

A system for continuous energy management to improve cement plant profitability

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ABSTRACT

Title: A system for continuous energy management to improve cement plant profitability

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Until 1996, the price of cement in South Africa was controlled by the government and a legal cartel, whereafter the industry became competitive. Today, new local entrants and increased international competition are placing strain on the oversupplied market. This, in combination with rising energy costs drive cement plants to focus more on the energy and cost effectiveness of their operations in order to be more competitive.

A number of energy management methods were investigated as part of the literature review, and it was found that these methods often require large capital investments. This study, however, used different strategies from literature to develop an electricity management system for improving cement plant profitability at a lower implementation cost. The automated specialised electricity management system uses the “*plan-do-check-act*” (PDCA) approach of the ISO 50001 energy management framework to provide feedback and create awareness on cement plants.

The system was developed in such a way that after investigating a plant and its data sources in detail, automated electricity performance reports are compiled. The system uses raw data captured from various sources and translates it into valuable information and graphs. This makes it possible to identify the largest electricity-consuming systems, monitor the performance of the equipment and compare it with continuously updating benchmarks. Specifically developed methods enable the system to identify missed saving opportunities and potential risks, which are reported to the relevant personnel.

The system was verified by continuously comparing it with the PDCA approach during the development process. Additionally, a self-assessment ISO 50001 checklist was used to determine to what extent the system contributes toward ISO 50001 compliance. Final verification was done by means of qualitative consultations with personnel involved in cement plant energy management.

As validation of the methodology, the system was implemented on a South African cement plant. The quantitative effect was evaluated over 14 months, which indicated that an electrical energy saving of about R4.8 million per annum is possible if performance is maintained. Qualitative studies further confirmed that the system also promotes the implementation of ISO 50001. The system makes it possible to monitor the energy performance of plant equipment and continuously improve operations. This study thus proved that cement plant profitability can be improved with minimum capital investment by using an energy management system.

Keywords: Energy management system; cement plant; profitability; risk identification; ISO 50001; plan-do-check-act; PDCA; equipment benchmarking; energy usage report; feedback system; performance evaluation.

SAMEVATTING

Titel: 'n Stelsel vir deurlopende energiebestuur om 'n sementaanleg se winsgewendheid te verbeter

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Die prys van sement in Suid-Afrika is tot en met 1996 deur die regering en 'n wettige kartel beheer, waarna die industrie meer kompetierend geword het. Nuwe toetreders tot die plaaslike mark, sowel as internasionale kompetisie, verhoog die druk op die oorvol mark. Dít, gekombineerd met die toenemende prys van energiebronne lei daartoe dat meer klem op die energie- en koste-effektiwiteit van bedrywighede geplaas word om meer kompetierend te wees.

'n Aantal bestaande energiebestuursmetodes vir kostebesparings is, as deel van die literatuurstudie, ondersoek en daar is bevind dat hierdie metodes dikwels groot kapitaalinsette vereis. Hierdie studie het egter verskillende strategieë vanuit literatuur geneem om 'n energiebestuurstelsel, wat sementaanlegte se wins teen 'n laer implementeringskoste verbeter, te ontwikkel. Die geoutomatiseerde elektrisiteitsbestuurstelsel is hoofsaaklik gebaseer op die "*plan-do-check-act*" (PDCA)-benadering, soos gedefinieer deur die ISO 50001-energiebestuursraamwerk, wat terugvoer aan personeel verskaf en bewustheid rakende energieprestasie beklemtoon.

Die stelsel is in so 'n mate ontwerp sodat verslae rakende elektrisiteitsprestasie outomaties saamgestel kan word nadat 'n aanleg en sy databronne in detail ondersoek is. Die stelsel gebruik rou-data vanaf verskeie databronne, en verwerk dit dan na bruikbare informasie en grafieke. Dit maak dit moontlik om die hoogste energieverbruikers op die aanleg te identifiseer, die elektrisiteitsprestasie van die toerusting te monitor, en dit dan te vergelyk met deurlopend opgedateerde maatstawwe. Uniek ontwikkelde modelle maak dit ook moontlik om besparingsgeleenthede waarvan nie gebruik gemaak is nie, asook potensiële risiko's, te identifiseer en aan die relevante personeel te rapporteer.

Die stelsel is voortdurend geverifieer deur dit, tydens die ontwikkelingsproses, met die PDCA-benadering te vergelyk. 'n Selfevalueringskontrolelys is ook gebruik om te bepaal tot hoe 'n mate die stelsel bydra tot die vereistes van ISO 50001. Die finale verifikasie is gedoen deur van kwalitatiewe konsultasies gebruik te maak onder verskeie personeel wat betrokke is by die energiebestuur van sementaanlegte.

Om die metodologie te valideer is dit geïmplimenteer op 'n Suid-Afrikaanse sementaanleg. Die kwantitatiewe effek van die implementering is oor 'n 14-maand periode geëvalueer, wat aangedui het dat 'n besparing van R4.8 miljoen per jaar behaal kan word indien die prestasie gehandhaaf word. Kwalitatiewe studies is ook gebruik om te bevestig dat die stelsel die implementering van ISO 50001 bevorder. Die sisteem maak dit moontlik om die energieprestasie van 'n aanleg te monitor en om aanhoudend operasies te verbeter. Die studie bewys uiteindelik dat dit moontlik is om die winsgewendheid van sementaanlegte te verhoog deur 'n energiebestuurstelsel te implementeer teen 'n minimale kapitaalbelegging.

Sleutelwoorde: Energiebestuurstelsel; sementaanleg; winsgewendheid; risiko-identifisering; ISO 50001; toerusting-evaluering; energieverbruikverslag; terugvoerstelsel; prestasie-evaluering.

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NOMENCLATURE

Tonne	1 tonne is equal to 1 000 kg (approximately 2 205 pounds). This is often referred to as a metric ton in American English, due to the different meaning of ton.
Power	Kilowatt is a measure of power, and is defined as the energy consumption of 1 000 joules for a period of 1 second ($1 \text{ kW} = 1 000 \text{ J/s}$).
Energy	Kilowatt-hour is a measure of the energy consumed. This can be calculated from the product of power (in kW) and the time period for which the power was consumed (in hours).
Pyro-processing	A chemical or mechanical change in material caused by high temperatures.
ISO 50001	<i>"ISO 50001:2011, Energy management systems"</i> is a voluntary standard developed by the International Organization for Standardization (ISO) that gives organisations the framework for energy management systems.

ABBREVIATIONS

CO ₂	carbon dioxide
DSM	demand side management
EnMS	energy management system
EnPI	energy performance indicator
ESCo	energy services company
GDP	gross domestic product
GNP	gross national product
ISO	International Organization for Standardization
PDCA	plan-do-check-act
SCADA	supervisory control and data acquisition
TOU	time-of-use
VRM	vertical roller mill
YTD	year-to-date

UNITS OF MEASURE

c/kWh	cent per kilowatt-hour
GJ	gigajoule
GJ/t	gigajoule per tonne
kWh	kilowatt-hour
kWh/t	kilowatt-hour per tonne
R/t	rand per tonne
t	tonne (metric ton)
t/h	tonne per hour

Chapter 1: Introduction and background

This chapter provides the reader with an introduction to the study. Background will be given to describe the problem that the study aims to solve. The situation regarding the cement industry in South Africa will then be discussed briefly in terms of positive economic growth and dependence on energy sources. A short introduction to ISO 50001 will also be given, which will be discussed in further detail in Chapter 2. Thereafter the problem is stated, and the aim and expected outcome of the research is given.

1. INTRODUCTION AND BACKGROUND

1.1. PREAMBLE

This chapter serves as an introduction to the dissertation. It aims to provide the basic background needed to understand the problem regarding the profitability of cement plants in South Africa. This will provide the reader with the required knowledge to comprehend the problem statement, which is also formulated in this chapter. The research objectives of the study will then be defined, followed by a brief overview of the remainder of the dissertation.

1.2. CEMENT MANUFACTURING IN SOUTH AFRICA

1.2.1. THE CEMENT INDUSTRY IN SOUTH AFRICA

Until 1996, the price of cement in South Africa was controlled by the government, and thereafter by a legal cement cartel [1], [2], [3], [4]. This was followed by the Competition Act, 1998 (No. 89 of 1998) [2], [5], [6], which was implemented to ensure that consumers were provided with competitive prices and a variety of product choices. These changes led to the cement manufacturing industry becoming a competitive market. Prices were no longer regulated, and the efficiency of a cement plant started to contribute to the price at which cement could be sold. Due to these changes, it has become even more important for cement plants to improve their profitability.

The first Portland cement in South Africa was manufactured in 1892 by the company now known as Pretoria Portland Cement (PPC) [1]. Between then and 1934, AfriSam, Lafarge and Natal Portland Cement (NPC) also entered the South African market [3]. Since then, the above-mentioned companies have been the four main suppliers of cement in the country, implying that several of the cement plants that are still used today were built between 1892 and 1934.

Upon construction of a new cement plant, manufacturers ensure that the most recent (and resultantly the most efficient) technology is chosen for equipment. With energy costs typically comprising about 30% of cement production cost [7], [8], more efficient equipment will result in lower energy usage [9]. The equipment in the new plants will also have higher production rates. Even though it is possible to maintain old equipment and continuously improve the technology thereof, the efficiency is largely determined by the original design according to *The World Business Council for Sustainable Development* [9]. The new plants will thus be able to produce cement at lower costs than the older cement plants [3].

The first new entrant in the South African inland market since 1934 has been Sephaku Cement with its two new plants in Lichtenburg and Delmas. These plants are expected to be able to produce about 2.6 million tonnes of cement per year when running at full capacity [3]. This is about 20% of the yearly sales in South Africa [10], and will resultantly have an influence on the country's market. Another threat to South African cement producers is the construction of the Chinese cement factory, Mamba Cement, near Northam in the Limpopo province. This cement plant is expected to be able to produce about 1 million tonnes of cement per annum, and was projected to be completed in 2016 [11], [12], [13].

The new Sephaku plants are estimated to be between 15% and 20% more efficient than existing cement plants in the country^a due to the updated technology that have been used. Sephaku will thus be able to produce lower cost cement, making it more difficult for the older plants to remain competitive in this market [3]. The Mamba Cement plant will also most likely be more energy efficient than the older plants as it will be constructed with the latest available technology for cement plants. If both of the new entrants in the South African market are able to sell all of the cement that they can produce, the market is reduced by 30% for the older plants.

PPC reported a 3% fall in their cement revenue for the first nine months of 2015. This decline was blamed on an increase in competition in the market [14]. Conversely, Sephaku Cement reported a revenue increase of 36% in the first three months of 2015 [15]. PPC reported that they experienced a further 3% fall in sales for the first part of the 2016 financial year [16]. This serves as a clear indication that new entrants in the market place strain on older cement suppliers. In order for the older plants to maintain their position in the market, they will have to sell cement at lower prices. The only way to achieve these lower prices is to reduce the production cost of their cement. Economical strain, however, causes the plants to not necessarily be able to spend significant amounts of money on methods for such improvements.

1.2.2. CEMENT MANUFACTURING AND THE SOUTH AFRICAN ECONOMY

A study done by Dlamini [17] indicates that construction has a positive correlation coefficient with the gross domestic product (GDP) and gross national product (GNP) in South Africa. The GDP and GNP are strong indicators of economic growth, while the construction sector is associated with the cement industry [17]. This implies that the price at which cement manufacturers in the country are able to produce their products will directly influence the economic growth thereof. If construction is able to take place at lower prices, more

a. <http://www.iol.co.za/business/companies/new-entrant-to-shake-up-cement-sector-1.1632864#.VktR8HYrKUK>

development (residential and industrial) can take place with a set amount of money made available therefor.

On the other hand, the state of the economy also influences the price at which cement can be sold. An industry analyst for First National Bank Economics, Jason Muscat, said that a damped economic growth negatively affects companies that supply products to the construction sector^b. This includes steel and cement producers. PPC also reported that the slow economic growth that led to less spending on infrastructure made it difficult to operate successfully in the South African market^c. This serves as a clear indication that cement plants in the country are under more pressure to remain competitive in the market, and that it is in the best interest of the local economy to have efficiently operating cement plants.

1.2.3. ENERGY SOURCES IN CEMENT MANUFACTURING

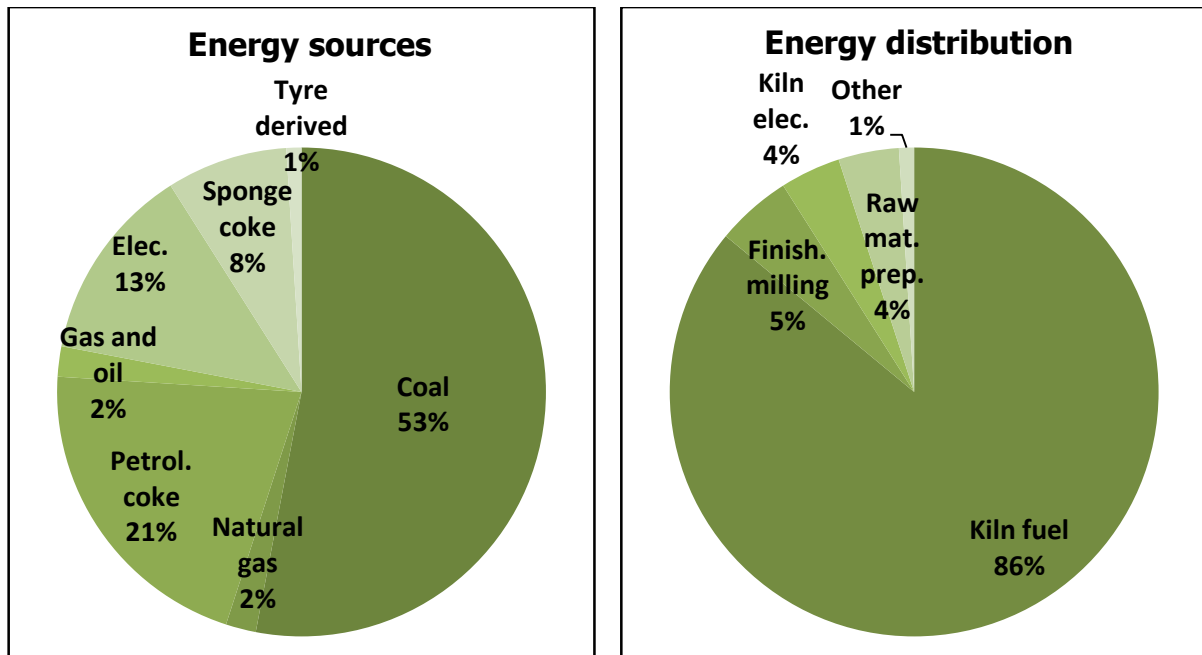
The production of cement is a highly energy-intensive process [18], contributing to about 2% of the primary global energy consumption [19]. The energy consumption of a typical cement plant makes up about 30% of the total production cost [7], [8], [20], and various energy sources are used in the process. These energy sources are typically distributed as shown in Figure 1.a [21], depending on the components on the plant and the fuels used in the kiln for burning. Petroleum coke can also be replaced by a larger coal consumption. Emission regulations in different countries also play a role regarding which fuels may be burnt in kilns.

Figure 1.b [21] shows the distribution of energy usage between the main components of a cement plant. This is once again dependent on the installed components of a specific plant. Many cement plants in South Africa do not have their own kilns, but rather import clinker from other cement plants. The number of finishing mills on a cement plant will also influence this distribution. “*Kiln fuel*” in the Figure 1.b pie chart includes various energy sources, and thus occupies a much larger sector due to the burning materials used. When “*kiln fuel*” is removed from the pie chart (Figure 1.b), the electricity consumption distribution of the cement plant components can then be represented as given in Figure 2.

Figure 2 indicates that finishing milling consumes the most electrical energy of all of the components on a cement plant [22]. As this study is done by mainly looking at cement plants in South Africa, the price of energy sources in the country is also taken into consideration. The continuous increase of electricity costs by Eskom forces consumers to initiate electricity cost savings initiatives.

b. <http://www.iol.co.za/business/companies/new-entrant-to-shake-up-cement-sector-1.1632864#.VktR8HYrKUK>

c. <http://www.bloomberg.com/news/articles/2014-09-15/ppc-says-south-africa-economic-slowdown-hurting-cement-volume>



a.) Energy source distribution

b.) Component energy usage distribution

Figure 1: Energy usage on a typical cement plant [21]

Kiln fuels were excluded from Figure 2 as the focus of this study is mainly on electrical energy. The management of energy obtained from coal on a cement plant typically originates from technological upgrades. Even though the literature aspect of the study will place some focus on the technology available to improve the coal consumption of the plant, this will not be the main focus. The literature can, however, still be used to determine what the best option would be when considering technological upgrades.

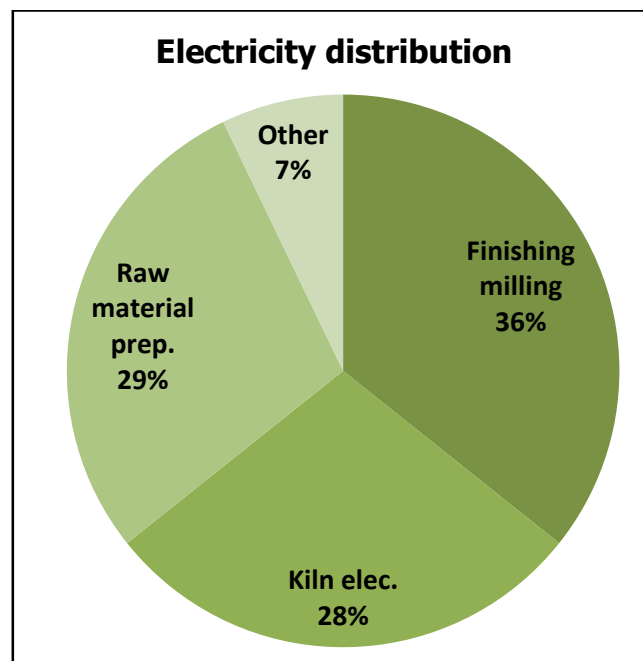
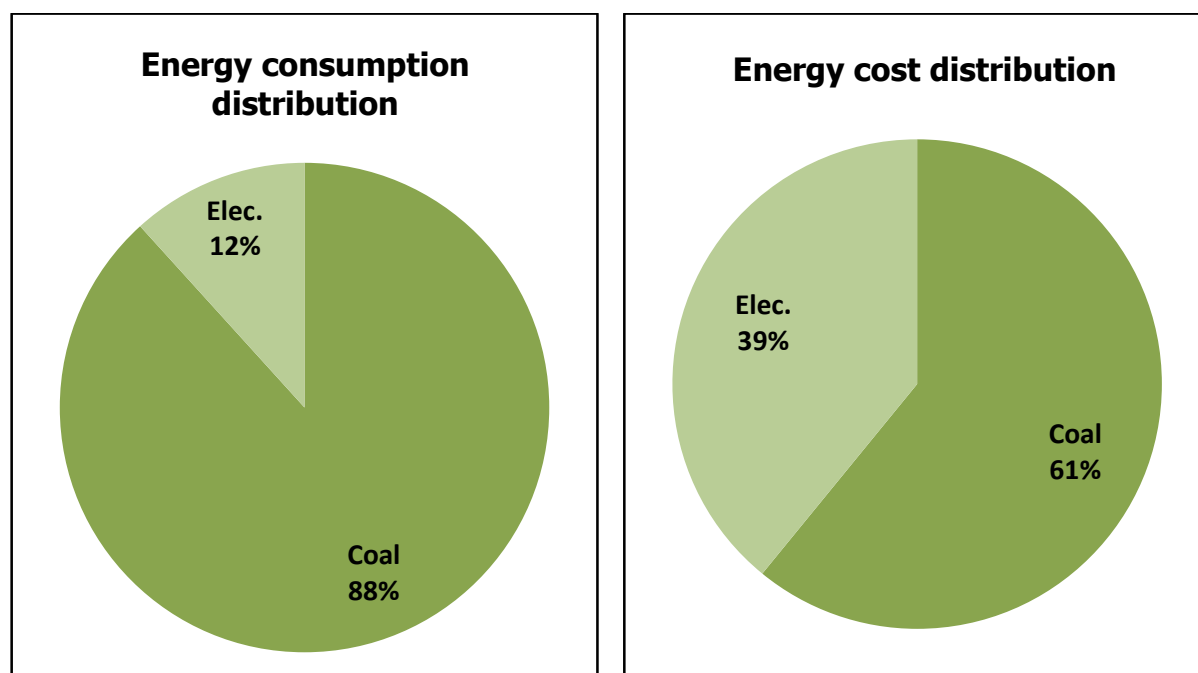


Figure 2: Electricity consumption distribution of cement plant equipment

Managing the coal usage of a kiln usually requires major upgrades to equipment, as will be discussed in Section 2.2.5 and Appendix B. The main focus of this study will thus be on electrical energy, as it is simpler to manage using an energy management system than coal usage. It is also more measurable and used on a wider variety of equipment, and is a low-cost implementation. It is further seen from Figure 3 that the electrical energy cost is significant. The literature study in Chapter 2 will still state different kiln technologies that are available, but these technologies will not be included in the developed system.



a.) Energy consumption comparison

b.) Energy cost comparison

Figure 3: Electricity versus coal: energy and cost analyses

The effect that high electricity cost has on a plant is illustrated in Figure 3.a and Figure 3.b. The process used to obtain the data in these figures is discussed in Appendix A. Coal and electricity data for one financial year from an actual South African cement plant was used to compare the consumption distribution of energy and the cost distribution thereof. Figure 3.a and Figure 3.b indicate that even though coal contributed to 88% of the energy dissipated on the plant during this period, it only contributed to 61% of the energy cost. This serves as motivation to focus on the management of electrical energy, rather than on all of the energy on the plant.

The fact that coal is a larger source of energy on a cement plant makes it a more attractive option for implementing energy savings initiatives. However, the high electricity price in South Africa motivates cement plants to rather consider electricity cost saving opportunities first. Historically, low electricity costs in the country have been reported to have caused a disregard for energy efficiency, as it did not play such a large role in operations [23]. This leads to a

slightly different approach for energy management of a South African cement plant than for international cement plants. The focus would be expected to be on the kilns in the case of international plants, where in South Africa the focus is rather set on the milling processes [24], [25].

Pyro-processing, which takes place as part of clinker production, is dependent on temperatures reaching typical highs of between 1 800 °C and 2 000 °C. This is dependent on the fuel used to provide the flame and complicates the management of coal energy [19]. Coal can thus also partially be seen as part of the production planning and management, instead of considering it as part of the energy planning of the plant. This further motivates the management of electrical energy instead of placing additional focus on coal.

As seen from qualitative studies among personnel involved with cement plant energy management in Appendix C (discussed in more detail later), current management methods do not focus extensively on energy management. Production forms the main basis for operational planning, and plants tend to neglect doing energy management and providing feedback regarding energy performance. All of the components that form part of the system will also not necessarily focus on energy efficiency, but rather on the cost efficiency of operations by considering electrical energy management methods. This is done by using aspects such as a time-of use (TOU) electricity tariff structure, where the time during which electricity is used influences the cost thereof.

1.2.4. ISO 50001 REQUIREMENTS

“ISO 50001:2011, *Energy management systems*” is a voluntary standard developed by the International Organization for Standardization (ISO) that gives organisations the framework for energy management systems [26]. Organisations can benefit from the savings obtained by implementing such systems and by certifying their ISO 50001 compliance. Energy management systems are based on a continuous improvement process where each organisation can set its own energy saving goals and evaluate their performance. As soon as a goal is achieved, the target can be adjusted in order to continuously improve.

The ISO 50001 framework is based on the “*plan-do-check-act*” (PDCA) process, which will be discussed in Chapter 2. The system developed in the remainder of this dissertation will be based on PDCA. The main focus will be placed on the feedback aspect of the process. This will enable cement plants to move toward obtaining an ISO 50001 compliance certificate by implementing the system. Being certified as compliant with ISO 50001 will be beneficial to companies by improving international operations; creating an innovative operational environment; and assisting with creating and entering new markets [27].

ISO 50001 is a trusted and approved method for improving the energy performance of industries with several advantages [26], [28], [29]. This framework will thus be referenced as part of the verification of the developed system. Due to the proven positive effect of the ISO 50001 framework, using it as the basis of the developed system will ensure that the system also has a positive effect on a cement plant's energy performance. The system will not contribute to all of the aspects of ISO 50001, but a checklist used for verification will be used to identify additional areas of ISO 50001 that need to be attended to.

Evaluating whether the plant achieves the requirements of ISO 50001 will also be an indication of the success of the study. The expected result is that the system will assist in improving the profitability of the plant. The system will be verified by comparing the developed methodology with the ISO 50001 framework, and ensuring that the system follows the same basic structure as ISO 50001 and contributes towards reaching the desired outcomes thereof.

1.3. PROBLEM STATEMENT

Until 1996, the price of cement in South Africa was controlled by the government and a legal cement cartel, whereafter the industry became a competitive market. A new entrant in the domestic market is placing strain on the older cement plants to remain competitive. Furthermore, the slow growth of the South African economy causes cement sales to decrease. This, in combination with the rising price of energy sources lead to cement plants to focusing more on the energy and cost effectiveness of their operations. Furthermore, current energy management strategies and systems tend to neglect the feedback and evaluation aspect of the process, and thus neglect utilising additional opportunities.

The fact that the older cement plants are performing worse [14], [16] also adds to the problem that they might not be willing or able to spend additional money on energy cost saving initiatives. Upgrading of equipment typically requires large investments with long payback periods [30]. Thus, the solution to the problem has to be of low initial cost. An energy management system will enable cement plants to improve their energy performance, and resultantly save costs without having to make major adjustments to equipment. The adjustments that will lead to energy savings will originate from adjustments to the operational aspects of the plant.

During this study, the energy management system will be implemented on one case study, which is one of the older cement plants in the country, and will serve as the quantitative validation of the methodology. The goal of the study is to make the plant more profitable by implementing the system and resultantly ensuring that the plant remains competitive in the current market. The system will focus on combining:

- Energy management methods previously implemented on cement plants;
- Energy management strategies and systems implemented in other industries; and
- Technological advancements and upgrades that would benefit the profitability of the plants.

1.4. RESEARCH OBJECTIVES

The aim of this dissertation is to investigate various energy management methods from literature and consultations with cement plant personnel, and to compile a combined energy management system that focuses on energy performance feedback. The energy management system will use the PDCA approach of the ISO 50001 framework as foundation.

The main outcome of the system will be the automated reporting aspect that focuses on the feedback loop of the approach. This feedback will enable the plant to identify missed opportunities and areas that require improvement and monitor the utilisation thereof. The system will aim to make cement plants in South Africa more profitable by considering their electrical energy management. The system will be evaluated by considering the effect that it had on the profitability of the case study.

1.5. DISSERTATION OVERVIEW

1.5.1. CHAPTER 1

This chapter provided the reader with an introduction to the study. Background was given to better understand the problem that the study aims to solve. The situation regarding the cement industry in South Africa, the dependence of cement plants on energy sources, and a positive economic growth were briefly discussed. A short introduction to ISO 50001 was also given, which will be discussed in further detail in Chapter 2. Thereafter the problem was stated, and the aim and expected outcome of the research were given.

1.5.2. CHAPTER 2

The second chapter of this dissertation will start by investigating the operation of a cement plant – including the different components and equipment used for cement manufacturing. The expected performance of the different components on the plant will also be investigated. The ISO 50001 framework will be discussed in more detail, along with its expected outcomes. Existing energy management methods that can be used in the system will also be evaluated. Qualitative studies among cement plant personnel will be used to determine what methods are currently used to provide feedback on cement plant energy performance.

1.5.3. CHAPTER 3

Chapter 3 will focus on developing the energy management system by using the investigations done in the previous chapter. The methods used for developing each step in the system and how they will be implemented on a cement plant will be discussed. Throughout the discussion of the steps, their relevance to ISO 50001 will be stated, which will also serve as the verification of the methodology. A self-assessment checklist for ISO 50001 certification will also be evaluated and compared with the system by using Appendix E. Additional verification will be done by considering the qualitative studies done among personnel involved with cement plant energy management.

1.5.4. CHAPTER 4

In this chapter, the system developed in Chapter 3 will be validated by implementing it on an older South African cement plant (referred to as Plant X). A case study will be considered in detail and over a long evaluation period to determine the continuous effect of the system in order to determine the quantitative effect. However, the system was also implemented on another cement plant (Plant Y) for a short test period to determine the feasibility of the system on another plant. Results will be given for the effect that the system had on the profitability of the major plant sections of Plant X, as well as on the entire plant. Further validation will be done by referencing the qualitative studies completed among personnel involved with the energy management of cement plants. The effect that the system can have on the entire cement industry will also be briefly considered.

1.5.5. CHAPTER 5

The last chapter of this dissertation will serve as a conclusion to the study. An overview of the procedure that was followed and the results that were obtained will be given. The results will be evaluated to determine the success of the developed system, and whether or not the objectives stated in Chapter 1 were reached. Recommendations will also be made for future work in the same study field.

Chapter 2: Literature study

This chapter of the dissertation starts with an investigation into the operation of cement plants, including different components and equipment used for cement manufacturing. The expected energy performance of the different components on the plant will be investigated. The ISO 50001 framework will then be considered in more detail along with its expected outcomes. Existing energy management methods that can be used in the system will also be evaluated. Additionally, qualitative studies among cement plant personnel will be used to determine what methods currently exist for giving feedback regarding cement plant energy performance.

2. ENERGY MANAGEMENT IN THE CEMENT INDUSTRY

2.1. INTRODUCTION

In this chapter, the necessary literature and detailed background surrounding the research of the dissertation will be discussed. In order to understand the energy management of a cement plant, it is necessary to first understand the operation thereof better. This chapter will thus start with an overview of a typical cement plant, with focus on the different components and the energy usage of the different sections. Thereafter, the technology of the equipment used on a cement plant will be discussed along with the energy usage benefits of the relevant technology. The benefits of the newer technology will be illustrated by indicating the benchmarked operating conditions of the equipment.

A closer look will also be taken at the previously mentioned ISO 50001 framework to understand exactly what it entails and how it is relevant to this study. ISO 50001, and existing implementations thereof, will be used as the basis of the system, and resultantly also the verification of the methodology in Chapter 3. This will ensure that the energy management system developed in this study is relevant, and has the desired effect of improving the profitability of cement plants. The energy management system will thus also contribute to the cement plants becoming ISO 50001 certified.

Existing energy management strategies and systems that are relevant to the study will then be discussed. Qualitative studies will also be used to determine what methods are currently used by cement plants to monitor their electrical energy consumption. Furthermore, possibly unfamiliar concepts that motivate energy management, such as carbon dioxide (CO₂) taxes and Section 12L tax deductions, will also be reviewed.

2.2. OVERVIEW OF A CEMENT PLANT

2.2.1. PREAMBLE

Energy saving methods on a cement plant can be identified most effectively by first comprehending the cement manufacturing process. The typical cement manufacturing process is illustrated in Figure 4. This figure illustrates the steps that limestone, the main raw material for cement, has to undergo to produce the end product [19]. The main steps in the process will be discussed individually in the remainder of this section, with additional details about some components presented in Appendix B. The main sections of a cement plant can be categorised as follows:

- Raw material preparation
- Raw milling
- Fuel preparation
- Burning
- Finishing milling
- Dispatch
- Services and buildings

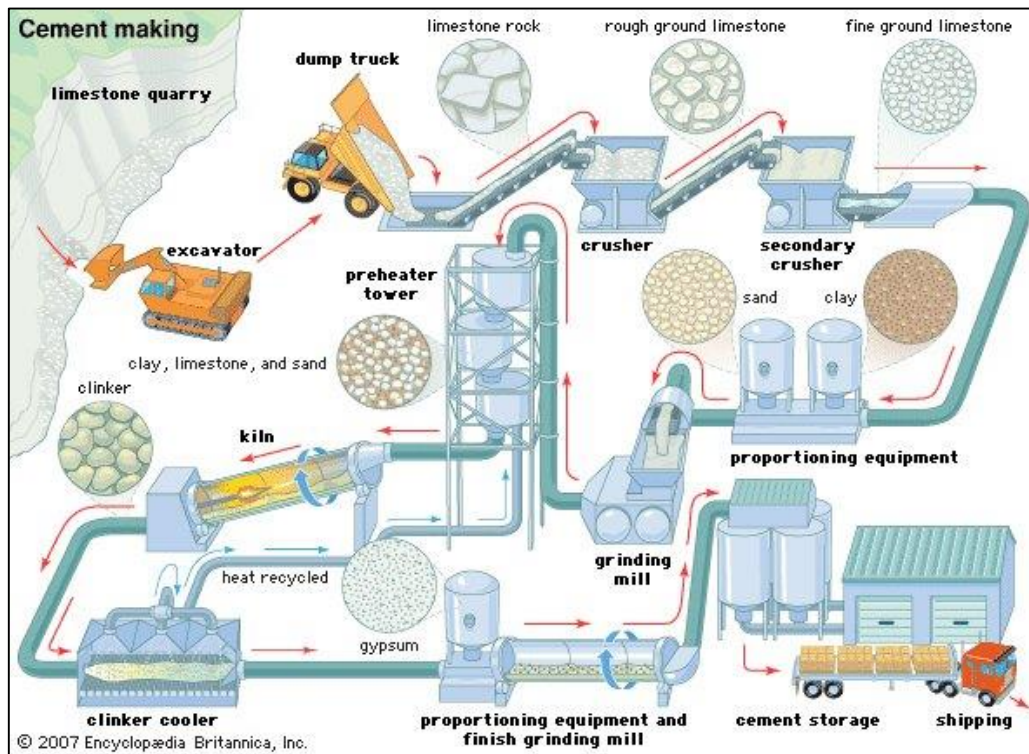


Figure 4: Typical cement manufacturing process^d

2.2.2. RAW MATERIAL PREPARATION

Limestone is the main material used in cement manufacturing, and is usually mined in an opencast quarry. In order to save money on transportation cost, cement plants are generally erected in close vicinity of such a quarry [19], [30]. Quarrying is done by using large equipment, which results in the inclusion of large chunks of limestone. The typical mining process consists of drilling, blasting, loading, hauling and then crushing and screening. The limestone thus has to be processed to a usable form by using primary and secondary crushers, and if necessary, tertiary crushers. The crushing process systematically crushes the limestone to smaller particles by screening and recrushing them until they are about 25 mm in diameter [30].

d. <http://global.britannica.com/technology/cement-building-material>

Other materials that are also used in the cement manufacturing process are imported by using conveyers, rail offloading (tippler) or truck offloading if necessary. These materials include iron, chalk, clay and sand. The coal used for burning in the kiln is obtained in the same way. Some cement plants do not have their own quarries and import limestone as well. The raw materials are either stored on storage beds (often in a warehouse) by using stackers, or in silos. Reclaimers are used to obtain the materials from the storage beds, from where all of the raw materials are transported with conveyers to be blended. From the blenders, the raw materials are conveyed to mills where they are prepared for burning.

2.2.3. RAW MILLING

The purpose of raw milling in a cement plant processing line is to prepare raw meal to be used for clinker production. Raw milling is mainly done by using either a ball mill or a vertical roller mill (VRM). Ball mills, as shown in Figure 5.a, contain different sized balls, and a classifying liner to position the balls. The larger balls are used to focus on impact grinding, while the smaller balls are responsible for attrition grinding [19], [30]. The problem with ball mills is that they are inefficient, as the process has several losses [31]. These losses include energy wasted due to heat, friction, sound and vibration. However, these mills are still often used for their low installation cost and lower maintenance expenses^e.

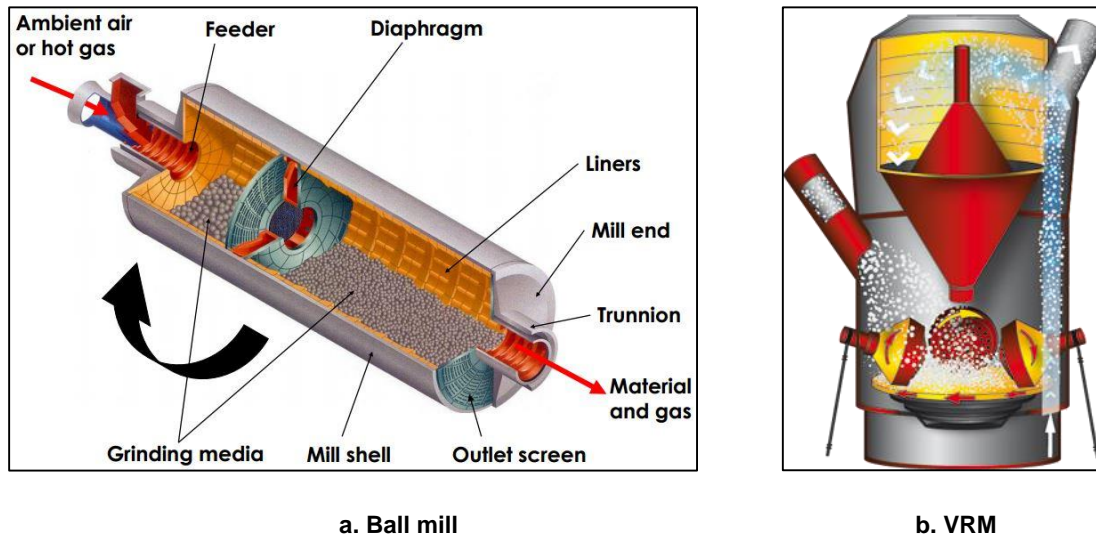


Figure 5: Examples of different raw mills

A VRM, as shown in Figure 5.b, uses a compression principle to produce raw meal [30]. It basically performs four desired functions as one piece of equipment, thus making it more efficient than a ball mill. A VRM first grinds the raw material between rollers and a grinding table, whereafter the dried materials are lifted with drying gases. This separates and dries the

e. PPC mini-technology course presentation

raw meal, leaving coarse raw materials behind in the grinding process. The drying gas is often waste gas from the kiln, but it can also be generated separately. The drying gases at the same time also serve as conveying media, used to transport the raw meal to its desired destination [32].

Other mills that can also be used for raw milling include hybrid milling systems, where different mills (typically a ball mill and roller mill) are combined to improve the performance of inefficient mills. An integral roller press is also often used; in this case, a roller mill is combined with a tube mill. This combination can also be implemented as a pregrinder for another mill to decrease the energy usage [8], [33]. The operational benchmarks for these mills will be further discussed in Section 2.3.3. Detail regarding the different approaches to processing the raw meal is given in Appendix B.

After processing raw materials, the raw meal is blended to obtain the best variation in the composition of the kiln feed. This plays a role in the efficiency of the kiln, and is done to reduce the natural chemical variations in the different raw materials. Raw materials have to be blended and homogenised efficiently. An increase in the correct blending additives could lead to a reduction in the clinker used for the desired end product. The blend is then usually stored in a blending silo until it is used to produce clinker [30]. These silos provide a buffer between the raw milling and burning sections of a cement plant, thus creating the opportunity to perform production scheduling on the raw mill.

2.2.4. FUEL PREPARATION

The flame in the kiln is required to produce clinker, the main component of Portland cement [19], [30]. Various materials, for example, petroleum coke, coal, natural gas, recycled materials or oil, can be used to fuel this flame, although poor environmental performance and opposition from society sectors oppose any form of thermal waste treatment in South Africa [34]. Thus, fuel preparation for kilns in South Africa focuses mainly on the preparation of coal, which is done by using coal mills. Coal milling usually uses a ball mill, similar to the illustration in Figure 5.a, and mills coal, coke and pet coke with the different sized balls [21]. Further detail on fuel preparation is given in Appendix B.

2.2.5. BURNING

The burning process in cement manufacturing is also often referred to as clinkering, and includes the process of converting raw material into clinker. Clinker is the main component of Portland cement, and is produced by pyro-processing in a kiln. Kilns have been reported to be the most important component in cement manufacturing as clinkering is regarded as the

main step in the process. The fuel used to heat the kiln is also the largest contributor to energy consumption on a cement plant [19], [30].

As mentioned in Chapter 1, this study does not focus on the management of energy obtained from coal, even though it is the largest contributor of energy consumption on a cement plant. Different kiln technologies are, however, discussed in Appendix B. This contributes to a better understanding of the cement manufacturing process. Improving the energy efficiency of a kiln usually requires major equipment upgrades, while this study focuses mainly on managing energy usage and identifying opportunities for improvement. This is done for the kiln by identifying the most efficient technology that can be installed when upgrading or replacing outdated equipment.

2.2.6. FINISHING MILLING

The final step in the manufacturing process of cement is to grind the clinker and add the remaining materials to the mixture. A small percentage of gypsum is added to control the hydration rate of the cement and to ensure that it does not harden prematurely when used. Blended cement types are also produced by most plants in order to produce more cement for the same quantity clinker. The blends allow materials such as limestone, fly ash and slag to be added to the end product [35]. The purpose of the finishing mill is to grind the clinker and mix all of these materials to produce a usable form of cement that can be sold to the consumer.

Cement milling is reported to be the most electrical energy-intensive section of the manufacturing process [35], consuming about 40% of the total electrical energy used on the plant [36]. The energy requirements are dependent on the hardness of the materials that are to be ground and the desired fineness of the cement, while the type of cement produced also has an influence. The cement milling process often consists of a grinding circuit of a series of mills, fans and separators that are used to mill and blend the materials. The size of the particles in the cement depends on the type of mill that is used. The variety of mills that can be used is similar to the mills used for raw milling, as described in Section 2.2.3 [35].

Ball mills were previously used almost exclusively as there is a wider range of particle size choices, even though VRMs are more energy efficient. However, VRMs were not used due to the limitations of the particle sizes. The latest technology assisted with overcoming this problem and grinding with VRMs is becoming the more preferred method [35]. The use of a VRM has also been reported in at least one South African cement plant [37]. Separators and classifiers are used in combination with the mills to ensure that materials that are not ground fine enough are fed back into the mill [35].

It is also common to have a precrusher that uses a high-pressure roller press as part of the finishing milling process. It has been reported that less energy is required to press clinker than to crush it with collision (as in the case of a ball mill) to obtain the desired fine particles. This addition will thus improve the feed rate as well as the efficiency of a finishing mill [30], [36]. The fans used for finishing milling are mainly for controlling the temperature of materials throughout the process. Excessively high temperatures during milling will cause the cement not to harden when used, deeming the cement unusable. It is thus critical to carefully monitor and regulate this temperature [38].

2.2.7. DISPATCH

After producing the finished cement, it is kept in storage silos from where it is prepared for dispatch. This typically consists of a packing and loading plant, where the cement is packed in specific sized bags and sold to the consumers or distributors. Some consumers prefer to purchase cement in bulk, in which case it will be distributed by truck or railway. The final option for purchasing cement is in premixed form, where the plant will have a premixing section where the preferred mixture is prepared. The demand at the dispatch section influences the process line management strategy, as it is the best indication of the demand for cement in the market.

2.2.8. SERVICES AND BUILDINGS

The services and buildings sections consist of all of the components that are used on the entire plant, but that are not associated with a specific section. Even though it is difficult to manage the energy usage of these components, it is still necessary to include them when monitoring and reporting the usage for abnormalities. Services will typically include components such as lighting, compressors, cranes, boreholes and sewage plants. Buildings can be classified as administration or main buildings on a plant, as well as workshops, stores and laboratories. If the plant has a village, hostels or employee housing that also feed from its incomers, they are usually also classified as part of buildings.

2.2.9. ENERGY USAGE IN CEMENT MANUFACTURING

The energy distribution of an average cement plant was briefly discussed in Section 1.2.3 by using the pie charts in Figure 1 and Figure 2. The energy used in each section of a cement plant is illustrated in Figure 6, as adapted from Madlool [30]. From this flow diagram it is seen that electrical energy, burning fuel (coal) and diesel are the most used energy sources on a cement plant. Diesel is mainly used by vehicles during mining operations, but also during the milling processes, depending on the type of mill. This will thus not form a major part of this study. The main focus will be on electrical energy.

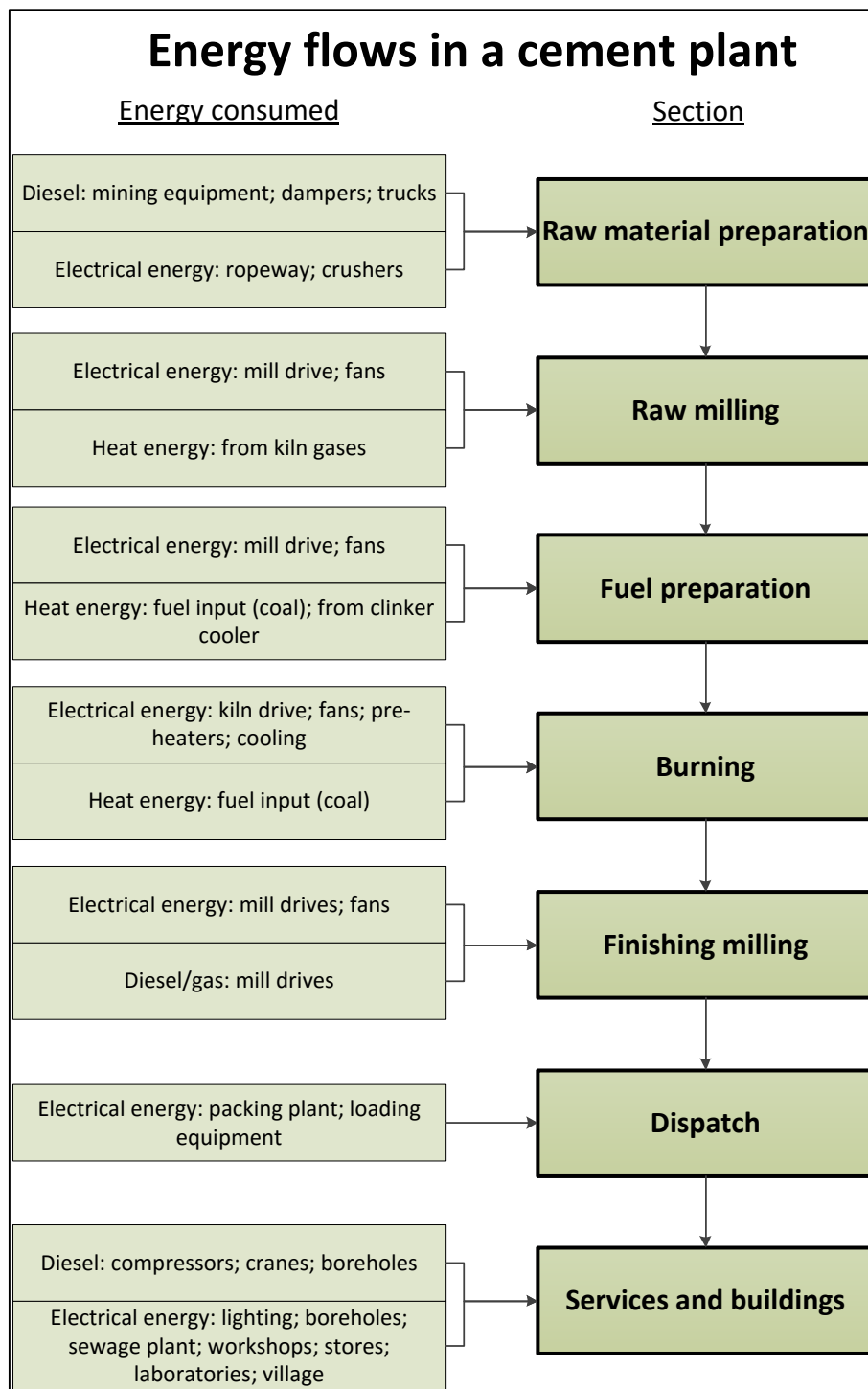


Figure 6: Typical energy sources for cement plant sections (adapted from [30])

As mentioned previously, the focus of this study will not consider energy efficiency by managing coal usage. However, kiln technologies were still discussed, and the most energy efficient kilns were presented as part of the literature study and Appendix B. This was done to emphasise that improvements in the energy efficient use of coal are mainly dependent on major upgrades to equipment. Such information will also contribute to a proper understanding

of the cement manufacturing process, as well as a better understanding of the statement that a new cement plant is more efficient than an older plant.

According to international figures, a modern cement plant consumes between 110 kWh/t and 120 kWh/t of total electrical energy to produce a tonne of cement [22]. The electrical energy usage for the components discussed in this section is given in Table 1, with the percentages as obtained from Madloul [30]. The percentages were converted to a kWh/t range according to the total consumption of a modern cement plant. This can thus be seen as a benchmark for the sections on a cement plant, from where it can be determined how energy efficient each section is.

Table 1: Electrical energy distribution of a modern cement plant

Section	Share of total usage (%) [30]	Electrical energy intensity (kWh/t cement produced)
Raw material preparation	2.0	2.2–2.4
Raw milling	24.0	26.4–28.8
Fuel preparation	29.3	32.2–35.2
Burning	6.7	7.4–8.0
Finishing milling	30.7	33.8–36.8
Dispatch	2.0	2.2–2.4
Services and buildings	5.3	5.8–6.4
Total	100.0	110–120

The difference in terms of energy usage and efficiency of specific equipment for each section on the cement plant will be discussed in the next section. The equipment installed on a plant will influence the electrical energy intensity as described in Table 1, from where it will be possible to identify the most advantageous equipment that can be installed.

2.3. CEMENT PLANT EQUIPMENT BENCHMARKING

2.3.1. PREAMBLE

There are various energy management methods that are used to improve the efficiency (and resultantly the profitability) of a cement plant. This section focuses on the difference that more technologically advanced equipment has on the performance of the equipment, and why it gives such a great advantage to newly built plants. The possibilities for upgrading or replacing current equipment with more technological equipment will also be considered.

The benchmarking of the sections on a cement plant given in Table 1 is dependent on the performance of the equipment used on each section. Different equipment influences the efficiency, with more technologically advanced equipment typically being more energy efficient. A study done in India indicated a potential energy efficiency improvement of about

33% by incorporating currently available technology on an average older plant [39]. Newly constructed cement plants are highly likely to be equipped with the latest technology, which gives them an advantage in terms of overall profitability.

All of the equipment on a cement plant will not necessarily be upgradable, or the payback period thereof might be too long. The efficiency of all of the sections on the plant can also not necessarily be improved by using new technology. More developments for energy efficiency improvements are expected on the more energy-intensive sections of the plant as these are the areas with the biggest opportunity for improvement. The sections of the plant with the highest variety of equipment and the most potential for improvement will thus be considered in this section.

2.3.2. RAW MATERIAL PREPARATION

Upon investigation of the raw material preparation section, it was found that there is a variety of crusher technologies that can be used on a cement plant. The energy efficiency of the crushers differs according to the methods used to crush the limestone. These different types of crusher, along with the benchmarked intensities (electrical energy used per tonne limestone crushed), according to Worrell [19], are presented in Table 2. According to this benchmarking, the most energy efficient crusher is a gyratory crusher, while hammer crushers are the least energy efficient. It would thus be beneficial for a plant that uses a hammer crusher to consider replacing it with a gyratory crusher.

Table 2: Crusher benchmarking

Crusher	Electrical energy intensity (kWh/t limestone crushed)
Jaw crusher	0.3–1.4
Gyratory crusher	0.3–0.7
Roller crusher	0.4–0.5
Hammer crusher	1.5–1.6
Impact crusher	0.4–1.0

2.3.3. RAW MILLING

The benchmarking of different technology available for raw mills in terms of the intensity per tonne raw meal produced is given in Table 3 [19]. The mills listed were briefly discussed in Section 2.2.3. According to this benchmarking, the most efficient mill to use is an integral roller press, which is an integration between a roller press and a ball mill. Without any modification, however, a VRM is much more efficient to use than a ball mill. Depending on the application, as well as the condition and specifications of a ball mill used on a plant, it would be advisable to either replace the mill with a VRM, or to add an integral roller press.

Table 3: Raw mill benchmarking

Raw mill	Electrical energy intensity (kWh/t raw meal milled)
Ball mill	22
VRM	16
Hybrid systems	18–20
Roller press – integral	12
Roller press – pregrinding	18

2.3.4. BURNING

As discussed in Section 2.2.5 and Appendix B, the burning section of the cement manufacturing process is the most energy intensive due to the fuel used for burning. However, electrical energy is still required for rotating the kiln and auxiliaries such as fans. The intensity of the electrical energy used per tonne clinker produced for different types of kilns are listed in Table 4 (according to Worrell [19]). This table indicates that a short dry kiln with a preheater uses the least electricity to produce a tonne of clinker. From Table 4 it can also be assumed that adding a precalciner increases the electrical energy usage of the burning section.

Table 4: Kiln electrical energy benchmarking

Kiln type	Electrical energy intensity (kWh/t clinker produced)
Wet	25
Lepol	30
Long dry	25
Short dry (with preheater)	22
Short dry (with preheater and precalciner)	26

The fuel (which in South Africa is usually coal) consumed by the kiln makes up about 75% of the total energy used by a cement plant [30]. It is thus vital to ensure that the kiln is fuel efficient. The fuel intensity of various kilns with added equipment for improved efficiency, as discussed in Appendix B, is given in Table 5. The intensity of the fuel usage is given in gigajoule (GJ) energy obtained from the fuel per tonne clinker produced. In the case of coal, the GJ value is calculated by using the calorific value and moisture level of the coal [40]. According to Table 5, a short dry-process kiln is the most energy efficient option, and adding preheaters, a precalciner and a cooler has a significant effect on the kiln efficiency [30]. As the kiln is such a large energy consumer, it would be beneficial for a plant to investigate the cost of replacing its old kiln, and comparing it with the benefits of a new kiln.

Table 5: Kiln fuel usage benchmarking

Kiln configuration	Fuel consumption (GJ/t clinker produced)
Wet process	5.9–6.3
Long dry process	4.6
1-stage cyclone preheater	4.2
2-stage cyclone preheater	3.8
3-stage cyclone preheater	3.6
4-stage cyclone preheater and precalciner	3.1
5-stage cyclone preheater, precalciner and cooler	3.0
6-stage cyclone preheater, precalciner and cooler	2.9

2.3.5. FINISHING MILLING

The electrical energy intensities for different combinations of finishing mills are given in Table 6, as adapted from Worrell [19]. These mills are similar to the mills discussed for raw milling, but the intensities are quite higher due to the harder texture of clinker that has to be milled. The two basic mills that are generally used are ball mills and VRMs. As seen in Table 6, the VRM is much more efficient than the ball mill. The other combinations of mills indicated in the table can be used when modifying a ball mill to be more efficient.

Table 6: Finishing mill benchmarking

Finishing mill	Electrical energy intensity (kWh/t cement produced)
Ball mill	55
Ball mill and separator	47
Roller press – ball mill – separator	41
Roller press – separator – ball mill	39
Roller press – separator (VRM)	28

2.3.6. PERFORMANCE BUDGETING AND TARGETS

The benchmarks specified for different equipment on a cement plant in this section will be used to set targets and budgets for the automated reporting system developed in this study. During communications with plant personnel and energy specialists, it was found that there are several budgeting methods that can be used. The most efficient methods use consistently updated targets based on historical performance. These methods will be used in Section 3.2.7 of the methodology to discuss the procedure to set performance targets during the implementation of the energy management system.

The first method is to use the past three months' performance, and to use its average as a target. This method serves as a measure of whether performance improved from the previous

performance, and indicates whether the energy consumption is being managed consistently. The problem with this method is that it merely indicates the latest performance compared with recent historical performance, but it does not include a target that motivates continuous improvement.

The next method that can be used is to compile a year-to-date (YTD) rolling average, which changes based on the previous reporting period's performance. This target can then be compared with the previous year's final YTD performance, or an alternative target. This will enable the plant to monitor how the latest energy management affected the performance towards reaching the same performance as the previous year. The plant will also be able to act swiftly if it is indicated that they are not on track to reach their target, and thereby identify areas that require urgent attention.

Another method is to use year-on-year comparisons and only compare these to the performance of the reporting period. This could be effective in some cases; for example, monthly totals of production and total energy consumption. By comparing a monthly total with the average of the same month for the past few years, it can be seen how a certain year differs from previous years. This can also further serve as an indication of the cement demand versus previous years as it is production-dependent. This method might, however, not work as effectively for weekly report targets as the cement demand for the same week in previous years will most likely differ too much.

The last method that can be used is to only consider benchmarking from literature as the target. This will ensure that the energy performance of equipment aims to improve to the best possible performance. It is possible that older equipment might not be able to reach such targets, and it might be regarded as unusable by personnel interpreting the report. Such a target is not always a realistic reflection of how the plant can perform as the age of the equipment and the components on the specific plant also play a role in the potential optimum performance.

2.4. ISO 50001 FRAMEWORK

2.4.1. PREAMBLE

"ISO 50001:2011, Energy management systems" [26] is an international standard developed by ISO. Compliance to the standard is voluntary, although it has been reported to be beneficial for organisations that implement it. The aim of the standard is providing organisations with a guideline for improved energy management. The developed energy management system will be based mainly on this framework, and will thus contribute towards ISO 50001 compliance.

This will also be used as the main verification for the developed methodology of the energy management system in Chapter 3. Some of the benefits listed by ISO include [26], [28]:

- Improving how the organisation uses its energy-consuming assets;
- Communicating how equipment is performing by better communication and interpretation of data, and setting of targets to ensure continuous improvement;
- Ensuring that equipment is operated as efficiently as possible, and identifying the need for implementation of new practices and technology;
- Promoting better energy management practices by improving the awareness thereof throughout the entire operation;
- Encouraging the benchmarking, measuring, documenting and reporting of the energy usage of operations;
- Improving the cost efficiency of energy-intensive operations; and
- Reducing the greenhouse gas emissions of operations.

Basing the energy management system on this framework will thus ensure that these benefits are obtained. Compliance to the ISO standard will also lead to ISO 50001 certification, declaring that the organisation achieved the following requirements by using an energy management system [28]:

- Developing a policy for improved efficiency of energy usage;
- Setting targets to enable meeting the policy goals;
- Improving decision-making about energy usage by analysing and interpreting the relevant data;
- Quantifying and measuring the results achieved;
- Evaluating how well the policy is working;
- Improving energy management continuously.

The above-mentioned requirements have to be achieved by implementing the developed energy management system if it is to be considered as developed from the same basis. During the methodology discussion in Chapter 3, these requirements will be revisited to verify how the system will contribute to compliance. By complying with these requirements, an organisation will resultantly share in the benefits of the system as discussed previously. These benefits include improved cost efficiency by managing energy usage. This will in turn result in improving the profitability of cement plants by using the energy management system.

The implementation of the ISO 50001 framework is based on the PDCA approach, which was designed to ensure continuous improvement of energy performance within an organisation [28]. The flow diagram in Figure 7 illustrates what each step in the PDCA approach represents.

The basic concept illustrated by this flow diagram is that there should be a feedback loop in the process. This will contribute to the continuous improvement of the energy management system and result in positive energy performance. Targets and benchmarks will thus be adapted according to previous performance. Each step is briefly discussed in more detail in the remainder of this section.

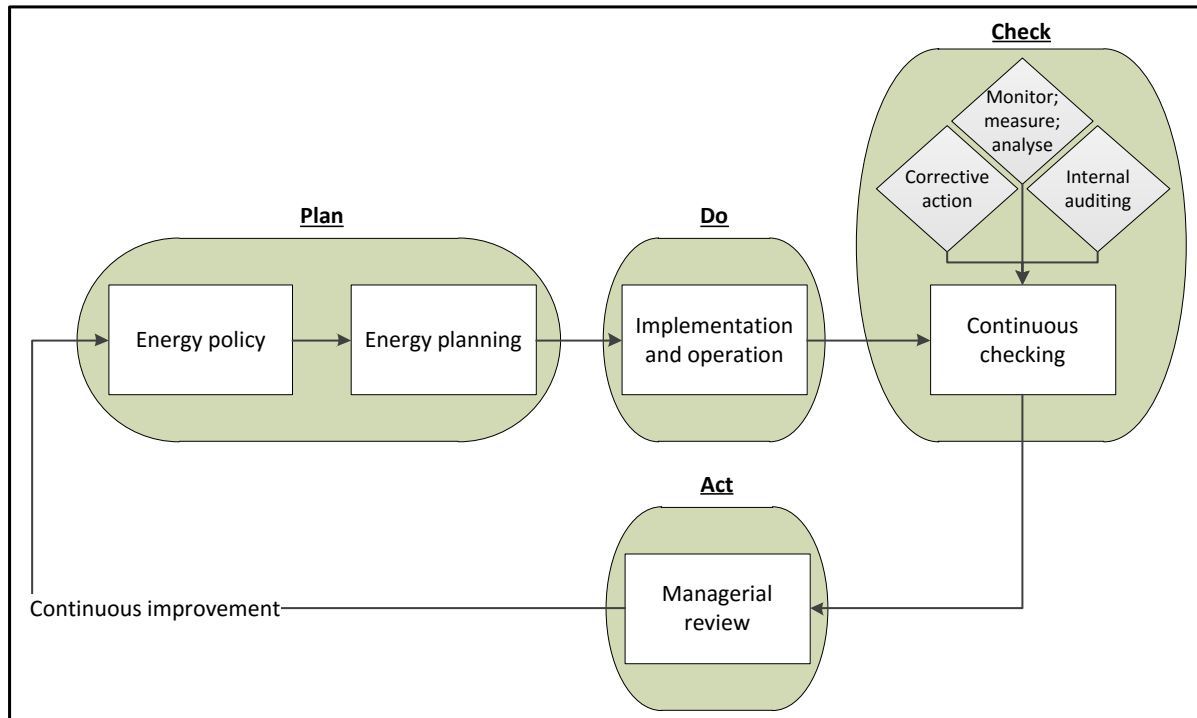


Figure 7: ISO 50001 framework (adapted from [26] and [28])

2.4.2. PLAN

From Figure 7 it is seen that the “Plan” step includes “Energy policy” and “Energy planning”. This entails establishing an energy management system by documenting the energy policy of the equipment included in the system. The energy planning will include investigating the equipment included and ensuring that its operation is understood. This will include evaluating the performance of equipment, and investigating from literature what the ideal performance would be. The organisation can then set targets and benchmarks for the desired performance of the equipment and identify performance indicators [26], [41].

The planning will further require the organisation to improve awareness of energy management in the organisation among all parties. The employees on all levels of the company should be aware of the policy and start implementing a culture of energy awareness. It will be ideal to have an appointed energy manager in the organisation, and establish communication channels for energy ideas originating from lower level employees. A system should also be set in place for processing ideas and determining whether they are viable to

further investigate their implementation. This step can be done from within the organisation, or by using consultants who specialise in energy management [26], [41].

During the original planning phase, all legal requirements should also be attended to. This will include ensuring that all paperwork is in place for ISO 50001 certification and that the energy policy does not violate any safety regulations. The responsibilities of different parties involved in the implementation of the system also have to be stipulated to prevent future disputes. Management should clearly state their involvement in the system and commit to improving the energy performance of the organisation.

2.4.3. DO

The next step in the approach is to practically implement the planned system, which is referred to as the “Do” part of the PDCA cycle. From Figure 7 it is seen that this includes “*Implementation and operation*”. This step would include turning the plan into a reality, and documenting the performance of the equipment. Where it is relevant, additional equipment and measuring instruments must be installed to ensure that the correct data is recorded. This will also include calibrating relevant meters to ensure that all regulations are met. Communication between all parties must be established, and the operations affecting energy performance must be monitored [26], [41].

2.4.4. CHECK

From Figure 7, the “Check” part of the PDCA approach requires “*Continuous checks*”. Checking includes monitoring the implementation of the system, measuring the performance, and analysing these measurements. This can be done by using a reporting system, where the targets and benchmarks set during the “Plan” phase are compared with the actual performance of equipment. These reports should be of such a nature that they can easily be interpreted from a managerial point of view, while simultaneously providing feedback to operators about their performance over the reporting period.

The reporting system should also make it possible to identify nonconformities in the process – both from a legal and an energy management point of view. If there are operations not conforming to the stated energy policy or meters that are not recording accurate data, the matter should be corrected and preventative action has to be taken to ensure that it does not happen again. This phase in the approach will thus also serve as a continuous internal audit of the energy management system. By continuously monitoring performance, problems can be identified early and rectified accordingly. The main outcome of this study is developing an automated reporting system, and focus will be placed on this step. Aspects of the reporting system will, however, be visible in all steps of the PDCA approach.

2.4.5. ACT

The “Act” phase in the approach includes “*Managerial review*”, which has “*Continuous improvement*” as a result, as illustrated in Figure 7. This implies that during this step the performance of the energy management system must be reviewed regularly by management. The reports generated during the “*Check*” phase will be used and management can compare the actual performance with the targets and benchmarks that were set during the “*Plan*” phase. The management will then react to the performance by adapting the targets accordingly. The new targets will set the bar higher and ensure that the energy performance of the plant does not stagnate.

2.5. CEMENT PLANT ENERGY MANAGEMENT

2.5.1. RISKS AND OPPORTUNITIES MOTIVATING ENERGY MANAGEMENT

Carbon tax

The South African government is motivating improved energy management by implementing certain regulations. Some of these regulations can be considered as potential risks from industry’s point of view, while others can be seen as opportunities to benefit even more from improved savings. One identified risk that can have possible repercussions in the future is the possible implementation of the suggested carbon tax policy that should have been implemented by mid-2016 [42], [43]. The initial suggested implementation date was scheduled for January 2015, but it was moved to mid-2016 early in 2014 [42].

From the suggestion in the discussion paper that was released by the National Treasury in 2010 [43], cement plants will have to pay tax for using fossil fuels such as coal. Additionally, it is also expected that electricity prices will rise due to carbon taxes that Eskom has to cover for their coal-driven power stations. A further suggestion is that industries will also be taxed on their energy outputs, such as electricity and transport fuels [42]. This further motivates savings on electrical energy as it is expected that the electricity price would increase drastically with the implementation of such an Act.

Even though this policy has not yet officially been implemented, there is a risk for companies being liable for such taxes in the future. By implementing an energy management system and reducing energy consumption, the amount that may be payable due to carbon tax will be reduced. An energy management system can also assist in quantifying the risk and possible liability, which will enable a company to plan ahead and include it in the budget. According to Kline [44], the CO₂ combustion of a cement plant depends on the system efficiency, which in

turn depends mainly on the technology used on the plant. This serves as further motivation for improving the energy management of older cement plants.

Kline [44] further indicates that the quantity of limestone used in the clinker is a main factor that determines the CO₂ levels of the calcination process. It is suggested that the CO₂ emissions can be reduced by using alternative sources of calcium oxide; for example, slag, fly ash or bottom ash. The quality of the cement, however, still has to be considered and should not be compromised in the process. Kline [44] states that alternative methods for reducing CO₂ emissions include improving fuel efficiency, using biogenic fuels or substituting clinker. The energy management system developed in this study thus addresses one of these methods.

Section 12L tax deduction

On the other hand, implementing an energy management system can also assist in identifying opportunities such as possible claims for Section 12L tax deductions. This refers to Section 12L of the Income Tax Act, 1962 [45], which aims to encourage the efficient use of energy in the industry. Section 12L is thus seen as the opposite of the proposed carbon tax policy, where companies can claim deductions from their taxes by proving verifiable energy savings. The Act stipulates that a company can apply for a 45 c/kWh tax deduction if they can prove that quantifiable energy savings were achieved by implementing an energy efficiency intervention [45].

The energy savings have to comply with the Section 12L Regulation; be acceptable by the SANS 50010 measurement and verification standard; and be an accurate and conservative reflection of the actual energy efficiency savings [45]. In preparation of Section 12L compliance, a plant will have to ensure that certain documentation is in place. The basic checklist for Section 12L documentation includes:

- Official documentation verifying the company's tax number;
- Official documentation verifying the beginning of the financial year;
- A list of energy saving initiatives – preferably including their performance;
- Basic production and energy layouts with the boundaries of the tax entity indicated;
- Layout of data traceability, including calibration certificates for all relevant meters;
- Quantification of concurrent projects (funded projects that need to be excluded from the investigation), including the necessary documentation.

Not only will an energy management system improve the opportunities for a Section 12L tax deduction, but it will also assist with the compliance thereof. An energy management system

based on ISO 50001 will ensure that all of the documentation is in place for Section 12L compliance. The system will also assist in identifying issues; for example, meters that need to be calibrated for the company to comply with measurement and verification standards. The continuous reporting aspect of the energy management system will ensure that all of the required data to prove that a Section 12L tax deduction is viable is available and on record.

2.5.2. GENERAL ENERGY MANAGEMENT METHODS

There are already several energy and cost saving projects that are implemented on cement plants internationally, some of which are listed by Madloul [30]. The saving measures listed by Madloul [30] focus mainly on upgrading existing equipment to improve the efficiency of the cement manufacturing process. These improvements to equipment are extremely important, and fairly efficient in reducing the cost of cement manufacturing. However, such upgrades are usually only once-off events with long payback periods, while the system developed in this study focuses on continuous improvement. This continuous improvement will be achieved by using ISO 50001 as discussed in the previous section.

The developed system will include benchmarking equipment and monitoring performance to ensure that it operates satisfactorily. From this benchmarking it will be possible to monitor equipment to decide whether it is necessary to replace the equipment. Such replacements or upgrades will require in-depth research to decide on the relevant technology, which is beyond the scope of this study. Some generic improvements mentioned by Madloul [30], which should be considered by cement plants and have relatively short payback periods, are listed below. An energy audit before system implementation will assist in identifying basic upgrades that can improve the energy efficiency of the plant.

- Changing to dry-process raw meal blending (if wet process is currently used);
- Adding adjustable speed drives to kilns' induced draught fans;
- Installing or upgrading a preheater and precalciner for a kiln, or increasing the number of preheating stages;
- Ensuring that the motors and drives of finishing mills are of high efficiency;
- Installing variable speed drives on general motors on the plant; and/or
- Replacing inefficient lighting on the plant with light-emitting diodes and automatic sensors.

Research on international energy management systems in the cement industry done by Serraino [46] lists the benefits of implementing operational changes to achieve energy cost savings. It is indicated that previous energy management strategies was based on the European standard EN 16001, but that the standard was since replaced by ISO 50001:2011.

Serraino [46] specifies that ISO 50001 is recognised as the best practice in energy management and that it is applicable to any kind of industry [46]. This study will thus focus on implementing a system for cement plant energy management based on ISO 50001 that brings into consideration the unique circumstances of the South African electrical energy supply environment.

2.5.3. DSM POSSIBILITIES FOR SOUTH AFRICAN CEMENT PLANTS

In South Africa specifically, ample emphasis has been placed on improved energy efficiency over the past few years. This led to several initiatives to be implemented in all industries, with great focus on demand side management (DSM). DSM aims to reduce the energy consumption on the consumer side rather than constructing more power stations. It thus promotes using less energy rather than providing more. This concept has also been the motivation behind several studies, which aimed to improve the implementation of DSM projects. Some of the relevant studies are discussed in the remainder of this subsection.

A study for the possibilities of DSM projects on cement plants in South Africa was done by Jordaan [47] in 2005. It was proven by this research that load shifting is possible on the raw mills of a cement plant by using the raw meal silos and ensuring that the minimum required level of raw meal is maintained. This includes production planning and creating awareness of the Eskom TOU tariffs among plant personnel. The raw mills could thus be operated in the less expensive off-peak and standard periods, rather than in the peak periods of the day during which electricity is more expensive (based on a Megaflex cost structure) [47].

As a conclusion to Jordaan's [47] study, it was pointed out that there was possible future work to investigate the possibility of load shifting on other components on a cement plant as well. This led to the new simulation model that was developed by Venter [48] in 2008. The simulation model proved that load shifting was also possible on the finishing mills of cement plants as long as the minimum required levels were maintained on a daily basis. Venter's [48] research indicated that with proper planning of maintenance stops and cement demands, the finishing mills could be switched off during peak periods.

The above two studies inspired the work of Lidbetter [25] in 2010. This study consisted of several pilot studies of raw mills and finishing mills on South African cement plants. Simulations were done to determine the load-shifting possibilities by planning production ahead for a 31-day period. However, Maneschijn [37] later indicated that the simulation models lost their resolution by planning so far ahead, and risked having cement levels fall below the minimum required silo level. Maneschijn [37] indicated through this research that the updated

simulation model developed by Swanepoel [49] in 2012 could be used more accurately to determine the level of the cement available if load shifting was to be done.

Swanepoel's [49] simulation model can be used to indicate cement silo levels at different time periods if load shifting is to be done. The simulation time periods stretch up to a year and also take maintenance, silo levels and predicted daily cement sales into account. This model also used the PDCA approach as a guideline. Maneschijn [37] used Swanepoel's [49] simulation model to implement an automated optimisation model on cement plants and display the planned load-shifting schedule to plant operators. The idea of this implementation was to indicate to control room personnel when it was safe to shift load, and to improve awareness and knowledge regarding TOU tariffs.

2.5.4. MONITORING OF CEMENT PLANT EQUIPMENT

The effect that DSM projects has on South African cement factories was investigated by Spangenberg [50] in 2015. This research indicated that the implemented DSM projects (specifically load shifting on raw mills and finishing mills) on nine South African cement plants did not negatively affect the daily sales and production targets, or the quality of the cement produced. The savings achieved from the projects were also proven to be sustainable as long as the concept of load shifting was adopted and awareness among employees was maintained.

Spangenberg [50] did, however, recommend that further research be done on the effect that load shifting has on electrical and mechanical equipment. The research done was over a too short period to be able to declare that without a doubt load shifting has no negative effect on equipment. This contributes to the concept of an energy management system that also monitors equipment and its operational performance. The developed system will thus also focus on monitoring the performance of the mills, and ensuring that damage is detected as soon as possible.

2.5.5. MAINTAINING DSM PROJECT PERFORMANCE

In the research done by Groenewald [51] in 2015, a strategy for an energy services company (ESCO) performing maintenance on implemented DSM projects in various industries was developed. His strategy was motivated by De Kock's [52] research in 2007 that indicated that South African mines that had an ESCo performing maintenance on their implemented DSM projects achieved 10% more savings on average. Groenewald's [51] research, however, indicated that applying performance-centred maintenance on DSM projects resulted in an average increase of about 64% in electricity cost savings generated by the projects.

This research indicates the benefits of performing maintenance on implemented DSM projects. The system developed in this study will thus also incorporate maintenance of existing energy saving projects, and resultantly contribute to ensuring that sustainable savings are achieved. By reporting on the energy saving performance of a cement plant on a regular basis, a high level of awareness will be maintained among plant personnel. The operators and cement plant management will also be able to see when performance declines and will be able to react swiftly.

2.5.6. SUSTAINABLE ENERGY SAVINGS THROUGH ISO STANDARDS

In 2014, Van Heerden [53] did research on how the implementation of ISO standards could improve the sustainability of savings achieved from implemented DSM projects. The research specifically considered the integration of ISO 90001 (quality management), ISO 14001 (environmental management) and ISO 50001 (energy management). These standards were combined to develop an energy management system that would improve sustainable energy savings. The developed system also used the PDCA approach, as discussed in Section 2.4, but specifically on DSM projects.

This research thus proved that implementing the PDCA approach can provide sustainable energy savings. Van Heerden [53] reported that the main benefits of the research were electricity consumption savings, and resultantly also electricity cost savings. Seeing as the purpose of this study is improving the profitability of a cement plant by managing its energy consumption, Van Heerden's [53] research motivates that this would be possible by using the PDCA approach as a guideline.

Further studies indicated that savings of over 20% are possible by implementing an energy management system such as ISO 50001 [29]. The research did, however, also indicate that it is important to have proper assistance, which includes experienced consultants, as well as the appropriate hardware and software [29]. This serves as motivation for using an ESCo when implementing an energy management system. The system developed from this study is based on the use of an external ESCo to assist with the implementation thereof.

Further research by Ottermann [7] also describes the opportunities for an energy management system in the South African cement industry. The study specifically refers to a South African cement manufacturing company implementing ISO 50001, where the target of the implementation was improving operational efficiency, investigating alternative energy sources and achieving energy cost stability. A further drive behind the investigation was to identify energy saving options in the cement industry [7]. Ottermann's [7] research thus also motivates implementing an energy management system that uses ISO 50001 as a basis.

2.5.7. CURRENT CEMENT PLANT ENERGY MANAGEMENT METHODS

Qualitative studies in the form of questionnaires were compiled and used as the basis of discussions with personnel involved with different cement plants. The studies are presented in Appendix C, and will also be referenced as part of the verification and validation of the study in the following chapters. Based on these discussions, the current methods of energy management at cement plants were evaluated and areas that required possible improvements were identified. The methods used before system implementation are assumed to be similar for other cement plants as these studies were based on three different plants.

The studies indicate that the plants have no form of feedback on the total plant energy performance, and that it is thus not possible to evaluate areas that require improvement. Even though the necessary metering was installed and systems to log the data were in place, there was no form of feedback or reporting to indicate and evaluate historical performance. The meters were thus not used to their full potential, and could not be used by plant personnel to make important decisions regarding operations. Awareness among plant personnel regarding energy cost efficiency was already in place and operators were aware of TOU tariffs and periods.

The implementation of DSM projects assisted with load shifting, which was done on a daily basis. The ESCo that implemented the projects also provided the plant with DSM performance reports, as discussed in more detail in Section 3.2.6 and Appendix D. These reports, however, only reported on the evening load-shifting performance of the specific components, and not on the energy performance of the entire plant. The DSM reports neither identified additional energy cost saving opportunities, nor adapted the baseline based on previous performance.

The “*supervisory control and data acquisition*” (SCADA) set-up in the control room of the plant was also available to monitor real-time energy usage. The main missing aspect of the SCADA system is that it merely monitors the real-time power usage of the major components for irregularities in operating performance. This system thus partially uses benchmarked parameters to ensure that the components operate according to desired specifications. The system is, however, not able to reflect the performance of equipment in retrospect, or to identify opportunities for improvement.

Lastly, monthly electricity bills could also be used to classify the electricity consumption of the plant. This, however, only made it possible to compare the total monthly usage and the usage in different TOU periods with previous months. An increase in usage during peak time, for example, could not be traced to a specific component or event, even though it did indicate that there was a change in operations and an opportunity for improvement. The current energy

management feedback systems that are in place are thus not sufficient to identify opportunities for improvement. These methods do not provide sufficient feedback, and cannot be used to indicate areas for improvement.

2.5.8. ENERGY PERFORMANCE FEEDBACK MECHANISMS

As seen from the discussions above, current methods for energy performance feedback include electricity bills, SCADA systems and DSM performance reports. The problems with using electricity bills and SCADA systems for energy performance feedback were discussed in the previous subsection. The problem with DSM performance reports was identified by Goosen [54] in an investigation of the feedback provided to mines on the performance of their compressed air DSM projects. The main issue that was identified was that data was obtained and reports generated manually, which led to a delay and a large number of man-hours to be invested in the feedback process [54].

Goosen [54] thus identified the need for an automatic feedback reporting system for mining compressed air DSM projects. This included automatically collecting, processing and storing data, as well as generating reports on a daily basis. It was found that the automatic feedback saved a great deal of man-hours and provided the mine with quicker feedback. This in turn was reported to have a positive effect on the sustainability of DSM project savings. The study also used the PDCA approach, with specific focus on improving the “*Check*” and “*Act*” steps [54].

The study done by Goosen [54] thus indicated that the PDCA approach of ISO 50001 is effective in providing feedback on DSM project performance. It was also proven that automatic reporting systems are much more effective and reliable than manual reporting. It was, however, pointed out that the study had potential for expansion to other industries and types of projects. It would thus be effective to use the same concept of an automatic energy performance feedback system, but to implement it on an entire plant, rather than only a single aspect, such as a DSM project.

A study performed by Boshoff [55] in 2015 proposed a load management implementation and evaluation strategy for DSM projects on the finishing mills of cement plants. The study obtained data from the SCADA system of the plant and automatically processed it to reports focusing on feedback regarding DSM project performance. The study considered electrical load analysis, production load analysis, energy consumption analysis and cost analysis of the plants. The reporting system that he developed used set baselines to identify DSM performance potential that was missed [55]. The main shortfall of the study was thus that it

focused only on DSM project performance and load management on finishing mills, and not on the performance of the entire plant.

Furthermore, Du Plessis [56] developed a supervisory system that provided feedback to mines on the performance of the energy management systems that were implemented on their sites as part of the DSM project implementation. The purpose of the study was to assist with maintaining DSM performance by providing the mines with graphical and document-based reports. The system also used ISO 50001 as a guideline. The study concluded that such a feedback system made it possible to maintain DSM savings and energy management systems implemented by an ESCo [56]. The study thus proved that energy performance feedback reports are effective in obtaining savings on a mine, with specific focus on older DSM projects.

These reporting methods thus focused mainly on DSM project performance. The qualities of these studies can be combined to develop an energy management system with an effective reporting and feedback aspect. These studies proved that it is possible to maintain energy cost savings by means of feedback methods. Two of the studies focused on systems implemented on mines, while the study by Boshoff [55] considered DSM projects on cement plant finishing mills. These feedback systems, however, do not report on the performance of the entire plant, but focused on maintaining DSM projects. The focus is also not on achieving cost savings by identifying opportunities, but rather on maintaining previously achieved performance.

2.6. CONCLUSION

This chapter served as the literature study of this dissertation, which presented the reader with the necessary basic knowledge required to understand the development of the energy management system. The chapter started by describing the cement manufacturing process by highlighting the main sections of a typical cement plant. These are also the sections that will be monitored and reported on in the developed energy management system. The main energy sources used on a cement plant were also discussed as part of the overview. It was explained that the developed system will focus on electrical energy rather than energy obtained from coal.

Benchmarking some of the equipment used on a cement plant was also done from literature. This will be used to assist in setting targets for the equipment performance as part of the “Plan” phase of the PDCA approach that was discussed. This approach will form the foundation for the development of the system in the following chapter. This will also serve as the verification of the system. Further motivation for this study was provided by briefly discussing the risk of paying for carbon tax in the future, and the opportunity that arises from Section 12L of the Income Tax Act.

Previous studies involving energy management on cement plants and ISO 50001 was included in the discussion. This also included a summary of qualitative studies among personnel involved with energy management on South African cement plants regarding the current methods used to monitor electrical energy usage. From these discussions it was seen that feedback is mainly provided on the performance of DSM projects. There is thus an opportunity to develop a reporting system that provides feedback on the performance of the entire plant, and that identifies opportunities for energy cost savings rather than maintaining previously achieved DSM savings.

Results from the previous studies, as well as the requirements for ISO 50001 compliance will be referred to during the development of the energy management system in Chapter 3. The development of the system will be done in the form of a methodology, where the end result is the energy management system. This system will then be implemented on a South African cement plant in Chapter 4.

Chapter 3: Methodology

This chapter places focus on the development of the energy management system by using the research done in the previous chapter. The methods used for developing each step in the system and how they will be implemented on a cement plant will be discussed. Throughout the discussion of the steps, the relevance thereof to ISO 50001 will be stated. This also serves as the main verification of the methodology. A self-assessment checklist for ISO 50001 certification will also be evaluated and compared with the system by using Appendix E, which serves as further verification. Additional verification will be done by again considering the qualitative studies among personnel involved with cement plant energy management. The main focus of the methodology is the reporting aspect, which can also be considered as the main outcome of the study.

3. DEVELOPMENT OF AN ENERGY MANAGEMENT SYSTEM

3.1. INTRODUCTION

This chapter describes the process that was used to develop the energy management system for improving the profitability of cement plants. The chapter thus serves as the methodology of the study. As mentioned in Section 2.4, the development of the system will be based on the ISO 50001 framework as well as previous research done on energy management. Data from different sources will be captured by the system and translated into valuable information and graphs. These indicators can then be used by plant personnel in the form of weekly and monthly reports to obtain improved energy cost savings, while still monitoring the production aspects of the plant's performance.

Plant personnel will be able to use the reports to investigate the overall electrical energy performance of the entire plant, as well as detail analyses of each section. Energy performance indicators (EnPIs) will be identified for the equipment on the plant, which will be monitored and measured against continuously adapting targets. This will make it possible for the plant to identify additional saving opportunities as well as potential risks. The relevant studies used in the development of the system were discussed in Chapter 2 as part of the literature study. These studies, along with ISO 50001, will be referenced throughout this chapter as verification of the system.

Further verification of the strategy will be done by using a self-assessment checklist. The checklist is discussed in Appendix E and serves as an evaluation of how an institution contributes toward ISO 50001 compliance. Additional tasks for achieving compliance will thus also be derived from this checklist. A final method of verification will be to use qualitative studies among personnel involved with cement plants. This will make it possible to determine what the effect of the system can be in practice, and how the methodology can be developed further to improve performance.

The system is presented in the form of a flow diagram in Figure 8. The system consists of several steps that will assist with improving the profitability of cement plants. These steps are grouped according to the ISO 50001 framework (presented in Section 2.4) in order to indicate compliance. Each of the steps is discussed in detail in the following section along with its relevance to the system, and how it will be implemented in the case study presented in Chapter 4. The core focus of the system is the reporting aspect that was developed, as indicated in the Step 5. All of the other steps contribute to this step in the system.

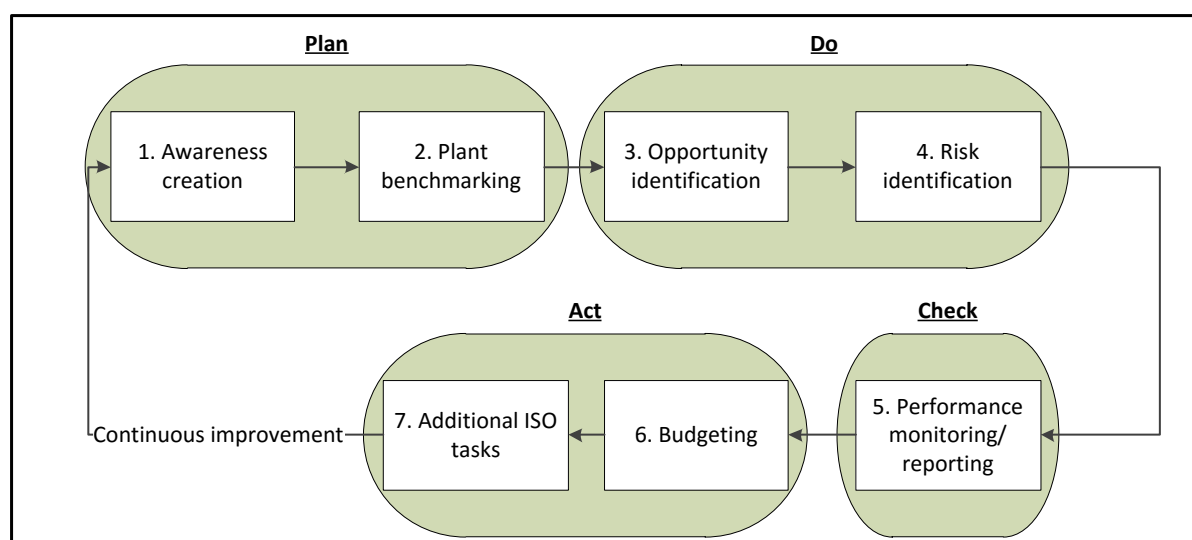


Figure 8: Energy management system

3.2. ENERGY MANAGEMENT SYSTEM

3.2.1. PREAMBLE

This section discusses the development of the energy management system as presented in Figure 8. As previously mentioned, the main focus of the discussion will be the development of an automated reporting system. This is the most measurable outcome of the system and is considered as the main contribution in enabling a cement plant to manage its electrical energy more efficiently. It is done by integrating the report into the complete system, and resultantly monitoring the operations of the plant. Improvements on the energy performance are then based on what the report indicated. The report will thus also be used to validate the effect of the system in the next chapter as it is the most measurable outcome.

The steps described in the system are designed to build up to developing the reporting system by using the PDCA approach. It is important to note that this system is not a direct implementation of ISO 50001, but rather an alternative system that is based thereon, which will contribute towards obtaining ISO 50001 certification. This section thus focuses on discussing each step in Figure 8 individually, stating the relevance of the step and verifying its use from literature discussed in Chapter 2. Step 7 of the system (*Additional ISO tasks*) is not considered as part of the scope of this study. It describes additional requirements for achieving ISO 50001 certification, which will be discussed as part of Section 3.3.

The basic process that will be followed in terms of data handling is as presented in Figure 9. The energy management system will capture and process raw data regarding the electrical energy consumption of the plant, as well as the production performance of the plant equipment. The processing of this data will entail translating the raw data into valuable

information and graphs, and compiling reports that contain this information. The reports will then be distributed automatically to the plant personnel, who can make decisions regarding plant operations based on the information provided. Correct use of the information provided in the report should lead to energy cost savings, as indicated in Figure 9.

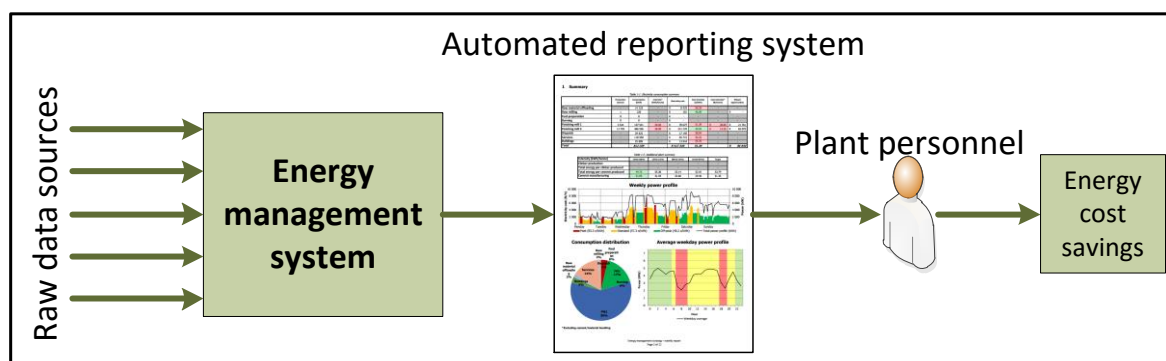


Figure 9: Basic data process

3.2.2. AWARENESS CREATION

The first step in the energy management system of Figure 8 is to create awareness surrounding efficient energy usage and the motivation behind it on different operational levels of the plant. This is categorised as part of the “Plan” step of the ISO 50001 framework. The first step towards creating awareness among all employees of the plant is for the management to commit to energy savings and to set their goals for the energy management system. The relevance of this step is verified by the “Energy policy” aspect in the ISO 50001 framework presented in Figure 7, and it will achieve the requirement of “Developing a policy for improved efficiency of energy usage”, as stated in Section 2.4.

After creating awareness under higher management by declaring an energy policy, it is also necessary to involve lower level employees in the awareness process as they are responsible for implementing the energy saving measures practically. Informing the relevant personnel about the energy policy stated by management will serve as a first step towards creating awareness. This will, however, not yet assist them in achieving energy savings. By implementing a system that these employees can use to suggest energy saving initiatives, they will feel more involved and considered in the movement. This system will provide a communication channel between operators and management for ideas to be evaluated.

A suggestion for future work is to develop a system by creating a web interface where employees can log in with unique credentials and fill in their suggestions. The ideas can then be categorised and distributed to the relevant people who will further assess them. Improving and implementing this concept is recommended as a possible future study. This will also

contribute to the ISO 50001 requirement of “continuous improvement of the energy management strategy”. As pointed out by Groenewald [51], the maintenance of implemented DSM projects is also critical. Daily DSM reports that are sent to the plant to report on the performance of the DSM project also improve awareness among personnel.

Basic awareness to remind operators of the TOU billing periods will be enhanced by including a TOU chart, similar to the one presented in Figure 10, in the control room. This will ensure that operators are aware of the more expensive peak and standard billing periods, and assist with interpreting the reports that they receive. Further awareness will be established by implementing the mill scheduler developed by Swanepoel [49] and Maneschijn [37] in the control rooms of cement plants. The mill scheduler enables cement plants to plan their production around the TOU hours, as discussed in Section 2.5.3. This will enable the operators to know when it is safe to switch off the mills without negatively influencing the production of the plant.

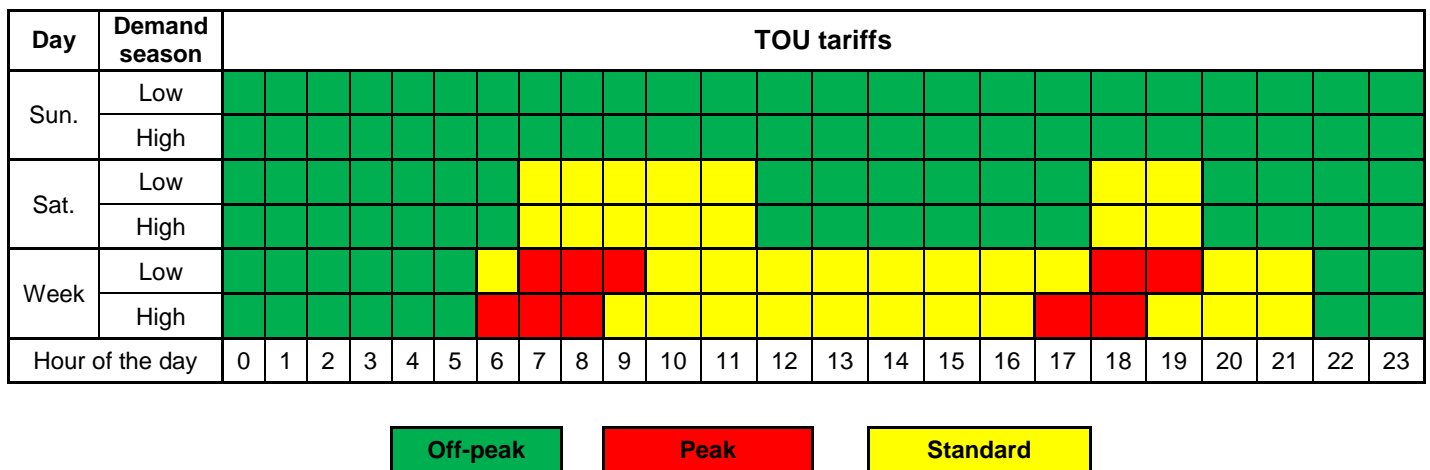


Figure 10: Eskom TOU billing periods

The final form of creating awareness on all levels of employees is by sending feedback reports. These reports will be developed in such a way that they provide feedback that can be interpreted by different levels of employees. The reports will be automatically sent out on a weekly basis. There will furthermore also be a monthly report. The reports will be continuously developed and improved with inputs from the cement plant personnel and adapting performance. This will enable personnel to interpret the performance of the energy management system and improve it continuously.

3.2.3. PLANT BENCHMARKING

The plant benchmarking is also categorised as part of the “Plan” step of the ISO 50001 framework. This step contributes to achieving the requirement of “setting targets to enable meeting the policy goals”, listed in Section 2.4. Benchmarking will be used to assist

in setting the original targets for the performance of equipment on the plant. This is done by comparing the expected performance from literature (Section 2.3) with the historical performance of the equipment, and setting a target that works towards the benchmarked value. These values will be adapted again in the “Act” phase, and compared with the benchmarked values when revisiting this step in the cycle.

Different methods of equipment benchmarking can be done as described briefly in Section 2.3.6. As this entails an extensive study, it is proposed as suggested future work. For this study, the initial benchmarking will be done based on three months’ historical performance, and the benchmarked values of Section 2.3. The values will then be updated continually based on the past performance, and it will be indicated in the reports whether or not targets have been reached. The targets will then also be adapted accordingly, considering whether the targets were reachable or not. Details on how the benchmarks are adapted (budgeted) are discussed in Section 3.2.7. It is important to investigate the sections on the plant and to know what equipment is used.

Investigate sections on a cement plant

A large part of developing the reporting system is investigating the systems on a cement plant. The main part of investigating these sections was done as part of the literature study in Section 2.2. It mainly consists of gaining an understanding of the cement manufacturing process and defining which equipment is included in each section. The sections that were investigated as part of the literature study are also the sections that will be used when compiling the report. The investigation of the different sections also includes the benchmarking of equipment compared with international standards. This was done in Section 2.3, and will assist in evaluating the performance of the equipment on the plant by setting targets for its performance.

After gaining an understanding of the cement plant, the procedures and meters used to measure and log the necessary data have to be identified. It might be necessary to analyse the electrical layouts of the specific plant to understand how electrical energy is distributed. This will also assist in ensuring that a system is not added multiple times. The meters are then grouped according to the different sections and documented for future use. This documentation will also assist with Section 12L investigations. The grouping of meters provides the ideal platform to identify additional meters that need to be installed. More meters make it possible to improve the breakdown of the sections by splitting them into smaller parts. The added total of the meters can also be used to verify the electricity bills.

A typical breakdown of the sections on a cement plant is presented in Table 7. This table is based on Section 2.2, where the different sections of a cement plant were analysed. Table 7 can be used as a checklist when determining whether all of the energy-consuming assets on the plant are being logged. The table is generic, and not all of the components will necessarily be applicable to all plants. The breakdown is, however, a basic framework from where it can be determined whether the plant contains a specific component or not. The grouping of meters is typically discussed with someone at the plant who has knowledge of the meters, in which case Table 7 can be used as a platform.

Table 7: Typical breakdown of cement plant sections

Section	Component
Raw material preparation	Raw material offloading
	Quarry
	Crushing
Raw milling	Main motor
	Auxiliaries
	Material handling
Fuel preparation	Main motor
	Auxiliaries
	Material handling
Burning	Main motor
	Auxiliaries
	Material handling
Finishing milling	Main motor
	Auxiliaries
	Cement handling
Dispatch	Blending plant
	Packer
	Palletiser
	Bulk loading
	Material handling
Services	Compressors
	Lighting
	Cranes
Buildings	Workshops
	Main office
	Laboratory
	Stores
	Village housing
	Hostel

This breakdown will differ depending on what is measured; what sections and components the plant has; and how the plant personnel prefer to group the information. It is preferable that the meters logging the electrical energy usage do so in kilowatt-hour (kWh) consumed in a period, rather than just the instantaneous kilowatt (kW) at a specific time. For TOU purposes, it would also be preferable that the data is logged at least hourly. This will make it possible to determine how well load is being shifted into less expensive time periods, as well as indicate exactly when the load could have been shifted more effectively. Lower resolution data (for example daily totals) will not be sufficient for such trends. Calculating the cost of electrical energy usage will also not be possible with such a resolution.

This part of the report contributes to both the “*Plan*” and “*Do*” phases of the ISO 50001 framework, as presented in Figure 7. It contributes to the “*energy planning*” part of the “*Plan*” phase by breaking the energy-consuming assets down, and ensuring that they are measured and logged sufficiently. The “*Implementation and operation*” part of the “*Do*” phase is also contributed to, as the first step towards analysing a specific plant and implementing the energy management system is to determine what sections it has and what is measured. The groundwork for the “*Setting targets to enable meeting the policy goals*” requirement is also laid as the equipment of a cement plant is analysed, benchmarked, and can now effectively be budgeted for.

3.2.4. OPPORTUNITY IDENTIFICATION

As part of this study, the main aspects of the “*Do*” phase of the ISO 50001 framework are identifying opportunities and risks. This is mainly because this study is based on the automated reporting system, where the plant is originally evaluated to establish the state thereof, from where opportunities for improvement are identified. A general opportunity, which does not directly originate from the report, is ensuring that all systems are in place for a potential Section 12L tax deduction, as described in Section 2.5.1.

In preparation of Section 12L compliance, a plant will have to ensure that certain documentation is in place. As part of the energy management system, a central database for documentation storage will be created. This will enable the energy manager to check what documentation is missing, and then work on obtaining these documents. A checklist will be used to ensure that everything is in place for future claims and that energy efficiency initiatives are listed to be investigated for claims. The basic checklist for Section 12L documentation was discussed in Section 2.5.1. The developed weekly and monthly reports will also be stored in this database. Other opportunities identified in the report are discussed in the subsections that follow.

Identify largest energy consumers

The first step in using opportunities originating from the report is to identify the largest energy consumers on the plant. As soon as the different sections on the plant have been benchmarked and all of the relevant components are being measured, the energy consumption of the different sections can be compared. In order to monitor the energy usage of a section or component, it is necessary to identify effective measures by which the energy usage can be compared. This is done by choosing EnPIs [28].

In terms of identifying the largest energy consumers on the plant for the specific reporting period, the total electrical energy consumption for this period will be considered as part of a summary of the report. This summary will include a brief overview of the report as well as various EnPIs that can be used to determine which sections need to be considered in more detail. The summary will thus indicate the total electrical energy consumption (kWh) of the sections for the reporting period. The consumption will also be indicated in terms of the TOU billing periods, along with the cost for each component in each TOU period. If the tonnes produced are measured, the cost and consumption per tonne will also be indicated. An example of such a summary captured from the monthly report is presented in Figure 11.

<i>Monthly electricity consumption summary</i>						
	Consumption (kWh)	Peak (kWh)	Standard (kWh)	Off-peak (kWh)	Production (tonne)	Intensity* (kWh/tonne)
Raw material offloading	56 987	12 174	31 225	13 589	-	-
Raw milling	1 527	43	180	1 304	0	-
Fuel preparation	1	1	0	0	0	-
Burning	0	0	0	0	0	-
Finishing mill 1	299 279	18 065	105 302	175 911	7 159	41.80
Finishing mill 2	1 656 711	70 747	549 610	1 036 355	45 063	27.82
Dispatch	133 105	23 465	61 299	48 341	-	-
Services	432 196	68 370	179 308	184 517	-	-
Buildings	76 972	12 682	31 386	32 904	-	-
Total	2 656 779	205 547	958 310	1 492 922		

<i>Monthly electricity cost summary</i>							
	Electricity cost	Peak cost	Standard cost	Off-peak cost	Cost intensity (c/kWh)	Cost intensity* (R/tonne)	Missed opportunities
Raw material offloading	R 34 713	R 11 358	R 17 892	R 5 463	60.91	-	-
Raw milling	R 667	R 40	R 103	R 524	43.70	-	R -
Fuel preparation	R 1	R 1	R 0	R 0	93.30	-	-
Burning	R 0	R 0	R 0	R 0	-	-	-
Finishing mill 1	R 147 909	R 16 855	R 60 338	R 70 716	49.42	R 20.66	R 71 951
Finishing mill 2	R 797 548	R 66 006	R 314 926	R 416 615	48.14	R 13.39	R 119 968
Dispatch	R 76 450	R 21 893	R 35 124	R 19 433	57.44	-	-
Services	R 240 709	R 63 789	R 102 744	R 74 176	55.69	-	-
Buildings	R 43 044	R 11 832	R 17 984	R 13 227	55.92	-	-
Total	R 1 341 041	R 191 775	R 549 112	R 600 155	50.5		R 191 919

Figure 11: Example of summary tables from monthly report

In order to determine which sections have the largest electrical energy consumption, a pie chart indicating the percentage of energy consumption distribution will be included in the summary. For a typical cement plant, it is expected that the pie chart will look similar to the one presented in Figure 2 (Section 1.2.3). This will, however, differ for each plant depending on the components and sections on the plant. The pie chart can then be used to determine what the largest consumer of electrical energy on the plant is, whereafter the components will be considered in more detail. The largest consumers will be the most likely to have energy and cost saving opportunities.

This part of the energy management system contributes to all aspects of the PDCA approach as it assists with:

- Planning energy management;
- Identifying where possible savings can be achieved;
- It is part of the energy management implementation;
- It assists in checking the performance of the plant;
- The remainder of the summary page can be used to improve the energy management system.

The ISO 50001 requirements achieved by this part of the system include *“Improving decision-making about energy usage by analysing and interpreting the relevant data”*; *“Quantifying and measuring the results achieved”*; and *“Evaluating how well the policy is working”*.

Investigate systems to monitor energy consumption

After using the summary part of the report to identify the largest energy consumers and other concerns that might have been noted, the recipients of the report can consider a specific section in more detail. This complies with ISO 50001 by contributing to the *“Check”* phase in terms of continuously checking the energy performance of the plant. It also contributes to the *“Managerial review”* of the *“Act”* phase, as shown in Figure 7, by enabling management to review the energy performance of the plant and making decisions based thereon. The main requirement that this part of the system contributes to is *“Improving decision-making about energy usage by analysing and interpreting the relevant data”*.

The data included in the detail discussion of systems was carefully selected by compiling a draft report and discussing it with the cement plant personnel. Their inputs were used to determine what they would like to change in the report. Different sections contain slightly different information, based on what is available and measured. The detail summaries follow a standard template with a few alterations where necessary. The monthly and weekly reports

also differ slightly as the same information cannot necessarily be indicated for a longer period than for a shorter period.

The standard details for all of the sections contain basic breakdowns, namely, electricity cost; electricity consumption; production; missed opportunities; and various graphs depending on the reporting period and section.

Electricity cost

The first breakdown is electricity cost, where the c/kWh, R/t and total cost for the reporting period are presented along with the targets where relevant. An example of such a summary is presented in Figure 12, as captured from the monthly report.

Monthly electricity cost		
	<i>Actual</i>	<i>Target</i>
Average electricity rate	49.42	49.75 c/kWh
Cost intensity (<i>excl. cement handling</i>)	20.66	18.06 R/t
Total cost	R 147 909	

Figure 12: Electricity cost breakdown example

Electricity consumption

The total cost is also accompanied by a pie chart (referred to as the cost distribution) indicating the cost allocated to each TOU billing period. The relevant tariff for the specific plant is also included in the cost distribution graph. An example is presented in Figure 13. From this example it is seen that the largest portion of the electricity cost is for peak and standard hours. Improved load shifting of the relevant components will thus benefit the plant in this case.

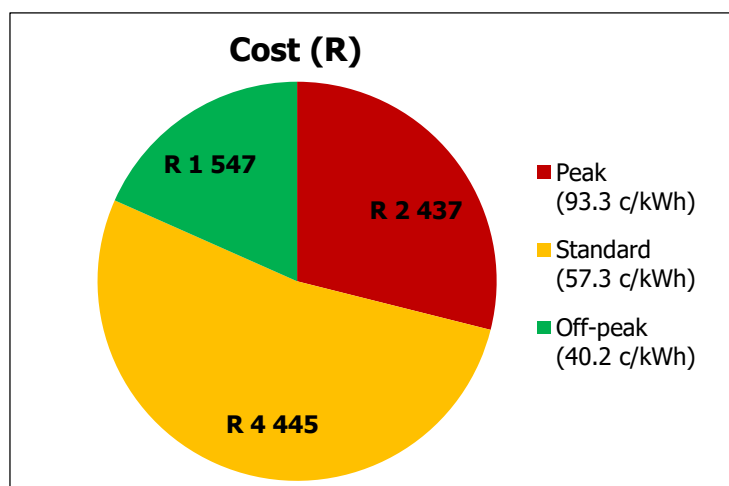


Figure 13: Total cost pie chart example

The next electricity consumption breakdown contains the total energy consumption for each component and the total energy consumption of the section. This breakdown is accompanied

by a stacked bar chart that indicates the consumption of the different components. In this chart, the auxiliary electricity consumption of the section is split between auxiliaries with motor, and auxiliaries without (w/o) motor. This is discussed later as part of the missed opportunities breakdown. An example of such a chart is presented in Figure 14.

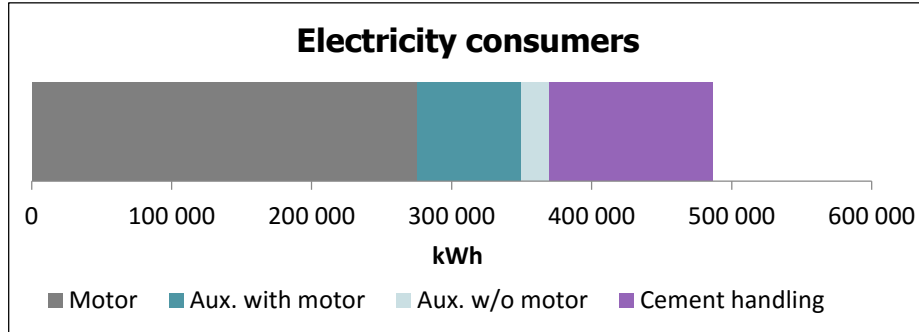


Figure 14: Electricity consumption breakdown chart example

The final part of this breakdown is a pie chart that indicates which percentage of the consumption was in each TOU billing period, as well as the percentage of unused hours for each billing period. This pie chart is referred to as a utilisation graph. The utilisation graph can alternatively be exchanged for a consumption distribution pie chart. This is mainly done for a section where load shifting is not a possibility, for example, buildings. The consumption distribution graph will simply indicate the distribution between the different TOU billing periods without indicating the unused hours for each period. An example of a utilisation pie chart is presented in Figure 15.

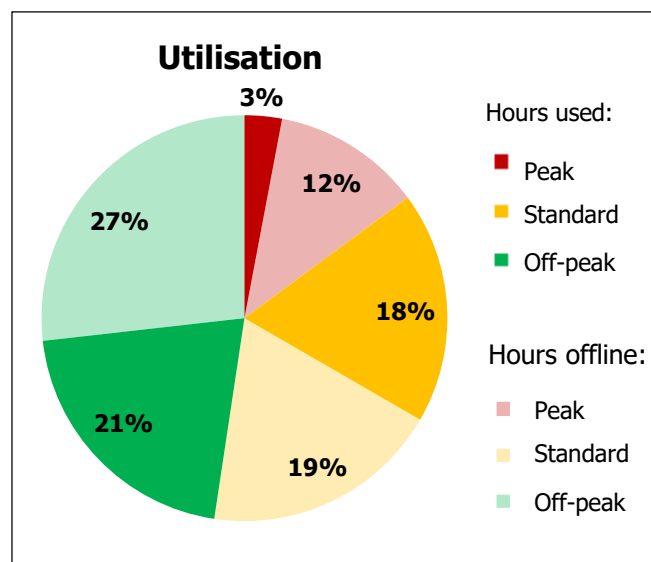


Figure 15: Utilisation chart example

Production

In terms of production, the monthly production breakdown firstly indicates the total production of the specific section. This production is then used to calculate certain EnPIs and indicate their targets. The first indicator is the t/h figure, which gives an indication of the production rate of the section. Secondly, the intensities (kWh/t) of the main motor and auxiliaries are calculated. Additional to this, the total production time of the reporting period is indicated along with the production hours as a percentage of the total available hours in the reporting period. The number of times that the section stopped during the reporting period is also indicated. An example of these production figures as captured from the monthly report is given in Figure 16.

Monthly production	<i>Product 1</i>		
	<i>Actual</i>	<i>Target</i>	
Total production	45 063	-	t
Average rate	116.74	114.50	t/h
Main motor intensity	20.47	17.29	kWh/t
Auxiliaries intensity	7.35	10.22	kWh/t
<i>Total</i>			
Production hours	386		h
Utilisation	51		%
Stoppages	28		

Figure 16: Production figures example

Missed opportunities

The missed opportunities (also referred to as possible savings) breakdown indicates the amount of money that could have been saved by improved energy management. This indicates where to investigate for possible cost saving opportunities by using better energy management, and can also be used as a way of measuring the improvement of the section from month to month. Missed opportunities are indicated in terms of South African rand, as the purpose of the energy management system is to improve profitability. Three different opportunities for improvement are identified through this breakdown, namely, possible TOU cost savings, intensity cost savings and auxiliary cost savings. An example of these figures as captured from the monthly report is given in Figure 17.

Missed opportunities			
TOU	Intensity	Auxiliaries	Total
R 79 961	R 39 473	R 534	R 119 968

Figure 17: Missed opportunity figures example

The missed opportunities due to TOU cost savings are based on the utilisation pie chart discussed in Figure 15, and basically consider the amount of money that could have been saved by improving the load shifting of the section. This is calculated by reallocating the operations during more expensive times of the day to less expensive timeslots, from where the potential savings are determined by comparing the ideal schedule with the actual cost. This is, however, calculated for an ideal situation where maintenance and demand for cement on different times during the reporting period are not taken into consideration. A method considering these factors will require more intensive research and regular feedback from plants regarding maintenance and demand schedules, and is recommended to be considered as a future study.

The potential intensity cost saving calculation uses the kWh/t target for each section and compares it with the actual performance. This is an indication of the amount of money that could have been saved if the equipment always operated according to the target. Each time the actual intensity is higher than the target (i.e. more energy is consumed than expected for a tonne of product to be produced), the difference is considered as a missed opportunity. This is an indication of how much money could have been saved if the equipment operated according to the target value. This calculation is accompanied by a graph in the weekly reports, which displays the periods during the week where targets were exceeded. An example of such a graph is shown in Figure 18.

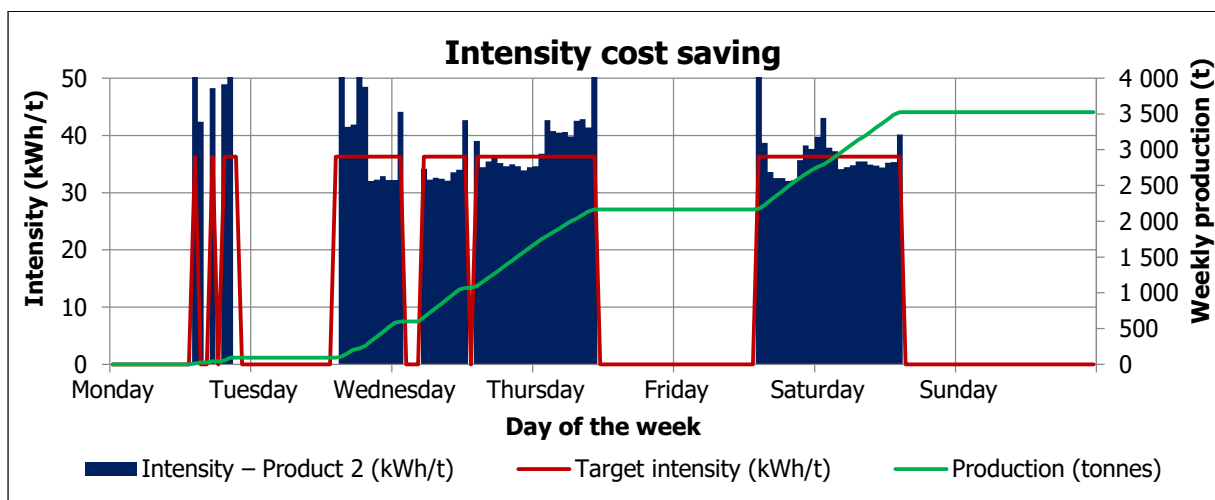


Figure 18: Intensity cost saving graph example

The final indicator of missed opportunities is in terms of auxiliary cost savings. This refers to the cost of electricity for auxiliaries that were used while the motor was not running. This is done by examining the electricity consumption of the main motor and its installed capacity, and determining a set point for when the motor is considered to be running. This is combined with an observation of the production rate at a specific time. If both the production rate and

the consumption of the motor are zero, then the auxiliaries that are still consuming electricity are identified as possible savings. This serves as an indication of how well the procedures for shutdowns are implemented.

Additional graphs (depending on the reporting period and section)

An additional graph that is also included in the detailed discussion of the sections is a graph indicating the electricity cost and the power consumption. An example of such a graph is given in Figure 19. This indicates how the use of electrical energy in more expensive TOU billing periods influences the cost of electricity.

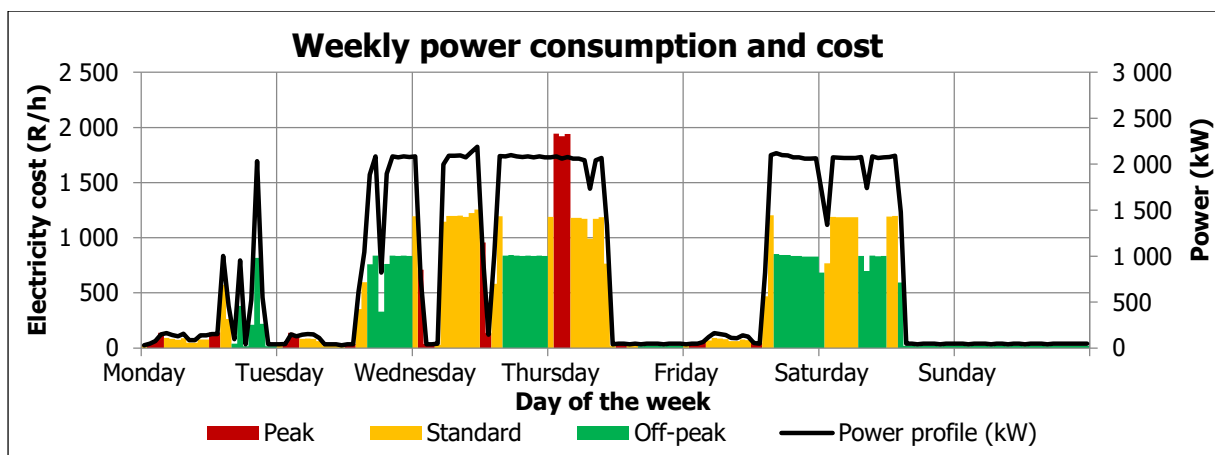


Figure 19: Weekly power consumption and cost graph example

This graph differs for the weekly and monthly reports. For a weekly report, the graph indicates the hourly cost of electrical energy, while in the monthly report it is indicated as daily totals. The daily totals in the monthly reports are stacked with different colours indicating how each TOU period contributed to the total electricity cost for a day. Weekends are also indicated on the monthly graph with a different background colour. An example of the graph in the monthly report is presented in Figure 20.

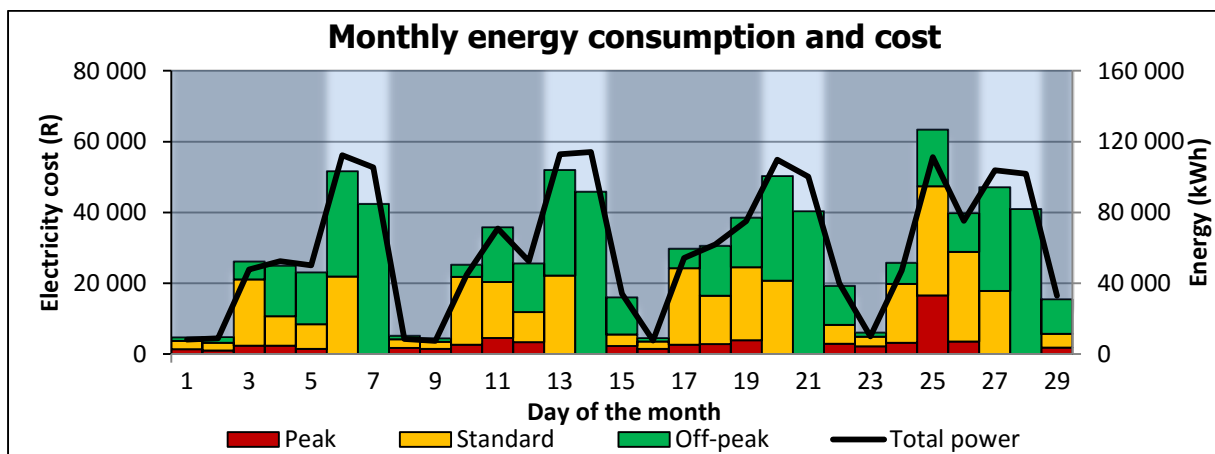


Figure 20: Monthly energy consumption and cost graph example

Investigate opportunities

The investigation of opportunities that arise from the energy management system forms part of the “*Check*” and “*Act*” phases of the ISO 50001 framework, and also contribute to improvements on the “*Plan*” phase. The main requirements that this step contributes to achieving is “*Improving energy management continuously*”. This is done by investigating the performance of the different sections, identifying where the greatest opportunities are, and improving the energy management system to optimise the savings that can be obtained from these opportunities.

The missed opportunities that can be identified from the detail pages of the different sections in the report were discussed in the previous part of this section. These opportunities include possible TOU cost savings, intensity cost savings and auxiliary cost savings. Further opportunities can, however, also be identified by considering the rest of the report. These opportunities are less quantifiable than the discussed missed opportunities, but should still be considered when interpreting the report. Setting targets is a good initiation point when looking for opportunities. If it is seen that a certain component does not reach its target on consequent reports or it differs too much from the target, then the component should be investigated further.

Equipment that does not reach the desired targets is most likely inefficient, or not enough effort is put into improving the energy performance thereof. This can serve as an indication of where to start working on improvements, and where awareness of energy management has to be enhanced. It is also possible to determine whether it is necessary to consider replacing or upgrading the relevant equipment if poor performance persists. The literature study can then be referenced to determine what technology would be the most applicable for the situation. This would include a process of calculating the payback period and considering whether it is viable to perform the upgrade or replacement.

The report will also be a good indication of where additional meters need to be installed. It is possible that more detail is required in the reporting, which would lead to identifying gaps in the metering system. This will also assist with having sufficient meters when investigating potential Section 12L tax deduction applications, or identifying where it might be a possibility. When the sum of all of the meters is compared with the electricity bill, it will be possible to identify problems with the calibration of meters. This will assist in identifying gaps in the system and ensuring that all meters are accurate. Inaccurate metering will lead to inaccurate reporting, causing a lack of trust in the information presented in the report.

3.2.5. RISK IDENTIFICATION

Risk identification consists of monitoring potential future risks and calculating the possible implications that they might have. These risks might not necessarily realise in the future, but it is still important to be aware of them and prepare appropriately. A large and inevitable risk is the price increase of energy sources – especially electricity tariffs in South Africa. It is important for companies to be aware of the potential electricity price increases and how they will influence company expenses in the following financial year. This will have budgeting implications, which might influence how the company spends its profits from the previous year.

By using the predicted increase in electricity prices, as well as the plant's previous electricity usage, it will be possible to determine by what amount the total electricity expenditure will increase from one year to the next. With the use of TOU electricity tariffs, it will be vital to the calculation to be aware of the usage distribution of the specific plant, as this will influence how much of the electricity usage will be more expensive. Using a report will enable the plant to identify this distribution and limit it as much as possible by performing load shifting. Electricity increases are usually announced in time for this calculated risk to be included in the budget for the next financial year. An improved method for determining such tariff increases is suggested as a future study.

Proper identification of risks will lead to the use thereof as opportunities. The opportunities discussed in the previous section can thus also result in risks if they are not used properly. Some of the largest risks identified by the reporting system are the incorrect use of TOU tariff structures, equipment not being operated optimally, and unnecessary auxiliaries not being switched off. These risks were discussed in terms of the use thereof as opportunities in the previous subsection, and will thus not be discussed again. The identification of opportunities and risks are thus viewed in parallel.

3.2.6. PERFORMANCE MONITORING AND REPORTING

The main outcome of the developed energy management system is a report that monitors the performance of the plant. The report will also be used for maintaining awareness of energy efficient operations, as well as ensuring that the plant maintains continuous improvement by adjusting targets according to previous performance and benchmarking. The report follows an adaption of the PDCA framework as it uses the steps in the process illustrated in Figure 8 to obtain reporting information. The results in Chapter 4 will mainly be based on information obtained from the reports to illustrate the effect of implementing the system.

The report was developed to be sent out automatically on a weekly and a monthly basis. Before the implementation of this system, the case study discussed in Chapter 4 already

received a daily DSM report, similar to the example presented in Appendix D. This, however, only reported on the relevant components, and only on the DSM performance in terms of evening load shifting. Even though this did assist in maintaining awareness, the report generated from the developed system uses electrical energy and production data, and reports on the performance of all of the sections on a cement plant. The report will thus be able to provide more insight in the performance of the entire plant, and not only on the load-shifting performance.

Detail on what the report will contain was discussed in Section 3.2.4. The essence of the system is that it captures data from different sources and translates it into valuable information and graphs that the plant can use to create energy cost savings. Both production and the electrical energy performance of the plant are taken into consideration. The reports will also be sent automatically to a predefined mailing list as determined by the energy manager of the plant. An example of the monthly report is presented in Appendix F, and the weekly report is presented in Appendix G. The contents of these reports will be discussed further during the implementation of the system on the case study in Chapter 4.

3.2.7. BUDGETING

Developing an effective budgeting system contributes to both the “*Plan*” and “*Act*” phases of the PDCA approach. It firstly forms part of “*Plant benchmarking*” of the “*Plan*” phase, and then also forms part of the “*Budgeting*” aspect of the “*Act*” phase. This is done by originally setting targets for the performance of equipment by using historical data as well as benchmarked values from literature. This assists with evaluating the status of the equipment’s energy performance. The budgeting system ensures that the targets and budgets are adapted according to the performance, resulting in continuous improvement. The ISO 50001 requirements that this step in the system achieve are thus “*Setting targets to enable meeting the policy goals*” and “*Improving energy management continuously*”.

Different budgeting methods were discussed in Section 2.3.6. For this energy management system, it was decided to combine two of the discussed methods, namely, using the past three months’ data and obtaining benchmarked values from literature. By considering the benchmark obtained from literature as a virtual month and using the previous three months as well, there will be a total of “*four months*” to consider. The target will thus be an average of the four months, resulting in a target that is realistic, but that still aims to reach the optimal performance. The performance of the past three months is an indicator of the ability of the plant, while the benchmarked target represents the ideal performance thereof.

The targets will be indicated in the report along with the actual performance, and as a quick indication the actual performance will be either green or red, depending on whether the target was reached or not. The budgeting strategy discussed above will be used for targets set for tonnes per hour (t/h) and kWh per tonne (kWh/t). The kWh/t benchmarked values will be obtained from Section 2.3, and the t/h benchmark values will be calculated from the kWh/t benchmarked values and power ratings of equipment by using Equation 1.

Equation 1: t/h_{Benchmark} calculation

$$t/h_{Benchmark} = \frac{kW_{Equipment\ rating}}{kWh/t_{Benchmark}}$$

For the c/kWh target, which reflects on the TOU performance of the plant, the benchmarked value will be replaced by a calculated value. This value is calculated by using Equation 2, where “ TOU_x ” is the tariff of the TOU period, and “ $Hours_x$ ” is the number of hours for the TOU period in the report. The budget can then be calculated by combining this value with the performance of the past three months.

Equation 2: TOU benchmarking

$$TOU_{Benchmark} = TOU_{Off-peak} \times Hours_{Off-peak} + TOU_{Standard} \times Hours_{Standard} + TOU_{Peak} \times Hours_{Peak}$$

The target for the R/t for a specific component can then be calculated from the kWh/t and the c/kWh targets by using Equation 3.

Equation 3: R/t_{target} calculation

$$R/t_{target} = \frac{c/kWh_{Target} \times kWh/t_{Target}}{100}$$

From discussions with cement plants it was also found that there are a few general desired EnPIs that should be shown as part of the summary of the report. For these indicators, the past three reporting period values will be presented along with the current period’s values. The average of the three values will then also serve as the target, which will be used to indicate the performance of the current reporting period. The calculations for each of the indicators are given in Equation 4 to Equation 7, and the descriptions used in the equations are based on the sections given in Table 7. The indicators are in terms of kWh/t. The first is referred to as “*Clinker production*”, as calculated in Equation 4. This is an indicator of how efficient the entire clinkering process is.

Equation 4: Clinker production (kWh/t)

$$Clinker\ production = \frac{(Raw\ milling + Fuel\ preparation + Burning)}{Tonnes\ clinker\ produced}$$

The next indicator is referred to as “*Total energy per clinker produced*”, which indicates the energy consumption of the entire plant per tonne clinker produced. This is calculated by using Equation 5.

Equation 5: Total energy per clinker produced (kWh/t)

$$\text{Total power per clinker produced} = \frac{\sum \text{Sections}}{\text{Tonnes clinker produced}}$$

The “*Total energy per cement produced*” is the next important indicator identified, which can be calculated from Equation 6. The energy consumption of the entire plant is used again, but compared with the total tonnes cement produced in this case. This will also be a key indicator of the success of this study, along with the cost of the energy per cement produced.

Equation 6: Total energy per cement produced (kWh/t)

$$\text{Total energy per cement produced} = \frac{\sum \text{Sections}}{\text{Tonnes cement produced}}$$

The final indicator that was identified is “*Cement manufacturing*”, which is calculated by considering the energy consumption of the finishing mill(s) on the plant per tonne cement produced. According to Figure 2 (Section 1.2.3), finishing milling is the largest consumer of electrical energy on the plant. This will thus serve as an indication of how efficient the finishing milling section of the plant operated. The calculation of this indicator is as shown in Equation 7.

Equation 7: Cement manufacturing (kWh/t)

$$\text{Cement manufacturing} = \frac{\text{Finishing milling energy consumption}}{\text{Tonnes cement produced}}$$

An example of these EnPIs as captured from the monthly report is presented in Figure 21. In this example, “*Clinker production*” and “*Total energy per clinker produced*” were not indicated as the plant did not produce clinker during this period. The performance of the current reporting period was better than the target, and is thus indicated by highlighting the value green.

<i>Additional plant summary</i>					
Intensity (kWh/tonne)	Feb 2016	Jan 2016	Dec 2015	Nov 2015	Target
Clinker production	-	-	-	-	61.63
Total energy per clinker produced	-	-	-	-	195.66
Total energy per cement produced	50.90	56.91	52.93	48.06	52.63
Cement manufacturing	37.46	40.00	38.14	35.82	37.99

Figure 21: Additional plant summary example

3.2.8. DEVELOPED ENERGY MANAGEMENT SYSTEM

This section discussed developing an energy management system for improving the profitability of cement plants. The system was presented in Figure 8, with each step as discussed in this section. The system used the PDCA approach, and each step was allocated to a certain phase of this approach. Some of the steps overflowed between phases, but were allocated to the most relevant phase. The applicability of each step to the PDCA approach was also discussed during system development. The additional ISO 50001 tasks indicated in the system flow diagram are discussed in Section 3.3.

As mentioned previously, the outcome of the energy management system is the reporting of Step 5. Even though the entire system is to be implemented on a cement plant, the reporting section is the most measurable part of the system. This will thus mainly be used to discuss the results obtained when implementing the system on a cement plant in Chapter 4. These results will serve as an indication of whether or not the developed system is a valid and effective method for improving the profitability of cement plants. Along with these results, the main indicator of cement production cost – rand per tonne cement produced – will also be discussed.

3.3. METHODOLOGY VERIFICATION

3.3.1. ISO 50001 COMPLIANCE

The main verification of the energy management system developed in Section 3.2 was done by using the ISO 50001 framework flow diagram (Section 2.4). The flow diagram of the developed energy management system is thus based on the PDCA approach flow diagram. Throughout the discussion of the steps of the system in the subsections of Section 3.2, the relevance of each step to ISO 50001 was stated and discussed. This served as the primary verification of the energy management system. ISO 50001 is an internationally adopted model for improved energy management, and thus using this model as the foundation of the developed system proves that it is a verified methodology.

As further verification of the methodology – a self-assessment checklist [57] evaluating a company's compliance with ISO 50001 (developed by the BSI Group [58]) – was completed. The BSI Group is a business standards organisation that assists companies in 150 countries with obtaining compliance with business standards such as ISO [58]. A discussion of how the system contributes to the different parts of the checklist is presented in Appendix E. It was previously mentioned that implementing the developed system would contribute to obtaining

ISO 50001 certification, but that additional tasks will be required. These additional tasks were identified from the checklist and are discussed in Section 3.3.2.

3.3.2. ADDITIONAL ISO 50001 TASKS

Additional tasks that have to be performed in order to obtain ISO 50001 certification is stated in this subsection. Most of these tasks have to be done during the initiation of the system, and should be reviewed periodically thereafter. It is acceptable that these tasks be evaluated at least annually, but preferably along with the monthly reports. These tasks are the final requirements that the plant will need to adhere to in order to be declared ISO 50001 compliant, and mainly have to be done by the company itself. The rest of the system was based on the implementation by an ESCo, and did thus not entail these company responsibility tasks. This step is classified as part of the “Act” phase of the PDCA approach. This part of the process does not contribute to the reporting system.

The first task is defining the system, which would consist of a summary of this study. The plant-specific boundaries of the study then have to be formally defined and officially documented. A policy declaring the company’s commitment to ISO 50001 has to be stated, made available to the public, and be distributed among all employees. These employees must then be assigned with responsibilities for achieving the policy goals, which include allocating internal energy managers on different levels. The internal energy managers will assist in selecting time frames for achieving set targets, as well as ensuring that the ESCo has access to everything required for implementing the system.

The responsibilities of personnel will further include that public relations employees become involved in the implementation of the system. Their main focus will be on performance monitoring aspects where it is necessary to identify which figures are important to communicate to the public. This will contribute to improving shareholder confidence in the company, as well as making the public more aware of the company’s contribution to energy performance. Such an external communication plan has to be documented officially and followed accordingly. The energy performance announced by other companies will also be evaluated by these personnel and they have to be informed that it is taken into consideration when choosing suppliers.

Another responsibility will be to ensure that all energy saving measures are in line with legal requirements. Records of compliance with legal requirements must be kept on a central document database to be easily available when required. Records of conformity with ISO 50001 must also be kept on the database. This will include proving that the plant

implements the stated policy and uses the documented system. Aspects such as the reviewing of targets and the savings achieved have to be kept on record as well.

Lastly, auditing the success of the implementation of the energy management system has to be done on a regular basis. The interval for such an audit must be predefined and conducted accordingly. The audit will serve as an evaluation of the system implementation to management, who can then decide whether they are satisfied and whether changes are required. The issues identified from these audits have to be attended to, and followed up on within the stipulated time frame. Top management can also review the system from the summary page of the report. It might not be sensible for certain personnel to receive the weekly reports as they will only be interested in an overview of the performance for the month. These reviews also have to be documented and distributed. By completing these tasks along with the developed system, a cement plant should be ISO 50001 compliant.

3.3.3. QUALITATIVE VERIFICATION

As a qualitative approach to verifying the system, questionnaire-based discussions were held with personnel involved at different cement plants, as first discussed in Section 2.5.7. The questionnaires are provided in Appendix C. Based on these discussions, the effect of the energy management system developed in this chapter was verified by determining how it would be beneficial to a cement plant. In Section 2.5.7 it was stated that the current methods available for feedback on the electrical energy management of the plants are not sufficient, as they do not contribute toward continuous improvement by identifying cost saving opportunities. This is thus the main aspect which this system contributes to.

Continuous improvement is achieved by the developed methodology by consistently adapting the targets and budgets for the performance of plant equipment. This ensures that realistic goals are set while simultaneously targeting improved performance. Furthermore, the developed system provides an analysis of all of the equipment on a cement plant, which makes it possible to identify the areas that require improvement. Different methods were discussed in this chapter that will assist with identifying cost saving opportunities, and ensuring that plants are able to use these opportunities. In order for the developed system to effectively improve the profitability of cement plants, the system has to be adapted and implemented by the cement plant personnel.

As presented in Appendix C.1 and Appendix C.2, the consultation with the process engineer and technical advisor of the case study indicated that the report was valuable to the plant. The discussion indicated that the developed methodology was effective and that it enabled the plant to achieve continuous improvement. The reports were interpreted upon receipt by the

relevant personnel, and concerns were discussed during biweekly operational meetings. This contributed greatly to improving awareness of energy management on the plant. The process engineer also indicated that the reports assisted in achieving basic savings, and that it would be beneficial over a longer implementation period.

Additionally, the reports were also sent to another plant for a test period of approximately two months. Even though this was not a long enough period to determine the quantitative effect on the plant, the questionnaire-based discussion presented in Appendix C.5 serves as a qualitative evaluation thereof. The discussion was with the engineering manager of the plant, who indicated that the reports would be a valuable addition to a cement plant, and that he believed that savings could originate from the reporting system. He also indicated that the reports were included in discussions during operational meetings, which led to an improvement among personnel regarding energy management awareness.

The engineering manager further indicated that the reporting system was an effective method for monitoring and improving energy management on the plant. The comparisons with targets and previous reports were indicated as a valuable aspect of the system, which highlights the effect of the feedback loop. A main focus of ISO 50001 is to have a feedback loop that enables continuous improvement. It was thus indicated by this discussion that this goal was achieved by the developed energy management system. This serves as further verification that the system is an effective method to achieve improved energy performance.

Discussions such as the ones documented in the questionnaires were held with personnel from different cement plants and ESCo personnel throughout the development of the system. During the implementation of the system (as discussed in the next chapter), such discussions were also held with the personnel of the specific plant. This made it possible to identify the requirements of the plant in terms of a feedback system for the energy performance.

During the discussions it was clear that certain aspects, such as the intensities (kWh/t) and TOU performance, were considered as primary indicators, while other aspects, such as the missed opportunities, were considered as additional indicators. The secondary indicators would thus become more important and effective as time progresses and the basic concerns are resolved. The plant personnel did, however, indicate that it was valuable to compare such indicators on a weekly basis, which again emphasises the effect of the feedback loop of the system. Such regular discussions thus verified that the system provides proper feedback to evaluate and improve energy management on a cement plant.

The verification of the methodology in this chapter was thus achieved by using the following three components:

- Continuous comparison of the methodology with the ISO 50001 framework, and using ISO 50001 as the foundation of the methodology;
- An ISO 50001 checklist (Appendix E) was used to evaluate how the developed methodology contributes to the different aspects of ISO 50001, and additional tasks were identified; and
- Qualitative discussions with personnel involved with cement plants (Appendix C) verified the effectiveness of the developed methodology.

Based on these verifications, it is seen that the developed methodology provided a sensible solution to the stated problem. The energy management system presented and discussed in this chapter thus provides a theoretically valid method to improve the profitability of cement plants. It is thus expected that a cost saving will be evident from a practical implementation of this methodology.

3.4. CONCLUSION

This chapter discussed the development of the energy management system. The end result of the system is as presented in Figure 8, which is based on the ISO 50001 process of Figure 7. The main step in the methodology is the “*Performance monitoring and reporting*” of Section 3.2.6, which is considered as the most measurable aspect of the developed system. The system captures production and electricity data from different sources, and automatically sends it to a centralised data hub. Data is processed into valuable information and graphs indicating the performance of all plant sections automatically.

This makes it possible for the entire plant to be investigated in detail and to identify the sections and equipment that require attention. The electrical energy consumption and production figures of the entire plant is thus monitored, summarised, and reported on. The reports are automatically sent to a recipient list defined by the energy manager of the plant. The plant summary section in the report makes it possible to identify the largest consumers, and to further investigate them in the detail discussions of each section. Specified EnPIs are monitored, which makes it possible to identify savings opportunities that could have been utilised, as well as potential risks.

The development of the energy management system as a whole was verified throughout the discussion by stating its relevance to ISO 50001 and the PDCA approach. The methodology was compiled by using the PDCA approach as foundation, and modifying it to be relevant to this study. The contribution of the developed system towards reaching the desired outcomes of ISO 50001 was also stated in the discussion of the steps in the system. Additional verification was referred to a checklist discussed in Appendix E. This checklist assisted in

identifying additional ISO 50001 tasks that are required for certification, but is not included in the system. Questionnaire-based discussions with the personnel of cement plants served as qualitative verification of the methodology.

The next chapter will discuss the results obtained from implementing the developed system on a cement plant. The results will be discussed by using indicators from the reports over a period of 14 months. As mentioned previously, the reports are the most measurable output of the energy management system, and will thus be the main point of discussion in Chapter 4. Each step in the energy management system will not be discussed as there are not measurable results for all of them. The purpose of this study is to improve on profitability, so the crucial indication of the success of the system will be the rand per tonne value for cement produced, and how it has changed over the evaluation period.

Chapter 4: Results

In this chapter the methodology developed in Chapter 3 is validated in terms of the results obtained when implementing the methodology on a South African cement plant. A case study will be considered in detail for this validation, evaluating the long-term effect that the system had on the energy performance of the plant. Results will be given for the effect that the system had on the profitability of the major plant sections, as well as on the entire plant. A qualitative validation will be done by referencing questionnaire-based discussions with personnel involved with cement plants. The effect that the system can have on the entire cement industry if implemented will also be briefly considered.

4. RESULTS

4.1. INTRODUCTION

The energy management system developed in Chapter 3 was implemented on a South African cement plant. The results obtained are discussed in this chapter. Performance monitoring was conducted on the plant by means of reporting, from which results were obtained over a 14-month period. Background about the plant and its operations are first presented, whereafter the results are discussed. The desired effect of the system developed during this study is improving the profitability of cement plants through energy management. The focus of the results will thus be to indicate how the system contributed to achieving this goal, and thus solving the problem stated in Section 1.3.

The problem identified during the initiation of this study was that the cement industry in South Africa has become more competitive. Thus, there is a need for the older cement plants to improve their profitability. The presented results serve as the main validation of the study, as these results will indicate that the methodology developed through research is a valid solution to the stated problem. Additional validation is, however, also provided in the form of the previously referenced questionnaire-based discussions with cement plant personnel. The results will thus serve as a validation of the methodology by addressing the quantitative data aspect, while the questionnaire-based discussions validate the qualitative aspect of the implementation.

4.2. CASE STUDY BACKGROUND

This section aims to provide background regarding the cement plant where the energy management system was implemented. Due to confidentiality reasons, the name of the cement plant is withheld and is hereafter referred to as “*Plant X*”. Plant X is a cement manufacturing plant in the Gauteng province of South Africa, with a process layout as presented in Figure 22. An evening load-shifting DSM project was previously implemented on the finishing mills of this plant, and the project still has three years of contractual performance to uphold. The plant does not have its own quarry and imports raw materials by using a tippler and trucks. Even though the plant does have a raw mill, coal mill (fuel preparation) and kiln (burning), it is economically more feasible to import clinker rather than produce it internally.

The plant reported that the demand for cement is too low to produce clinker continuously, and that the cost associated with regularly switching the kiln on and off is much higher than obtaining clinker from another cement plant. The raw mill, coal mill and kiln are thus operated occasionally when the demand increases excessively, or when the supplier has a problem

providing clinker. When the clinkering process is initiated, it has to continue for at least a few months to be economically feasible. The plant thus has to be confident in a continuous demand for such a period. For the implementation period discussed in this study, the kiln (and thus also the raw mill and coal mill) was operational for five consecutive months, and again for two months later in the period.

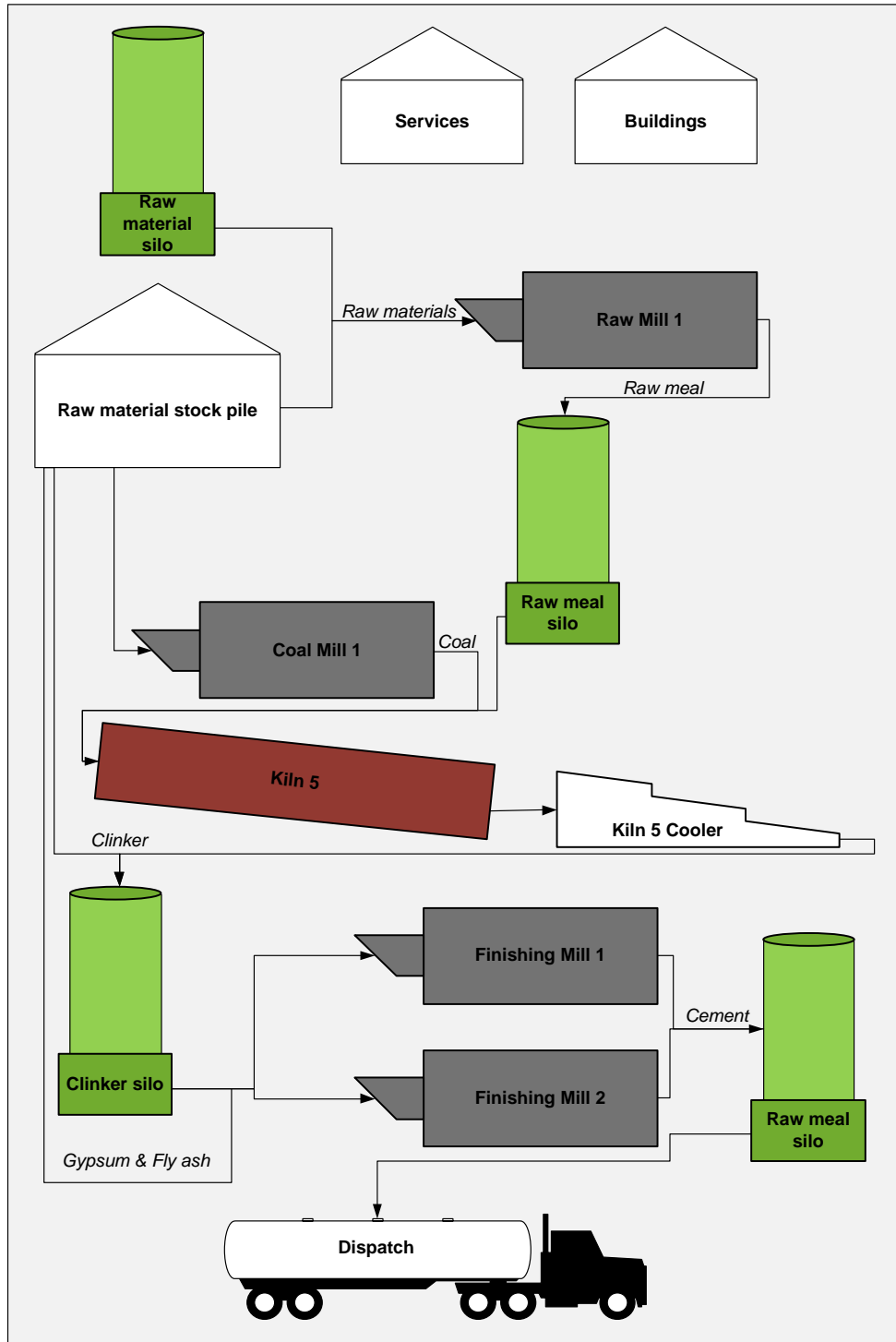


Figure 22: Plant X process layout

The plant has silos and stockpiles to store raw materials before they are milled. Additional silos are positioned between the raw mill and the kiln, where the raw meal is stored until it is to be used. This makes it possible to schedule the production of the raw mill as desired. Plant X further consists of two finishing mills – Finishing Mill 1 is a ball mill and Finishing Mill 2 is a VRM, as described in Section 2.2.3. There are also silos that store the produced cement, making it possible to schedule the production of these mills as well. It is, however, not possible to schedule the production of the coal mill as the process uses direct firing of the fine coal to the kiln.

Other components of the plant are a packing and loading plant, services (compressed air, lighting and cranes) and buildings (workshops, a laboratory and the main offices). This layout was used along with the suggested generic component breakdown as presented in Table 7 to obtain a more specific breakdown of the components being measured on the cement plant. This breakdown is as shown in Table 8. A few additional meters that should be installed for improved reporting were identified by comparing this breakdown with Table 7. These meters include coal mill material handling; Kiln 1 distinctive measurements; and Finishing Mill 1 auxiliaries and motor distinctive measurements.

Table 8: Plant X component breakdown

Section	Subsection	Electrical energy component measured
Raw material preparation	Raw material offloading	Raw material offloading
Raw milling	Raw Mill 1	Main motor
		Auxiliaries
		Material handling
Fuel preparation	Coal Mill 1	Main motor
		Auxiliaries
Burning	Kiln 1	Kiln 5 total
Finishing milling	Finishing Mill 1	Main motor and auxiliaries
		Cement handling
	Finishing Mill 2	Main motor
		Auxiliaries
Dispatch	Dispatch	Packing and loading plant
		Material handling
Services	Services	Compressors
		Lighting
		Cranes
Buildings	Buildings	Workshops
		Main office
		Laboratory

The breakdown in Table 8 was used to compile the reports for this system, as this was the electrical energy data that was logged on the plant. The electrical layouts were analysed to determine where meters were located to ensure that the meters were used correctly. The handling of data and calibration of meters were done by an external company. The data was thus obtained from the database created by the external company. Upon receipt of the monthly reports, the personnel at Plant X compared the figures in the report with those of the Eskom bill. This ensured that nothing was added to or left out of the reports.

Additional to the electrical energy, it was also necessary to determine which production parameters were measured for the sections in Table 8. The sections that had meters logging production are presented in Table 9, along with the nature of the data that can be used for the reports. These measurements are important as they make it possible to compare the electrical energy usage with the production figures of the plant. This makes it possible to analyse the productivity of the plant and its sections, and resultantly improve thereon. The meters used to measure this data were installed and maintained by the plant itself, and were also used for their production reports. The provided data was thus accepted as accurate as it was also critical for the plant to maintain the quality of these measurements.

Table 9: Plant X production measurement logged

Section	Production measurement
Raw milling	Raw Mill 1 production
Fuel preparation	Coal Mill 1 production
Burning	Kiln 1 raw meal feed (in)
	Clinker produced
Finishing milling	Finishing Mill 1 cement produced
	Finishing Mill 2 cement produced

As part of the system implementation, the data handling set-up presented in Figure 23 was established. The energy data was captured by using the installed power meters on the plant. The data logged by the power meters was collected on a server, from where it was written into data files and automatically sent to the centralised data hub. The production data was already logged on the SCADA using installed meters. An open platform communication connection was used to access this data on a data collection server at the cement plant. This server also sent the collected data to the centralised data hub.

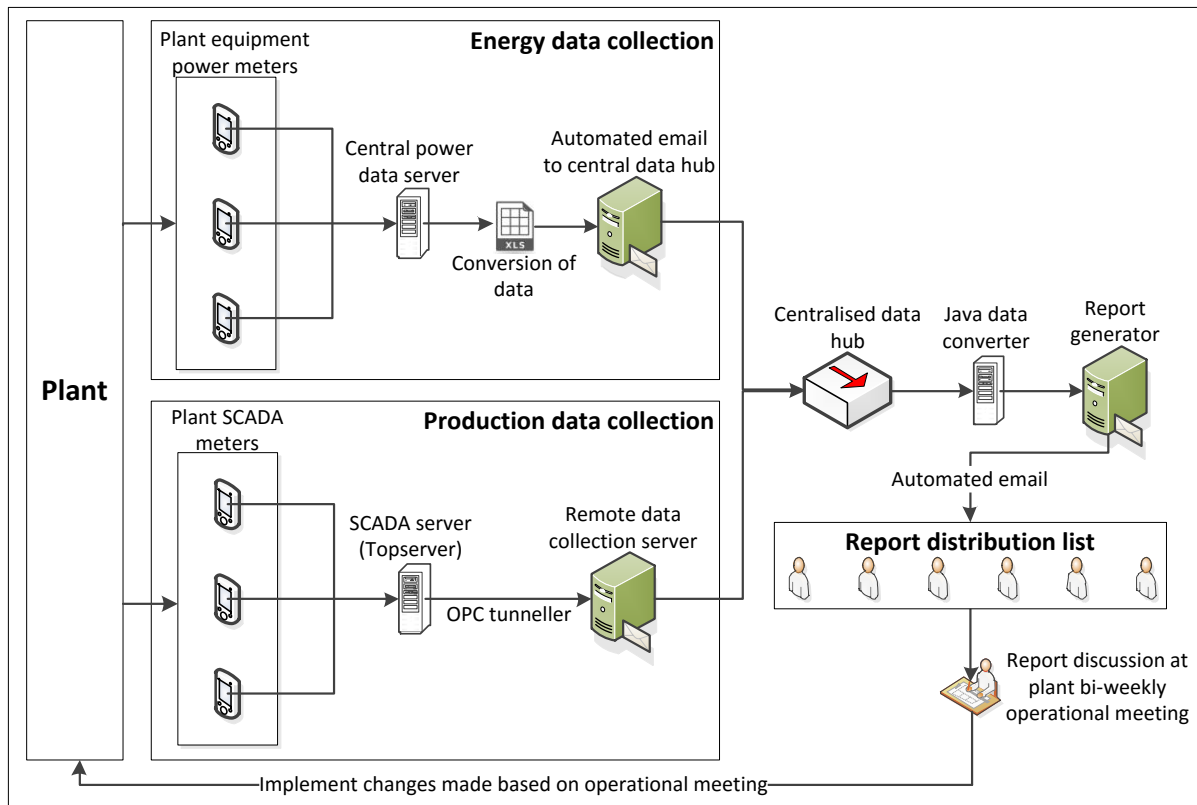


Figure 23: Plant X data handling set-up

The centralised data hub used data conversion techniques to provide all of the data in a usable form to the report generating system. This accentuated the importance of having all of the plant's data on a centralised database. It simplified the accessibility of the data, and made it usable for a greater variety of functions. The data could thus be compared and processed by one system without having to be modified. This reduced the possibility for human error, although the data was still closely monitored to ensure that there were no irregularities.

The reports were generated automatically, whereafter quality checks were done to ensure that there was no missing data or irregularities. As soon as the reports were approved, they were sent to predetermined recipients. All of the recipients had the opportunity to investigate the reports and highlight concerns before discussing it at the biweekly operational meeting. The discussion of the reports was raised as an additional point of discussion in the operational meetings as there was no basis for discussing the energy performance before. Decisions regarding changes in operations based on the findings of the report were held during the operational meetings, and communicated accordingly to the rest of the plant.

Regular meetings with the process engineer of Plant X provided feedback regarding the content of the report. The reports were continuously improved by using these inputs, thus ensuring that the most valuable information was provided. Different personnel also used different parts of the reports, and it was attempted to provide a report that was universal for

the entire plant. The discussions in the operational meetings were mainly based on the summary pages, while the implementation of the decisions made in these meetings required investigating the section summaries.

The implementation of the energy management system developed in Chapter 3 was initiated in February 2015. The first report was thus compiled and provided to the plant personnel for January 2015 to analyse the performance and start implementing changes. The discussion of the results aims to indicate the continuous effect that the system had on the components of Plant X by presenting the results from January 2015 to February 2016 (14 months). Among these 14 months, 11 were classified as “*summer*” and three as “*winter*” according to the Eskom TOU billing periods. During these 14 months, the kiln was on for seven months and off for seven months. Table 10 provides the specific months’ descriptions. The next section will focus on the results obtained from implementing the system on Plant X for the months indicated in Table 10.

Table 10: Implementation month descriptions

Implementation month	Kiln status (On/Off)	Eskom billing season
Jan-15	Off	Summer
Feb-15	On	Summer
Mar-15	On	Summer
Apr-15	On	Summer
May-15	On	Summer
Jun-15	On	Winter
Jul-15	Off	Winter
Aug-15	Off	Winter
Sep-15	On	Summer
Oct-15	On	Summer
Nov-15	Off	Summer
Dec-15	Off	Summer
Jan-16	Off	Summer
Feb-16	Off	Summer

4.3. EFFECT OF THE ENERGY MANAGEMENT SYSTEM

4.3.1. PREAMBLE

The energy management system presented in Figure 8 was implemented on Plant X by following the steps in the methodology. Based on these steps, weekly and monthly reports were sent to the relevant personnel, which made it possible to continuously monitor the performance of the plant and adapt the system accordingly. These reports are characterised

by Step 5 in the energy management system, and were also the main source of data for the results presented in this section.

Part of the feedback was evaluating the performance of the plant equipment and comparing it with literature and previous performance. From the qualitative evaluation of the implementation of the system at Plant X, as presented in Appendix C, it was clear that the feedback reports were used on a regular basis and provided valuable information on the energy performance. The plant was thus able to adapt its operations according to the feedback, and to identify focus areas for improved energy management. A key indicator that was reportedly considered was the intensities (kWh/t) of the finishing mills. This was also a key factor in the improvements seen on the plant, and resultantly motivated the causality of savings originating from the energy feedback reports.

The first step of developing an automated reporting system was to create awareness, which included becoming familiar with the sections on a cement plant. The information obtained regarding the sections on Plant X, as well as the specific metering points and available measurements and data were discussed as part of the background of the plant in Section 4.2. The operations on the plant were also investigated to gain an understanding of the general working procedure. This made it possible to identify initial opportunities, and to obtain an idea of where to start looking for possible energy saving opportunities. The effect of the system is discussed in the remainder of this section by highlighting key factors that influenced the performance of the plant.

4.3.2. IDENTIFY THE LARGEST ENERGY CONSUMERS

The initialisation of obtaining energy savings by using the energy management system was identifying the largest energy consumers on Plant X. This was done by comparing all of the sections on the cement plant for the first month (January 2015), and identifying the largest consumers of electrical energy. This distribution of electrical energy consumption is presented in Figure 24. As expected from Section 1.2.3, the finishing mills consumed the largest portion of electrical energy and contributed 71% to the total electrical energy usage of the plant for January 2015. Finishing Mill 1 and Finishing Mill 2 were thus identified as the largest consumers of electrical energy on Plant X.

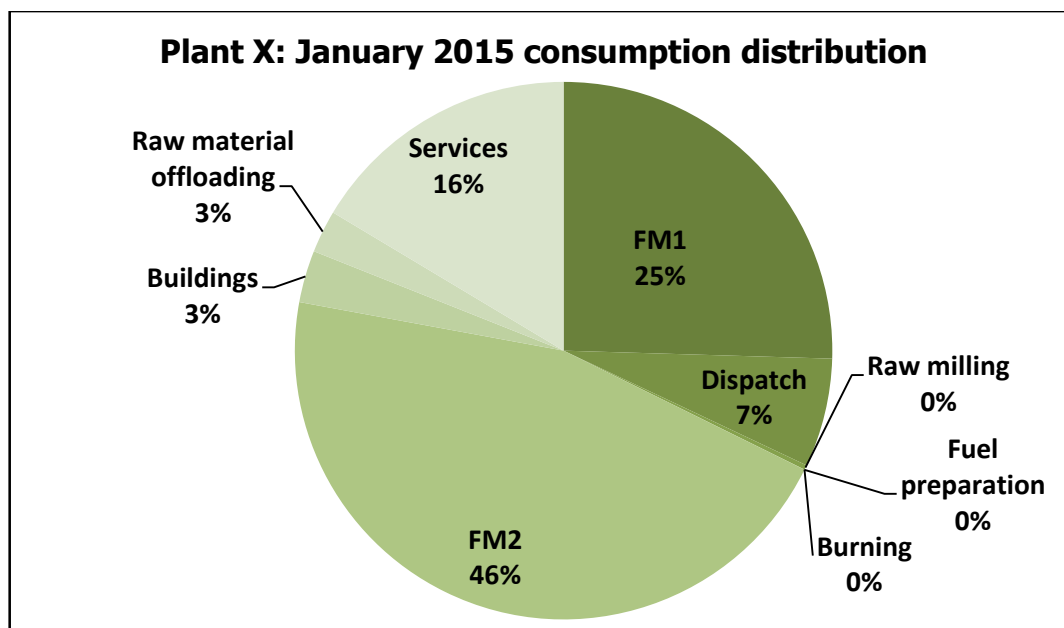


Figure 24: Electrical energy distribution of Plant X sections

4.3.3. INVESTIGATE SYSTEMS TO MONITOR ENERGY CONSUMPTION

From Figure 24, the finishing mills were identified as the most likely source of achieving cost savings by managing the electrical energy usage. EnPIs that were considered for the mills are listed in Table 11.

Table 11: EnPIs of finishing milling before project implementation

January 2015 Parameter	Finishing Mill 1		Finishing Mill 2	
	Actual	Target	Actual	Target
Production rate (t/h)	52.00	49.23	89.89	112.50
Intensity (kWh/t)	37.16	39.00	33.08	28.00
Cost intensity (c/kWh)	48.19	53.90	52.92	53.90
Production cost (R/t)	17.91	21.02	17.50	15.09

These values were calculated with cement handling excluded in order to use values that were comparable with the information obtained from literature. The EnPIs were compared with the initial targets as obtained from literature, and calculated according to the developed budgeting system step in Section 3.2.7. The intensity target for Finishing Mill 1 as obtained from Table 6 (Section 2.3.5) was 39 kWh/t; Finishing Mill 2 was 28 kWh/t. It was desired for the mill performance to be below this value.

The target for the production rate of Finishing Mill 1 was calculated as 49.23 t/h by using Equation 1 (Section 3.2.7), where the rating of the motor and its auxiliaries were used as 1 920 kW. This was obtained by comparing the information obtained from the plant with the power data of the mill. The initial target for the production rate of Finishing Mill 2 was calculated

as 112.5 t/h, with the rating of the motor and its auxiliaries used as 3 150 kW. It was desired for the equipment to achieve higher production rates than these set targets.

The targets for the cost intensities were calculated by using Equation 2 and Equation 3 respectively, as discussed in Section 3.2.7. It was desired for the equipment to achieve values lower than these targets. Compared with the targets, Finishing Mill 1 performed well during the first month of reporting and had an efficient production rate. Finishing Mill 2, on the other hand, performed worse than the targeted performance. The performances of both mills were monitored closely for possible savings opportunities, and to ensure that the performance of Finishing Mill 1 was maintained.

Figure 25 presents the production rate, average trend and target of Finishing Mill 1 based on the monthly averages over the 14-month evaluation period. The target was adjusted as discussed, and served as an indication of continuous feedback and adjustment. From the trend line of the production rate of Finishing Mill 1, it is seen that the overall performance of the mill improved. This reflected positively on the implementation of the system. The regular reporting enabled the plant to notice a decrease in the mill performance, and react swiftly to ensure that acceptable performance was maintained. Irregularly poor production performance of the mill was observed during February 2015, which could not be explained by the plant personnel. This did, however, assist in ensuring that more focus was placed on regular maintenance of the mill, and ensuring that its maximum performance was utilised.

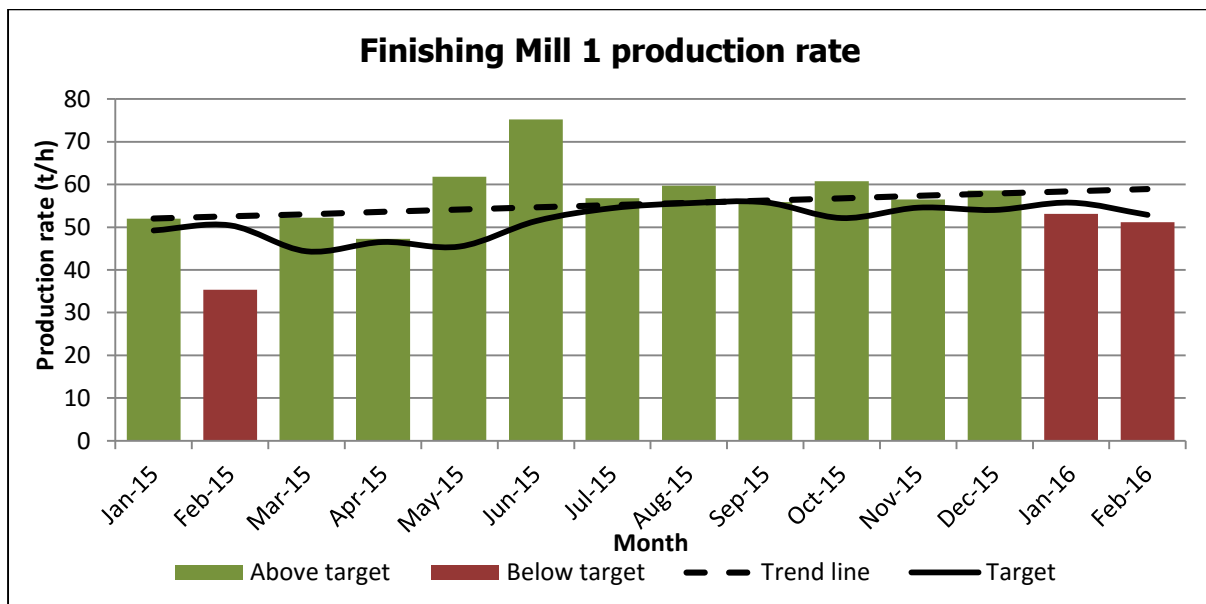


Figure 25: Finishing Mill 1 production rate over evaluation period

The production rate of Finishing Mill 2 for the 14-month period is presented in Figure 26. As stated previously, the initial performance of 89.89 t/h was below the targeted 112.50 t/h. This

enabled the plant personnel to identify that there was a problem with the performance of the mill, and that there was room for improvement. As seen from the trend line of this mill, the performance improved firmly over the 14-month period, and the production rate of the mill increased to 117.97 t/h by February 2016. This was well over the initial target that was set, and reflected the positive effect that the energy management system had on the mill by identifying a problem with its performance.

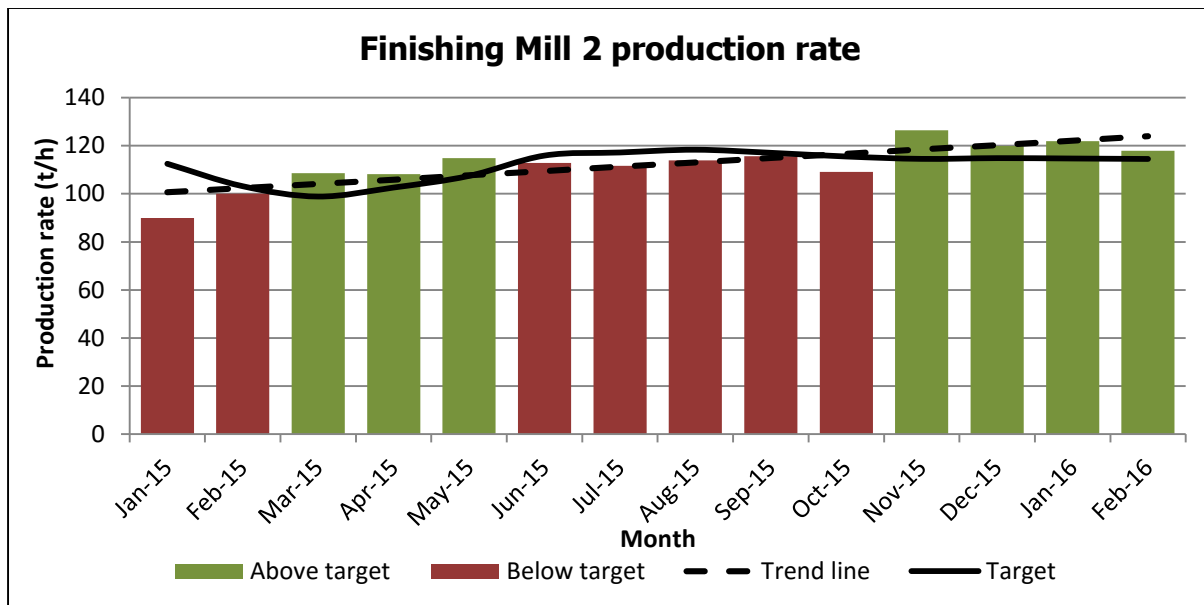


Figure 26: Finishing Mill 2 production rate over evaluation period

By knowing where to look for a problem, the maintenance of the mill was improved. Upon noticing that the performance of the mill was lower than expected, possible improvements to its performance were investigated. The following changes were made, which improved its performance:

- Installation of a rotary clinker feeder to reduce “false air”, which also improved the diesel consumption;
- Modification of the nozzle ring, which lead to the improvement of the mill’s pressure profile; and
- The pump used for transporting the cement was replaced with a ceramic rotary feeder, improving the production efficiency.

As part of the maintenance of the load-shifting project that was implemented on the finishing mills, it was also important to monitor the cost intensity in terms of c/kWh. This figure serves as an indication of how well load is being shifted from the peak and standard hours to the less expensive off-peak hours. The approach with this system differs slightly from that of a DSM project, as DSM load-shifting projects aim to shift load from the evening peak period only. In

terms of improving the profitability of the plant, it would be beneficial to rather shift load from the morning peak as well, and if possible, also from the standard periods to the off-peak periods.

From the reports it became clear that it was preferable to use Finishing Mill 2 when possible rather than Finishing Mill 1 to produce cement. This was due to a VRM (Finishing Mill 2) performing better than a ball mill (Finishing Mill 1). It was, however, still important to not overuse Finishing Mill 2 during peak periods, but to rather use Finishing Mill 1 during off-peak periods, as this entailed cost benefits for the plant. Thus it was critical to monitor the TOU performance of the plant by considering the cost intensity. It was desired for the cost intensity to be below the targeted value.

Figure 27 shows the TOU performance for Finishing Mill 1 along with the trend lines for the winter and summer months. The targets for winter and summer were also calculated separately due to the tariff difference. The TOU performance remained constant, and the plant was able to see a difference in performance and act accordingly, as seen in December 2015 and January 2016. In total, the TOU performance did not contribute to any new savings, but the performance was well-maintained.

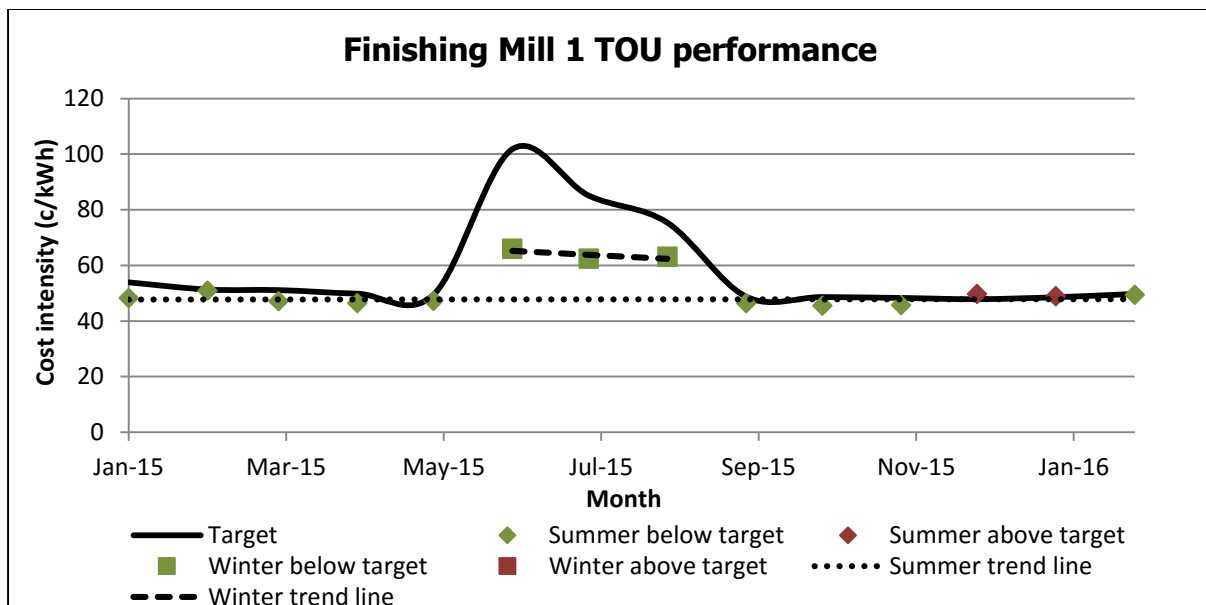


Figure 27: Finishing Mill 1 TOU performance over evaluation period

Figure 28 shows the TOU performance for Finishing Mill 2. This mill also maintained a good average performance throughout the summer months, and improved during the more expensive winter months. During winter, Finishing Mill 1 was used more after seeing that it had more capacity, which reduced the use of Finishing Mill 2 in standard and peak hours.

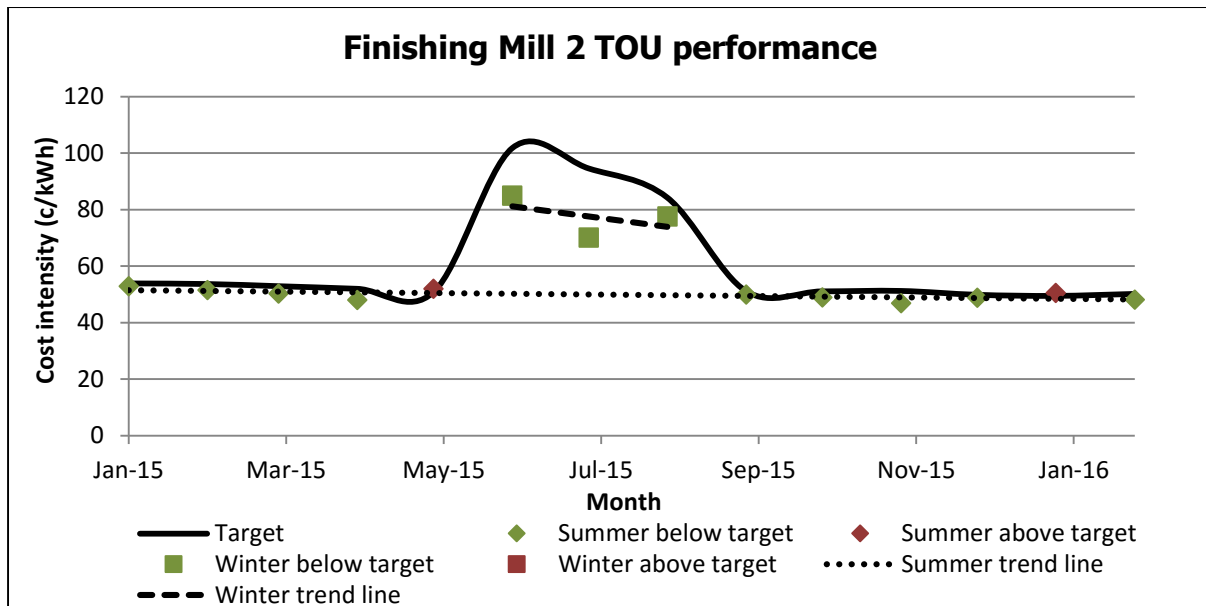


Figure 28: Finishing Mill 2 TOU performance over evaluation period

The next important parameter to monitor is the electrical energy required by the mill for cement production. This was an important benchmarked value that was obtained from literature, and is a good way to evaluate the performance of the mills regardless of electricity tariffs. A reduction in this value is expected to reflect a reduction in the production cost (R/t), as the cost intensity (c/kWh) performance remained relatively constant for both mills. The production energy performance of Finishing Mill 1 is presented in Figure 29 along with the trend line and target. The original target was used as the benchmarked performance of 39 kWh/t that was obtained from literature.

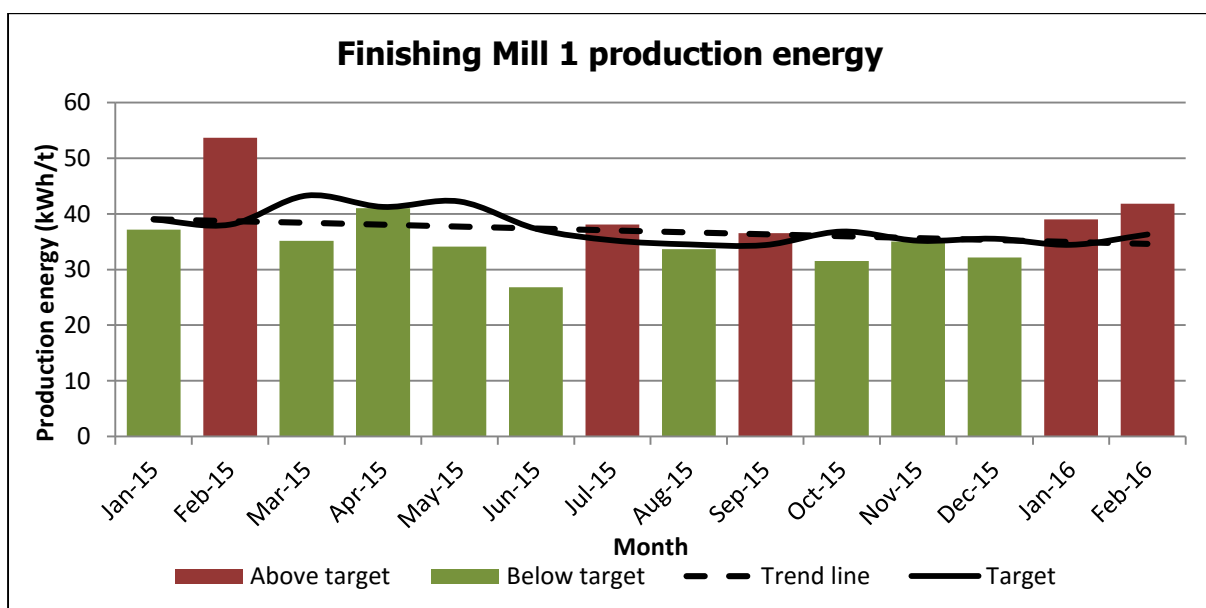


Figure 29: Finishing Mill 1 production energy over evaluation period

Even though the performance was below this target at the beginning of the system implementation, as desired, it is seen from the graph that it did increase to above the target at times. This shows the vitality of continuously monitoring the performance of equipment and acting on indicated problems. The trend line does, however, indicate an overall improvement in the performance of the mill. This is mainly due to the poor performance obtained in February 2015.

Figure 30 indicates the electrical energy required to produce cement for Finishing Mill 2. As seen from this graph, the performance in the first two months was much higher than the desired benchmarked target of 28 kWh/t. This indicated that there was room for improvement on the mill, which initiated the investigation for improved performance. The trend line indicates that the average performance of the mill improved over the 14-month period. It is also seen from the graph that the performance started to stabilise towards the end of the assessment period.

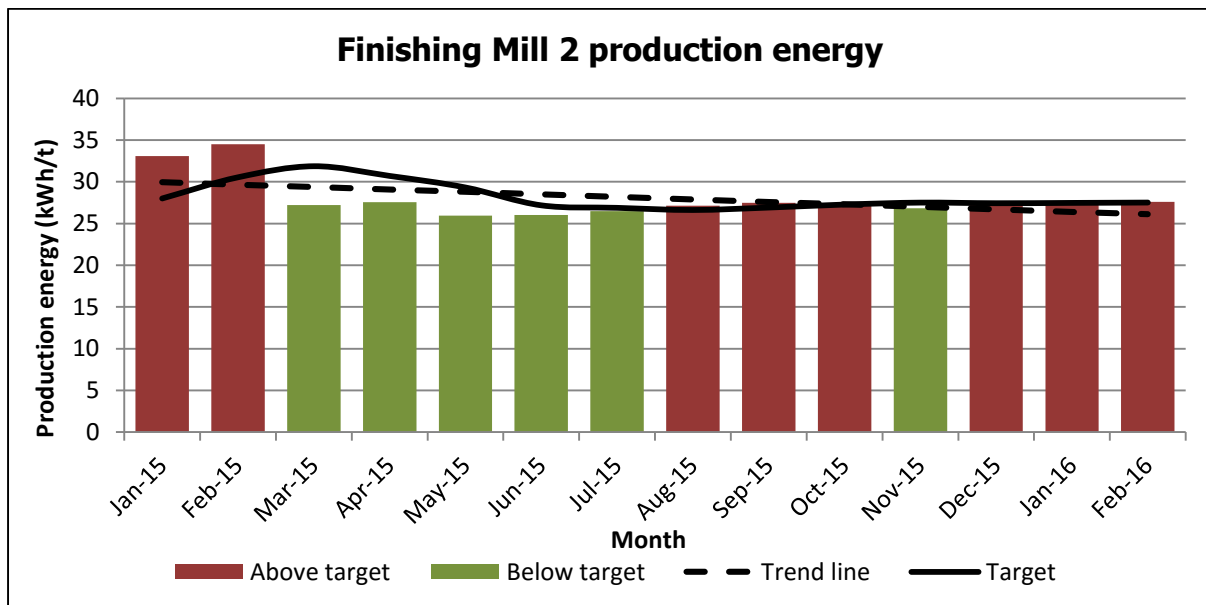


Figure 30: Finishing Mill 2 production energy over evaluation period

The essence of this study is to improve the profitability of cement manufacturing by managing the use of electrical energy on the plant. This can best be evaluated by determining the effect that the system had on the production cost of cement, in terms of R/t. All three of the parameters previously discussed in this section contribute to the production cost of the finishing mills. In order to distinguish between the tariff structures for the winter and summer months, the trend lines were generated separately for the two cases in the graphs. The targets for these periods are also independent of one another.

In the production cost graph for Finishing Mill 1 in Figure 31 it is seen that the average performance for the summer months improved as desired. This was an indication of the positive effect that the implementation of the energy management system had on the profitability of Finishing Mill 1. The poor production performance of the mill in February 2015 was clearly seen in its cost performance. The winter trend line, however, indicated a negative performance for the mill. This observed increase in production cost during the winter months originated from the improved production rate of 75.22 t/h during June 2015, as seen in Figure 25. The performance during July 2015 and August 2015 were considered average compared with the other months, and not worse as expected when considering the winter trend line.

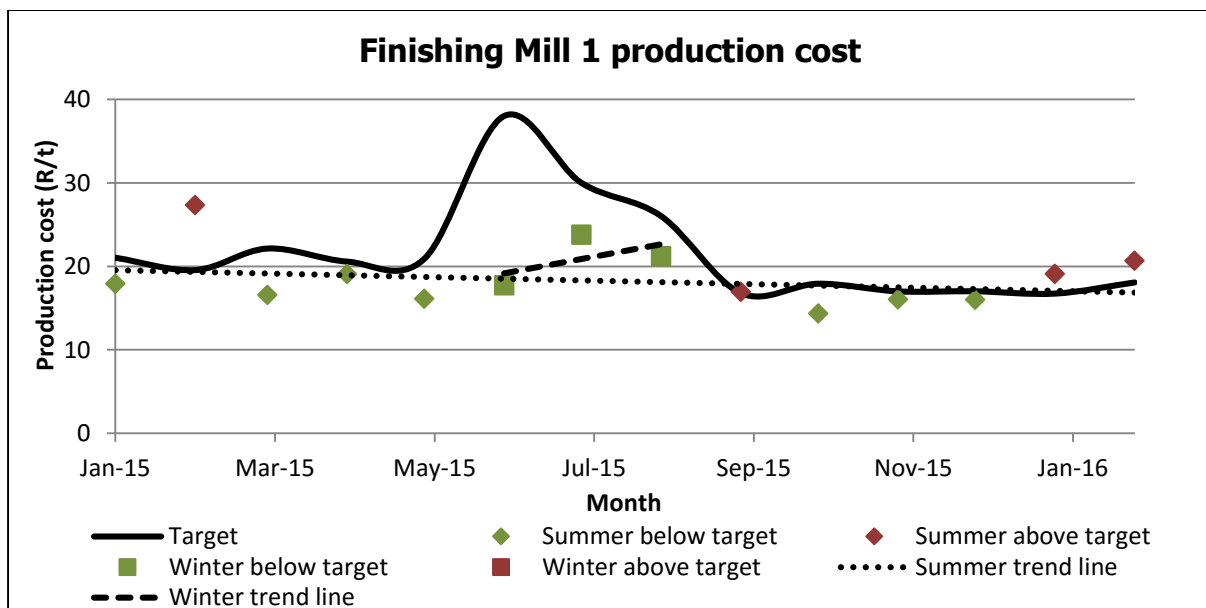


Figure 31: Finishing Mill 1 production cost over evaluation period

The winter performance can thus not be considered as negative, but rather as unordinary positive during June 2015. The plant investigated what affected the change in performance in June 2015, but could not duplicate the improved performance. This serves as further motivation for the benefit of installing more meters on Finishing Mill 1, which will make it possible to better distinguish between the main motor and the auxiliaries.

Figure 32 presents the production cost for Finishing Mill 2 over the 14-month period. As expected from the positive performance observed in the previous parameters, the profitability of Finishing Mill 2 increased over the evaluation period. This is seen in the decrease of the trend lines in the graph, indicating an improvement in the production cost.

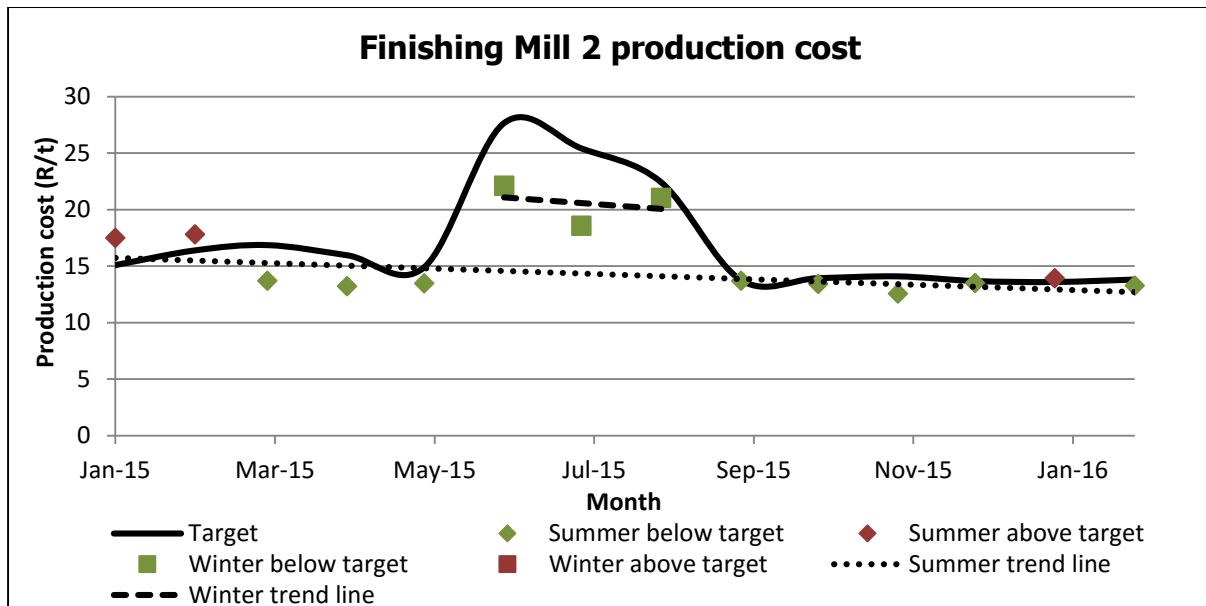


Figure 32: Finishing Mill 2 production cost over evaluation period

4.3.4. IDENTIFY RISKS AND OPPORTUNITIES

The implementation of the developed energy management system aimed to improve the profitability of the cement plant by identifying saving opportunities and then utilising them. This was already illustrated through the improved production efficiency that was achieved by the finishing mills by monitoring their performance and thereby identifying potential improvements. Improving risk management by identifying risks and making them a focus area can also be seen as an opportunity if it is utilised correctly. Three such quantifiable risks were classified as “*missed opportunities*” in the discussion of Section 3.2.4, namely possible TOU savings; intensity cost savings; and auxiliaries running without the motor.

Managing the auxiliaries, which were operational while the motor was switched off, was considered as one of the simpler risks to utilise as an opportunity. This was done by improving awareness regarding energy efficient behaviour, and ensuring that operators were aware of which auxiliaries were unnecessary when production stopped. This was calculated for Finishing Mill 1 by recording the stoppages based on production data as no separate meters were installed to distinguish between the auxiliaries and the main motor. The intensity cost savings could only be improved by improving on the production energy usage of the mill, as illustrated in Figure 29 for Finishing Mill 1. TOU savings for Finishing Mill 1 was dependent on the performance of Figure 27.

Figure 33 presents the potential savings that were not utilised in each month of the 14-month period for Finishing Mill 1. The greatest improvement was seen in the intensity cost saving, which reduced by R25 240 from January 2015 to February 2016. This reduction indicated an

improvement in usage. A slight improvement was also observed in the TOU cost saving of the mill, indicating that the implementation of load shifting improved slightly. There was no observable improvement in the auxiliaries that ran when production was stopped, which was a concern that has to be given more attention in the future. The measurement of this risk could be improved by installing more meters on the equipment. In general, the trend line indicated that the risks were identified and effectively utilised as opportunities, and the risk was reduced by about R40 000.

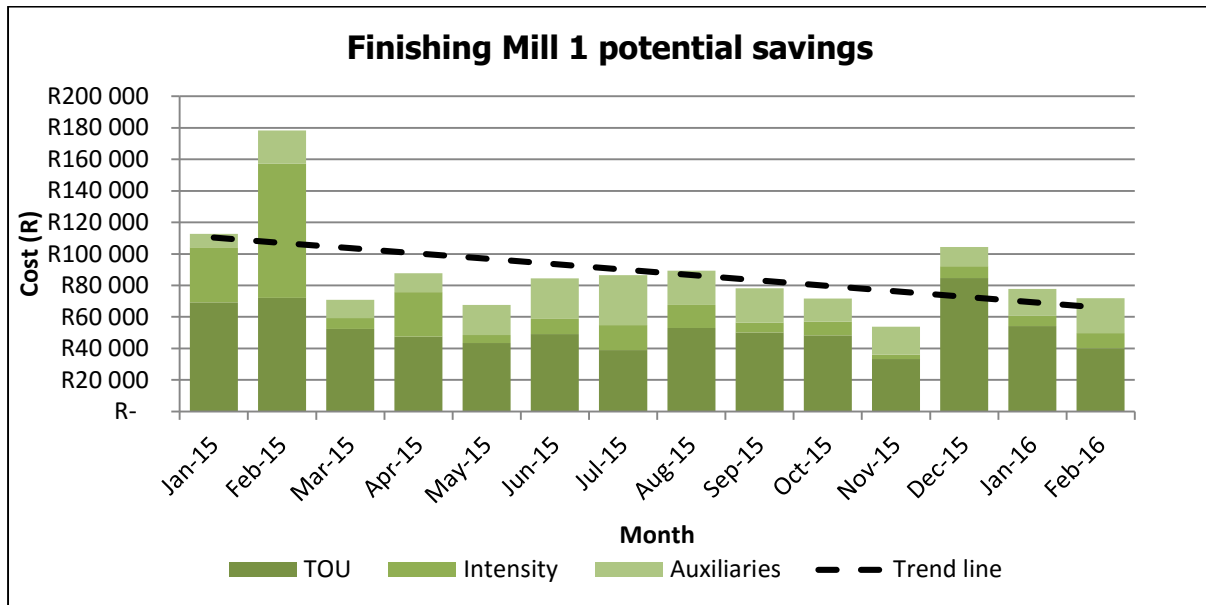


Figure 33: Finishing Mill 1 monthly savings missed over evaluation period

The potential savings for each month for Finishing Mill 2, as presented in Figure 34, reduced by about R65 000 from January 2015 to February 2016, which can also be seen in the trend line. The most savings originated from an improvement in the intensity, as expected from Figure 30. The TOU performance of the mill also improved slightly over this period, while the auxiliaries were switched off efficiently while the mill was not operational from the beginning. Potential risks identified were effectively translated into savings over the 14-month period.

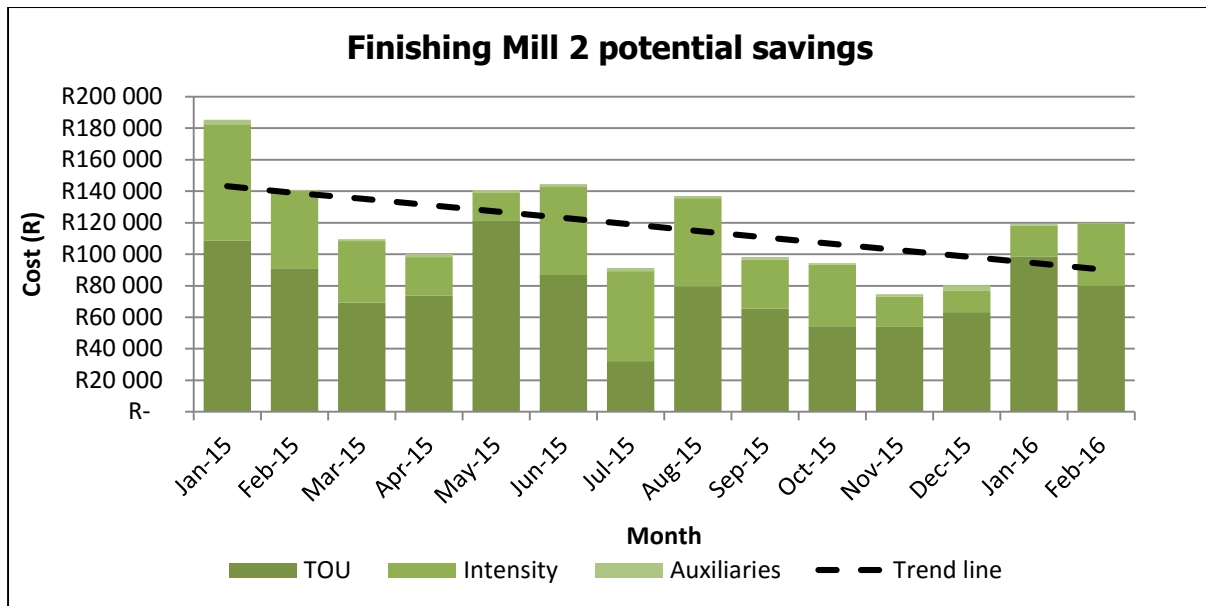


Figure 34: Finishing Mill 2 monthly savings missed over evaluation period

An additional opportunity that was identified was the possibility of a Section 12L tax deduction on Finishing Mill 2, as the energy consumption thereof improved from one year to the next. The energy management system ensured that the required metering points were available and compliant, and that the relevant documentation was kept on record. A 12-point regression model for Finishing Mill 2 was compiled, which is presented in Figure 35. From this model it was calculated that the 7.06 GWh quantifiable saving qualified for a Section 12L tax deduction application.

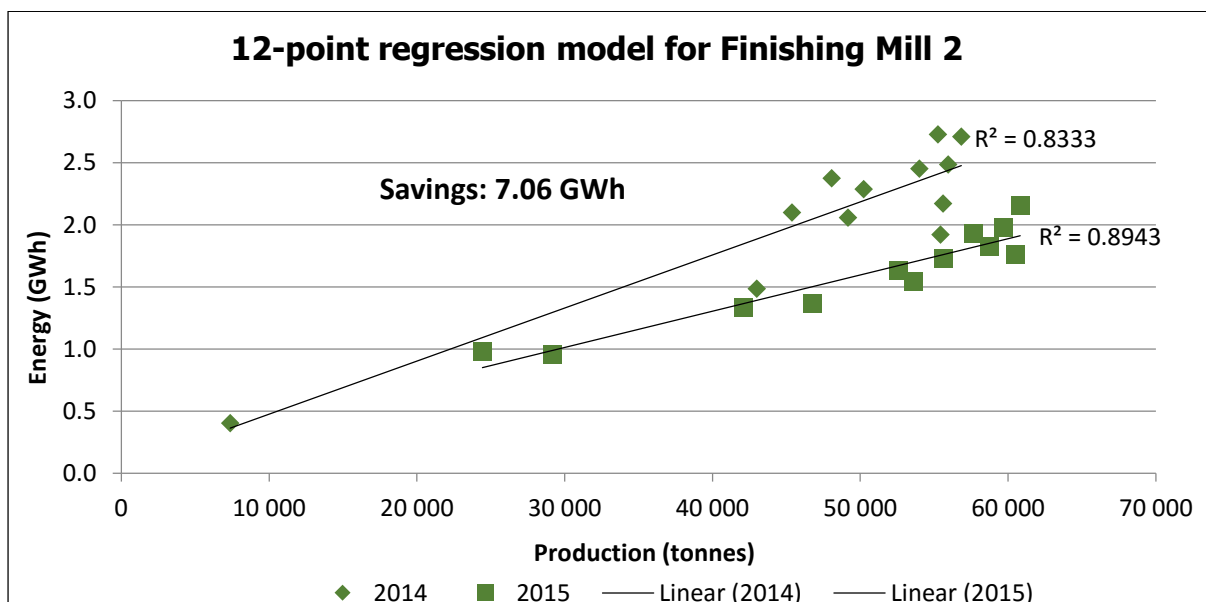


Figure 35: Finishing Mill 2 Section 12L 12-point regression model

As part of Section 12L compliance, it was necessary to also evaluate an alternative model to determine the claimable savings. A year-on-year energy intensity comparison was done, which is presented in Figure 36. From this model, a 7.09 GWh claimable saving for a Section 12L tax deduction was found.

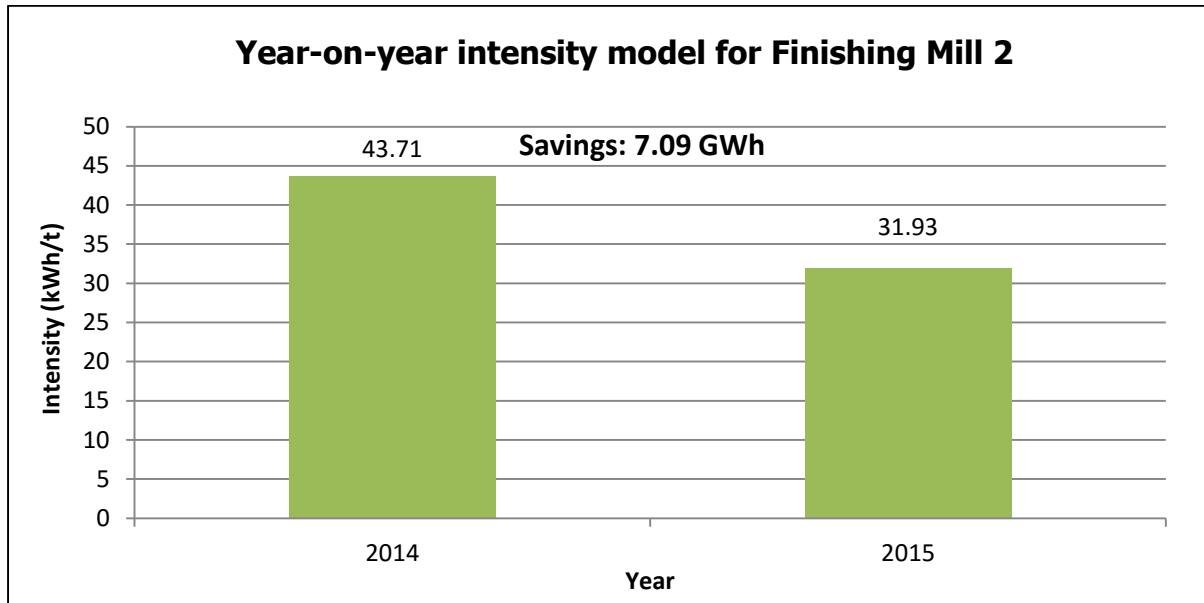


Figure 36: Finishing Mill 2 Section 12L intensity model

According to Section 12L regulations, the most conservative model has to be used to claim a tax deduction. The most conservative model was thus the 12-point regression model as this indicated the smaller saving of 7.06 GWh. At a claimable rate of 45 c/kWh, as discussed in Section 2.5.1, the plant qualified for a tax deduction of R3 177 000 for the improvement in energy efficiency of Finishing Mill 2. This amount was considered an additional saving achieved from implementing the energy management system, and not a direct opportunity that was used. It will thus not be considered as part of the effect of the energy management system.

4.3.5. GENERAL EnPIs

In Section 3.2.7, four important EnPIs for cement plants were identified, namely, “*Clinker production*”; “*Total energy per clinker produced*”; “*Total energy per cement produced*”; and “*Cement manufacturing*”. The calculations for these EnPIs were given in Equation 4 to Equation 7 (Section 3.2.7). This section discusses the results obtained for these EnPIs. The kiln was only operational for certain months during the implementation period, as listed in Table 10, which affected the data available for “*Clinker production*” and “*Total energy per clinker produced*”. These parameters were thus disregarded for the comparison of the EnPIs in January 2015 versus February 2016 in Table 12.

Table 12 compares the performance of the plant recorded in the first monthly report that was sent out for January 2015 with the last monthly report that forms part of the implementation period for February 2016. The first EnPI that is compared is “*Total energy per cement produced*”, which reduced by 14.33 kWh/t. This indicates a clear improvement in the electrical energy required to produce a tonne of cement, and shows that the energy management system positively contributed to the electrical energy usage of the plant.

The main focus of the results obtained from implementing the energy management system was on the finishing mills, as they were identified as the largest consumer from Figure 24. The biggest improvement on the cement plant is thus seen in “*Cement manufacturing*” with a reduction of 8.89 kWh/t. The fact that there is still a difference of 5.44 kWh/t between the total electrical energy intensity improvement and the electrical energy intensity improvement of the finishing mills serves as an indication that there were also improvements on the rest of the plant. This is most likely due to savings obtained through improved awareness and unnecessary wastages recorded in the reports.

The final indicator presented in Table 12 is the “*Cost per cement produced*”, which refers to the cost of electrical energy required to produce a tonne of cement. As seen from this summary, the cost reduced by R8.61 per tonne. This EnPI can be viewed as the key evaluation of the success of the system implementation, as its aim was improving the profitability of a cement plant by managing its electrical energy more effectively.

Table 12: EnPIs before and after system implementation

Parameter	Jan-15	Feb-16
Total energy per cement produced (kWh/t)	65.23	50.90
Cement manufacturing (kWh/t)	46.36	37.46
Cost per cement produced (R/t)	R34.30	R25.69

To better quantify the improvement in the profitability of the plant due to electrical energy management, the average monthly production of Plant X was calculated. This production figure was used to calculate the average monthly cost saving that could be achieved if the same energy performance and average monthly production were maintained. The average monthly production was calculated as 62 351 tonnes, and the average possible monthly cost saving that could be achieved was calculated as about R537 000, as indicated by Equation 8. This was based on the summer billing period. As discussed later (Figure 38), the evaluation of the winter periods did not indicate the same success due to different operational conditions. If this saving is thus considered as sustainable for the nine summer months in a year, then it translates to a possible saving of about R4.8 million per annum.

Equation 8: Average future monthly cost saving

Average future monthly cost saving

$$= (\text{Average monthly production}) \times (\text{Cost reduction per cement produced})$$

$$\text{Average future monthly cost saving} = (62\,351 \text{ tonnes}) \times (R8.61)$$

$$\text{Average future monthly cost saving} \approx \mathbf{R536\,840 \text{ per month}}$$

The reduction in the cost of electrical energy per tonne cement produced can be seen as the main indicator of the success of implementing the developed energy management system. The cost improvement achieved by the system was also discussed by using Table 12. Due to TOU tariff differences in summer and winter, as well as the different production periods of clinker, the cost per cement produced was split up into two separate graphs.

Figure 37 presents the “Cost of electrical energy per tonne cement produced” for the summer months included in the evaluation period. These months were further split into months where the kiln was operational, and months that it was not, as listed in Table 10. The trend lines for both cases decrease over the evaluation period, indicating the positive effect of the energy management system. The trend line for the months where clinker was produced is clearly higher than the trend line where clinker was not produced, which is as expected.

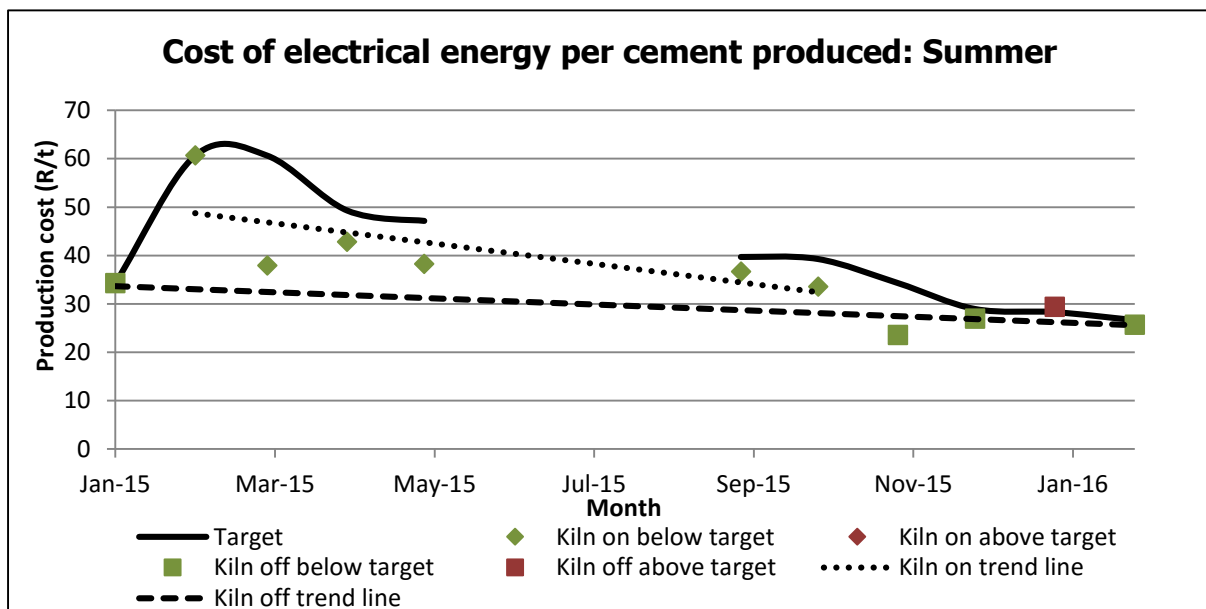


Figure 37: Improvement of electrical energy cost (summer) per tonne cement (R/t)

The same illustration is given for the “*Cost of electrical energy per tonne cement produced*” during the winter months of the evaluation period, as shown in Figure 38. The month where the kiln was operational is again clearly more cost intensive than the months where it was not operational, which is as expected. The trend line for the months where the kiln was off, however, increases slightly, indicating an increase in the cost of electrical energy required to produce a tonne of cement. This is a bit concerning, and has to be noted for future winter periods.

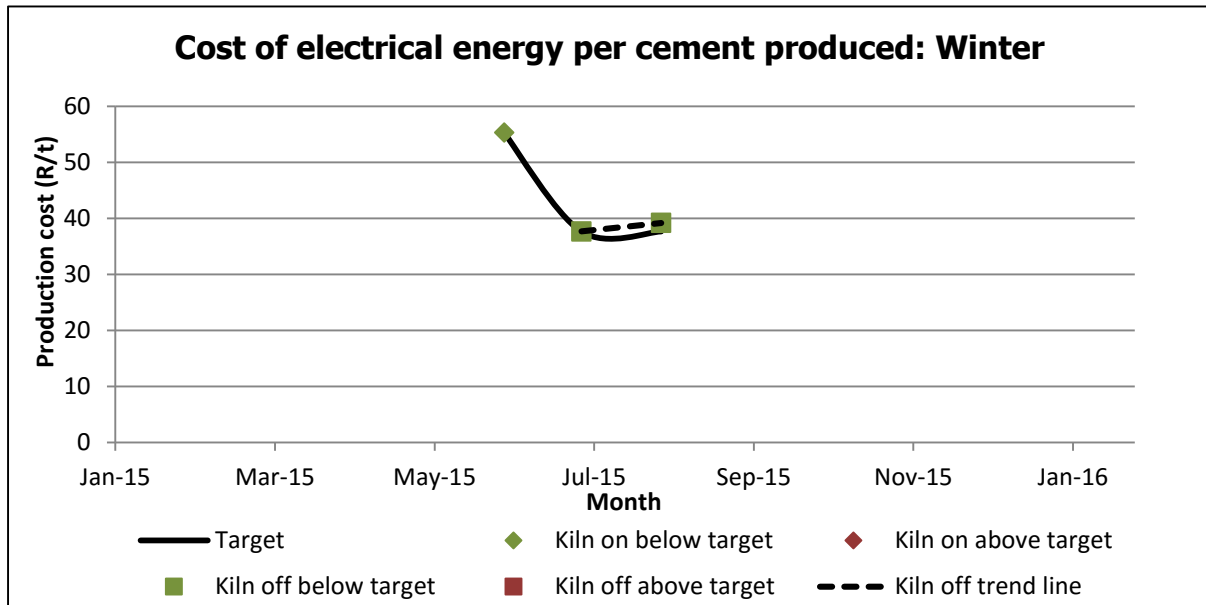


Figure 38: Improvement of electrical energy cost (winter) per tonne cement (R/t)

Additional EnPIs as discussed in Section 3.2.7 are discussed in Appendix H. These EnPIs include “*Clinker production*”; “*Total energy per clinker produced*”; “*Cement manufacturing*”; and “*Total energy per cement produced*”.

4.3.6. REPORTING SYSTEM

The data used for the results presented in this chapter was summarised from the reports that were sent to the personnel of Plant X. The reports contained this and additional information regarding the total plant electrical energy consumption. As mentioned previously, the reports are the most measurable indication of the effect of the implementation of the developed energy management system. An example of the monthly report that was distributed for February 2016 is presented in Appendix F, and an example of the weekly report that was distributed for the last week in February 2016 is presented in Appendix G.

The qualitative aspect of the automated reporting system was validated based on consultations with personnel involved with Plant X, as presented in Appendix C, and discussed in Section 2.5.7 and Section 3.3.3. From these discussions, it was indicated that the feedback

reports were investigated by the recipients on a regular basis. A group discussion of the reports was done on a biweekly basis during the operational meetings, during which concerns regarding the report were pointed out and addressed by various plant personnel. The reports thus provided the cement plant personnel with a basis for discussing the energy performance of the plant, and making relevant changes to their planned operating procedures.

There were often enquiries regarding the information provided in the reports, upon which the ESCo was contacted and the problems resolved. These problems mainly arose from data quality issues, or misinterpretation of the report. Misinterpretations were attended to and the report was adapted according to the plant personnel's suggestions. The system was thus continuously improved by ensuring that it was effective in a practical environment. It was further indicated that the main indicators in the report were the intensity (kWh/t) and TOU figures. These are also reflected in the improvements achieved in terms of production rate and the intensities of the finishing mills in Section 4.3.3.

It was, however, pointed out that indicators such as the missed opportunities did not play a big role in the plant operations. The process engineer reported that the feedback system was still quite new and that it was used at a very high level. He did, however, indicate that he could see the value in such indicators, and that they would become a greater focus point as soon as the basic operational procedures were in place more effectively. The plant also indicated that they did not want to remove these indicators as they are a good method for comparing the performance of different periods and preventing a decline in performance.

The technical advisor indicated that different people interpreted different aspects of the reports, depending on the information that they valued most. He specifically used the trends that equipment followed and the operational conditions of equipment more. The reports added value to his work by enabling him to identify opportunities for new projects and to be able to compare the performance of equipment before and after changes to operations were made. He said that older reports served as baselines for the performance of equipment, and that he was able to improve the performance of equipment by using the reports.

Ultimately, it was indicated that the reports were beneficial to the electrical energy management of the plant, and that they were a useful tool for improving cost savings. The general management methods placed more focus on the operational performance and productivity of equipment, rather than the energy management thereof. Feedback and recommendations on the energy performance would thus benefit the plant greatly. It was reported that the feedback led to taking advantage of cost saving opportunities and eliminating unnecessary wastages. It also assisted with performance monitoring and the identification of inefficient equipment.

The two qualitative studies that were done among personnel at Plant X are considered as sufficient samples to determine the effect that the energy management system had on the plant as these are the personnel who were mostly involved with the system implementation. The process engineer was the main contact person, who was also the main energy manager of the plant. The technical advisor was more involved with the practical aspects of the plant, and was involved with the practical set-up of the systems to obtain the data. They were both primarily involved with different aspects of the plant and had different approaches to the work that they do. Additionally, the discussions with ESCo personnel and the engineering manager of Plant Y also indicated similar results.

4.4. INDUSTRY IMPLEMENTATION

The final purpose of this study is to improve the profitability of multiple cement plants. Due to multiple differences in the energy usage and billing between cement plants in different countries, it was decided to focus on the effect that implementing the system can have on older South African cement plants. The production capacity of the plants in South Africa owned by PPC, AfriSam, NPC and Lafarge (as they were described in Section 1.2.1 as the older cement manufacturers) is about 16.9 million tonnes per annum [59]. This amounts to about 1.4 million tonnes per month. If the achieved improvement of R8.61 per tonne cement is achieved at all of these plants, then a saving of about R12.1 million per month can be achieved on the older South African cement plants. This translates to about R145.2 million per annum.

4.5. CONCLUSION

This chapter served as the results chapter of the study, and was mainly based on summarising data obtained from the developed reporting system. It can thus be seen as the validation of the methodology. The energy management system developed in Chapter 3 was implemented on an older cement plant in the Gauteng province of South Africa. The main focus of the results was on the improved performance of the two finishing mills on the plant. The plant also has a kiln that occasionally produces clinker when it is essential to do so. Examples of the monthly and weekly reports are given in Appendix F and Appendix G.

The discussion started by providing background on the plant where the energy management system was implemented. An electrical energy consumption distribution graph based on the first monthly report was used to identify the largest consumers on the plant as the finishing mills. Based thereon, the focus of the results was placed on the energy performance of the finishing mills. The “*Production rate (t/h)*”; “*Intensity (kWh/t)*”, “*Cost intensity (c/kWh)*”; and “*Production cost (R/t)*” of the two mills were listed for January 2015 along with the set targets.

These results were also presented graphically as monthly averages for the 14-month evaluation period. The potential savings of the mills were also presented.

The effects of the improved performance of the finishing mills were thereafter evaluated by considering certain EnPIs. These figures were compared for January 2015 (before implementation of the system) and February 2016 (last month in the evaluation period). It was found that the electrical energy performance of the plant improved when comparing these months. These indicators included “*Total energy per cement produced (kWh/t)*”; “*Cement manufacturing (kWh/t)*”; and “*Cost per cement produced (R/t)*”. The figures were also accompanied by graphs of the monthly performances of the evaluation period (some of which are discussed in Appendix H).

The main EnPI of the success of the implementation of the system on Plant X was identified as the “*Cost per cement produced (R/t)*”, as the aim of the system was improving the profitability of cement plants. From the results it was seen that this figure improved by R8.61 per tonne when comparing the first and last months of the evaluation period. The possible cost saving that could be achieved from the improved performance if it is maintained was resultantly calculated as about R4.8 million per annum. This is an indication of the success of the implementation of the energy management system, and how it contributed to improving the profitability of Plant X by managing its energy performance.

Additional to the quantitative validation that was done based on the savings that were achieved, a qualitative validation of the developed system was done from consultations with personnel involved with cement plants. These discussions served as validation that the implementation of the methodology on the plant led to energy cost savings, and that the cement plant personnel recognised the value of the report in a practical environment. The methodology developed from research and literature was thus confirmed to be a valid method for improving the profitability of a cement plant by focusing on energy management.

In order to achieve the goal of improving the profitability of cement plants, and specifically older cement manufacturing plants in South Africa, the energy management system can be implemented on other plants as well. The system proved to not only assist with energy management, but also to identify problems with the production performance. The main focus of cement plants is usually improved production, while energy management is neglected. This system, however, combines the two aspects and resultantly focuses on improving energy management while also considering the production performance.

Chapter 5: Conclusion

The last chapter of this dissertation serves as a conclusion to the study. An overview of the procedure that was followed and the results that were obtained will be given. The results will be evaluated in order to determine the success of the developed system, and whether or not the objectives stated in Chapter 1 were reached. Recommendations will also be made for future work.

5. CONCLUSION

5.1. INTRODUCTION

This chapter serves as the conclusion of this dissertation and will summarise the matters discussed in the preceding chapters. The problem statement will first be revisited, whereafter the nature of the literature study will be discussed. The methods used during the development of the energy management system will then be mentioned, along with how ISO 50001 was used to verify the methodology. The effect that the implementation of the developed energy management system had on Plant X will then briefly be revisited as it is the validation step of the study. Opportunities for possible future work will also be addressed.

5.2. OVERVIEW OF THE STUDY

The problem identified during the initiation of this study was that the cement industry in South Africa has become more competitive. Thus, there is a need for the older cement plants to improve their profitability. It was indicated through literature that an improvement of the energy management on a cement plant would lead to an improvement in the profitability thereof. This would enable the plant to improve and maintain its competitiveness in the market.

The background and literature survey investigated the operation of a cement plant along with the main energy sources and the expected energy performance of the equipment. Previous research on cement plants and electrical energy management were also investigated. Qualitative evaluations by means of consultations with personnel involved at different cement plants (Appendix C) were used to determine what methods of energy performance feedback and evaluation are available on cement plants in South Africa.

The suggested solution was to develop and implement an energy management system that focuses on the feedback reporting of electrical energy usage of a cement plant. It was decided to use the PDCA approach, which forms part of in the ISO 50001 framework, as a foundation for developing the energy management system.

The methodology was developed and discussed in Chapter 3, with ISO 50001 used as the main verification by comparing the framework with the developed system throughout the discussion. Additional verification of the system was done by using a self-assessment checklist, as discussed in Appendix E. The final component that served as verification for the developed system was the qualitative consultations with personnel of different cement plants. The main and most measurable outcome of the system was identified as the monthly and

weekly reports that were sent to the plants, as presented in Appendix F and Appendix G respectively.

The essence of the system is that it captures data from different sources and sends it to a centralised data hub. The data is then processed into valuable information and graphical representations of the performance of the plant equipment. The entire plant is investigated in detail, and areas that require attention are highlighted. The electrical energy consumption of the entire plant is thus monitored and reported. The reports are then automatically sent to a predefined recipient list on a weekly and monthly basis.

The reports were compiled in such a way that they provided summarised information regarding the sections of the plant in general. From this summary, the largest energy consumers on the plant could be identified and considered in detail. EnPIs were identified for the specific equipment with continually adapting benchmarks (based on feedback from the previous performance) set for the operation of the equipment. The main indicators considered were the production rate, energy intensity, cost intensity and production cost of the equipment. This made it possible to identify opportunities for additional savings as well as identify potential risks. These reports thus enable plants to simultaneously monitor the energy consumption and production of the plant.

The validation of the study was done by implementing the methodology on Plant X, one of South Africa's older cement plants. A case study was investigated in detail over a long evaluation period, which made it possible to assess the value of the study in practice. The results were presented based on data obtained from the monthly reports that were sent to the plant. The effect of the system was evaluated over a 14-month period by considering certain EnPIs of the plant and its major equipment.

The critical performance indicator that summarises the success of the study was identified as the change in price per tonne cement produced. From the results it was seen that this indicator improved by R8.61 per tonne. The effect of this improvement was calculated as a saving of about R4.8 million per year if the performance is maintained. The qualitative consultations with personnel at Plant X were used again to confirm that the developed system contributed towards these savings, which serves as a qualitative aspect of the validation.

The developed solution thus contributes towards reaching the stated research objectives of improving the profitability of cement plants by focusing on the electrical energy management. Research was done to identify current methods available to manage electrical energy in various industries, and a methodology was compiled to achieve this at cement plants. By using the stated additional ISO 50001 tasks along with the developed system, it should be able for a plant to achieve ISO 50001 compliance.

The dissertation investigated various energy management methods from literature and qualitative assessments, and compiled an energy management system that focuses on energy performance feedback. The energy management system used the PDCA approach of the ISO 50001 framework as foundation. The automated reporting enabled Plant X to identify missed opportunities and areas that require improvement, and to monitor the utilisation thereof. It was proven that the system can make cement plants in South Africa more profitable by considering their electrical energy management.

Throughout implementing the study and recording the work that was done, a few areas where further research is required were identified. These aspects were beyond the scope of this study, or required additional work to be more effective. These aspects are briefly discussed in the following section. Manners in which the energy management system developed in this study can be continued are also briefly mentioned.

5.3. RECOMMENDATIONS FOR FUTURE WORK

The first area that was identified for future work is an online communication database that employees can use to submit their energy management ideas. The purpose of this database is to provide a method for all personnel to be able to submit their initiatives for energy efficient initiatives. These ideas will then be evaluated and investigated further to determine their feasibility. Operational staff is more involved with the actual operation of equipment, but do not always have the means to implement changes. Such a database will enable them to do this. At the moment this is done verbally, and does not always follow the required steps to be evaluated.

The next area that was identified as work that requires further research is a study regarding plant benchmarking. Section 2.3.6 briefly mentioned a few methods that could be used when setting targets for the performance of the plant, and a basic method was derived from these options. Extensive research can, however, be done on setting proper targets for the performance of equipment. The energy usage targets can be combined with the production targets or targets can be implemented based on the sales forecasts. The main goal of this research would be to develop a budgeting system that set realistic goals for the performance of the plant, while still promoting continuous improvement.

The next suggestion is to improve the calculation of TOU savings by including maintenance schedules and production demand. At the moment, the TOU savings are calculated by determining how many peak and standard used hours can be moved into unused off-peak hours. This is, however, not a completely accurate portrayal of the possible savings that could be achieved by improved load shifting as maintenance schedules and production demand

often force the plant to operate during more expensive periods. The goal of such a study would thus be to develop a method that calculates a more realistic saving that could be achieved due to improved load shifting.

Incorporating the management of other energy sources used on a cement plant, as presented in Figure 6, into the developed system will also be beneficial. It was seen from Figure 1 that coal is the largest source of energy on a cement plant. It would thus be beneficial to incorporate this more efficiently into the energy management system and monitor it closer. This will also assist when preparing for a Section 12L tax deduction investigation as most of the savings are likely to originate from an improvement in coal usage. The installation and record-keeping of calibration of meters measuring coal usage can then also be improved.

Another matter that would be beneficial as part of risk identification in the energy management system is a model that predicts electricity price increases and how they affect a specific plant. In this study, the risk of increases in electricity prices were discussed briefly, and it was mentioned that the announcement of price increases will be used to predict the future cost of electricity. It would, however, be beneficial to predict this risk even further into the future, in which case the price increase will have to be predicted long before the announcement date. Predictions regarding cement demand and historical energy usage data can then also be included in the prediction model.

The reporting aspect that was developed as part of the energy management system focused on weekly and monthly reports. From the comparison of these reports, it was seen that a different reporting interval benefits from different information and graphs. Developing an annual report that summarises the performance for the entire financial year will thus also take some time and discussions with plant personnel. Such a report can then be used for energy planning for the next financial year, and can be useful when developing prediction models. Such information can also be used for budgeting purposes.

A further improvement of the system would be to implement the performance reporting onto a web interface and to transform it into a real-time performance evaluation system. This will enable operators to monitor in real-time what the effects of their actions are, and to notice when their actions affect the energy performance of the plant negatively. This can also be used in combination with a budgeting system, where it can be seen on a more regular basis where operations deviated from the desired performance, and how far they are from reaching the daily targets.

The aim of this energy management system was to improve the profitability of cement plants. It was proven that that the system could do this at Plant X for the period of the study. It is thus recommended for future work to determine the long-term benefit of the system at Plant X,

while it does not form part of such a study. This will serve as an indication of the sustainability of the performance of the system.

The system was also designed to be adaptable for other plants as well. To reach the final goal of actually improving the profitability of older cement plants in the country, it is necessary to physically implement the system on these plants as well. By managing the energy performance of more plants, the cement industry would become more profitable, which will also positively affect the economy as pointed out in Section 1.2.1.

5.4. CLOSURE

Thus, after revisiting the stated problem and objectives of the study, and considering the improved performance discussed above, it can be stated that the study did contribute towards solving the stated problem. The aim of this study was to develop an energy management system that could be used to improve the profitability of cement plants. This was done based on the ISO 50001 framework, and it was proven that the profitability could be improved by the developed system. Energy management can thus be used to improve cement plant profitability, and thus assist older cement plants in remaining competitive in the current market.

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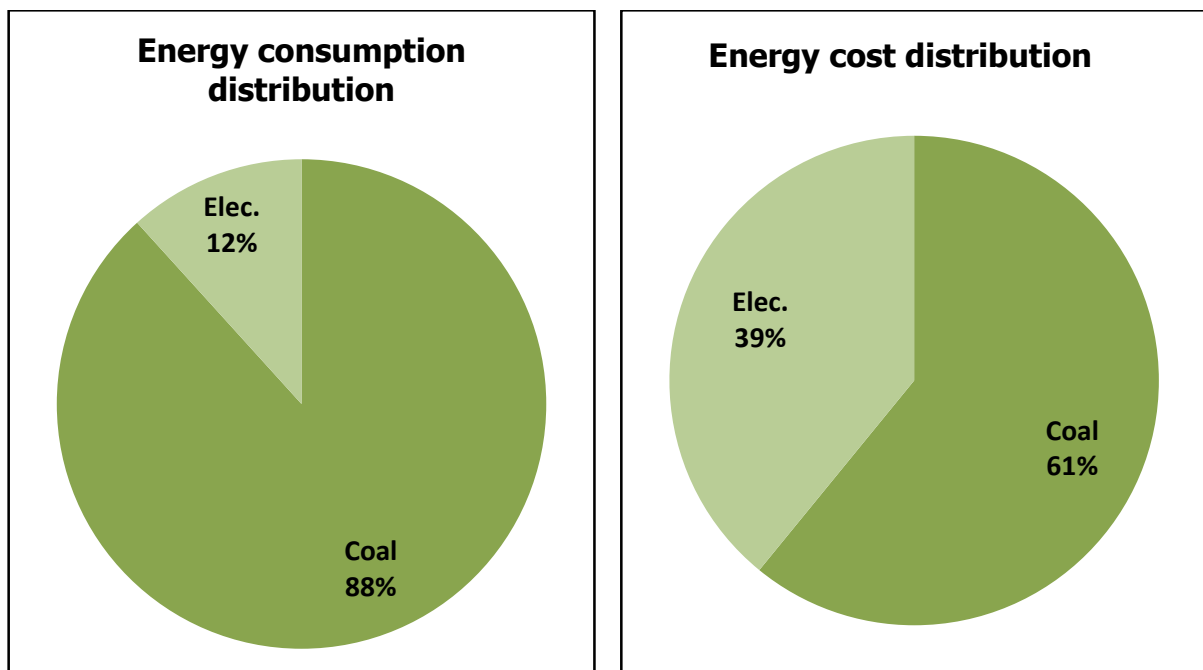
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Appendices

The appendices contain additional information for the study, as referred to throughout the dissertation. This information contributes to the knowledge and background of the reader, but did not necessarily contribute to the flow of the document.

APPENDIX A: ENERGY COST AND CONSUMPTION DISTRIBUTION

This appendix presents the process that was used to obtain the data presented in Figure A 1 (first presented in Figure 3 in Section 1.2.3). This figure indicates that even though 88% of the energy consumed on a cement plant is obtained from coal, it only makes up 61% of the cost. This data was obtained by using actual data of a South African cement plant, of which the name is withheld due to confidentiality reasons. This appendix presents the origin of this data and how it was processed in order to portray the information in this figure.



a.) Energy consumption comparison

b.) Energy cost comparison

Figure A 1: Electricity versus coal

A.1. COAL DATA

The data was used for one financial year of the cement plant. In order to determine the energy produced by the coal consumed it was necessary to obtain the tonnes coal consumed, as well as the average calorific value of the coal for the specific period. Calorific value is measured in GJ/t, making it possible to calculate the GJ value of the energy obtained from the coal. In terms of energy, 1 Watt is equal to 1 J/s. GJ can thus be converted to kWh by multiplying the GJ value by (1000/3.6), as indicated in Equation A 1.

Equation A 1: GJ to kWh conversion

$$kWh \text{ value} = (GJ \text{ value}) \times \frac{1000}{3.6}$$

The tonnes coal consumed during each month of the financial year, along with the average calorific value and calculated coal energy value is as presented in Table A 1. It is seen that the total energy consumed through coal consumption is 1.36 GWh for the year.

Table A 1: Coal consumed energy value

Month	Coal consumed (tonne)	Calorific value (GJ/t)	Coal consumed (kWh)
Oct-14	17 701	24.35	119 746 539
Nov-14	17 582	24.87	121 482 699
Dec-14	13 641	25.83	97 888 673
Jan-15	16 288	25.26	114 286 671
Feb-15	16 230	24.20	109 091 862
Mar-15	16 540	24.48	112 487 316
Apr-15	20 917	24.50	142 359 053
May-15	20 407	24.29	137 677 257
Jun-15	11 534	24.69	79 114 269
Jul-15	10 845	25.50	76 807 632
Aug-15	16 639	25.13	116 146 244
Sep-15	18 979	24.78	130 637 769
Total	197 303		1 357 725 985

By making use of the South African coal export price^{A.1} for each month of the financial year, as well as the tonnes coal consumed, the cost of the coal consumed for each month of the financial year was estimated. This amount was calculated as about R143 million for the financial year, as indicated in Table A 2.

Table A 2: Consumed coal cost

Month	Coal consumed (tonne)	Coal cost (R/t)	Coal cost (R)
Oct-14	17 701	R727.75	R12 881 902.75
Nov-14	17 582	R729.15	R12 819 915.30
Dec-14	13 641	R758.00	R10 339 878.00
Jan-15	16 288	R719.60	R11 720 844.80
Feb-15	16 230	R732.94	R11 895 616.20
Mar-15	16 540	R733.99	R12 140 194.60
Apr-15	20 917	R713.01	R14 914 030.17
May-15	20 407	R740.60	R15 113 424.20
Jun-15	11 534	R749.87	R8 649 000.58
Jul-15	10 845	R710.85	R7 709 168.25
Aug-15	16 639	R702.30	R11 685 569.70
Sep-15	18 979	R700.26	R13 290 234.54
Total	197 303		R143 159 779.09

A.1 <http://www.indexmundi.com/commodities/?commodity=coal-south-african&months=60¤cy=zar>

A.2. ELECTRICITY DATA

The electricity data was obtained from the Eskom bills for the specific plant. From the summary of the electricity cost and consumption of the plant in Table A 3, the total electricity consumption for the financial year is 180 GWh, while the electricity cost is almost R92 million.

Table A 3: Electricity consumption and cost

Month	Electricity consumed (kWh)	Electricity cost (R)
Oct-14	11 504 947	R6 938 569.09
Nov-14	64 676 003	R6 840 332.52
Dec-14	9 124 464	R5 671 208.41
Jan-15	10 516 897	R6 403 655.00
Feb-15	10 211 812	R6 265 059.07
Mar-15	10 951 481	R6 690 472.42
Apr-15	11 166 799	R7 461 742.21
May-15	11 074 300	R7 435 034.64
Jun-15	9 471 136	R9 747 800.12
Jul-15	8 947 897	R9 553 060.62
Aug-15	11 565 384	R11 311 493.00
Sep-15	11 090 833	R7 585 654.93
Total	180 301 953	R91 904 082.03

A.3. COMPARISON

Upon comparing the consumption and cost for the two sources of energy, the ratio of consumption to cost was calculated for each source. This provided a R/kWh value, which makes it possible to compare the price of the two energy sources. These ratios were calculated as R0.11/kWh for coal, and R0.51/kWh for electricity. By dividing these figures, it is calculated that the cost of electricity is about 4.83 times higher than that of coal. This motivates that the management of electrical energy is a critical component of energy management on a cement plant, even though it only contributes to 12% of the energy consumption of the plant.

APPENDIX B: CEMENT PLANT COMPONENTS BACKGROUND

This appendix provides more information about specific cement plant equipment, as discussed in Chapter 2. The information is not critical to the study, but will enhance the reader's background knowledge for a better understanding of a cement plant. The information is thus presented in the form of this appendix, as it is not essential, but still valuable information. Some of the information might be repeated to fit into context.

B.1. RAW MILLING

As mentioned in Section 2.2.3, detail regarding the approaches of raw meal to be used in the raw mills is discussed in this section of the appendix.

The choice of raw mill is generally based on a few deciding factors. These factors include the moisture factor of the raw material, the level of energy that is consumed, the reliability of the equipment, and the size of the plant [30]. The raw meal can further be prepared by either wet or dry processing. If the raw materials contain more than 20% water, wet processing is usually recommended. During this process water is included in the grinding of raw material, producing a slurry that contains between 24% and 28% water. The wet materials increase the fuel consumption of the kiln, which is why various degrees of wet processing are used to reduce the moisture levels. This process is less efficient, but it will reduce the dust resistivity in the kiln and raw mill [19].

During dry processing, the raw materials are ground into an even powder. In order for raw meal to be fed to a dry kiln, the moisture content should be about 0.5%. The raw meal can be dried further by making use of kiln exhaust gases; the clinker cooler vent; or auxiliary heat from an air heater. This type of raw material processing can be done in either a ball mill or a VRM [19]. Dry-kiln processing, making use of the dry feed from the raw mill, is more energy efficient. The exhaust gases from the kiln can also be reused for the drying process, resultantly saving even more energy.

B.2. FUEL PREPARATION

As mentioned in Section 2.2.4, additional information for the preparation of kiln fuels are presented in this section of the appendix.

The flame in the kiln is necessary to produce clinker, the main component of Portland cement [19], [30]. Various materials, for example, petroleum coke, coal, natural gas, recycled materials or oil can be used to fuel this flame, although poor environmental performance and opposition from society sectors opposes any form of thermal waste treatment in South Africa [34]. The

fuel preparation for the kilns in South Africa thus focuses mainly on the preparation of coal, which is done by making use of coal mills. Coal milling usually also makes use of a ball mill, similar to the illustration in Figure 5.a, and uses coal, coke and pet coke with the different sized balls [21].

The coal can be fed to the kiln during this process by making use of three different methods. The first of these methods is direct firing [60], which is also the most commonly found. By making use of direct firing, there is no silo between the mill and the kiln, and exhaust gases from the kiln is used to convey the coal. Advantages of this method include the low construction cost, simple operation, and simpler equipment that are used. This method, however, causes the kiln to be directly dependent on the coal mill. Maintenance on the coal mill will thus result in a forced kiln stoppage. The coal feed to the kiln can also not be controlled as accurately as desired.

The second method that can be used for fuelling a kiln is semi-direct firing [60], during which the coal is conveyed by gas into the kiln. A screen is used to ensure that only fine coal is included in the gas passing through the kiln. This causes the gas to be much more reactive, and thus more efficient. The third method used is indirect firing [60], during which the fine coal is stored before being fed to the kiln. This method is preferable for accurately controlling the feed [60], and effectively performing load management on a coal mill [37]. A direct firing coal mill can be remodelled to an indirect firing coal mill, but this increases the precautions that have to be taken in order to prevent an explosion of stored coal powder [60].

B.3. BURNING

As mentioned in Section 2.2.5, additional information on the burning section and kilns are presented in this section of the appendix. This is due to the fact that this section mainly consumes energy from sources such as coal, whereas this study focusses on the management of electrical energy.

The burning process in cement manufacturing is also often referred to as clinkering, and includes the process of converting raw material into clinker. Clinker is the main component of Portland cement, and is produced by pyro-processing (a chemical or mechanical change in material caused by high temperatures) in a kiln. Kilns have been reported to be the most important component in cement manufacturing, with clinkering being the main step in the process. The fuel used to heat the kiln is also the largest contributor to energy consumption on a cement plant [19], [30].

As mentioned in Chapter 1, this study does not focus on the management of energy obtained from coal, even though it is the largest contributor of energy consumption on a cement plant.

Different kiln technologies are, however, discussed in this appendix. This contributes to a better understanding of the cement manufacturing process. Improving the energy efficiency of a kiln usually requires major equipment upgrades, while this study focuses mainly on managing energy usage and identifying opportunities for improvement. This is done for the kiln by identifying the most efficient technology that can be installed when upgrading or replacing outdated equipment.

The benchmarking of equipment in Section 2.3.4 serves as a measure to determine how effective the current equipment is working, and whether it is necessary to consider upgrading it. Various types of kilns are used to produce clinker, which can mainly be split into wet- and dry-process kilns, and vertical or rotating kilns. Most vertical kilns have been replaced by rotating kilns, due its high production cost, higher heat consumption, and the lower grade cement produced by its clinker [61]. These types of kilns will thus be left out of this discussion. Rotating kilns are metal tubes lined with ceramic tiles, with a horizontal slope of about three to four degrees. As the tube slowly rotates, the raw material moves towards the direction of the flame at the lower end of the tube [30].

Rotating kilns can typically have a diameter of up to 8 meters [30], with the length of the kiln varying depending on the type of kiln and supporting heating components that are installed. A short kiln will have a length of 10 to 20 times its diameter, while a long kiln can have lengths of between 32 and 35 times its diameter [30]. The combustion gas (mostly coal in South Africa, as discussed in Section B.2) reaches temperatures of between 1 800 °C and 2 000 °C during operation [19]. The flame provides the temperature needed for the chemical reactions that lead to the raw meal transforming to clinker.

The difference between wet- and dry-process kilns is based on the classification of the raw material feed. The classification is based on the moisture content of the raw material, with the raw meal for a wet-process kiln containing approximately 36% moisture. Wet-process kilns were designed to improve the chemical uniformity of the raw meal. This method resultantly also improved the energy consumption of the crushers, as the higher moisture level caused the raw meal to have slurry-like characteristics. This, however, led to an increase in the overall energy consumption due to water that needs to evaporate from the slurry [19].

The wet-process kilns had to be designed as long kilns, as the water was evaporated in the cooler part before clinker could be formed closer to the firing end. Even though this method is still in use it has been replaced by dry-process kilns in most cement plants. The preference of the dry-kiln process over the wet-kiln process came after the improvement of grinding processes, specifically in terms of their energy consumption. The dry-kiln process thus had

more advantages in terms of energy consumption, as the raw meal did not have to be dried first before it could be transformed to clinker [19], [30].

The use of dry raw meal with a lower moisture content of about 0.5% meant that the kilns could be much shorter, as the moisture evaporation stage of the raw meal was eliminated [19]. A shorter kiln has the ability of producing more tonnes per day [30], which makes it more effective in terms of production rate. Additions to dry-process kilns that assist in making it more energy efficient are the multistage cyclone preheaters. These cyclones are stacked above each other in towers, and use large fans to induce a draught that extracts heat from the kiln to the raw meal. This heats the raw meal before it enters the kiln, and assists the calcination process by reusing lost thermal energy from the kiln [19], [30].

A later addition to the preheaters is the precalciner, which also makes use of fossil fuels to heat the raw meal before it enters the kiln. A precalciner is in the form of a combustion chamber installed between the preheater and kiln. Such combustion chambers have been reported to use about 60% of the fossil fuel that a kiln uses, while between 80% and 90% of the calcination takes place in it [30]. The addition of such a precalciner enables plants to reduce kiln lengths, which in turn increases the production rate even further. The energy consumption of a kiln is also reduced by between 8% and 11% by adding these systems [30].

The last step in the clinkering process is to rapidly cool the clinker produced by the kiln, as this contributes to the hardening properties of the cement. This is usually done by the flow of cool air over the clinker on a grate or tube [19]. Once the clinker is cooled it can be stored in silos or shipped to other cement plants in order to be grinded to produce cement as an end product. Cement plants sometimes do not have their own burning sections, but rather import clinker and grind it to produce cement. This is often dependent on the demand for cement in the area, as it is quite expensive to operate a kiln and it cannot be started and stopped on a regular basis.

APPENDIX C: QUALITATIVE ASSESSMENTS

This appendix provides qualitative assessments that were filled in based on consultations with personnel at different cement plants and an ESCo. The purpose of this was to firstly evaluate what energy management feedback and evaluation systems were in place before the implementation of the developed system. This was used as part of the literature study in Section 2.5.7. The second motivation behind the assessments was to determine how the developed reporting system contributes to the needs of cement plants, and was discussed as part of the verification of the developed system in Section 3.3.3. Lastly, the effect that the system had on Plant X was also evaluated by making use of the assessments for the validation of the system in Section 4.3.6.

C.1 QUALITATIVE ASSESSMENT 1

This section of the appendix provides a questionnaire that was used as the basis of a consultation with the process engineer of “Plant X”. The questionnaire was filled in based on the consultation.

Questionnaire 1	
Position at cement plant:	Process engineer (Plant X)
How was electrical energy consumption monitored before the implementation of the system?	
No methods for monitoring the electrical energy consumption of the plant were in place. A system is available from where data can be extracted and analysed as required, but this was not done on a regular basis. This is the same database that is used to obtain data for the system.	
How regularly did the plant interpret the feedback reports?	
Upon receiving the reports on a weekly and monthly basis it was interpreted by the recipients. It was then discussed again as part of the biweekly Friday operational meeting. During these meetings concerns indicated in the report were addressed by the entire group in the meeting.	

<p style="text-align: center;">Who made use of the plant feedback reports?</p>
<p>The recipient list for the reports included various personnel, including the plant engineer, process engineer, general manager, electricians, etc. The reports were further interpreted by all of the attendees present in the operational meetings.</p>
<p style="text-align: center;">In how much detail were the reports investigated? (Were only highlighted areas considered?)</p>
<p>The use of the reports was still very new, and it was thus interpreted on a high level. The more it was used, the more detail was considered. Initially it was mainly used to see how the TOU billing periods were utilised, and where areas for improvement existed. Later, the kWh/t figures became critical and were more closely monitored. It was also nice to compare the performance with that of previous weeks and months.</p>
<p style="text-align: center;">Did the indicated missed opportunities and identified saving areas influence the operation of the plant?</p>
<p>The reports were still quite new and the depth at which it was considered increased as time went by. The missed opportunities were considered, but not to such an extent that it influenced the plant operation. With time it will be possible to make use of these indicators, but it is important to first sort out the more basic issues.</p>
<p style="text-align: center;">Did the use of the reports lead to the plant achieving any savings?</p>
<p>The influence of the reports alone did not necessarily contribute toward achieved savings, but it did assist in identifying areas that require improvement. It is very important to achieve feedback on historical performance of energy usage, which is exactly what the reports provide. As the reports are used more it will become more and more valuable.</p>

Are there any additional features that you would like to see implemented in the report?

There are several suggested ideas that can be discussed, some of which include improved comparisons with previous reporting period figures, a more basic summary of whether the reporting period was “good” or not, and also a more real-time energy reporting system. Additionally, it would be beneficial if other energy sources such as diesel and coal consumption were included in the report.

C.2 QUALITATIVE ASSESSMENT 2

The technical advisor of Plant X was also consulted to determine how he made use of the automated reports. The questionnaire was filled in based on the consultation.

Questionnaire 2	
Position at cement plant:	Technical advisor (Plant X)
How was electrical energy consumption monitored before the implementation of the system?	
There were no means of monitoring this, except by obtaining raw data and interpreting the data manually. This was only done if something specific was being investigated.	
How regularly did the plant interpret the feedback reports?	
The reports were interpreted upon receipt, and specific sections were investigated if it was of interest to possible new projects. If we suspected that certain equipment did not perform as desired it was also investigated in the report. The reports were further used in the operational meetings.	
Who made use of the plant feedback reports?	
Everyone who received the reports and who was in the operational meetings was involved with interpreting the reports. Everybody made use of it for different reasons, depending on what your work required of you.	

In how much detail were the reports investigated? (Were only highlighted areas considered?)
I mainly made use of sections that we were busy investigating new projects for. Highlighted areas were also considered for these aspects, but I had more interest in the trends and benchmarks of the equipment. After the implementation of new initiatives, I would make use of old reports to determine the effect. I would also sometimes request data for the baselines in order to evaluate improved performance.
Did the indicated missed opportunities and identified saving areas influence the operation of the plant?
For me it did not really, but I think that other personnel must have considered it in more detail.
Did the use of the reports lead to the plant achieving any savings?
I feel that it did enable the plant to identify opportunities and to increase cost savings.
Are there any additional features that you would like to see implemented in the report?
I am happy with the report as it is. I feel that a lot of work has been done for the development of the reports and that it is at a standard where it is usable for a variety of personnel.

C.3 QUALITATIVE ASSESSMENT 3

The ESCo project manager involved with the implementation of the energy management system at Plant X was consulted in order to establish how she feels the system benefitted the plant. An alternative questionnaire was used for the consultations with ESCo personnel.

Questionnaire 3

What was your involvement at the cement plant?

Project engineer implementing a DSM project for load shifting; project manager at Plant X during the implementation of the energy management system.

What methods for energy performance monitoring were used at the cement plant where you were involved?

SCADA data; power logger database; Eskom bills; GRI reports; M&V performance tracking.

Do you feel that the energy reports could/did lead to energy cost savings at the plant where you were involved?

Yes indeed, the impact of electricity costs versus electricity consumption can clearly be seen for every component as well as for the plant in total. The potential cost savings are also stated which emphasises the opportunity for better energy management.

C.4 QUALITATIVE ASSESSMENT 4

One of the ESCo project engineers involved with the implementation of the energy management system at Plant X was also consulted. The same questionnaire that was used for "Questionnaire 3" was also used in this case.

Questionnaire 4

What was your involvement at the cement plant?

Project Engineer (Plant X).

What methods for energy performance monitoring were used at the cement plant where you were involved?
SCADA and Eskom bills; Weekly production reports.
Do you feel that the energy reports could/did lead to energy cost savings at the plant where you were involved?
Yes, it created awareness for the TOU opportunities that were being utilised and missed.

C.5 QUALITATIVE ASSESSMENT 5

This questionnaire in this section refers to a discussion with the engineering manager at “Plant Y”. Plant Y is a cement plant where the reporting system was briefly implemented for a test period of approximately two months in order to determine whether it would be usable at this plant. The implementation period was not of long enough duration to determine the quantitative effect on the plant. It was thus decided to rather make use of the opinion of the engineering manager (who was one of the recipients of the report) to determine the qualitative effect of the system.

Questionnaire 5	
Position at cement plant:	Engineering manager (Plant Y)
How was electrical energy consumption monitored before the implementation of the system?	
There are currently no methods to monitor electrical energy consumption. The reports that were sent out during the proof time were very valuable to the plant. It made it possible to identify opportunities, and to ensure that the plant electricity was billed correctly.	

How regularly did the plant interpret the feedback reports?
Most of the key personnel were on the mailing list for the reports, so it was investigated upon receipt. The concerns were then pointed out during operational meetings, and decisions were made regarding the further steps that had to be taken.
Who made use of the plant feedback reports?
Among the recipients of the reports were the process engineer; production manager; engineering manager; technical engineering advisor; electrical foreman; mechanical foreman; and technicians. The additional personnel present in the operational meetings were resultantly also included in discussions of the reports.
In how much detail were the reports investigated? (Were only highlighted areas considered?)
The reports were mainly used to monitor the TOU consumption, and ensuring that minimum electricity was consumed during peak times. Comparisons with previous reporting periods were also done to determine which sections of the plant performed worse. The reports do have a lot of potential to be implemented on a permanent basis, and should lead to additional savings. All of the recipients made use of a different part of the report to improve on their area of specialties.
Did the indicated missed opportunities and identified saving areas influence the operation of the plant?
The plant did not yet investigate the reports in such depth, but the missed opportunities were compared with previous months to ensure that it did not increase.
Did the use of the reports lead to the plant achieving any savings?
The reports were not implemented for a long enough period to absolutely declare that it did lead to savings, but it definitely has the potential.

Are there any additional features that you would like to see implemented in the report?

The reports were not implemented for a long enough period to determine what is missing.

C.6 QUALITATIVE ASSESSMENT 6

Consultations with project engineers at an ESCo that worked on another cement plant were also held. The purpose of these discussions was to determine what reporting systems were already implemented at these plants, as well as to determine whether they felt that the reporting system would be beneficial for their plants. The first consultation was with a project engineer that was involved with various energy management initiatives at “Plant Z”.

Questionnaire 6

What was your involvement at the cement plant?

Project engineer at an ESCo that worked on another cement plant (Plant Z).

What methods for energy performance monitoring were used at the cement plant where you were involved?

The only feedback that Plant Z received on their electrical energy consumption was the information displayed in real-time on the SCADA, and the monthly electricity bills.

Do you feel that the energy reports could/did lead to energy cost savings at the plant where you were involved?

I believe that Plant Z would benefit from a reporting system such as the one discussed in this dissertation.

C.7 QUALITATIVE ASSESSMENT 7

The other consultation was with a project engineer who was involved with DSM project implementations at two different cement plants, “Plant A” and “Plant B”.

Questionnaire 7

What was your involvement at the cement plant?

Project Engineer at two cement plants (Plant A and B).

What methods for energy performance monitoring were used at the cement plant where you were involved?

Plant A: Weekly scheduling reports based on silo level and sale forecast data (data manually gathered) and monthly energy cost saving reports based on SCADA data (also manually gathered).

Plant B: Monthly energy cost saving reports based on municipal electricity bills (data manually gathered).

Do you feel that the energy reports could/did lead to energy cost savings at the plant where you were involved?

It is evident that the reports will be helpful to manage and optimise TOU period utilisation (c/kWh); to identify improvement or degrading energy intensity of specific processes (kWh/t); and to identify operation of unnecessary auxiliaries.

The reports will therefore be able to trigger activities that could lead to energy cost savings. It is important that the reports are sent to plant personnel with the authority and drive to act on the reported triggers. A report without the subsequent action will not lead to savings.

Automated reports will add to the sustainability of the of the energy savings targeted by reporting. It must be considered to expand reporting to look at other energy carriers, such as coal and gas.

APPENDIX D: DAILY DSM REPORT

This appendix presents an example of the daily DSM report that was sent to Plant X before the energy management system was implemented. This report only reported on the daily DSM performance of the specific equipment, and not on the total plant energy performance.

Daily report for

Plant X

23 December 2014

1 Project information

Project name: Plant X process line
Project number:
Target impact: 2.28 MW

2 Performance (Tuesday 2014-12-23)

Performance of day:		Month-to-date performance:	
Impact:	2.64 MW	Average impact:	3.54 MW
Cost saving:	R 6 046	Cumulative cost savings:	R 21 877
Missed opportunities:	-	Cumulative missed opportunities:	-

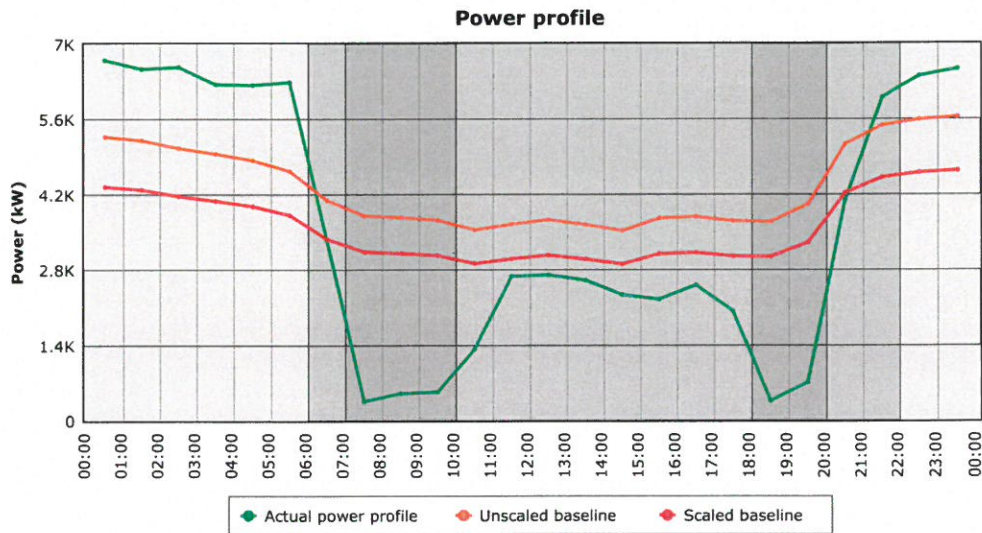


Figure 2.1: Power profile and baseline for 23 December 2014

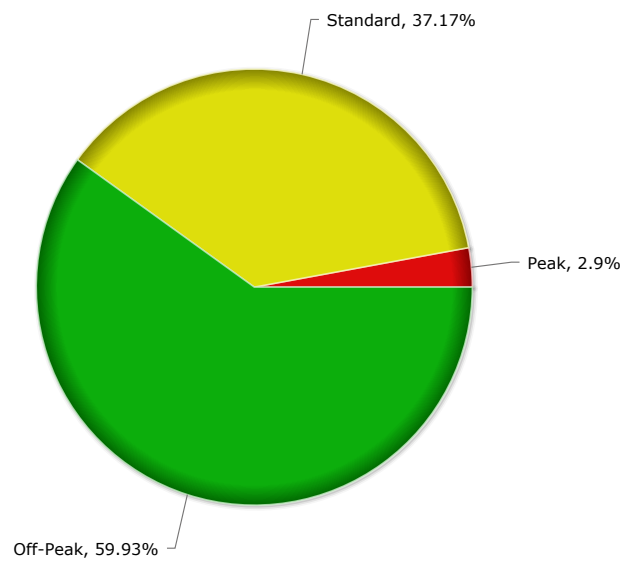


Figure 2.2: *Daily energy usage distribution - 23 December 2014*

APPENDIX E: ISO 50001 VERIFICATION CHECKLIST

The checklist referred to in Section 3.3 is discussed in this appendix. This checklist contributes to the verification of the developed energy management system, by discussing how the system contributes to reaching all of the checkpoints. The developed energy management system presented in Section 3.2 was evaluated according to this checklist. The checklist was developed by the BSI Group [57], which is a business standards organisation that assists companies in 150 countries to obtain compliance with business standards such as ISO [58]. The checklist is a self-assessment questionnaire that evaluates a company's compliance with ISO 50001 [57].

The different sections of the checklist and how the energy management system contributes to ticking off the requirements thereof are discussed in the remainder of this appendix. This discussion should thus be considered along with the checklist, as it is written in parallel. The paragraphs will briefly discuss how the energy management system conforms to the checklist, without stating the exact requirement that is being ticked off in each case. The subsections and paragraphs are, however, written in accordance with the checklist.

E.1 COMMITMENT AND POLICY

This part of the checklist consists of evaluating the energy management policy stated by the company. Such a policy is unique to each company, and is included as an additional ISO 50001 task in Section 3.3.2. The first step in the system presented in Figure 8, "*awareness creation*", also stated that an energy management policy has to be developed by the company. The requirements of this policy are also listed in the checklist. Technical aspects of the policy that have to be addressed are, however, included in the development of the energy management system.

These technical aspects include having a plan to ensure continuous improvement, as described as part of the development of a budgeting system in Section 3.2.7. The reporting system as a whole will also assist with this continuous improvement. The energy management system further contributes to ticking of defining the scope and boundaries of the implementation. The boundary is chosen as the entire plant, with in-depth focus on the sections specifically identified from the overview of the energy consumption. The system will also assist in ensuring that all the relevant information is available by identifying meters that need to be installed, and centralising all relevant documents on a database.

The objectives and targets of the system will also be reviewed as part of the budgeting step, as required on the checklist. Creating awareness among employees includes distributing the

policy to all personnel of the company, as required. By sending out weekly and monthly reports and continuously improving on the targets, the company commits to periodically reviewing the system and thus also the policy. Further compliance with this section of the checklist is the responsibility of the company, as it requires drafting the policy with the various commitments, and announcing it to the public. All of the possible requirements in this section of the checklist can thus be ticked off by the developed energy management system and listed additional ISO 50001 tasks.

E.2 PLANNING

Energy aspects

This part of the checklist requires the system to firstly conduct a review of the energy aspects, and then updating it periodically. The largest energy consumers should then be identified and prioritised for energy management purposes. This is all done as part of the awareness creation of Section 3.2.2, in *“identification of the largest energy consumers”* and *“investigation of systems to monitor energy consumption”*. The *“opportunity identification”* discussion in Section 3.2.4 then enables the plant to identify opportunities, and keeping it on record, as required. Any changes in energy aspects will be seen in the report by maintaining an updated meter list, and thus also be documented as required.

Legal

The first step in the reporting phase of the energy management system is to perform a literature study and investigate all sections on a cement plant. As part of this step, all legal aspects of the operation were identified, such as which materials may be burnt in a kiln in South Africa. Other legal requirements for conformity to Section 12L regulations for example were also listed as part of the investigation. Standard operational safety procedures should also be in place at the cement plants, which contributes to adhering to legal requirements of operations and resultantly also energy management.

Energy objectives, targets and programmes

As part of developing a reporting method during the implementation of the system, EnPIs were identified. A budgeting system that will be used to set targets for the performance of equipment was also described to ensure that continuously improving targets are used to evaluate the energy performance of equipment. The plant itself can determine what the time limit is for reaching targets, and how failure to complying with these time limits will be handled. Such

responsibilities have to be allocated to the relevant personnel, as discussed in the additional ISO 50001 tasks of Section 3.3.2.

E.3 IMPLEMENTATION AND OPERATION

Resources, roles, responsibilities and authorities

The allocation of resources and personnel to assist with the energy management system will be the responsibility of the plant management. However, allocating a distribution list for the reports that have to be sent out implies that personnel assume roles to assist with the system. Implementation of certain missed opportunities such as improved TOU and switching off unnecessary auxiliaries will automatically be the assumed role of the operators who has the ability to do so. Choices such as replacing or upgrading equipment will be the assumed role of management personnel on a plant. By making use of an ESCo to implement the system, the largest portion of the responsibilities is allocated to them.

Awareness, training and competence

As part of the first step in the developed system, awareness among all personnel will be created. This will include giving training to relevant individuals, and resultantly establishing a culture of energy efficient behaviour. Implementation of the mill scheduler developed by Swanepoel [49] and Maneschijn [37], as well as displaying the TOU billing periods, as shown in Figure 10, in the control room will assist with basic awareness. Further awareness will be established by sending the reports to relevant personnel, and giving training on how to interpret the information. As stated in the “*opportunity identification*” of Section 3.2.4, the need for further training will also be identified by interpreting the reported results.

Communication

Internal communication about the energy performance will mainly be done by means of the reporting system. This will ensure that all personnel involved receive feedback on how well the energy is being managed, and also provide the basis to identify further opportunities for savings. External communication of the energy performance is the choice of the organisation, and can be done if desired. Such communication can make use of the summarised recorded performance in the monthly reports by restructuring it to portray the desired information.

Energy management system documentation

As mentioned in Section 3.2.2, part of the energy management system will include having a central database to store all relevant documentation. This is an online database that grants

access to authorised personnel to upload relevant documents. This system will also ensure that all documents required for opportunities such as a Section 12L tax deduction application are available and centralised. The elements of the energy management system are similar to what is documented in Section 3.2, and will also be stored on this database.

Control of documents

As part of the “*opportunity identification*” paragraph in Section 3.2.4, it was also discussed that missing meters will be identified, and calibration requirements will also be monitored. This will ensure that such documents are in place, along with the Section 12L required documents listed in Section 3.2. All of these documents will be available on the centralised database, and only accessible by the relevant authorised personnel, including energy managers. This will ensure the proper control of records, and that all of it is traceable, current, available, and protected, as required.

Operational controls

The regular reporting on progress and continuous adaption of targets will ensure that deviation from the policy is identified promptly, and acted on accordingly. Criteria for operations, maintenance, upgrades, and replacement of equipment will be improved by the investigation of different technologies identified through investigating the sections of a cement plant. By making use of the system the plant will be able to identify opportunities to improve on equipment and the operation thereof, as the benchmarking and budgeting of equipment is an indication of the expected operational conditions. As a result of the company’s commitment to their energy policy, they will inform the public of their preference to make use of suppliers committed to energy efficiency.

E.4 CHECKING

Monitoring and measuring

The budgeting was discussed as in Section 3.2.7 and forms part of the “*act*” phase, which ensures that the targets are reviewed and updated regularly. The entire reporting system will be used to monitor and measure the energy performance of the plant compared with the set targets. The general measurements of sections and components on a cement plant required for sufficient reporting was listed in Table 7. This forms part of the plan to improve metering on a cement plant. The identification of opportunities such as a Section 12L tax deduction also provides for the monitoring of meters to identify the need for calibration and additional meters to be installed.

The reporting system will further measure the energy consumption of major consumers in weekly and monthly intervals. The reports will indicate EnPIs compared with their targets, enabling plant personnel to review it. Budgeting and the setting of targets include performance of other plants from literature, and will thus compare the plant's performance to that of other plants. The central document database will ensure that records demonstrating accuracy of metering, for example, calibration certificates, are maintained and kept on record. The detail sections in the reports will assist in seeing exactly where energy savings originated from, while such improvements and the reason therefor will be documented as part of the identification of Section 12L opportunities.

Evaluation of compliance

The evaluation of compliance is done as part of the additional ISO 50001 tasks, as well as during the preparation for possible opportunities such as a Section 12L tax deduction application. The evaluation of compliance with legal requirements will be kept on record and stored on the central document database. This will enable the plant to conform to this requirement of ISO 50001.

Nonconformity, corrective action and preventative action

Evaluation of the system by management by reviewing the reports and the audit results will assist in identifying nonconformities. The responsibilities of personnel will be re-evaluated if it is found that a certain aspect of the system is not being attended to. Action will have to be taken by personnel within a set time limit, and the result thereof has to be evaluated again to establish if it had the desired effect. An action plan for preventing the nonconformities to be repeated will also be documented, and evaluated more regularly.

Control of records

All actions will be kept on record, as stated as part of the additional ISO 50001 tasks. Apart from the stated energy management system, and how the steps are to be implemented, the changes made to the system also have to be documented. The energy management system is based on a concept of continuous improvement, and the modification of the system to adapt to the conditions of a specific plant has to be indicated. All records of how energy savings were obtained are kept on the central database, and can also be used to indicate the origin of energy savings if necessary.

Internal audit

The additional ISO 50001 tasks stated that an audit has to be done on a regular basis to evaluate the success of implementing the system. The audit results will be presented to top management, from where decisions will be made to determine if any changes are required. These changes will be accompanied by completion dates, which will be followed up on as indicated. A checklist such as the one in Section E.6 will be used as a guideline for the audit. This will enable the company to identify where it is not conforming to the requirements of ISO 50001, and adapt the system accordingly.

E.5 REVIEW OF THE ENERGY MANAGEMENT SYSTEM

The internal audits and summary pages of the monthly reports that will be presented to top management will enable them to review the system. These reviews will also be documented and kept on the central document database. The results of these reviews then have to be implemented as changes to the system, and will resultantly be communicated to personnel on the plant. This will lead to the continual improvement of the energy management system, and thus the energy performance of the plant.

E.6 ISO 50001 CHECKLIST

The checklist used for the above discussion is as presented by the BSI Group website [57].

APPENDIX F: PLANT X MONTHLY ELECTRICITY CONSUMPTION REPORT

The monthly electricity consumption report developed as Step 5 of Section 3.2, and referred to in Section 4.3.6 is presented in this appendix. This appendix presents the last report that was sent out during the 14-month evaluation period. The monthly report for February 2016 is the most recent version of the report, as it was developed and improved on continuously with inputs from the plant. The data used in the results discussed in Chapter 4 was obtained from such reports that were sent to the plant personnel on a monthly basis. In Chapter 4, this data was compiled into explanatory graphs in order to provide a summarised interpretation thereof.

Plant X

Monthly electricity consumption report Plant X

01 Feb 2016 - 29 Feb 2016

1 Summary

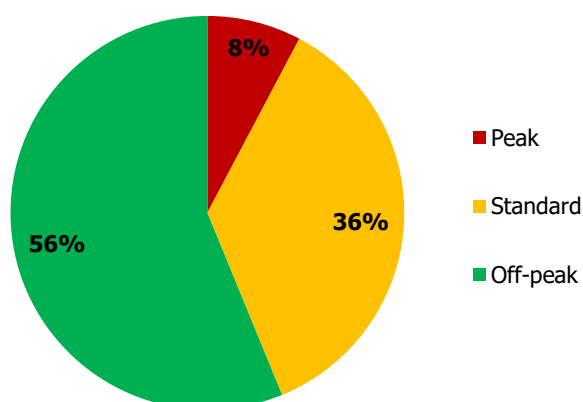
Table 1-1: Monthly electricity consumption summary

	Consumption (kWh)	Peak (kWh)	Standard (kWh)	Off-peak (kWh)	Production (tonne)	Intensity* (kWh/tonne)
Raw material offloading	56 987	12 174	31 225	13 589	-	-
Raw milling	1 527	43	180	1 304	0	-
Fuel preparation	1	1	0	0	0	-
Burning	0	0	0	0	0	-
Finishing mill 1	299 279	18 065	105 302	175 911	7 159	41.80
Finishing mill 2	1 656 711	70 747	549 610	1 036 355	45 063	27.82
Dispatch	133 105	23 465	61 299	48 341	-	-
Services	432 196	68 370	179 308	184 517	-	-
Buildings	76 972	12 682	31 386	32 904	-	-
Total	2 656 779	205 547	958 310	1 492 922		

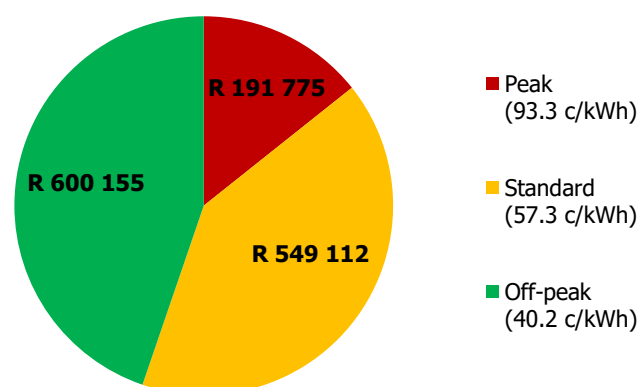
Table 1-2: Monthly electricity cost summary

	Electricity cost	Peak cost	Standard cost	Off-peak cost	Cost intensity (c/kWh)	Cost intensity* (R/tonne)	Missed opportunities
Raw material offloading	R 34 713	R 11 358	R 17 892	R 5 463	60.91	-	-
Raw milling	R 667	R 40	R 103	R 524	43.70	-	R -
Fuel preparation	R 1	R 1	R 0	R 0	93.30	-	-
Burning	R 0	R 0	R 0	R 0	-	-	-
Finishing mill 1	R 147 909	R 16 855	R 60 338	R 70 716	49.42	R 20.66	R 71 951
Finishing mill 2	R 797 548	R 66 006	R 314 926	R 416 615	48.14	R 13.39	R 119 968
Dispatch	R 76 450	R 21 893	R 35 124	R 19 433	57.44	-	-
Services	R 240 709	R 63 789	R 102 744	R 74 176	55.69	-	-
Buildings	R 43 044	R 11 832	R 17 984	R 13 227	55.92	-	-
Total	R 1 341 041	R 191 775	R 549 112	R 600 155	50.5		R 191 919

Monthly TOU consumption distribution



Monthly electricity cost (R)

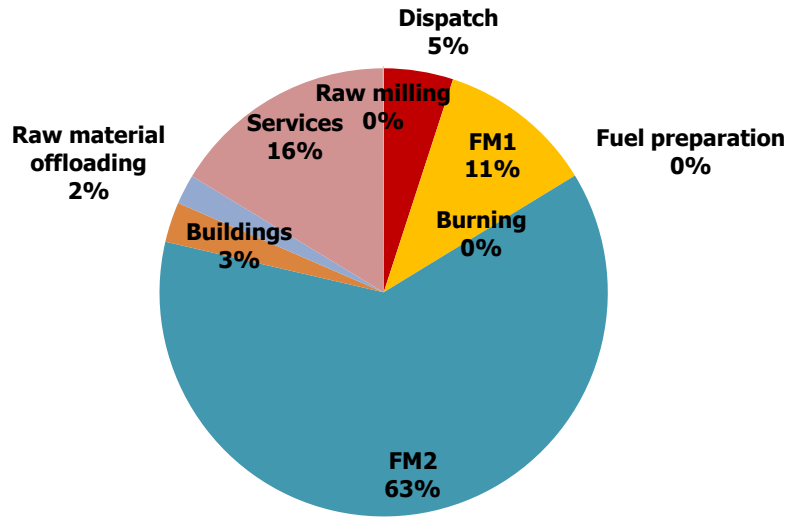


*Excluding cement/material handling

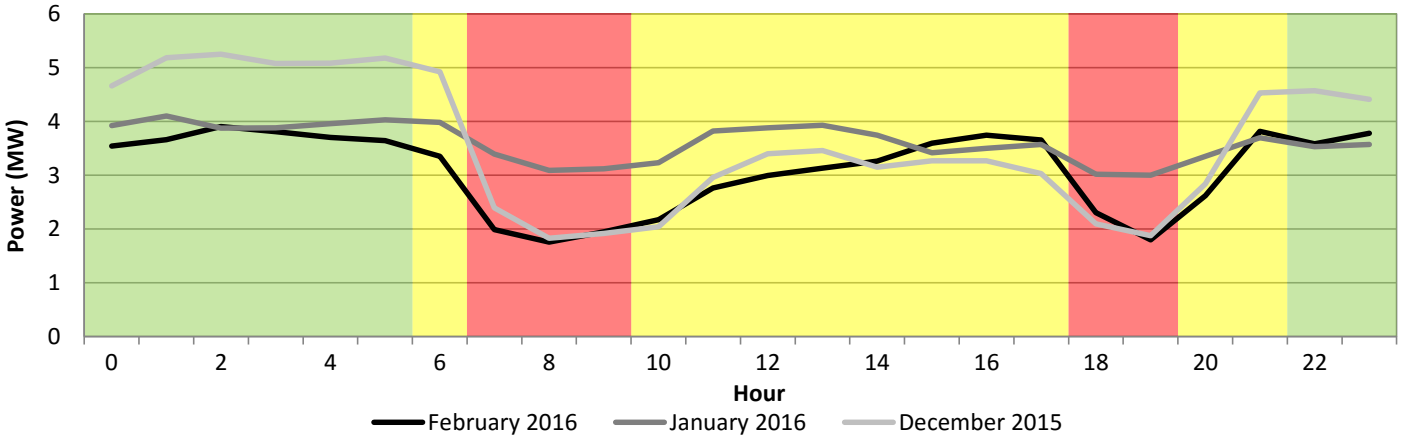
Table 1-3: Additional plant summary

Intensity (kWh/tonne)	Feb 2016	Jan 2016	Dec 2015	Nov 2015	Target
Clinker production	-	-	-	-	61.63
Total energy per clinker produced	-	-	-	-	195.66
Total energy per cement produced	50.90	56.91	52.93	48.06	52.63
Cement manufacturing	37.46	40.00	38.14	35.82	37.99

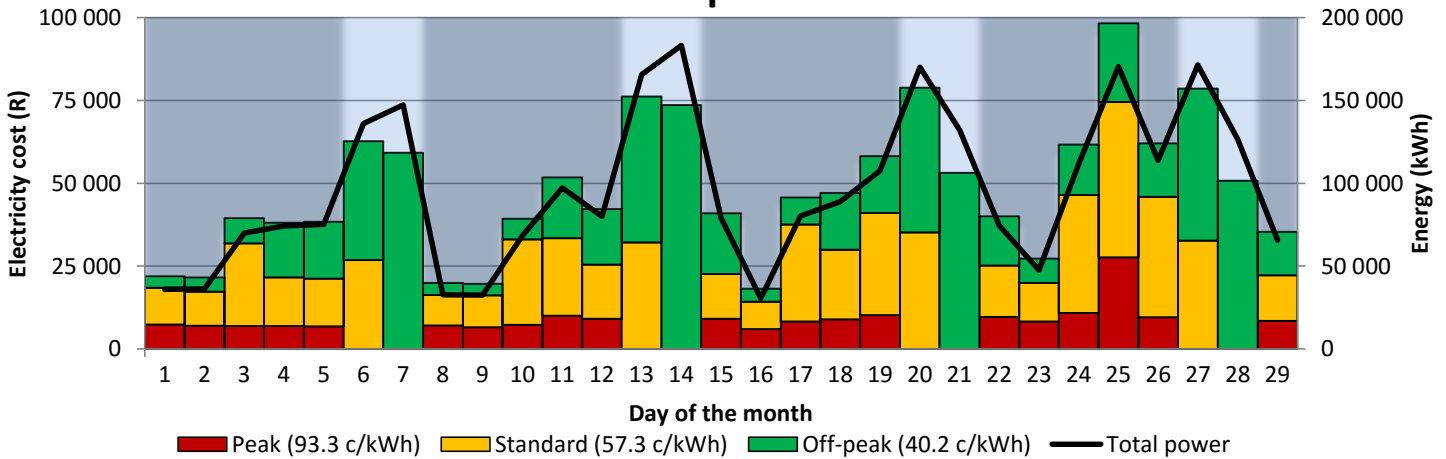
Monthly electricity consumption distribution (kWh)



Average weekday power profile



Power consumption and costs



2 Section Summaries

2.1 Raw material offloading

Monthly electricity cost

	Actual	Target
Average electricity rate	60.91	56.95

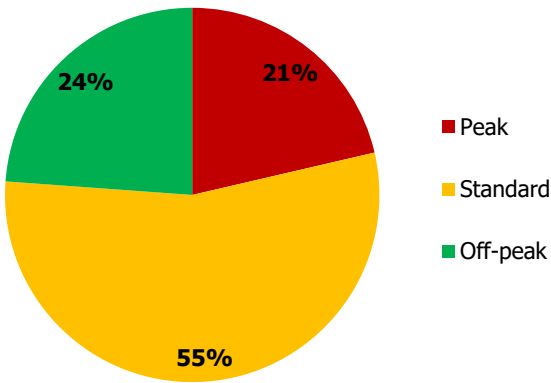
Total cost

R 34 713

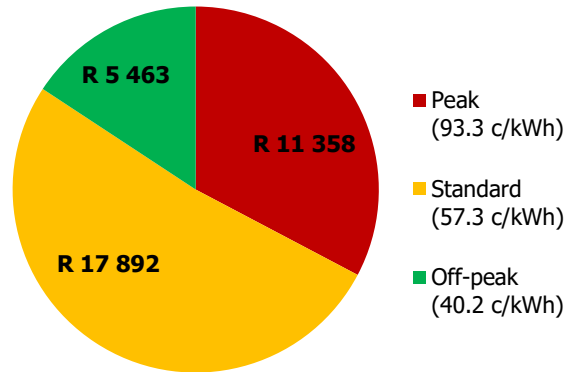
Monthly electricity consumption

Raw material offloading **56 987** kWh

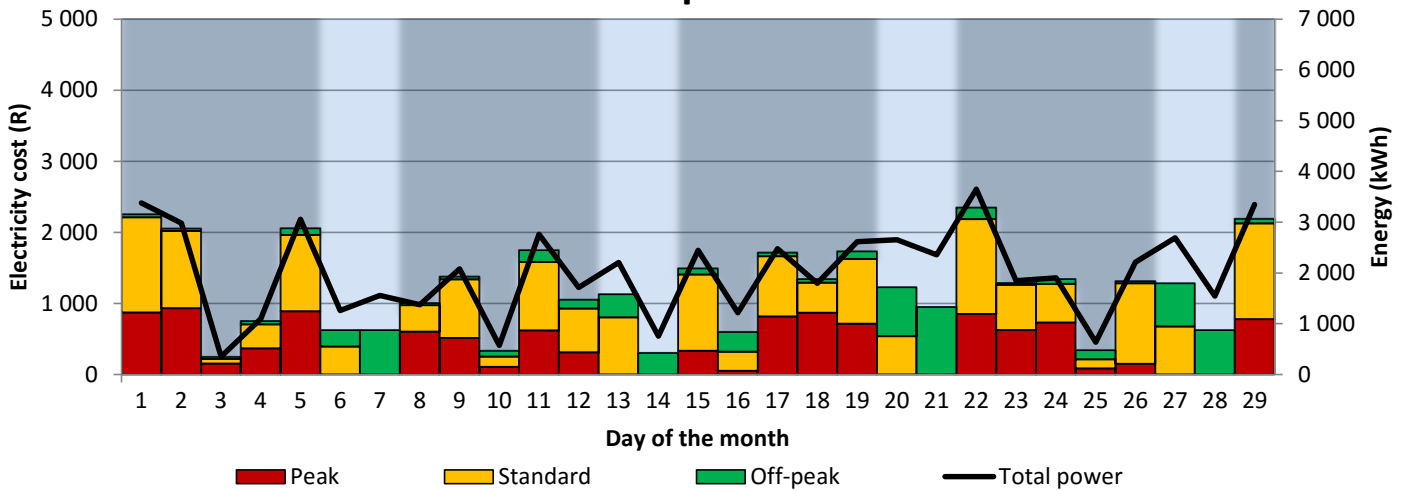
Consumption distribution



Cost (R)



Power consumption and costs



2.2 Raw milling

(Currently not operational)

Monthly electricity cost

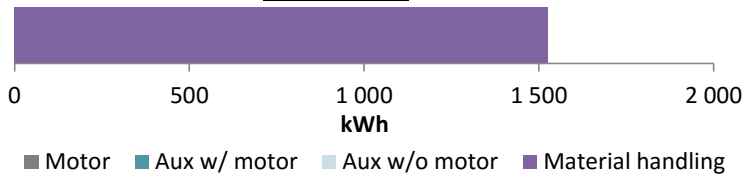
	Actual	Target	
Average electricity rate	43.70	49.81	c/kWh
Cost intensity	-	-	R/t

Total cost

R 667

Monthly electricity consumption

RM main motor	0	kWh
RM aux	0	kWh
RM material handling	1 527	kWh
Total	1 527	kWh



Monthly production

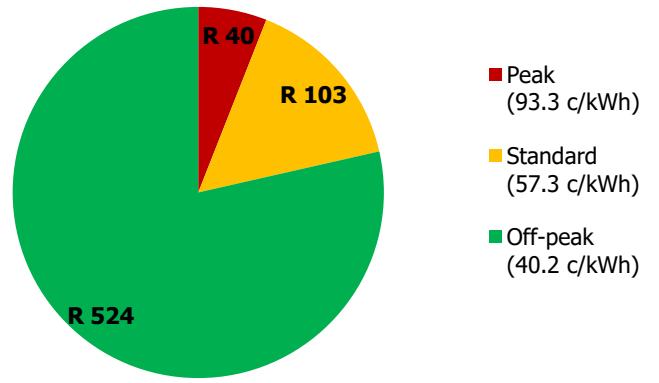
	Actual	Target	
Total production	0	-	t
Average rate	1	-	t/h
Main motor intensity	0.00	-	kWh/t
Auxiliaries intensity	0.00	-	kWh/t

Production hours	0	h
Utilisation	0	%
Stoppages	0	

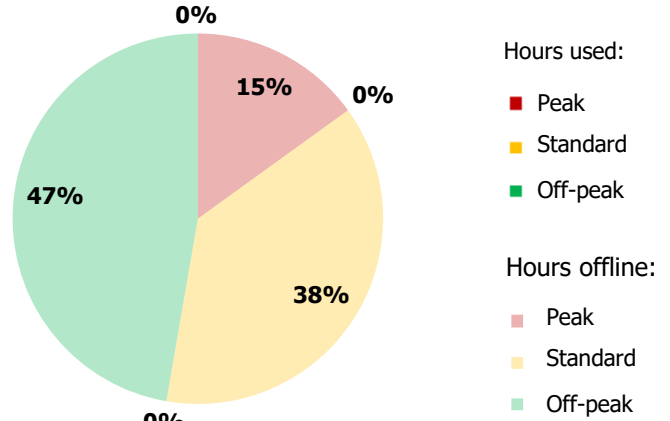
Missed opportunities

TOU	Intensity	Auxiliaries	Total
R -	R -	R -	R -

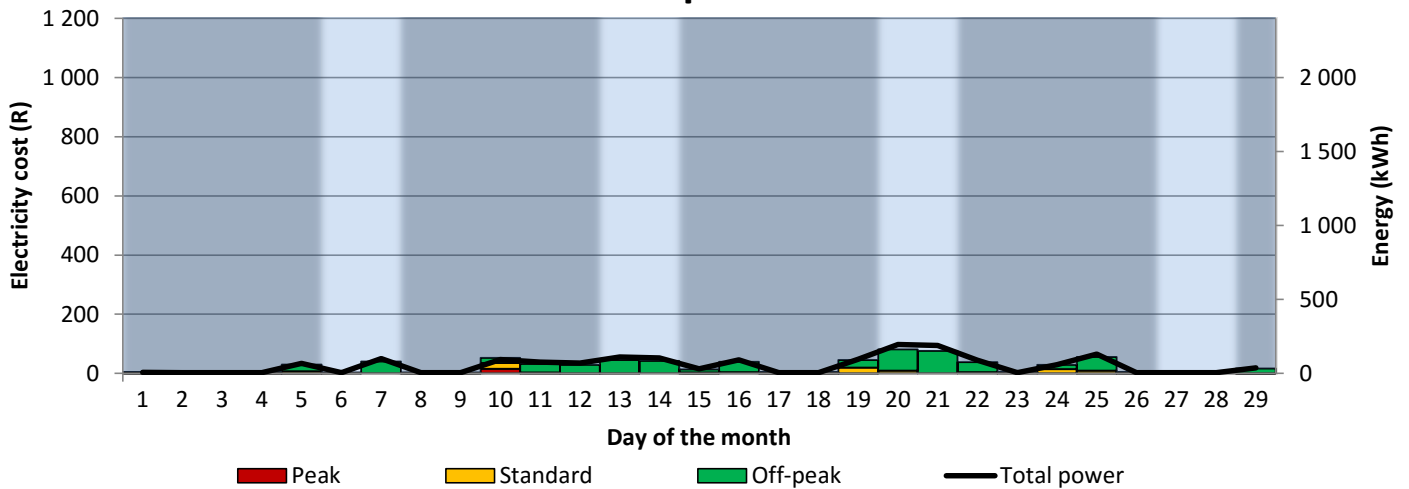
Cost (R)



Utilisation



Power consumption and costs



2.3 Fuel preparation

(Currently not operational)

Monthly electricity cost

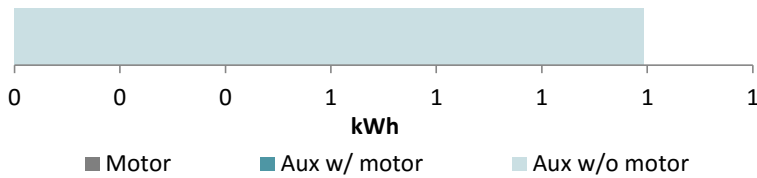
	Actual	Target	
Average electricity rate	93.30	61.13	c/kWh
Cost intensity	-	-	R/t

Total cost

R	1
----------	----------

Monthly electricity consumption

Coal mill main motor	0	kWh
Coal mill auxiliaries	1	kWh
Total	1	kWh

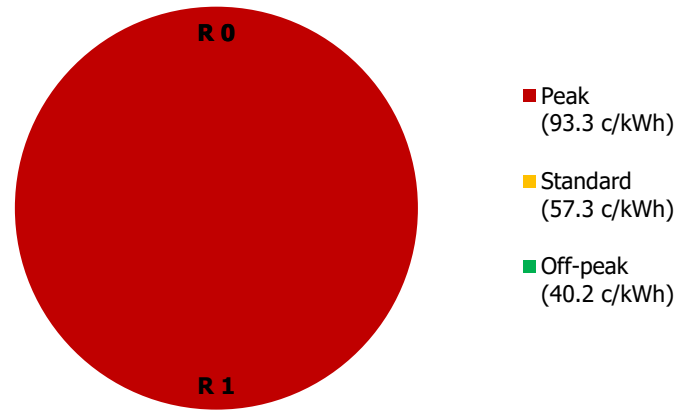


Monthly production

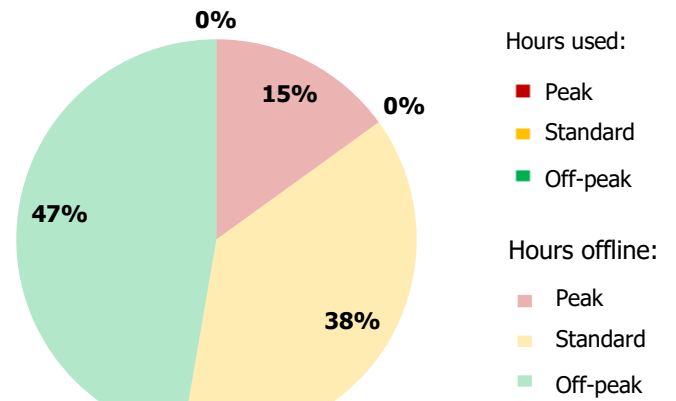
	Actual	Target	
Total production	0	-	t
Average rate	-	-	t/h
Main motor intensity	-	-	kWh/t
Auxiliaries intensity	-	-	kWh/t

Production hours	0	h
Utilisation	0	%
Stoppages	0	

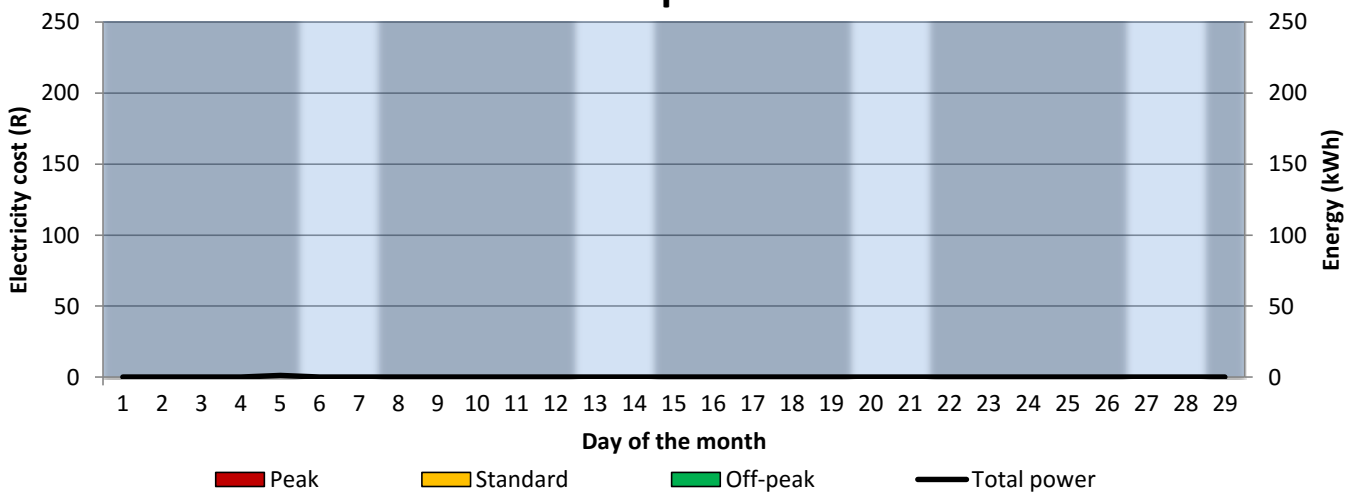
Cost (R)



Utilisation



Power consumption and costs



2.4 Burning

(Currently not operational)

Monthly electricity cost

	Actual	Target	
Average electricity rate	-	73.99	c/kWh
Cost intensity	-	-	R/t

Total cost

R -

Monthly electricity consumption

Kiln 5 total

0 kWh

Monthly production

	Actual	Target	
Total coal consumed	0	-	t
Clinker produced	0	-	t
Average rate	-	-	t/h
Intensity	-	-	kWh/t

Production hours

0 h

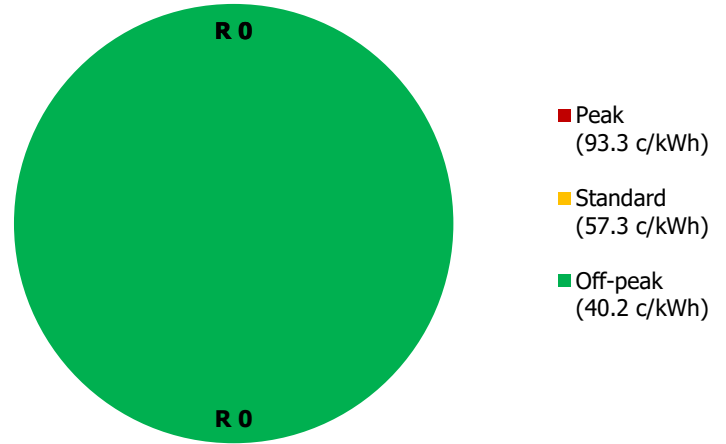
Utilisation

0 %

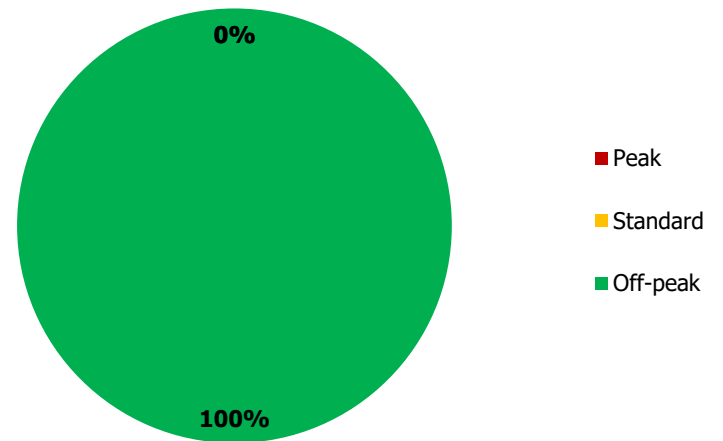
Stoppages

0

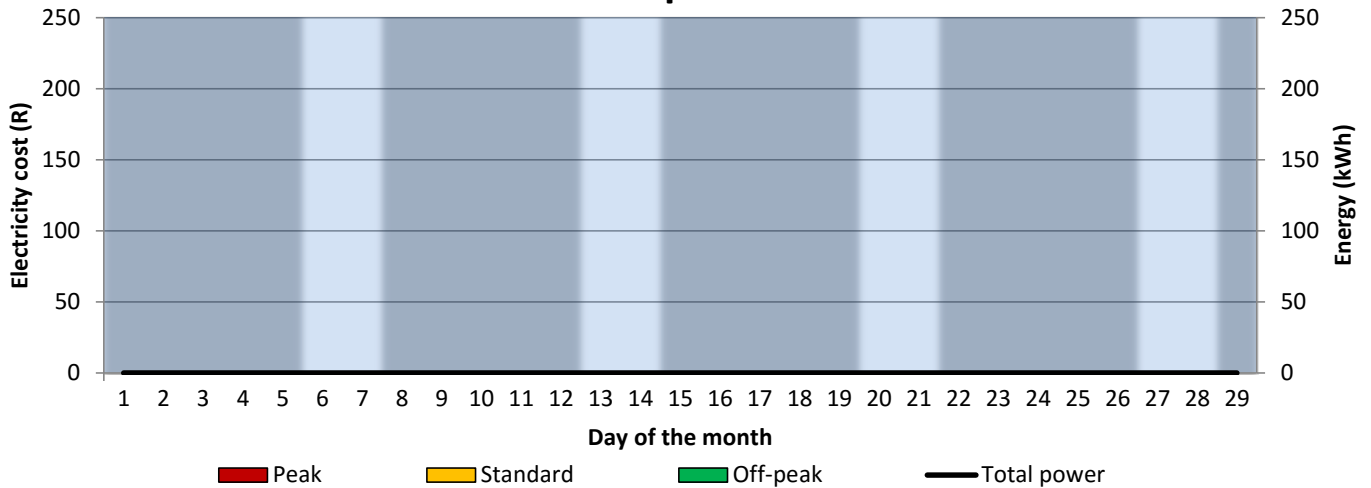
Cost (R)



Consumption distribution



Power consumption and costs



2.5 Finishing milling

2.5.1 FM1

Monthly electricity cost

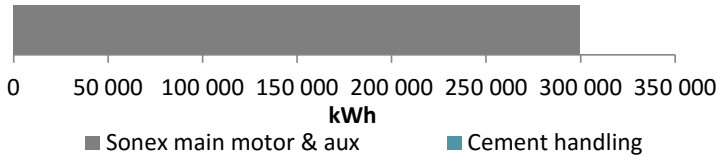
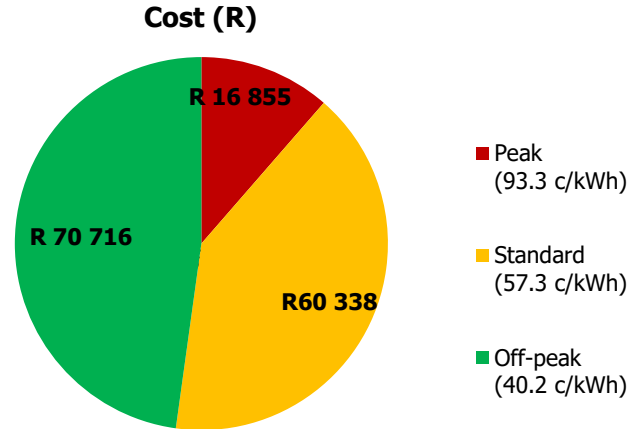
	Actual	Target	
Average electricity rate	49.42	49.75	c/kWh
Cost intensity (excl. cement handling)	20.66	18.06	R/t

Total cost

R 147 909

Monthly electricity consumption

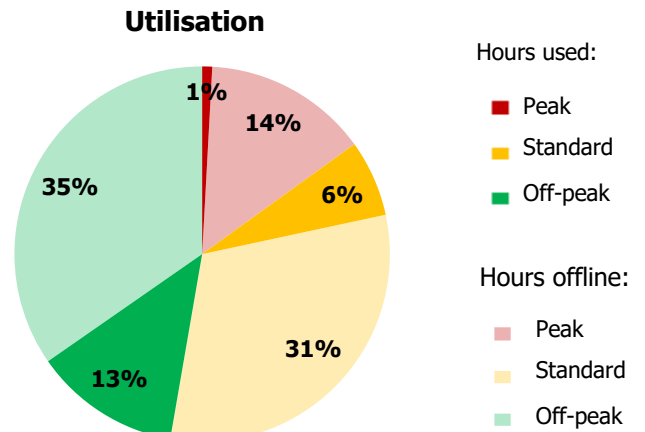
Sonex main motor and aux*	299 267	kWh
Sonex cement handling**	12	kWh
Total	299 279	kWh



Monthly production

	Actual	Target	
Total production	7 159	-	t
Average rate	50.06	52.89	t/h
Intensity (excl. cement handling)	41.80	36.30	kWh/t

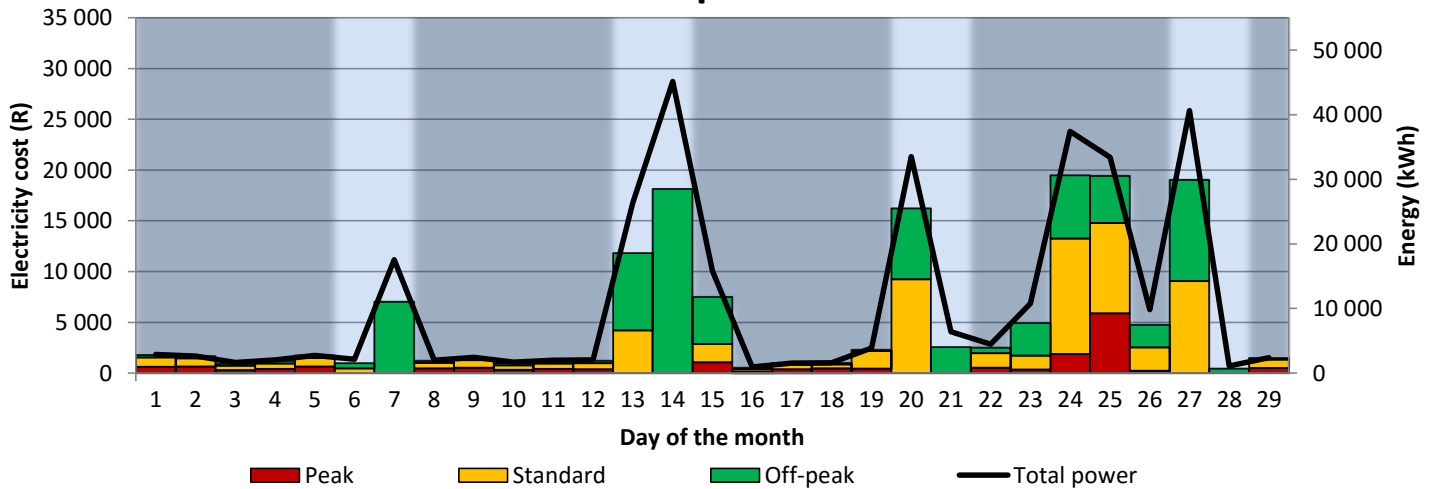
	Total
Production hours	143 h
Utilisation	20 %
Stoppages	5



Missed opportunities

TOU	Intensity	Auxiliaries	Total
R 40 054	R 9 795	R 22 102	R 71 951

Power consumption and costs



* If production < 10 t/h, assume auxiliaries without motor

**Potential data loss

2.5.2 FM2

Monthly electricity cost

	Actual	Target	
Average electricity rate	48.14	50.19	c/kWh
Cost intensity (excl. cement handling)	13.39	13.81	R/t

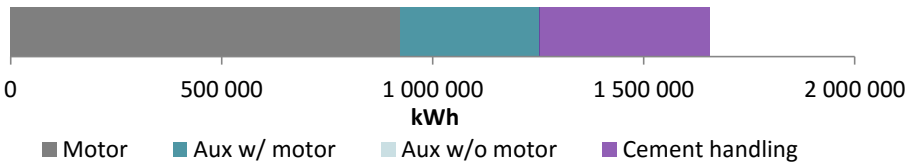
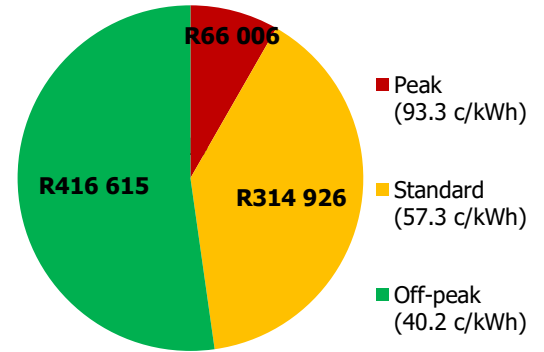
Total cost

R797 548

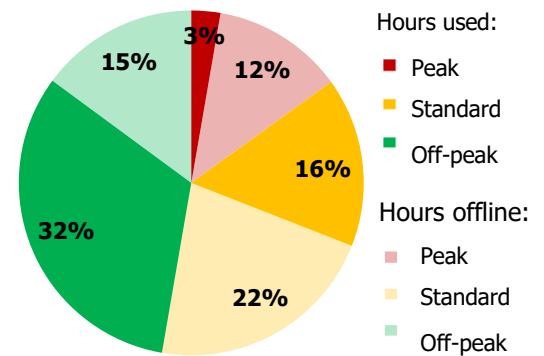
Monthly electricity consumption

VRM main motor	922 556	kWh
VRM aux	331 056	kWh
VRM cement handling	403 100	kWh
Total	1 656 711	kWh

Cost (R)



Utilisation



Monthly production

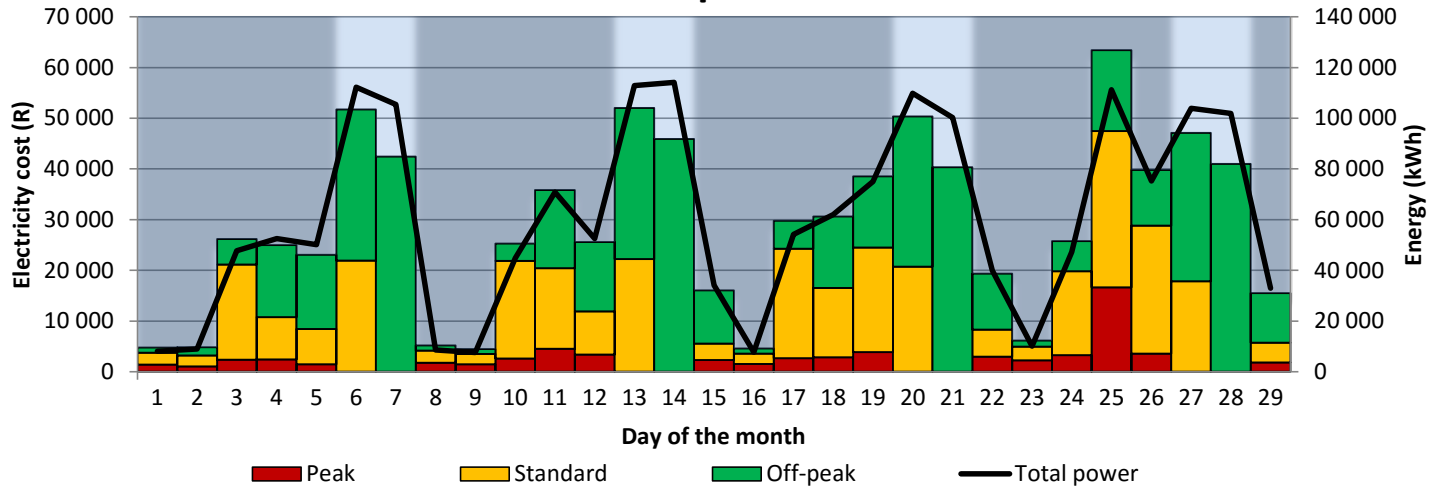
	Actual	Target	
Total production	45 063	-	t
Average rate	116.74	114.50	t/h
Main motor intensity	20.47	17.29	kWh/t
Auxiliaries intensity	7.35	10.22	kWh/t

	Total	
Production hours	386	h
Utilisation	51	%
Stoppages	28	

Missed opportunities

TOU	Intensity	Auxiliaries	Total
R 79 961	R 39 473	R 534	R 119 968

Power consumption and costs



2.6 Dispatch

Monthly electricity cost

	Actual	Target
Average electricity rate	57.44	55.60

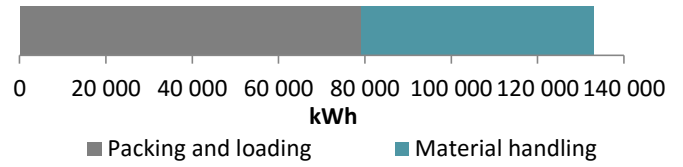
c/kWh

Total cost

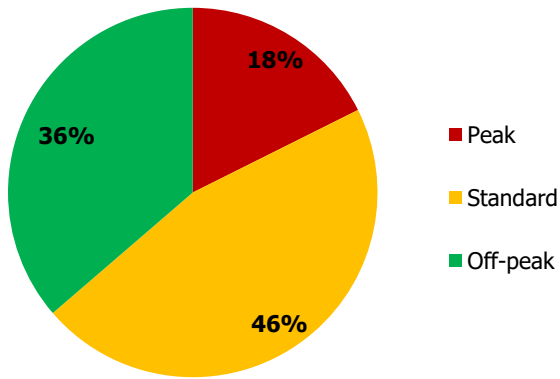
R 76 450

Monthly electricity consumption

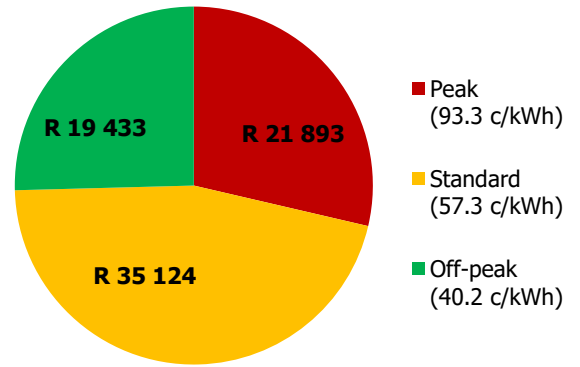
Packing and loading	79 230	kWh
Material handling	53 876	kWh
Total Dispatch	133 105	kWh



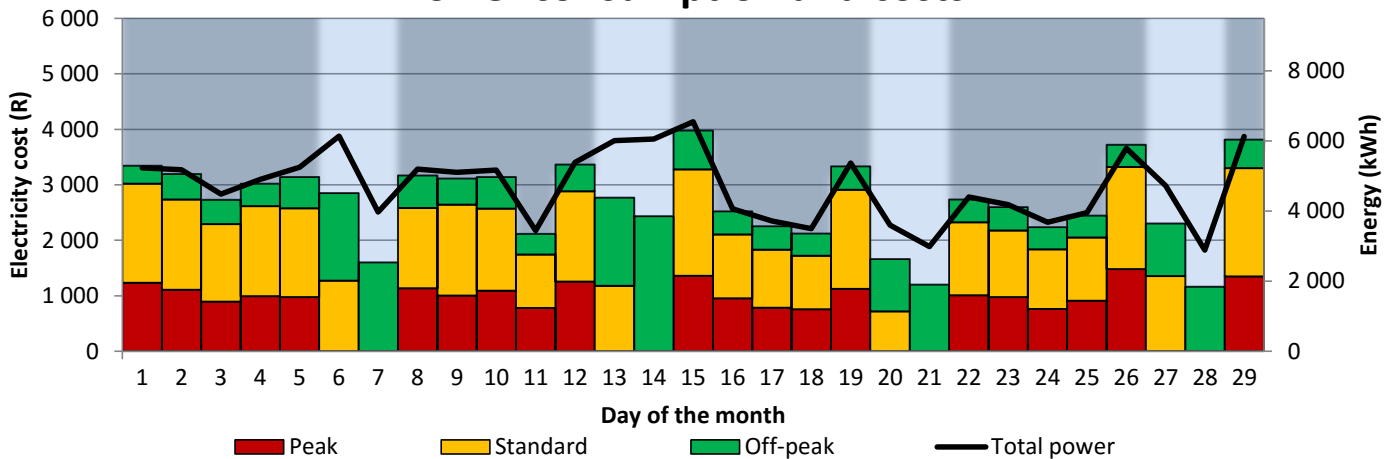
Consumption distribution



Cost (R)



Power consumption and costs



2.7 Services

Monthly electricity cost

	Actual	Target
Average electricity rate	55.69	54.71

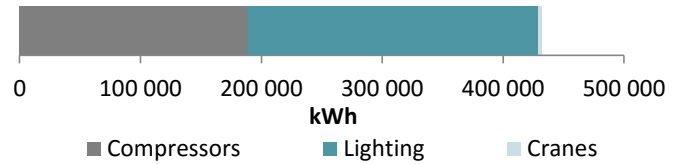
c/kWh

Total cost

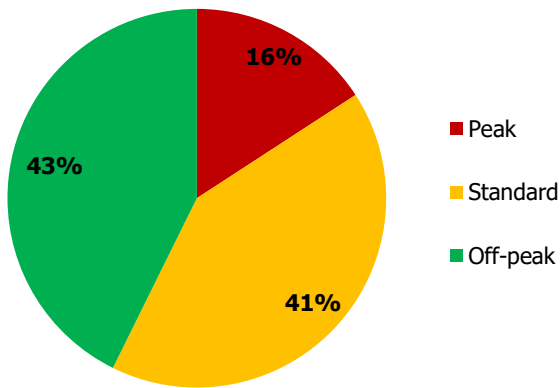
R 240 709

Monthly electricity consumption

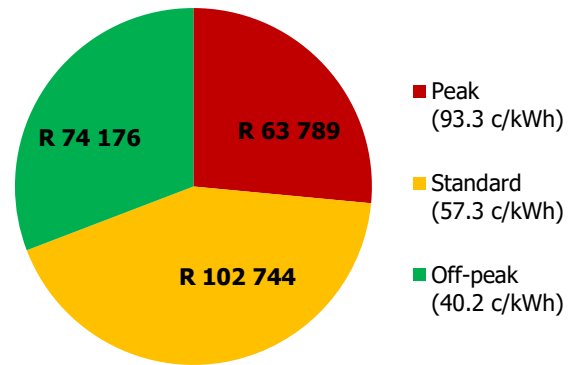
Compressors	189 186	kWh
Lighting	239 496	kWh
Cranes	3 514	kWh
Total	432 196	kWh



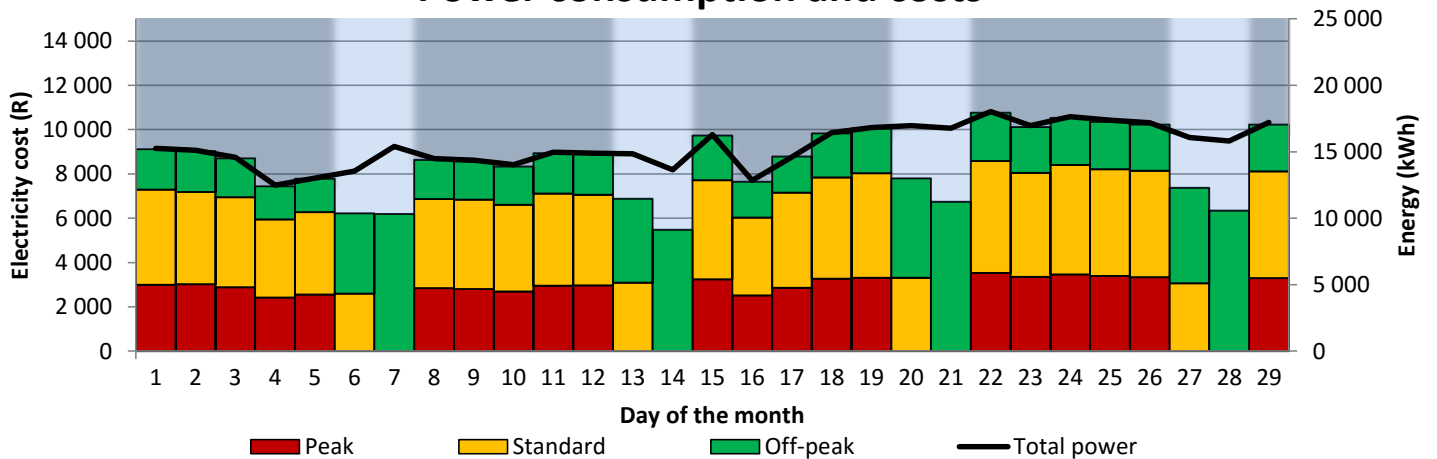
Consumption distribution



Cost (R)



Power consumption and costs



2.8 Buildings

Monthly electricity cost

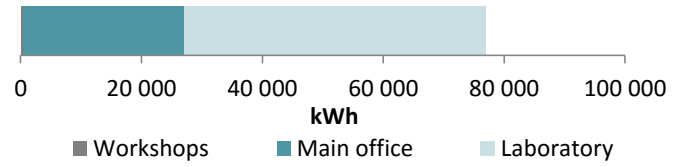
	Actual	Target	Unit
Average electricity rate	55.92	55.22	c/kWh

Total cost

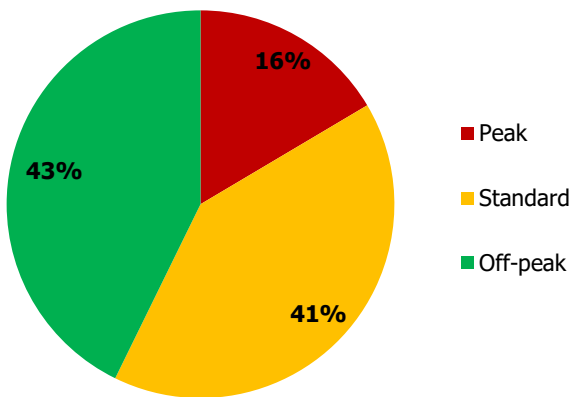
R 43 044

Monthly electricity consumption

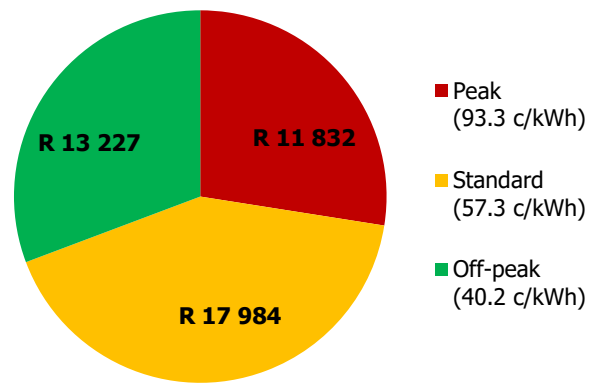
Workshops	468	kWh
Main office	26 511	kWh
Laboratory	49 992	kWh
Total Buildings	76 972	kWh



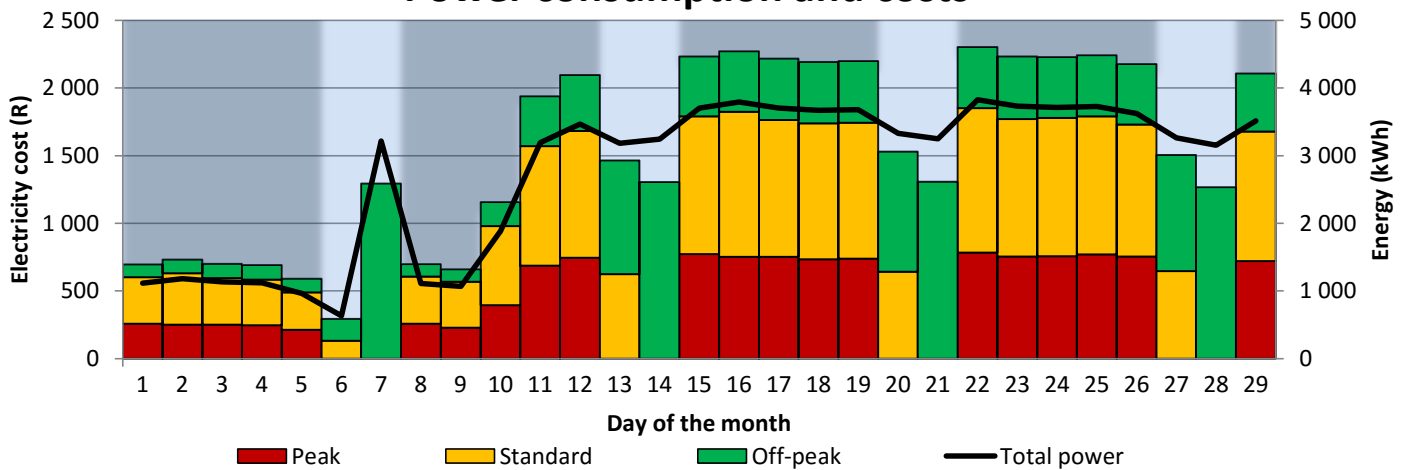
Consumption distribution



Cost (R)



Power consumption and costs



APPENDIX G: PLANT X WEEKLY ELECTRICITY CONSUMPTION REPORT

The weekly electricity consumption report was developed in Step 5 of Section 3.2, and is also referred to in Section 4.3.6. This appendix presents the last weekly report that was sent out during the evaluation period for the last week in February 2016. The graphs and summarising information of this report differs slightly from the monthly report, as discussed during the development of the reporting system. These reports were sent out on a weekly basis throughout the 14-month evaluation period, providing more regular feedback on the plant performance. This enabled the plant to notice deviations in electrical energy consumption throughout a month, without having to wait for a monthly report.

Plant X

Weekly electricity consumption report Plant X

22 Feb 2016 - 28 Feb 2016

1 Summary

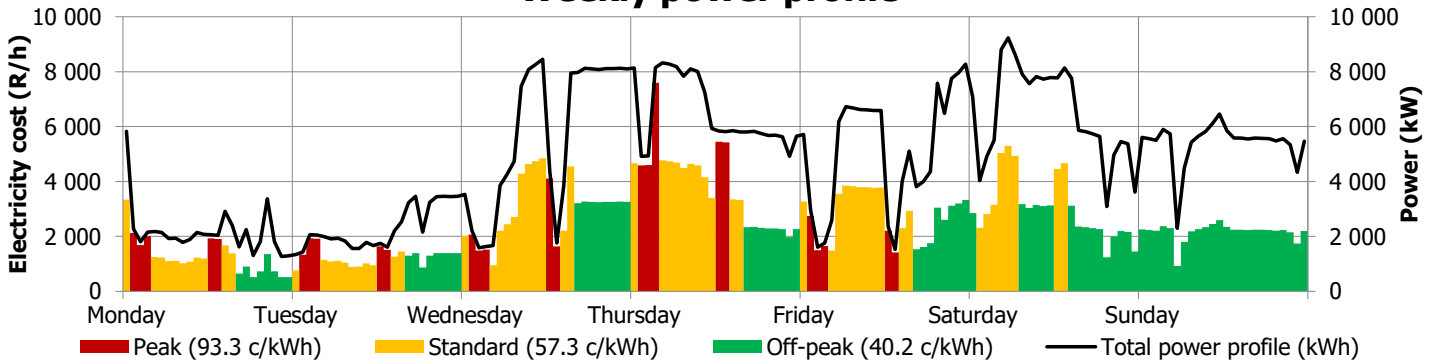
Table 1-1: Electricity consumption summary

	Production (tonne)	Consumption (kWh)	Intensity* (kWh/tonne)	Electricity cost	Cost intensity (c/kWh)	Cost intensity* (R/tonne)	Missed opportunities
Raw material offloading	-	14 218	-	R 8 429	59.29	-	-
Raw milling	1	220	-	R 101	46.09	-	R -
Fuel preparation	0	0	-	R -	-	-	-
Burning	0	0	-	R -	-	-	-
Finishing mill 1	3 524	137 541	39.03	R 70 677	51.39	R 20.05	R 21 761
Finishing mill 2	12 799	486 596	28.90	R 241 279	49.59	R 14.33	R 65 079
Dispatch	-	29 625	-	R 17 195	58.04	-	-
Services	-	118 950	-	R 65 715	55.25	-	-
Buildings	-	25 009	-	R 13 944	55.76	-	-
Total		812 159		R 417 340	51.39		R 86 840

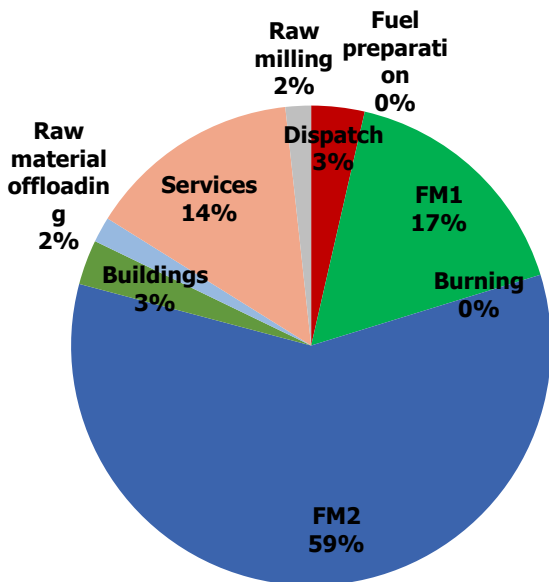
Table 1-2: Additional plant summary

Intensity (kWh/tonne)	22Feb-28Feb	15Feb-21Feb	08Feb-14Feb	01Feb-07Feb	Target
Clinker production	-	-	-	-	-
Total energy per clinker produced	-	-	-	-	-
Total energy per cement produced	49.75	55.30	53.14	52.92	53.79
Cement manufacturing	31.09	31.94	32.66	29.46	31.35

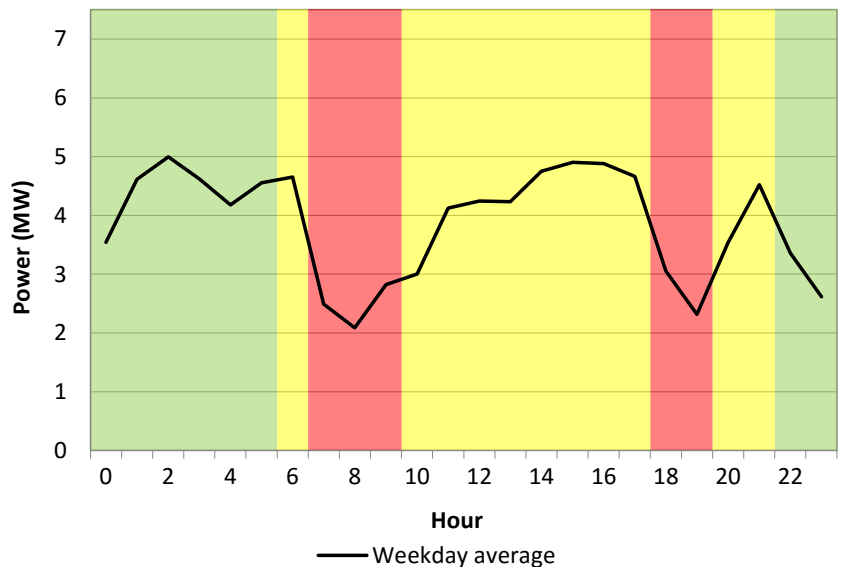
Weekly power profile



Consumption distribution



Average weekday power profile



*Excluding cement/material handling

2 Section Summaries

2.1 Raw material offloading

Weekly electricity cost

	Actual	Target
Average electricity rate	59.29	56.95

c/kWh

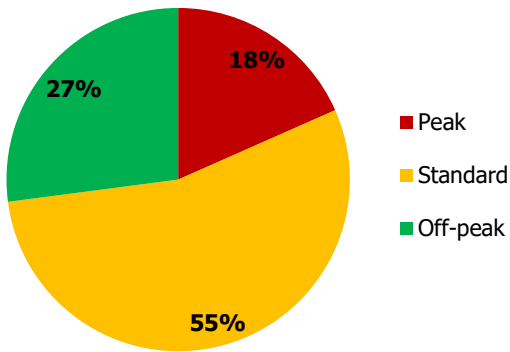
Total Cost

R 8 429

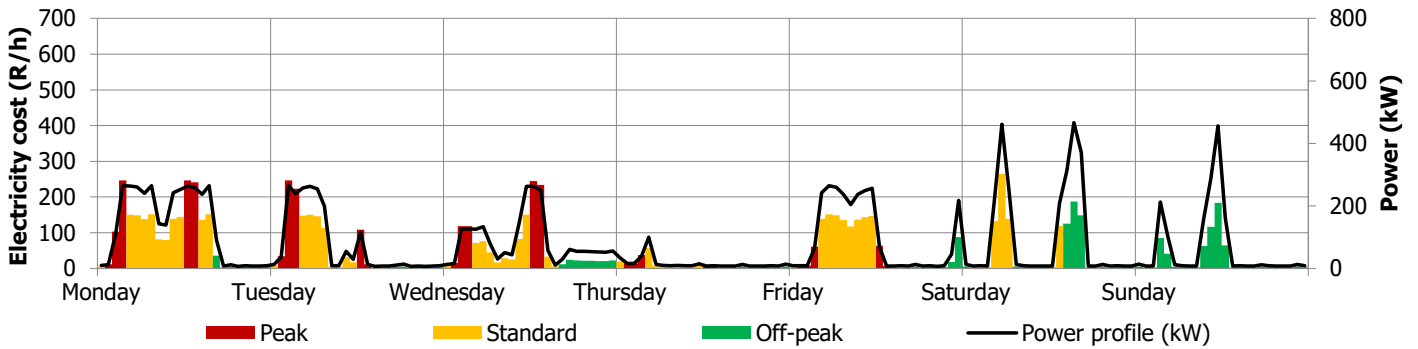
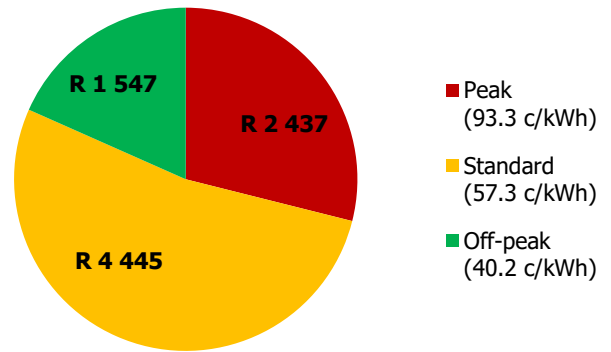
Weekly electricity consumption

Raw material offloading **14 218** kWh

Consumption distribution



Cost (R)



2.2 Raw milling

(Currently not operational)

Weekly electricity cost

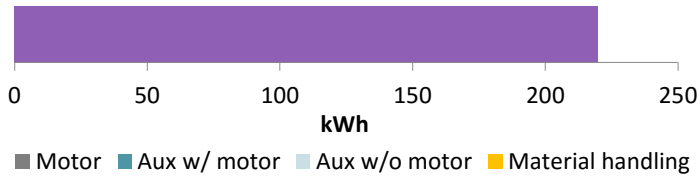
	Actual	Target	
Average electricity rate	46.09	49.81	c/kWh
Cost intensity	-	-	R/t

Total Cost

R 101

Weekly electricity consumption

RM main motor	0	kWh
RM aux	0	kWh
RM material handling	220	kWh
Total	220	kWh



Weekly production

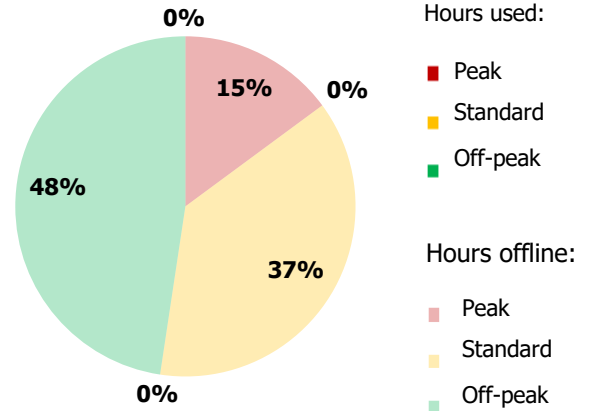
	Actual	Target	
Total production	0	-	t
Average rate	1	-	t/h
Main motor intensity	0.00	-	kWh/t
Auxiliaries intensity	0.00	-	kWh/t

Production hours	0	h
Utilisation	0	%
Stoppages	0	

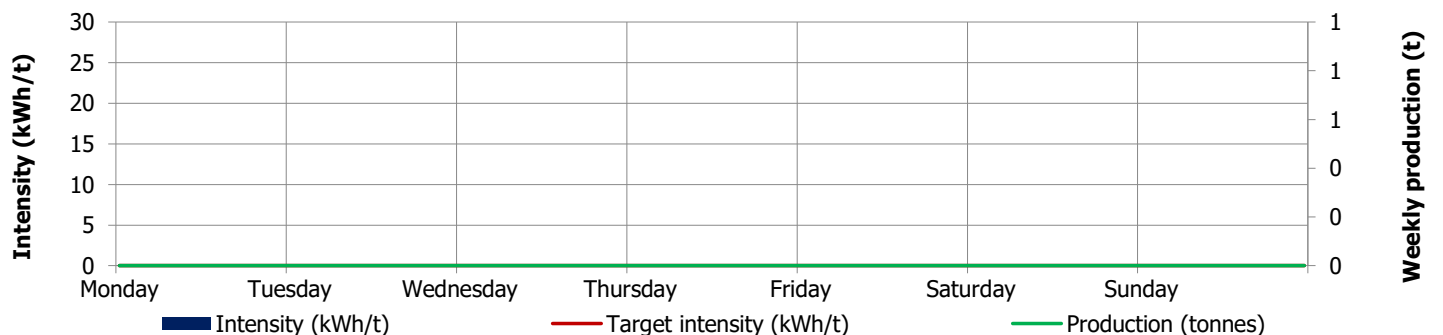
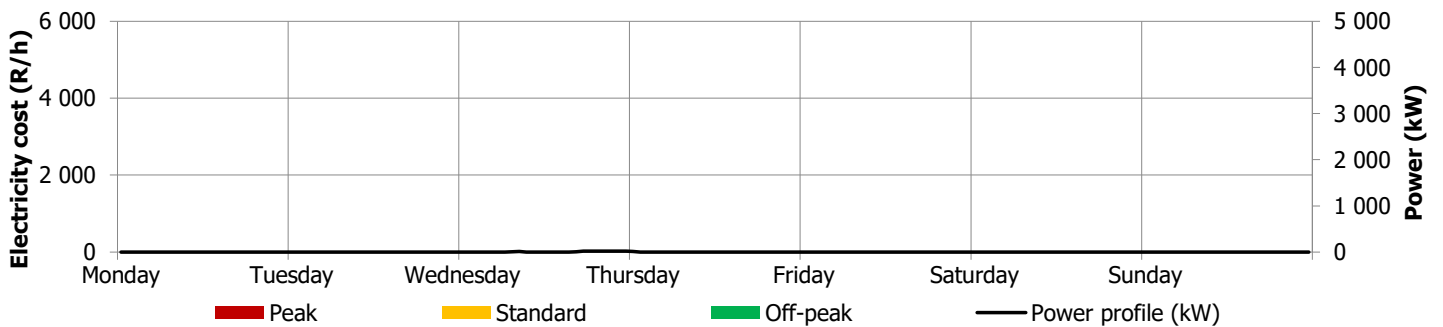
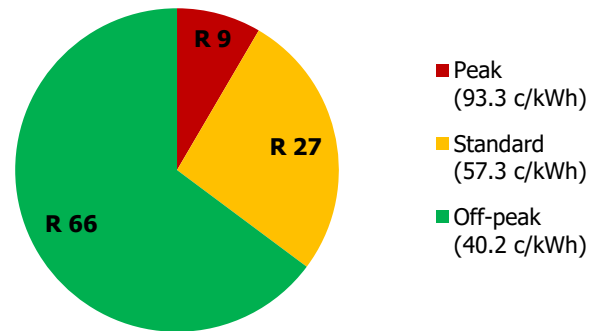
Missed opportunities

TOU	Intensity	Auxiliaries	Total
R -	R -	R -	R -

Utilisation



Cost (R)



2.3 Fuel preparation

(Currently not operational)

Weekly electricity cost

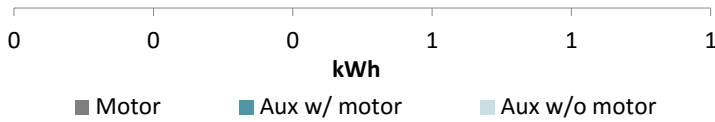
	Actual	Target	
Average electricity rate	-	61.13	c/kWh
Cost intensity	-	-	R/t

Total Cost

R -

Weekly electricity consumption

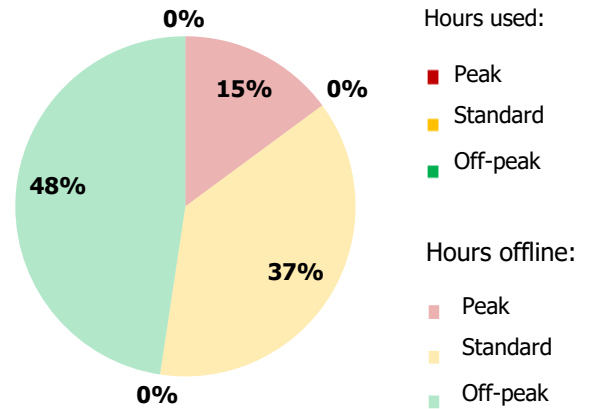
Coal mill main motor	0	kWh
Coal mill auxiliaries	0	kWh
Total	0	kWh



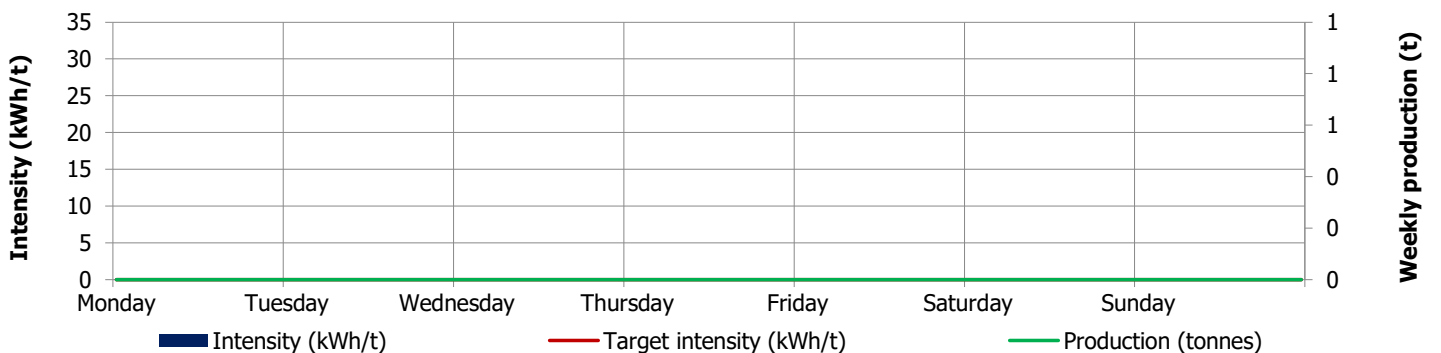
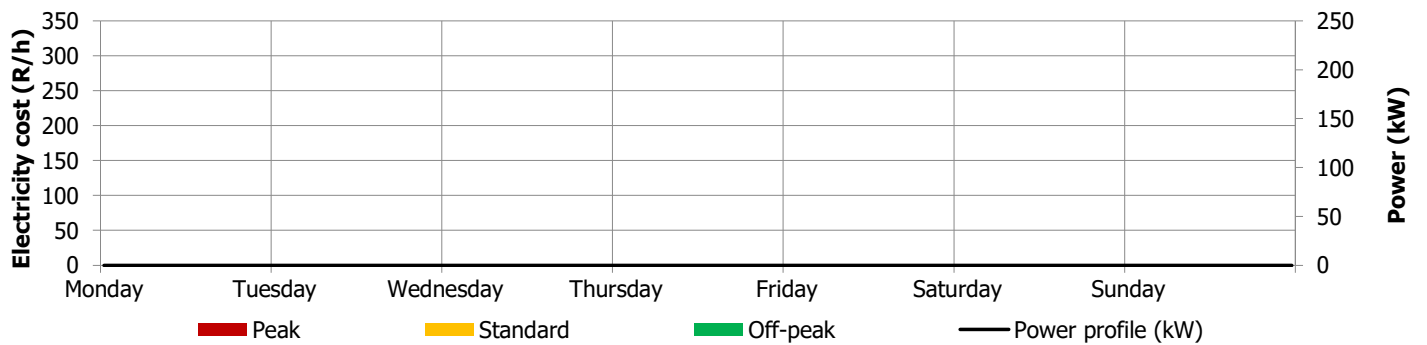
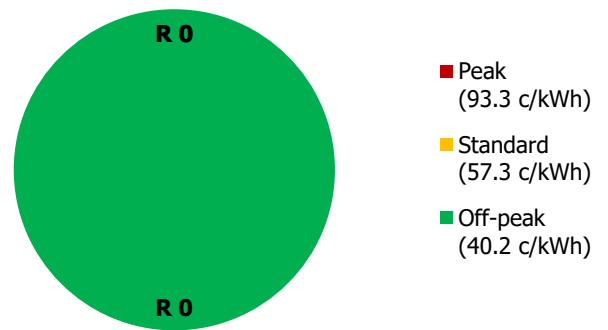
Weekly production

	Actual	Target	
Total production	0	-	t
Average rate	-	-	t/h
Main motor intensity	-	-	kWh/t
Auxiliaries intensity	-	-	kWh/t
Production hours	0		h
Utilisation	0		%
Stoppages	0		

Utilisation



Cost (R)



2.4 Burning

(Currently not operational)

Weekly electricity cost

	Actual	Target	
Average electricity rate	-	73.99	c/kWh
Cost intensity	-	-	R/t

Total Cost

R -

Weekly electricity consumption

Kiln 5 total

0 kWh

Weekly production

	Actual	Target	
Total coal consumed	0	-	t
Clinker produced	0	-	t
Average rate	-	-	t/h
Intensity	-	-	kWh/t

Production hours

0 h

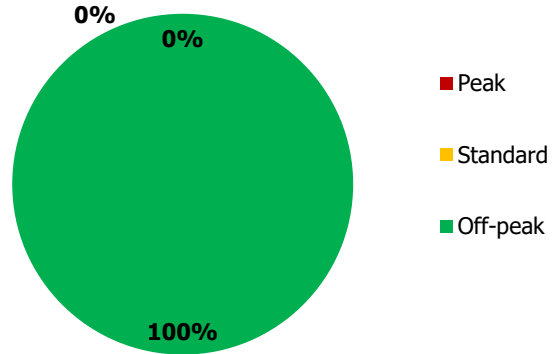
Utilisation

0 %

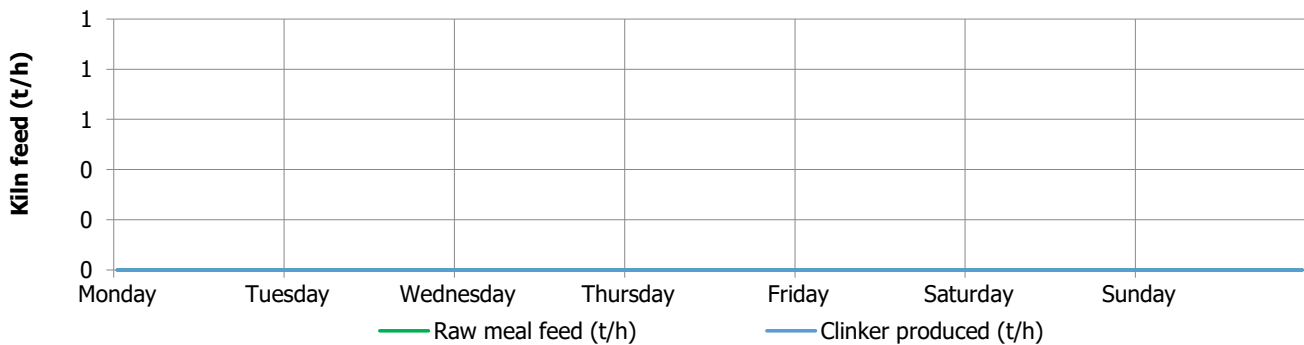
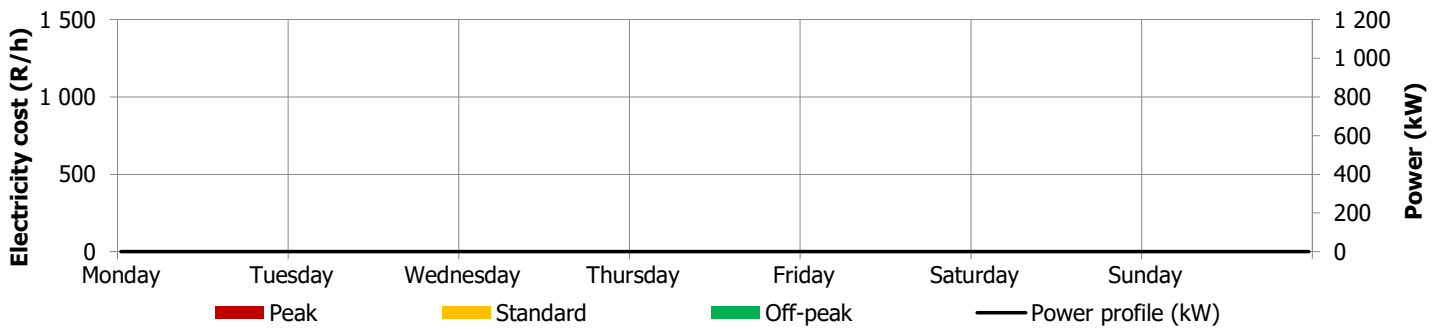
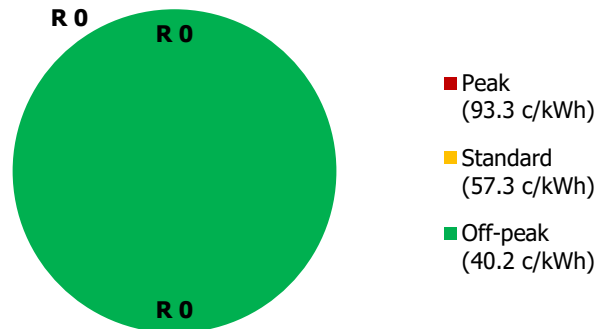
Stoppages

0

Consumption distribution



Cost (R)



2.5 Finishing milling

2.5.1 FM1

Weekly electricity cost

Average electricity rate

Cost intensity (excl. cement handling)

	Actual	Target	
Average electricity rate	51.39	49.75	c/kWh
Cost intensity (excl. cement handling)	20.05	18.06	R/t

Total Cost

R 70 677

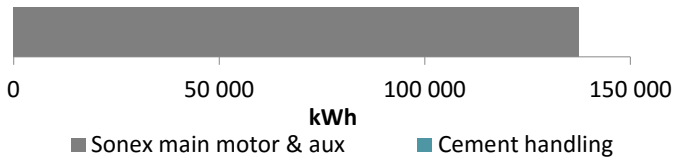
Weekly electricity consumption

Sonex main motor and aux*

Sonex cement handling**

Total

Sonex main motor and aux*	137 541	kWh
Sonex cement handling**	0	kWh
Total	137 541	kWh



Weekly production

Total production

Average rate

Intensity (excl. cement handling)

	Actual	Target	
Total production	3 524	-	t
Average rate	48.95	52.89	t/h
Intensity (excl. cement handling)	39.03	36.30	kWh/t

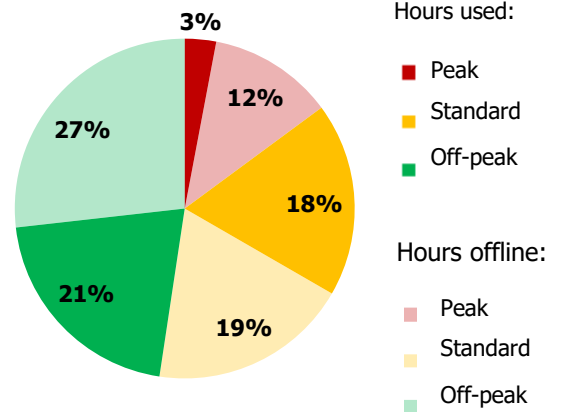
Production hours
Utilisation
Stoppages

Total	
Production hours	72 h
Utilisation	42 %
Stoppages	7

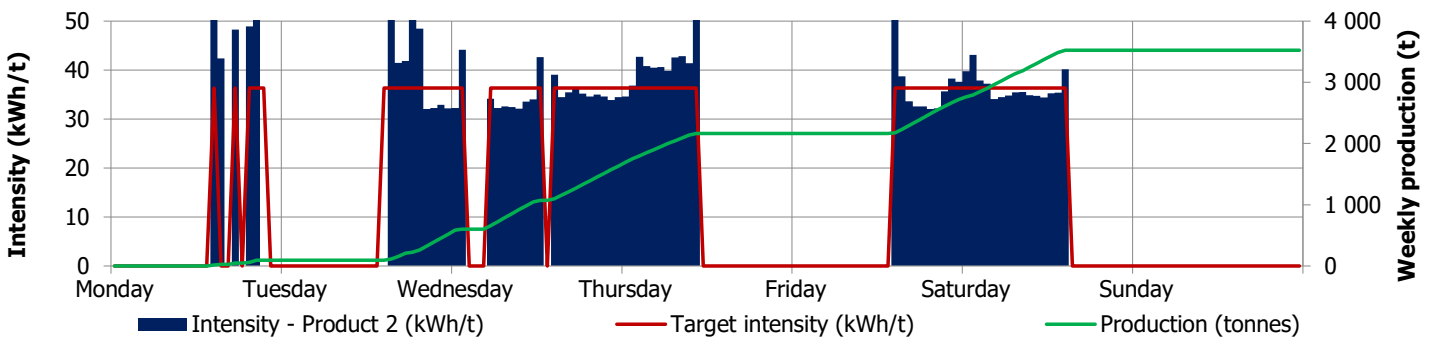
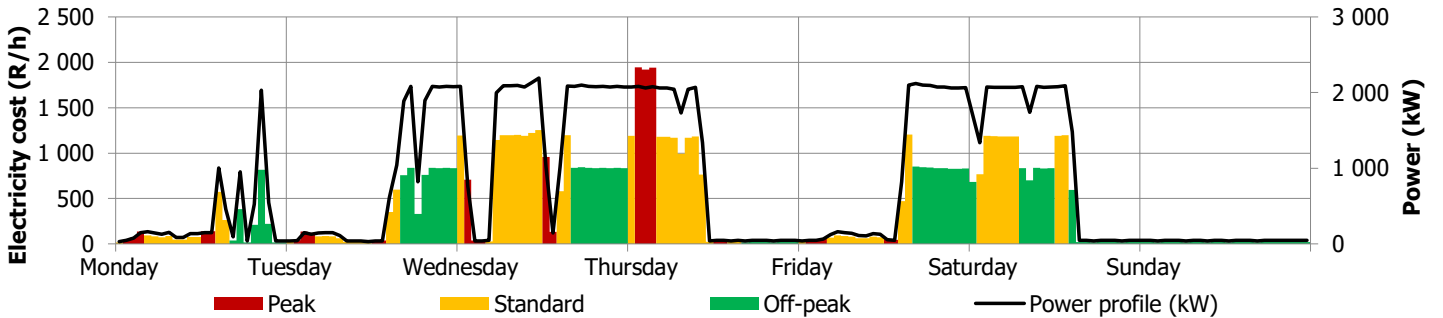
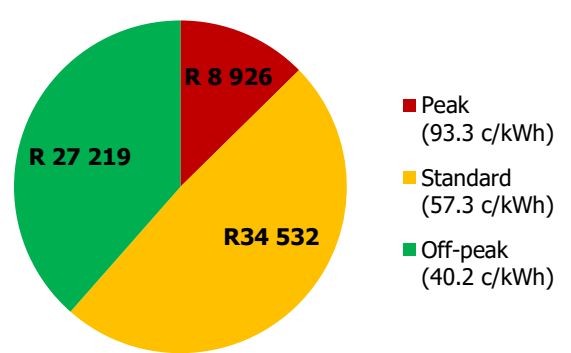
Missed opportunities

TOU	Intensity	Auxiliaries	Total
R 15 385	R 1 731	R 4 645	R 21 761

Utilisation



Cost (R)



* If production < 10 t/h, assume auxiliaries without motor

**Possible data loss

2.5.2 FM2

Weekly electricity cost

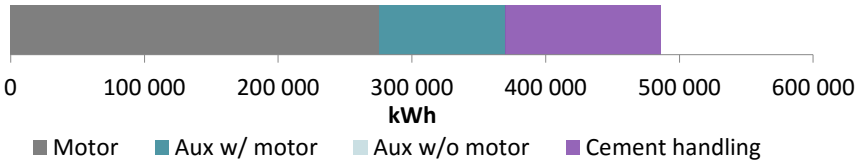
	Actual	Target	
Average electricity rate	49.59	50.19	c/kWh
Cost intensity (excl. cement handling)	14.33	13.81	R/t

Total Cost

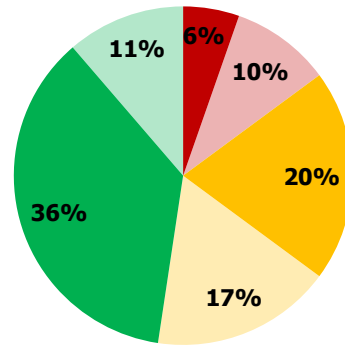
R 241 279

Weekly electricity consumption

VRM main motor	275 648	kWh
VRM aux	94 227	kWh
VRM cement handling	116 721	kWh
Total	486 596	kWh



Utilisation



Hours used:

- Peak
- Standard
- Off-peak

Hours offline:

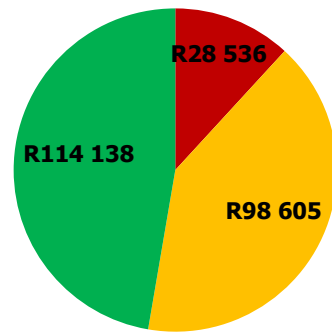
- Peak
- Standard
- Off-peak

Weekly production

	Actual	Target	
Total production	12 799	-	t
Average rate	117.42	114.50	t/h
Main motor intensity	21.54	17.29	kWh/t
Auxiliaries intensity	7.36	10.22	kWh/t

	Total	
Production hours	109	h
Utilisation	62	%
Stoppages	6	

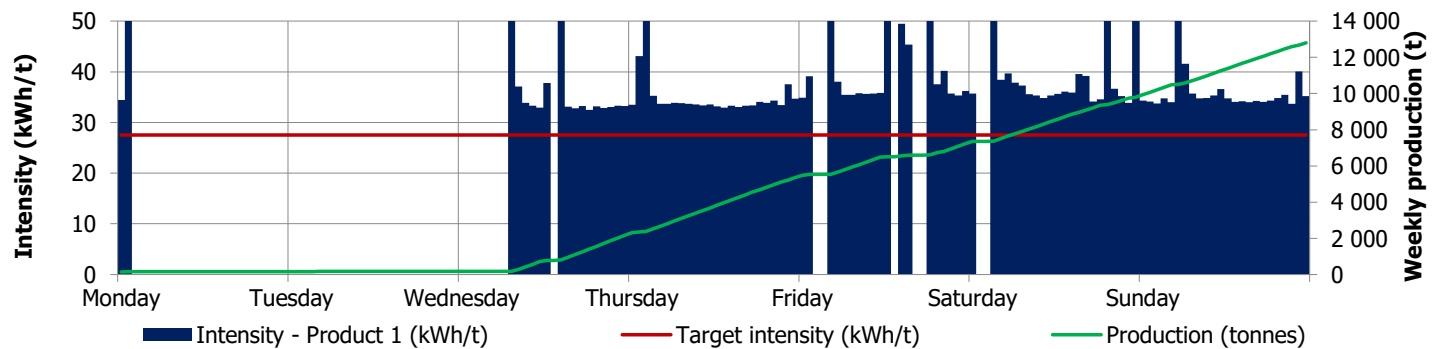
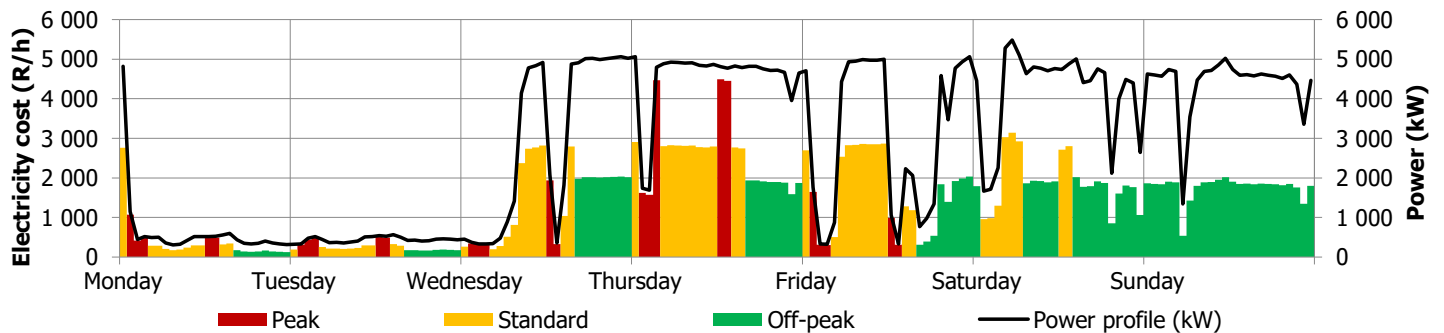
Cost (R)



- Peak (93.3 c/kWh)
- Standard (57.3 c/kWh)
- Off-peak (40.2 c/kWh)

Missed opportunities

TOU	Intensity	Auxiliaries	Total
R 16 056	R 49 012	R 11	R 65 079

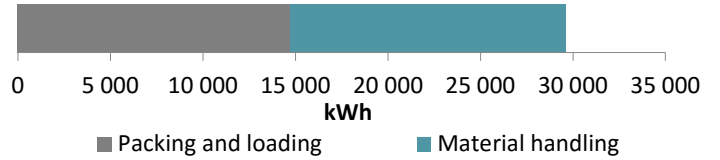


2.6 Dispatch

Weekly electricity cost

	Actual	Target
Average electricity rate	58.04	55.60

c/kWh



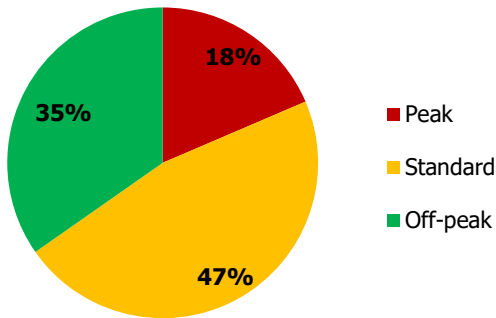
Total Cost

R 17 195

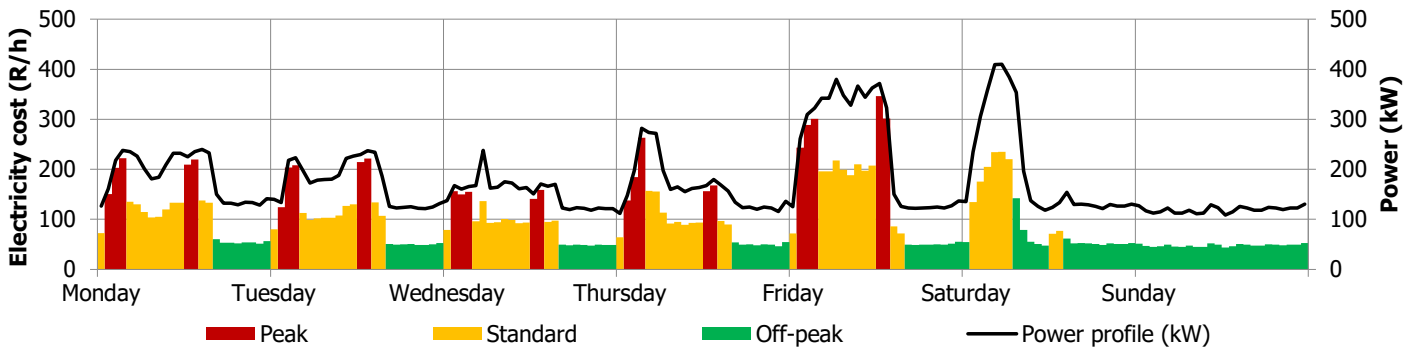
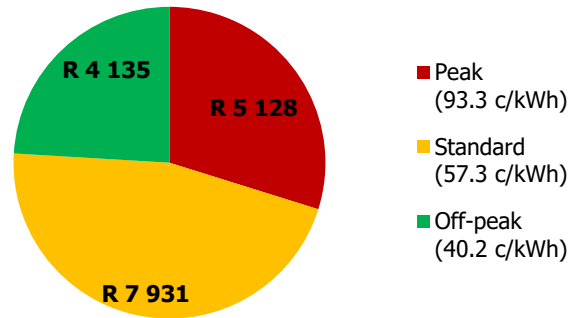
Weekly electricity consumption

Packing and loading	14 746	kWh
Material handling	14 879	kWh
Total Dispatch	29 625	kWh

Consumption distribution



Cost (R)



2.7 Services

Weekly electricity cost

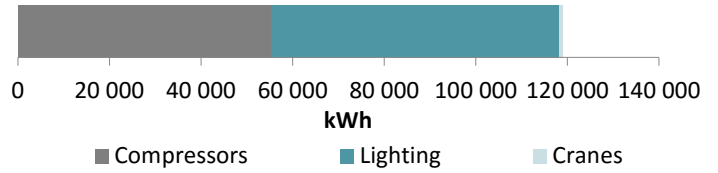
	Actual	Target	Unit
Average electricity rate	55.25	54.71	c/kWh

Total Cost

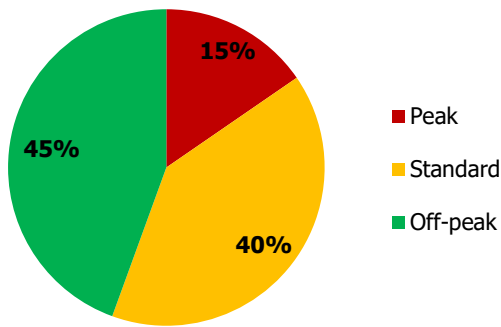
R 65 715

Weekly electricity consumption

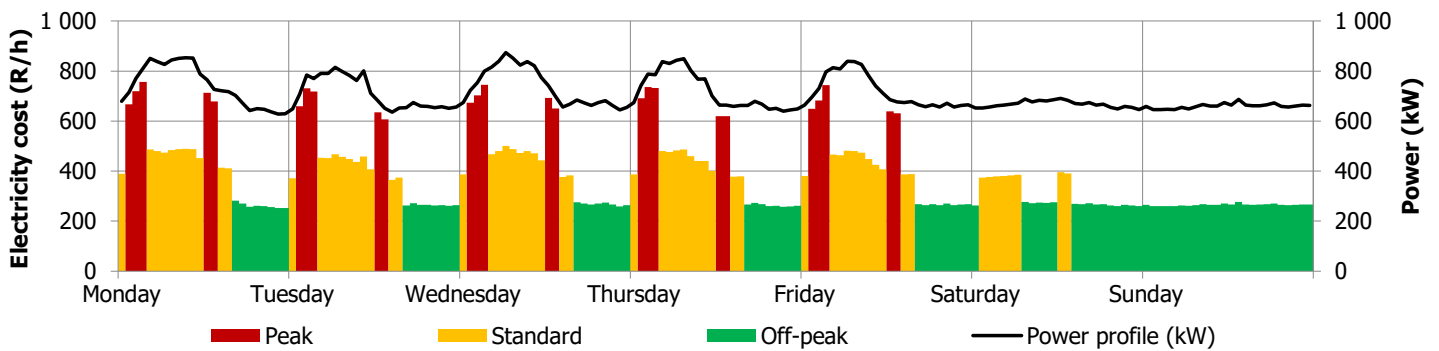
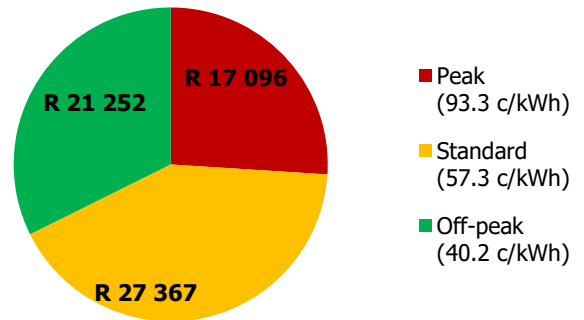
Compressors	55 328	kWh
Lighting	62 725	kWh
Cranes	897	kWh
Total	118 950	kWh



Consumption distribution



Cost (R)



2.8 Buildings

Weekly electricity cost

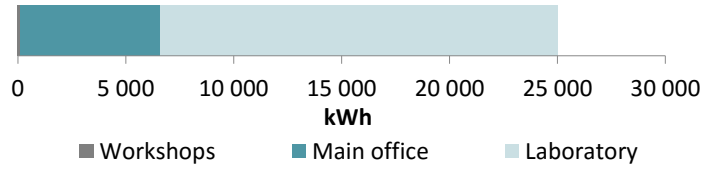
	Actual	Target	
Average electricity rate	55.76	55.22	c/kWh

Total Cost

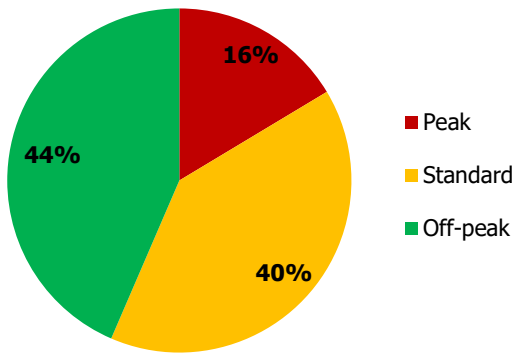
R 13 944

Weekly electricity consumption

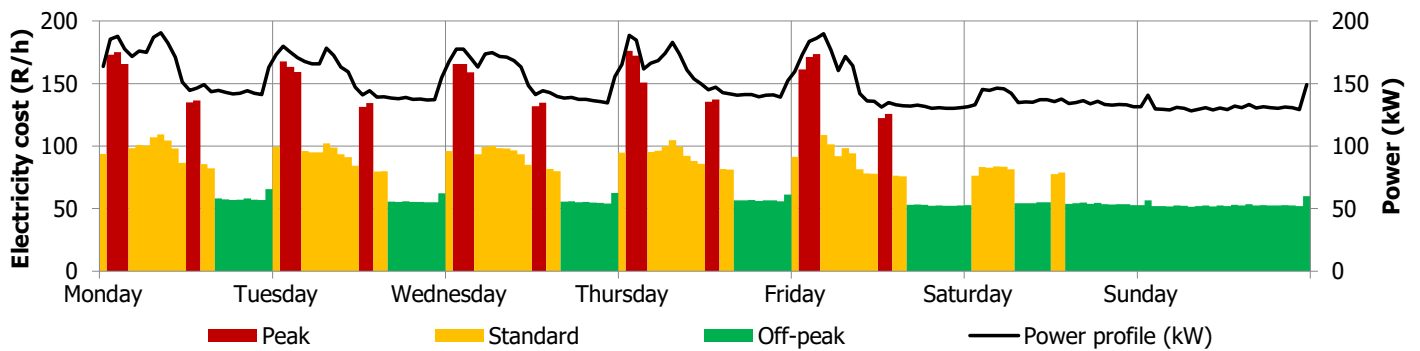
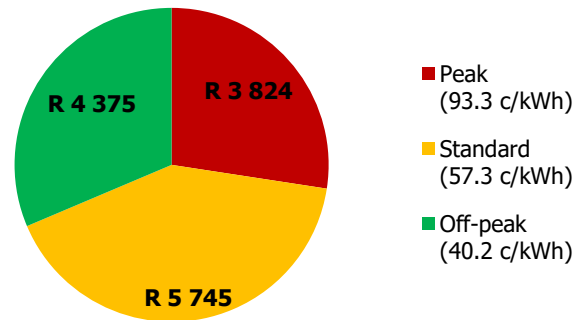
Workshops	101	kWh
Main office	6 477	kWh
Laboratory	18 430	kWh
Total Buildings	25 009	kWh



Consumption distribution



Cost (R)



APPENDIX H: ADDITIONAL ENERGY PERFORMANCE INDICATORS

This appendix focuses on additional performance of the EnPIs over the 14-month period evaluated in Chapter 4. Figure H 1 indicates the electrical energy intensity of “Clinker production” for the months that the kiln was used during the evaluation period. The trend line indicates an overall improvement in the intensity of the raw mill, coal mill and kiln per tonne clinker produced. This improvement originates mainly from the raw mill, where similar indicators as that of the finishing mills enabled the risks to be utilised as opportunities, and savings to be obtained. The higher intensity in February 2015 is most likely due to higher costs associated with initially starting the kiln equipment.

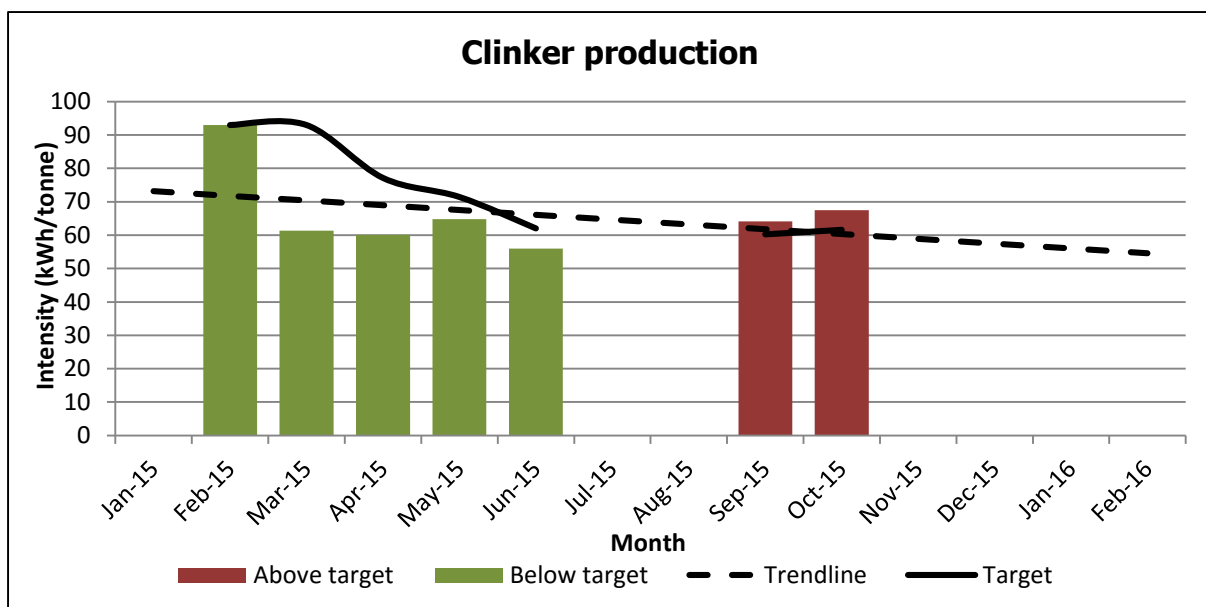


Figure H 1: Clinker production indicator over evaluation period

The “Total energy per clinker produced” is presented in Figure H 2 for the months that the kiln was operational during the evaluation period. This figure increased over the 14-month period, and does not reflect positively on the implementation of the energy management system. This could be due to the lack of correlation between finishing milling and clinker production. The clinker silos provide a buffer for the kiln to produce clinker for a period without the finishing mills having to produce cement. The finishing mills are mainly dependent on sales demand, and are the highest consumer of electrical energy on Plant X. The mills could thus possibly have been more utilised in certain months than others, while the clinker production remained approximately constant.

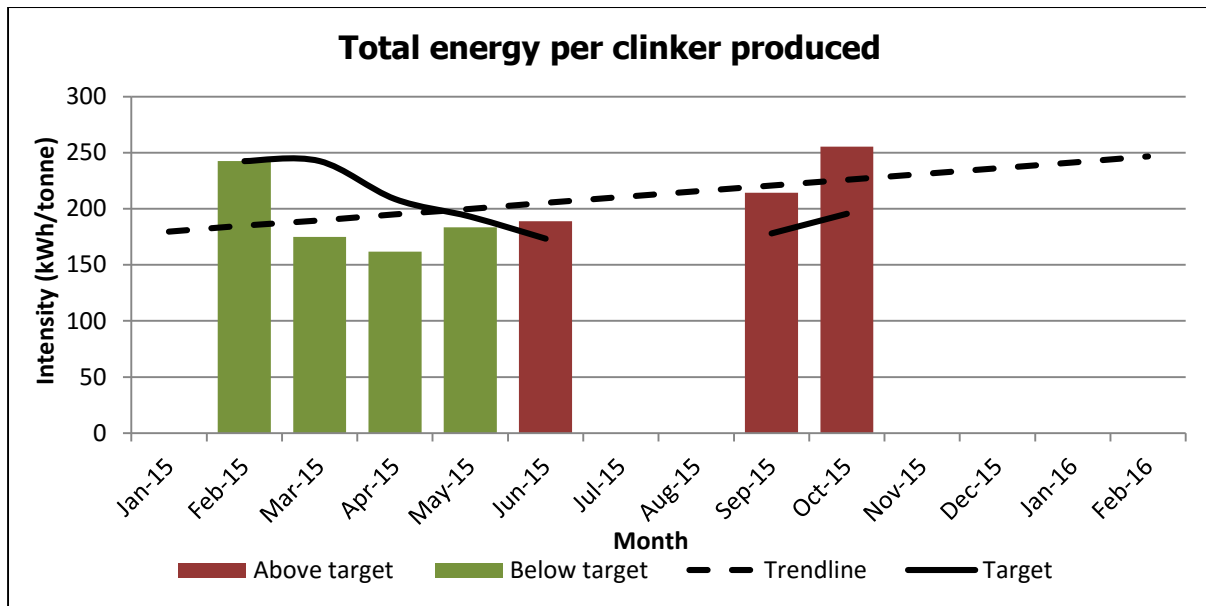


Figure H 2: Total energy per clinker produced over evaluation period

As discussed from Table 12, the “Cement manufacturing” presented in Figure H 3 improved over the evaluation period. This is also indicated by the trend line in this graph, which decreased over the evaluation period. This further indicates the reduction in energy consumption per tonne cement produced, and thus the continuous positive effect of the implementation of the energy management system.

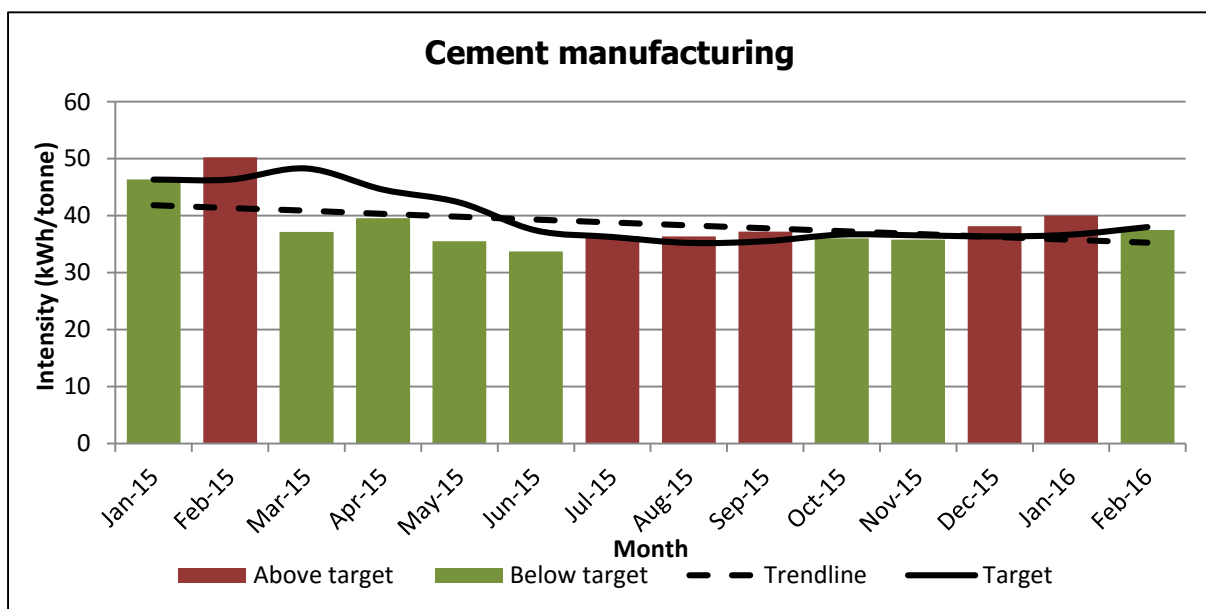


Figure H 3: Cement manufacturing indicator over evaluation period

Figure H 4 presents the “Total energy per cement produced” for the evaluation period. This figure was also discussed previously based on the figures presented in Table 12. The graph indicates the continuous positive effect that the implementation of the energy management

system had on the energy required to produce cement. A few spikes occur in some of the months, which can mainly be allocated to the production of clinker that increased the overall usage of electrical energy on the plant.

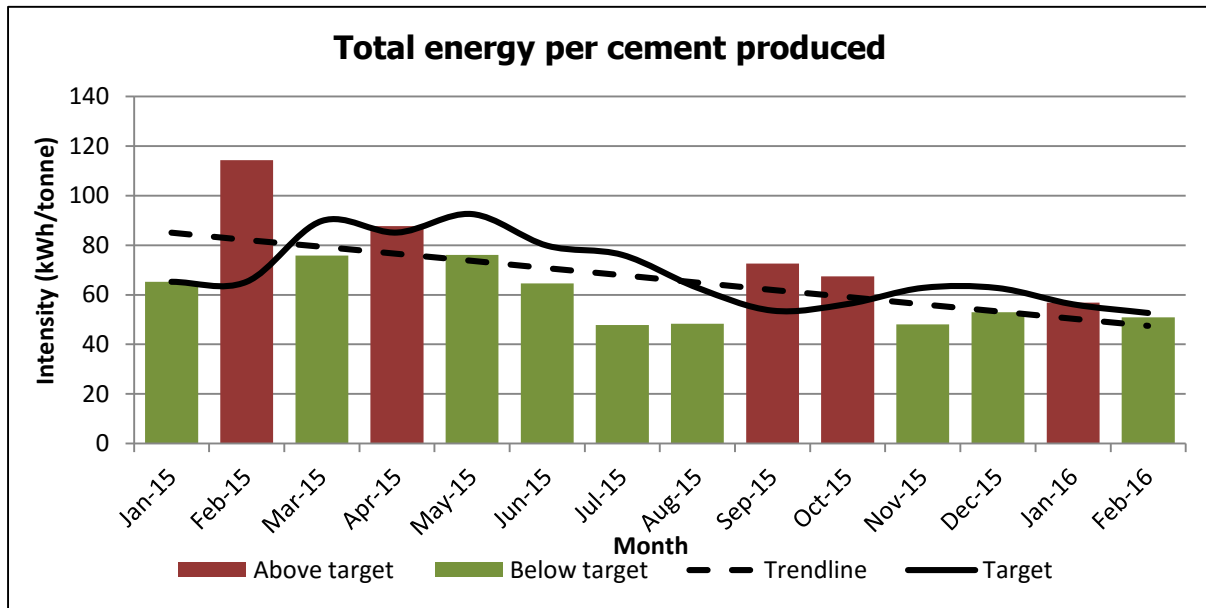


Figure H 4: Total energy per cement produced over evaluation period