efficiency, it became evident that there are several opportunities for electrical energy savings within the cement industry. To what extent can the South African industry exploit these benefits and help Eskom reduce the demand? This is what was set out to be investigated in this study.

The research scope covered an investigation into electricity efficiency options that are applicable to the typical South African cement plant. It also evaluated the opportunity of load-shifting for a particular cement plant. Following these investigations, it is now possible to establish what opportunities there are for South Africa, and to provide recommendations for the future. This is what is discussed in this final chapter of the dissertation.

5.2. Energy efficiency options for the typical South African cement plant

Energy audits and efficiency investigations have been conducted on many international cement plants. This study has looked at investigations conducted on cement plants in Shandong Province, China; United States of America; Canada; Thailand; California; and Germany. All of these provided much insight into the possible energy efficiency opportunities within the cement industry.

The South African cement plant under investigation measured well against the benchmark of the cement plants in the international studies. This is based on the fact that many of the energy saving opportunities had already been implemented by the plant, or they were feasible. The opportunities declared unfeasible were as a result of limited financing or production disruption. They are however still possibilities should these barriers be overcome.

To gain insight into whether the energy efficiencies are applicable to other typical South African cement plants, a preliminary investigation into seven other plants was conducted. General information on plant layout, installed equipment, baselines and power management procedures, was gathered to gain perspective on how South Africa performs against the international cement industries. Table 5.1 lists this information.

The last column of Table 5.1 presents a short list of energy efficiency initiatives adopted by some of the plants. As can be seen, many of the opportunities have already been implemented, and some already have load-shifting schemes in operation. As a result, the South African cement industry compares well with the international industry.

Because of this good level of comparison, all of the opportunities listed in Table 2.1 are applicable to the entire South African cement industry. The degree to which these opportunities are reaped is dependent on how the companies and plants themselves can overcome the barriers and deterrents.

5.3. Load-shifting opportunities for the typical South African cement plant

The process of cement making opens up opportunities for a DSM load-shifting programme. The mills' higher material flow rates compared to those of the kilns, and the storage buffers, can allow the mills to be periodically turned off without adversely effecting production. If the shutdown hours are planned for morning and evening peak periods, the plant can increase utilisation during the lower tariffs of off-peak periods and thereby reduce electrical costs.

The theoretical study on load-shifting produced promising results. It showed that, for the cement plant under investigation, there is a considerable opportunity to save electrical costs by shifting the loads of the raw and cement mills to off-peak periods. Four of the seven additional South African cement plants investigated were also found to have similar opportunities. This is shown in Table 5.1.

Table 5.1 - Information on additional typical South African cement plants, the green shaded rows represent plants with good load-shifting potential, orange represents an intermediate load-shifting potential and red shows no scope for load-shifting

Plant	Plant details					Baselines – load-shifting opportunities. Number of hours available for load-shifting and possible demand reduction per hour.	Notable energy efficiency equipment or load-shifting scheme
	Crushers	RM	CM	Kiln	Coal mill		
A		2	2	2		RM2 RM3 CM1 CM2 kW 190 2200 1660 1302 hours 4 5 1 1	Vertical roller mill, high-efficiency fans, bucket elevators, kiln waste gas used for RM, grate cooler, 4-stage preheater, VSD on kiln & RM fans
B	3	2	2	2	2	No Scope - only using off-peak periods	Grate cooler, Kiln waste gas used for RM, 4-stage pre-heater, full load-shift off standard and peak periods
C	4	2	1	2	2	RM1 RM2 CM kW 1170 1060 1650 hours 6 3 4	No information collected
D	0	1	4	2	2	Only has scope on the RM as one CM operates constantly and the other CM is used only for contingency	Vertical roller mill, high-efficiency fans, kiln waste gas used for RM, load-shifting implemented
E	4	2	2	2	2	No Scope - only using off-peak periods	Full load-shift off standard and peak periods, no information on equipment collected
F	0	2	4	2	2	RM3 RM4 CM1 CM2 CM3 CM4 kW none none 680 620 1040 none hours 6 6 2	VSD on kiln & RM fans, kiln waste gas used for RM, morning load-shift
G	1	1	2	1	1	RM CM5 CM6 kW 2360 2960 3630 hours 3 2 3	Vertical roller mill, high-efficiency fans, bucket elevators, kiln waste gas used for RM, grate cooler, 4-stage preheater, VSD on kiln & RM fans

From the pilot study however, it is evident that performing a load-shifting scheme according to idealised theoretical results is difficult. The mills' operating hours are easily influenced by unpredictable breakdowns. This, together with changes in production, often requires the mills to run when possible to meet demand. Therefore electrical cost savings become a lower priority for plant managers.

Despite this, the electrical cost of load-shifting can be realised if incident hours do not interfere with production, such as in the case of the raw mill 3 pilot study. The ease of shut-down and start-up of the mill motors allows the mills to be turned off without excessive inconvenience to operators to save money. For cement mills, however, the influence of mill temperature over the cement setting quality may deter cement plants from initiating a load-shifting scheme.

5.4. Recommendations

It is therefore suggested that a flexible load-shifting scheme be developed with more focus on load-shifting hours than used in Chapter 3. The previous silo simulation took into account the changing incident hours of the mills and auxiliary equipment, but it did not allow for an adjustable load-shifting scheme.

For example, previous results suggested that although 4 hours of load-shifting were possible, the baselines would only allow 2 hours of evening peak period shutdown every day, with a few hours available during the month to allow for extra incidents or other load-shifting during morning peak periods. A new simulation was created to adjust for the part of the day during which the load-shifting hours occur, morning or evening, and how many times during the month.

In this way, the simulation can be used in a supplementary, dynamic manner and not only calculate a number of hours for every weekday. This would also improve relevance to the morning load-shifts required by the less reliable mills, such as preferred for raw mill 4 in the investigated plant.

Figure 5.1 is a snap shot of the simulation operating window. A full description can be found in Appendix E. As can be seen in the expansion box, it provides a choice as to when the load-shifting shutdowns occur. In this example, the mill can, not only, be shut down every weekday for 2 hours during the evening peak period, but also 3 hours in the morning for three days a week.

This would provide improved flexibility to incident hours that prevent planned load-shifting from occurring. The simulation still relies on an averaging of incident hours over the 31 days, but the improved resolution does, however, serves as an aid to improve the flexibility of the load-shifting scheme.

Figure 5.1 - Improved silo simulation

5.5. Final Conclusion

There are substantial opportunities for energy efficiency and cost savings within the cement industry. Many of the energy efficiency options, however, require large financial expenditures and are highly disruptive to production during installation. If the barriers against such opportunities are overcome, the companies can reap the benefits of significant electrical demand reductions.

Load-shifting provides a good opportunity in the cement making process to save electrical cost. This is however highly dependent on the reliability of the mills, levels of material and the current market demand. Load-shifting schemes should therefore be highly adaptable on a daily basis to shift load when possible.

Because most raw and cement mill motors have power outputs in the order of megawatts, when they are able to shift load, they can greatly reduce demand during peak periods. This is a goal Eskom aims for in a DSM programme. By promoting a habitual procedure of shutting down mills during peak periods, the typical cement plant can help the country avoid power shortages in the near future.

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APPENDIX A – QUESTIONNAIRE

Eskom DSM Feasibility Questionnaire for Cement Plants

General

Date:
Name of plant:
Plant capacity:
Baseline (MWh/year):
Contact Person:
Contact Details: **email:**

Basic Plant Layout

Please list the following

Number of crushers: ____

Number of raw mills: ____ Type: vertical roller mill / ball mill / hammer mill /other (please specify) ___________________

Are the raw mills provided hot air from: a furnace / kiln waste gases / other yes / no

Type of transport system between raw mill and stock: mechanical /pneumatic. . /other _______________________

Type of particle size separator following raw mill:

Type of pre-heater:

Number of kilns: _____ Type: _______

If more than one, are they fed by separate silos? yes / no

Do they feed into one set of silos? yes / no

If not, please explain layout____________________________________

Type of clinker cooler: (example: grate cooler)

Number of cement mills:________ Type: vertical roller mill / ball mill / roller press (crusher) /other (please specify)

Type of particle size separator following cement mill:

Do you prepare your kiln fuel on site, i.e. coal mills? yes / no

Please draw a basic layout of the plant

SCADA Data

Does the SCADA display information on the:

Crushers	yes / no
Raw mills	yes / no
Silo levels -Raw meal	yes / no
-Clinker	yes / no
Kiln	yes / no
Cement mills	yes / no
Coal mills	yes / no

What information does the SCADA log? (Example: electrical demand, flow rate)

Does it provide historic profiles?

It is possible to provide at least 3 months of SCADA data?

Raw Mill

	Example	RM _	RM _	RM _	RM _
Type	Ball mill				
Installed capacity (kW)	2160 kW				
Running capacity (kW)	1620 kW				
How often does planned maintenance occur?	2 Times per month				
How long is this planned maintenance? (hours)	9 Hours				
On what day of the week does planned maintenance occur?	Tuesdays				
Average running hours on Weekdays	24				
Average running hours on Saturdays	24				
Average running hours on Sundays	24				
Mill flow rate (t/h)	300 t/h				

Raw Meal Silo

	Example	Silo ___	Silo ___	Silo ___	Silo ___	Silo ___
Fed by Raw Mill number?	RM 1 &2					
Maximum level	12, 000 tons					
Minimum allowable level	6, 000 tons					
Feed to kiln (t/h)	215 t/h					

Kiln

	Example	Kiln __	Kiln __	Kiln __
Kiln Type	Rotary			
Maximum capacity (tpd)	2500			
Average flow rate (t/h)	104			
Size of motors rotating the kiln (kW)	1000			
Electrical consumption by fans (kW)	100			
Variable speed drive for fans (yes / no)	Yes			
Preheater, and number of stages?	5 stage			
In line calciner? (yes/no)	No			

Finishing Mills

	Example	FM _	FM _	FM _	FM _
Type of mill	Vertical roller mill				
Installed capacity of mill motor (kW)	1044 kW				
Running capacity of mill motor (kW)	783 kW				
How often does planned maintenance occur?	2 Times per month				
How long is this planned maintenance? (hours)	9 Hours				
On what day of the week does planned maintenance occur?	Tuesday				
Average running hours on weekdays	24				
Average running hours on Saturdays	24				
Average running hours on Sundays	24				
Mill flow rate (t/h)	350 t/h				

Clinker Silo

	Example	Silo__	Silo __	Silo __	Silo __	Silo ___
Fed by Kiln number?	Kiln 1					
Maximum level	12, 000 tons					
Minimum allowable level	6, 000 tons					
Feeds into finishing mill number?	FM 1 & 2					

APPENDIX B – DATA COLLECTION AND SUMMARY

STOPPAGE HOURS:

Stoppage hours of raw mills from May - July stoppage records (Stoppage data)						
	RM3			RM4		
Type	May	June	July	May	June	July
Power management	0	0	96.86	0	0	4.86
Storage	1.89	0	75.08	2.06	4.44	28.14
Incident	84.07	70.17	18.68	62.02	85.71	37.01
Maintenance	16.23	14.27	22.77	12.03	0	2.43
Upstream	209.33	177.03	9.42	58.94	127.46	370.67
Total shutdown	311.52	261.47	222.81	135.05	217.61	443.11
Average Daily Incident	5.6			6.0		

Stoppage hours of cement mills from May - July stoppage records (Stoppage data)						
	CM1			CM2		
Type	May	June	July	May	June	July
Storage	53.02	61.17	55.95	7.59	60.37	29.58
Incident	52.66	22	70.02	34.96	46.16	61.95
Maintenance	195.61	6.14	30.36	36.74	145.74	0
Upstream	7.38	34.89	0	0	0	0
Total shutdown	308.67	124.2	156.33	79.29	252.27	91.53
Average Daily Incident	3.88			2.59		

Daily stoppage hours of kilns from daily reports May - July						
	Kiln 3			Kiln 4		
	May	June	July	May	June	July
			0.28	5.71	14.55	
			1.29	11.18	2.52	
			0.00	8.57	0.00	
			0.00	0.00	0.00	
	0.00		0.00	0.00	0.00	
	0.00	18.72	0.00	0.00	3.24	
	1.29	9.04	0.54	6.25	20.11	
	0.37	0.00	0.00	0.10	0.00	
	0.00	1.44	0.00	0.00	0.00	
	0.00	0.82	0.00	0.00	0.00	
	0.90	0.19	0.00	0.29	0.45	
	0.31	0.00	23.84	0.00	0.00	
	0.00	0.44	2.03	0.00	0.00	
	0.00	0.00	0.00	0.00	12.65	
	0.00	0.00	0.00	0.00		
	0.00	0.00	0.00	0.00	5.55	1.75
	0.00	0.00	1.03	0.00	0.00	1.56
	0.61	0.00	0.06	0.00	0.05	9.23
	0.00	0.00	0.48	0.00	8.36	1.21
	0.00	0.00	0.00	0.41	0.88	3.33
	0.00	0.00	0.00	0.00	0.40	0.00
	5.15	0.00	0.00	9.66	0.00	0.00
	14.33	0.00	0.00	0.00	0.00	0.00
		0.00	0.00	0.00	0.06	0.00
		0.78	5.63	0.00	0.00	2.33
		0.20	0.00	0.00	0.00	0.00
		0.21	0.29	0.06	0.00	0.71
		0.37	0.35	0.19	0.00	0.00
		0.00	0.00	0.04	8.57	0.17
		0.00	1.08	0.00		0.00
			0.00	5.02		10.00
Average	1.23			2.07		

Note: The shutdown times of 24hrs were removed from the data set. This is because they greatly reduce the accurately of the average incident hours for while the kiln is operational

FLOW RATES:

Average flow rates are taken from daily reports May - July 2010 (t/h)

date	*RM3*	*RM4*	*CM1*	*CM2*	*Kiln 3*	*Kiln 4*
01-May		163	131	174		90
02-May		147	170			83
03-May		153	84	179		50
04-May		167	130	176		83
05-May	238	158	112	180	99	84
06-May	183	154	139	177	99	55
07-May	226	158	145	178	102	64
08-May	239	161	151	174	90	85
09-May	251	162	132	174	115	90
10-May	233	161	130	202	97	90
11-May	216	146	91	177	108	67
12-May	245	156	85	174	115	90
13-May	202	150		169	133	86
14-May	229	114		175	131	78
15-May	241	165		173	127	88
16-May	239	167		177	131	92
17-May	242	164		157	127	93
18-May	218	161		160	119	90
19-May	236	164		186	118	86
20-May	145	135	107	191	130	74
21-May	216	165	149	186	125	73
22-May	238	159	134	180	116	82
23-May		167	135	178	120	85
24-May		161	198	179		90
25-May		161	97	190		90
26-May		163	90	191		90
27-May		161	132	187		90
28-May		153	157	186		91
29-May		159	151	188		91
30-May		143	155	187		91
31-May		148	167	182		85
Average	224	156	132	180	116	83

date	*RM3*	*RM4*	*CM1*	*CM2*	*Kiln 3*	*Kiln 4*
01-Jun		147	149	186		54
02-Jun		146	147	171		80
03-Jun		160	131	190		88
04-Jun		153	132	186		90
05-Jun		160	109	300		91
06-Jun		146	132	217	58	78
07-Jun	199	161	132	176	105	75
08-Jun	238	169	155	174	120	91
09-Jun	233	143	155	174	123	91
10-Jun	243	421	99	176	119	60
11-Jun	226	128	85	180	126	55
12-Jun	223	143	142	178	126	69
13-Jun	218	138	149	175	122	84
14-Jun	218	123	164	183	123	61
15-Jun	208	0	150	184	123	
16-Jun	198	108	148	192	123	62
17-Jun	215	130	132	193	123	61
18-Jun	228	102	103	197	123	50
19-Jun	226	130	128	199	120	47
20-Jun	229	141	163	193	95	65
21-Jun	357	167			128	71
22-Jun	254	143	104	193	129	84
23-Jun	254	155	137	193	129	82
24-Jun	258	158	164		132	85
25-Jun	274	164	128		123	89
26-Jun	266	160	119	179	128	90
27-Jun	242	159		101	120	90
28-Jun	245	159	105	174	125	90
29-Jun	207	171	127	173	128	83
30-Jun	244	0	121	172	127	
Average	238	146	132	186	120	76

date	*RM3*	*RM4*	*CM1*	*CM2*	*Kiln 3*	*Kiln 4*
01-Jul	253		130	176	133	
02-Jul	252		135	192	127	
03-Jul	260		118	190	133	
04-Jul	248		72	181	130	
05-Jul	230		79	175	128	
06-Jul	230		99	184	129	
07-Jul	249		144	180	119	
08-Jul	260		119	173	128	
09-Jul	261				123	
10-Jul	254				126	
11-Jul	261				120	
12-Jul	0		128	146	138	
13-Jul	247				117	
14-Jul			136	177	129	
15-Jul	261		140	181	115	
16-Jul	252	37	145	198	128	44
17-Jul	259	141	147	189	125	73
18-Jul	255	170	147	171	124	80
19-Jul	242	163	170	186	130	87
20-Jul	229	151	138	185	132	84
21-Jul	266	154	132	196	123	90
22-Jul	265	152	159	107	124	88
23-Jul	266	156	128	101	129	82
24-Jul	265	165	136	145	125	87
25-Jul	258	155	124	140	115	87
26-Jul	267	167	84	184	136	91
27-Jul	268	167	82	169	127	79
28-Jul	269	166	113	175	131	91
29-Jul	264	167	123	179	133	89
30-Jul	262	167	142	166	132	90
31-Jul	268	156	129	159	133	62
Average	247	152	126	171	127	81

Raw mill 3	235 t/h
Raw mill 4	150 t/h

Cement mill 1	130 t/h
Cement mill 2	180 t/h

Kiln 3	120 t/h
Kiln 4	80 t/h

Note:

Blank spaces represent data loss

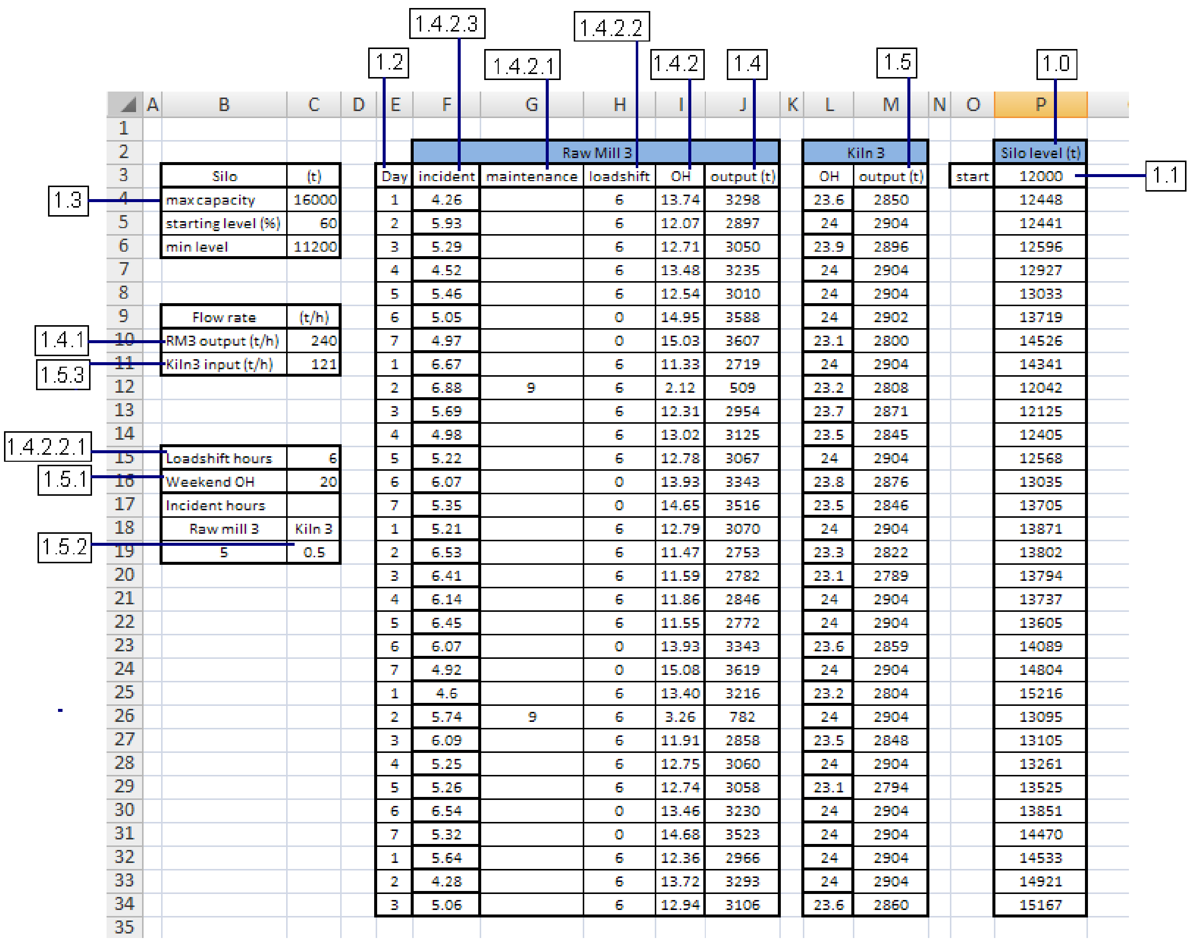
Average flow rate values are rounded to the nearest number dividable by 5

APPENDIX C – SIMULATION SOFTWARE

Raw Meal Silo Simulation Explanation

The simulation is run on an Excel spreadsheet, as shown in Figure C1. The simulation spreadsheets can be found on a CD appended to this dissertation. The labels in the figure relate to the function numbers of the influential factors used in the silo simulation schematic in Chapter 3. This is shown again in Figure C2 for convenience.

The numbers indicate where the values for the factors are stored in the simulation to calculate the changing silo level over a period of one month. It also gives an indication where equations are used in calculations. Table C1 provides further explanation of the influencial factors and Table B2 lists the set of equations used in the spreadsheet. The list in Table C2 provides the equations for the first day of the simulation which are adapted for the remaining 30 days.



Silo	(t)
max capacity	16000
starting level (%)	60
min level	11200

Flow rate	(t/h)
RM3 output (t/h)	240
Kiln3 input (t/h)	121

Loadshift hours	6
Weekend OH	20
Incident hours	
Raw mill 3	Kiln 3
5	0.5

	Raw Mill 3					Kiln 3			Silo level (t)
Day	incident	maintenance	loadshift	OH	output (t)	OH	output (t)	start	12000
1	4.26		6	13.74	3298	23.6	2850		12448
2	5.93		6	12.07	2897	24	2904		12441
3	5.29		6	12.71	3050	23.9	2896		12596
4	4.52		6	13.48	3235	24	2904		12927
5	5.46		6	12.54	3010	24	2904		13033
6	5.05		0	14.95	3588	24	2902		13719
7	4.97		0	15.03	3607	23.1	2800		14526
1	6.67		6	11.33	2719	24	2904		14341
2	6.88	9	6	2.12	509	23.2	2808		12042
3	5.69		6	12.31	2954	23.7	2871		12125
4	4.98		6	13.02	3125	23.5	2845		12405
5	5.22		6	12.78	3067	24	2904		12568
6	6.07		0	13.93	3343	23.8	2876		13035
7	5.35		0	14.65	3516	23.5	2846		13705
1	5.21		6	12.79	3070	24	2904		13871
2	6.53		6	11.47	2753	23.3	2822		13802
3	6.41		6	11.59	2782	23.1	2789		13794
4	6.14		6	11.86	2846	24	2904		13737
5	6.45		6	11.55	2772	24	2904		13605
6	6.07		0	13.93	3343	23.6	2859		14089
7	4.92		0	15.08	3619	24	2904		14804
1	4.6		6	13.40	3216	23.2	2804		15216
2	5.74	9	6	3.26	782	24	2904		13095
3	6.09		6	11.91	2858	23.5	2848		13105
4	5.25		6	12.75	3060	24	2904		13261
5	5.26		6	12.74	3058	23.1	2794		13525
6	6.54		0	13.46	3230	24	2904		13851
7	5.32		0	14.68	3523	24	2904		14470
1	5.64		6	12.36	2966	24	2904		14533
2	4.28		6	13.72	3293	24	2904		14921
3	5.06		6	12.94	3106	23.6	2860		15167

Figure C1 - Raw meal silo simulation schematic

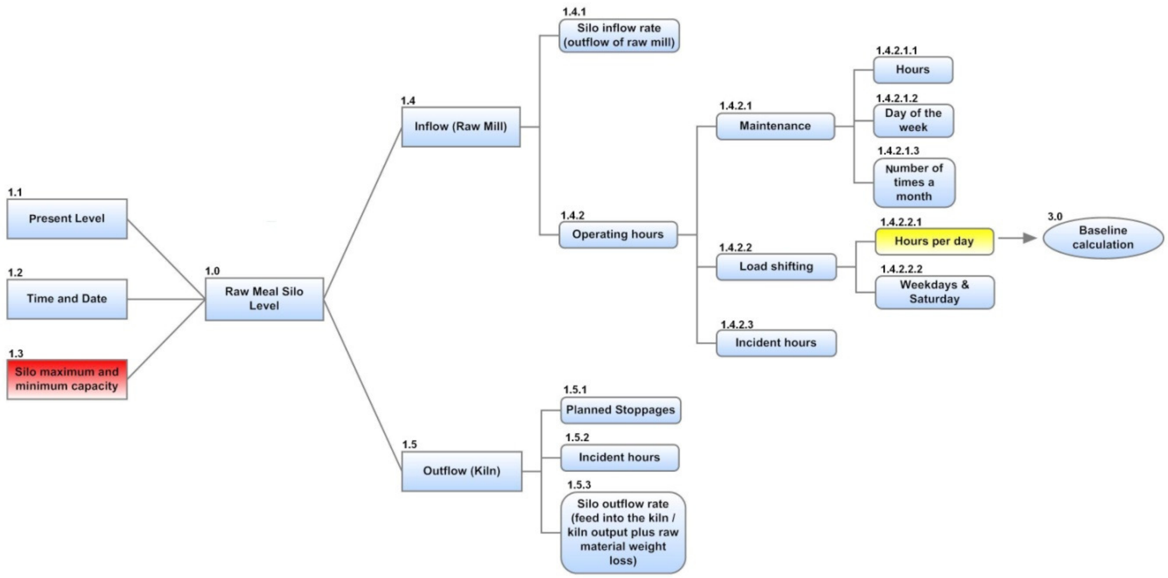


Figure C2 - Raw meal silo flow diagram

Table C1 - Raw Meal Silo Simulation

Number	Label	Description
1.0	***Raw meal silo level***	Simulating the change in silo level
1.1	**Current level**	Input variable from silo SCADA
1.2	**Time and date**	Hour of the day and day of the week
1.3	**Silo max and min capacity**	Changing level must be between the maximum and minimum level
1.4	**Inflow (Raw mill)**	Flow of material into the silo
1.4.1	Silo inflow rate	Rate at which the raw mill feeds material into the silo
1.4.2	Operating hours	Running time of the cement mill per day
1.4.2.1	Maintenance	Planned stoppages
1.4.2.1.1	Hours	Number of hours the maintenance is planned for
1.4.2.1.2	Day of the week	What day of the week maintenance is performed
1.4.2.1.3	Number of times a month	How many times in one month the maintenance is performed
1.4.2.2	Load-shifting	Load-shifting possibilities for the raw mill
1.4.2.2.1	Hours per day	How many hours are available to turn off during peak periods
1.4.2.2.2	Weekdays and Saturdays	How many days a week the load-shifting can be performed
1.4.2.3	Incident hours	Number of unplanned stoppages per day
1.5	**Outflow (Kiln)**	Flow of material out of the silo
1.5.1	Planned stoppages	Stoppages of the kiln due to maintenance or low production requirements
1.5.2	Incident hours	Number of unplanned stoppages per day
1.5.3	Silo outflow rate	Rate at which material is removed from the silo

Table C2 – Raw meal silo simulation equations for first row in Figure B1

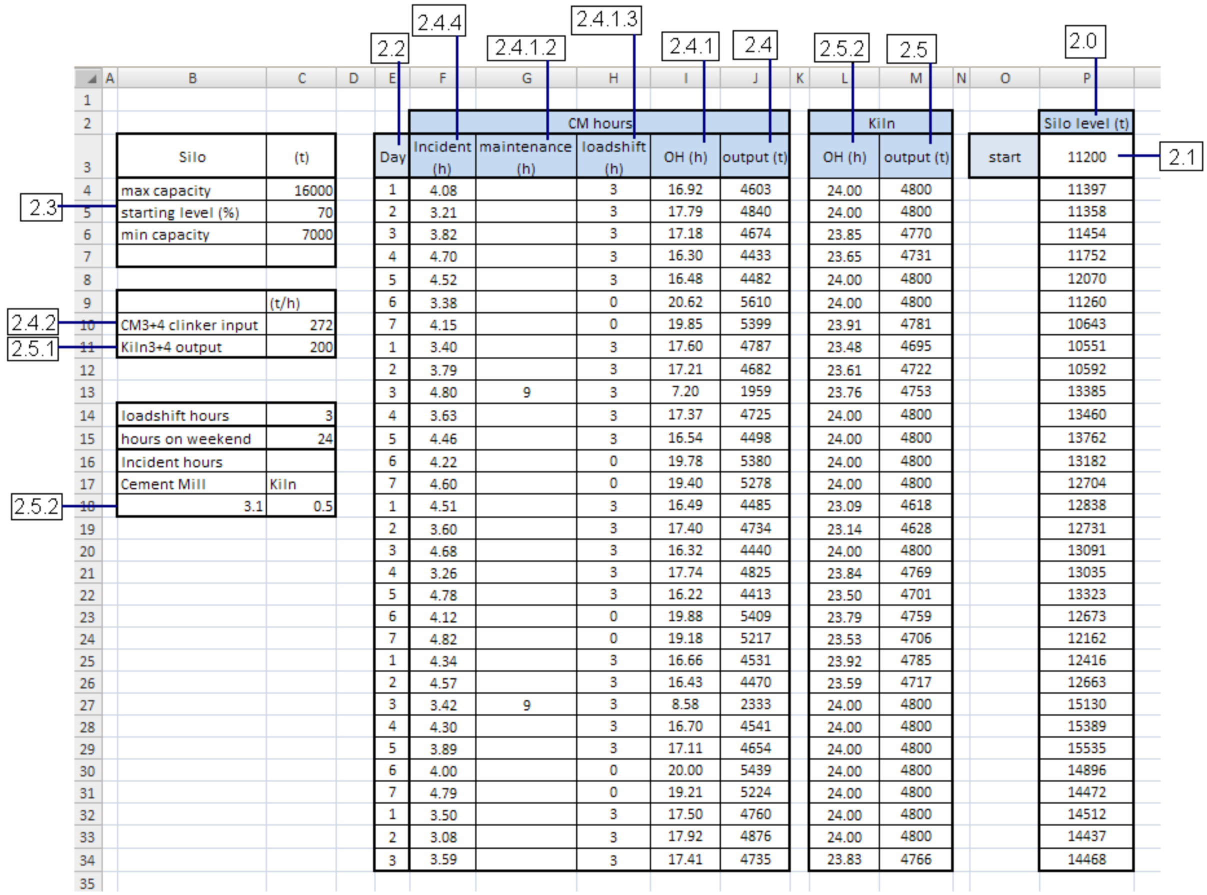
Simulation number	Equation	Description
1.0	$P4 = P3 + J4 - M4$	New silo level is equal to the previous silo level plus raw mill output minus kiln output
1.4	$J4 = I4 * \$C\$10$	Output of the raw mill is equal to flow rate multiplied by operating hours
1.4.2	$I4 = IF(IF(E4 > 5, \$C\$16 - F4{,}24 - H4 - F4 - G4) < 0{,}0, IF(E4 > 5, \$C\$16 - F4{,}24 - H4 - F4 - G4))$	OH is equal to 24hrs minus maintenance and incident hours on a weekday and 20hrs maintenance and incident hours on a weekend. Cannot be less than 0hrs
1.4.2.2:	$H4 = IF(E4 < 6, \$C\$15{,}0)$	Load-shifting only on weekdays
1.4.2.3:	$F4 = RANDBETWEEN(\$B\$19 * 0.7, \$B\$19 * 1.3) + RAND()$	Generated incident hours around a 30% range of average historical incident hours
1.5	$M4 = L4 * \$C\$11$	Output of the kiln is equal to flow rate multiplied by operating hours
1.5.2	$K4 = RANDBETWEEN(23.5 * 0.95{,}23.5 * 1.05) + RAND()$	*Hidden: operating hours reduced by generated incident hours around a 5% range of average historical incident hours
	$L4 = IF(K4 > 24{,}24, K4)$	Kiln operating hours cannot be greater than 24hrs

Clinker silo simulation

The clinker silo simulation is the same as the raw mill silo simulation with two exceptions:

1. The equation for changing silo level equals previous level plus the kiln output minus the mill output
2. Flow rate of the cement mills vary according to brand of cement

Figure C3 provides a screen shot of the clinker silo level simulator. Figure C4 is the schematic of the simulation used in Chapter 3. Tables C3 and C4 provide descriptions for the schematic and the equations for the simulation.



Silo	(t)
max capacity	16000
starting level (%)	70
min capacity	7000

	(t/h)
CM3+4 clinker input	272
Kiln3+4 output	200

loadshift hours	3
hours on weekend	24
Incident hours	
Cement Mill	Kiln
3.1	0.5

	CM hours					Kiln			Silo level (t)
Day	Incident (h)	maintenance (h)	loadshift (h)	OH (h)	output (t)	OH (h)	output (t)	start	11200
1	4.08		3	16.92	4603	24.00	4800		11397
2	3.21		3	17.79	4840	24.00	4800		11358
3	3.82		3	17.18	4674	23.85	4770		11454
4	4.70		3	16.30	4433	23.65	4731		11752
5	4.52		3	16.48	4482	24.00	4800		12070
6	3.38		0	20.62	5610	24.00	4800		11260
7	4.15		0	19.85	5399	23.91	4781		10643
1	3.40		3	17.60	4787	23.48	4695		10551
2	3.79		3	17.21	4682	23.61	4722		10592
3	4.80	9	3	7.20	1959	23.76	4753		13385
4	3.63		3	17.37	4725	24.00	4800		13460
5	4.46		3	16.54	4498	24.00	4800		13762
6	4.22		0	19.78	5380	24.00	4800		13182
7	4.60		0	19.40	5278	24.00	4800		12704
1	4.51		3	16.49	4485	23.09	4618		12838
2	3.60		3	17.40	4734	23.14	4628		12731
3	4.68		3	16.32	4440	24.00	4800		13091
4	3.26		3	17.74	4825	23.84	4769		13035
5	4.78		3	16.22	4413	23.50	4701		13323
6	4.12		0	19.88	5409	23.79	4759		12673
7	4.82		0	19.18	5217	23.53	4706		12162
1	4.34		3	16.66	4531	23.92	4785		12416
2	4.57		3	16.43	4470	23.59	4717		12663
3	3.42	9	3	8.58	2333	24.00	4800		15130
4	4.30		3	16.70	4541	24.00	4800		15389
5	3.89		3	17.11	4654	24.00	4800		15535
6	4.00		0	20.00	5439	24.00	4800		14896
7	4.79		0	19.21	5224	24.00	4800		14472
1	3.50		3	17.50	4760	24.00	4800		14512
2	3.08		3	17.92	4876	24.00	4800		14437
3	3.59		3	17.41	4735	23.83	4766		14468

Figure C3 - Clinker silo simulation schematic

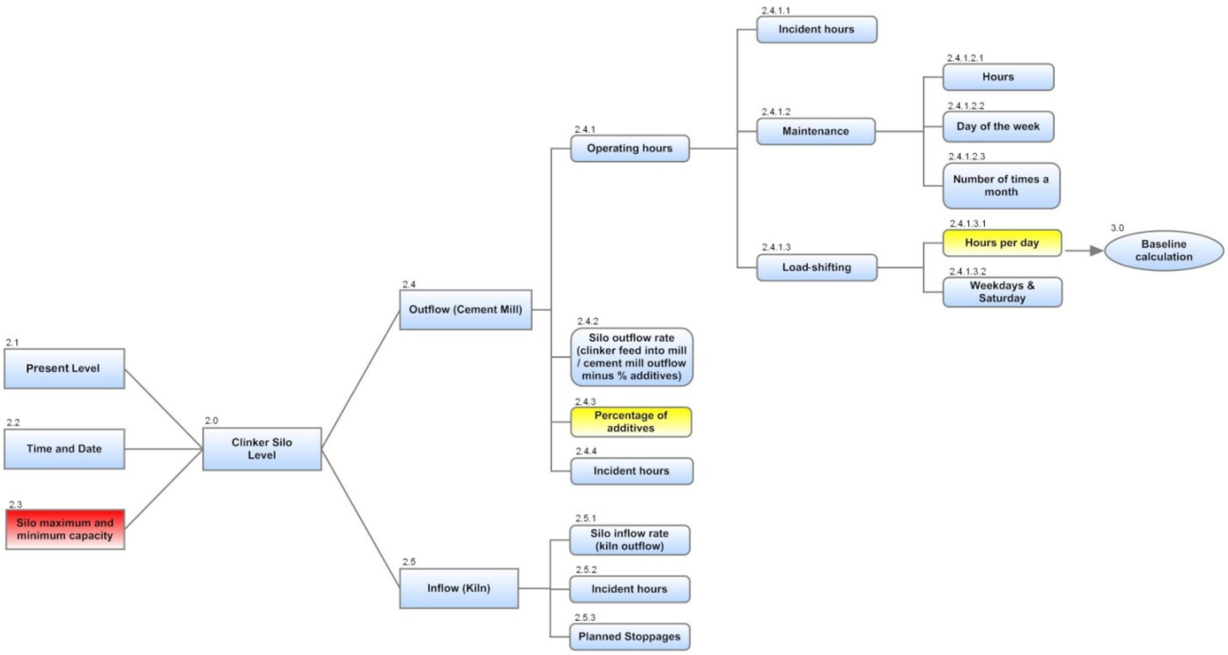


Figure C4 - Clinker silo flow sheet

Table C3 - Clinker Silo Simulation

Number	Label	Description
2.0	***Clinker silo level***	Simulating the change in silo level
2.1	**Current level**	Input variable from silo SCADA
2.2	**Time and date**	Hour of the day and day of the week
2.3	**Silo max and min capacity**	Changing level must be in range between the maximum and minimum level
2.4	**Outflow (Cement mill)**	Flow of material out of the silo
2.4.1	Operating hours	Running time of the cement mill per day
2.4.1.1	Incident hours	Number of unplanned stoppages per day
2.4.1.2	Maintenance	Planned stoppages
2.4.1.2.1	Hours	Number of hours the maintenance is planned for
2.4.1.2.2	Day of the week	What day of the week maintenance is performed
2.4.1.2.3	Number of times a month	How many times in one month the maintenance is performed
2.4.1.3	Load-shifting	Load-shifting possibilities for the raw mill
2.4.1.3.1	Hours per day	How many hours are available to turn off during peak periods
2.4.1.3.2	Weekdays and Saturdays	How many days a week the load-shifting can be performed
2.4.2	Silo outflow rate	Rate at which material is removed from the silo
2.4.3	Percentage of additives	The amount of fly ash added to the cement mill with the clinker
2.4.4	Incident hours	Number of unplanned stoppages per day
2.5	**Inflow (Kiln)**	
2.5.1	Silo inflow rate	Rate at which the raw mill feeds material into the silo
2.5.2	Incident hours	Number of unplanned stoppages per day
2.5.3	Planned stoppages	Stoppages of the kiln due to maintenance or low production requirements

Table C4 - Clinker silo simulation equations for the first row of Figure B3

Simulation number	Equation	Description
2.0	$P4 = P3 - J4 + M4$	New silo level is equal to the previous silo level plus kiln output minus cement mill output
2.4	$J4 = I4 * \$C\$10$	Output of the raw mill is equal to flow rate multiplied by operating hours
2.4.1	$I4 = IF(IF(E4 > 5, \$C\$16 - F4, 24 - H4 - F4 - G4) < 0, 0, IF(E4 > 5, \$C\$16 - F4, 24 - H4 - F4 - G4))$	OH is equal to 24hrs minus maintenance and incident hours on a weekday and 20hrs maintenance and incident hours on a weekend. Cannot be less than 0hrs
2.4.1.1	$F4 = RANDBETWEEN(\$B\$18 * 0.7, \$B\$18 * 1.3) + RAND()$	Generated incident hours around a 30% range of average historical incident hours
2.4.1.3	$H4 = IF(E4 < 6, \$C\$14, 0)$	Load-shifting only on weekdays
2.4.2	$C10 = 302 * \%clinker\ (0.85; 0.8; 0.75)$	Flow rate of clinker depends of % fly ash used
2.5	$M4 = L4 * \$C\$11$	Output of the kiln is equal to flow rate multiplied by operating hours
2.5.2	$K4 = RANDBETWEEN(23.5 * 0.95, 23.5 * 1.05) + RAND()$	*Hidden: operating hours reduced by generated incident hours around a 5% range of average historical incident hours
	$L4 = IF(K4 > 24, 24, K4)$	Kiln operating hours cannot be greater than 24hrs

Baseline simulation

The baseline uses the approach described in Chapter 3. The flow schematic is included in Figure C5 and described in Table C5.

Figure C5 - Baseline calculation schematic

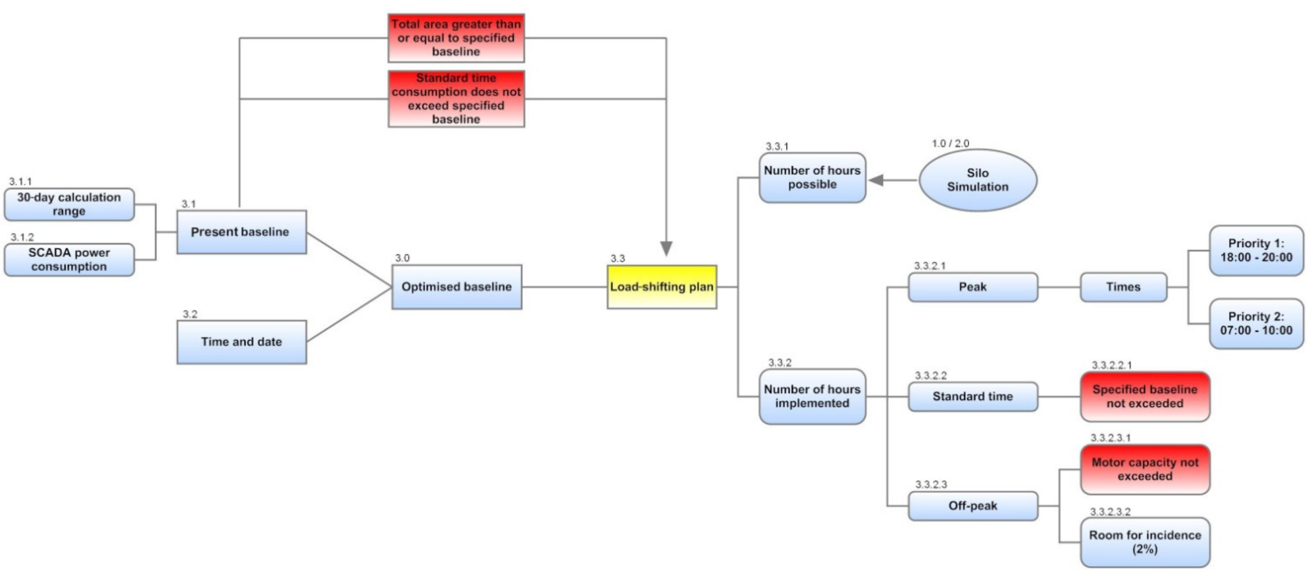


Table C5 - Baseline Calculation Description

Number	Label	Description
3.0	***Action baseline***	The baseline that will be implemented for load-shifting
3.1	**Current baseline**	The actually baseline of the time
3.1.1	Calculation range	30-day calculation range from present day
3.1.2	SCADA power consumption	Average kW used for every hour of the day; 0h - 23h
3.1.a	Area	Area of the action baseline must be equal to original baseline
3.1.b	Standard time usage	Load-shifting can only take place if the standard time usage of the current baseline is not exceeding the original baseline
3.2	**Time and date**	Hour of the day and day of the week
3.3	**Load-shifting plan**	Load-shifting potential
3.3.1	Number of hours possible	Number of hours calculated by the silo simulation
3.3.2	Number of hours implemented	The actual amount of hours to be load-shifted in the baseline profile
3.3.2.1	Peak	Eskom's peak time periods where load is shifted away from
3.3.2.2	Standard time	Eskom's standard time where load may not be shifted to
3.3.2.2.1	Specified baseline	Original standard time baseline may not be exceeded
3.3.2.3	Off-peak	Eskom’s off-peak period where load is shifted to
3.3.2.3.1	Motor capacity	Off-peak consumption cannot exceed the motor possibilities
3.3.2.3.2	Room for incidence	Extra incident hours allowed should unplanned stoppage occur during standard time and production need to be taken up during off-peak periods

APPENDIX D - PROBABILITY OF A POSITIVE SILO CHANGE

The probabilities were determined by recording the effect of randomly generated incident hours of the simulation. If the silo ended with a negative change at the end of 31 days, the probability matrix was assigned a zero. If the effect was a positive change it was assigned a one. The average value of the matrix provides the probability of a positive silo level change.

RM3 probability of positive effect with 6 hrs load-shift

	Number of times										
	0	10	20	30	40	50	60	70	80	90	
1	1	1	1	0	1	1	0	1	0	1	
2	1	0	1	0	1	1	1	1	1	1	
3	0	1	1	0	1	1	1	1	0	0	
4	1	1	0	1	1	0	0	1	0	1	
5	1	1	0	1	0	1	1	1	1	1	
6	1	1	1	1	1	1	1	1	0	1	
7	1	0	1	0	1	1	0	1	1	0	
8	1	1	1	1	1	1	1	1	1	0	
9	0	1	1	1	0	1	1	0	1	1	Avg
0	1	1	1	0	1	1	0	1	0	1	0.73

RM3 probability of positive effect with 7 hrs load-shift

	Number of times										
	0	10	20	30	40	50	60	70	80	90	
1	0	0	0	1	0	0	1	0	0	0	
2	1	1	0	1	1	1	0	0	0	1	
3	0	0	0	1	1	0	0	1	0	0	
4	1	1	1	0	1	1	0	0	0	1	
5	0	1	0	1	0	1	0	0	0	0	
6	0	0	0	0	0	1	0	1	0	1	
7	1	0	1	1	1	0	0	0	0	0	
8	0	0	1	1	0	0	0	1	0	1	
9	0	1	0	0	1	0	1	1	1	0	Avg
0	1	0	0	0	0	1	0	0	0	0	0.38

RM4 probability of positive effect with 4 hrs load-shift

	Number of times										
	0	10	20	30	40	50	60	70	80	90	
1	1	1	1	1	1	1	1	1	1	1	
2	0	1	1	1	1	1	0	1	1	1	
3	1	1	0	1	1	1	1	1	1	1	
4	1	1	1	1	1	1	1	1	1	1	
5	1	1	0	1	1	1	1	0	1	1	
6	1	0	1	1	1	1	1	1	1	1	
7	1	1	1	1	1	1	1	1	1	1	
8	1	1	1	1	1	1	1	0	1	1	
9	1	1	1	0	1	1	1	1	1	1	Avg
0	1	1	1	1	1	1	1	1	1	1	0.92

APPENDIX E – RECOMMENDED SIMULATION SOFTWARE

The recommended simulation uses the same principles as the previous simulation used in Chapter 3. However, it has an added ability to shift a number of hours for both the morning and evening, peak periods for a different number of times during the month.

The eight choices for number of times during the month are shown in Table D1:

Table D1 - Load-shifting expansion box

Number	Option	Priority day
1	1 time a month	1st Mon
2	2 times a month	1st, 2nd Mon
3	3 times a month	1st, 2nd, 3rd Mon
4	one day a week	Mon
5	two days a week	Mon, Wed
6	three days a week	Mon, Wed, Fri
7	four days a week	Mon, Tue, Wed, Thu
8	every weekday	Mon to Fri

These are used in a draw out box in the simulation to choose from, as seen in the Figure D1. The simulation uses a priority day of load-shifting for each option as seen in Table D1. This is used for both the morning and evening shift.

The simulation uses scale buttons (see Figure D1) to easily change the number of load-shifting hours for each period. It also allows an easy change of planned maintenance for the mills and starting and minimum silo levels. For ease of switching simulations between the different production lines, a check dot (see Figure D1) can be used to automatically load the values used for each simulation.

A similar simulation can be made to calculate changing clinker silo levels with a scale button to change fly ash percentage. This would automatically alter the flow rate of the clinker out of the silo and change the silo level graph.

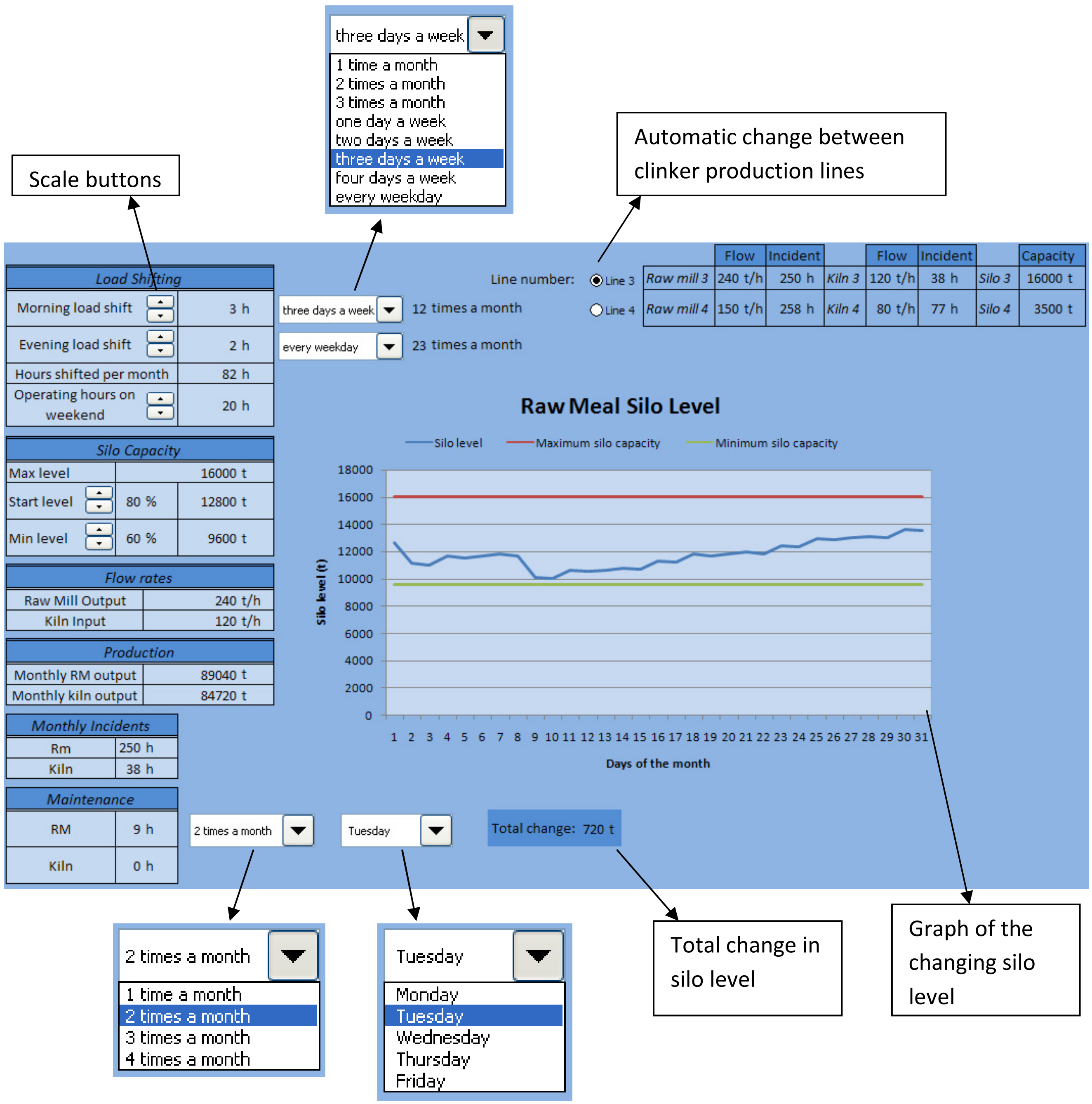


Figure D1 - Recommended simulation