

Evaluation and implementation of DSM strategies to improve the profitability of marginal cement grinding plants

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Dissertation submitted in fulfilment of the requirements for the degree
Magister in Mechanical Engineering at the Potchefstroom campus of
the North-West University

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November 2015

ABSTRACT

Title: Evaluation and implementation of DSM strategies to improve the profitability of marginal cement grinding plants

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The cement industry in South Africa is becoming increasingly competitive. Established cement producers have old inefficient production plants that have to compete with new cement producers abroad. These new cement companies are entering South Africa with more energy efficient production equipment that gives them an advantage when the current increases in electricity tariffs are considered. Established local cement plants have to investigate new initiatives to become more competitive.

Replacing old and inefficient equipment with modern energy-efficient equipment is in most cases not a viable option. This is due to the large initial capital expenditure, long payback periods and installation downtime. Cement producers must rather aim to decrease their energy consumption with minimal capital expenditure and zero influence on production output, quality or safety.

Established cement grinding plants are among the industries most affected by steep electricity tariff increases. In most cases the pre-clinker processes of marginal plants are already decommissioned and thus the majority of these operations focuses on performing finishing/cement milling due to the plants geographic distribution advantage. These plants seldom run at full capacity as a result of inefficiencies. This spare capacity can, therefore, be utilised by implementing demand-side management electricity savings initiatives.

Load management was proven a cost-effective method for reducing energy costs on marginal cement grinding plants. Load management takes advantage of Eskom's time-of-use tariff structures by shifting the operation of electricity intensive components from high demand (high cost) periods to low demand (low cost) periods while still maintaining the same production output. Effective load management will reduce electricity cost without influencing production output, quality or safety.

An effective load management method was researched and implemented on two marginal cement grinding stations. Previous evaluation strategies have not created a platform on which the performances of different cement plants could be compared; therefore, a more comprehensive method for evaluating load management was developed. The evaluation strategy analyses the reduced electricity cost and compares it with the electricity cost of a more modern cement grinding plant to determine whether the marginal cement plant remains competitive.

In this study, the electricity costs of marginal cement plants are lowered by more than 10% by executing the proposed load management strategy. The evaluation strategy also found that load management could improve a marginal cement grinding plant's electricity cost intensity to such an extent that the electricity cost differs by only 1% when compared with modern cement grinding plants operating as per normal production schedules. Load management was, therefore, a cost-effective solution to reduce electricity costs on marginal cement grinding plants and remains competitive with modern cement grinding plants.

ACKNOWLEDGEMENTS

First, I want to thank the Lord for His guidance throughout my life and His blessings that enabled me to complete this master's dissertation. I hope that my work and accomplishments bring honour and glory to His name.

Thank you to my parents and family for your continuous support, encouragement and wisdom that led me to complete this study. To my wife, Christelle, thank you for the patience, cheer and love throughout this process of hard work.

Special thanks to Dr Jan Vosloo, Dr Riaan Swanepoel and Mr Waldt Hammer for your time, technical guidance and constructive criticism regarding this study. Thank you to Prof. Eddie Mathews and Prof. Marius Kleingeld for allowing me to be part of TEMM International and Enermanage, and for the financial support from these institutions.

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LIST OF ABBREVIATIONS

DSM	Demand-Side Management
EMS	Energy Management System
ESCO	Energy Services Company
IDM	Integrated Demand Management
NERSA	National Energy Regulator of South Africa
NPC	Natal Portland Cement
OPC	OLE for Process Control
PMT	Production Management Tool
PPC	Pretoria Portland Cement
PTB	Process Tool Box
SCADA	Supervisory Control and Data Acquisition
PLC	Programmable Logic Controller
TOU	Time of Use
VSD	Variable Speed Drive

GLOSSARY OF TERMS

Cement grinding plants – Type of cement plant that only performs finishing/cement milling due to a geographic distribution advantage.

Electricity cost intensity – The total electricity cost to produce one unit of cement.

Blaine fineness – The fineness of a powdered material, such as cement, as determined by the Blaine apparatus; usually expressed as a surface area in square centimetres per gram.

Calcination – Heat treatment in the presence of oxygen.

Simulation – A virtual replication of a physical system.

Weightometer – Device that automatically weighs and records the tonnage of ore in transit on a belt conveyor.

Cementitious – Substance that has the characteristics of cement.

CHAPTER 1

Introduction

Chapter 1

Motivates the relevance of the study. The background, objectives and scope of the study are discussed. A full dissertation overview is also included in the chapter.

1 INTRODUCTION AND BACKGROUND

Cement production is an energy-intensive process. The cement industry uses as much as 12–15% of the total industrial electricity consumption [1]. Cement production in South Africa is a competitive industry. Some producers were founded as far back as the nineteenth century.¹ Electricity constraints, rising electricity costs and challenging economic conditions motivate existing producers to seek electricity savings initiatives with low capital expenditure.

Cement producers strive to produce high quality cement at minimal electricity cost to remain competitive. This, however, is challenging when old and inefficient plants contribute to a cement company’s production capacity. There is a need to reduce electricity cost by methods that require low capital expenditure. In addition, an effective method of evaluating electricity usage is vital for reducing electricity cost and benchmarking performance between plants.

1.1 CEMENT PRODUCTION IN SOUTH AFRICA

Five major cement companies produce cement in South Africa. A sixth cement producer has started building a new plant; it will be commissioned in 2016. Table 1-1 ([2], [3]) lists the major cement producers in South Africa with their respective cement-manufacturing plants and production capacities per annum.

Table 1-1: The production capacity of the South African cement industry

Company	Plants in South Africa	Production capacity [Mt per annum]
Pretoria Portland Cement (PPC)	Jupiter, Hercules, De Hoek, Dwaalboom, Slurry, Riebeeck	7.5
Natal Portland Cement (NPC)	Durban, Simuma, New Castle	1.7
Sephaku	Delmas, Aganang	2.6
Lafarge	Lichtenburg, Randfontein, Richards bay	3.5
Afrisam	Roodepoort, Ulco, Vanderbijlpark, Dudfield	4.2
Mamba (planning phase)	Northam	1.0
Total	19	20.5

¹PPC, ‘PPC history,’ 2015. [Online]. Available: <http://www.ppc.co.za/zimbabwe/about-us/our-history/>. [Accessed: 31-Jan-2015].

PPC, NPC and the multinational Lafarge and Afrisam are well-established cement manufacturers in South Africa. In 2013, Sephaku Holdings Limited opened its Delmas and Aganang cement plants that added 2.6 Mt per annum production capacity to the South African market.^{II} Engineering News announced that the R1.8 billion Mamba cement plant would be opened by Jidong Development Group and the China–Africa Development Fund. The plant is expected to be completed early 2016, thus adding another one million tonne per annum capacity to the South African cement market.^{III}

South African cement producers experience competition on a local and international level. According to an article published in Business Day Live, 1.1 million tonne of cement was imported from India, Vietnam and Pakistan in 2013. Imported cement poses a big risk to local producers as it is sold cheaper than locally produced cement. The cheaper price of imported cement can be attributed to South Africa's electricity price hikes and cement plants that are energy inefficient.^{IV}

New analysis from market researcher, Frost & Sullivan, predicts massive growth within the South African cement industry. The government plans to spend an estimated R4 trillion on rail, road, energy and water infrastructure upgrades that will incentivise cement manufacturers abroad to invest in South Africa.^V South Africa's cement sale volume amounted to only 12.07 Mt in 2014.^{VI} The producing capacity is much larger than the demand; this adds to market share competition between companies.

Cement companies have both marginal and modern cement grinding plants that contribute to their production capacities. A marginal plant is an aging cement grinding plant utilising horizontal balls mills that is less efficient than other cement grinding plants utilising modern vertical roller mills. The demand for cement is lower than the supply, modern grinding plants

^{II}Sephaku Cement, "Projects," 2015. [Online]. Available: http://www.sephakucement.co.za/media/pdf/sephaku_brochure.pdf. [Accessed: 31-Jan-2015].

^{III}Engineering News, "Mamba cement," 2015. [Online]. Available: <http://www.engineeringnews.co.za/article/mamba-cement-manufacturing-plant-project-south-africa-2014-08-22>. [Accessed: 31-Jan-2015].

^{IV}BusinessDay Live, "Cement imports," 2015. [Online]. Available: <http://www.bdlive.co.za/business/industrials/2014/04/29/imports-supply-glut-pressure-cement-sector>. [Accessed: 31-Jan-2015].

^VSouth Africa Info, "Investment," 2015. [Online]. Available: <http://www.southafrica.info/business/investing/opportunities/cement>. [Accessed: 31-Jan-2015].

^{VI}Engineering News, "Q4 domestic cement sales up 1.7% y/y," 2015. [Online]. Available: <http://www.engineeringnews.co.za/article/q4-domestic-cement-sales-up-17-yy-2015-04-07>. [Accessed: 21-Oct-2015].

are fully utilised before any production is allocated to marginal plant. Marginal plants are also first in line to be decommissioned when a company's production capacity becomes too high for the sales demand.

The South African cement market is becoming increasingly competitive as a result of rapid increases in local production capacity and cheap imports. Manufacturers must lower their cement production cost, especially on marginal plants to increase profitability and remain competitive locally and internationally.

Cement production electricity usage

Cement production is electricity intensive. South African cement plants use the dry cement production method, which is more electricity intensive than the wet cement production process. A typical modern cement plant uses between 110–120 kWh of electricity to produce a tonne of cement. Electrical energy can account for 10–30% of total cement production cost [1], [4], [5]. Electrical energy is mainly used to operate crushing equipment, grinding equipment and supporting auxiliaries such as blowers, small motors and compressors [6].

Figure 1-1 shows electricity cost as a percentage of total operational cost for companies from various sectors in South Africa. Two of the major South African cement producers, Lafarge and Afrisam, are compared with other electricity intensive industries.

On average, Lafarge attributed 15% and Afrisam 10% of their operational cost to electricity cost. Electricity usage in the cement industry is higher than for most other electricity intensive industries listed in the Figure 1-1 [7].

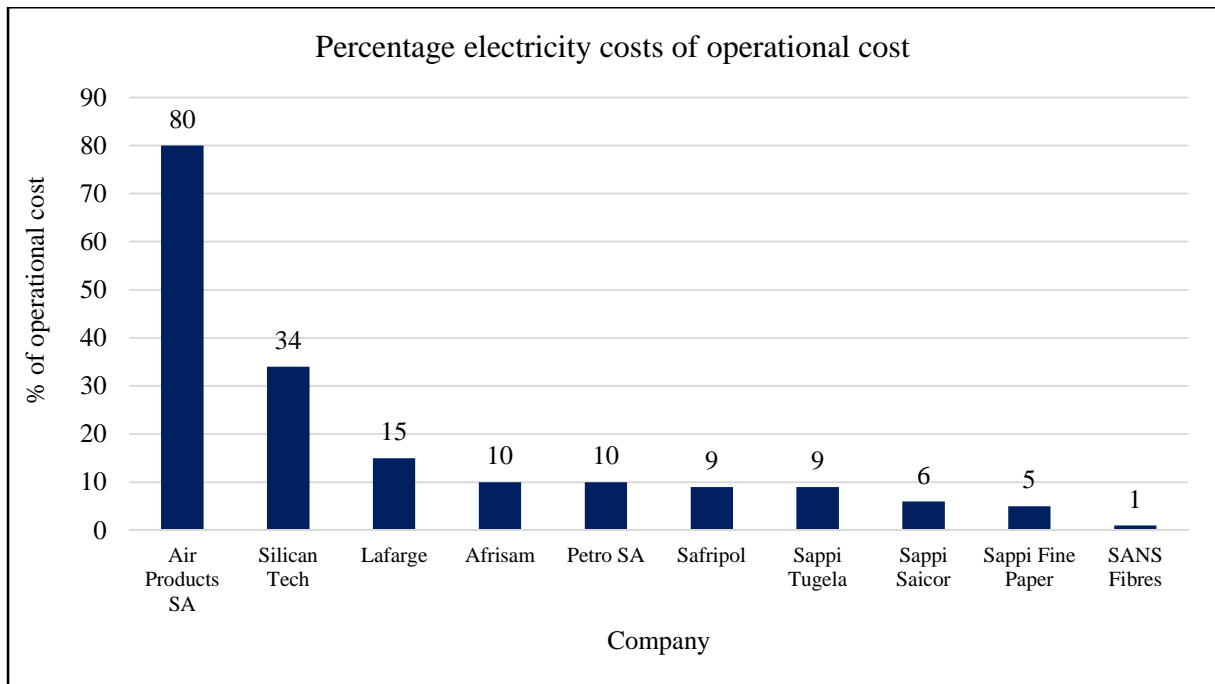


Figure 1-1: Electricity cost as a percentage of operational cost

1.2 SOUTH AFRICAN ELECTRICITY CONSTRAINTS

Eskom is the leading power utility in South Africa. The company generates, transmits and distributes electricity to South Africa and parts of sub-Saharan African. Eskom supplies electricity to residential, industrial, mining, commercial, agricultural and municipal entities. In 2014, the total nominal capacity of the 27 power plants operated by Eskom is 41 995 MW. The type of power generation and the total capacity that each type contributes are listed in Table 1-2 [8].

Table 1-2: Eskom power generation capacity

Power generating station type	Total megawatt
Coal-fired power station	35 726
Nuclear power station	1 860
Gas-fired power station	2 409
Hydro and pump-storage plants	2 000
Total	41 995

Increase in Eskom tariffs

The power utility, Eskom, cannot meet the peak-time consumer demand, thus electricity tariffs rapidly increase each year. In 2004, the economy was growing faster than expected and with it the electricity demand. The country experienced its first power crisis in 2008. Mines, factories, business and households were left without electricity for extended periods of time [9].

Eskom implemented load shedding that essentially interrupted electricity supply to certain areas due to insufficient supply. In addition to electricity constraints, the power utility also faces a R225 billion funding shortfall for the period up to March 2018. As a result, Eskom does not have enough capital to complete new power plants. To remedy the crisis, tariff hikes and government capital injections were approved.^{VII}

According to Business Day Live, Eskom applied for a cost increase of 16% per annum for the five years. Their proposal was reduced by the National Energy Regulator of South Africa (Nersa) to only an 8% increase per annum after opposition by business, trade unions and civil society groups at public hearings.^{VIII} Pressure from financial and electricity supply fronts forced Nersa to approve a 12.69% tariff hike in 2015.

Deloitte conducted a study that assessed the vulnerability of rising electricity prices on different sectors in the South African economy. The study focused mainly on employment, output and profitability of various sectors. The study proved that increases in electricity costs have a negative impact on the growth of employment and output of all sectors except the electricity, gas and water sectors [7].

Figure 1-2 shows that the rising electricity price does not correspond with general inflation in South Africa. Inflation from 2005 to the 2015 shows a steady incline compared with the steep incline of electricity prices from 2008. The rapid electricity tariff increase (as shown by Figure 1-2) supports the notion by the Deloitte study that the electricity intensive cement industry is affected negatively.

^{VII}BusinessDay Live, "Tariff hikes," 2015. [Online]. Available: <http://www.bdlive.co.za/business/energy/2014/10/06/tariff-hike-for-eskom-will-be-just-the-start>. [Accessed: 31-Jan-2015].

^{VIII}BusinessDay Live, A. Seccombe, "BDlive," BusinessDay, 28 February 2013. [Online]. Available: <http://www.bdlive.co.za/business/energy/2013/02/28/nersa-grants-eskom-8-annual-increases-over-next-five-years>. [Accessed: 04-Jun-2015].

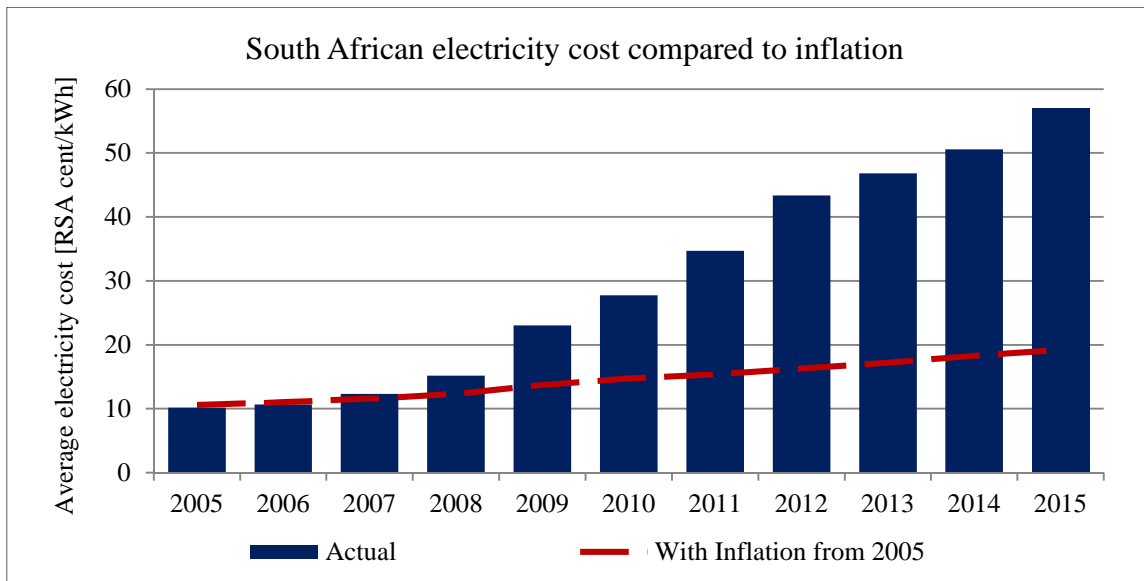


Figure 1-2: South African electricity cost and inflation trend^{IX,X}

The financial constraints Eskom is experiencing will continue to support an upwards electricity cost trend. The tariff increases will continue for the foreseeable future and most likely stay high to alleviate the power utility’s accumulated debt. Cement producers should lower their electricity costs through effective electricity management to counteract the effect of tariff increases. Demand-side management (DSM) is an effective method for lowering the electricity cost of a cement plant.

1.3 DEMAND-SIDE MANAGEMENT

The Integrated Demand Management (IDM) programme was established by Eskom to help relieve the demand pressure that the power utility is facing. This initiative focuses on optimising energy use and balancing electricity supply and demand. DSM is an initiative under the IDM programme that modifies major consumers’ electricity demand profiles by providing financial incentives.^{XI} DSM can be divided into load management, peak clipping and energy efficiency. The three methods of DSM are shown in Figure 1-3 [10], [11].

^{IX} Eskom Enterprises (Pty) Limited, “Tariffs and charges,” 2015. [Online]. Available: <http://www.eskom.co.za/c/article/145/tariffs/>. [Accessed: 23-Jun-2015].

^X Statistics South Africa, “Consumer price index (CPI),” 2015. [Online]. Available: <http://www.statssa.gov.za/keyindicators/cpi.asp/>. [Accessed: 08-Aug-2015].

^{XI} Eskom, “About,” 2015. [Online]. Available: <http://www.eskom.co.za/sites/idm/AboutUs/Pages/About>. [Accessed: 08-Aug-2015].

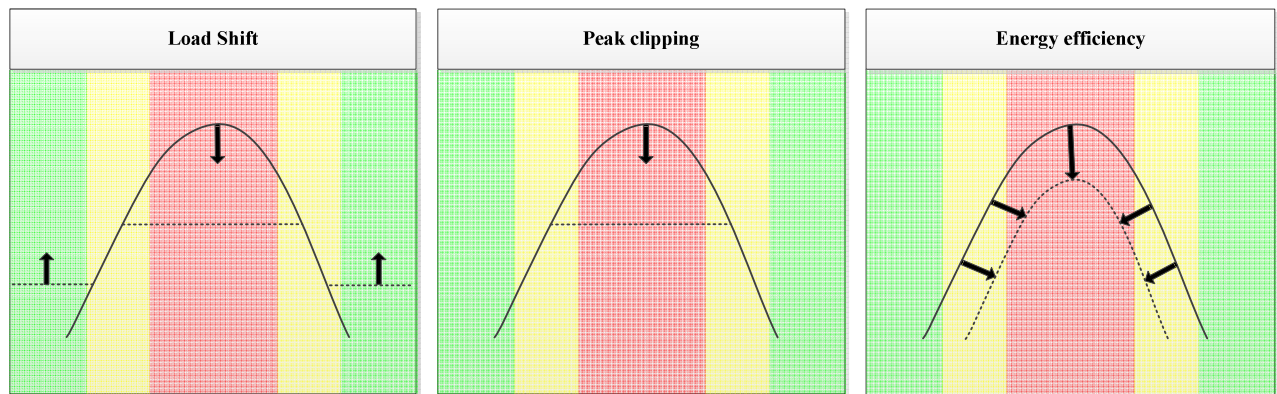


Figure 1-3: DSM strategies

Load management is the effective utilisation of low-cost periods presented by the time-of-use (TOU) tariff structure. A TOU tariff structure assigns high electricity tariffs to periods when a power utility experiences high demand from consumers; lower tariffs are assigned to low demand periods. The three main load management strategies are load shifting, energy efficiency improvement and, when combined, peak clipping [12].

Effective load shifting shifts the use of electricity intensive units from high demand periods to low demand periods while maintaining the same production output. The energy consumption remains the same before and after load management implementation with a reduction in electricity cost. Energy efficiency lowers electricity usage while maintaining the same production output. This method lowers electricity evenly throughout a day and does not give preference to a specific time period [12].

Peak clipping is achieved when energy efficiency improvements are combined with load shifting. The two most common examples of peak clipping are applying energy efficiency improvement to TOU peak periods or improving production capacity and subsequently using the excess capacity to reduce production during high demand periods.

DSM strategies will be investigated further during the literature review. Energy efficiency, load management and peak clipping will be evaluated individually and the most cost-effective solution will be implemented on marginal cement grinding stations.

1.4 STUDY DESCRIPTION

1.4.1 Problem statement

Electricity prices are rapidly increasing operational cost in an electricity intensive cement market. Cement producers abroad enter the competitive South African cement market with efficient modern plants. Marginal cement grinding plants of existing cement companies must participate in electricity savings initiatives to improve their overall plant competitiveness. This study is aimed at reducing electricity cost to improve a marginal cement grinding plant's profitability.

1.4.2 Hypothesis

Implementing DSM on a marginal cement grinding plant will ensure competitiveness in the market.

1.4.3 Research objectives

The objectives of the study are as follows:

- a) Research load management implementation and evaluation strategies in the cement industry.
- b) Propose an implementation and evaluation strategy for load management on a marginal cement grinding plant.
- c) Evaluate the electricity cost intensity of a marginal and modern cement grinding plant.
- d) Conclude whether load management can improve the profitability of a marginal cement grinding plant when compared with a modern cement grinding plant.

1.4.4 Scope of study

The focus of the study is to examine the effect that DSM strategies have on a marginal cement grinding plant's electricity costs. The production lines of cement grinding plants have different production methods, rates, equipment, capacity, products and tariff structures. Electricity cost intensity is most commonly associated with the electricity cost of producing one tonne of cement, hence cost per tonne.

The marginal cement plants considered for DSM are cement grinding plants. Cement grinding plants buy clinker from other cement plants that produce clinker via kilns. The electricity costs only represent finishing/cement grinding. No costs preceding the clinker storage and no processes following the cement silos are considered.

Cement grinding plants were specifically chosen because they mostly use electrical energy compared with clinker-producing cement plants that use more thermal energy [1], [13]. Since electricity prices are increasing, DSM will have the greatest impact on cement grinding plants. The electricity costs of a cement grinding plant can only be determined by specific electricity cost per tonne.

1.5 DISSERTATION OVERVIEW

1.5.1 Chapter 1: Introduction

In Chapter 1, the study is motivated by discussions on the cement industry in South Africa. The degree of competitiveness, electricity usage and rising electricity prices in the South African cement industry are outlined. Electricity constraints in South Africa and the impact it has on the cement industry are addressed. A solution in the form of DSM is proposed and motivated. In addition, the study research goals, problem statement, a hypothesis and the scope of the study are given.

1.5.2 Chapter 2: Literature review

The literature review starts by researching cement manufacturing to understand the process. Building on the knowledge of cement manufacturing, energy usage on a typical cement grinding plant is identified. Thereafter, electricity intensive components are selected for DSM. Load management, energy efficiency and peak clipping are researched and evaluated. Evaluation strategies are researched.

1.5.3 Chapter 3: Methodology

Chapter 3 presents a methodology for implementing DSM load management on a cement grinding plant. A comprehensive DSM load management evaluation strategy is developed, which is the focus of the methodology. The evaluation strategy attempts to derive a true reflection of plant operations and electricity usage. It also presents a method for evaluating DSM load management effectiveness and benchmarks electricity usage on different plants.

1.5.4 Chapter 4: Case studies

Chapter 4 implements DSM load management on two marginal cement grinding stations. The data gathered from the pre- and post-DSM implementation is analysed using the evaluation strategy developed in Chapter 3. The results from Chapter 4 determine whether DSM load management can lower the electricity cost required to operate a marginal cement grinding plant in order to compete with modern cement grinding plants.

1.5.5 Chapter 5: Conclusion

Chapter 5 summarises each chapter in the study. It highlights important findings, methods and achievements. Chapter 5 also evaluates the study outcomes to determine if the study goals were reached. Further research recommendations are presented.

1.6 CONCLUSION

The cement industry in South Africa is facing challenging circumstances. Additionally, new cement producers such as Sephaku and Mamba increase market saturation. Imported cement is often cheaper than locally produced cement, thus flooding the market further.

Rapid increases in electricity prices influence the electricity intensive cement industry in South Africa negatively. It is vital for industry to reduce operational costs to remain competitive. DSM is an effective method for minimising electricity costs.

This study focuses on some of the current issues faced by the South African cement industry. The findings in the dissertation will determine whether implementing load management strategies can improve the production profitability of a marginal cement plant.

CHAPTER 2

Literature review

Chapter 2

This chapter reviews the cement-making process together with electricity consumption on cement grinding plants. DSM strategies are researched to determine the most cost-effective strategy for reducing electricity consumption. Once the most cost effective DSM strategy is identified, the implementation and evaluation of the identified strategy are researched.

2 ENERGY MANAGEMENT ON CEMENT PLANTS

2.1 PREAMBLE

Since the first power crisis in 2008, energy management and optimisation have become popular topics in South Africa. Industry is prioritising energy management and optimisation in an attempt to counter electricity tariff hikes. Eskom sub-contracts energy services companies (ESCOs) to implement energy management and optimisation strategies. These strategies are designed to balance the electricity supply with the demand. Strong technical knowledge of the industry is required to implement energy savings initiatives and to evaluate the savings accurately.

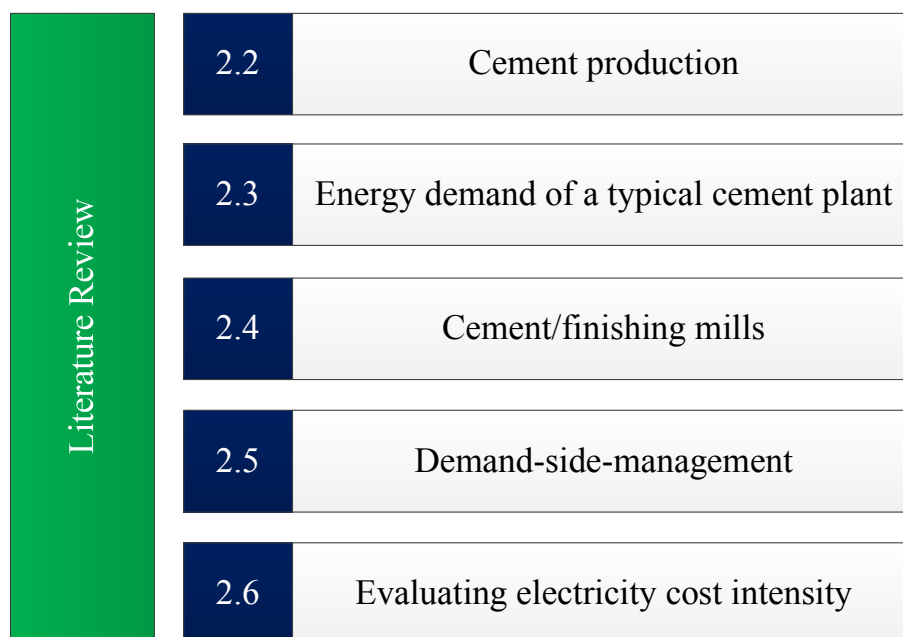


Figure 2-1: Literature review outline

The energy consumption of a typical plant is researched to determine the possibility of energy savings. Types of DSM strategy and their application on a cement plant are researched to identify an appropriate implementation strategy. Once the appropriate strategy has been determined, electricity intensive components on which the strategy will be implemented are identified. Previous evaluations of DSM savings will be researched.

2.2 CEMENT PRODUCTION

Cement production is a complex and integrated process from mining to end product. In order to identify energy savings opportunities, it is important to understand the cement production process and the flow of operations on a typical plant first. The following section explains the cement production process in detail.

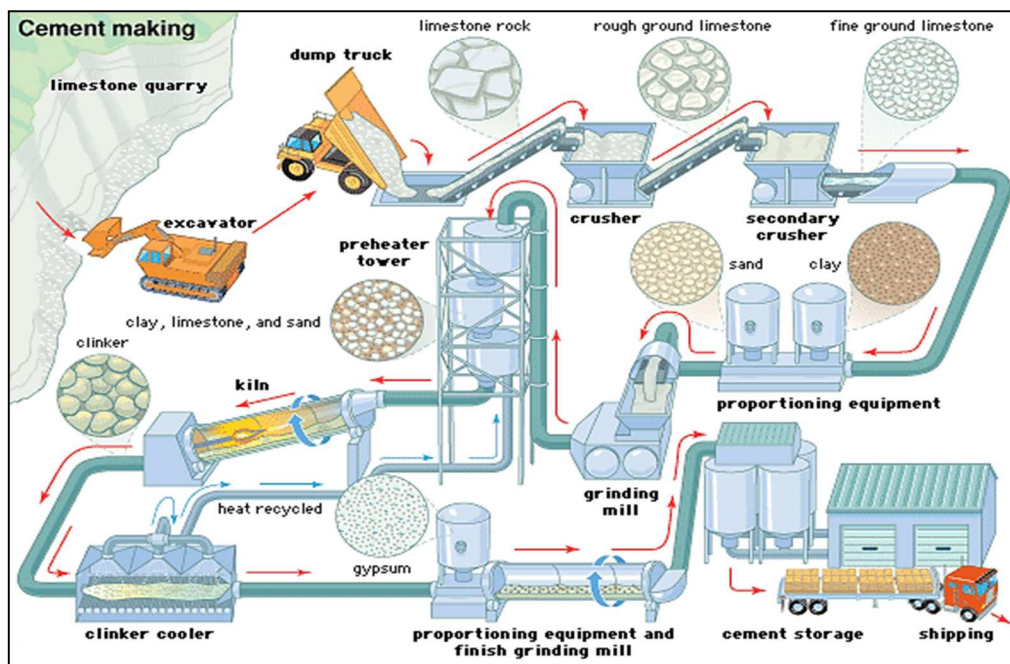


Figure 2-2: The cement-making process^{XII}

- I. **Mining** – The cement production process begins at large limestone quarries. Holes drilled with compressed air are packed with explosives and detonated to break up limestone deposits. Excavators load the limestone on to dump trucks or conveyor belts to be transported to crushers [14], [15].

- II. **Crushing** – The raw limestone is fed into the primary crusher. Jaw crushers reduce the limestone rock to rough ground limestone. Thereafter, the rough ground limestone passes through a secondary cone crusher. The secondary cone crusher crushes the rough limestone to a fine ground limestone [14], [15].

^{XII} Picture retrieved from Britannica Encyclopaedia, 2015. [Online]. Available: <http://kids.britannica.com/comptons/art-114024/To-make-cement-limestone-is-crushed-mixed-with-other-materials>. [Accessed: 31-Jan-2015].

- III. **Raw milling** – The fine ground limestone along with other quarried raw material are stored in feed hoppers. The raw material is fed into the raw mill using weigh feeders at the required proportions. Vertical roller mills or horizontal ball mills can be used for raw milling. The raw material is grinded into a flowable powder called raw meal before being fed to the kiln [14], [15].
- IV. **Coal milling** – In most cases, the kiln is heated using pulverised coal. Before coal is fed to the kiln, it passes from the stockpiles through a coal mill to be dried and pulverised. The coal is dried in the coal mill using hot air from the clinker cooler or pre-heater. A ball mill or a vertical roller mill can be used to pulverise the coal [14], [15].
- V. **Pyroprocessing** – Clinker is produced by the kiln. The kiln converts CaCO_3 into CaO that reacts with aluminium oxide, ferric oxide and silicon oxide with free limestone to produce clinker. Heat is generated in the kiln by introducing the pulverised coal at the lower end in a counter-current manner [14], [15].

In addition to coal, other fuels such as oil, gas and petroleum coke can also be used as fuels. The kiln slowly rotates as raw material is fed into the kiln at the elevated end. The rotation of the kiln helps the raw meal to move down the kiln. As the raw material flows down the kiln, the heat moves up and evenly heats the raw meal to induce pyroprocessing [14], [15]. The detailed process in the kiln is as follows:

1. Remaining moisture in the raw meal evaporates as the material heats up to 100 °C.
2. Temperatures approaching 430 °C stimulate iron oxide, silicon oxide and aluminium oxide formation [16].
3. Carbon dioxide (CO_2) separates from CaCO_3 to form CaO at roughly 900 °C. This process is called calcination [16].
4. CaO reacts with the oxides at approximately 1 510 °C to form cement clinker [16].

- VI. **Pre-heater and pre-calciner** – A pre-heater or pre-calciner is a series of vessels stacked in a vertical tower called a pre-heater tower. The hot exhaust gases generated by burning fuel flow up the kiln and into the pre-heater vessels. Raw meal flows from the top of the pre-heater tower downwards into the kiln. As the hot gases flow up and the raw meal flows down, more effective heat transfer between the gases and solids occur than in the kiln [14], [15].

Heating raw meal before it enters the kiln reduces the overall length of the kiln and improves production. In most cement plants, further heat transfer optimisation is achieved by diverting some of the kiln fuel to a calciner vessel. The increased heat transfer in the calciner vessel speeds up the calcination process [14], [15], [17].

- VII. **Clinker cooler** – Hot clinker flowing out of the kiln must be cooled rapidly from 1 100 °C to 90 °C to ensure maximum yield and suitable temperatures for downstream equipment. A clinker cooler uses a number of fans to air-cool the clinker. During air-cooling, the clinker absorbs heat from the hot clinker and feeds it back into the process.

As much as 30% of the thermal energy from the hot clinker can be reverted back into the process. The hot air is mainly used as pre-calciner fuel and main burning air. A planetary cooler and reciprocating grate cooler are most commonly used for clinker cooling [14], [15].

- VIII. **Finishing milling** – Clinker, along with additives such as fly ash, gypsum and slag are fed into proportioning equipment where a specific recipe is mixed. Additives determine specific characteristics such as strength and hydration rates of the cement. Different recipes will produce different types of cement [14], [15].

The mixed materials are fed into the finishing/cement mill to be grinded to a predefined fineness. The fineness of cement is measured in a unit called Blaine [cm^2/g]. High Blaine values specify a finer cement. Mills generally use more energy to make finer cement. Ball mills and vertical roller mills are most commonly used in finishing milling [14], [15].

2.3 ENERGY DEMAND OF A TYPICAL CEMENT PLANT

Section 2.2 provided a good basis for understanding the cement-manufacturing process. With knowledge of the production process and components, energy usage can now be researched. Cement plants are energy intensive with the cement sub-sector consuming 12–15% of the total industrial energy usage. Studies show that 50–60% of total production costs are allocated to energy. Energy cost reduction can, therefore, significantly increase the overall cement production profitability [1], [2].

In the cement-manufacturing process, there is a clear distinction between energy obtained from fuels and energy obtained by using electricity. Fuels can include coal, natural gas, petroleum coke, diesel and paraffin that are mostly converted to thermal energy. Electrical energy is used to power the motors of compressors, fans, pumps, crushers, conveyor belts, separators and mills. Table 2-1 shows the energy sources used by each stage of production [1].

Table 2-1: Energy source allocation to process

Stage	Energy Source	Description
Limestone milling	Fuel	Diesel for earthmovers.
	Electricity	Electricity/fuel for compressors.
Transport	Fuel	Diesel for dump trucks.
	Electricity	Electricity for conveyor belts.
Crushing	Electricity	Electricity for crushers.
Raw milling	Electricity	Electricity for mill motor drive, fans and auxiliaries.
Pre-calcination	Fuel	Fuel to generate heat energy.
Coal milling	Electricity	Electricity for mill motor drive and fans.
	Fuel	Fuel to generate heat energy.
Pyroprocessing	Electricity	Electricity for kiln drive and fans.
	Fuel	Fuel to generate heat energy.
Clinker cooling	Electricity	Electricity for clinker breaker, drive and fans.
Cement grinding	Electricity	Electricity for mill motor drive, fans and auxiliaries.
	Fuel	Fuel for heating vertical roller mills.
Packaging and dispatch	Electricity	Electricity for packing plant and
	Fuel	Fuel for transport.

This study focuses on reducing electricity costs of grinding plants. From this point onwards, the literature review will focus on electricity use on processes after clinker production.

Figure 1-1 showed that two of the largest cement producers in South Africa accredit 10–15% of their total operational cost to electricity [7]. Grinding plants attribute the majority of their energy usage to electrical energy because they do not use fuel-intensive pyroprocessing.

Table 2-2 ([1], [18], [19]) shows the specific electrical energy consumption for different sections and components on a typical cement production line. When considering grinding plants, the major electricity users are finishing/cement mills, transport (conveyor belt motors), packing plants, plant lighting, pumps and services such as compressors.

Table 2-2: Electrical energy distribution on a typical cement plant

Electrical energy distribution on a typical cement plant		
Section/components	Electrical energy consumption [kWh/t]	Share [%]
Mine, crusher and stacking	1.50	2.0
Reclaimer, raw meal grinding and transport	18.0	24.0
Kiln feed, kiln and cooler	22.0	29.3
Coal mill	5.0	6.7
Cement grinding and transport	23.0	30.7
Packing	1.5	2.0
Lighting, pumps and services	4.0	5.3
Total	75.0	100.0

Full clinker and cement-producing plants allocate about 61.4% of their electricity consumption to raw meal grinding, coal milling and cement grinding. Approximately 80% of the electricity on grinding plants is consumed by the cement/finishing mills. The high electricity consumption of grinding plants is because the largest components are cement mills that primarily consume electrical energy. The cement mills are, therefore, key components when reducing electricity cost on grinding plants [13].

2.4 CEMENT/FINISHING MILLS

In section 2.3, cement mills were identified as the major electricity-consuming component of cement grinding plants. It is thus necessary to research cement mills further to understand their features, operational characteristics and energy savings potential fully. In addition, a grinding

station's classification as a modern or marginal plant is directly dependent on the type of cement milling equipment it uses since 80% of a typical plant's electricity is consumed by the cement/finishing mills [13].

South Africa's cement producers predominantly use conventional ball mills for cement grinding since most cement plants in South Africa were constructed when ball mills were considered the most modern and proven cement milling component [20], [21]. Figure 2-3 shows a picture of a conventional ball mill. A ball mill is a large rotating steel tube with grinding media. The grinding media are mostly steel balls. Depending on the type of cement that is being produced, clinker and other additives are crushed by the steel balls when the steel tube rotates [14], [22].

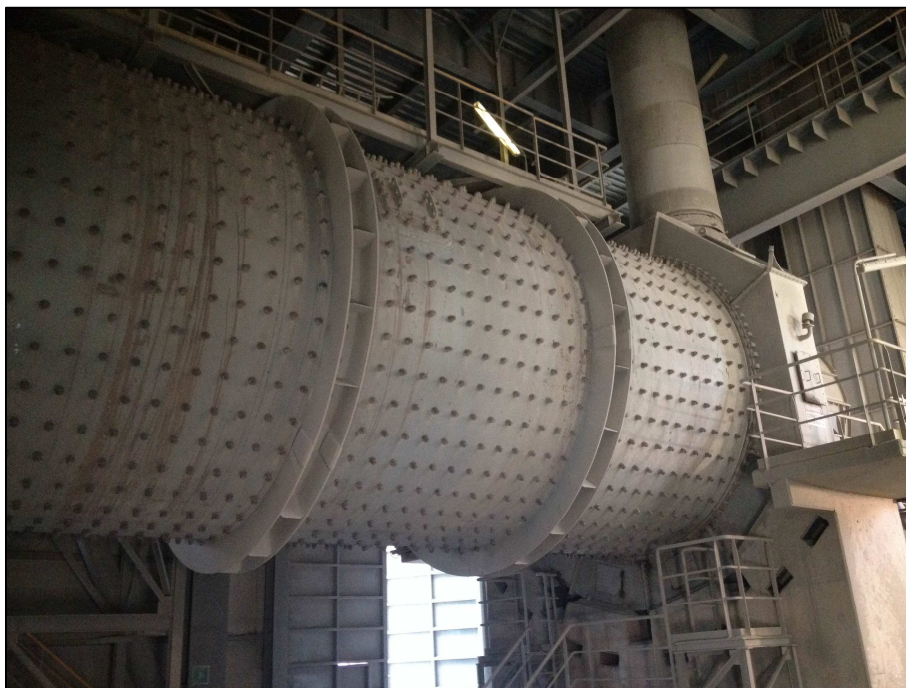


Figure 2-3: Photo of a conventional ball mill^{XIII}

The tube is normally divided into two or more compartments containing different sizes of steel balls. As the raw material passes through the mill it is grinded down by continuously smaller steel balls in the second and third chambers. The smaller grinding media greatly improve the grinding efficiency as the raw material particle size reduces [14], [22].

^{XIII} Photo taken by author on a marginal grinding plant, 2015.

The vertical roller mill shown in Figure 2-4 is more complex. Raw material is introduced into the mill. The raw material falls onto a rotating grind table and centrifugal force from the rotation grind table moves the material outwards underneath grinding rollers pressing down on the grinding table by means of hydraulic pressure. Water conditions the grinding bed between rollers.

A hot gas generator produces hot gas by burning fuel, which in turn drives the fine ground material to the classifier located above the mill. As the finished material dries, it conveys with the hot gas to the classifier. The classifier returns oversized material back to the grinding bed for another grinding cycle. The finished material and hot gas mixture passes through the classifier to a downstream filter. Hot gases are removed from the finished material and are returned to the cycle [23], [24].



Figure 2-4: Photo of a modern Loesche vertical roller mill^{XIV}

^{XIV} Photo taken by the author on a modern grinding station, 2015.

Ball mills are less efficient than more modern vertical roller mills in terms of electrical energy consumption. Compared with other milling equipment, ball mills have the highest electricity consumption. Ball mills consume approximately 35 kWh/t to grind cement to a Blaine fineness of 3 500 cm²/g. Vertical roller mills use 20–25% less electrical energy than ball mills [25], [26].

During a Loesche symposium held in Düsseldorf, a vertical roller mill was compared with a ball mill. Decision criteria were formulated considering total cost investment, operational cost, product quality and production flexibility of installing either a vertical roller mill or a ball mill. The total investment of installing a vertical roller mill is slightly higher than installing a ball mill. The operational cost of a vertical roller mill is 25% lower than a ball mill when considering specific energy consumption [27].

Product flexibility is better when using vertical roller mills because all cement types can be produced. The same product quality can be achieved when using a vertical roller mill. Vertical roller mills are more maintenance intensive. Compared with a ball mill, a vertical roller mill has more mechanical moving parts resulting in more frequent breakdowns [27].

Stable operation is more difficult to achieve as operational parameters such as separator/classifier rotor speed, airflow rate, hydraulic grinding pressure and dam ring heights need to be carefully adjusted to maintain product quality. Vertical roller mills need to be heated up before grinding can commence. Burners use fuel to heat air flowing into the vertical roller mill. Ball mills operate without heating, which reduces cost [28].

Sephaku recently built the Delmas cement grinding station and the Aganang cement plant. In both plants, vertical roller mills were installed in raw milling, coal milling and cement grindings [3]. This clearly shows that South African cement producers prefer the vertical roller mill. It also proves that a grinding station fitted with a vertical roller mill is modern.

In conclusion, vertical roller mills and ball mills are the cement milling equipment used by South African cement producers. Ball mills are more electricity intensive than vertical roller mills. Ball mills have a more stable operation and are less maintenance intensive. Vertical roller mills need hot process gases generated by a hot gas burner that consumes fuel. A grinding

station is classified as modern when using vertical roller mills and marginal when using conventional ball mills [28].

The next section will identify DSM opportunities on grinding plants. The most effective and viable DSM solution will be researched extensively to derive an implementation and evaluation strategy.

2.5 DEMAND-SIDE MANAGEMENT

DSM consists of load management and energy efficiency. Load management primarily uses load shifting to optimise electricity costs. Energy efficiency reduces electricity consumption, which translates into electricity cost reductions. Peak clipping is a combination of energy efficiency and load management. Peak clipping reduces electricity use during peak periods without shifting the peak period load. Energy efficiency improvements recover production lost as a result of peak clipping [10], [29].

2.5.1 Energy efficiency improvements

Table 2-3 shows energy efficiency improvements on a typical cement grinding station. The energy efficiency improvements identified are divided into processes found on a typical cement grinding plant. Respective electricity and thermal energy savings for each energy efficiency improvement are shown with corresponding payback periods.

Finishing grinding

Table 2-3 ([1], [22], [17]) confirms that energy efficiency improvements on cement plants are both diverse and abundant. Replacing traditional ball mills with variations of high-pressure roller mills delivers substantial savings. But, retrofitting old mills are expensive, have lengthy payback periods of up to 10 years and installation results in prolonged plant downtime.

High-efficiency classifiers can also be installed on existing mills, but are expensive with the payback period estimated at 10 years. Utilising improved grinding media can deliver

substantial savings at an estimated payback period of eight years. Advanced process control improves mill throughput and has lower payback periods but remain expensive.

General

A less expensive energy efficiency measure is to replace all motors and drives with high-efficiency motors and drives. The payback period is estimated to be less than a year and could deliver substantial savings. In addition, variable speed drives (VSDs) can be installed on electric motors to reduce speed, torque or rotational force to the minimum required set points. This will produce substantial savings with acceptable payback periods of up to three years.

Compressed air system

The compressed air system is mainly used for transporting raw material and finished product. Reducing air leaks and sizing the pipes in the air network correctly will reduce electricity usage by 20%. Further savings on the compressed air network can be achieved by reducing the temperature of the inlet air and applying compressors control.

Lighting

Lighting control by means of day/night and sensor switches can reduce lighting cost by up to 20%. Metal-halide and high-pressure sodium lighting drastically improve the electricity efficiency of lighting cost by as much as 60%.

Energy efficiency is an effective method of saving electrical and thermal energy on cement plants. However, long payback periods, installation downtime and large initial capital expenditures limit a cement producer's ability to improve the energy efficiency of marginal plants. Table 2-2 confirmed that close to 80% of the electricity on grinding plants is consumed by the cement/finishing mills. Energy efficiency is, therefore, not a viable solution for a cement DSM project as the project would have to replace the mills to have a significant impact on electricity consumption.

Table 2-3: Energy efficiency improvements

Process/component	Energy efficiency opportunity	Thermal saving [GJ/t]	Electricity saving [kWh/t]	Payback period Year	Reference
Finishing grinding	Process control and management	0.04–0.05	3.2–4.2	< 1–2 years	[30], [31], [32], [33], [34], [35]
	Vertical roller mill	0.02–0.29	10.0–25.9	-	[30], [31], [32], [36], [37]
	High-pressure hydraulic roller press	0.03–0.31	8.0–28.0	> 10 years	[17], [30], [31], [32], [38], [32], [39],
	Horizontal roller mill	0.10–0.30	-	-	[17], [38]
	High-efficiency classifiers	0.01–0.03	1.6–7.0	> 10 years	[13], [30], [32], [35], [38], [40]
	Improved grinding media	0.02–0.10	1.8–6.1	8 years	[30], [31], [32], [38], [41]
General	High-efficiency motors and drives	0.02–0.31	3.0–25.0	< 1 year	[30], [31], [32], [38], [42], [43]
	VSDs	0.03–0.10	0.1–9.2	2–3 years	[30], [31], [38]
Compressed air system	Reduce leaks	-	20%	-	[44]
	Compressor controls	-	3.5–12%	-	[44], [45], [46]
	Reduce inlet air temperature	-	1%	2–5 years	[45]
	Size pipe diameter correctly	-	20%	-	[44]
Lighting	Control for plantwide lighting	-	10–20%	< 2 years	[47]
	Replace mercury lights with metal-halide or high-pressure sodium lights	-	50–60%	-	[18]

2.5.2 Peak clipping

Peak clipping can only be achieved on production plants by improving production efficiency. The energy efficiency section (section 2.5.1) determined that energy efficiency is not a viable DSM solution. Peak clipping is also not a suitable solution for a DSM project as it has the same limitations as energy efficiency, namely, long payback periods, installation downtime and large initial capital expenditures.

2.5.3 Load management

Load management, also known as load shifting, is an effective DSM strategy to reduce electricity cost on a cement plant. This was proven by Lidbetter when she implemented a pilot DSM load management project on a South African cement plant in 2010 [48], [49]. Lidbetter followed a simple approach by prioritising production during specific times of a day to achieve electricity cost reductions.

The method is as follows (refer to Figure 2-5 ([48], [49])):

- Operate mills primarily in off-peak periods (green) between 21:00–06:00.
 - Use the standard periods (yellow) as secondary operational periods.
 - Stop operation during evening peak periods if silo levels are acceptable.
 - Perform a second load shift during morning peak periods if silo levels are acceptable.
- Consider silo levels so that pending evening-peak load shifting can still be performed.

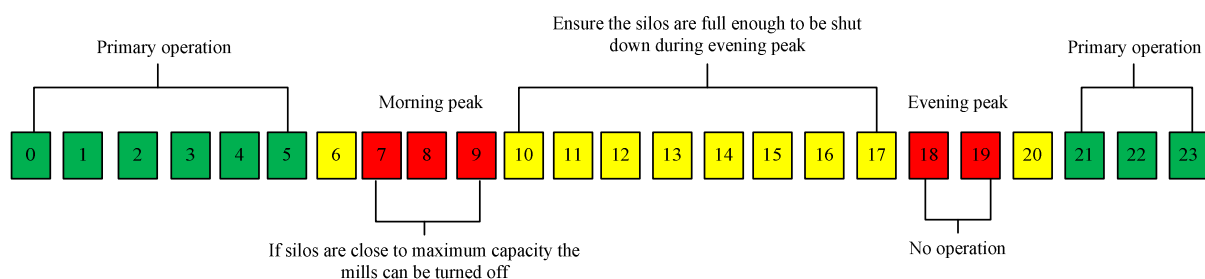


Figure 2-5: Lidbetter's load management method

Lidbetter's study proved that the cement production process presents opportunities for load management with high production rates, moderate cement sales and sufficient buffer capacity. Building on Lidbetter's previous findings and other previous studies, Swanepoel proposed an energy management system (EMS) [12], [50], [51], [52], [53].

An EMS collects data and uses an integrated optimisation model to create an operational plan/production schedule for the considered cement plant. The objective of the optimisation model is to create an operational plan with minimum electricity use and cost. The production schedule is created by a third-party optimisation engine that uses mathematical modelling to incorporate multiple plant constraints [54].

Maneschijn incorporated Swanepoel's model into an automated computer system using the following [54]:

1. Automatic data collection from various sources;
2. Process input data and information;
3. Processed data integration with Swanepoel's model;
4. Application of optimisation engine to the model;
5. Record and communication optimised running schedules.

The automated operations modelling system enabled the widespread implementation of load management on multiple cement plants across South Africa. The results of the widespread implementation were evaluated and showed a substantial decrease in electricity costs. The impact of the savings on the production profitability of a plant is investigated further.

2.6 EVALUATING ELECTRICITY COST INTENSITY

Electricity cost intensity refers to the electricity cost per tonne of cement produced. Reducing the electricity cost intensity contributes significantly to a marginal plant's profitability. Evaluating the electricity consumption of cement plants is vital when savings measures are implemented. This allows companies to assess the effectiveness of the savings measure implemented and benchmarks performance between plants and previous performances.

Load management requires a change in behaviour and attitude of managers and employees towards the consumption and cost of electricity. Many studies show that positive behaviour and attitudes of managers and employees towards energy saving initiatives will result in energy cost reductions[55]. Interest and support towards energy management and optimisation from plant personnel is key to the successful implementation and sustainability of load management.

Currently, some South African cement producers evaluate a plant's production cost intensity when considering electricity consumption by calculating the cost of electricity per tonne [21], [56]. Previous studies focused on implementing load management and did not evaluate the implication of reduced production costs on the competitiveness of marginal cement plants further.

Venter described the potential for load management interventions on South African cement plants. He showed that by considering the adjacent buffer levels, large electric equipment such as mills could be used to manage peak loads. Though Venter identified and outlined possible savings on cement plants, these possible savings were not compared with more energy-efficient and more modern equipment. Additionally, Venter's results were theoretical and did not describe implementation [57].

Jordaan furthered the research conducted by Venter and identified possible hurdles and parameters that need to be considered during the practical implementation of load management interventions. These parameters included equipment fatigue, silo capacity, production targets and product quality. The study by Jordaan described relevant evaluation criteria better, but did not, however, compare real-world implementation on operational cement plants [58].

Lidbetter used the potential that was identified by Venter and the evaluation criteria identified by Jordaan to implement a load management trial on a South African cement plant. The study showed electricity cost savings. Lidbetter developed a thorough cost evaluation technique to evaluate the success of load management [48].

Lidbetter presented the first real-world implementation of DSM load shifting on South African cement plants. Lidbetter focused on working weekdays and eliminated weekends, public holidays and operational outliers. The study also focused on the main drive motors of the grinding mills and excluded other electric equipment [48].

The study calculated average operating electricity consumption on the grinding mills using supervisory control and data acquisition (SCADA) data. Stoppage records were used to identify when mills were operating and when they were not. These stoppage records were used to calculate an average usage of the mills for each hour of the working weekday. These operating averages were multiplied with the mill operating electricity consumption to obtain an average weekday baseline [48].

Lidbetter also calculated the total mill usage to identify the possibility for load shifting. By implementing a pilot study, the study results showed that a load-shifting strategy is feasible on cement grinding equipment. The baselines calculated using the operating electrical demand and the total stoppages were compared with the load profiles obtained during the pilot study [48].

However, the baselines were not scaled to represent a similar production scenario. The effect and total savings that these load-shifting interventions would generate were also not investigated. A load-shifting intervention was also not compared with normal operation [48].

Swanepoel's and Maneschijn developed a modelling technique and automated computerised system to evaluate multiple components and production constraints to identify load management potential on cement plants. This EMS was implemented on various South African cement plants.[22]

The integrated EMS enabled plant personnel to consider multiple variables, which allowed a wide focus that included load management for electricity cost savings. The EMS showed widespread electricity cost improvements. The studies used an evaluation method to quantify the achieved savings during the implementation of the operations modelling system.

The evaluation method used electricity data for a three-month period to compile an electricity consumption baseline. The baseline represented a working week rather than the daily cycle as was represented by Lidbetter. By using an operational week, load shifting from weekdays to weekends could also be accounted for.

The electrical demand after the implementation was also recorded and represented on an average working-week profile. The recorded baselines were scaled to represent a similar production scenario as was present during the implementation. The weekly load-shifting representation is shown in Figure 2-6 (Adapted from [12]).

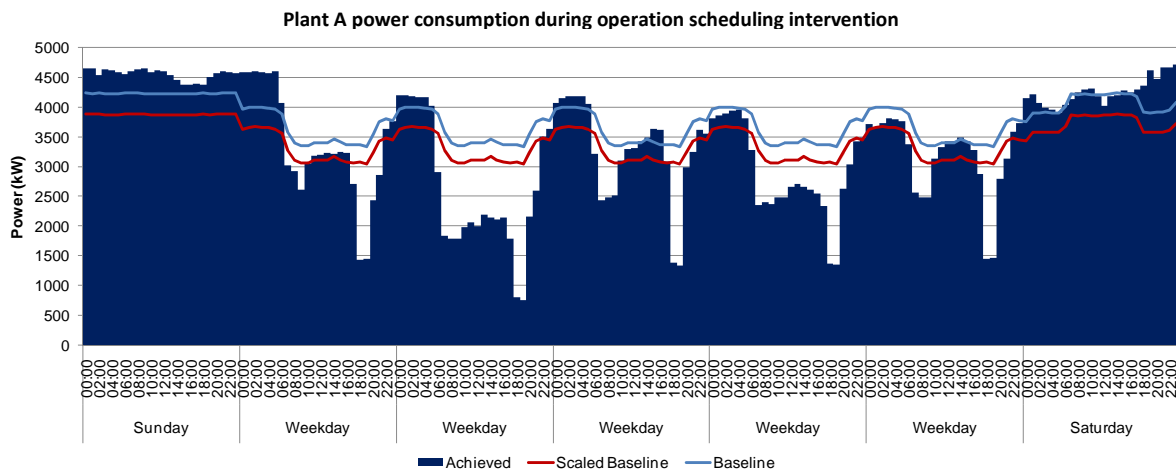


Figure 2-6: Weekly electrical demand load shifts results profile presented by Swanepoel

Swanepoel also evaluated the load shifted from weekdays to weekends and the load shifted between the peak-, standard- and off-peak periods of a working week [12]. An example of the evaluation method is shown in Figure 2-7 (Adapted from [12]). Swanepoel used the plant characteristics to generate an optimal cumulative production cost with utilisation representation. The cumulative production cost representation is shown in Figure 2-8 (Adapted from [12]).

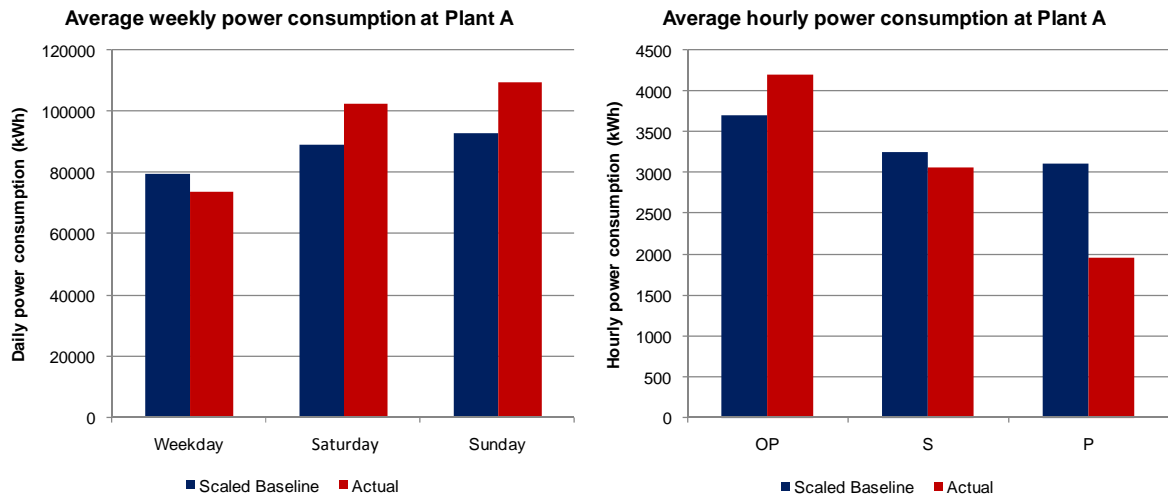


Figure 2-7: Average weekly and hourly evaluation presented by Swanepoel

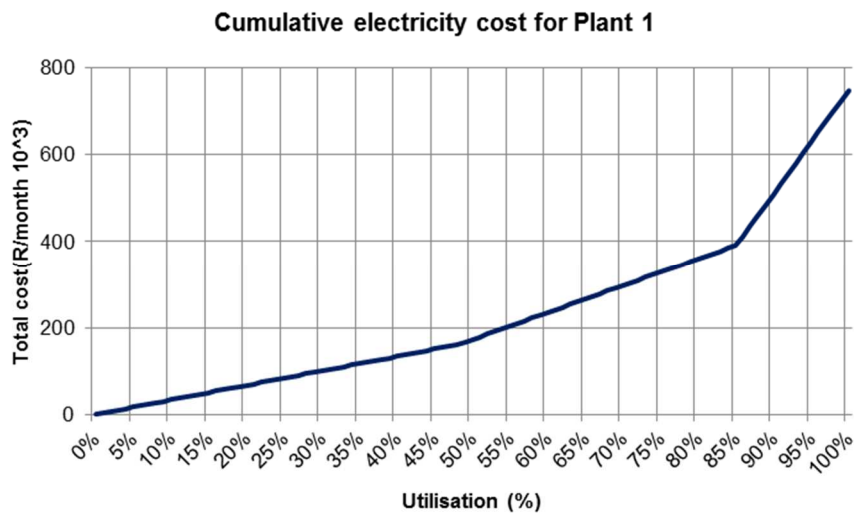


Figure 2-8: Optimal cumulative electricity cost with utilisation as presented by Swanepoel

The weekday baseline profile represents load-shifting results more accurately than the daily baseline profile generated by Lidbetter. The weekly and peak/standard/off-peak representation also indicate the impact of the load-shifting intervention on the specific cement plant more clearly. The studies, however, did not evaluate and compare the cost savings with more efficient equipment to identify the profitability of marginal cement plants.

The optimal cumulative production cost graph shows the perfect load-shifting scenario, however, it does not show how close the intervention came to being optimal. A clearer

comparison of plant cost improvement when considering a competitive environment between cement plants is required.

A study by Spangenberg evaluated the effects and savings incurred by DSM load management interventions on the South African cement industry [22]. Five concerns and evaluation criteria were identified and evaluated by considering multiple South African cement production plants. The evaluation criteria included energy and cost savings; effect on production; impact on cement-manufacturing equipment; effect on the cement quality and; increased awareness.

The study calculated the energy cost savings by considering the electricity costs for an entire year. A weekly electricity demand profile and baseline were used to calculate the electricity cost savings incurred by implementing the load-shifting intervention on the specific cement plant. The electricity cost evaluation method is shown in Figure 2-10 (Adapted from [22]).

Spangenberg considered the total production output of the cement plant before and after the load-shifting interventions to evaluate the effect on production [22]. Production volumes were considered for the storage silos. The level of the storage silos were evaluated at the start and at the end of the working week to determine the difference in stock levels. The storage levels are shown in Figure 2-9 (Adapted from [22]).

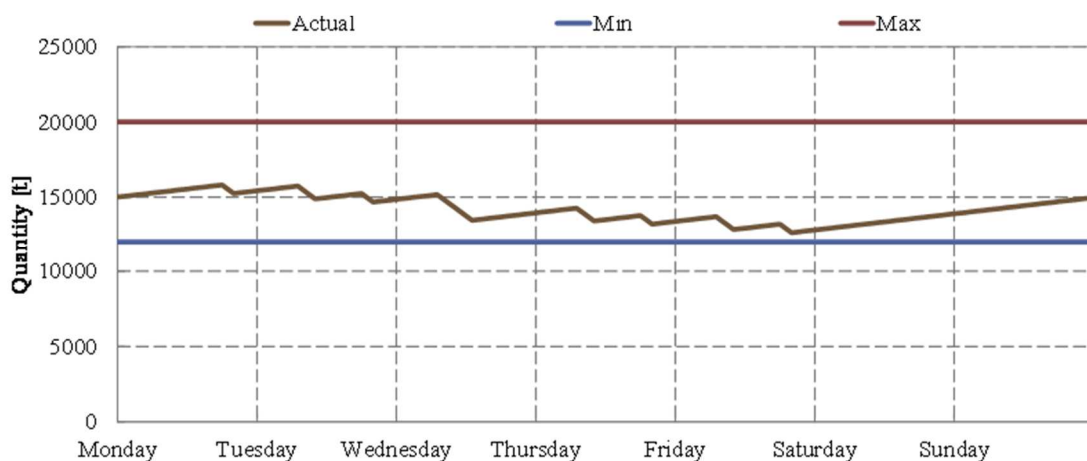


Figure 2-9: Storage level evaluation presented by Spangenberg

Actual profile energy cost [R]				Proposed profile energy cost [R]			
Hour	Weekday	Saturday	Sunday	Hour	Weekday	Saturday	Sunday
0:00	4840.67	5299.90	4294.48	0:00	5261.20	5261.20	5261.20
1:00	5306.13	5323.08	5413.20	1:00	5261.20	5261.20	5261.20
2:00	5391.83	5104.52	5586.31	2:00	5261.20	5261.20	5261.20
3:00	5400.91	5101.88	5193.78	3:00	5261.20	5261.20	5261.20
4:00	5348.56	5304.60	5219.93	4:00	5261.20	5261.20	5261.20
5:00	5300.86	5079.13	5081.84	5:00	5261.20	5261.20	5261.20
6:00	8714.62	4978.02	4345.83	6:00	8979.34	5261.20	5261.20
7:00	23103.71	9072.04	5410.70	7:00	25345.60	9640.40	5261.20
8:00	22661.71	8777.31	5502.05	8:00	25345.60	9640.40	5261.20
9:00	22853.87	9422.32	5446.40	9:00	25345.60	9640.40	5261.20
10:00	7120.73	9732.69	5150.33	10:00	7712.32	9640.40	5261.20
11:00	6995.49	9881.24	5048.88	11:00	7712.32	9640.40	5261.20
12:00	7623.00	5095.61	5181.25	12:00	7712.32	5261.20	5261.20
13:00	7830.82	5503.21	4936.65	13:00	7712.32	5261.20	5261.20
14:00	7854.28	5432.92	5247.17	14:00	7712.32	5261.20	5261.20
15:00	7797.22	5737.06	4762.56	15:00	7712.32	5261.20	5261.20
16:00	7885.73	5802.22	5063.15	16:00	8373.38	5261.20	5261.20
17:00	8433.80	5518.40	5165.82	17:00	8373.38	5261.20	5261.20
18:00	27752.62	10536.40	5222.23	18:00	21272.20	9640.40	5261.20
19:00	28670.64	9512.61	4789.93	19:00	21272.20	9640.40	5261.20
20:00	8582.92	4700.86	5708.92	20:00	8373.38	5261.20	5261.20
21:00	9790.13	5020.99	5641.47	21:00	9640.40	5261.20	5261.20
22:00	4991.70	5234.25	5844.94	22:00	5261.20	5261.20	5261.20
23:00	5580.60	5314.97	5255.16	23:00	5261.20	5261.20	5261.20
	255832.53	156486.20	124513.00		250684.59	156923.20	126268.80

$$\begin{aligned}
 & \text{R } 5,147.94 \times 5 \\
 & + \text{R } (437.00) \\
 & + \text{R } (1,755.80) \\
 & \hline
 & = \text{R } 23,546.89
 \end{aligned}$$

Summer electricity cost saving			
	Weekday	Saturday	Sunday
Total	R 1,149.42	-R 310.62	-R 1,522.66

Avg Daily Savings	R 559.11
Summer Savings	R 152,638.25

Classified as	Saturday	Sunday
Public Holiday	5	6

Total Summer Savings	R 141,938.19
----------------------	--------------

Winter electricity cost saving			
	Weekday	Saturday	Sunday
Total	5,147.94	-437.00	-1,755.80

Avg Daily Savings	R 3,363.84
Winter Savings	R 309,473.35

Classified as	Saturday	Sunday
Public Holiday	2	0

Total Winter Savings	R 308,597.35
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Total annual savings R 450,535.54

Figure 2-10: Electrical cost calculation method as presented by Spangenberg

Spangenberg's study used data acquired from multiple load management interventions over extended periods of time [22]. The study concluded that DSM load management interventions generated substantial electricity cost savings. The savings are produced without affecting production negatively or increasing wear on production equipment. The quality of the cement produced also showed an improvement.

The study, however, did not compare the savings produced by DSM interventions with more modern cement production facilities. The cost savings were not compared with the operational electrical cost of other more effective cement plants. Production rates and production volumes of competing cement plants were also not considered.

From literature on cement plant load management, it was found that thorough evaluation techniques were compiled by different authors. The evaluation techniques, however, did not adequately describe how the interventions improved the cement plant cost savings when compared with the competitive cement production environment that is found in South Africa.

A thorough comparison of electricity cost is required to assess the impact that load management has on marginal cement plants. Furthermore, these results must be compared with more modern and more energy-efficient equipment to identify the effectiveness of load management interventions. Load management interventions on marginal cement plants are redundant if they cannot compete with more modern plants.

2.6.1 Results verification

It is necessary to compare the results obtained from any new methodology with a published method to verify the cost savings calculations. Lidbetter derived a simple method for calculating energy efficiency and load-shifting cost savings. Using Lidbetter's method, the accuracy of the case study results can be evaluated as a percentage difference [49].

The method uses weighted averages of the TOU tariffs to quantify the cost savings during peak period reduction. In Equation 2-1, the method divides the total energy usage [Q kWh] for the considered period into peak [Q1 kWh], off-peak [Q2 kWh] and standard [Q3 kWh] energy usage.

Equation 2-1:

$$Q = Q1 + Q2 + Q3$$

Using Equation 2-2 and Equation 2-3, the consumption ratio during peak periods [S1] and off-peak periods [S2] are determined.

Equation 2-2:

$$S1 = \frac{Q1}{Q}$$

Equation 2-3

$$S2 = \frac{Q2}{Q}$$

The weighted averages [W] of the tariffs are calculated by Equation 2-4. Tariffs during peak, off-peak and standard periods are represented by w1, w2 and w3 respectively.

Equation 2-4:

$$W = S1w1 + S2w2 + (1 - S1 - S2)w3$$

The load-shifting cost savings [C] are calculated using Equation 2-5 by multiplying the total energy usage [Q kWh] with the difference in pre- and post-DSM weighted averages.

Equation 2-5:

$$C = Q \times \Delta W$$

Lidbetter's method for calculating load-shifting savings is simple and provides a good means for verifying results. TOU tariffs usually differ during winter and summer months. When considering annual savings, separate cost savings should be calculated during summer and winter months and thereafter added together to derive the annual cost savings [48], [49].

2.7 CONCLUSION

Financial and operational implications make energy efficiency improvements unattractive to cement plants because of the high cost of replacing hardware and the installation downtime thereof. Peak clipping incorporates energy efficiency and shares the same limitations. The most viable load management strategy for reducing electricity cost on a marginal cement plant is load shifting. This method of electricity cost reduction will be further investigated and applied to improve the profitability of a marginal cement plant.

Previous DSM load management studies focused predominantly on implementation and not on evaluating the effect of DSM load management on production cost intensity when considering electricity consumption. A need exists for a comprehensive evaluation strategy with which the effectiveness of DSM load management can be assessed and different plants' electricity consumption can be compared. The evaluation strategy will be crucial in answering the research question.

CHAPTER 3

Methodology

Chapter 3

Discusses the load management implementation strategy and presents the developed evaluation strategy. This chapter also states the assumptions that are necessary for the study.

3 PROPOSED LOAD MANAGEMENT IMPLEMENTATION AND EVALUATION STRATEGY

3.1 PREAMBLE

The methodology presents both a generic DSM load management strategy and an effective evaluation strategy. The main objective of the study is to determine the effect of load management on the electricity costs of a marginal cement grinding plant. Therefore, the methodology will mostly focus on the method for evaluating the proposed DSM load management strategy effectively and not on its implementation. The diagram in Figure 3-1 shows the outline of the methodology.

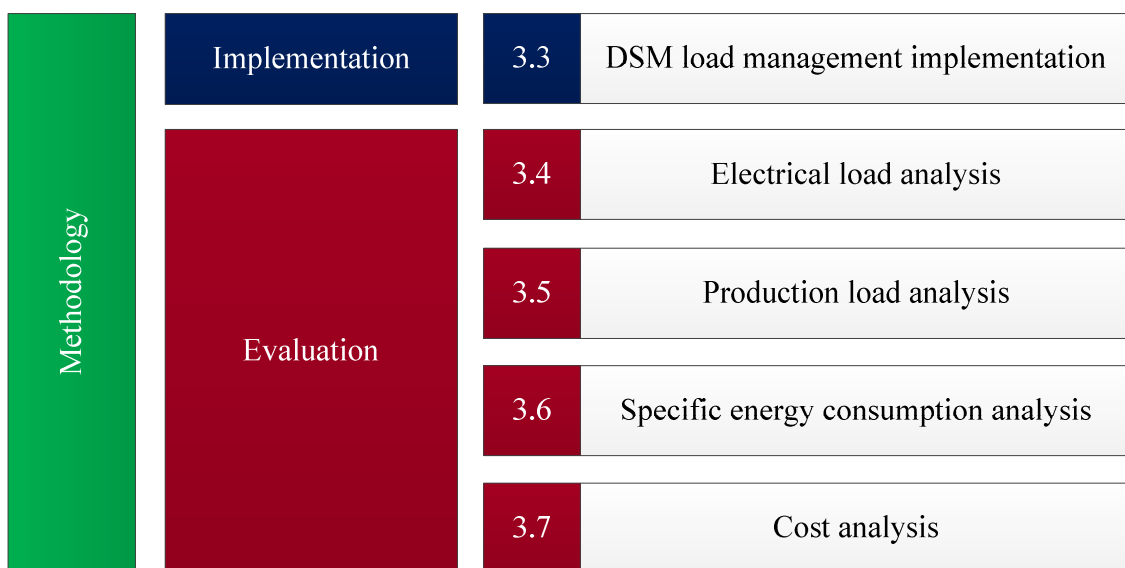


Figure 3-1: Methodology outline

The cement plants selected for the study are cement grinding plants. Grinding plants are normally located at more favourable locations for end product distribution and only incorporate finishing/cement mills in their production lines. Two marginal grinding plants from two different companies will participate in the study. Both of these plants use horizontal ball mills.

A generic load management strategy will be identified and implemented. Once the electrical costs have been reduced on a marginal cement grinding plant, it will be compared with a

modern cement grinding plant using the evaluation strategy. The evaluation strategy will determine whether load management is effective in keeping marginal cement grinding plants competitive.

3.2 ASSUMPTIONS

The following assumptions were necessary for the study:

Assumption 1

The analysis boundary represents only finishing/cement grinding. No costs preceding the clinker storage and no processes following the cement silos are considered. Figure 3-2 shows the analysis boundary.

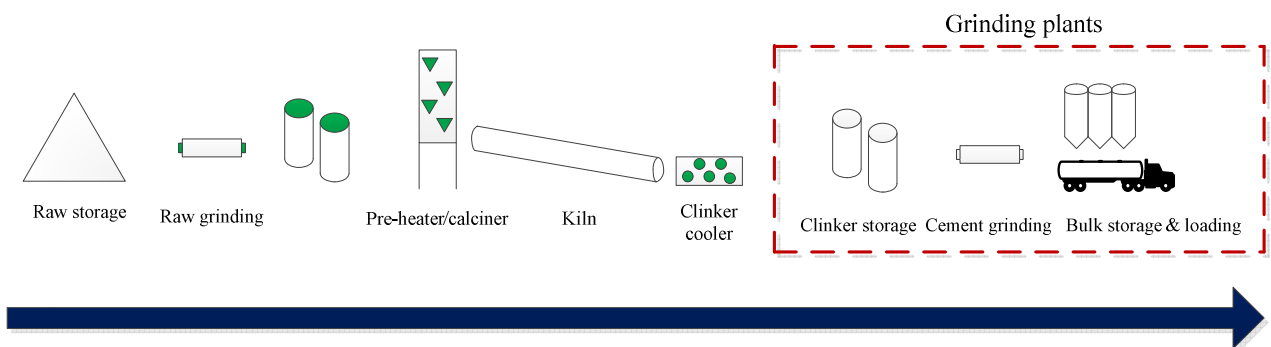


Figure 3-2: Analysis boundary

The two respective grinding plants receive clinker and other raw materials from the same sources and are located similar distances from the source. It is assumed that all the energy costs associated with clinker production and transport are equal for the different plants.

Packing and dispatch represent a relatively small amount of electricity when compared with finishing grinding. Additionally, most packing and dispatch components are similar between the different plants. It is thus assumed that all costs associated with packing and dispatch for the respective grinding plants are equal.

Assumption 2

Both the finishing mills characterise one mode of operation, i.e. the mills are either on or off. Most of the mills at cement grinding plants have a specific internal load set point. Since the mill feed consists of materials with consistent hardness and abrasiveness, it remains stable when the mill is operational. The plants under consideration do not include variable feed mills or VSD controlled mills.

Assumption 3

Both the participating plants are on TOU tariff structures. The analysis will assume that both plants have the same tariff costs. When assuming tariff costs to be equal, the load management results will be emphasised. Subsequently, the analysis can effectively determine whether load management can improve the profitability of a marginal cement grinding plant when compared with a modern grinding plant.

Assumption 4

Table 2-2 shows that cement grinding uses about 80% of a grinding station's electrical energy. Lighting, packing plants and other auxiliaries use the same electricity as grinding plants. These auxiliaries will not be subjected to load management. Therefore, only the mills and the associated auxiliaries will be considered when comparing the plants.

3.3 DSM LOAD MANAGEMENT IMPLEMENTATION

3.3.1 Load management strategy

The main focus of the dissertation is evaluating the effect that DSM strategies have on cement grinding stations. Previous studies have extensively researched and implemented DSM load management on cement plants. These studies describe proven generic DSM load management implementation strategies that can be applied to the marginal grinding plants. A generic DSM load-shifting implementation strategy will be identified and applied to the marginal cement grinding plant in each case study.

3.3.2 Energy management system

An EMS is a computer-based system that has autonomous data acquisition, processing, optimisation and reporting capabilities. The EMS used in this study was developed by the ESCO to manage energy consumption actively and to reduce costs. The EMS has been implemented and proven to reduce electricity cost on cement plants across South Africa [22]. It will be applied to the marginal cement grinding stations in this study.

Cement plants receive weekly sales forecasts. The production manager evaluates the current stocks available in silos, considers the planned maintenance on production equipment for the coming week and manually creates a weekly production/milling schedule. The control room operators run the mills according to the schedule received from the production manager. Very often, the production managers do not prioritise low-cost tariff periods in their production schedules.

Load management is achieved by using the Production Management Tool (PMT) that is built into the EMS. It was developed by Swanepoel to monitor and optimise the weekly production schedules.[52] The PMT uses a series of algorithms to analyse current silo levels, sales forecast and planned maintenance. An optimised production schedule is automatically generated by the PMT, which is used to allocate production to the least expensive timeslots available. Figure 3-3 shows the process [12].

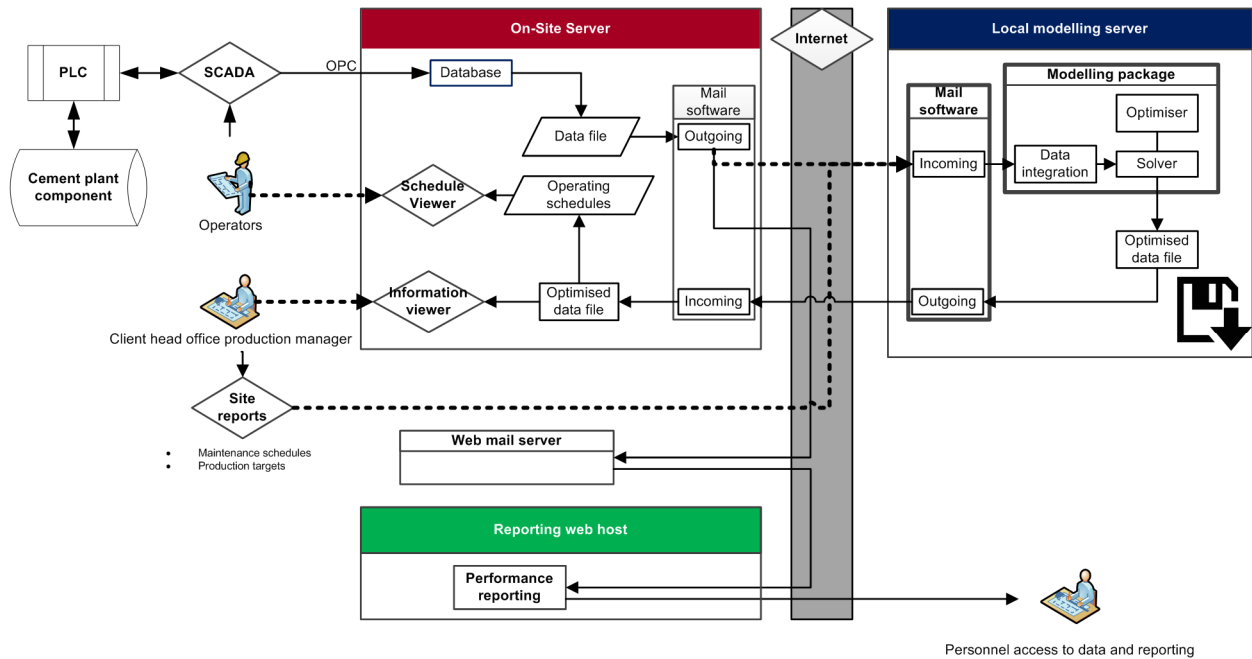


Figure 3-3: Production management tool

A virtual server is installed in the control room of the marginal cement plant. The server connects to the SCADA via an OPC connection. Access is granted to the EMS to acquire the relevant data necessary for the PMT. The data package is sent via the Internet to the ESCO's local modelling server at which point the PMT generates an optimised weekly production schedule.

The local modelling server sends the optimised weekly production schedule back to the on-site server. The on-site server displays the optimised weekly production schedule via the schedule viewer on the computer monitor. The control room operator runs the milling equipment according to the optimised schedule received.

Figure 3-4 shows an example of a schedule viewer display. The schedule viewer display allows control room operators to view key production parameters necessary for load management. It also ensures clear communication of the running schedule, especially when control room operators change shifts.

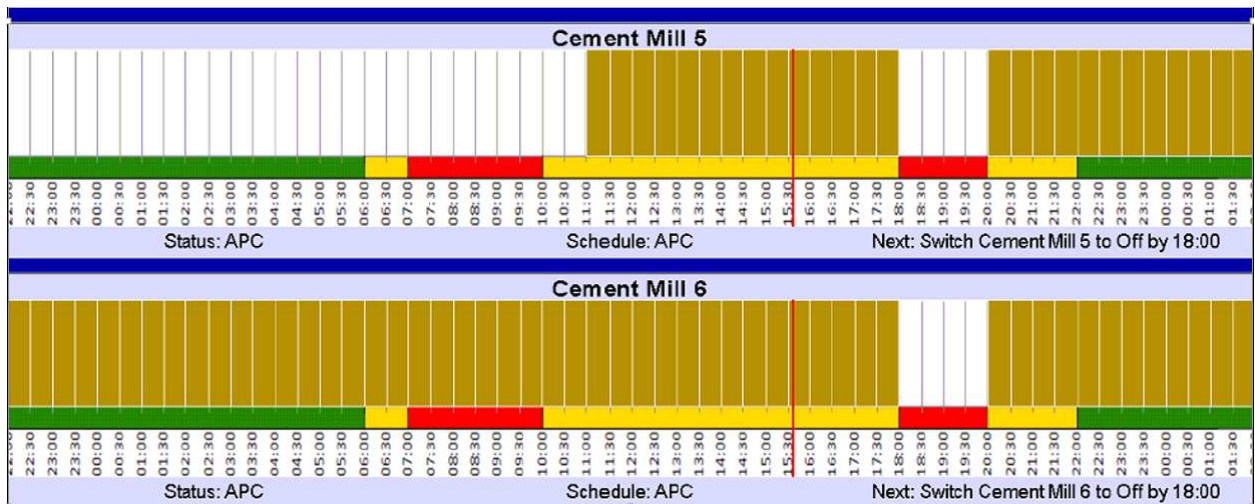


Figure 3-4: Example of the schedule viewer

Figure 3-5 shows an example of the EMS platform database installed on the virtual server. The EMS platform links, displays and logs SCADA tags as part of the EMS data acquisition capabilities. The logged data is sent directly from the platform to the ESCO's local modelling servers where it is processed by the PMT.

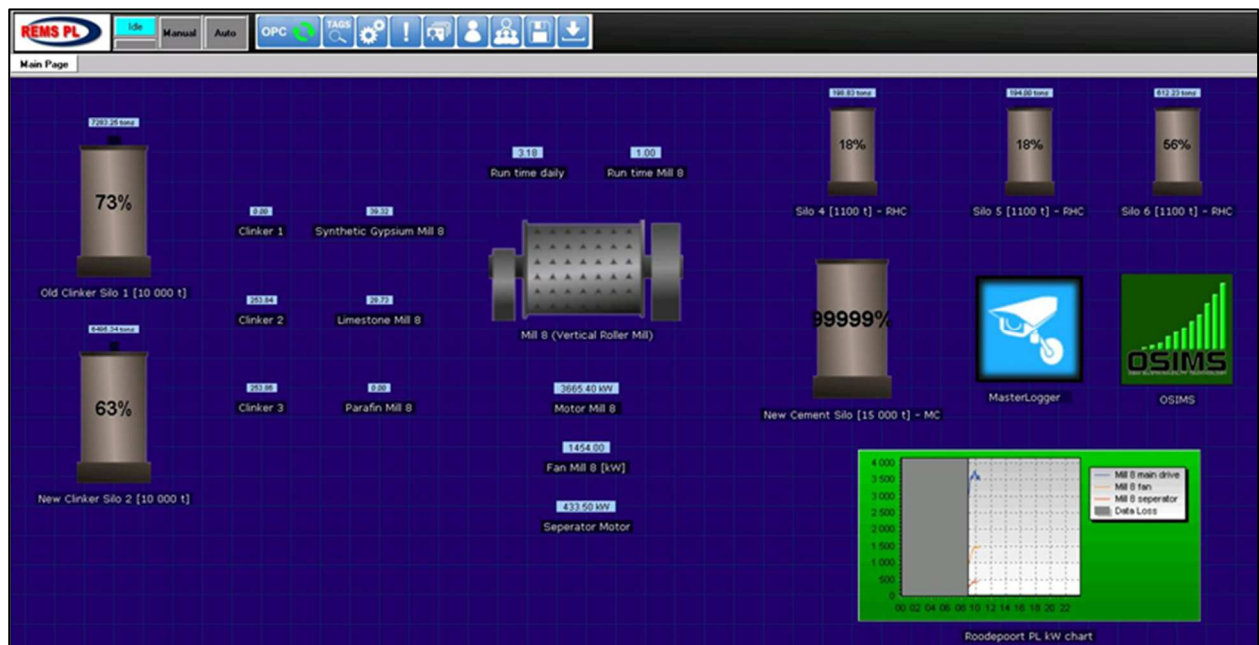


Figure 3-5: Example of EMS database platform

3.4 ELECTRICAL LOAD ANALYSIS

Since grinding plants consume energy primarily in the form of electricity, an electrical load analysis is a universal starting point. The outcome of the electricity load analysis is to determine an average operational profile and to identify load-shifting potential.

3.4.1 Baseline analysis

An electrical load baseline analysis is used to determine the operational trend of the grinding facilities. Electrical load/power (kW or MW) is used instead of electrical energy (kWh or MWh) to ensure that different data intervals or analysis periods do not influence or affect the accuracy of the calculated results.

It is essential for an electrical load baseline to represent the operation of a component or a system of components accurately. An analysis period must be chosen that will reflect a comparable trend for a full operational cycle accurately. The operational cycles for most industries can be reflected accurately using a daily baseline. The large components in these systems do not regularly cycle (switch on and off) more frequently than once an hour. This shows that using hourly intervals for these components is suitable.

The operational profile for cement production, and more specifically, cement finishing, follows a weekly trend (due to the large storage buffers and demand trends). These components also cycle on an hourly basis. Deductively, a weekly baseline, with hourly intervals reflects the operational trend of a cement plant accurately. The weekly baseline is divided into weekdays, Saturdays and Sundays. Sales dispatch for weekdays tend to remain constant with a sharp decline in weekend dispatch trends.

To obtain an accurate trend and exclude abnormal circumstances, data for an extended period is used to compile the weekly baseline. Data for a period representing at least four operational cycles is required to ensure that all unforeseen or unrepresentative circumstances are excluded from the baseline representation. For a weekly representation, this means data for a minimum

period of four weeks is required. The electrical demand is averaged for each hour of the operational cycle. This is represented by Equation 3-1.

Equation 3-1

$$P_{BL,i} = \frac{\sum_i^n P_{data}}{i}$$

With:

- $P_{BL,i}$ – Baseline power value for interval i [kW]
- P_{data} – Power value from extracted data [kW]
- i – Baseline profile time interval

3.4.2 Operational maximum and minimum profiles

An operational maximum power profile is required to calculate the amount of operational variance that can be applied, i.e. the amount of load that can be shifted to other periods of the operational cycle. The installed capacities of the milling components are combined to determine the plant’s maximum operational profile.

Unforeseen maintenance (breakdown maintenance) and preventative maintenance can, however, reduce the statistical maximum operational capacity of the equipment. To ensure that the maximum operational demand of the milling equipment represents actual circumstances more accurately, an availability factor is used to scale the maximum operational demand profile. The availability factor can be calculated using Equation 3-2.

Equation 3-2

$$A_o = 1 - \frac{t_{BDM} + t_{PM}}{t_{total}}$$

With:

- A_o – Availability factor [%]
- t_{BDM} – Time allocated to breakdown/unplanned maintenance [hrs]
- t_{PM} – Time allocated to preventative/routine/planned maintenance [hrs]
- t_{total} – Total interval length [hrs]

The actual operational load profile is calculated by multiplying the maximum operational load profile with the availability factor. As a result, the influence of maintenance downtime is incorporated into the power profiles. The actual operational electrical demand is calculated using Equation 3-3.

Equation 3-3

$$P_{OM} = P_M \times A_O$$

With:

- P_{OM} – Operational electrical demand [kW]
- P_M – Operational maximum electrical demand [kW]
- A_O – Availability factor [%]

In the case of forecasting possible load management in the form of load shifting, the load can only be reduced to a set minimum or so-called baseload. A baseload represents components that cannot be shut down with the mill during a load-shifting event. The components might include mill auxiliaries but not lighting, transport, packing plants and services (Assumption 4).

The following example clarifies the method used to calculate the baseline. The example represents a plant with a baseload of 200 kW, a maximum operational load (P_M) of 9 000 kW and an availability (A_O) of 85%. The actual operational maximum load (P_{OM}) is calculated as 7 650 kW. Figure 3-6 shows an example for the different concepts.

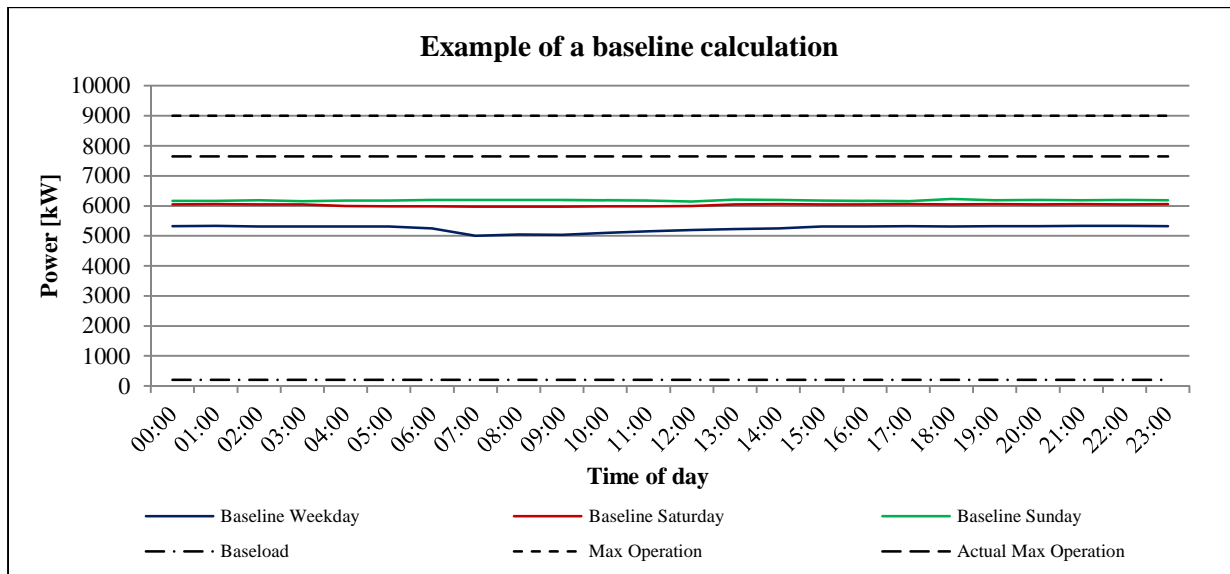


Figure 3-6: Example of baseline calculation

3.4.3 Baseline scaling

A pre-implementation baseline is used to analyse the effect of load management on the electricity demand profile of a specific cement plant. The post-implementation profile is compared with the pre-implementation baseline to evaluate the changes in operational profiles for the different times of the week (i.e. peak reduction or off-peak electricity demand increase).

The cement industry’s demand fluctuates throughout the year. During periods of fluctuating demand, the average baseline will not be representative of the specific operational conditions of the plant. Consequently, the baseline is scaled to represent similar operational circumstances. Once the baseline has been scaled, the actual profile can be compared with the baseline profile to analyse the effect of the operations management strategies.

Since the milling components have only two modes of operation (Assumption 2), scaling the baseline *energy neutral* to the actual profile will be accurate. A small deviation might occur when including the operational baseload (the baseload remains constant in spite of the demand); however, this deviation is small when considering the entire operational profile.

The baseline is scaled on a weekly basis since the considered operational cycle is weekly. The baseline is divided into weekdays, Saturdays and Sundays. Subsequently, the baseline is scaled

using five times the weekday energy consumption with one Saturday and one Sunday. The scaled baseline is calculated by multiplying the original baseline with a scaling factor. This calculation is represented in Equation 3-4.

Equation 3-4

$$P_{SBL,i} = SF \times P_{BL,i}$$

With:

- $P_{SBL,i}$ – Demand for the scaled baseline for interval i
- SF – Scaling factor
- $P_{BL,i}$ – Demand for the original baseline for interval i

The scaling factor for weekly energy neutral analysis is shown in Equation 3-5.

Equation 3-5

$$SF = \frac{(5E_{W,BL} + E_{Sat,BL} + E_{Sun,BL})}{(5E_{W,Act} + E_{Sat,Act} + E_{Sun,Act})}$$

With:

- SF – Scaling factor
- $E_{W,BL}$ – Total energy consumed in the baseline during weekdays [kW]
- $E_{Sat,BL}$ – Total energy consumed in the baseline during Saturdays [kW]
- $E_{Sun,BL}$ – Total energy consumed in the baseline during Sundays [kW]
- $E_{W,Act}$ – Total energy consumed in the actual profile during weekdays [kW]
- $E_{Sat,Act}$ – Total energy consumed in the actual profile during Saturdays [kW]
- $E_{Sun,Act}$ – Total energy consumed in the actual profile during Sundays [kW]

An example of a weekly scaled baseline and actual profile is shown in Figure 3-7. From the example, it is clear that the plant production output decreased as indicated by a lower scaled baseline. The total load shifted is calculated using the energy neutral scaled baseline. The scaled Saturday and Sunday profiles are not displayed on the graph, because no load shifting occurs on weekends. The calculations in Equation 3-5, however, consider these effects.

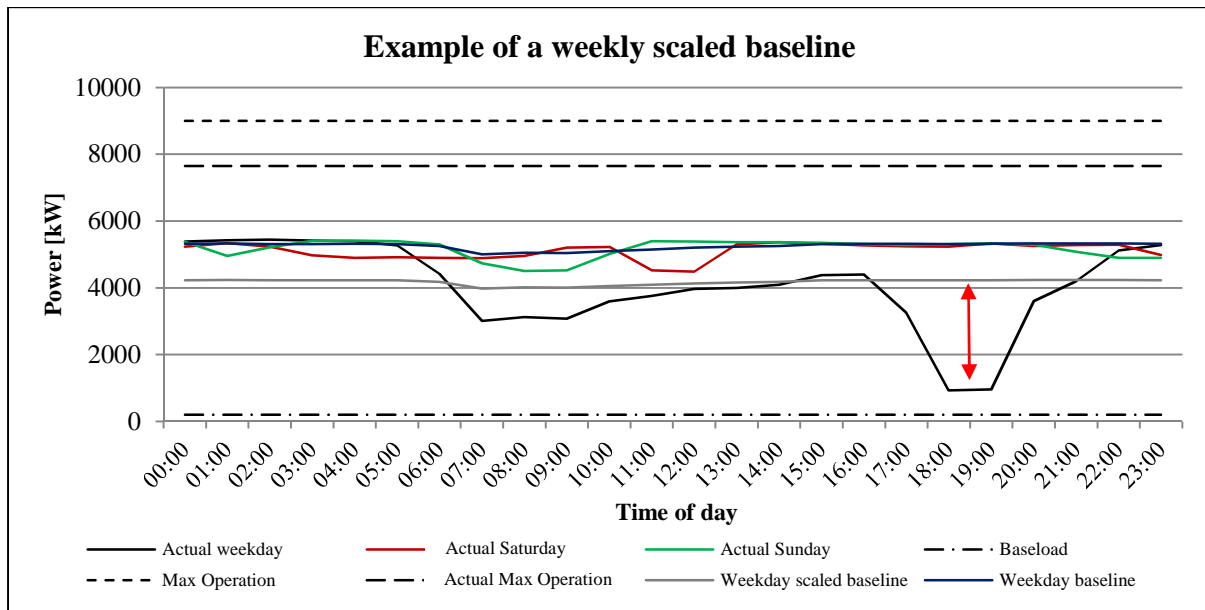


Figure 3-7: Example of a weekly scaled baseline

3.5 PRODUCTION LOAD ANALYSIS

Production rate is another common factor when evaluating cement plants. All grinding mills consume electricity; the feed rate determines the rate at which cement plants consume energy. The production load analysis will link the mean production rate to the mean power consumption for each mill.

3.5.1 Feed rate frequency

During the analysis of any cement plant, the efficiency of the grinding mills is not only dependent on the electrical demand of the different mills, but also on the production rate of the mentioned mills. The production rate of the different mills is measured by the belt weightometer on the feed conveyor to the cement silos. Analysing the feed rate of this feed conveyor will generate an accurate account of the average operation of the mill.

The feed rate of a mill is analysed by considering the percentage of incidences of a specific feed rate that occur in comparison with other values of the feed rate. The feed rates are divided into intervals of the frequency with which a specific feed occurs in a data set. Intervals represent the data set clearly and they can be compared with other mills at different plants.

As an example, consider a dataset where the maximum feed rate recorded was 200 t/h. If the data is divided into intervals of 5% of the maximum feed rate, the intervals will show the total number of data points between 0 t/h and 10 t/h. The next interval will show the number of data points between 10 t/h and 20 t/h etc.

This distribution is then normalised/non-dimensionalised by calculating a percentage of the total data points for different analysis periods. The results then, for example, show the specific percentage of the total time the mill operates between a feed rate of i and o . An example of the feed rate analysis is shown in Figure 3-8.

3.5.2 Mean feed rate

The production rate distribution provides a sound description of the mill control and production stability. For the purpose of further analysis, a single characteristic feed rate is required. A mean feed rate is calculated from the data set. This means that feed rate is used in further analysis to calculate the specific energy consumption and the production capacity of the entire grinding plant. The mean feed rate for the example is shown in Figure 3-8.

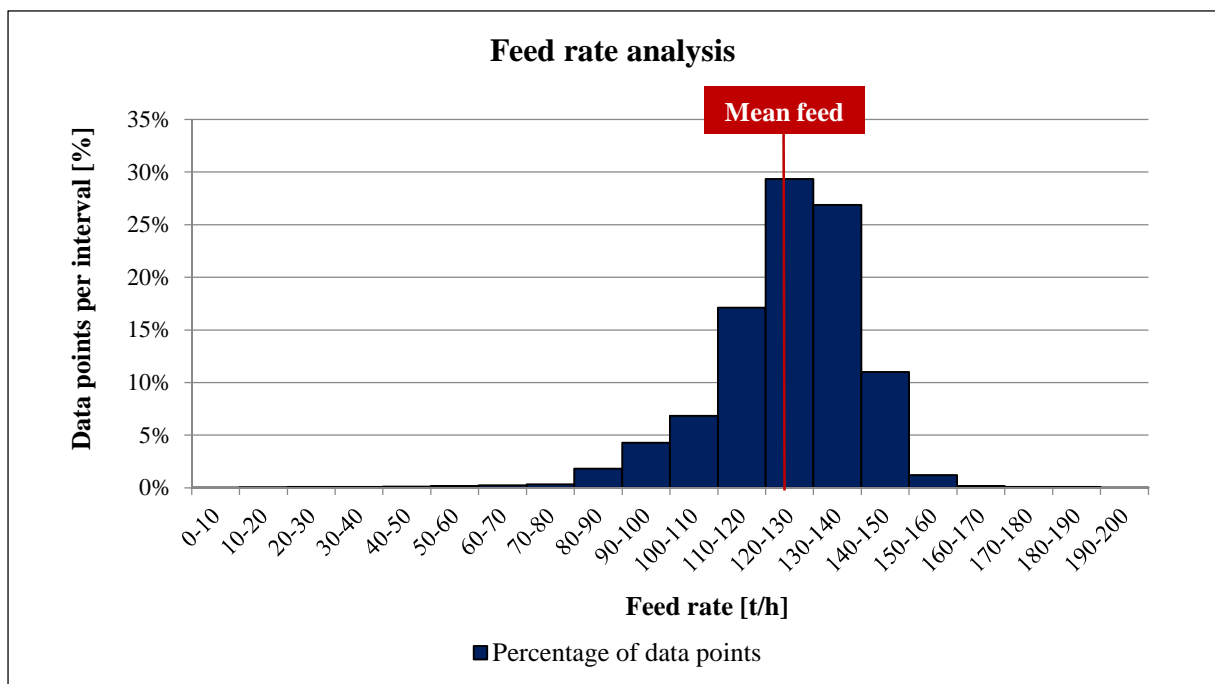


Figure 3-8: Feed rate analysis

The mean feed rate is compared with the feed rate distribution to better characterise the normal operation of the considered mill. Figure 3-8, for example, shows that the mean feed rate moves towards the lower end of the feed rate distribution spike. This might indicate that the control of the mill is poor or that start-up mill is lengthy, thus taking an extended period to reach stable operating conditions. The mean might also indicate that the mill experienced a great number of stops in the considered dataset.

3.5.3 Mean power consumption

A similar analysis technique is repeated on the power consumption of the different mills. This will generate an accurate mean power consumption that excludes data logging irregularities recorded by the SCADA systems. The mean production rate of the mill is linked to the mean power consumption of the mill. These means will be used to generate a specific energy consumption ratio for each mill considered in the two case studies.

3.6 SPECIFIC ENERGY CONSUMPTION ANALYSIS

The electrical load analysis and production load analysis for the considered mills provide thorough building blocks to generate the specific energy consumption of a plant. The mean production rate and power consumption are combined to generate a benchmark against which different plants can be analysed.

The specific energy consumption analysis will take the utilisation of more and less efficient mills into account and create a specific energy consumption trend. This creates a platform with which different plants can be compared. The energy consumption trend is a key indicator of plant efficiency. The specific energy consumption is simply defined as the amount of energy required to produce one unit of cement. In basic form, this is represented by Equation 3-6.

Equation 3-6

$$E_S = \frac{P_{OM}}{R_\mu}$$

With:

E_S	–	Specific energy consumption [kWh/t]
P_{OM}	–	Operational electrical demand [kW]
R_μ	–	Mean feed rate [t/h]

The average specific energy consumption is calculated using the mean production rate and power consumption in Equation 3-6. This, however, does not provide enough information to compare different production plants accurately. Another factor that needs to be considered is the combined specific energy consumption between plant mills.

Consider a plant with two mills as an example. One of the two mills is less efficient when considering specific energy consumption. The most optimal control strategy (when only energy consumption is considered) is to operate the most efficient mill at maximum production capacity before using the second mill. Though most cement plants do not follow this control strategy, the use of different mills has to be considered when calculating the total plant-specific energy consumption.

Using the total daily plant energy consumption, a specific energy consumption figure is calculated that accurately the energy consumption at a grinding plant reflects when considering electrical demand. The total daily energy consumption is plotted against the total daily production for the considered analysis period to generate specific plant energy consumption. Figure 3-9 shows an example.

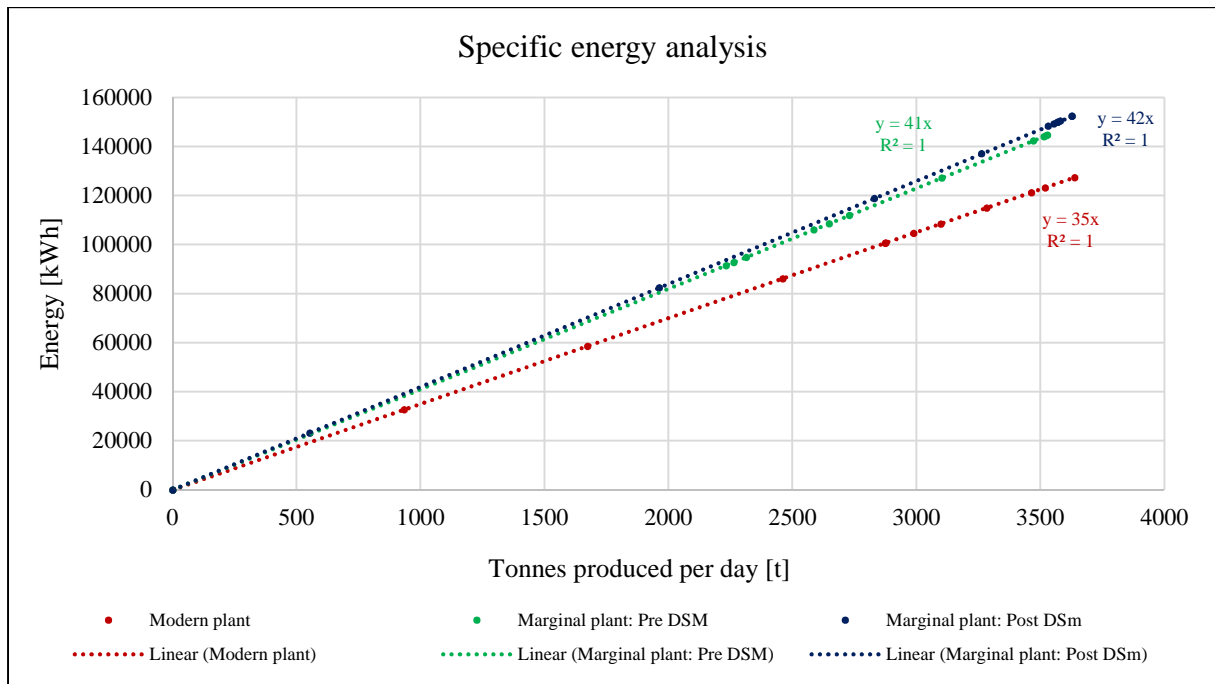


Figure 3-9: Specific energy analysis

When considering the calculated mean production rate and power consumption, the two respective mills may have different specific energy consumptions. When combining these two mills to calculate the plant-specific energy usage, the mill usage must be considered. Load management does not influence energy usage and yet there can be a difference between the pre- and post-plant energy efficiencies due to differences in mill efficiencies.

In the example shown in Figure 3-9, the majority of the production was allocated to the more efficient mill during the pre-DSM period. By using the efficient mill more, the overall specific energy usage of the plant was improved. The specific energy usage of a plant is thus influenced by using more and less efficient mills. Although load management does not influence specific energy, its effect will influence the cost analysis and, therefore, have to be analysed using this method.

Load management uses TOU tariff structure to align production with the cheapest combination of time periods to achieve target production. The energy analysis ensures that the energy usage is reflected accurately. The TOU tariffs can now be allocated to the energy usage to calculate the electricity cost of production.

3.7 COST ANALYSIS

Since different cement plants operate during different electricity tariff cost periods, it is necessary to include cost in the comparison. Cost also determines the profitability of a cement plant. The specific energy consumption of the different cement plants and the tariffs charged for electrical energy are combined to generate a specific cost curve that is used to analyse the final electricity cost intensities of the different cement grinding plants.

A cost analysis that uses the specific energy consumption analysis is compiled. The cost analysis incorporates the specific timeous cost of electrical energy with the energy consumption graph to calculate the actual cost of operation when considering electrical energy consumption. An optimal cost operation line will evaluate the effectiveness of the load management. To revise the Eskom TOU tariff structure, Figure 3-10 shows the price period allocation [59].

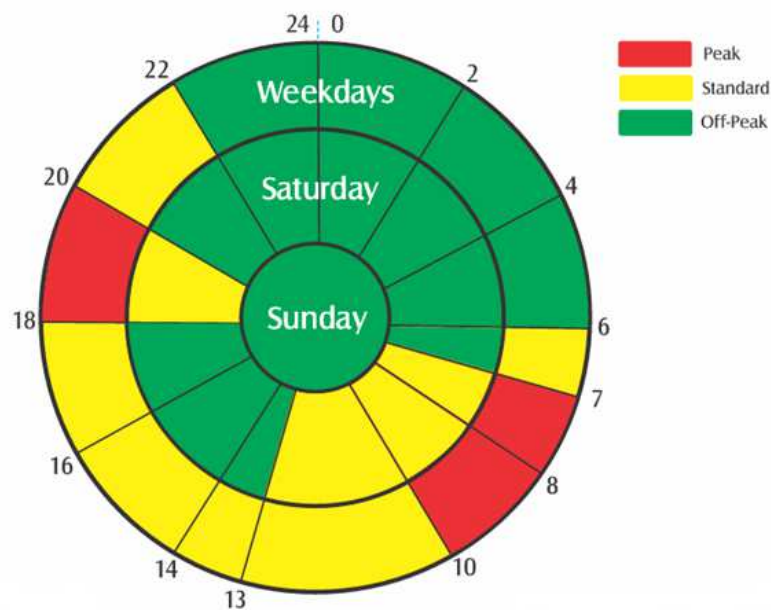


Figure 3-10: TOU price period allocation

The cost allocation will be assumed the same for all participating plants (Assumption 3). The Johannesburg City Power TOU tariff structure is used as an example to describe the cost of operation. The analysis period is divided into the different time periods of the TOU tariff

structure. The different costs are allocated to these time periods and the cost of production is calculated.

The most cost-effective scenario will be to operate the mills during the off-peak periods first. Should production targets require more operational hours, the mills will be operated during the standard periods, and finally during the peak periods. Using the weekly analysis method, the total hours per week is used to calculate the amount of time available for production in each of the tariff periods. The total hours for the different tariff periods are shown in Table 3-1 [59].

Table 3-1: TOU available hours

	Weekday	Saturday	Sunday	Week
Peak	5	0	0	25
Standard	11	7	0	62
Off-peak	8	17	24	81
Total	24	24	24	168

In Figure 3-11, the black line shows the optimal operational cost for a plant. The optimal line is calculated using the mean production rates; power consumption is identified by the distribution graphs. The optimal cost line shows the best possible operation of the marginal plant when implementing load management.

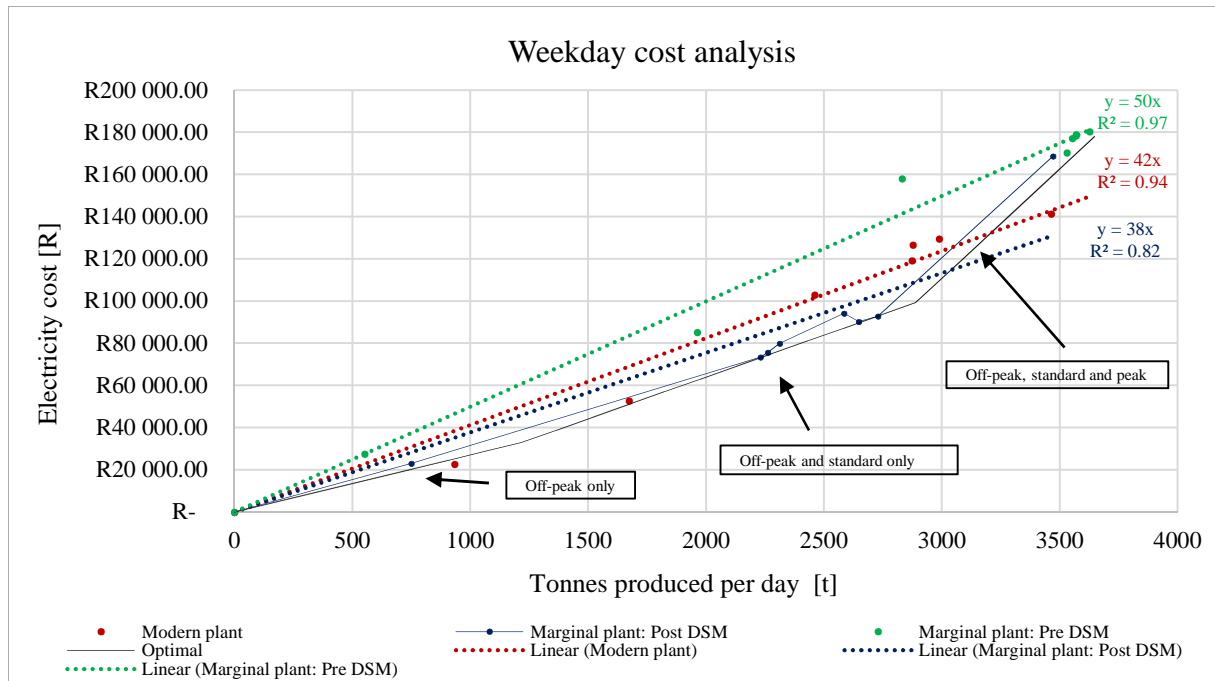


Figure 3-11: Example of a weekday cost analysis

As with the energy analysis, the cost analysis captures the total cost of electricity in daily data points. The data points of the plant will get closer to the optimal line as load management becomes more effective. Linear trend lines indicate the average cost per tonne produced for the combined data points. The slope of the linear trend lines' equations is the cost per tonne value. A solid line is drawn through the post-DSM implementation data points to show how cost efficient the plant was during load management.

A similar cost analysis has to be done for the weekends (as shown in Figure 3-12). The weekends do not have an optimal line, as the plants will be run at full capacity to catch up with lost production because of load management during weekday peak periods. Linear trend lines show the average cost per tonne.

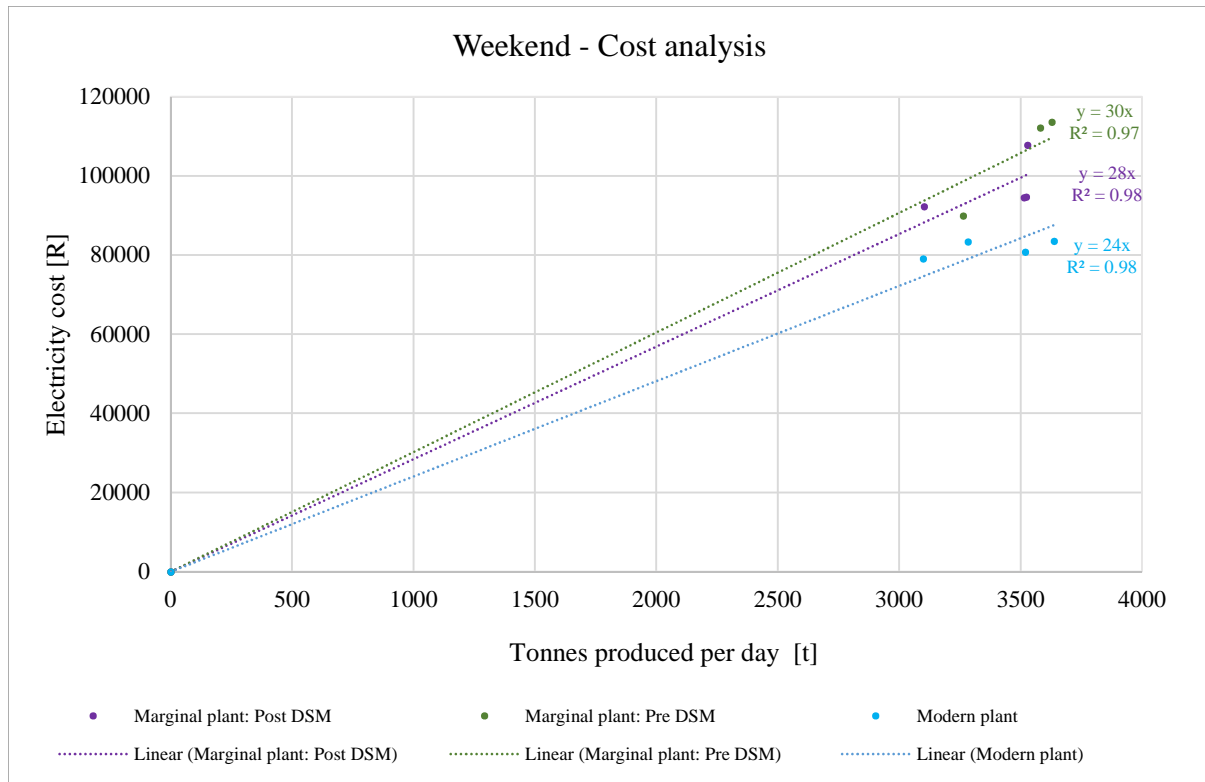


Figure 3-12: Example of weekend cost analysis

The different cost per tonne for weekdays and weekends can now be quantified to simulate the average cost per tonne for a year. To calculate the average cost per tonne that includes summer and winter tariffs, the averages from the weekday and weekend graphs are substituted into Equation 3-7. Equation 3-7 allocates the correct portion of weight to the average yearly cost when considering summer, winter, weekday and weekend tariff differences.

Table 3-2 shows how all the averages are grouped. The table summarises the performances of the marginal plant before and after load management was implemented and compares them to the modern plant’s performance. The cost effectiveness of the plants is shown on a weekday, weekend, summer, winter and yearly basis. Production can be allocated to different plants depending on the effectiveness of the load management strategies.

Table 3-2: Results summary table

	Summer tariffs			Winter tariffs			Year
	Nine months			Three months			
	Weekday	Weekend	Total	Weekday	Weekend	Total	
Marginal plant: Pre-DSM	C_{SWD}	C_{SWE}	C_S	C_{WWD}	C_{WWE}	C_W	C_{Year}
Marginal plant: Post-DSM	C_{SWD}	C_{SWE}	C_S	C_{WWD}	C_{WWE}	C_W	C_{Year}
Modern plant	C_{SWD}	C_{SWE}	C_S	C_{WWD}	C_{WWE}	C_W	C_{Year}

Equation 3-7

$$C_{Year} = \frac{9}{12} C_S + \frac{3}{12} C_W$$

$$C_S = \left[C_{SWD} \times \frac{5}{7} + C_{SWE} \times \frac{2}{7} \right] C_W = \left[C_{WWD} \times \frac{5}{7} + C_{WWE} \times \frac{2}{7} \right]$$

With:

- C_{Year} – Quantified yearly average rand per tonne
- C_S – Quantified summer average rand per tonne
- C_W – Quantified winter average rand per tonne
- C_{SWD} – Summer tariff weekday average rand per tonne
- C_{SWE} – Summer tariff weekend average rand per tonne
- C_{WWD} – Winter tariff weekday average rand per tonne
- C_{WWE} – Winter tariff weekend average rand per tonne

The average annual cost presents a universal benchmark that can be used to compare different plants. The quantified cost per tonne will determine whether DSM load management strategies can lower the electricity cost to compete with modern plants. Using the energy cost analysis, the present energy consumption of the plant can be compared with the optimal energy cost to illustrate the effectiveness of load management. Similarly, the electricity cost per tonne for two different grinding plants can be compared to calculate which of the two plants operates at the lower cost.

3.8 CONCLUSION

A proven DSM load-shifting implementation strategy was identified and discussed. A methodology for developing a benchmark to evaluate cement grinding plants was developed. The aim of the methodology was to develop a specific description of electricity cost of production between different plants. This methodology is required in order to display the effect that load management has on a cement grinding plant accurately and how the new operational strategy compares to other more efficient grinding facilities. The development was divided into four steps.

The first step – baseline development – described how an electricity demand baseline is compiled and how the developed baseline is scaled to evaluate the effect of load management. The second step – production load analysis – linked the mean production rate and mean power consumption. It also identified variances that can be expected during normal operation.

The third step – specific energy consumption – developed a profile that evaluates the actual plant energy consumption when considering differences in mill efficiency and utilisation. The results from the first three steps were combined to develop an optimal energy cost curve that is used to evaluate the effectiveness of present plant operation and to compare the operation of different plants with each other.

The methodology developed a complete framework to evaluate the production cost intensity of a marginal grinding cement plant when considering electrical energy. Using actual data from real-world sites, this analysis method can be applied to measure the influence of load management interventions on cement grinding energy consumption. The new methodology can also assist in evaluating the cost effectiveness of present control strategies for the grinding plants.

CHAPTER 4

Results

Chapter 4

Implements the identified load management strategy on the marginal cement grinding plants. The data collected before and after implementation is evaluated using the developed evaluation strategy. This chapter delivers results that will answer the research question.

4 MARGINAL CEMENT PLANT IMPLEMENTATION AND COMPARISON

4.1 PREAMBLE

Load management will be implemented on marginal grinding plants in two separate case studies. The case studies share the same characteristics and validate each other's results. The implementation and analysis methods will determine whether load management strategies can improve the profitability of a marginal cement grinding plant when considering more efficient cement grinding plants.

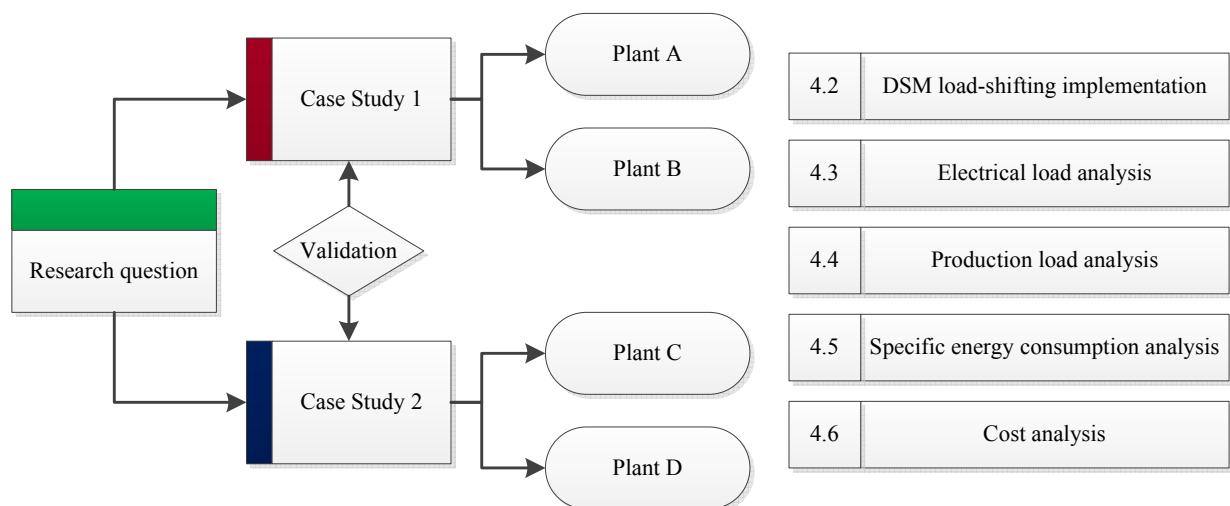


Figure 4-1: Implementation and evaluation outline

The plant characteristics are as follows:

- Both cement plants are grinding plants and are located the same distance from the clinker-producing plants. The costs preceding the clinker silos are equal, thus making the grinding plants comparable to clinker-producing cement plants.
- The plants are on a TOU tariff structure but receive electricity from different service providers with different costs. One tariff cost structure will, however, be applied to the grinding plants to identify the effect of load management.

- The marginal cement grinding plants use ball mills and the modern cement plants use vertical roller mills for cement grinding.
- The cement products in each case study are the same and cancel out any differences in electricity usage the product type may cause.

4.2 DSM LOAD-SHIFTING IMPLEMENTATION

4.2.1 Plant description

DSM load-shifting implementation and evaluation begin with investigating the considered plants. It is important to gather critical plant details and preferences as they affect the load-shifting implementation and subsequently the plant evaluation method. All required information is gathered either from plant personnel or from installed computer systems.

Production flow, buffer capacities and milling equipment specifications are summarised in different plant layouts. The layout will also be programmed into the EMS and linked to SCADA tags. The data retrieved from the tags will be used by the EMS to generate optimal production schedules. The plant layouts will be discussed in detail with other influential factors.

Case Study 1

Company 1 – Plant A (marginal)

Plant A consists of two identical horizontal ball mills in a parallel configuration. The mills are used exclusively for finishing grinding. Plant A produces two cementitious products; the volumes depend on the sales demand. One of the products is high-strength cement (52.5 MPa) and the other is medium-strength cement (42.5 MPa). The high-strength cement contains a greater proportion of clinker than the medium-strength cement, which uses more electrical energy to be ground to a Blaine fineness of 400 m²/kg as required by the company.

The company classifies the plant as a “swing” plant. A swing plant is perceived to be less efficient than other cement plants. The plant is limited in the amount of cement it can grind and

store in silos. When more efficient cement plants break down, the lost production is recovered by ramping up production at the swing plant.

Plant A is considered marginal because it is preferred that production takes place at more efficient plants. Running at a lower production capacity creates ample idle time, which makes the implementation of DSM load shifting possible. The large silos are sufficient buffers to supplement cement sales during scheduled load-shifting events.

The PMT will generate an optimal schedule that utilises the large cement storage silos to supplement cement sales when production is shifted to less expensive time periods. The optimal schedule is only a proposed running schedule. The production manager has the ability to change the schedule according to production and maintenance requirements. The simplified plant layout is given in Figure 4-2:

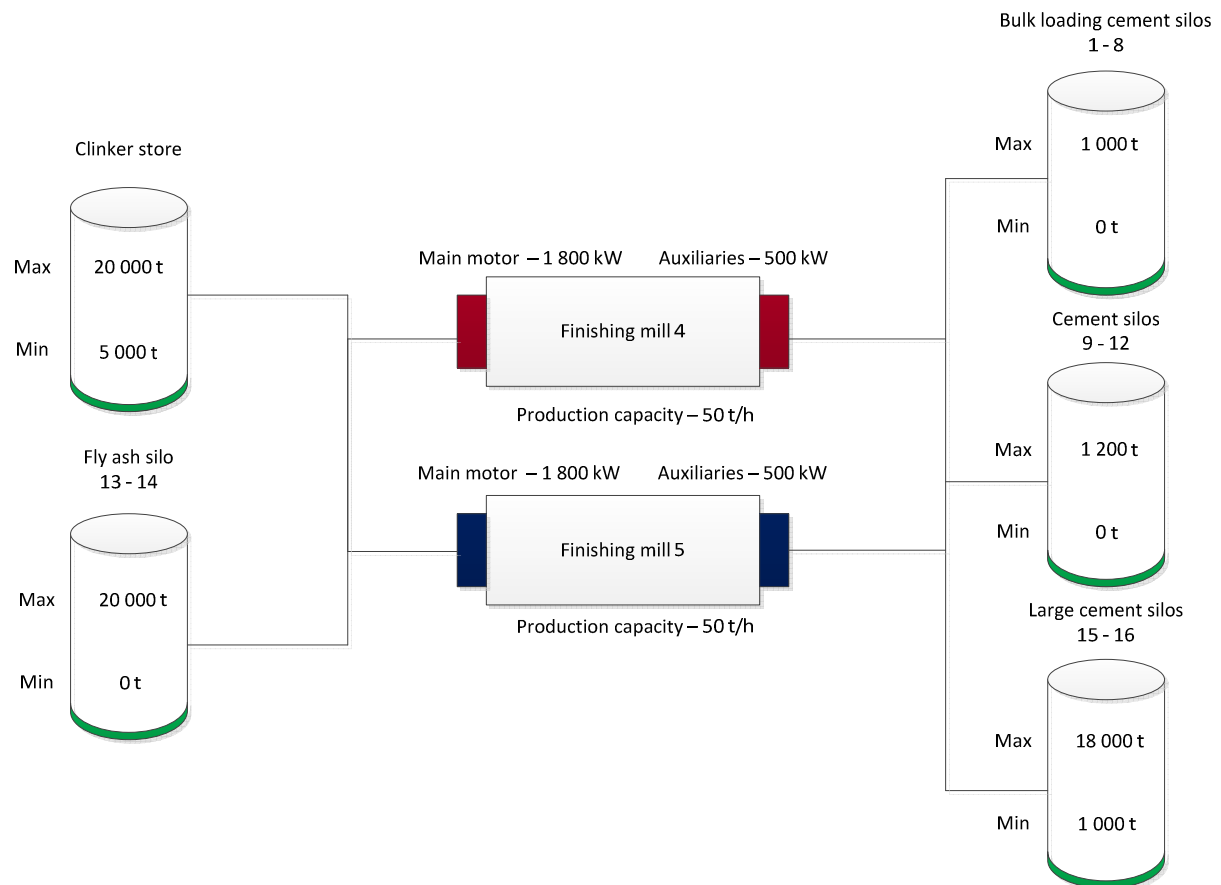


Figure 4-2: Plant A layout

Company 1 – Plant B (modern)

Plant B is classified as a grinding station as it only has one vertical roller mill, which is used for finishing grinding. The plant was built after Plant A to supplement the growing sales demand. A vertical roller mill was installed instead of ball mills to reduce energy consumption. Plant B is, therefore, classified as a modern plant because it uses modern vertical roller mill technology instead of traditional ball mill technology.

Similarly to Plant A, Plant B also produces high-strength cement (52.5 MPa). The vertical roller mill is used exclusively for high-strength cement production, which is the only product the plant produces. Plant A and Plant B are comparable as they receive clinker from the same clinker-producing plant and use the same recipes for the high-strength cement product.

Plant B personnel perceive DSM load management on the vertical roller mill to carry a high risk of failure. The plant raised concerns regarding quality, fuel costs, equipment wear and production output that might be affected negatively by the frequent stops because of DSM load shifting. Plant B, therefore, does not allow DSM load-shifting interventions on the vertical roller mill.

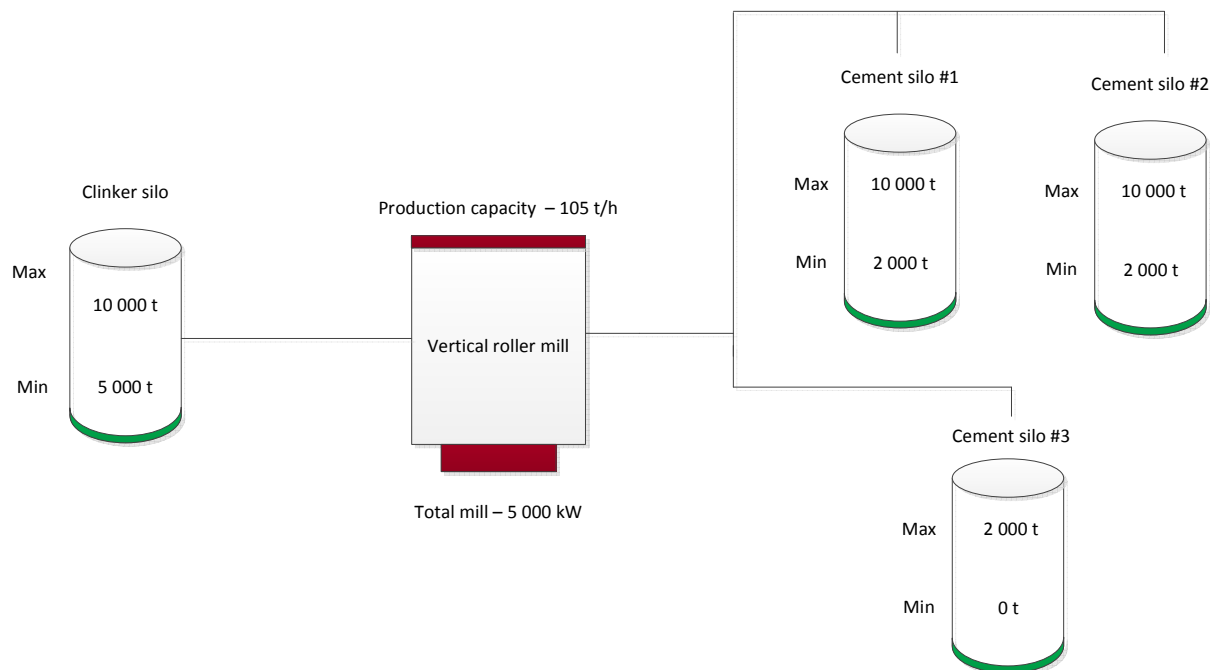


Figure 4-3: Plant B layout

Plant A and Plant B are two grinding stations contributing to the same cement company's production capacity. The plants follow opposite production strategies, which are linked to the type of milling equipment available. Plant B is more efficient than Plant A. DSM load shifting will be implemented to improve the competitiveness of Plant A when compared with B. The results will determine whether DSM strategies can improve the profitability of a marginal cement plant.

Case Study 2

Company 2 – Plant C (Marginal)

Plant C incorporates two ball mills in its production line – Cement Mill 1 and Cement Mill 2. Cement Mill 1 is a medium-sized ball mill with a production rate capacity of 65 t/h and a power demand of 2.2 MW. Cement Mill 2 is larger with a production capacity of 125 t/h and power demand of 5.2 MW. The two mills are used exclusively for cement grinding.

Two types of cement product are produced at Plant C. One of the products is high-strength cement (52.5 MPa) and the other is all-purpose cement (32.5 MPa). The volume of each product produced in a month is dependent on the sales demand. Plant C is deemed marginal because it uses traditional ball mills instead of modern vertical roller mills. The simplified layout is given by Figure 4-4.

Plant C has large buffer capacities that can be utilised effectively by the PMT to maintain process flow during load-shifting events. Production demand is acceptable for load management to be implemented. Plant personnel welcome the implementation of DSM load management.

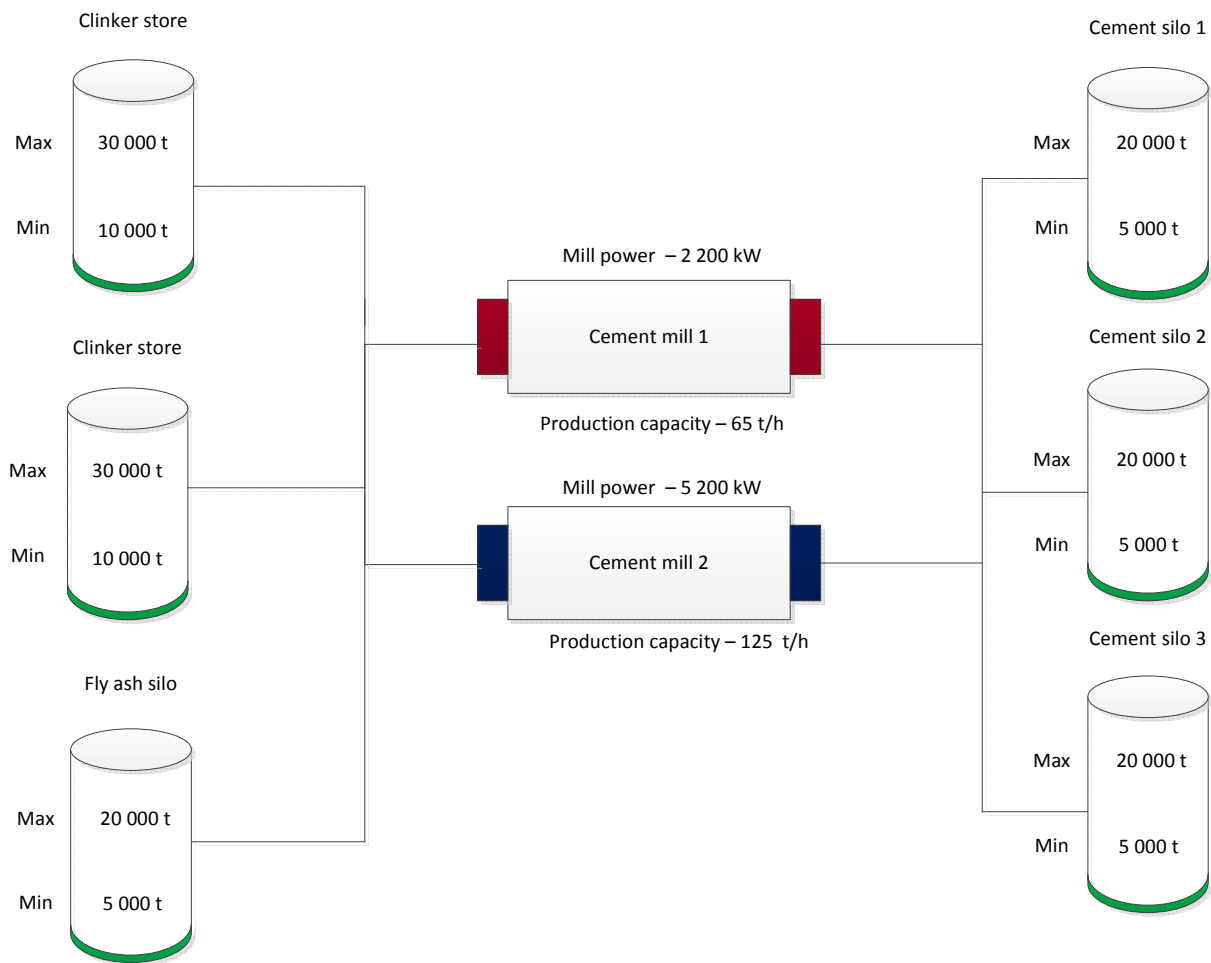


Figure 4-4: Plant C layout

Company 2 – Plant D (modern)

Plant B consists of a modern vertical roller mill and a horizontal ball mill. The horizontal ball mill was decommissioned since all production targets could be met by the more efficient vertical roller mill. The simplified layout is given by Figure 4-5.

The vertical roller mill produces high-strength cement (52.5 MPa) and medium-strength cement (42.5 MPa). The volume of each product that is produced is dependent on month-to-month sales demands. The high-strength cement is the same product that is produced by Plant C. Plant C and Plant D receive clinker from the same clinker-producing plant, making electricity cost preceding the clinker stores negligible.

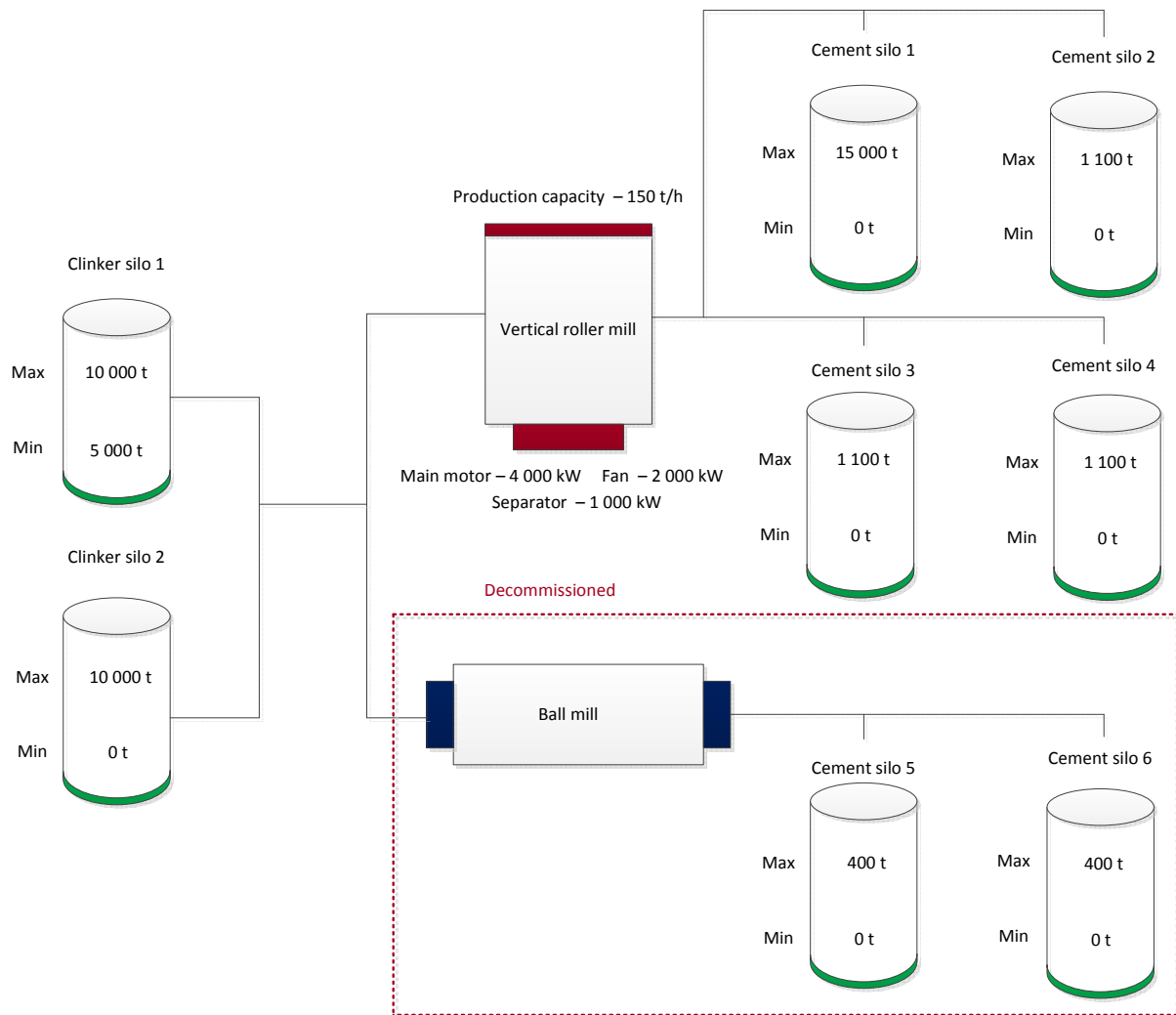


Figure 4-5: Plant D layout

As with Plant B in Case Study 1, Plant D is also opposed to DSM load management. The main reason for the opposition is possible equipment damage, fuel cost and product quality concerns. Plant D management, therefore, does not allow DSM load management on the vertical roller mill. Plant particulars were collected from plant personnel and the SCADA system.

4.2.2 DSM load shift implementation

A virtual server was placed on each of the marginal cement plants. The EMSs were loaded on the servers and connected to the plants' SCADAs via OPC connections. The EMSs have the data acquisition capabilities developed by Maneschijn and retrieve relevant data from the

respective SCADA systems. Once the data has been acquired, it is sent to the ESCO's local server to be processed by the PMT containing the modelling algorithms developed by Swanepoel.

Marginal Plant A's data communication with the ESCO's modelling servers was done via a mobile device connection as the company did not give the ESCO Internet access to its domains. Marginal Plant B gave Internet access and data was sent and received through their secured Internet domain.

Once approved by the production managers, the optimised schedules were sent back to the plant and displayed on the Process Toolbox (PTB) viewers. The plants for the most part ran the cement mills according to the milling schedule received. A performance report was also sent to the plant on a daily and monthly basis and frequent meetings with relevant plant personnel were held to ensure continuous motivation and support.



Figure 4-6: Picture of virtual server installed on marginal Plant A

Figure 4-6 and Figure 4-7 show pictures of the virtual servers installed on the marginal cement plants. In addition, EMS screenshots are added in Appendix A. The implementation strategy is generic and autonomous. It proved to be successful on the two marginal cement grinding plants.

The results obtained from implementing the DSM strategy will be analysed by the evaluation strategy in the following sections.



Figure 4-7: Picture of virtual server installed on marginal Plant C

4.3 ELECTRICAL LOAD ANALYSIS

Firstly, the cement grinding plants' load profiles are calculated. Plant load profiles will show the plants' operational trends. Cement plants reach a full production cycle in a week. The power profile comprise one month's data to ensure that a minimum of four production cycles are captured. The analysis will be done on both the modern and marginal plants.

In addition to the load profile, a simulation is done to determine the maximum load shifting possible on the marginal plants. The simulation determines the amount of power the ESCO agrees to shift on the plant. Once the ESCO determines the maximum load-shifting potential and Eskom agrees to the funding, the ESCO will undertake the project in order to achieve that load-shifting potential or higher.

4.3.1 Case Study 1

Company 1 – Plant A (pre-DSM/baseline)

Figure 4-8 shows the load profile of Plant A before the ESCO implemented DSM load management. The maximum operation is determined by the average power consumption when the mill is at full operation. Plant A plans eight hours of maintenance during weekdays. Production is maximised during weekends to benefit from the lower tariffs. Additionally, unforeseen maintenance accounts for an average of four hours a week.

The availability factor is determined by comparing the total available production hours to the scheduled and unplanned maintenance hours. Multiplying the operational maximum power usage by the availability gives an actual maximum operation as shown in Figure 4-8. Knowing the actual maximum operation is important when simulating maximum load shifting. As a result, realistic amounts of operation can be shifted from peak to standard and off-peak periods.

The weekday baseline shows the actual operation of Plant A between Mondays and Fridays. The drop in power demand between 06:00 and 20:00 can be accredited to maintenance that is conducted in standard and peak time periods. The Saturday and Sunday baselines are close to the maximum operation indicating that the plant is maximising production during the weekend low-cost time periods. The plant also operates above the actual maximum operation indicating that breakdowns occurred on weekends during the baseline period.

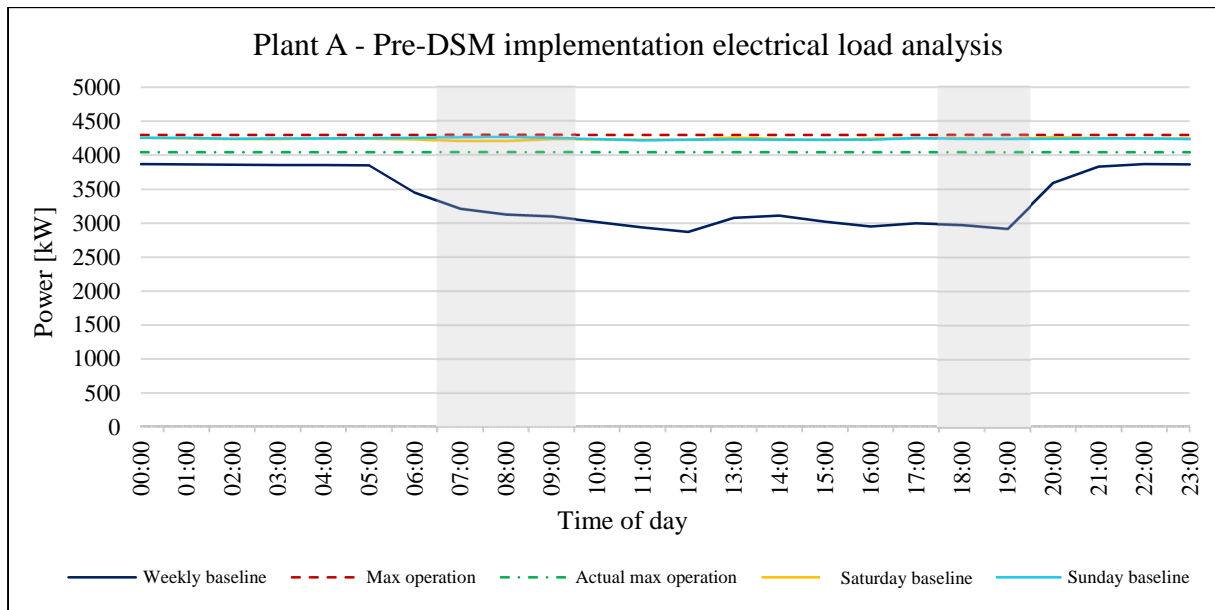


Figure 4-8: Plant A pre-DSM electrical load analysis

Company 1 – Plant A (simulated load shifting)

The simulated load-shifting profile is determined by using the actual maximum operation as a limit to the shiftable load. The simulated load-shifting profile is scaled energy neutral with the baseline profile, as the load is only shifted to different time periods and not reduced. Weekend production is fully utilised. Therefore, the weekday standard periods will be fully used along with the off-peak periods.

No baseload should exist as the mill auxiliaries can be switched off with the mills. Eskom experiences the highest demand during the evening peak period. The ESCO is, therefore, only contracted to shift load from the evening peak. The simulations show a maximum achievable evening load shift of 2.1 MW.

Peak-time load is shifted to all available standard and off-peak periods as shown in Figure 4-9. The maximum achievable load-shifting value will be submitted to Eskom as the contractual load-shifting target. The ESCO will attempt to achieve the simulated load-shifting target.

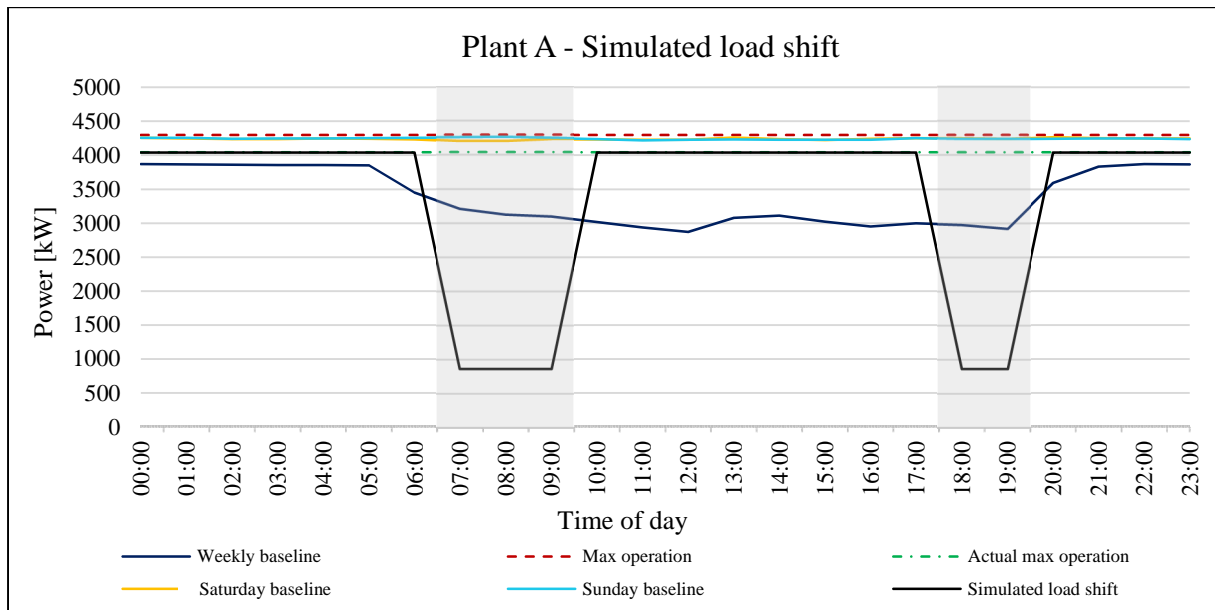


Figure 4-9: Plant A simulated load shift

Company 1 – Plant A (post-DSM)

Figure 4-10 shows a definite decline in production in the post-DSM production month. As a result, the scaled baseline dropped significantly compared with the baseline profile. The PMT used the reduced production demand to shift load to off-peak and standard periods. Plant A was very effective in reducing load during peak periods with no use during peak periods.

The weekend production declined as well due to the drop in production demand. An evening load shift of 2.3 MW was achieved on an Eskom contractual target of 2.1 MW. The results show that a decrease in production can lower or increase the amount of shiftable load. High production demand, as seen in the pre-DSM data, can reduce the maximum shiftable load because idle standard and off-peak periods are available.

Low production demand will also decrease the amount of shiftable load. If production is low, the baseline decreases. The baseline reduction decreases the demand for peak-time load shifting which poses a threat to the Eskom contractual target. In this case study, production declined sufficiently to influence the shiftable load positively. Good load-shifting executions by the plant resulted in an overperformance of 0.2 MW or 10% of the contractual target.

The simulated load shifting is accurate within 10% of the contractual target. This verifies the results derived from the simulation model and proves that it has an acceptable accuracy when production remains constant.

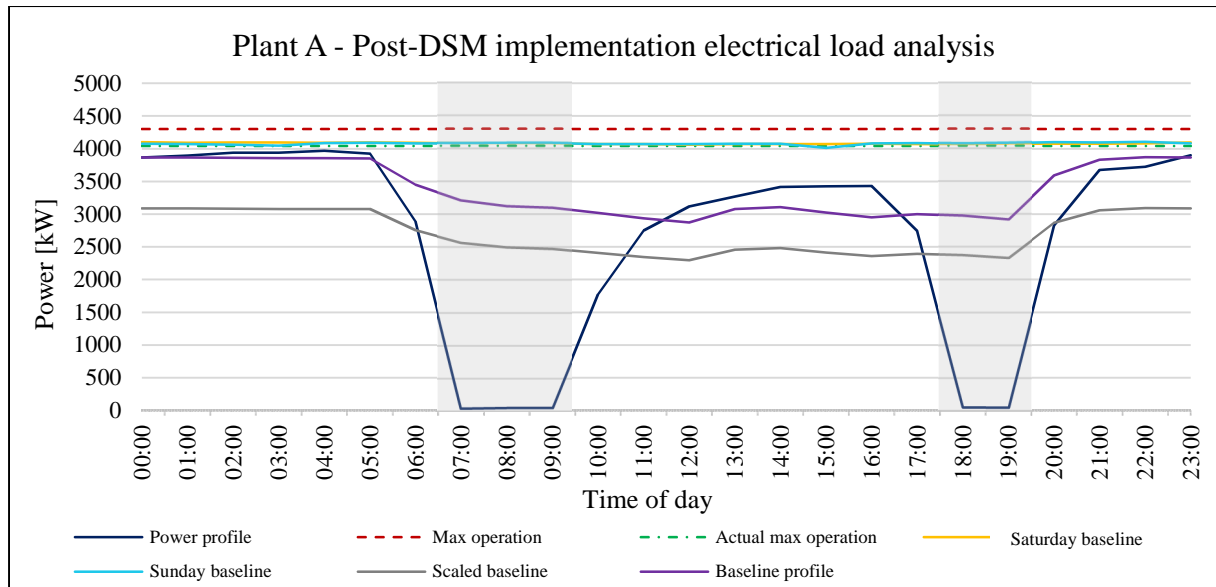


Figure 4-10: Plant A post-DSM electrical load analysis

Company 2 – Plant B (modern)

The vertical roller mill is fully utilised during weekend production. During some weekends, the silos were filled to their maximum and the mill had to be stopped. Stops caused the volatility that can be seen in the average weekend power profiles. Other factors such as breakdowns and poor control added to the volatility as can be seen in Figure 4-11. The weekday baseline was lower than the weekends as a full day of maintenance was scheduled once a week.

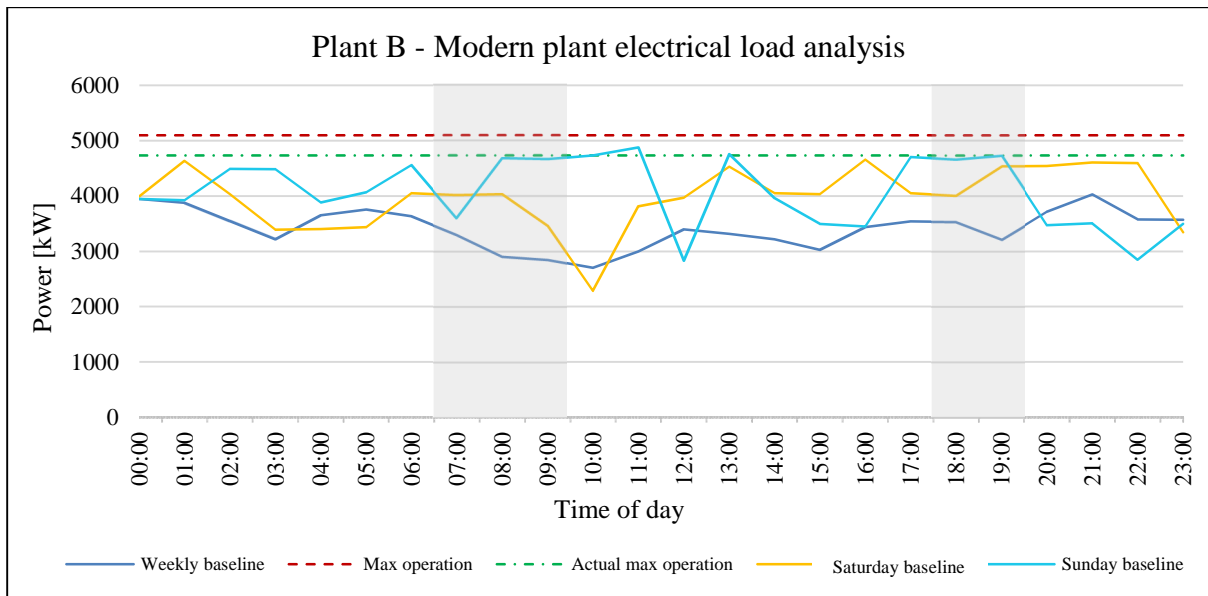


Figure 4-11: Plant B electrical load analysis

Case Study 1’s marginal cement plant executed excellent load management as seen in Figure 4-10. The simulated load shifting gave a good indication of the available shiftable load. Using weekly scaling, the total evening load shift was calculated as 2.3 MW. Further evaluation will take cost and production into account.

4.3.2 Case Study 2

Company 2 – Plant C (pre-DSM/baseline)

The pre-DSM implementation electrical load analysis (displayed in Figure 4-12) shows no production being allocated to less expensive tariff periods. The Saturday baseline drops slightly after 11:00 and stays low throughout the Sunday profile. The drop indicates lower production during the end of the weekends as silos are filled to their maximum level. The weekday baseline profile also runs lower because planned maintenance decreases the daily average.

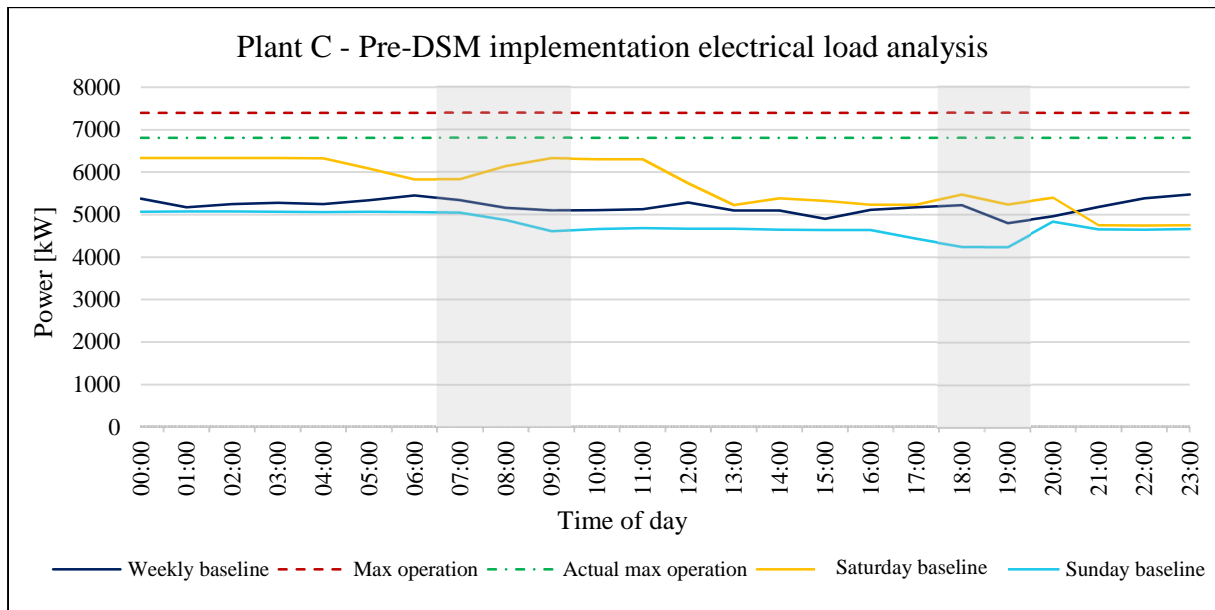


Figure 4-12: Plant C pre-DSM electrical load analysis

Company 2 – Plant C (simulated load shift)

The optimal load-shifting profile is displayed in Figure 4-13. All of the production is shifted out of the peak periods and reallocated to the standard and off-peak periods. The maximum evening peak load shifting is calculated at 5 MW when production demand stays the same.

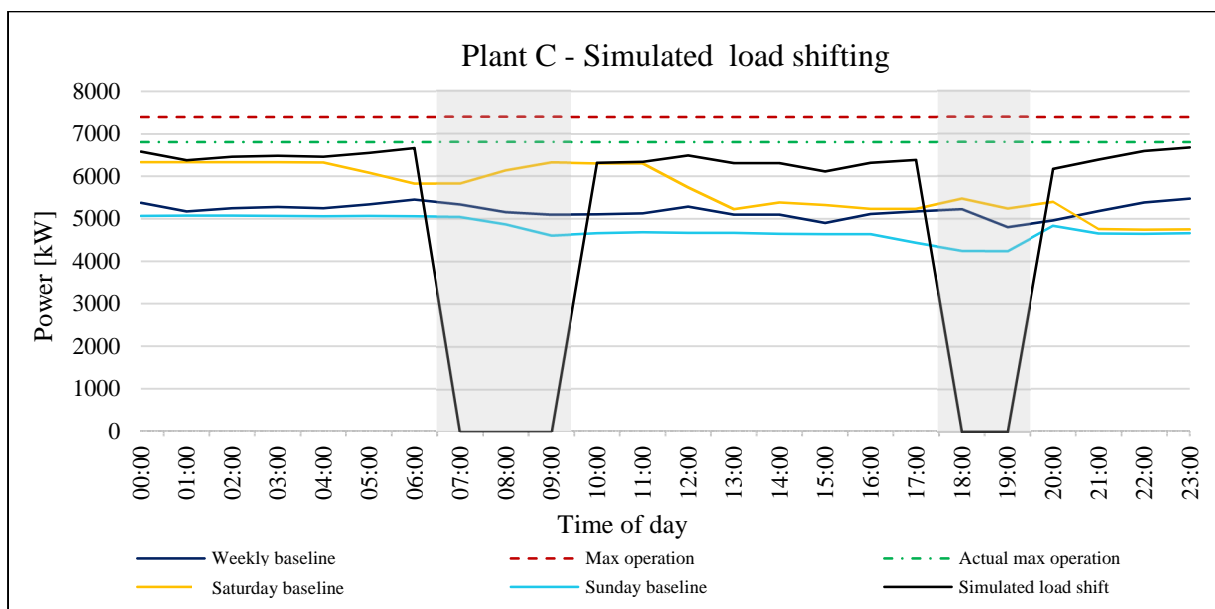


Figure 4-13: Plant C simulated load shift

Company 2 – Plant C (post-DSM)

During the post-implementation period, a large reduction in production occurred. Low production volumes created opportunity to shift most of the peak load to off-peak periods, which are substantially cheaper than standard periods. The power profile does not drop all the way to zero during peak periods, indicating some missed load-shifting opportunities.

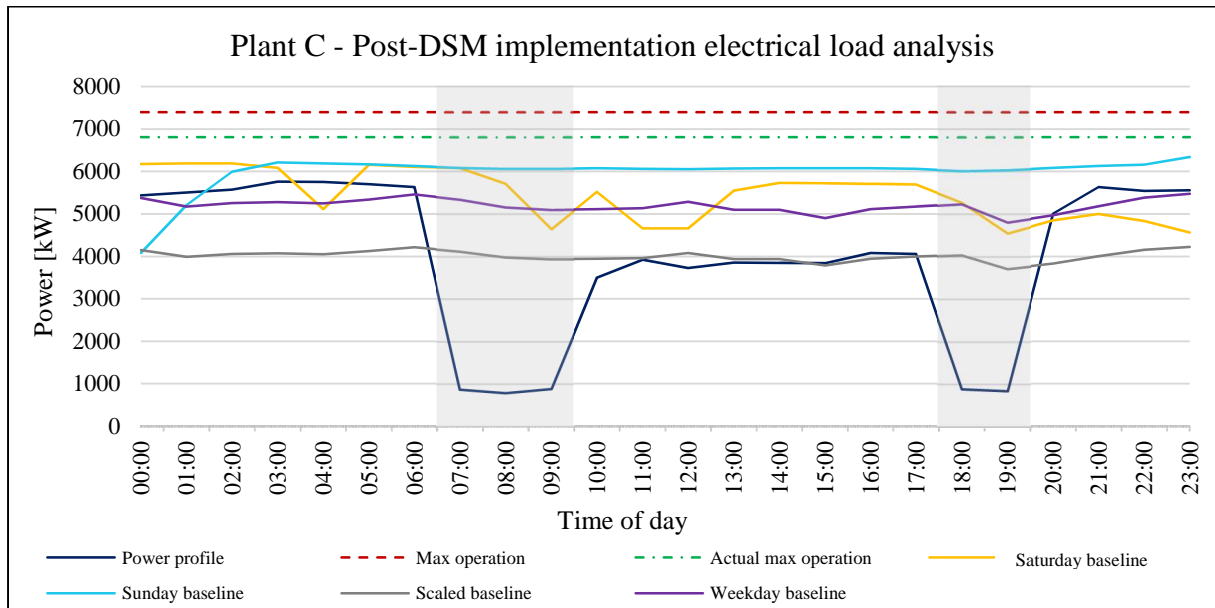


Figure 4-14: Plant C post-DSM electrical load analysis

An evening load shift of 3 MW was achieved for the post-DSM implementation month. The plant underperformed by 2 MW on the Eskom contractual target because of a significant baseline drop and missed load-shifting opportunities. Although the achieved target was below the contractual target, substantial cost savings were still achieved.

The simulation model in this case study did not produce an accurate (within 10%) load-shifting potential. This, however, does not mean that the simulation model is inaccurate. The simulation model's accuracy is greatly influenced by total production or utilisation of the mills. It is impossible to know exactly what the production demand of a plant may be, thus it makes it difficult to predict an accurate load-shifting potential.

Company 2 – Plant D (modern)

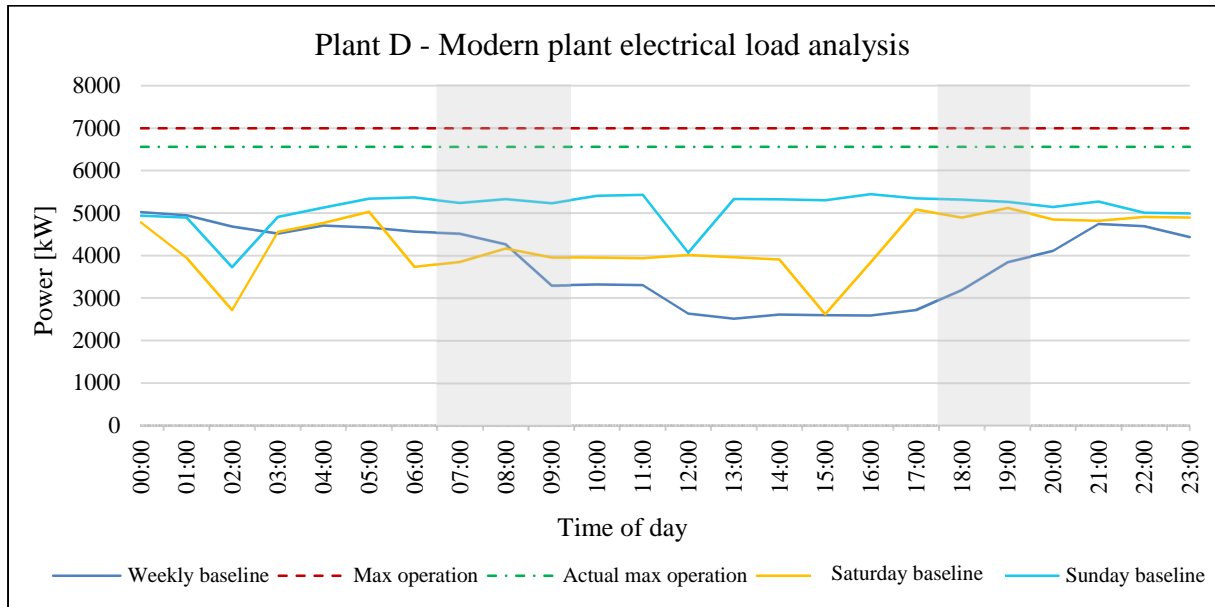


Figure 4-15: Plant D electrical load analysis

The vertical roller mill on Plant D operates well under its capacity due to a decrease in cement sales largely influenced by the recent weak economic position of South Africa. Unforeseen breakdowns cause dips in the weekend profiles. A decline in power usage between 10:00 and 20:00 during the weekday profile can be attributed to scheduled maintenance.

The vertical roller mill at Plant B shows unstable production trends, which are evident in the volatility shown in Figure 4-11 and Figure 4-15. These can be attributed to poor control and frequent breakdowns. Unstable production is one of the reasons why plant personnel do not allow DSM load management on the vertical roller mills. Good load management was achieved by marginal Plant C. The results will be analysed further in the production load analysis.

4.4 PRODUCTION LOAD ANALYSIS

The production load analysis will determine a statistically sound average production rate and corresponding power consumption for each mill considered in Case Study 1 and Case Study 2. The production rate and power consumption will be influenced by the type of mill, mill efficiency and type of product being produced.

A statistical average production rate is derived by capturing feed rate data in distribution graphs. The distribution graph highlights the production rate and power consumption that occur most often on a particular mill when producing a particular product. Deriving the mean production rates and power consumptions from distribution graphs eliminates outliers and reflects a trustworthy normal mill operation.

4.4.1 Case Study 1

Plant A – Finishing Mill 4 and Finishing Mill 5

Plant A produces high-strength (52.5 MPa) and medium-strength cement (42.5 MPa). Products with different strengths contain different ratios of clinker, fly ash, gypsum and slag. Clinker is harder than the other additives and requires more electrical energy to grind to a particular fineness [28]. Products with higher volumes of clinker tend to have more strength and subsequently mill at lower production rates.

Mills producing more than one product will show two peaks in the power consumption and production rate of each product in distribution graphs. Figure 4-16 and Figure 4-17 show the power and production distribution rate for Finishing Mill 4. The high-strength means are indicated on the distribution graphs by the grey dotted lines; the medium-strength means by the dark red dotted lines.

The high-strength product has a production distribution rate of between 30 t/h and 46 t/h and a power distribution of 1 910 kW to 1 980 kW. As indicated by the peaks on the graphs, the mean production of high-strength cement on Finishing Mill 4 is 40.5 t/h and demands 1 947 kW of electrical power.

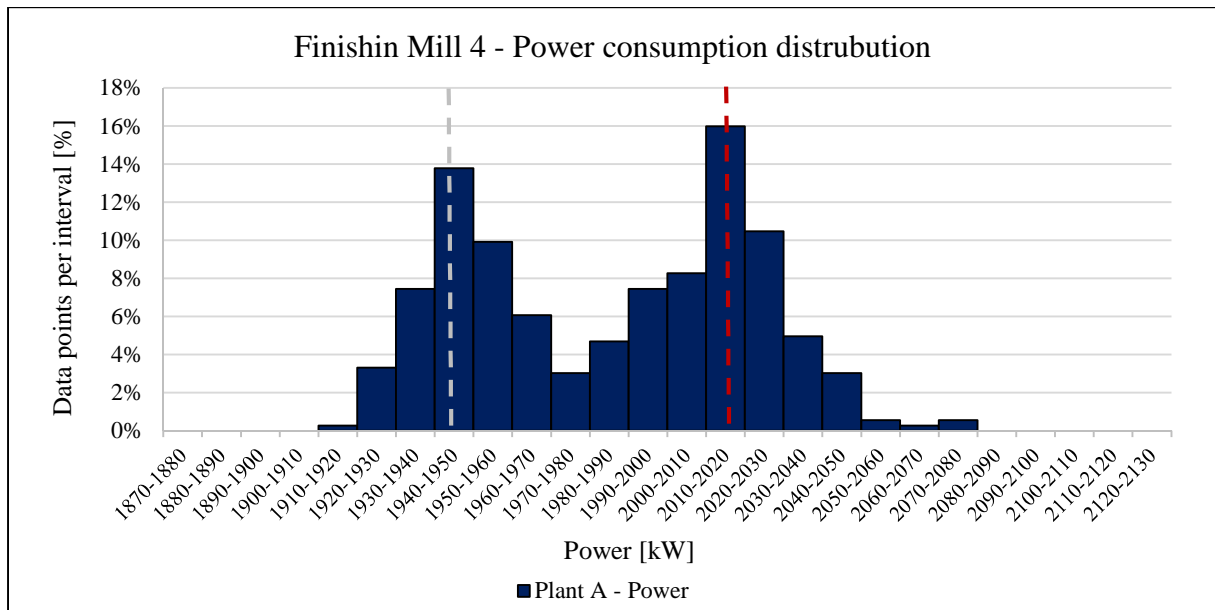


Figure 4-16: Finishing Mill 4 mean power analysis

Medium-strength cement contains smaller amounts of clinker, thus making the product easier to grind. The medium-strength product shows a production distribution rate of 46 t/h to 62 t/h and a power distribution of 1 980 kW to 2 080 kW. Finishing Mill 4 produces medium-strength cement at an average of 52.5 t/h while demanding 2 016 kW of power.

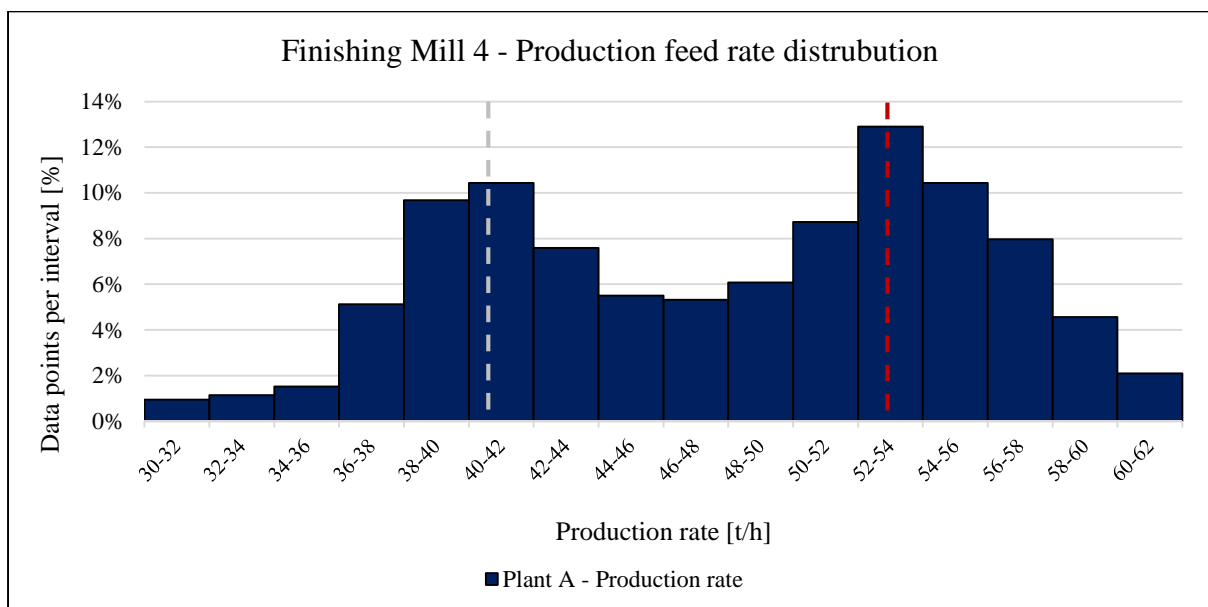


Figure 4-17: Finishing Mill 4 mean production rate analysis

Finishing Mill 5 also produces the high- and medium-strength products as indicated by the two peaks in Figure 4-18 and Figure 4-19. The peak on the left contains the bulk of the production occurrences, which is an indicator that more medium-strength than high-strength cement was produced.

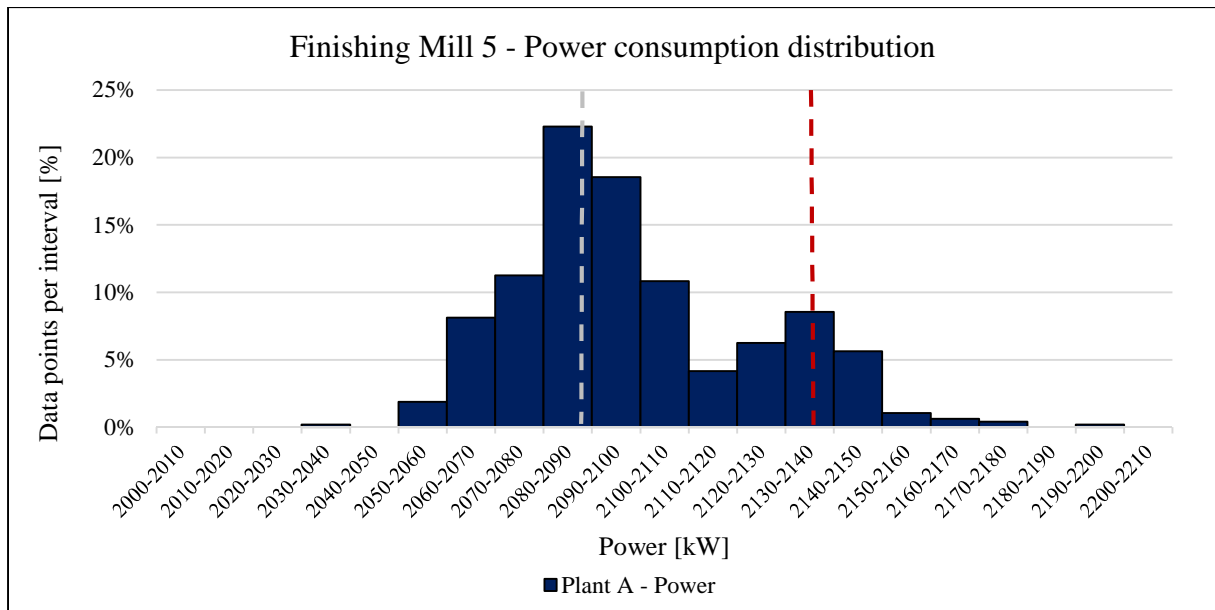


Figure 4-18: Finishing Mill 5 mean power analysis

The high-strength cement was produced at a mean production rate of 44.1 t/h at a corresponding 2 088 kW power consumption. The medium-strength cement was produced at a much higher production rate of 53 t/h and averaged at 2 135 kW power demand.

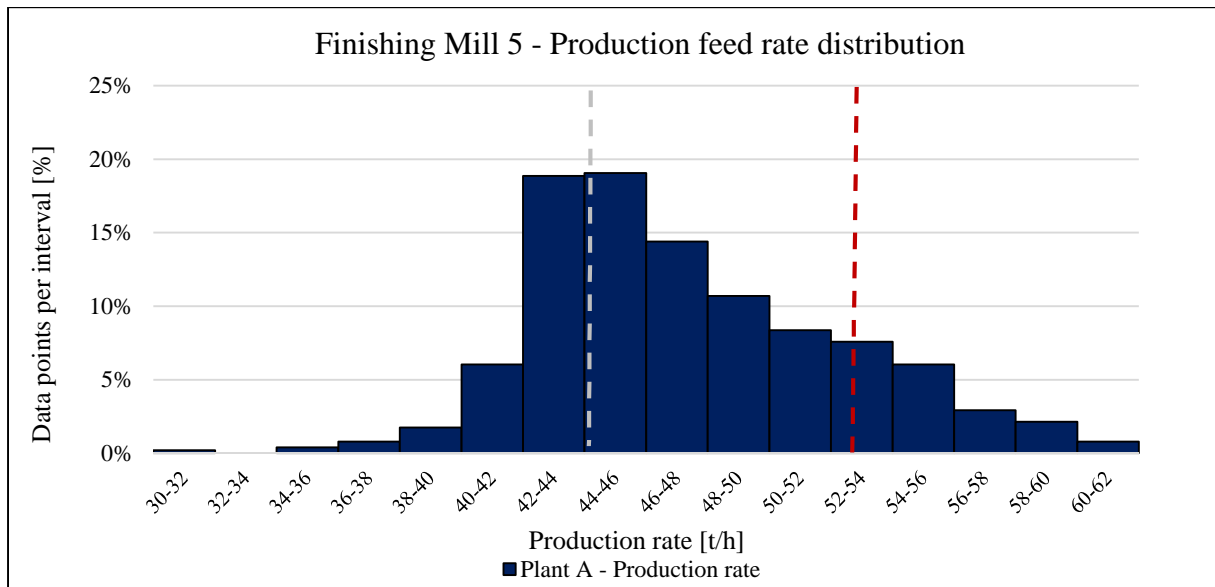


Figure 4-19: Finishing Mill 5 mean production rate analysis

Plant B – Vertical roller mill

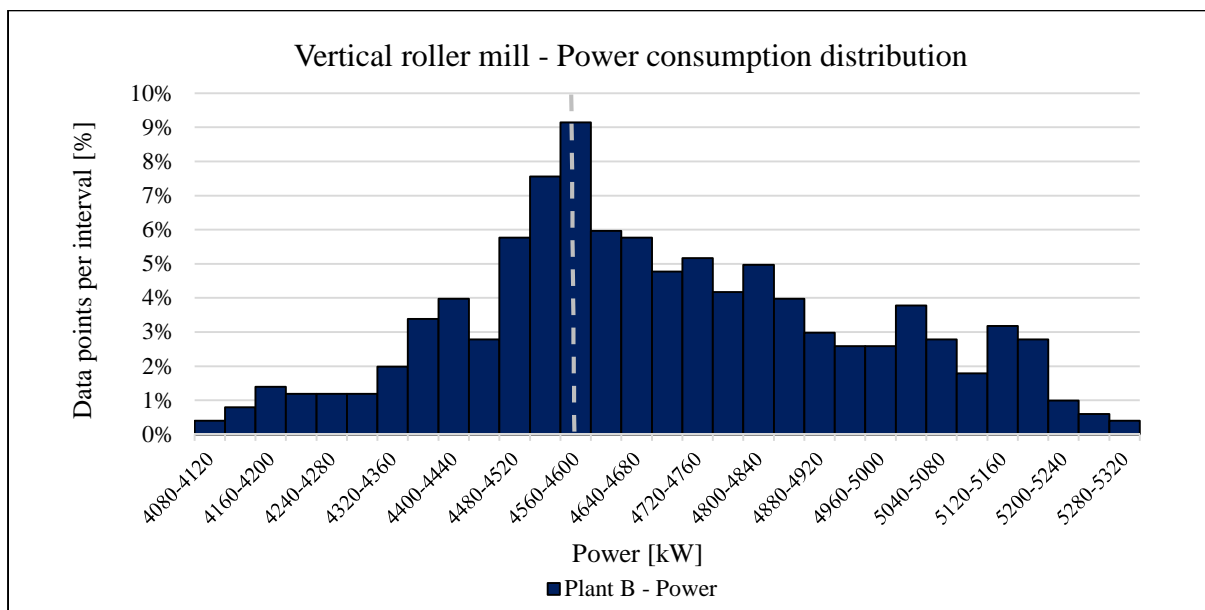


Figure 4-20: Plant B vertical roller mill mean power analysis

The vertical roller mill on Plant B only produces high-strength cement. The mill has a wider production rate and corresponding power consumption distribution than the ball mill in Plant A. This is an indication of lengthy start-ups and poor control by control room operators.

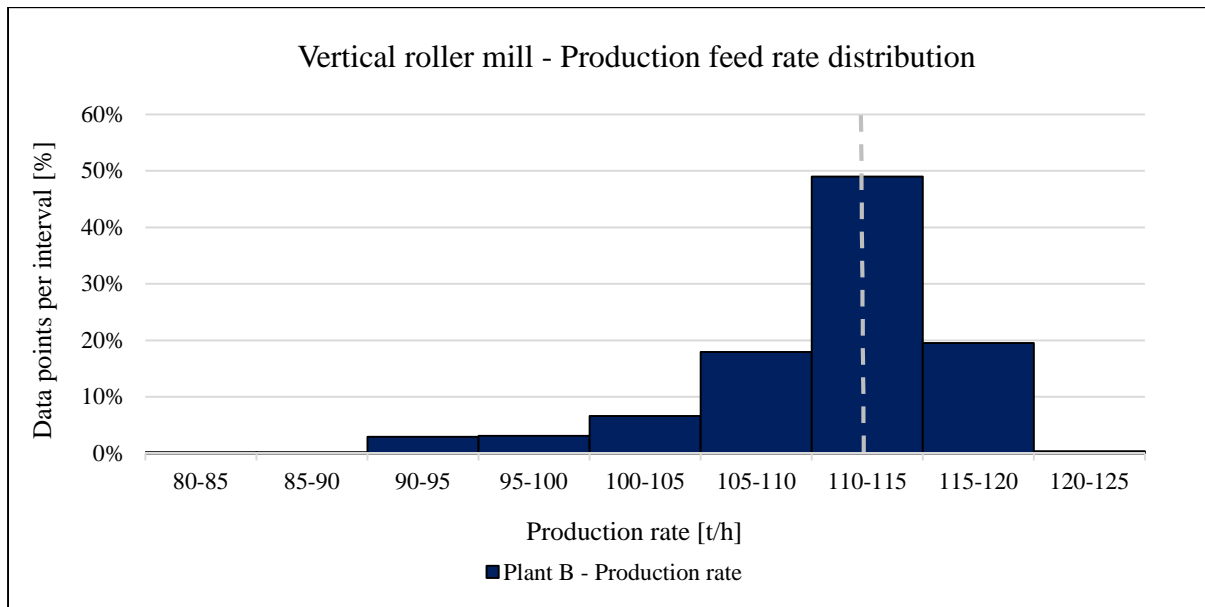


Figure 4-21: Plant B vertical roller mill mean production rate analysis

The vertical roller mill produces high-strength cement at a mean production rate of 112 t/h and 4 570 kW power demand. The mean data gathered from the mills in Case Study 1 is listed in Table 4-1. The specific mean energy is also calculated to determine the efficiency of the mills.

Table 4-1: Case Study 1 production load analysis summary

Case Study 1	Plant A		Plant B		
Finishing Mill	Finishing Mill 4	Finishing Mill 5	Finishing Mill 5	Vertical roller mill	
Product [MPa]	52.5	42.5	52.5	52.5	
Power [kW]	1 947	2016	2 088	2 135	4 570
Production rate [t/h]	40.5	52.5	44.1	53.0	112.0
Specific energy [kWh/t]	48.1	38.4	47.3	40.3	40.8

Finishing Mill 4 and Finishing Mill 5 produce both high- and medium-strength cement at close to the same specific energy consumption. The vertical roller mill of Plant B is roughly 12% more efficient when considering electricity usage than the ball mills of Plant A when producing high-strength cement. The fact that the vertical roller mill on Plant B only produces high-strength cement limits the analysis to simulate only the effect of DSM load management on the plants when producing high-strength cement. Medium-strength cement cannot be compared

with Plant B as there is no data available to analyse the vertical roller mill’s response to the product type.

The primary objective of the study is to determine whether DSM strategies can improve the profitability of a marginal cement plant when compared with a modern plant. The goal can still be achieved by assuming all production on the plant was high-strength cement. The high-strength cement production will be simulated by multiplying the power data with the inverse of the mean specific energy. An accurate high-strength cement production can be derived using this method.

4.4.2 Case Study 2

Plant C – Finishing Mills 1 and Finishing Mill 2

Plant C produces high-strength and low-strength cement. The production load analysis will only be done on the high-strength product as it is the only product produced by the vertical roller mill of Plant D as well, keeping in mind that the two mills can only be compared accurately when producing the same product. Hence, there is no need for analysing the low-strength product on Plant C’s ball mills.

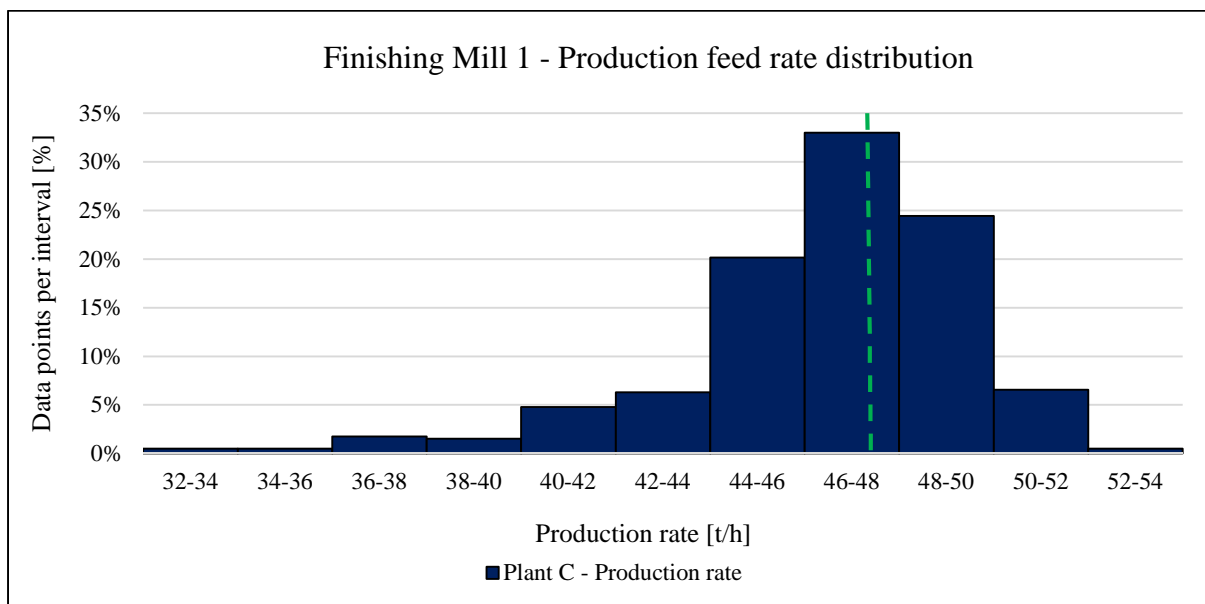


Figure 4-22: Finishing Mill 1 mean production rate analysis

Finishing Mill 1 produces high-strength cement at a mean production rate of 47 t/h while demanding an average of 1992 kW of power as shown in Figure 4-23 and Figure 4-24. The power distribution varies from 1 880 to 2 080 kW and the production rate from 32 t/h to 54 t/h.

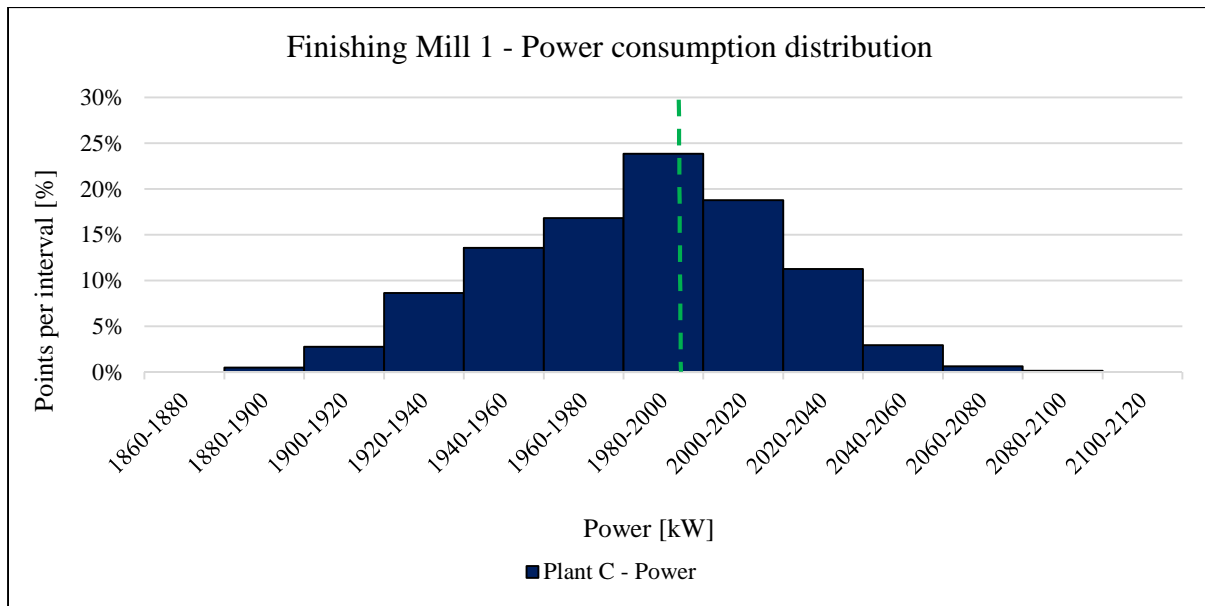


Figure 4-23: Finishing Mill 1 mean power analysis

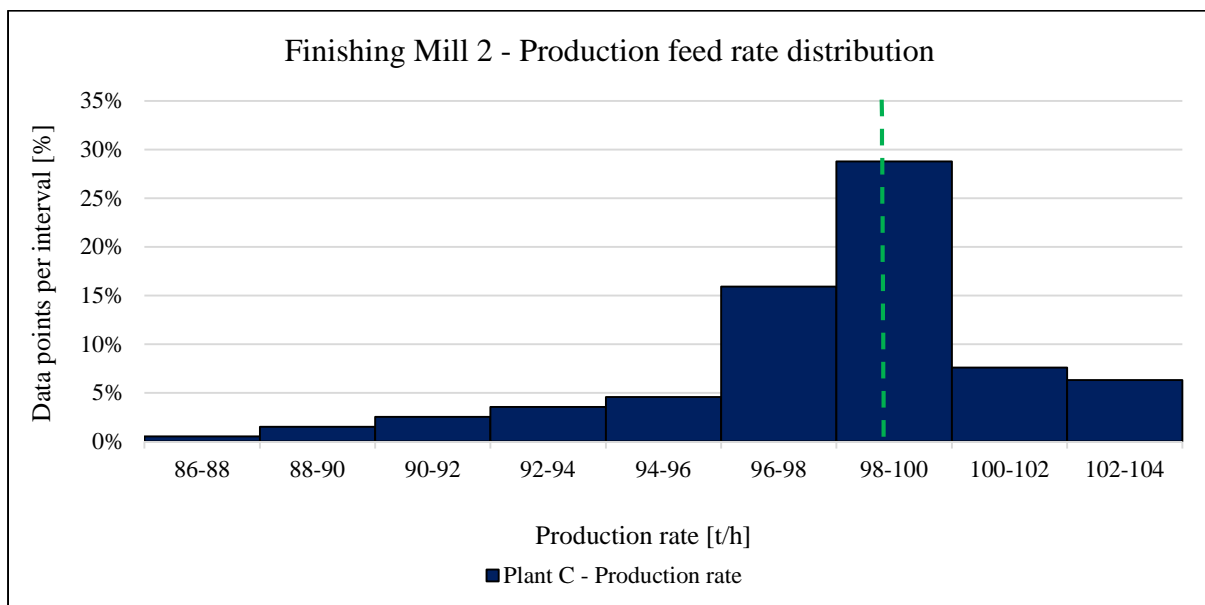


Figure 4-24: Finishing Mill 2 mean production rate analysis

Finishing Mill 2 is larger than Finishing Mill 1. Finishing Mill 2 produces high-strength cement at a mean production rate of 98 t/h while demanding an average of 4 330 kW of power as seen in Figure 4-24 and Figure 4-25. The power distribution varies from 4 260 to 4 410 kW and the production rate between 86 t/h and 104 t/h.

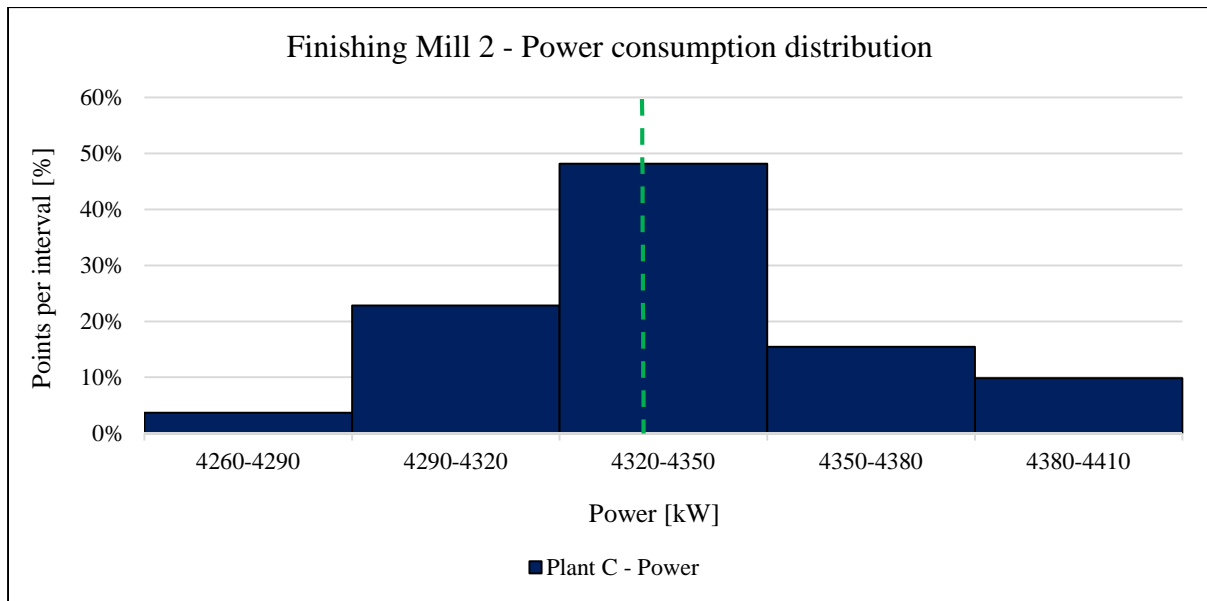


Figure 4-25: Finishing Mill 2 mean power analysis

Plant D – Vertical roller mill

Plant D produces high- and medium-strength cement. The production load analysis will only consider the high-strength cement as the same product is produced at Plant C. Plant C does not produce the medium-strength cement, therefore, the product cannot be compared on both mills. The vertical roller mill produces high-strength cement at a mean production rate of 143 t/h while consuming power at 5 550 kW as shown in Figure 4-26 and Figure 4-27.

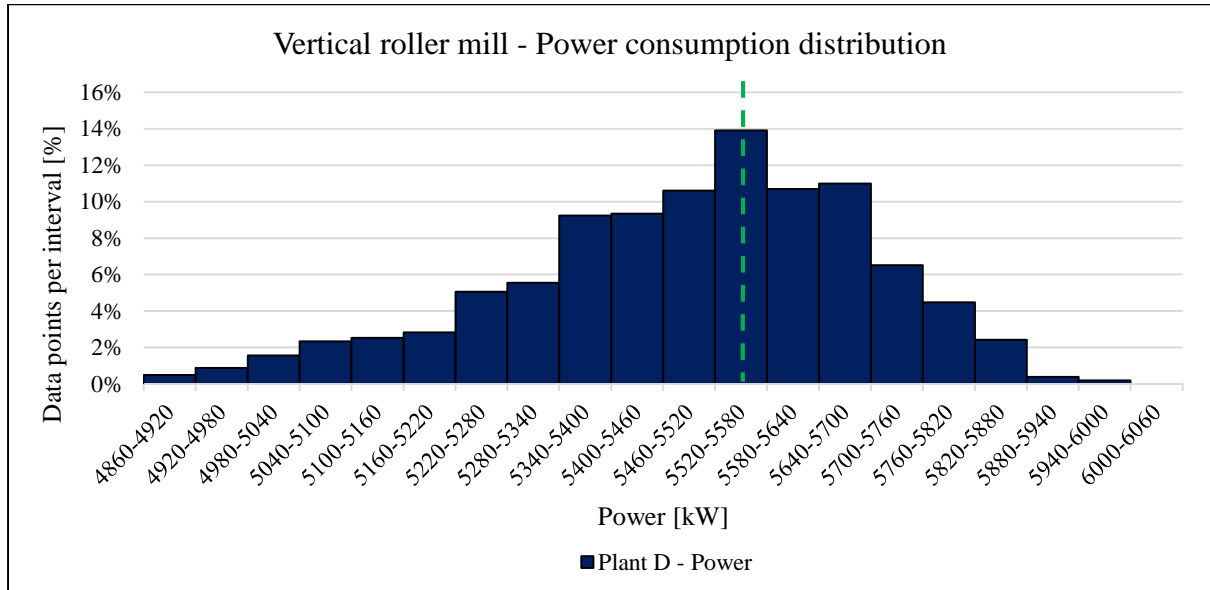


Figure 4-26: Plant D vertical roller mill mean production rate analysis

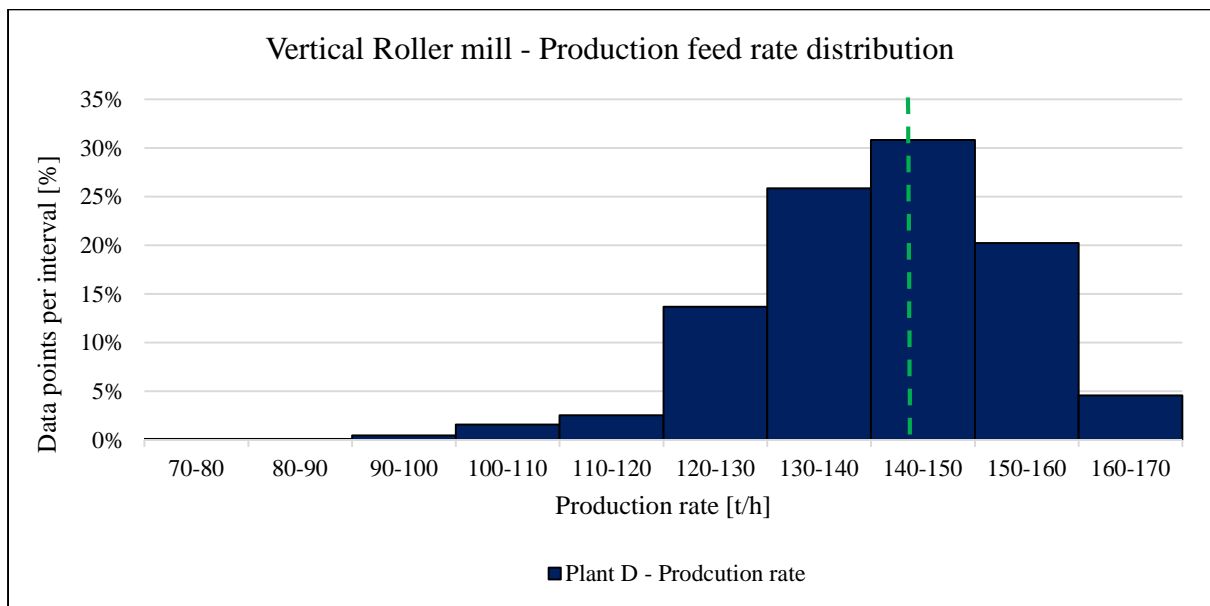


Figure 4-27: Plant D vertical roller mill mean power analysis

Table 4-2: Case Study 2 production load analysis summary

Case Study 2	Plant C		Plant D
Mill	Finishing Mill 1	Finishing Mill 2	Vertical roller mill
Product	High-strength cement	High-strength cement	High-strength cement
Power [kW]	1 992	4 330	5 550
Production rate [t/h]	47.0	98.0	143.0
Specific energy [kWh/t]	42.4	44.2	38.8

Finishing Mill 1 and Finishing Mill 2 produce high-strength cement at close to the same efficiency, with Finishing Mill 1 being slightly more efficient for the considered dataset. Plant D's vertical roller mill is approximately 10% more efficient when considering electricity usage than the ball mills of Plant B when producing high-strength cement.

Deriving mean power consumptions and production rates are accurate methods for determining a mill's specific energy consumption. The specific energy consumption analysis will determine the plant-specific energy by taking the utilisation of mills into account.

4.5 SPECIFIC ENERGY CONSUMPTION ANALYSIS

4.5.1 Case Study 1

The specific energy is defined as the amount of energy required to produce one unit of cement. The power and production rate distribution graphs in the production load analysis derived sound averages to generate plant-specific energy consumption. The graph displayed in Figure 4-28 shows the mill energy consumption plotted against the corresponding tonnes produced by the plant.

One month of data was used to compile the plant-specific energy consumption graph. The data points capture four operational cycles and provide a comprehensive reflection of the plant-specific energy usage. Plant A (pre-DSM and post-DSM implementation) and Plant B are shown in the specific energy graph.

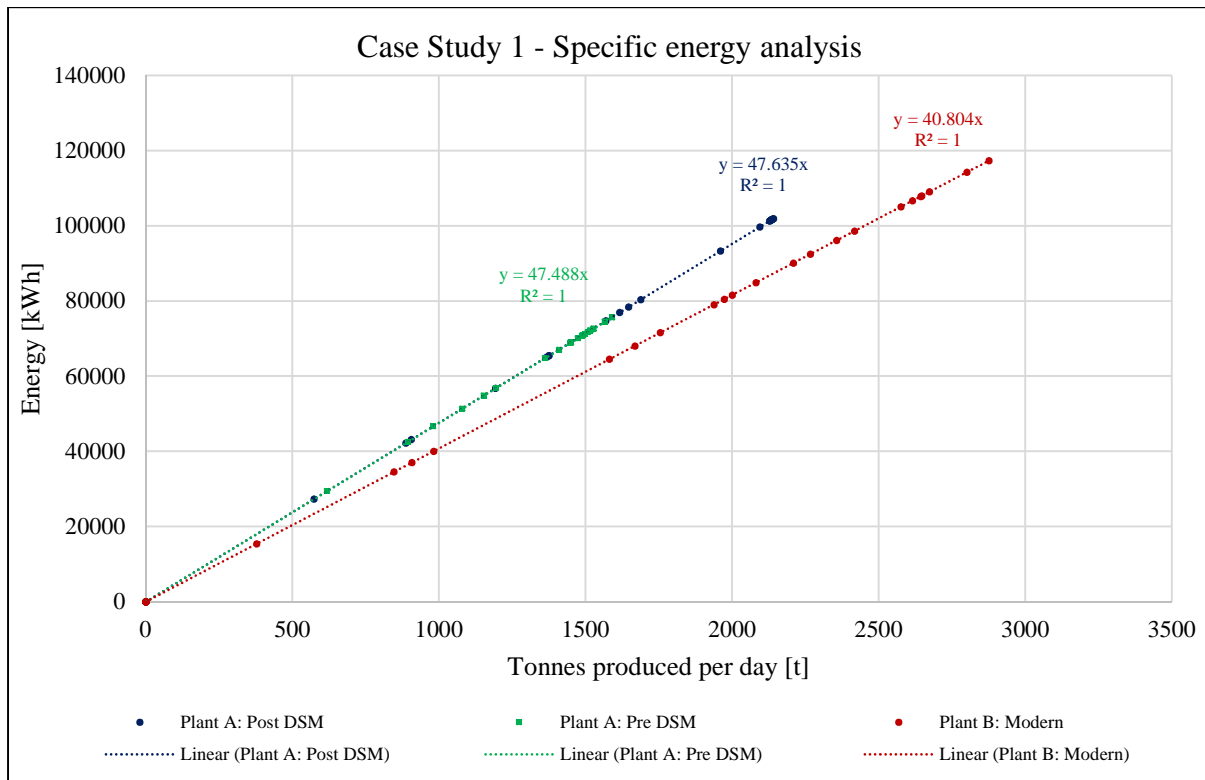


Figure 4-28: Case Study 1 specific energy analysis

The linear trend lines drawn through the respective data points show a perfect regression ($R^2=1$). This occurs when using the simulated ratio derived from the production load analysis. The hourly power data is multiplied by the calculated production ratio resulting in the perfect regression. The specific energy consumption is thus a simulated representation based on sound averages derived from the detailed mill production and electrical load analysis.

DSM load management does not reduce the energy consumption of a plant. The load is only shifted to different time periods of a day. The pre-DSM and post-DSM data for Plant A show the respective average specific energy consumption of 47.488 kWh/t and 47.635 kWh/t. The slight difference can be accredited to Finishing Mill 5 being more efficient and being used more frequently during the pre-DSM implementation period. The average daily production during the post-DSM implementation period decreased significantly from a maximum of between 2 100 and 1 600 tonne per day.

The reduction in average daily production is due to the classification of Plant A as a swing plant and the production limits that were imposed as a result. The vertical roller mill on Plant B

produces high-strength cement at an average of 40.804 kWh/t. The company in Case Study 1, therefore, prefers maximum production at Plant B.

The difficulty in stabilising the vertical roller mill and frequent maintenance stops cause the scatter in daily production between 1 500 and 2 700 tonne. The specific energy analysis confirms that the vertical roller mill is more electricity-efficient than the conventional ball mills of Plant A. A cost analysis will be done to quantify the cost savings of DSM load-shifting interventions.

4.5.2 Case Study 2

The production load analysis indicated that Cement Mill 1 is more efficient than Cement Mill 2. The analysis will calculate and display Plant C’s specific energy consumption by considering the usage of efficient mills. Plant D’s efficiency will be then be the same as shown in Table 4-2, because it is the only mill running.

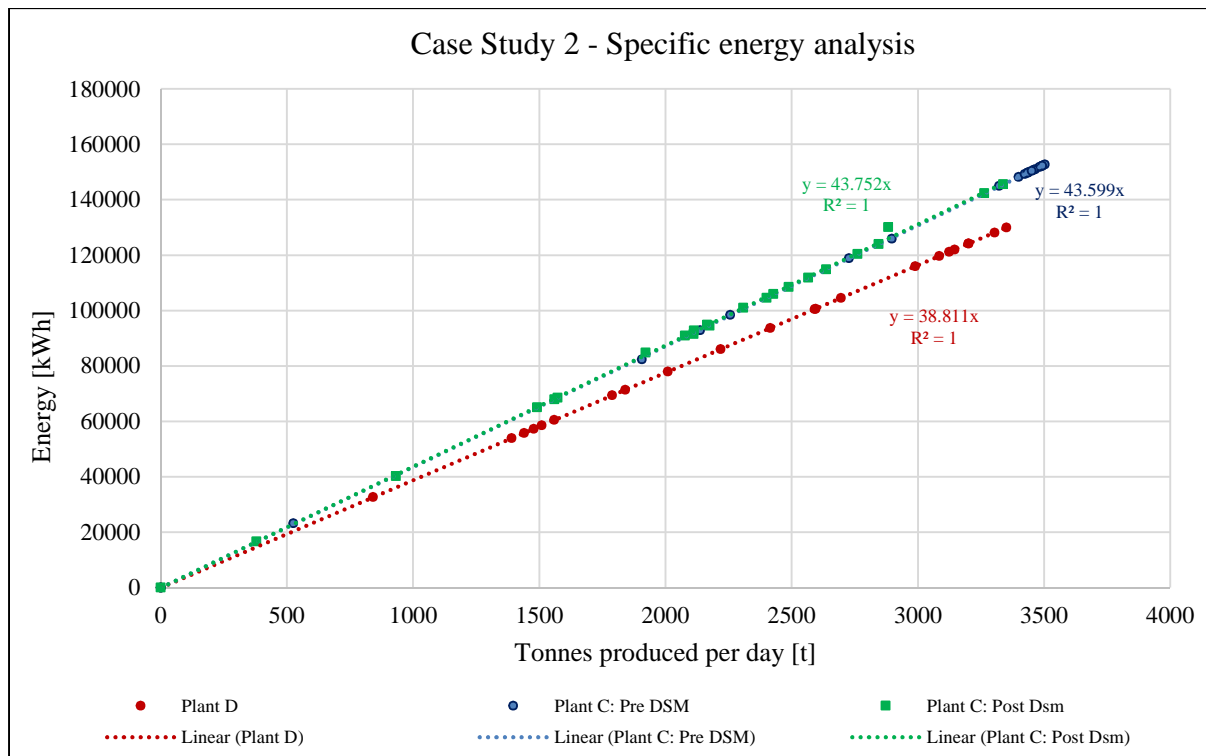


Figure 4-29: Case Study 2 specific energy analysis

During the post-DSM period, Plant C was less efficient. The difference between pre-DSM and post-DSM specific energy consumption is small. A reduction in energy efficiency can be attributed to Cement Mill 1 being used more than Cement Mill 2. Inadequate maintenance also contributed to the drop in plant energy efficiency.

Figure 4-29 shows that the vertical roller mill is approximately 11% more efficient than the marginal cement plant. The energy efficiency results are in line with literature and also prove that vertical roller mills are more efficient than ball mills. The cost analysis will quantify the effect of DSM load management on the marginal cement plant.

4.6 COST ANALYSIS

The cost analysis determines the cost of electricity to produce one unit (tonne) of cement. Cement products use different recipes that significantly influence the amount of energy required to grind. The increase or decrease in required energy affects the cost. It is thus important to note that electrical cost can only be compared when two mills produce the same product.

4.6.1 Case Study 1

Cost analysis is the final analysis that determines the effect of DSM load management on marginal cement plants. The cost analysis shown in Figure 4-30 depicts the weekday total daily electricity cost compared with the total daily tonnes produced for the analysis period. Data points deviate from a perfect regression because of the different tariffs charged at different times. Table 4-3 [59] shows the cost billed to the respective periods.

Table 4-3: Tariff structure cost

TOU tariff structure cost [c/kWh]			
Period	Off-peak	Standard	Peak
Summer	60.74	79.02	101.67
Winter	65.62	96.49	251.74

Let us consider a day where Plant B only needs to produce 500 tonne. Compared with a daily capacity of about 2 100 tonne, 500 tonne is a small production target. The most cost-effective way to produce the 500 tonne is by using off-peaks periods only. The data point will align with 500 tonne on the x-axis and a very low cost on the y-axis.

Consider a scenario with the same production target during which the plant broke down in the off-peak period and only standard or peak times are used to produce the required 500 tonne of cement. The data point will now align with 500 tonne on the x-axis and a very high cost on the y-axis. The efficiency in load management, therefore, causes the scatter of data points.

The black optimal line in Figure 4-30 shows the most effective running schedule for Plant B during weekdays. The optimal line simply indicates the production at minimum cost by using inexpensive timeslots effectively. The optimal line is a benchmark from which the effectiveness of the post-DSM profile can be measured and predicts the amounts of cement that can be produced per day to stay more efficient than or just as efficient as the modern plant.

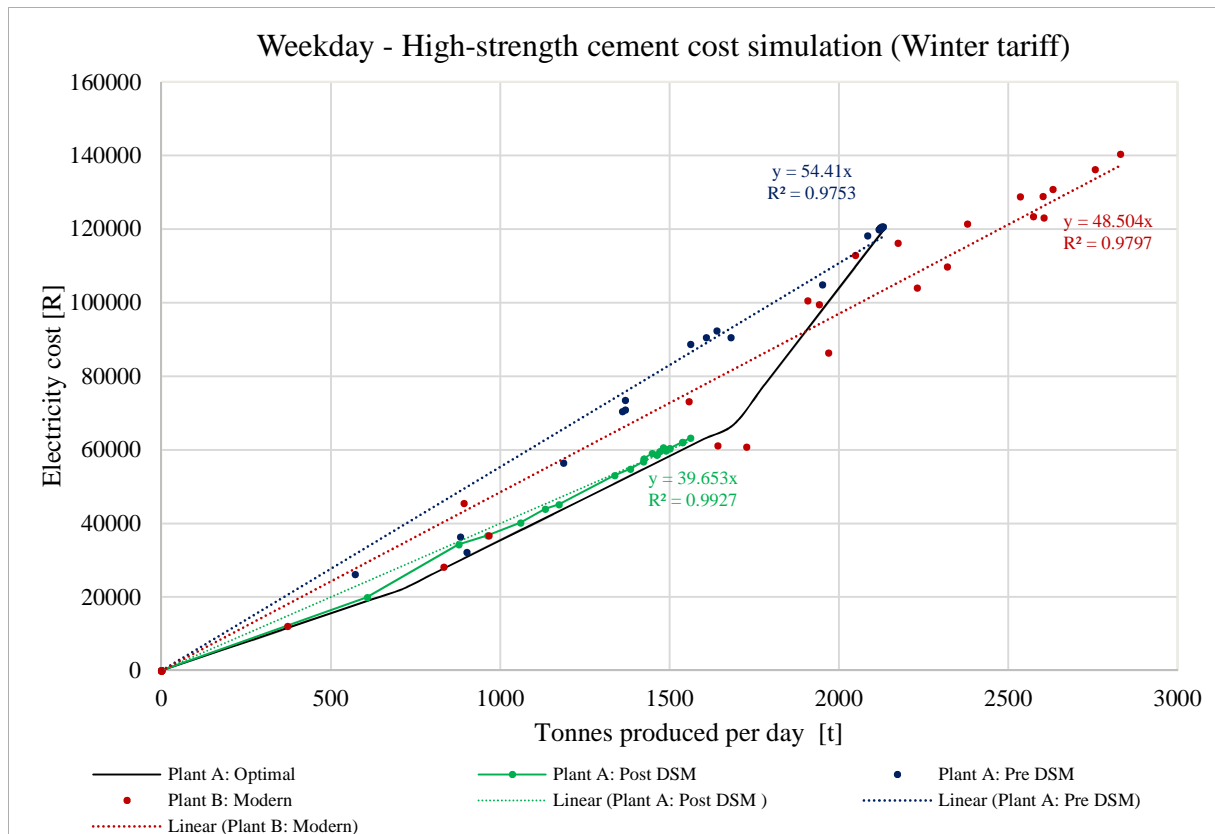


Figure 4-30: Case Study 1 weekday cost analysis using winter tariffs

Figure 4-30 shows that when Plant A executes load management perfectly, up to 1 900 tonne of high-strength cement can be produced at a lower or similar electricity cost as the more modern Plant B. A trend line with the best possible regression specifies the average electricity cost per tonne of cement produced.

The post-DSM results show a reduction in cost per tonne cement produced as production was allocated to less expensive timeslots. Producing high-strength cement at Plant A without DSM interventions costs on average R5.90 per tonne more than at modern Plant B during weekdays. The electricity cost of producing high-strength cement on weekdays is 10.9% higher for Plant A than for Plant B.

After DSM implementation, the average electricity cost of Plant A was reduced to R39.65 per tonne for weekdays. This amounts to a R14.76 per tonne electricity cost reduction. The cost of producing high-strength cement was reduced by 27.12% compared with pre-DSM implementation and 18.25% compared with Plant B. These values are only applicable to the current situation as it is an analysis of historical data.

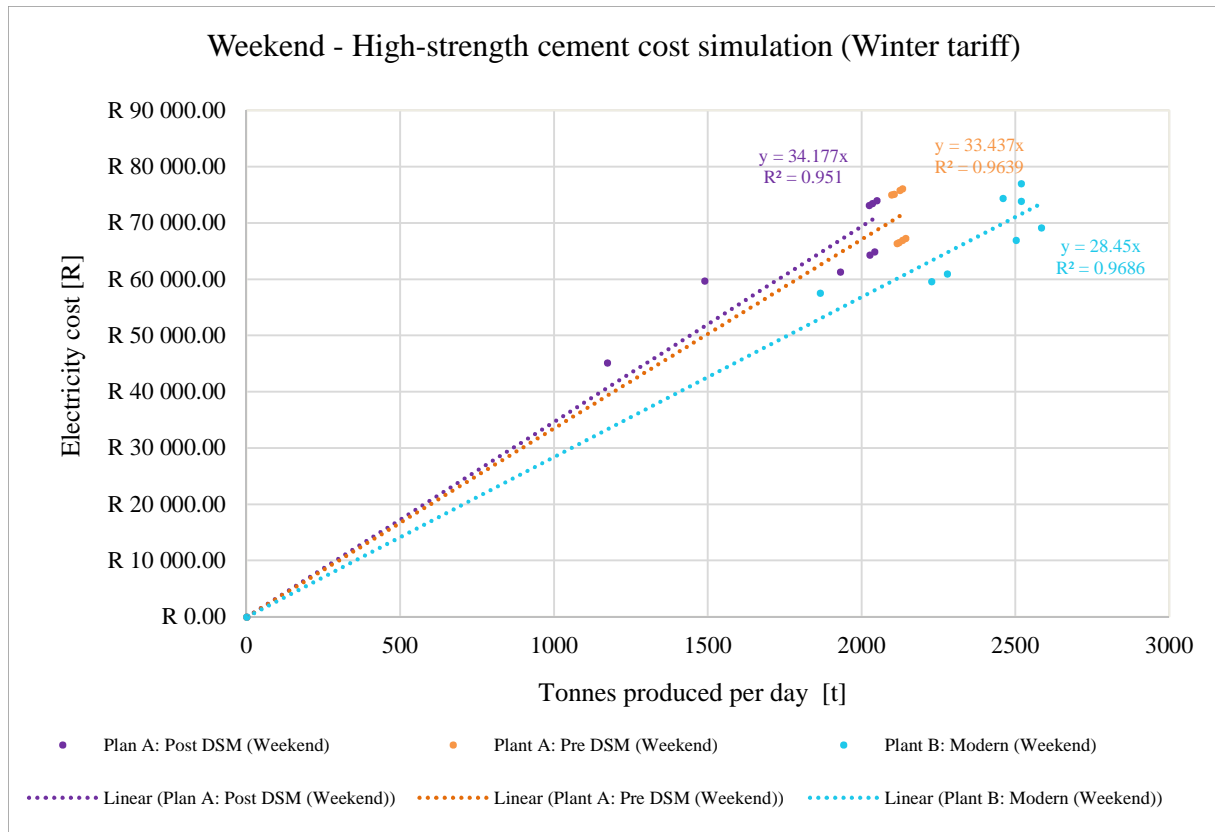


Figure 4-31: Case Study 1 weekend cost analysis using winter tariffs

Figure 4-31 shows the daily electricity cost during weekends using winter tariffs. The post-DSM cost is higher than the pre-DSM cost during weekends. This can be attributed to load being shifted from weekday peak periods to weekends resulting in more standard periods being used. The modern plant produces high-strength cement at an average of R28.45 per tonne, which is roughly 14.9% cheaper.

The same data is simulated using summer tariffs. Figure 4-32 shows the effect that summer tariffs have on load management cost savings. Compared with the modern plant, the post-DSM plant is less feasible than simulating winter tariffs. The plant, when executing optimal load management, can produce approximately 1 100 tonne of cement and still maintain the same electricity cost as the modern plant. This is a reduction of 800 tonne compared with winter tariffs.

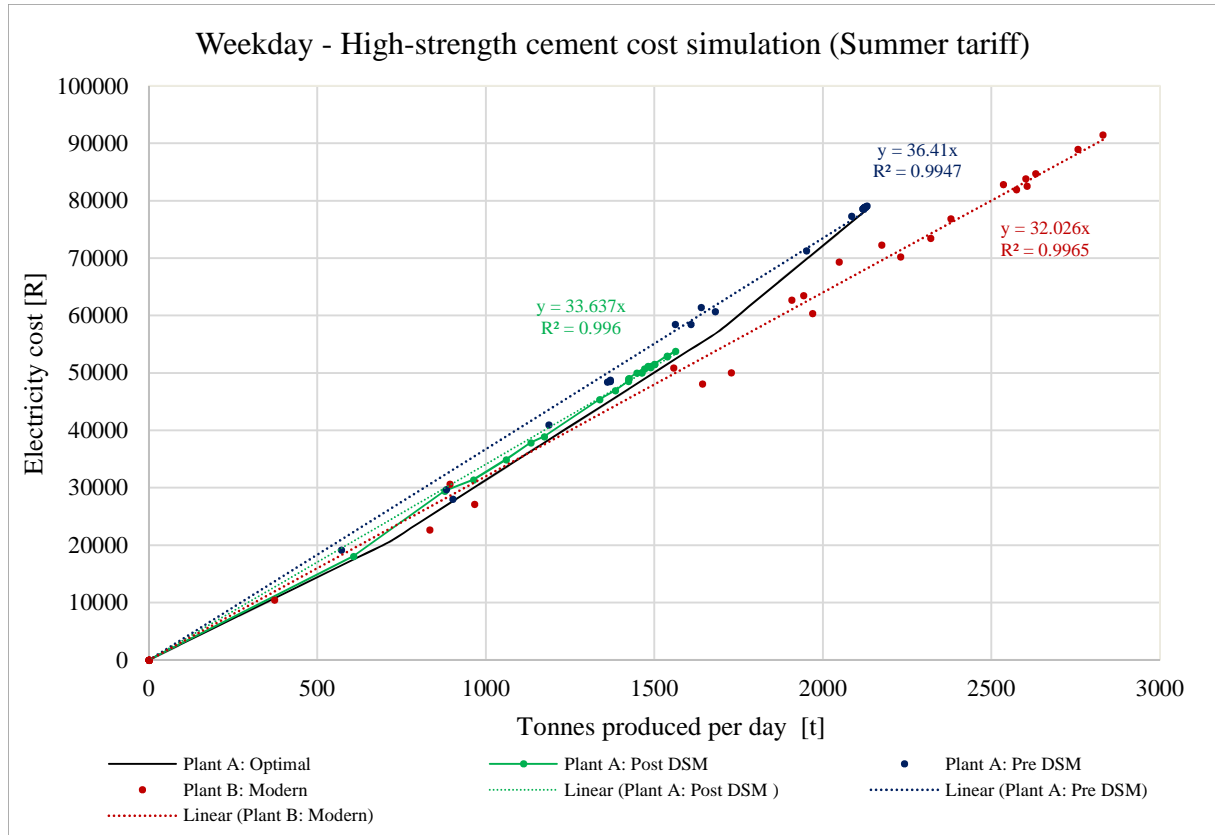


Figure 4-32: Case Study 1 weekday cost analysis using summer tariffs

Load management resulted in R2.70 weekday savings on Plant A, which translate to a 7.6% cost reduction between the pre-DSM and post-DSM cost. The modern plant produces high-strength cement at R32.03 per tonne. Figure 4-33 shows the cost of weekend production decreases proportionally when using summer tariffs.

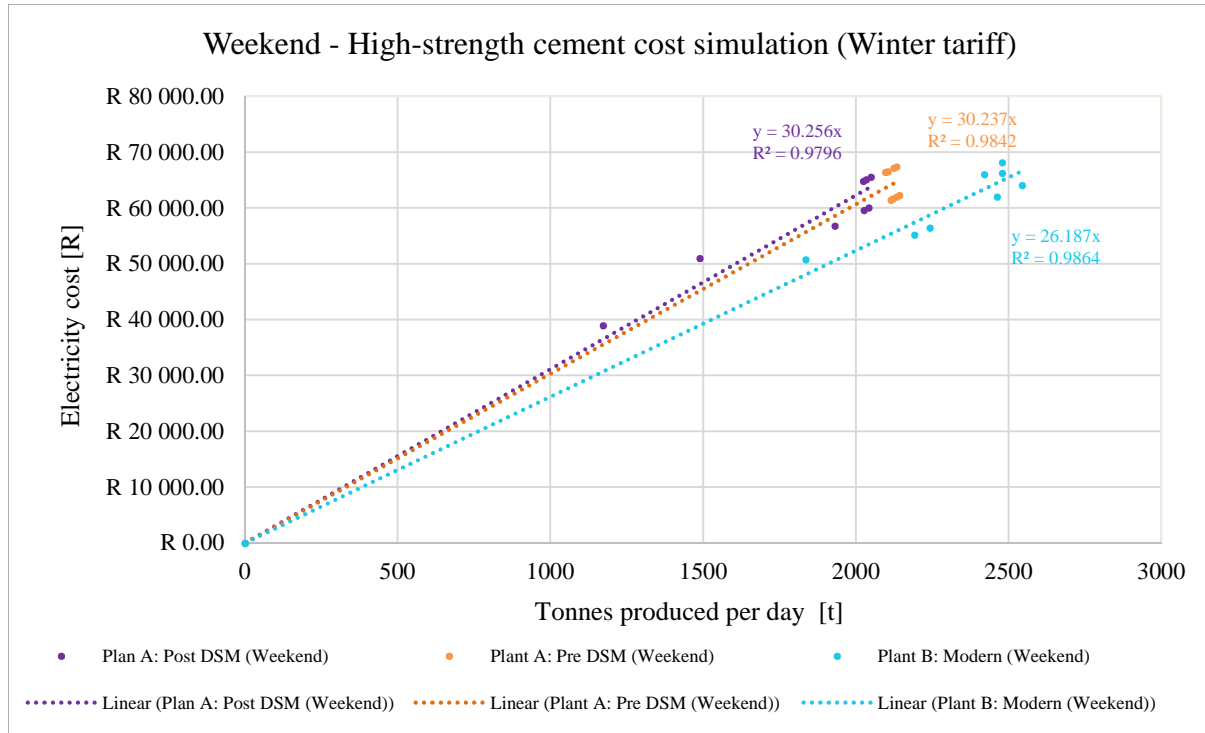


Figure 4-33: Case Study 1 weekend cost analysis using summer tariffs

The average derived from the regression lines in both summer and winter simulated cost analysis are described in Table 4-4. Using Equation 3-7, the summer, winter and yearly average electricity cost per tonne are quantified for pre-DSM Plant A, post-DSM Plant A and modern Plant B.

Table 4-4: Case Study 1 summary table

Case Study 1	Summer tariffs			Winter tariffs			Year
	Weekday	Weekend	Total	Weekday	Weekend	Total	
Marginal plant: Pre-DSM	R36.41	R30.23	R34.76	R54.41	R33.44	R48.82	R38.28
Marginal plant: Post-DSM	R33.64	R30.26	R32.66	R39.65	R34.18	R38.06	R34.00
Modern plant	R32.03	R26.19	R30.47	R48.50	R28.45	R43.15	R33.64

Summer tariffs

The peak charge ratio of summer tariffs is much lower than winter tariffs. Reducing load in peak periods subsequently has less impact on cost than winter periods. During summer periods, Plant A saves R2.11 per tonne of high-strength cement produced. The reduction in cost closes the gap between the marginal and the modern plants but does not make the marginal plant as efficient as the modern plant.

The modern plant remains 6.7% more electricity-efficient than the marginal plant. Load management, therefore, increases the competitiveness of the marginal plant, but not to the same degree during summer periods.

Winter tariffs

During winter months, load management has a substantial impact on the cost efficiency of the marginal cement plant. The post-DSM saving is R10.75 per tonne which translates to a 22% cost reduction. Load management made the marginal cement plant R5.09 or 11.7% more electricity cost efficient than the modern plant. During winter months, load management is an effective method of increasing the profitability of a marginal cement plant and will surpass the profitability of a modern plant when considering electricity cost.

Annual quantification

The analysis concludes that load management is not effective during summer months and that it is extremely effective during winter months. Quantifying the findings to a yearly average will ultimately answer the research question. On an annual basis, load management is expected to reduce the cost per tonne by R4.27 or 11.1% for marginal plants. The annual cost intensity of the modern plant, however, remained more efficient by 1%.

Load management will thus dramatically improve a marginal plant's profitability to close to the same efficiency as a modern plant when considering electrical cost. The modern plant, however, remains slightly more efficient than the marginal plant. The specific cost comparison for Case Study 1 is summarised in Figure 4-34.

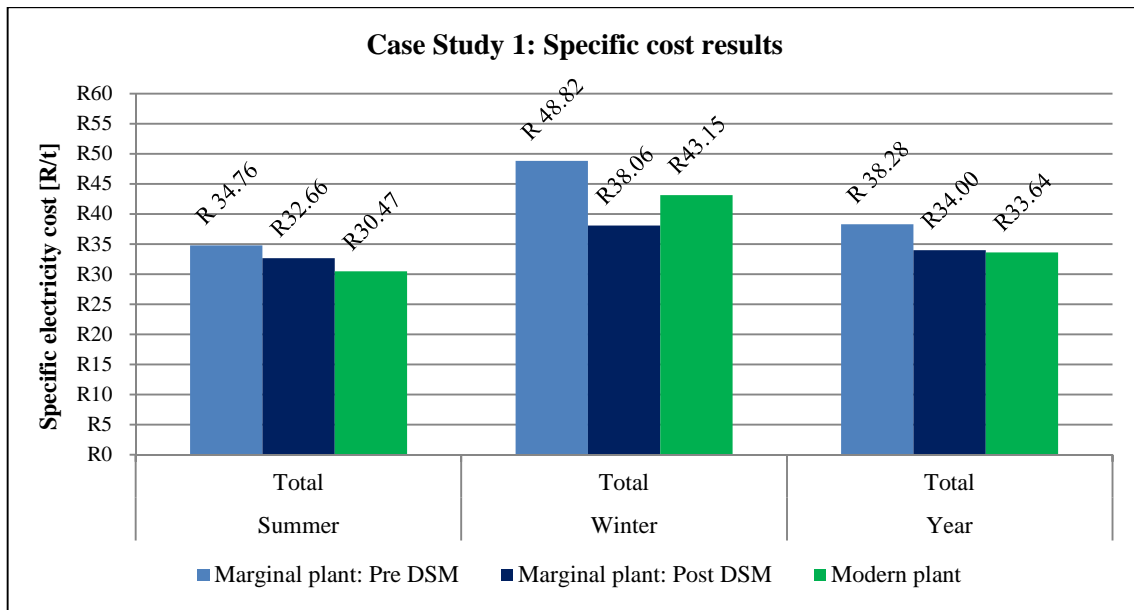


Figure 4-34: Specific electricity cost results for Case Study 1

Results verification

Lidbetter’s DSM savings calculator will be used to verify the cost savings found [49]. The calculations are completed in Appendix B with the result shown in Table 4-5. The average cost per tonne savings for summer, winter and annually are multiplied by the tonnes produced during the post-DSM period.

The results are compared with Lidbetter’s calculated results and the accuracy of the calculations is determined. The results derived from the cost analysis are accurate within 1.5% when compared with Lidbetter’s method. The accuracy is acceptable and proves that the cost analysis shows credible results.

Table 4-5: Case Study 1 results verification table

Case Study 1	Tonnes produced	Summer tariffs	Winter tariffs	Year
Savings per tonne		R2.11	R10.75	R4.27
Total savings	47 540	R902 784.60	R1 533 165.00	R2 435 949.60
Lidbetter savings		R886 124.80	R1 511 078.39	R2 397 203.19
Results accuracy		1.9%	1.5%	1.6%

4.6.2 Case Study 2

Figure 4-35 shows the cost analysis of Case Study 2. During the baseline period, Plant C mostly produced cement at maximum capacity as is evident by a number of data points in the 3 400–3 500 tonne region. The modern Plant D, which is more efficient, produced high-strength cement much cheaper than pre-DSM implemented Plant C.

Post-DSM implementation Plant C experienced a drop in cement sales with daily production rarely reaching maximum capacity. The plant leveraged the lower production and shifted most of the production to low-priced tariff periods. The line drawn through the scatter data of post-DSM Plant C shows the operational trend for a month that matches the optimal plant running profile closely.

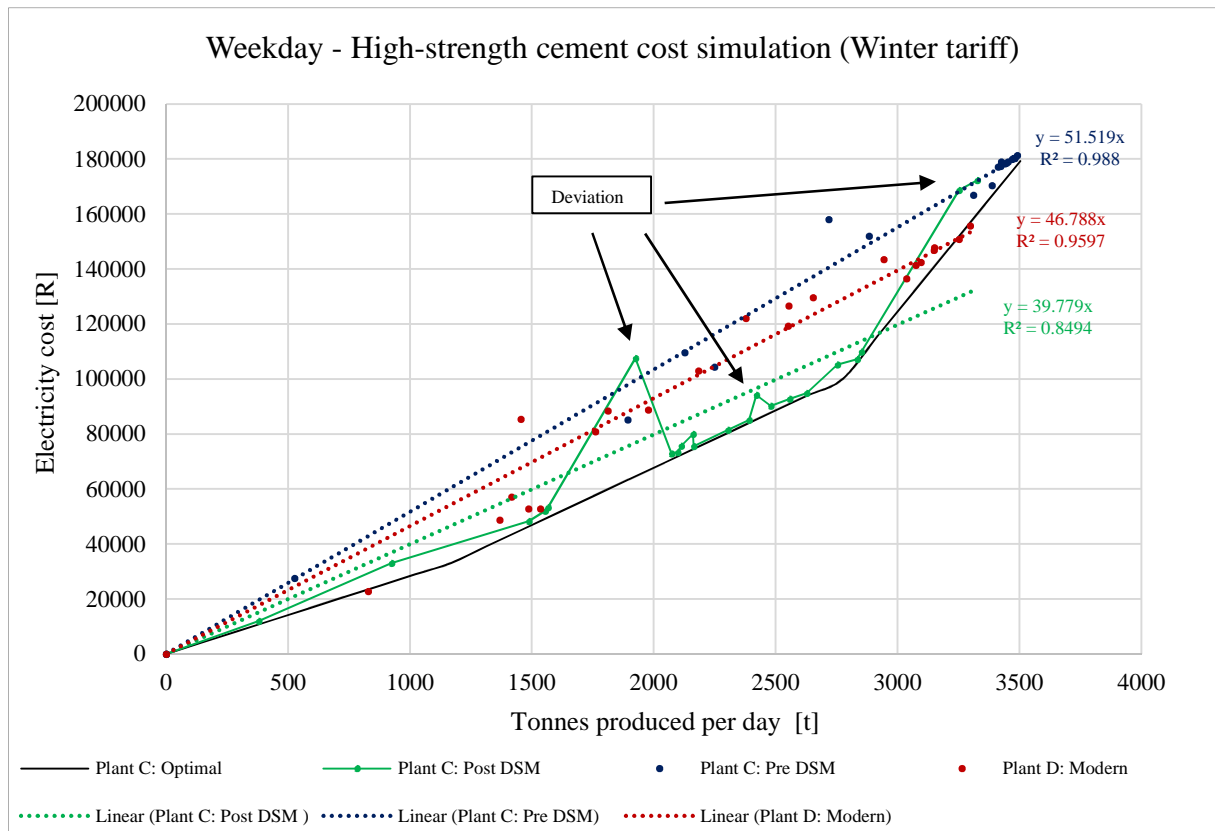


Figure 4-35: Case Study 2 weekday cost analysis using winter tariffs

Deviations occur on days when the plant used peak and standard periods when off-peak periods were still available. The cost rapidly increased for the same amount of tonnes that could have been produced during off-peak periods. The trend lines indicate that Plant C was more cost efficient than the modern plant during winter periods after DSM load management was implemented.

Plant C, when executing load management perfectly, can produce up to 2 950 tonne of high-strength cement at less or the same electricity cost as modern Plant D. The load management during weekdays resulted in a 22.7% cost reduction. Post-DSM Plant C is 14.9% more feasible than the modern Plant D when considering electrical cost.

Figure 4-36 shows the cost analysis during weekends using winter or high demand tariffs. The pre-DSM cost is slightly more than the post-DSM results. The differences in cost can be attributed to the utilisation of different mills during the pre- and post-DSM periods. Modern Plant D is roughly 10.8% more electricity-efficient than marginal Plant C during weekends.

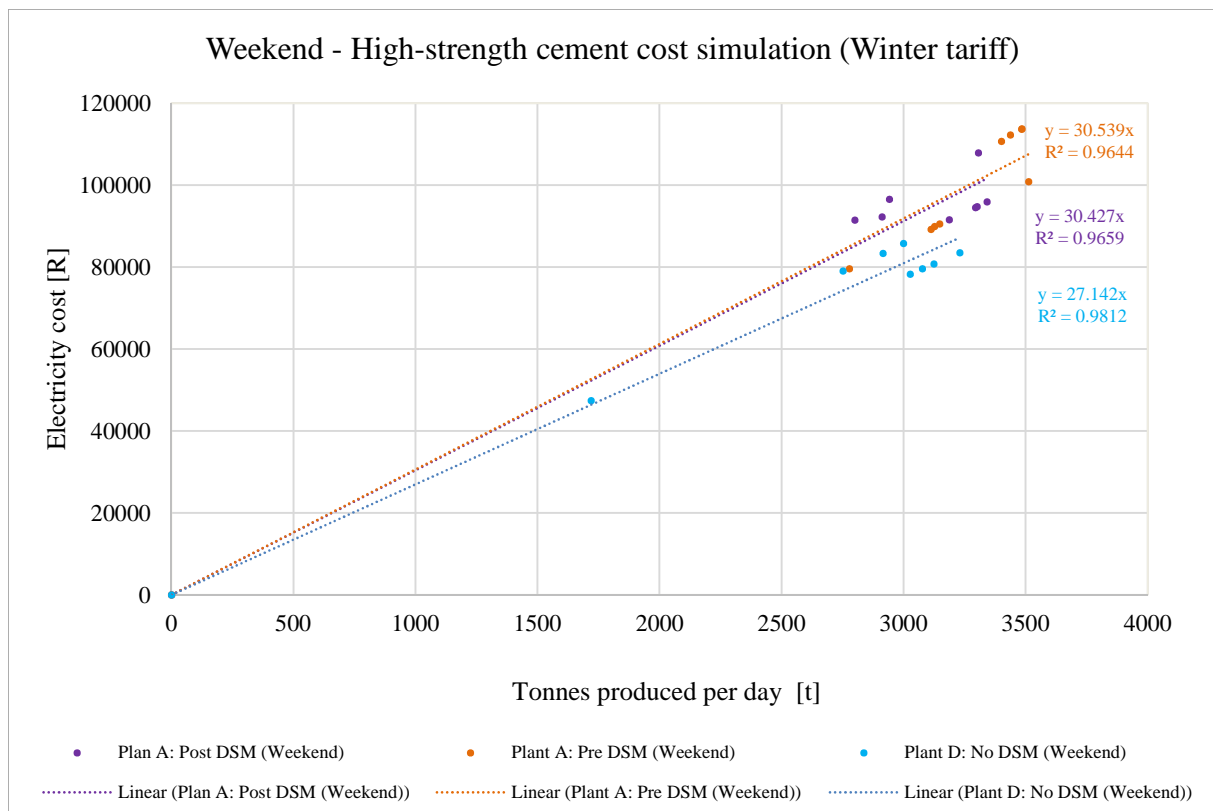


Figure 4-36: Case Study 2 weekend cost analysis using winter tariffs

The winter tariffs prove to be very effective when implementing load management. Figure 4-38 shows the weekday analysis when considering summer tariffs. The effect of summer tariffs on cost savings display the same characteristics as seen in Case Study 1. The most noticeable effect is the decrease in load management effectiveness. The modern plant remains more electricity cost effective than the marginal cement plant after the implementation of load management.

Also, the maximum competitive tonnes that can be produced is reduced to 2 250 tonne per day when executing optimal load shifting. A total cost per tonne reduction of R2.37 or 7% was achieved after the implementation of load management. Modern Plant D, however, remains 4.9% more efficient than the marginal cement plant during weekdays.

Weekends benefit from lower tariff charges and show a reduction in cost per tonne. There are no peak periods during weekends, thus no cost savings are achieved. Modern Plant D is roughly 11.9% cheaper than marginal Plant C as seen in Figure 4-37.

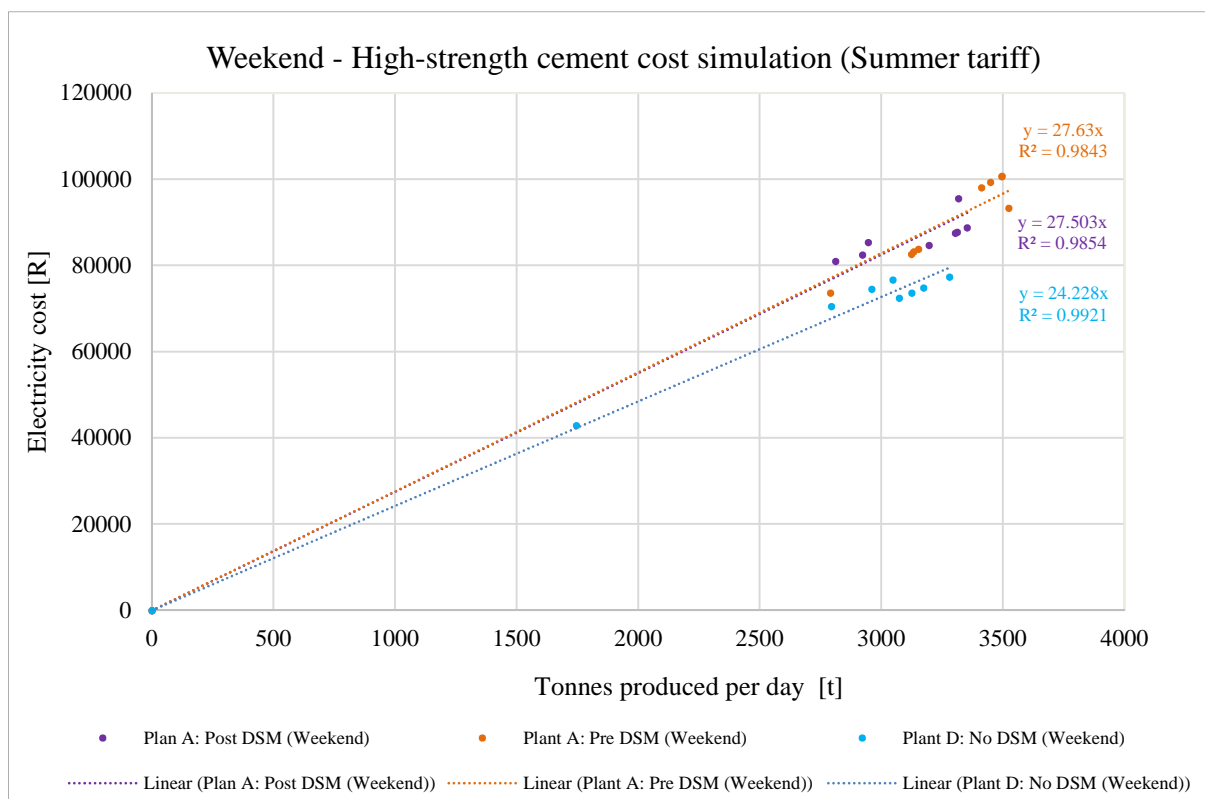


Figure 4-37: Case Study 2 weekend cost analysis using summer tariffs

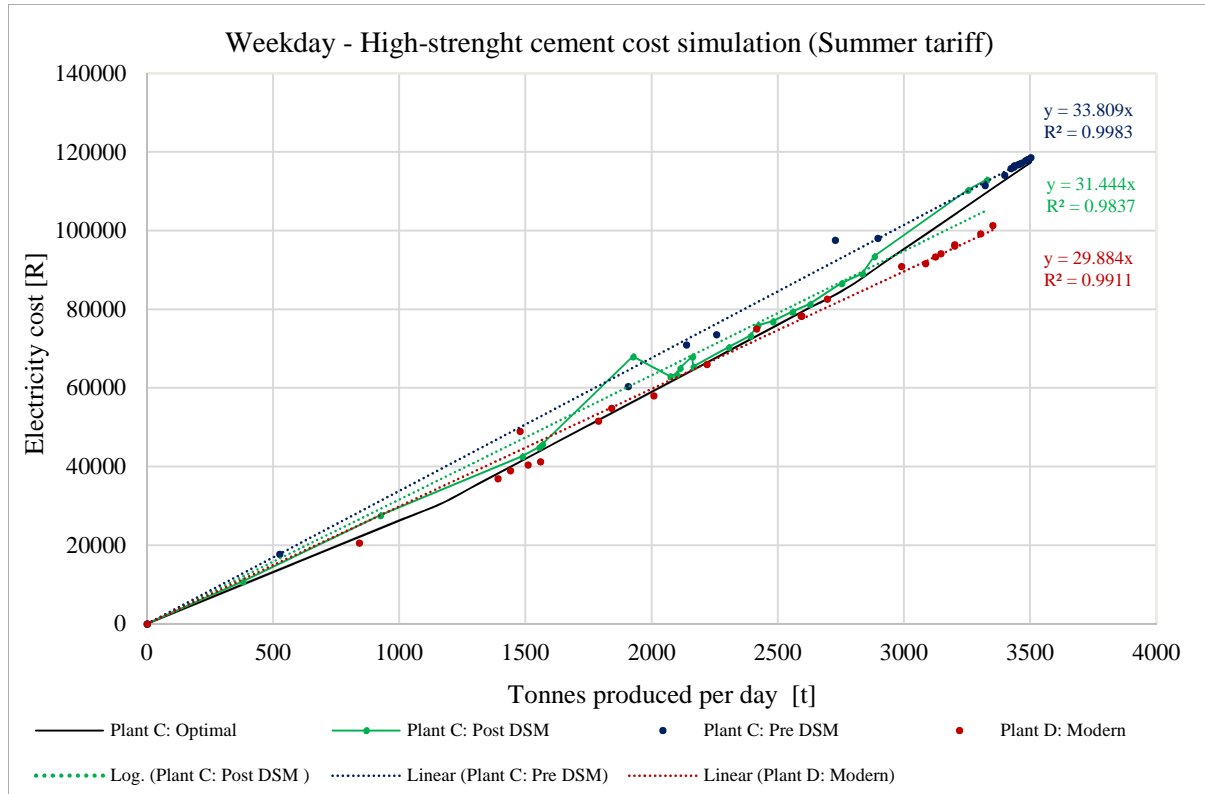


Figure 4-38: Case Study 2 weekday cost analysis using summer tariffs

Table 4-6 contains the average cost per tonne results derived from the cost analysis graphs. As with Case Study 1, the summer, winter and average annual cost per tonne are quantified using Equation 3-7.

Table 4-6: Case Study 2 summary table

Case Study 2	Summer tariffs			Winter tariffs			Year
	Weekday	Weekend	Total	Weekday	Weekend	Total	
Marginal plant: Pre-DSM	R33.81	R27.63	R32.16	R51.52	R30.54	R45.92	R35.60
Marginal plant: Post-DSM	R31.44	R27.50	R30.30	R39.78	R30.43	R37.06	R31.99
Modern plant	R29.88	R24.23	R28.37	R46.79	R27.14	R41.55	R31.67

Summer tariffs

Load management effectiveness declines when comparing summer tariffs with winter tariffs. Although load management does not reduce the cost enough to be as efficient as a modern plant, it still delivers substantial savings. For the summer period, a 5.78% cost reduction was achieved. The modern plant remained 6.4% more efficient than the marginal plant.

Winter tariffs

The inflated cost of peak period winter tariffs results in significant cost savings when peak periods are reduced. Case Study 2 also shows that load management can reduce a marginal plant's electricity cost so that it is more efficient than a modern plant. Load management delivered substantial savings of 19.3% on marginal Plant C. The post-DSM Plant C cost per tonne is 10.8% lower than modern Plant D.

Annual quantification

Annual load management produces a 10.1% cost reduction for the marginal cement plant. Compared with the modern plant, post-DSM costs are 1% higher. Load management is extremely effective in reducing electricity costs of marginal plants. The modern plant remains slightly more efficient than the post-DSM marginal plant. The specific cost comparison for Case Study 2 is summarised in Figure 4-39.

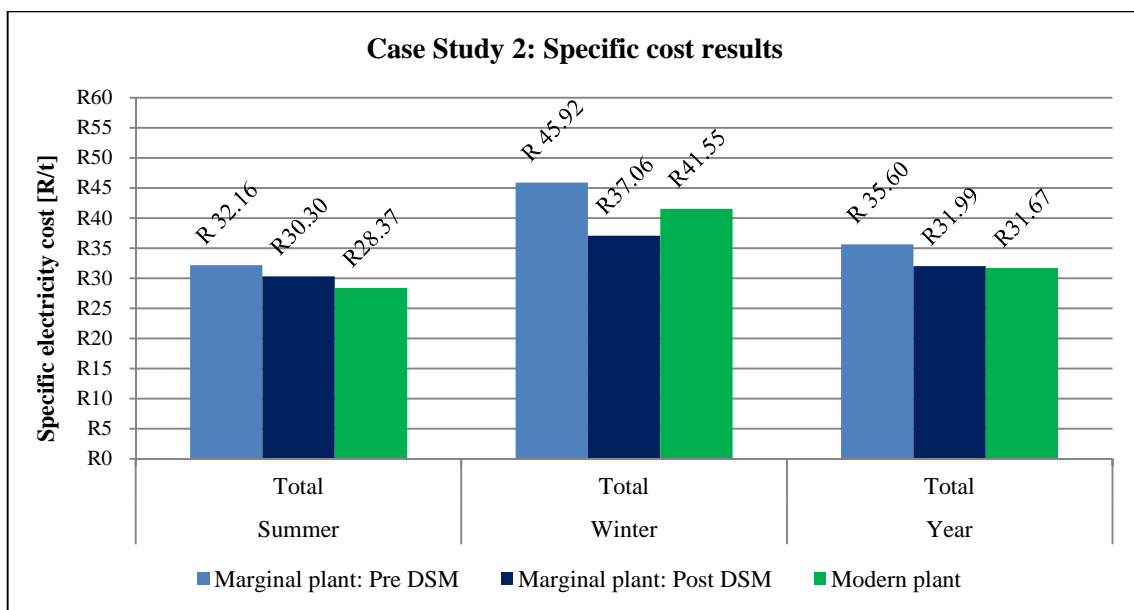


Figure 4-39: Specific electricity cost results for Case Study 2

Results verification

The calculated cost per tonne savings will now be verified using Lidbetter’s savings calculator. Lidbetter’s detailed calculations can be found in Appendix B. Table 4-7 shows the calculated Lidbetter results and compares it with the cost analysis savings. The results derived from the cost analysis are accurate within 0.08% when compared with Lidbetter’s method. The accuracy is very good and proves that the cost analysis derived trustworthy results.

Table 4-7: Case Study 2 results verification table

Case Study 2	Tonnes produced	Summer tariffs	Winter tariffs	Year
Savings per tonne		R1.86	R8.86	R3.61
Total savings	73 449	R1 229 536.26	R1 952 274.42	R3 181 810.68
Lidbetter savings		R1 232 857.87	R1 946 252.41	R3 179 110.28
Results accuracy		0.27%	0.31%	0.08%

4.7 CONCLUSION

The load management implementation investigates the participating plants and delivers substantial savings. The implementation on the various sites is documented and corresponds with peer-reviewed research. In the electrical load analysis, the baseline development evaluates operating profiles and predicts the effect of load management implementation.

The production load analysis successfully derived the mean production rates and power consumptions expected during normal operation of a mill. In further analysis, it also identified products produced by both plants to be compatible. The specific energy consumption analysis considered mill efficiencies and utilisation. The mill efficiencies and utilisation successfully identify plant-specific energy usage.

The cost analysis predicted the maximum amount of tonnes a marginal plant can produce to remain competitive when compared with a modern plant. Ultimately, the cost analysis determined that load management could only make a marginal plant more electricity cost efficient during winter periods and cost competitive to within 1% on an annual basis.

CHAPTER 5

Conclusions

Chapter 5

This chapter lists important findings of the study and also evaluates whether the goal statement has been reached.

5 CONCLUSION

5.1 INTRODUCTION AND BACKGROUND

Cement production is an energy, and specifically electricity intensive process. A low cement demand compared with production capacity in South Africa and rapid electricity price increases have also contributed to a competitive market amongst South African cement producers. Additionally, increasing international competition is adding to the present market pressure due to low price imports of cementitious products.

Older cement producers with outdated production equipment produce cement at lower efficiencies, in turn increasing the production costs due to the high energy intensity of the production process. These factors have forced South African cement producers to explore energy-related savings during cement production.

Rapid growth of the South African electricity demand has reduced Eskom's electricity supply reserve margin to alarming levels in recent years. To increase the possible reliability of aging electricity production infrastructure and support a high-pressure electricity market, Eskom increased electricity tariffs at a rapid rate. The rapid electricity tariff hikes have placed considerable pressure on the profitability of energy-intensive industries in South Africa.

For South African industries, DSM is a means to alleviate pressure caused by rapidly increasing electricity prices. DSM strategies include load shifting, peak clipping and energy efficiency improvement. Load shifting is the primary method used to implement DSM on the South African cement industry.

Literature thoroughly investigates and describes the potential for DSM load-shifting interventions on the South African cement industry. Literature also describes the implementation of load management strategies to achieve the identified DSM load-shifting potential. The studies describe savings achieved; however, the achieved results are not compared with more modern or higher efficiency equipment.

This study focused on comparing DSM interventions at aging cement production facilities with more modern and more energy-efficient production plants. The aim was to evaluate the savings achieved by the DSM interventions and determine if the aging, marginal cement plants cost effectiveness can become more competitive when considering modern cement production facilities.

5.2 ENERGY MANAGEMENT ON CEMENT PLANTS

Two major milling stages are used in cement production. The largest of these milling stages is finishing milling. Different mill configurations are used in the finishing process. Older mills include roller mills and horizontal ball mills. More modern mills have proven to be more energy efficient. These mills include vertical roller mills. Vertical roller mills have been proven to be 20–25% more energy efficient than horizontal ball mills and are used in most modern cement plants.

Since DSM in South Africa focuses on electricity consumption, the grinding circuits in cement production forms the primary focus of these interventions. Most of the energy efficiency interventions require large initial capital expenditure and present extended payback periods. In the very competitive cement market in South Africa, this extended payback period often discourages cement producers from implementing these large interventions.

Peak clipping also entails energy efficiency improvements or production rate improvements, which also require the installation of physical infrastructure. Peak clipping is, therefore, also not considered by South African cement producers to reduce production costs.

Load shifting has been widely implemented in the South African cement industry. Load shifting is implemented by improved load and production management with focus on electricity consumption trends and buffer management. A study by Lidbetter described the implementation of a trial study implementing load shifting on cement plants.

Her study was followed by Swanepoel and Maneschijn who implemented various load-shifting interventions on South African cement plants using automated computerised EMSs and

integrated modelling techniques. These systems used operational management to integrate multiple cement production constraints and proposed extended production schedules to reduce average peak period and weekday demand.

Various authors identified and quantified possible DSM intervention savings in the South African cement industry. Lidbetter used a load-shifting trial to quantify electricity savings that can be achieved by implementing load management. Swanepoel also described savings achieved during the widespread implementation of load management.

Spangenberg identified five areas that were evaluated: energy and cost savings; effect on production; impact on cement-manufacturing equipment; effect on the cement quality; and increased awareness. The study evaluated influences and savings thoroughly, thereby proving that DSM interventions are highly feasible.

The various studies and literature identified cost savings; however, these studies did not compare the achieved savings to more modern South African cement plants. To evaluate the influence of load management interventions effectively, the saving results must be compared to modern cement plant production costs to determine the profitability of aging cement plants in a competitive market.

5.3 PROPOSED LOAD MANAGEMENT IMPLEMENTATION AND EVALUATION STRATEGY

Load-shifting interventions were implemented using an automated EMS and an integrated optimisation model. The automated computer systems comprised an on-site database server, a central data processing, modelling and optimisation server and different forms of communication, depending on the site requirements.

Data was acquired directly from the plant SCADA system and sent to the centralised modelling server. The modelling server simulated the specific set of conditions that was extracted from the plant SCADA system and the sales forecasts acquired from planning personnel. The server optimised a production schedule for the operation of milling components. The optimised

schedule was sent back to the on-site server, approved and displayed to the plant operators in the control room.

The data that was extracted from the SCADA system was also compared with previously optimised schedules to evaluate the effectiveness of the plant operations. The results were compiled into an automated report that reports the savings achieved and missed savings to the plant operations and management personnel on a daily and monthly basis. The continuous reporting improved the sustainability of the implemented DSM load-shifting intervention.

The study focused on the evaluation of previously implemented load management strategies as was described by Swanepoel. The different implemented interventions were evaluated in a four-step approach including: electrical load analysis; production load analysis; specific energy consumption analysis; and cost analysis.

The electrical load analysis calculated the statistical average for normal operation at the cement plants. The average was calculated by compiling an electrical demand baseline setting out the average load profile during a normal operational cycle. The operational and sales trends for cement plants formed weekly cycles. The baseline was thus compiled to depict the average weekly load profiles for normal operation accurately.

In addition to the weekly baseline, a maximum and minimum operational demand was also calculated. The maximum operational load represented the operational demand from the milling components when the circuits experienced 100% utilisation. The minimum load represented the components that remained operational when the milling circuit was offline or experienced 0% utilisation. The minimum and maximum load profiles indicate the amount of load that could be shifted between the different tariff periods in a working week.

Since the operation of the cement plants varied from month to month, the operational baseline was scaled to represent similar production volumes. The single mode of operation allowed a linear, energy neutral scaling of the baseline profile. The scaled baseline enabled the comparison between the pre-implementation operational trends and the post-implementation operational trend.

To evaluate the production rate of the milling components, the mill feed rate was recorded over an extended period. The feed rate of the mill did not vary dramatically due to the constant hardness and abrasiveness of the clinker and different additives. The feed rate data that was collected was represented in a frequency graph. The frequency graph indicated how often the mill operated at a specific feed rate. The frequency distribution gave an accurate visual indication of how well the mill was controlled.

The feed rate data was then used to calculate the mean feed rate for the baseline period. The mean feed rate was then also depicted on the frequency distribution to give a better description of the start-up conditions and general operational accuracy of the mill. In addition to the mean feed rate values, the mean power consumption was also analysed in frequency graphs.

The mean feed rate distribution and mean power consumption values that were calculated in the feed rate analysis were used to compile a specific energy consumption distribution. The specific energy consumption distribution indicated the amount of energy consumed to produce a unit of cement. The specific energy consumption was plotted against increasing production. Since mean power usage and production rate were used to calculate the mill-specific energy consumption, the distribution was a linear correlation.

The specific energy consumption correlation was used to calculate the specific cost of production during different tariff periods. The optimal production distribution was also calculated according to the tariff periods and available production hours of the plant. The specific cost correlation formed a sound basis with which the profitability in the form of operational costs between different plants could be compared.

5.4 MARGINAL CEMENT PLANT IMPLEMENTATION AND COMPARISON

Four different plants were used to evaluate the impact of DSM load management interventions on the profitability of marginal cement plants. Two different South African cement producers were selected for the study. One marginal cement grinding plant and one modern cement

grinding plant were selected from each of the cement producers to ensure that the operational procedures of the different cement producers did not skew the results that were obtained.

The modern cement plants from the two cement producers made use of vertical roller mills and did not participate in DSM load management interventions. The two marginal cement plants made use of older horizontal ball mills and actively implemented load management strategies to reduce electricity costs. The two marginal cement plants made use of the automated energy management and modelling system to implement an optimal operational schedule.

The marginal cement plants showed an altered load profile due to the load management interventions. A clear reduction in peak demand was evident and reduced the specific operational costs during production. The achieved load shifting compared well with the maximum simulated load shift, which showed that the marginal cement plants implemented and maintained the load management strategies effectively.

The modern cement plants did not implement load management due to various concerns that were raised by the plant personnel. The load analysis showed a flat baseline that reduced slightly during certain periods of the day as a result of routine maintenance. Additionally, the modern cement plants also showed no preference to weekday or weekend operations, and produced constantly throughout the week.

The production load analysis showed that if a plant produced more than one product it would show as two saturation points on the feed rate frequency distributions. It was necessary to compare plants when producing the same product as the product type had a large influence on the specific energy usage. The analysis isolated products, which were produced by the marginal and modern plants, to depict the specific production costs more accurately.

The production and load frequency distribution also indicated lengthy start-up times on the more modern cement plants. This indicated poor control of the equipment. The feed rate and load distributions showed that the vertical roller mills at the more modern cement plants produced cement at much higher rates than the horizontal ball mills at the marginal cement plants.

The specific energy analysis showed that the more modern cement plants produced cement at a lower energy consumption than the marginal cement plants. This was to be expected as the more modern cement plants used vertical mills and the marginal cement plants used horizontal ball mills. The marginal cement plants also showed identical specific energy consumption before and after the implementation of the load management intervention. This proved that no major energy efficiency improving equipment was installed during the load shift interventions. However, the effect of the specific demand profile and load shifting on the specific cost, remained the most important criterion for evaluating the marginal plant's profitability.

The specific cost analysis showed that the more modern cement plants operated at a lower production cost than the marginal cement plants before the load management intervention was implemented. The post-implementation results, however, showed that the marginal cement plants produced at a more competitive specific cost. Though the specific cost of the marginal cement plant were still higher during lower cost summer periods, the marginal cement plants produced at a lower specific cost during winter months. The specific cost savings are summarised in Figure 5-1.

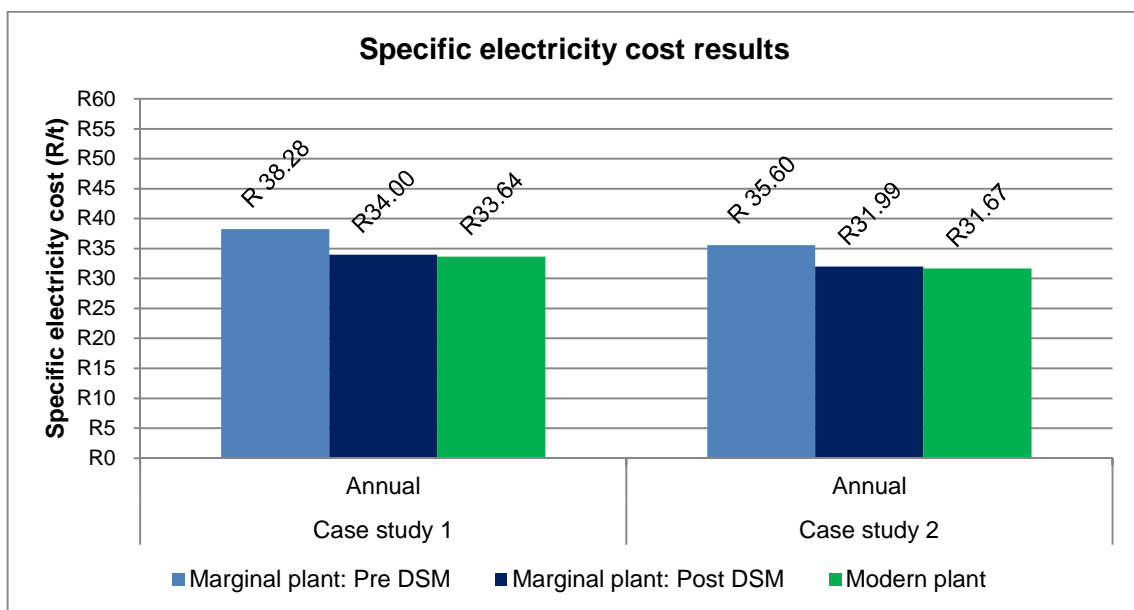


Figure 5-1: Specific annual electricity cost results

The annual averages of the different cement plants showed that the marginal cement plants produced cement at similar specific costs (within 1%) as the modern cement plants, verifying

that when load management interventions are implemented, marginal cement plants will become more feasible when compared with modern cement plants. The results were compared with the cost calculation as proposed by Lidbetter and proved accurate. These results served to validate the methodology.

5.5 VERIFICATION AND VALIDATION

5.5.1 Verification

The cost savings calculated from the evaluation strategy were verified using Lidbetter's savings calculator. The results from Case Study 1 and Case Study 2 differed by only 1.6% and 0.08% respectively. This shows that the evaluation method was accurate in showing the load management savings that were achieved. The study results and conclusion derived from the results could therefore be trusted.

5.5.2 Validation

The methodology was repeated on a second case study. The second case study implemented the load management strategy on a different marginal cement grinding plant owned by a different company. The evaluation strategy compared the reduced electrical costs with a modern grinding plant, also owned by the same company, and showed similar results as Case Study 1. Both case studies proved that the load management strategy would deliver more than 10% electricity cost reduction and make the marginal cement grinding plant competitive. Case Study 1 and Case Study 2 validated each other's findings by delivering similar results.

5.6 CONCLUSION AND RECOMMENDATIONS

The results showed that for the first cement producer, the marginal cement plant still produced at a higher specific cost than the modern cement plant. However, the differences between the annual averages were small. The marginal cement plant at the second cement producer, however, produced at the same specific cost than the modern plant. These results indicated

that the load-shifting intervention made the marginal cement plants competitive with the more modern cement plants.

Plant personnel at modern grinding plants should be convinced to implement the load management strategy on vertical roller mills. The evaluation strategy can be expanded to include all other cost associated with producing one tonne of cement. When including all costs, for example labour and material, a true reflection of a plant's competitiveness can be determined.

6 REFERENCES

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7 APPENDICES

7.1 APPENDIX A

Figure 7-1 and Figure 7-2 shows screenshots taken of the EMS installed on Marginal Plant A and C.

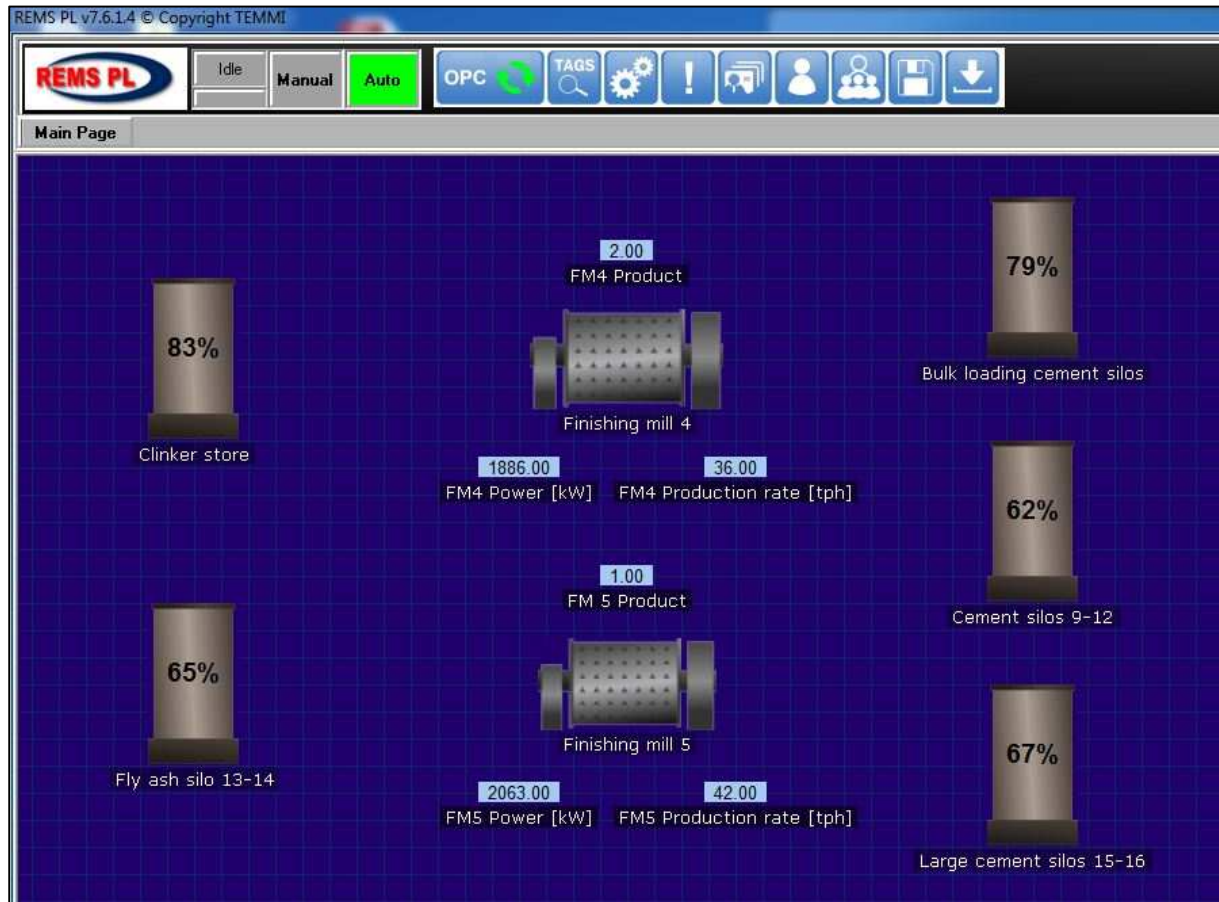


Figure 7-1: Marginal Plant A EMS screenshot

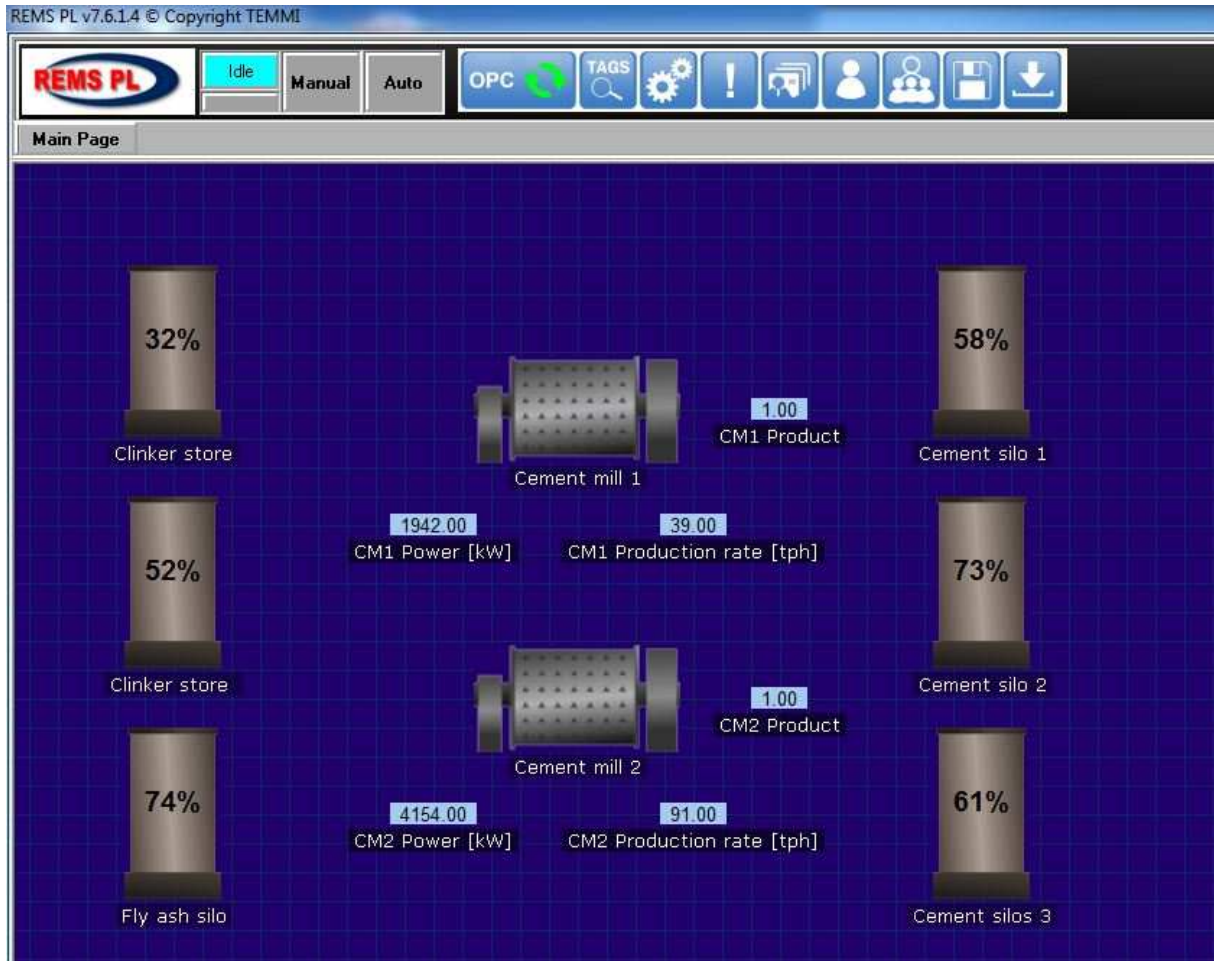


Figure 7-2: Marginal Plant C EMS screenshot

7.2 APPENDIX B

Table 7-1 and 2 show the detailed results verification results using Lidbetter's method.

Table 7-1: Results verification for Plant A

Post-DSM	Pre-DSM	Plant A
1 380 875	1 373 388	Off-peak
880 489	885 406	Standard
6 078	337 133	Peak
2 267 441.573	2 595 926.98	Q
48.43373	47.85736	Kwh
0.00268	0.12987	S1
0.609001	0.529055	S2
67.94817	72.29043	W(S)
78.10627	100.3204	W(W)

Table 7-2: Results verification for Plant B

Post-DSM	Pre-DSM	Plant B
1 938 131.545	2 058 329.15	Off-peak
1 182 081.1	1 429 525.3	Standard
94 457.967	569 512.79	Peak
3 214 670.652	4 057 367.21	Q
43.63135	43.75632	Kwh
0.029383	0.140365	S1
0.602902	0.507307	S2
68.66448	72.92571	W(S)
82.44019	102.6211	W(W)