The development and implementation of an energy management information system for industries

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Abstract

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There is a global drive to reduce energy consumption and improve energy efficiency. These drivers include the taxation of carbon emissions and the increase in energy costs. Companies therefore need to improve their operational efficiency to reduce operational costs. Systems and initiatives are therefore implemented to reduce energy consumption. References in this study shows that the performance of initiatives deteriorates if they are not monitored and maintained continuously.

An energy management system could help to sustain initiative performance if it follows the plan-do-check-act cycle of continuous improvement described by the ISO 50001 standard. Part of this cycle includes gathering, analysing and reporting measurement data in order to manage energy performance. However, this process is time and resource intensive. Commercial energy management information systems exist that aid this process. However, none of these systems include models that can analyse bill data automatically to identify risks and opportunities. Furthermore, only a few of them support efficiency initiative performance monitoring.

This study therefore develops and implements an energy management information system that aids to improve the energy efficiency of large industries in South Africa. The study is presented in the form of three articles, which combine to address the topic. The first article focuses on the need for an energy management system. Literature regarding the drivers and barriers of energy management is investigated. The research shows that the most important benefit of the system is the ability to process and analyse large volumes of data, which frees resource time to gain knowledge of the energy system and find ways in which it can be optimised further.

References mentioned in the second article show that data available in electricity bills could provide valuable information. Suppliers provide bills freely, which makes it a reliable data source even if the consumer's own measurements are lacking. However, the operational scale of large energy consumers means they have many electricity bills. This leads to the need for a system that processes, organises and analyses electricity bills automatically. The system could help to avoid risks such as cost inflation and reactive power penalties as well as aid in identifying cost-saving opportunities such as time-of-use optimisation and notified maximum demand reduction.

Finally, when the holistic system is understood and the identified efficiency initiatives implemented, the need arise to monitor the performance of the system and initiatives. The third article focuses on the development and implementation of a generic performance monitoring system. The system automatically collects, processes and stores the data related to the initiative. It calculates the performance of the initiatives based on the configuration set up via a web application. The same web application presents the performance analysis in various forms and allows the creation of reports, which are signed off by stakeholders. This system is in line with the principles of the International Performance Measurement and Verification Protocol.

The study achieves its goal to develop and implement an energy management information system for industries. Results show that the two mining groups that have implemented the system process 9.3 million efficiency initiative data points every year. A particular mining group implemented the efficiency initiative performance monitoring system for 81 initiatives over 24 different sites. In the first 29 months since the implementation of the first initiative, the mining group lowered their average electricity demand by 14.8 MW, which resulted in cumulative cost savings of more than R170 million.

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Finally, thanks to all my friends and family for their support.

List of papers

This thesis is in an article format. It is based on the work described in the articles listed below. With permission from the copyright holders, these articles are appended to this document. The student, P. Goosen, was responsible for the technical work in each article. The co-authors, Dr J. C. Vosloo, Dr M. J. Mathews, Dr J. N. du Plessis and Dr J. A. Swanepoel, granted permission to submit the thesis in this format. Their statements are appended to this document.

1. P. Goosen, J. A. Swanepoel, and J. N. du Plessis, "The need for a comprehensive energy management information system for industries," *South African Journal of Industrial Engineering*, vol. 27, no. 3, pp. 1–11, 2016.
2. P. Goosen, M. J. Mathews, and J. C. Vosloo, "Automated electricity bill analysis in South Africa," *South African Journal of Industrial Engineering*, vol. 28, no. 3, pp. 66–77, 2017.
3. P. Goosen, M. J. Mathews, and J. C. Vosloo, "Generic efficiency initiative monitoring system," *Computers in Industry*, 2019. (Under review)

Other publications by the author:

- P. Goosen, R. Pelzer, and G. Bolt, "Efficient monitoring of mine compressed air savings," in *Proceedings of the Conference on the Industrial and Commercial Use of Energy, ICUE*, 2013, pp. 113–118.
- P. Goosen, I. M. Prinsloo, and R. Pelzer, "Simplified performance monitoring of energy systems," in *Proceedings of the Conference on the Industrial and Commercial Use of Energy, ICUE*, 2014, pp. 123–126.
- P. Goosen, R. Pelzer, and H. J. du Plessis, "A method for accurate electricity budget cost calculations for a deep mine," in *Proceedings of the Conference on the Industrial and Commercial Use of Energy, ICUE*, 2015, pp. 155–160.

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Nomenclature

Abbreviations:

CPI	Consumer Price Index
DSM	Demand-side Management
EMC	External Metering Company
EMS	Energy Management System
EMIS	Energy Management Information System
ESCo	Energy Services Company
HVAC	Heating, Ventilation and Air Conditioning
IoT	Internet of Things
IPMVP	International Performance Measurement and Verification Protocol
ISO	International Organisation for Standardisation
KPI	Key Performance Indicator
M&V	Measurement and Verification
PME	Proportional Monthly Energy
POD	Point of Delivery
SAJIE	South African Journal of Industrial Engineering
SCADA	Supervisory Control and Data Acquisition
SQL	Structured Query Language

Units:

kVAr	kilovolt-ampere	Reactive power
kW	kilowatt	Power
kWh	kilowatt-hour	Energy
GW	Gigawatt	Power
GWh	Gigawatt-hour	Energy
ML	Megalitre	Volume
MVA	Megavolt-ampere	Apparent power
MW	Megawatt	Power
MWh	Megawatt-hour	Energy
R	South African Rand (ZAR)	Currency

Chapter 1

Introduction

1.1 Background

1.1.1 The need for energy management

Global land and ocean surface temperatures in 2019 were 0.88 °C above the 20th century average. These temperatures tie with 2007 as the third-highest temperatures ever recorded.[1] 2016 remains the hottest year ever recorded on earth.[1, 2] In fact, since 2001, 18 of the 19 warmest years on record have been recorded.[1, 2] Global warming is caused by an increase in the amount of carbon dioxide (CO_2) in the earth's atmosphere. A large contributor to this is the consumption of energy from burning fossil fuels [1]. Global pressure to reduce carbon footprint and CO_2 emissions is applied in the form of legislation and incentives [2]. However, the regular increase of energy costs remains one of the major motivators for industries to reduce their energy consumption.

In South Africa, the cost of energy has increased significantly in the last decade compared with the consumer price index (CPI). Figure 1.1 shows the increase in energy cost normalised to January 2006 [3,4]. Of the different energy sources, electricity increased the most: by April 2016 it was 364% more expensive than in 2006 compared to the CPI increase of 75%. This increase means that although industries' operational costs are increasing, their production is not necessarily increasing accordingly. Industries therefore need to improve their energy efficiency in order to stay profitable [5].

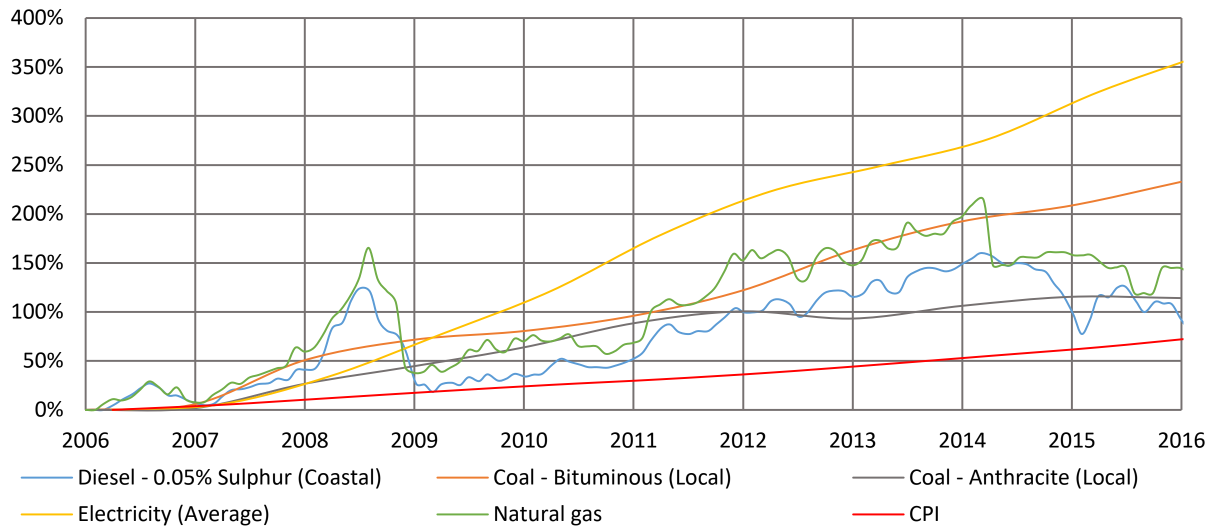

Figure 1.1: *Energy cost increase compared with CPI* [3,4]

Apart from the increase in energy costs, industries face various other technical, economic and social challenges. To remain competitive, they need to adapt to overcome these challenges. In South Africa, these challenges include labour issues; political, social and environmental issues; and escalating cost of production [6].

[1] NOAA (National Centers for Environmental Information), "State of the Climate: Global Climate Report for January 2019." 2019. [Online]. Available: https://www.ncdc.noaa.gov/sotc/global/201901 [Nov. 23, 2019].

[2] S. Potter, M. Cabbage, and L. McCarthy, "NASA, NOAA data show 2016 warmest year on record globally." 2017. [Online]. Available: https://www.nasa.gov/press-release/nasa-noaa-data-show-2016-warmest-year-on-record-globally [Nov. 23, 2019].

Labour productivity is affected by various human factors such as labour availability and utilisation, labour–management relations, labour–labour relations, and crew quality [6, 7]. In 2011, 2012 and 2014, strikes took place in various mining sectors, which had a considerable financial impact on the industry and national economy [6, 8]. In these cases, the Chamber of Mines of South Africa stepped in to handle the wage negotiations.

Political, social and environmental issues place considerable pressure on industries. Non-compliance with regulations such as section 54 and section 55 of the Mine Health and Safety Act 29 of 1996 can lead to closures until the mines become compliant [9]. During such closures, employees still need to be paid, thereby increasing costs and decreasing production and revenue [6, 7].

Additionally, companies face social unrest, such as xenophobic attacks in 2009, 2015 and more recently in 2019, which strains international relations and could scare away foreign investors [6, 10]. Political interference such as the call to nationalise mines further concerns foreign investors [6, 11, 12].

Companies must also be aware of their environmental impact. Governments implement legislation that penalise the emission of CO_2. This comes in the form of environmental levies added to energy invoices as well as carbon tax. As of June 2019, the South African government implemented carbon tax at a rate of R120 per tonne of CO_2 emitted [13]. This poses a major financial risk to consumers and they have no choice but to manage energy consumption as efficiently as possible.

For a typical gold mine in South Africa, 50% of the major production costs consist of labour, energy and water [14, 15]. The costs of these resources have been growing substantially. As mentioned, specifically electricity cost has increased considerably which, coupled with the erratic supply thereof, places considerable strain on production operations.

Water is an important resource for most industries; however, as in many countries, water is becoming an increasingly scarce resource in South Africa [16, 17]. The availability of fresh water is dependent on the season and rainfall, making the supply highly variable. South Africa is considered among the top 20 water-stressed countries in the world due to relatively low rainfall and high evaporation rates [17].

Sibanye-Stilwater released their Integrated Annual Report in 2017, which discussed the water usage of the company. The company purchased 18 284 ML of municipal drinking water at a cost of R230.9 million in 2017 [18]. This highlights the need to use water sparingly – both from an environmental and financial point of view.

To improve energy efficiency, companies implement efficiency initiatives (also known as Energy Conservation Measures) to reduce energy consumption, increase production, or both [19–22]. Implementing efficiency initiatives can be expensive [2]. In order to assist consumers to use energy more efficiently, there are various incentives and energy efficiency programmes available. These are investigated in more detail in Article 1. Some examples from South Africa include: the Demand-side Management (DSM) programme, tax rebate incentives based on section 12L of the Income Tax Act, and free energy audits conducted by the National Cleaner Production Centre.

Navigating the complexities of the relevant regulations and legislation can be overwhelming. That is where an energy services company (ESCo) applies their expertise. ESCos provide energy solutions to consumers who want to improve their energy efficiency. ESCos stay up to date with changes in legislation and incentives in order to help their clients in the best possible way. In South Africa, the main utility company, Eskom, uses ESCos to implement DSM projects [23,24]. The ESCos provide their expert services to obtain the optimal results for each DSM project.

Energy consumers also contract ESCos directly to manage their energy usage. To ensure sustainability, a maintenance agreement between the consumer and the ESCo is put in place [23,25]. Groenewald introduced a performance-centred maintenance strategy used by an ESCo to maintain the performance of a client's DSM projects [25]. His results showed that the ESCo was able to increase the performance of a DSM project by 70% using performance-centred maintenance. The strategy is dependent on an energy management system (EMS) to monitor the performance of the projects. The following section analyses literature regarding EMSs.

1.1.2 Energy management systems

Although industrial sectors have made significant improvements concerning energy efficiency, a significant share of untapped energy efficiency remains. The difference between the actual energy efficiency and the potential energy efficiency is known as the energy efficiency gap [26–28]. Backlund *et al.* concluded that the efficiency gap is extended by applying energy management because the potential for energy efficiency is increased [26].

Schulze *et al.* conducted a comprehensive review of industrial energy management [27]. In their study they found that improving energy efficiency is difficult due to the complexity of industrial systems [27]. This complexity leads to the need for EMSs. An EMS is defined as the procedures to control energy usage and improve efficiency in industries [29,30].

The international standard for EMSs (ISO 50001) assists consumers with the implementation of an EMS by providing guidelines and basic requirements [27,31–33]. Gopalakrishnan *et al.* summarised the general requirements of ISO 50001: "to establish, document, implement and continuously improve an energy management system" [31,33].

This continuous improvement concept is the core of the ISO 50001 standard and is discussed in many other energy management studies [5,26–29,32–36]. The plan-do-check-act cycle was developed to assist with the continuous improvement process and is summarised in Figure 1.2. Key performance indicators are measured against a baseline in order to determine energy-related improvement or deterioration. The baseline defines the initial state of the energy system before any changes were made.

Many of the items listed in the figure are dependent on data. For example, data is collected from measurements whereafter the data is analysed and evaluated to make informed decisions. In an effort to make these decisions, increasingly more sensors are installed to gather as much data as possible [37]. With the increase in the amount of data, some new challenges and solutions have emerged, which are discussed in the following section [37–39].

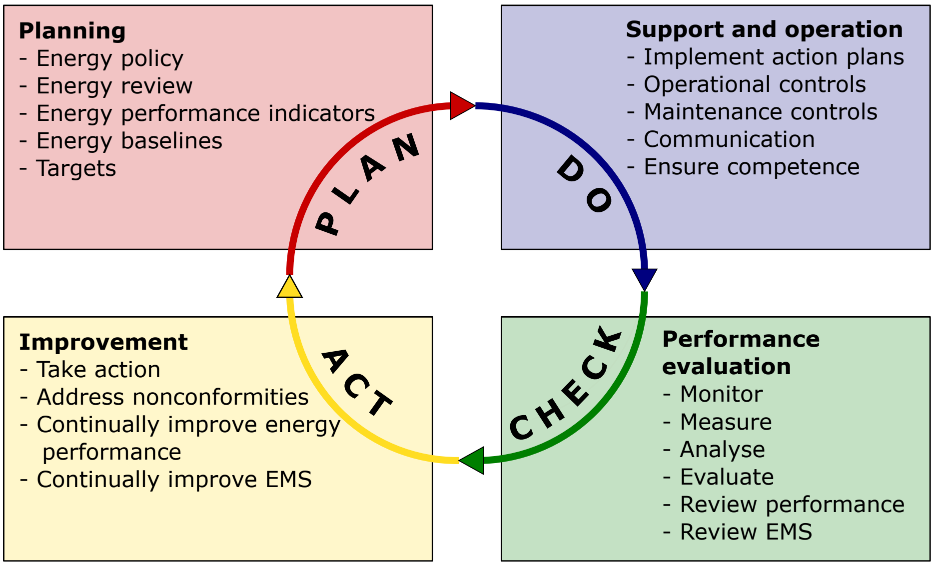

Figure 1.2: *Plan-do-check-act cycle of ISO 50001* [25, 31]

1.1.3 Data in energy management

To simply *monitor* energy consumption, only energy measurements are required. However, for energy personnel to *manage* energy consumption properly, they require other types of measurement data as well. This data includes parameters related to the system's efficiency, limitations and condition. For example, for a mining company's water reticulation system, it is beneficial to know the water flow rates, dam/reservoir levels, and a magnitude of pump-related data. The availability of this data makes it possible to identify potential energy efficiency opportunities in relation to the water demand (current and predicted).

There are some challenges to use this data effectively. Zhou *et al.* identified two challenges: i.) how to analyse the data effectively to uncover the hidden information; and ii.) how to collect and store the vast amounts of data effectively while ensuring that the quality and reliability of the data stays intact [37]. They focused on solving the latter challenge by developing a pattern-based compression algorithm.

In many cases, data have multiple sources. The data must be collected from the sources before it can be analysed holistically. Different sources could have different data formats, which means the data should be translated before it can be used. Translating data into a usable format takes time, especially if it is done manually on large amounts of data. Ideally, data should be collected automatically and regularly, which means collecting and translating data put substantial strain on human resources, even before any analysis has been done.

1.1.4 Commercial systems

Commercial energy management information systems (EMISs) exist. They provide various features, but have shortcomings that are uniquely addressed by this study. The first product is the ISO 50001 compliant SIMATIC Energy Manager PRO by Siemens.[3] It provides support to reduce energy consumption and costs and identify inefficient energy-consuming systems. SIMATIC Energy Manager PRO supports bill verification, but does not analyse bill data using models similar to those developed in Article 2.

Energy Insight provides two products for managing energy information, namely eiEnterprise and StruxureWare. eiEnterprise is used to track energy consumption and supports bill verification.[4]

StruxureWare collects low-level data and allows the user to control, manage and monitor the infrastructure.[5] While both these systems allow users to verify utility bills to determine discrepancies, neither analyse the bill data in further detail to identify risks or opportunities. Furthermore, these systems do not track the performance of initiatives based on predetermined fixed or adjustable baselines according to the International Performance Measurement and Verification Protocol (IPMVP) principles.

Energy Cybernetics developed a system called PowerWatch.[6] The system is used to track energy consumption and verify utility bills. Similar to the systems mentioned above, it cannot analyse bill data. The system does support performance monitoring based on energy baselines, but only for fixed and non-scalable baselines.

Although all these systems are able to track energy consumption and verify utility bills, only the SIMATIC Energy Manager PRO supports performance tracking based on scalable baselines. None of these systems use electricity bill data to identify risks or opportunities directly. Thus none of these commercial systems provide initiative performance monitoring integrated with utility bill analysis. Finally, no academic literature is available that presents verifiable results of the implementation of these systems.

1.2 Problem statement and study objective

With the rise of CO_2 in the earth's atmosphere, the increase in energy costs and the implementation of carbon tax, there is a drive for large energy consumers to reduce their carbon footprint by improving their energy efficiency. Therefore, consumers use the expertise of ESCos to increase the efficiency of their operations [23, 25]. The ISO 50001 standard for EMSs helps energy personnel to improve energy performance continually despite the complexity of the industrial systems.

In order for energy personnel to manage the energy consumption of industrial systems effectively, they need to collect large volumes of data [37, 40]. The data enables energy performance to be tracked and potential initiatives for improving energy efficiency to be identified. However, collecting and processing data is a labour-intensive process. Furthermore, analysing the data requires additional intensive labour and knowledge. An EMIS for industries is required to assist with managing large volumes of energy-related data [23, 25–27, 37–39].

[3] Siemens, "Company-wide energy management with SIMATIC Energy Manager." [Online]. Available: https://c4b.gss.siemens.com/resources/images/articles/dffa-b10256-01-7600.pdf [Feb. 16, 2020].

[4] EOH, "eiEnterprise – Energy Management Suite." [Online]. Available: http://www.energyinsight.co.za/product/eienterprise-energy-management-suite [Nov. 23, 2019].

[5] EOH, "Optimize your power network with data-driven decisions." [Online]. Available: http://www.energyinsight.co.za/wp-content/uploads/2015/08/power-monitoring-expert-brochure.pdf [Nov. 23, 2019].

[6] Energy Cybernetics, "PowerWatch." [Online]. Available: http://new.cpowerwatch.com [Nov. 23, 2019].

Study objective

The objective of this study is to develop and implement an EMIS for industries. The EMIS should aid industry to manage energy efficiency effectively by automating the data collection, translation and storage processes. The EMIS should aid energy personnel to analyse the data to extract meaningful information and identify potential opportunities to improve energy efficiency.

The aim of the first step (and first article) of this article-based thesis is to understand the need for an EMIS. Article 1 explains in more detail why such a system is required and what is required of such a system. From this article, the two main next steps are identified, which lead to the second and third articles. The second article focuses on analysing electricity bill data, which is the most basic data that is definitely available even without the need for expensive measurement instrumentation. The final article discusses the performance tracking of efficiency initiatives, which is important to complete the plan-do-check-act cycle and improving continually. The developed EMIS referred to in this thesis and the three articles is known as Management Toolbox or MTB.

1.3 Novel contributions

From the study objective in the previous section, the need to develop and implement an EMIS for industries is identified. The main contribution of each individual article in this study combines to solve the holistic problem stated.

Article 1

The first article of this thesis [2], published in the South African Journal of Industrial Engineering (SAJIE), focuses on the need for the EMIS and makes the following contribution:

> Identify the need for an EMIS to enable a new energy management strategy, which is strengthened by a data audit of the EMIS, and implement the EMIS in the South African industrial sector.

Due to the rising energy costs, companies must improve their operational efficiency to remain competitive. Therefore, companies need tools to process and analyse large amounts of raw data to identify and monitor savings initiatives. Although commercial systems exist, no academic literature could be with verifiable results. Various studies have been conducted to determine the need for EMSs; however, few studies have progressed further than developing proposed frameworks to address the problem.

This study solves the problem by creating a structured energy management strategy. The strategy focuses on enabling better communication between departments to improve energy efficiency. An EMIS supports the energy management strategy by processing and analysing large amounts of data. The system is implemented at a number of South African industries. An investigation into the large volumes of data emphasises the need for such a system.

In order to identify potential initiatives to improve energy and operational efficiency, companies first need to understand the holistic state of their energy usage. Electricity bills provides this information, but only if the data is analysed meticulously.

Article 2

The second article of this thesis [41], also published in the SAJIE, makes the following contribution:

> Develop and implement a scalable system to automatically analyse data available in electricity bills of South African industries.

To gain a broad understanding of a company's energy usage, a need exists to gather high-level energy data. Valuable data can be obtained from electricity bills without the need for additional metering infrastructure. Large industrial companies receive numerous monthly bills, which become cumbersome and labour intensive to analyse. This creates a secondary need for an automated bill analysis system.

Presently, bill analysis is used to monitor building energy efficiency in East Asian countries. In South Africa, such systems are predominately used by residential households and are lacking in the industrial sector. Commercial systems support bill verification, but do not analyse bill data directly to identify risks and opportunities, and are lacking verifiable results in literature. In academic literature, existing systems are either only used for educational purposes or are not automated, which makes it difficult to scale for large industrial companies. South Africa also has a unique time-of-use tariff structure that provides different savings opportunities.

In this study, a system is developed to analyse industrial electricity bills automatically. Data is extracted from the bills and organised to aid system level analysis. Various methods are developed to analyse and present the variety of data collected from the bills. The system makes it easy to identify savings opportunities such as time-of-use and notified maximum demand optimisations.

Article 3

The final article focuses on the performance of these savings initiatives and makes the following contribution:

> Develop and implement a scalable system to monitor the performance of efficiency initiatives.

To improve operational efficiency and cost, companies implement energy efficiency initiatives such as those identified by the electricity bill analysis system. The obvious goal of these initiatives is to save energy, which leads to cost savings, which in turn improves profitability. As prescribed by the ISO 50001 standard, these initiatives need to be monitored continually to maintain their performance.

Studies was conducted to develop performance monitoring strategies. Many studies focused on defining performance monitoring, but lacked practical solutions. Other studies developed frameworks, which are not suitable for large industrial companies due to a lack of scalability. Commercial systems exist that are able to monitor system performance, but only one system supports adjustable baselines. None of these systems provides initiative performance monitoring integrated with bill analysis.

This study develops and implements a performance monitoring system for large industrial companies in South Africa. The system allows users to configure efficiency initiatives for performance tracking on various systems. Data is automatically collected, stored and processed in line with the principles of the IPMVP. The performance of the configured initiatives is calculated automatically and available via a web application and reports.

1.4 Thesis overview

Chapter 1: *Introduction*

This chapter provided a brief introduction as to why energy consumption should be managed. It considered EMSs and uncovered a major challenge, namely the vast amounts of data to be handled. This led to the problem statement and objective of this study.

Chapter 2: *Article 1 – The need for an energy management information system*

This chapter provides a summary of Article 1, titled: "The need for a comprehensive energy management information system for industries". As the title suggests, the article focuses on the need and the requirements for such a system. It concludes with a data investigation of the system in an effort to prove that the vast amounts of data cannot be converted efficiently to valuable information without the system.

Chapter 3: *Article 2 – Automated electricity bill analysis*

This chapter provides a summary of Article 2, titled: "Automated electricity bill analysis in South Africa". One of the main subsystems identified in the first article is the analysis of bill data received from the utility companies. This is a logical initial step to review and understand the state of the energy system. The article develops various methods for analysing the data and potentially identifying energy-saving opportunities.

Chapter 4: *Article 3 – Generic efficiency initiative monitoring system*

This chapter provides a summary of Article 3, titled: "Generic efficiency initiative monitoring system". Article 1 identified another subsystem, namely the performance monitoring of implemented efficiency initiatives. Article 3 focuses on the development and implementation of such a system.

Chapter 5: *Conclusion*

Chapter 5 concludes the thesis with a discussion of the three articles and the EMIS as a whole. Finally, recommendations for future research are provided.

Chapter 2

Article 1 – The need for an energy management information system

2.1 Preamble

In South Africa, energy costs are increasing faster than the CPI (see Section 1.1.1), which means that industries need to reduce their operational costs to stay profitable. However, energy efficiency improvement is a slow and expensive process. To alleviate the expense, rebate programmes provide financial assistance for energy efficiency. Unfortunately, rebate programmes are decreasing and becoming more difficult to obtain, which means that efficiency initiatives need to be self-funded.

One solution is to improve energy efficiency by applying better operational energy management. However, improving operational energy management requires experience. This is where ESCos can help. ESCos use tools to assist with efficient energy management. The aim of this article is to investigate and motivate the need for an EMIS.

The next section investigates common obstacles that restrict effective energy management. Thereafter, literature regarding other EMISs is investigated, which is followed by the proposal of a structured energy management strategy. Together with the strategy, a comprehensive EMIS is delineated. The system helps an ESCo to manage the energy of large consumers. The amount of data processed by the system is investigated to further emphasise the need for the system.

2.2 Literature

The concept of energy management and how to successfully implement continuous energy management in industry have been studied from both a policy perspective [26, 27, 42], and from a company perspective [42, 43]. According to Lawrence *et al.* [29], energy management implies energy efficiency – both through the implementation of technology and efficiency practices.

2.2.1 Drivers and barriers for energy management

Drivers for energy management

It is important to understand what drives and what blocks energy management practices in an organisation. The drivers for energy management should not be confused with drivers for the implementation of energy efficiency measures.

Solnørdal and Foss conducted a comprehensive review of energy efficiency drivers [44]. The review identified four main energy management driver categories; namely, economic, organisational, market-related, and policy-related drivers. Figure 2.1 shows the distribution of drivers for energy efficiency according to the study conducted by Solnørdal and Foss [44].

Of the energy management categories mentioned, 44% were organisational drivers, with economic drivers comprising 30% of the sampled drivers [44]. Additionally, market-related drivers and policy-related drivers accounted for 14% and 10% of drivers, respectively. Figure 2.1 clearly shows that organisational drivers and economic drivers are vital to energy management.

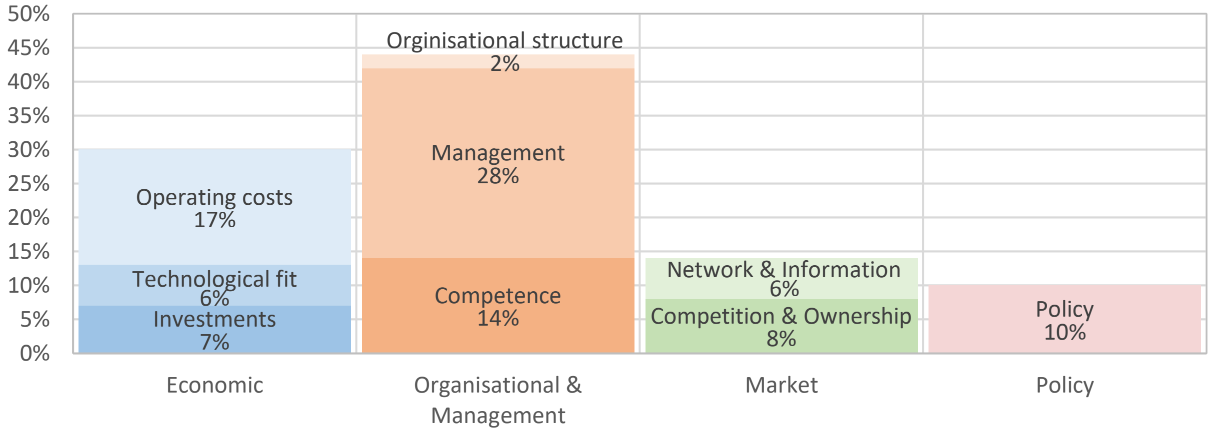

Figure 2.1: *Categories for energy efficiency drivers* [44]

Organisational drivers include cooperation between units within a firm, organisational structure, awareness of energy efficiency, energy audits, performance indicators, long-term energy strategy, commitment and support, the competence and motivation of employees, training and education [28, 29, 42, 44].

Organisational drivers comprise tasks and processes that affect the entire organisation; for example, the organisational structure, the cooperation between business units, the organisation's strategy, and the competence of employees. These drivers further include energy audits, energy efficiency awareness, and various performance indicators.

Economic drivers are critical motivational drivers for energy efficiency. Energy use and energy tariffs have a measurable impact on operational costs; thus, reducing energy use results in increased energy efficiency [29, 42]. A firm's investment in energy efficiency is driven by its internal financial resources, its historical earning growth, and its expected future earnings. However, one of the largest financial drivers is the investment cost and payback period for an energy efficiency initiative [44].

Market-related drivers are defined as drivers that originate externally to the firm, excluding policy-related drivers [44]. Knowledge transfer and cooperation between companies have been shown to be valuable drivers for energy efficiency [29]. Companies can find inspiration for new efficiency initiatives by sharing information with other cooperating institutions such as ESCo consultancy services, suppliers, academia and government programmes [29,44]. For small and medium enterprises that lack internal resources, such cooperation is crucial. Competition and international ownership are also considered to be market-related drivers. Competition drives firms to become more cost-driven and solution orientated [44].

Policy-drivers are prescriptive, economic or supportive drivers that stimulate energy efficiency by increasing energy taxes and emission fees or by providing investment subsidies [42]. Legal compliance is dictated by prescriptive policies. In order for companies to conduct business activities, they must comply with legal requirements [44].

Barriers for energy management

In previous years, industrial organisations solely focused on production to the extent that energy efficiency was not a consideration. However, organisations have realised that energy efficiency has an increasingly large impact on their bottom line. Although this led to energy efficiency initiatives being considered more carefully, there are still barriers that could prevent these initiatives from becoming a realisation.

Some of the largest barriers are economic in nature [29,32,42,45]. Projects that require large capital investments with long payback periods are less likely to be implemented than projects that require small capital investments and shorter payback periods [29, 32, 42]. According to a study done for the Ontario Mining Association's Energy Committee in 2008, projects require payback periods of less than 6 years [32]. In the South African landscape, the payback periods need to be even shorter.

Another large barrier is the lack of performance incentives. These incentives should be tied to energy efficiency key performance indicators (KPIs) [29, 32]. Without these and similar incentives, production personnel are not motivated to conserve energy, thereby leading to missed energy efficiency opportunities.

Lack of time is also a major barrier in industrial organisations [29, 45]. Mines that are nearing end of life do not have time to recuperate investments through long-term projects [32]. Organisations tend to focus on other priorities, leading to more missed opportunities. Personnel struggle to maintain energy efficiency projects by trying to focus on too many tasks at once. On the other hand, personnel could be too focused on their responsibilities, thereby potentially failing to take note of newer procedures that could help them. Energy efficiency is neglected in both scenarios.

Different departments have different areas of expertise. Each department tends to focus on its own objectives. A lack of communication between departments could inhibit energy efficiency measures. Older systems, or the lack of any systems, make information transfer difficult. This restricts energy management because there is no feedback or reporting to indicate problem areas or potential opportunities.

As mentioned in the introduction, an EMS based on the ISO 50001 standard could help to overcome many of these barriers. However, proper energy management requires large amounts of data as discussed in Section 1.1.3. With limited personnel available to analyse the data, it becomes necessary for organisations to have tools in place to organise and analyse energy-related data.

2.2.2 Energy management information systems

Watson, Boudreau and Chen proposed a framework to stimulate information system research in order to address environmental sustainability. Naturally, an information system was at the core of their framework [1]. They suggested that information systems play a role in reducing energy consumption, and in turn, CO_2 emissions. They proposed *energy informatics* as a subfield of information systems. Their core idea is that energy consumption coupled with information lead to less energy consumed as illustrated with the following expression:

$$Energy + Information < Energy$$

Their energy informatics subfield requires that data from the energy-consuming systems is collected and analysed to optimise the energy efficiency of these systems. However, their framework is only conceptual and it has not been implemented.

McMahon and Ball conducted research on challenges experienced with information systems regarding life cycle engineering [46]. Although their research does not mention energy systems specifically, the challenges they highlight apply to EMISs as well, which include:

- data compatibility and interoperability;
- data sustainability across hardware and software revisions;
- data organisation and context;
- data quality; and
- data security and privacy.

Swords, Coyle and Norton developed a prototype energy information system using Microsoft Office tools [47]. It provides energy monitoring, targeting, and supports measurement and verification. The prototype system was implemented and tested at an industrial site and a college in Dublin. Although results seem promising, the system lacks scalability due to the dependence on Microsoft Office tools.

Pusnik *et al.* analysed the effect of energy management systems on 50 industrial organisations in Slovenia [5]. The companies chosen in this study represent the largest energy consumers in Slovenia. The research by Pusnik *et al.* included a questionnaire with five categories, namely: energy efficiency, future and innovation, environment, quality and management, and horizontal issues. The results were used to calculate statistical benchmark indicators and company-specific benchmarks. Nearly half of the companies that participated indicated that the EMS did not include monitoring and targeting, which made it difficult for the companies to monitor their energy consumption continuously. The companies also observed that EMSs had a positive impact on their energy efficiency. However, authors noted that the lack of proper data collection and analysis tools is a significant barrier to the implementation of EMSs.

Sucic *et al.* developed a framework to improve production planning by using ambient intelligent data acquisition and context processing, energy modelling and emissions calculations, decision support services, and knowledge repositories [48]. The framework divides an industrial organisation into energy cost centres, which are then controlled and monitored in isolation. The framework is used to calculate the most cost-effective process control by using the calorific values and historical data to predict future energy requirements. The work, however, is a prototype with shortcomings. The study was only tested on a rotary kiln using production data from the Slovenian cement industry. The study noted that changes in caloric values of fuels had to be taken into account. The particle sizes caused instability in the rotary kiln and influenced energy consumption. These issues led to the authors recommending that the company investigates additional process control solutions. Even though the authors mention the use of intelligent data acquisition systems, the framework's historical data is collected from existing supervisory control and data acquisition (SCADA) systems.

Velázquez *et al.* proposed the use of data-mining techniques to identify key energy performance indicators for use with ISO 50001 compliant EMSs [49]. The proposed system identified energy performance indicators for a naphtha refining plant. The energy performance indicators were used to determine whether the implemented EMS was effective. The study failed to indicate if the same process could be used by other industrial organisations. The proposed system used proprietary software to identify the energy performance indicators, making it less accessible to financially strained organisations. The authors further noted the need for improved decision-making processes to assist with decision-making within the EMS.

Martirano *et al.* defined an EMIS as a system that combines software, hardware and data models to support people in their daily efforts to manage energy at varying levels in an organisation [50]. The authors defined an architectural approach to creating an EMIS that is both user and efficiency orientated. The proposed architecture is divided into four layers, namely: information presentation; data correlation and analysis; data classification, transformation and storage, and; data acquisition, collection and adaptation. For information presentation, a software layer is required to organise and display appropriate information. The data correlation and analysis layer is used to provide value-added information. The data classification, transformation and storage layer analyses, cleans, transforms and stores data for later use. The data acquisition layer is critical for collecting the data required for the EMIS. The authors further discussed a method for scoring the implemented EMIS based on various factors. However, they did not provide an example of an EMIS implemention using their proposed architecture.

Herman *et al.* identified the need for sustainable energy consumption [51]. They used big data methods to design a system for an ESCo. This system was implemented for the mining and industrial sectors, helping the ESCo to analyse and manage their clients' energy consumption. Although the system is deployable to cloud services, it is self-managed. This means that personnel with specific expertise with this system are required to maintain it. Cloud-managed services are available, which make it easier for small businesses to take advantage of the technology, because they are not limited by existing infrastructure as mentioned by the authors.

According to Robison, Sengupta and Rauch the interconnection and convergence of intelligent industrial systems are driving the industrial internet, which further drives Industry 4.0 [52]. New layers of data have become accessible with the improvement of sensors and measuring equipment. These data layers could include weather data, traffic flow, pricing optimisation etc. The data needs to be correlated and analysed continuously to provide insight and optimisations for resource management. The interconnection between devices across sectors will also expand existing analysis capabilities. However, the interconnection of sectors come with some challenges such as security-related challenges, financial challenges, and proper data management and organisational challenges. As more systems become connected, more data needs to be transported, stored and analysed to provide meaningful insights.

As mentioned in Section 1.1.4, commercial EMISs exist that aid with this process. However, none of these systems analyses bill data to identify risks and opportunities, and only a few of them support efficiency initiative performance monitoring.

2.2.3 Structured energy management

The article proposes a structured energy management strategy. Personnel focus is a key element for sustaining initiative performance. KPIs help to maintain focus and, by defining the right KPIs, awareness and sustainability of energy initiatives are improved. For example, a typical energy efficiency indicator is the amount of energy consumed per unit of product (kWh/tonne or MJ/tonne). Adding a cost efficiency indicator (energy cost/tonne) raises the awareness of how well operational personnel are using electricity time-of-use tariff structures. This in turn could help personnel to improve the profitability of the company.

The second important element is creating a communication platform. Energy management is an interdisciplinary task that requires inputs from various departments such as production, maintenance, operations and energy. Frequent communication between these departments is required to focus on improving operational costs and energy efficiency. Although some industries might employ dedicated energy personnel, they are not always in executive positions. It is therefore important to ensure good communication and trust between executives and energy departments.

As mentioned before, more data helps personnel to make informed decisions. However, converting raw data into useful information is time-consuming if done by hand. Therefore, tools are developed to process and analyse data. The following section describes such an EMIS used by an ESCo to help manage their clients' energy.

2.3 Article summary

The methodology of this article is divided into two main sections. The first section is a brief discussion of the system design. This includes the data collection process as well as two important features of the system, namely, the capturing and analysis of electricity bill data and the performance monitoring of efficiency initiatives. These two features are respectively "portrayed" in more detail in Article 2 and Article 3 of this thesis. The second section of the methodology explores the results of a data investigation of the system. The goal is to highlight the need for an automated system. Due to the amount of data analysed on a daily basis, it is not feasible for personnel to analyse the data manually.

2.3.1 Design of a comprehensive EMIS

Data collection, processing and storage

The first step is collecting data as shown in Figure 2.2. Data is collected from various sources and each source could have a unique format. These data sources include:

- External metering companies (EMC): data from energy meters in 30-minute intervals;
- Electricity utility companies (e.g. Eskom): monthly data from electricity bills;
- Supervisory Control and Data Acquisition (SCADA) systems: this includes high-resolution data collected from on-site systems.

As seen in Figure 2.2, data from different external sources is collected and passed to the EMIS. The data is processed from the different potential formats to a generic format and stored in the database. Thereafter, the stored data is extracted, analysed and finally presented in the form of energy reports and energy information dashboards. The different analysis types are discussed in the following sections.

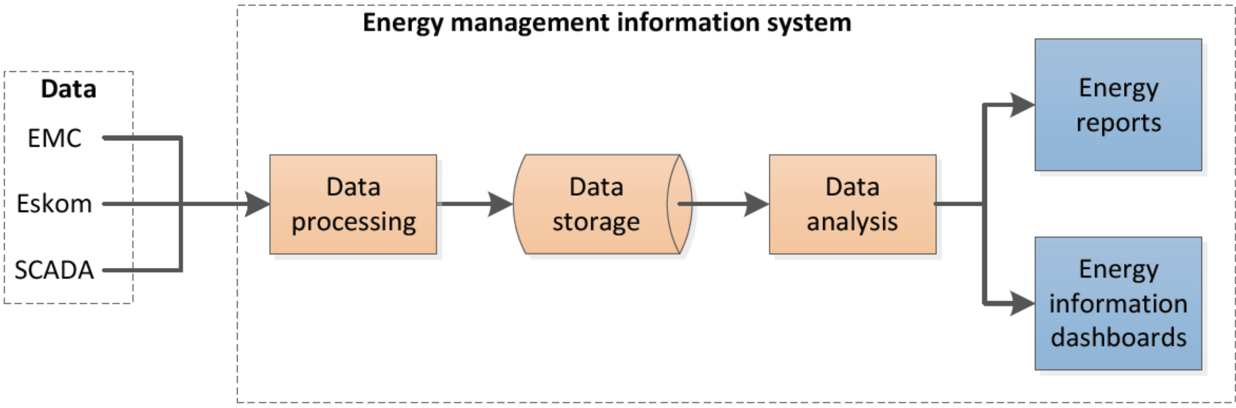

Figure 2.2: *Data flow diagram of the EMIS* [2]

Electricity bill analysis

Bills are a good starting point for collecting data because they are always available. Even if the client does not have their own electricity meter infrastructure, the utility company sends valuable data in their monthly electricity invoices. This data includes electricity cost and usage breakdowns for each billing period, various administration charges, maximum demand consumption and charges, and more. The data from the bills is combined with monthly budgeting to identify optimisation opportunities as well as potential risk areas.

Some of the opportunities include time-of-use optimisation (shifting load from expensive periods of the day to less expensive periods) as well as adjusting notified maximum demand based on actual system demands. Future risks that could be identified by analysing electricity bill data include electricity cost inflation, the impact of carbon taxation, and penalties for excessive reactive power consumption.

The electricity bill analysis is discussed in more detail in Chapter 3, Article 2 [41]. The methodologies are derived and explained whereafter the implementation thereof on a large mining group with many electricity bills is discussed. The large amount of bill data makes it infeasible to process data manually and the system eases that process. Various case studies show different cost-saving opportunities that have been identified with the help of the system.

Efficiency initiative performance monitoring

The potential opportunities identified by electricity bill analysis could lead to the implementation of energy efficiency initiatives. The logical next step of the EMIS is monitoring the performance of implemented initiatives. According to the ISO 50001 plan-do-check-act cycle, the performance of the intervention should be monitored continually in order to take action if the goals are not met.

The performance of the initiatives is measured by comparing the actual energy consumption of the system with the baseline energy consumption before implementing the initiative (based on IPMVP procedures). This feature is designed to be generic to cater for various types of initiatives on various energy sources. It consists of various reports and dashboards that engineers or energy personnel could use on a daily basis to analyse the performance of the initiatives.

The generic efficiency initiative monitoring system is discussed in more detail in Chapter 4, Article 3. The methodology explains the performance calculation process as well as the data configuration steps. The system is implemented at a mining group consisting of 24 sites. A total of 81 efficiency initiatives are monitored with the system.

Other analysis types

Other types of analysis are also discussed in more detail in the article, but it does not form part of the scope of this thesis. They are listed for reference in Table 2.1.

Table 2.1: *List of other analysis types*

Analysis type	**Description**
System tracking	Monitors the performance of all energy-consuming areas.
Environmental reporting	Environmental data captured for reporting compliance and audits.
Custom views	User-specific analysis and reporting.
Document manager	A repository for organising and storing documents.
Condition monitoring	A tool for monitoring the condition of equipment.

2.3.2 Outcome of a data investigation

In September 2019, a new data investigation was done for this thesis to obtain more recent results than those in the article done in 2016. The investigation analysed the amount of data collected and processed by the EMIS for two client groups. The system was implemented at multiple industrial clients, with the majority being mining companies. Data from various sources were collected and processed daily. Individual data objects or measuring points are referred to as tags. Each tag has a specific resolution depending on the type of data and the source thereof.

Table 2.2 shows the results of the data investigation. Electricity bill data is collected on a monthly basis and, therefore, each tag only has one value per month. Efficiency initiative and condition monitoring tags comprise 30-minute data and, therefore, record millions of data points per year. The results highlight the need for a system that can manage these large volumes of data. It would be too resource intensive for an ESCo to process this data manually, which would have a negative influence on its profitability.

Table 2.2: *Data investigation results (number of tags and total annual data points)*

	Electricity bills		**Efficiency initiatives**		**Condition monitoring**	
	Tags	**Data points**	**Tags**	**Data points**	**Tags**	**Data points**
Mining Group A	2 785	33 420	73	1 278 960	2 725	47 742 000
Mining Group B	1 962	23 544	457	8 006 640	–	–

2.4 Discussion

Various drivers and barriers for energy management were identified from literature. Due to large volumes of data and limited man-hours, it is necessary to implement systems to help energy personnel to analyse the data in a timely manner. The literature regarding EMISs is lacking in terms of scalability and implementation. However, from this research, the need for a comprehensive EMIS is apparent.

The need for an EMIS is further highlighted by the data investigation done in the previous section. The limited personnel available simply cannot process these large volumes of data manually to identify initiatives and do condition monitoring. It is perhaps possible for one person to capture the electricity bill data from Table 2.2, but it is beneficial to analyse the data as soon as possible after the bill is received, which would be a tall order. To capture the bill data of Mining Group A in one eight-hour workday, for example, equates to 348 data points per hour, which might lead to errors. Furthermore, the captured data is not usable unless it is organised and structured for efficient analysis.

Chapter 3 follows the development and implementation of an electricity bill analysis tool. Analysing bill data is valuable as the study shows. It creates awareness of the status of energy consumption and cost even though data is only available on a monthly basis. Furthermore, even if instrumentation infrastructure is scarce, suppliers definitely provide utility bills, potentially making it the only available data source.

Chapter 3

Article 2 – Automated electricity bill analysis

3.1 Preamble

This article focuses on automated electricity bill analysis in South Africa. Ideally, electricity should be measured at as many nodes as possible. However, it is expensive to install measuring equipment at each node. On a higher level, electricity bills are available without the need for additional equipment installation. Electricity bills provide valuable information, which could provide insights to assist energy management efforts.

The scale of operations for large consumers creates a new challenge. The larger the scale of the operation, the more points of delivery (PODs) there are; each with its own set of data. This complicates the bill analysis process because there are numerous factors that should be considered. This creates the need for a system that automatically analyses electricity bill data for the entire company.

3.2 Literature

3.2.1 Industrial bill analysis

Energy consumption is growing globally due to the increasing energy consumption per capita coupled with the growing population. There is a growing need to implement energy efficiency initiatives and decrease energy consumption. The benefits of energy efficiency is listed below [53]:

- Reduces maintenance and operational costs, which improve competitiveness.
- Give consumers greater control over their energy costs.
- Reduces air pollution.
- Reduces the impact of future tariff increases.

Different tariff schemes have been used to influence consumer behaviour regarding energy consumption. Several utilities have implemented a variety of time-based pricing programmes [53]. These tariff schemes can be time-invariant such as flat-rate pricing, declining block-rate pricing, or inverted block-rate pricing. Alternatively, tariff schemes can be time-variant schemes such a time-of-use pricing, critical peak pricing, or real-time pricing.

Using the different tariff schemes, electricity meters play an important part in changing the consumption behaviours of consumers, but these meters are expensive to install. Industrial consumers require many meters to be installed in order to reap the benefits thereof [53].

The utility bills received by consumers have been shown to be an effective feedback medium [54]. As utility bills are usually received long after the energy has been consumed, they are a form of indirect feedback. Although the saving potential is higher when using direct feedback, the saving potential from indirect feedback methods should not be discounted.

A reliable short-term solution to influence consumer behaviour is using different pricing structures. However, to be effective consumers need to understand the information that is conveyed to them [54]. Complex and non-transparent pricing structures often obscure the relationship between energy consumption and pricing.

Electricity bills are complex and consumers tend to struggle to interpret the information provided in the utility bill. Even though useful information is conveyed about usage and charges, consumers often find it challenging to find and interpret the provided information [54].

These factors create a need for an automated bill analysis tool to help consumers understand the information provided in the bills, draw meaningful conclusions regarding their consumption from the bills, and act on the information provided.

3.2.2 State of the art

As discussed in the previous section, utility bills is an effective feedback mechanism for consumers; however, these bills are complex and consumers have difficulty understanding the data presented therein.

Brühl, Smith and Visser analysed the effectiveness of a utility bill [54]. They found that the bill is the most frequent interaction point between residential consumers and energy providers. As such, a bill is the most efficient method of providing feedback to consumers regarding their energy consumption. It is also cost-effective and readily available [54].

The study conducted by Brühl *et al.* focused on the way data is presented in utility bills. They found that a well-designed utility bill increases consumer awareness and leads to lower energy consumption; however, utility bills are rarely well designed, and thus fails in this regard. The study focused on residential consumers and not large industrial consumers. Furthermore, electricity bills of large industrial consumers are even more complex than bills received by residential consumers [54].

Eryilmaz *et al.* conducted a study on the impact that daily billing has on energy efficiency [55]. The study analysed the electricity consumption of residential customers in Texas for the years from 2014 to 2016. They found that customers who received daily feedback regarding their energy consumption were 9.6% more efficient than customers who received monthly feedback. The reasons for the energy efficiency benefit are attributed to better information through more frequent communication and more engagement with energy consumption choices.

Teke *et al.* developed an educational tool for calculating electricity costs based on three tariff structures [53]. The tool is used to analyse electricity usage and determine when electricity would be cheaper to use. This can lead to load-shifting projects, which enable consumers to save money by using electricity in off-peak time periods when electricity is less expensive. However, the developed tool is very limited. It is intended for educational purposes and only allows a single user to use it at a time. It is developed as an executable program, requiring that it be installed on a computer. Therefore, it is less portable and further relies on a specific operating system.

Industrial clients can use utility bill analysis to improve operational efficiency. For instance, studies conducted in China focused significantly on improving building efficiency. These buildings are built with an expected efficiency, yet the buildings fail to reach these projected efficiencies. Geng *et al.* conducted a study to determine the effect of ambient outside temperature on the heating requirements of an office building [56]. The study used energy consumption information from electricity bills to determine how much energy was used for heating and cooling in a one-year period. The results of the study could be used to identify large energy consumers in a system. However, the study only focused on building-related energy efficiency.

Yan, Wang and Xiao developed a method for analysing a building's energy efficiency. The proposed method analysed data from monthly electricity bills, building design data, weather conditions, and heating, ventilation and air-conditioning (HVAC) data [57]. In this study, the electricity bills contained the aggregated electricity consumption across all end users. A large part of the study 'de-aggregated' the consumption data to use it for energy efficiency monitoring. This study also only focused on building-related energy efficiency in Hong Kong.

Yan *et al.* continued the study and added a method for diagnosing energy efficiency problems in buildings with limited data [58]. The study used the same data as the previous study [57] to determine the energy consumption of different systems in a building; i.e. electricity bill data, weather data, building design data and HVAC data. The authors developed a method for estimating a building's energy performance at building level (overall), at system level (HVAC systems, internal consumers, other consumers), and at component level (fans, pumps, etc.). They noted that multi-level assessment is necessary to analyse and identify high energy consumers effectively. They also noted that due to the varying nature in different energy consumers, generic benchmarks cannot be used to monitor energy performance.

The studies conducted by Yan *et al.* [57,58] and Geng *et al.* [56] are unsuitable for large industrial corporations to use. Some roadblocks include the lack of automated data gathering, including gathering data from electricity bills. The data contained in the bills also differs between buildings in Hong Kong and industrial corporations in South Africa.

Rodrigues *et al.* developed a forecasting tool to predict the monthly energy consumption of energy users for a electricity provider [59]. The forecasted value is used to determine whether the energy bill generated is correct by analysing whether the billed values correspond with the predicted energy consumption values.

As mentioned in Section 1.1.4, commercial systems are available that support bill verification, but they do not analyse bill data directly to identify risks and opportunities, and are lacking verifiable results in literature.

The studies discussed in this section show that there is a need for an automated electricity bill analysis system. The system should be able to read relevant information from electricity bills, making it easier for the user to understand the information that is presented therein. The studies showed that utility bill analysis is an effective feedback mechanism for consumers to understand their energy consumption, which could lead to improved energy consumption awareness and implementation of energy efficiency initiatives. Additionally, forecasting can be used to predict the energy consumption, but this relies on too many different variables to be effective and accurate.

3.3 Method

The method is divided into three main steps: 1) data retrieval, 2) data linking and organisation, and 3) data analysis and presentation. It is designed for electricity bills from Eskom, the main electricity supplier in South Africa. Larger industrial consumers receive their electricity directly from Eskom. Each bill contain several PODs that are billed individually.

3.3.1 Data retrieval

The data retrieval step consists of three substeps:

- **Document collection**
  Electricity bill documents are collected via email. It is sent to mailboxes where the documents are downloaded automatically by the EMIS. The documents are stored in predefined folders where they await the next steps.
- **Data extraction**
  Data is extracted from the documents using a regular expression. Each billing item is extracted as a single data point, which is referred to as a tag.
- **Data storage**
  Tag data is stored in a centralised SQL database. Additional relational data regarding each tag is also stored in the database.

3.3.2 Data linking and organisation

To analyse the captured data, context is necessary. The relational database makes it possible to link and organise the data in a logical manner, thereby adding context to the data. Figure 3.1 shows an example of how the data is organised. Each tag is assigned a data type, for example '*Admin charge*' or '*Peak usage*'. This makes it possible to identify all the tags of a specific type for analysis. Furthermore, tags from the same POD are linked to a '*System*' object, for example '*Shaft A1*'. This organises all the data from a POD into one system.

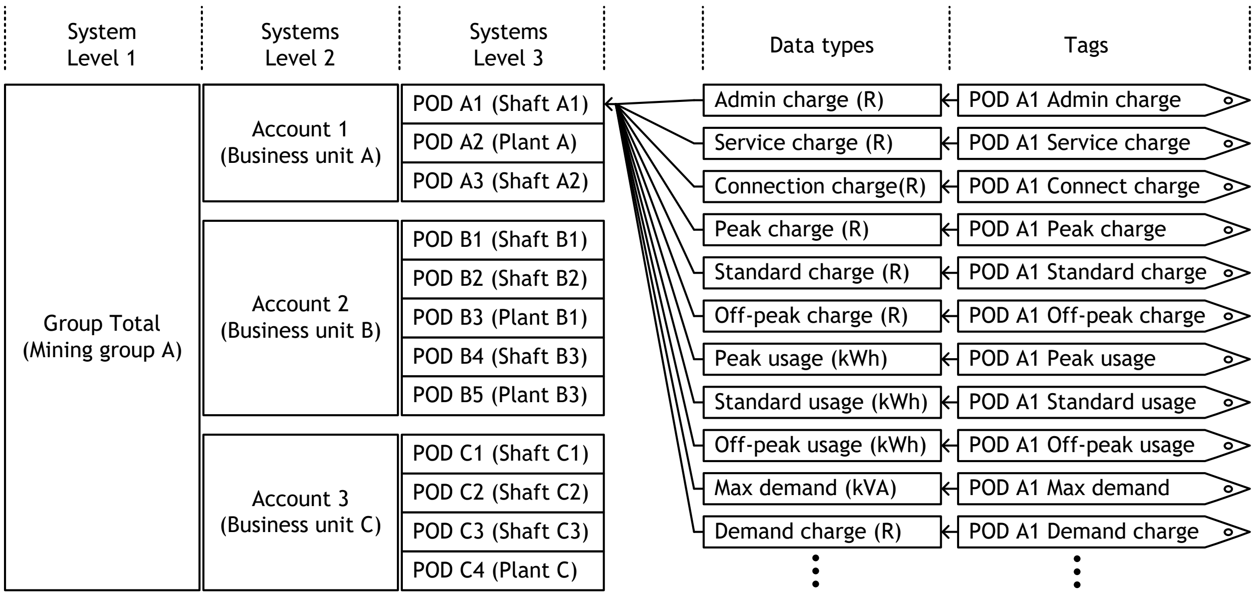

Figure 3.1: *Data linking and organisation example* [41]

For higher level analysis, systems are linked to other systems. For example, multiple shafts or plants can be grouped into a single business unit. Finally, from a top-level perspective, an entire company group system is created with multiple business units linked to it, and multiple PODs are linked to each business unit. From this structure, a company-wide analysis can be done on a specific data type.

3.3.3 Data analysis and presentation

Data collected and organised, as mentioned in the previous sections, is now analysed and presented to relevant persons. The performance is analysed on different levels, and different units within the company are benchmarked against each other. There are several different ways for analysing and presenting the data, of which a summary is provided below. A select few will be discussed in more detail using case studies.

Monthly electricity cost and usage

The actual electricity cost and usage are compared on a monthly basis to a budget. The budget is usually determined by the client and align with their yearly budgets, but it could also be any target value that motivates them to use energy more efficiently.

Electricity cost and usage breakdown by consumer

This provides a breakdown of the electricity cost and usage of individual consumers or business units. With this analysis, outliers are detected; for example, where electricity consumed does not correlate proportionally with the cost of the electricity.

Electricity charges breakdown

This provides a breakdown of the different charges on the electricity bills. For example, administration charges, network access charges and active energy charges. Potential opportunities for reducing costs are identified by viewing all the charges holistically.

Electricity cost inflation

Potential electricity costs for the next five financial years are calculated based on estimated electricity tariff inflation. The estimated tariff increases are calculated from the average confirmed tariff increase over the previous five years.

Time-of-use breakdown

Electricity usage is displayed for each time-of-use period for 12 months. A proportional monthly energy (PME) value is also displayed on the chart. The PME values are determined by calculating the proportional number of peak and standard hours of the applicable 12-month period. For example, if 14% of hours in the period are peak hours, the peak PME value for each month is 14% of the total amount of energy for that month. Comparing the PME values with the actual usage data helps to analyse the time-of-use information more effectively. For example, the further the peak PME value is above the actual peak usage, the more load is shifted to less expensive periods.

Maximum demand

Consumers and the electricity supplier agree upon a maximum electricity demand that the consumer will not exceed, which is called the notified maximum demand. If consumers exceed the notified maximum demand, they pay additional penalty charges. Therefore, in some cases the notified demand is chosen conservatively (high) to avoid penalties. In other scenarios, the notified demand is not reduced when the actual demand declines. Herein lies an opportunity. If the margin between notified maximum demand and measured maximum demand remains large, the notified demand could be reduced to save cost.

Reactive power and power factor

During peak and standard periods in winter months, consumers are charged for excessive reactive energy consumption. This charge is only applicable if the reactive energy during a 30-minute period is more than 30% of the active energy, which implies a power factor below 0.96[7] [60]. It is imperative that all power factor correction systems, such as capacitor banks, are in optimal condition to reduce reactive power consumption. Equation 3.1 is derived in Article 2, where pf is the power factor, P is active power (kW) and Q is reactive power (kVAr). Because the active and reactive energies in the bill are measured over the same period, they replace active and reactive powers in the equation to calculate an average power factor for the period.

$$pf = \frac{P}{\sqrt{P^2 + Q^2}} \tag{3.1}$$

3.4 Results

Time-of-use breakdown

The case study for an individual POD is shown in Figure 3.2. The peak and standard PME values for this selected period were 14.3% and 36.2%, respectively. The further the peak PME value is above the actual peak usage, the more load is shifted to less expensive periods. From the chart it can be deduced that the existing load-shifting initiatives performed poorly in August, September and October. Although November and February appears to be under performing as well, it is inconclusive because of the high amount of energy consumed.

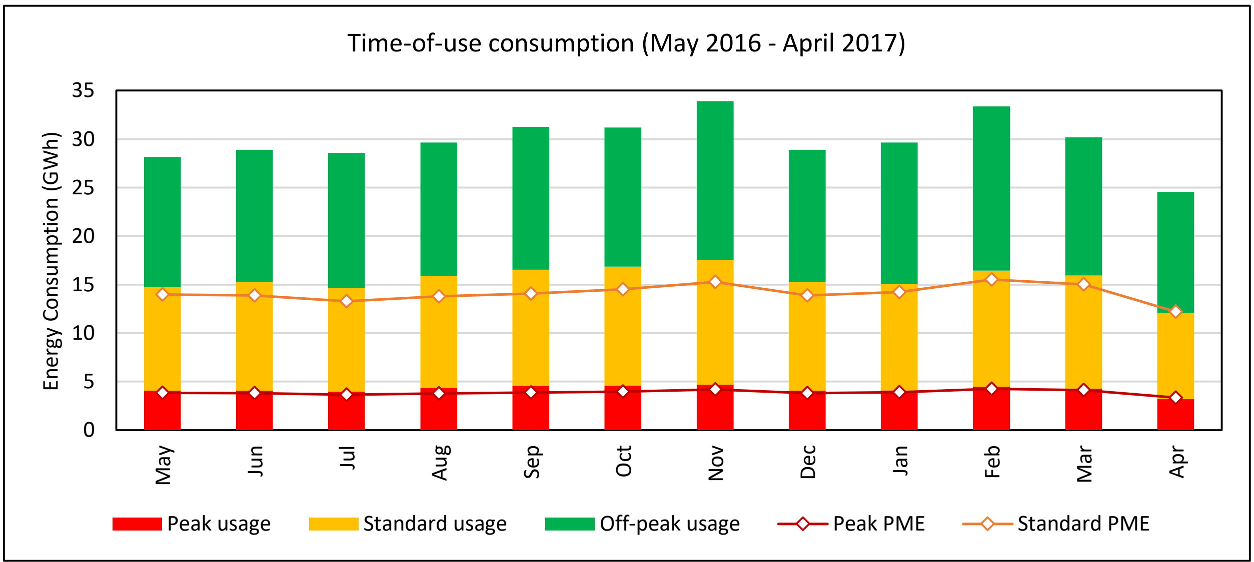

Figure 3.2: *Time-of-use breakdown of electricity usage* [41]

[7] Eskom, "Tariffs & Charges 2019/2020." [Online]. Available: http://www.eskom.co.za/CustomerCare /TariffsAndCharges/Documents/Complete Tariff 2019 web1.pdf [Feb. 17, 2020].

Maximum demand

Figure 3.3 shows notified and measured maximum demand of an individual POD for 12 months. The charges associated with the notified maximum demand are also displayed for comparison purposes. Electricity tariffs increased in April 2015, which in turn increased the cost of the notified maximum demand.

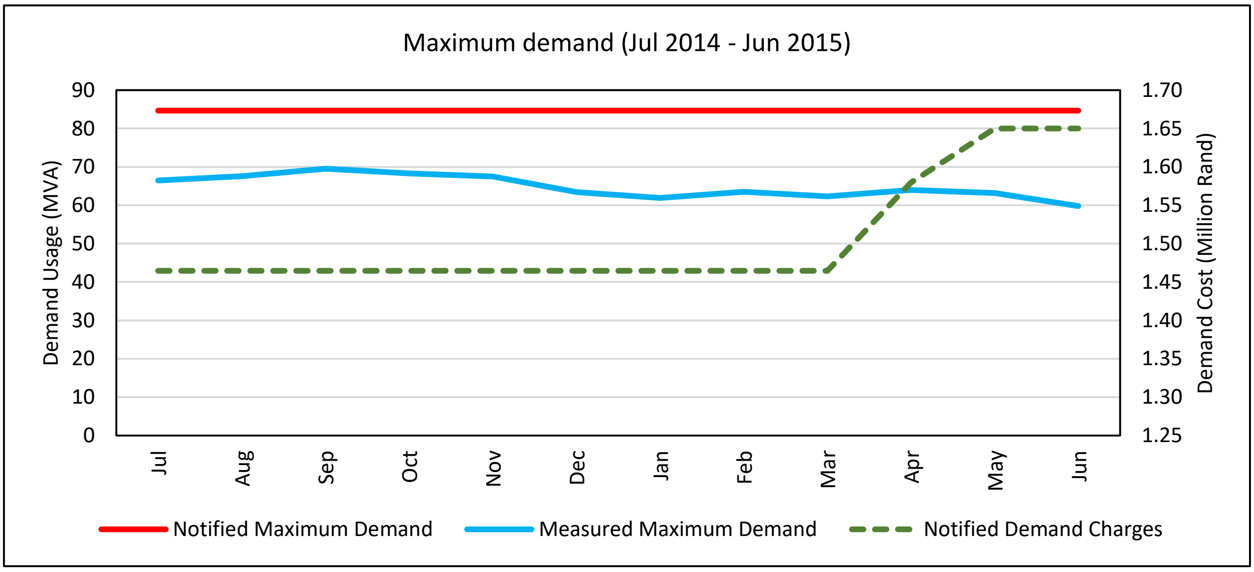

Figure 3.3: *Notified vs measured maximum demand* [41]

In this case, the notified maximum demand was 84.66 MVA. The average measured demand for July 2014 to December 2014 was 67.12 MVA and for January 2015 to June 2015 62.45 MVA, which equate to safety margins of 20.7% and 26.2%, respectively. The client decided to reduce the notified maximum based on this information and the future electricity demand of the operation. If the notified maximum demand is reduced to 72 MVA (13.3% margin based on the current demand), it reduces the future notified demand costs by R246 743 per month and R2.96 million per annum.

Reactive power and power factor

The primary axis in Figure 3.4 shows the average power factors of an individual POD for each time of use. The secondary axis displays the average cost for the reactive energy. This POD was charged R 132 687 on average for the winter months from June to August 2016 because the PODs' power factor was below 0.96. A big concern visible in this example is the severe power factor decline from February 2017. This decline shows a large financial risk for the following winter months starting June 2017.

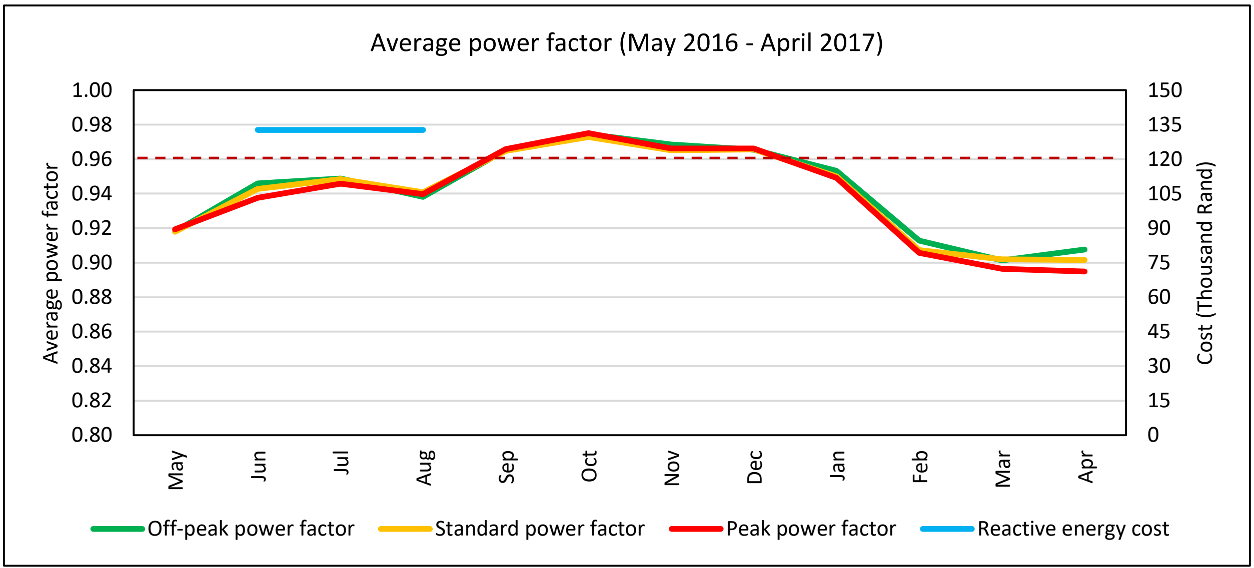

Figure 3.4: *Average power factor per time-of-use period* [41]

3.5 Discussion

In order for the EMIS to be effective, a broad understanding of a company's energy usage is required, which creates the need to gather high level energy data. Electricity bills provide valuable insights regarding electrical energy usage, as seen from the results of the study. Consumers could become more cost aware and see how their actions affect energy consumption. This is possible on POD level from a holistic company perspective. Automating this process helps to minimise the potential for typical mistakes made during manual processes. However, an automated electricity bill analysis would probably only be beneficial for large numbers of PODs. The benefit of automated analysis increases as the number of PODs increases due to the time required to manually analyse the data.

Some relatively basic improvements could be made to the analysis. For example, electricity cost inflation could be adapted to use the previous 12 months instead of the fixed financial year period which would give a monthly update on the risk. The accuracy of time-of-use analysis could be improved by calculating the time-of-use hours of each billing period, instead of using a yearly average. A more complex improvement is to add an analysis tool to forecast electricity cost and usage from electricity bill data similar to what Rodrigues *et al.* did [59].

Although analysing electricity bill data could effectively create awareness and help to identify potential energy-saving initiatives, there is still a need to monitor energy consumption more frequently. If data is available at a higher resolution, it could provide valuable detail that would aid in understanding the energy system. Furthermore, as discussed in previous chapters, the plan-do-check-act cycle of the ISO 50001 standard requires continuous measurement and verification against a predetermined baseline. The following chapter looks at the requirements and design of a generic efficiency initiative monitoring system.

Chapter 4

Article 3 – Generic efficiency initiative monitoring system

4.1 Preamble

Article 1 identified the need for an EMIS. Article 2 described the system that analyses high-level electricity bill data on a large scale. The next step is to monitor the performance of efficiency initiatives implemented in order to reduce energy consumption. In this article, the need for a performance monitoring system is investigated. The best methods are extracted from literature and a system is developed to address the needs and shortcomings of existing systems.

4.2 Performance monitoring

In light of the issues mentioned in Section 1.1.1, industries implement efficiency initiatives in order to decrease their operational costs [19–22]. However, if these initiatives are not monitored and maintained, their performance deteriorates over time [25, 61]. The results of Groenewald's implementation of performance-centred maintenance strategies show that cost savings on deteriorated initiatives could be increased by 64% [25].

Three main initiative types exist with regard to energy systems [25, 62]:

- **Energy efficiency**
  Energy efficiency initiatives aim to reduce overall energy usage. For example, on a mine's water reticulation system, reducing the amount of water consumed underground reduces the amount of water to be pumped back to surface, which in turn reduces the energy consumed by the dewatering pumps.
- **Peak clipping**
  Peak-clipping initiatives aim to reduce energy usage only during peak periods. For example, on a compressed air system, the compressors' pressure set points and down-stream valves are controlled to ensure that the supply and demand of compressed air match as closely as possible.
- **Load shifting**
  Load-shifting initiatives aim to shift the energy load from peak periods to non-peak periods. For example, on a mine dewatering system, dam levels are optimised in non-peak periods in order to reduce or eliminate the need for pumping during peak periods. In this case, dams act as energy storage systems.

Booysen conducted an in-depth literature analysis of measurement and verification (M&V) frameworks and guidelines [62]. The most predominant M&V guides are the International Performance Measurement and Verification Protocol (IPMVP) and the Federal Energy Management Program. He identified a lack of guidance for practical M&V of industrial DSM initiatives. Thereafter, he developed practical methodologies for three important areas of M&V:

- data quality;
- baseline model selection; and
- project performance monitoring.

Data quality and baseline model selection are not in the scope of this study. The functions of performance measurement and monitoring are to evaluate performance, identify performance gaps, provide goals against which progress can be measured, and provide data for determining appropriate courses of action and strategic planning [43].

As mentioned earlier, if initiatives are not monitored and maintained, the performance deteriorates, leading to reduced savings. This means that performance monitoring is crucial for maintaining energy initiative performance; however, few systems exist to monitor initiative performance properly.

4.2.1 State of the art

Schulze *et al.* did a systematic review of 44 journal publications on industrial energy management [27]. From this comprehensive study, the researchers developed an integrated energy management framework. The framework has a feedback loop for continuous improvement, similar to the plan-do-check-act cycle of ISO 50001 [33]. The feedback loop is an important part of maintaining saving initiatives.

A crucial part of the feedback look is the 'check' step, which includes data collection, monitoring and reporting [63]. In order to execute this step as efficiently as possible, an automated information system is required to monitor the performance of efficiency initiatives. Such a system will make maintaining the initiatives more efficient and sustainable.

Literature describes numerous information systems that have been developed for different aspects of energy usage in industry. These systems vary from very specific applications such as online energy efficiency monitoring of machine tools [43, 64] and real-time M&V [65] to energy platforms for entire industrial facilities [66].

Many of the monitoring systems used by energy intensive industries are, however, lacking. According to Sivill *et al.*, these systems were originally developed for maximising production efficiency, quality and safety [43]. Deficiencies in energy performance measurement are caused by the slow rate of technical adoption and behavioural change within an organisation.

Hu *et al.* proposed an online approach to collect measurements and monitor the real-time efficiency of machine tools automatically [64]. The system, however, does not implement a historical database for in-depth analysis and cannot be adapted for other uses. Alternatively, the real-time M&V solution of Ke, Yeh and Su tracks historical data that is monitored using a web application [65]. This system does not support the reporting functionality required to complete the feedback loop identified by Schulze *et al.* [27].

More generic energy information systems have been proposed, but these systems lack real-world implementation as well as the ability to develop, target and track specific efficiency initiatives. Such systems include the energy management platform that is based on IoT developed by Wei, Hong and Adam [66] and the simulations of decentralised manufacturing as proposed by Ilsen *et al.* [67].

Zampou *et al.* introduced a generic framework for energy-aware information systems in manufacturing based on the fundamental principles of energy monitoring and energy-aware analytics [68]. These core principles could well benefit the mining industry if implemented correctly.

May *et al.* created a framework for energy management in manufacturing [69]. The framework was developed by analysing the research conducted by numerous researchers. The authors found consensus among researchers that consistent performance monitoring is a crucial part of any efficiency initiative [69].

Appropriate KPIs are also vital for successful performance monitoring. The data from appropriate KPIs could provide hints for optimising energy consumption. Furthermore, it could provide better decision support by establishing the verifiable and measurable benefits of implementing efficiency initiatives [69].

May *et al.* divide performance measures into three categories [69]:

- energy efficiency indicators;
- energy efficiency analysis and optimisation; and
- trade-off analysis.

The study by May *et al.* focused on existing literature regarding energy performance measurement in manufacturing. Their framework can be used to create strategies to monitor and measure energy performance. Although the study does not provide a method to do so, the study highlights important considerations when planning a performance monitoring system.

Cárdenas *et al.* developed an intelligent EMS for the textile industry [70]. This study was built on top of an existing EMS and used the data collected by the EMS to create forecasts for the following day's energy consumption. This is a good example of how an EMS used to create more business value. However, the study failed to compare the forecasted values of a day's energy consumption with the day's actual energy consumption. Another disadvantage is that the system does not make use of continuous monitoring [70].

Benedetti, Cesarotti and Introna developed a methodology to monitor energy performance indicators [7]. The study focuses on energy performance indicators only and does not analyse KPIs for other systems and processes. The study was developed as a methodology not implemented at a large scale. The methodology further failed to provide users with automated systems such as reporting tools and data analysis tools to facilitate baseline calculations.

As mentioned in Section 1.1.4, although there are commercial systems that monitor system performance, only one system supports adjusted baselines. None of these systems provide initiative performance monitoring integrated with bill analysis.

Therefore, based on the limitations of existing systems in literature, a need exists for a generic system to monitor various types of efficiency initiatives. As mentioned in Section 2.2.2, Watson *et al.* proposed a framework to stimulate information systems research in order to address environmental sustainability [1]. Such a system would be the start of remedying the concerns highlighted by Watson *et al.* in terms of the lack of information and the slow uptake of information systems for sustainable production.

The role of such an information system should be to automate the monitoring and performance tracking of efficiency initiatives to complete the feedback loop of the ISO 50001 plan-do-check-act cycle consistently, accurately and reliably. This will aid managers to improve the performance of efficiency initiatives continuously.

4.3 Article summary

The method is described in more detail in the article, and shortly here to focus more on the results.

4.3.1 Data processing

- **Configuration of properties**
  A web application is used to configure the properties, such as baselines and targets, of an initiative. Depending on the type of initiative, its target could either be to reduce the consumption baseline or exceed the production baseline.
- **Data translation**
  Data can be obtained from various sources in different formats. The data translation step converts this data into a standard format to be used in performance calculations.
- **Data storage**
  The configuration properties of the initiatives as well as the translated data are stored in a relational SQL database. The data storage unit also does some basic data verification; for example, verifying the number of data points per day. This information is used at a later stage to indicate the validity of the performance calculations to the user.
- **Performance calculations**
  The performance calculation unit starts by collecting the configurations for all the initiatives from the database. Then, each initiative's tags are inspected for new data. If new data is available, the initiative is added to a queue to be processed. After all initiatives with new data have been added to the queue, their performance is calculated based on the new data.

4.3.2 Performance analysis

The performance analysis is explained with the case studies. In short, the web application provides a number of visualisations for users to analyse the performance of the initiatives. Reports can be generated, which are used to sign performances off.

The system was implemented on a number of initiatives at different client sites. Figure 4.1 shows the daily performance of various initiatives for a specific mining client. This view provides a holistic perspective of all the initiatives, which makes it easier to identify underperforming initiatives. The user can then view more detail for a specific initiative for a single day. For this summary, three case studies from the article are discussed in more detail.

The different colours in Figure 4.1 indicate the following:

Green	Overperformance	Target achieved
Red	Underperformance	More than 10% from target
Orange	Underperformance	Within 10% of target
Blue	Partial data loss	Performance cannot be calculated
Grey	No data available	Performance cannot be calculated

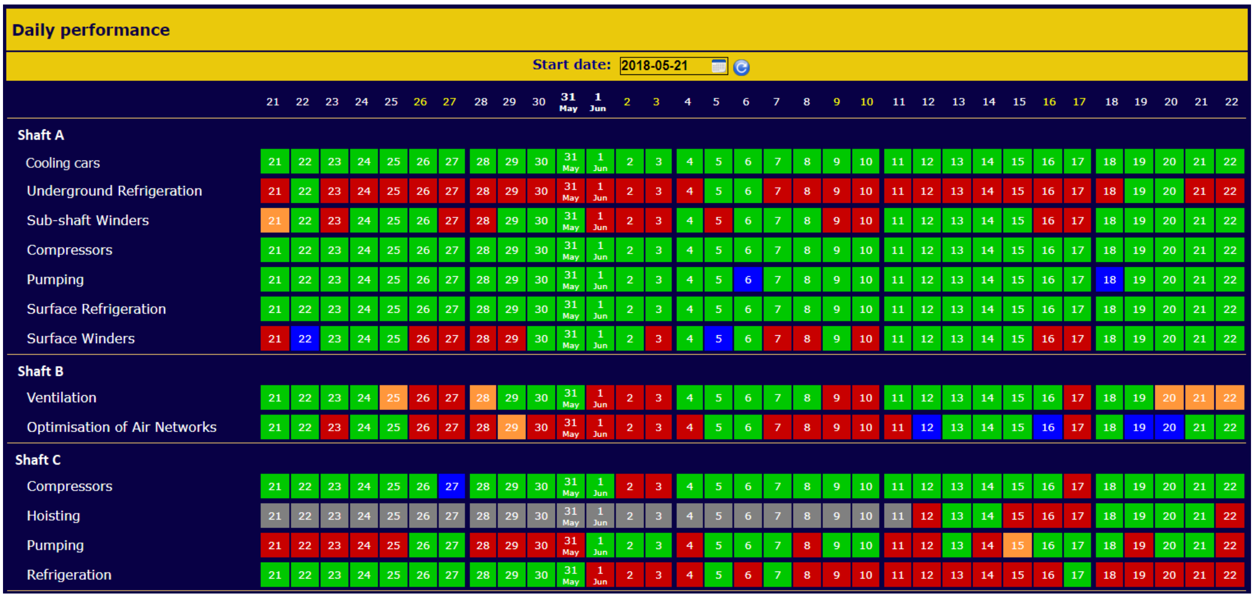

Figure 4.1: *Daily performance overview of all initiatives accessible by a user*

Case study 1

An energy-saving initiative was implemented on a mine pumping system. The aim of this initiative was to shift electrical load in order to save electricity cost. Electricity is shifted from the most expensive peak periods to the less expensive periods. The peak period of the applicable tariff for June 2018, was 3.3 and 6 times more expensive than the standard and off-peak periods, respectively. Before the inception of the initiative, a baseline electricity profile was selected. The baseline scaling method, as well as the electricity and cost reduction targets are agreed on by all parties.

Because the purpose of this initiative is purely to shift load, the baseline is adjusted (also known as scaled) energy neutral with the actual electricity consumption. Effectively, the total daily energy equals the adjusted energy baseline. The equations for this scaling method are available in the article. Baseline adjustment helps to isolate the impact of the initiative from other changes in the system that might have affected its energy consumption (for example, changes in production).

The performance of this initiative for June 2018 is analysed in Figure 4.2. The non-cost savings target implies an average power consumption reduction of 0.3 MW during the morning (06:00–09:00) and evening (17:00–19:00) peak periods. The average performance profile chart in the figure (top right) shows that load was only shifted during the evening peak period. This resulted in an average weekday power reduction of 0.39 MW, which is a 30% overperformance.

The initiative has a conservative cost-saving target of R36 353 for June 2018. By shifting electrical load from peak to standard periods, a cost saving of R84 696 was achieved for the month. The bottom-left chart in Figure 4.2 shows the daily cost savings achieved. Most weekdays performed well, except for 5 June, which had a negative financial impact. The effect of this underperforming day is also shown in the cumulative performance chart (bottom right), which was only recovered by 13 June.

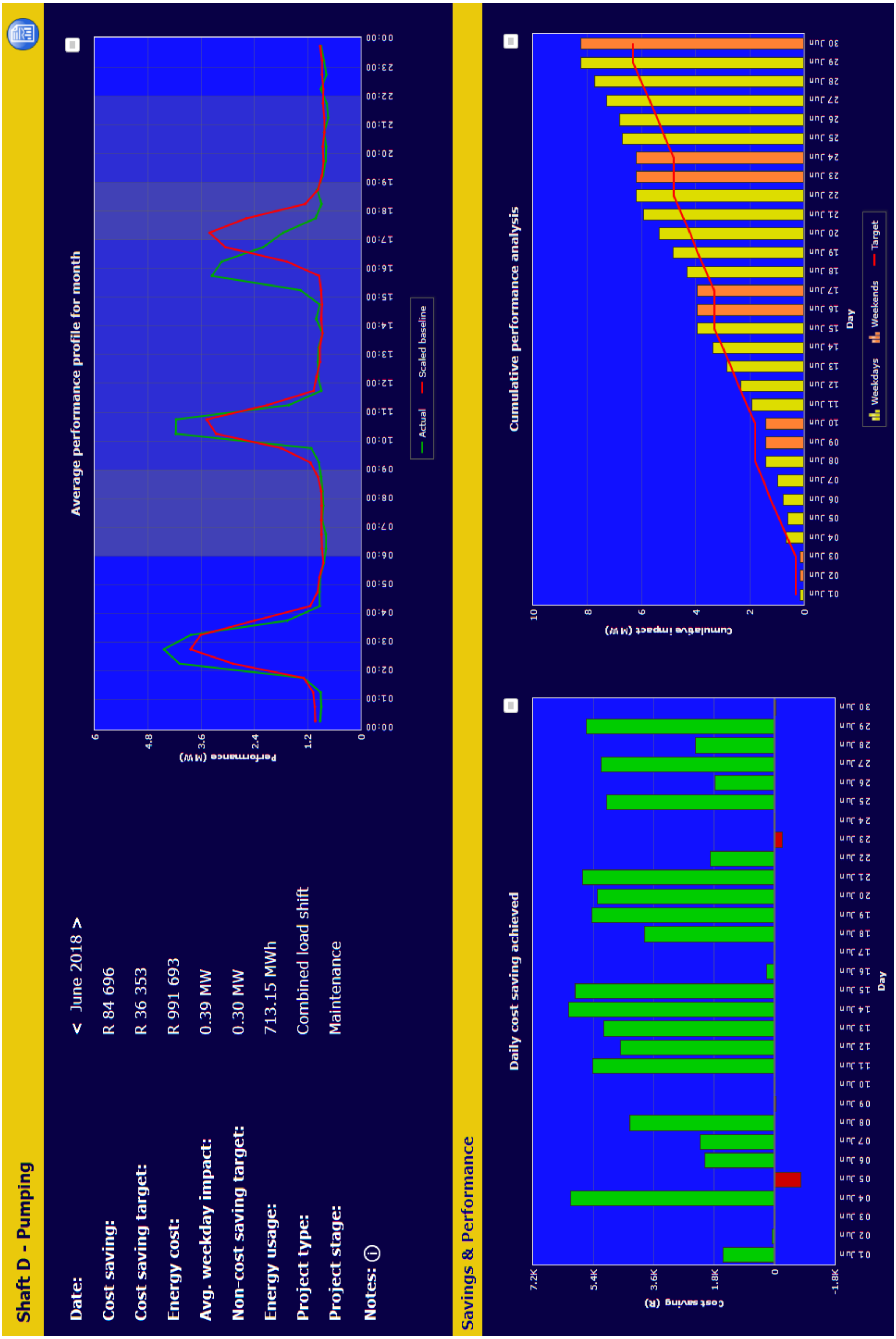

Figure 4.2: *Case study 1 – Monthly performance detail*

Case study 2

In this case study, an initiative to improve the energy efficiency of a mine compressed air system was implemented. The aim was to save on electricity cost by reducing overall energy consumption without compromising mining production. The baseline is adjusted energy neutral during the drilling period (08:30-14:00). Essentially, the entire baseline is adjusted, but is only energy neutral with the actual consumption during the drilling hours. This means any energy reduction before and after the drilling period will not affect the scaled baseline. The equations used for this scaling method are available in the article.

This initiative has a non-cost-saving target of 0.9 MW for each day of the week. The performance summary for June 2018 is shown in Figure 4.3. The performance profile chart (top right) shows the energy is reduced shortly before the drilling period starts at 08:30, and again when it ends at 14:00. However, this reduction is only enough to achieve an average power reduction of 0.58 MW. The initiative is therefore 35.6% below target.

The cost-saving target for this initiative is R287 657. This is relatively conservative considering the achieved cost saving of R618 040. Drilling is usually only done on weekdays, which means the initiative underperforms during weekends. This can be seen in both the daily cost-saving chart (bottom left) and the cumulative impact chart (bottom right) of Figure 4.3.

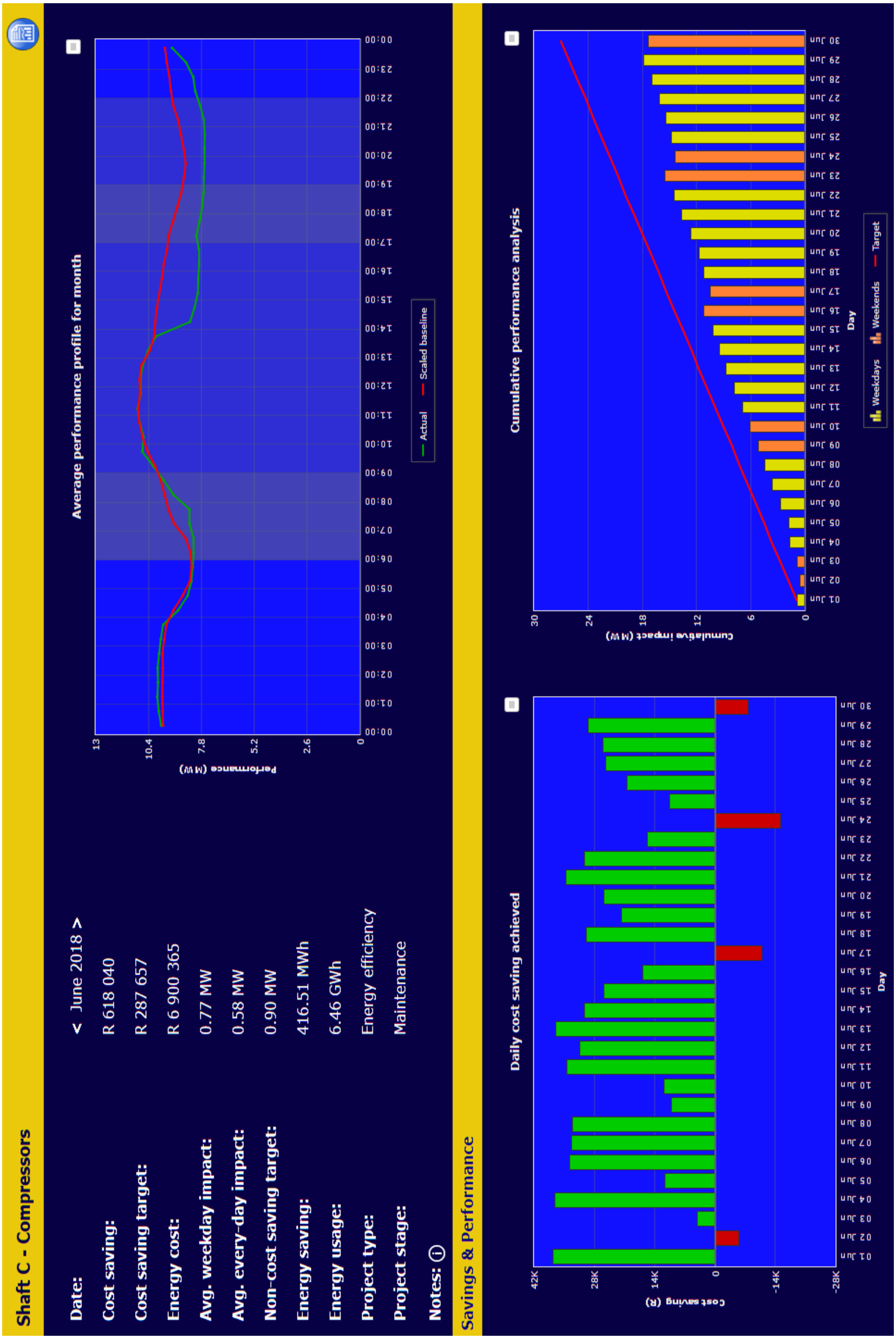

Figure 4.3: *Case study 2 – Monthly performance detail*

Case study 3

For this case study, the performance of a number of energy initiatives is analysed over the lifetime of the initiatives. In total 81 initiatives over 24 different sites were implemented in a 29-month period. The cumulative performance analysis for all the initiatives is shown in Figure 4.4. This analysis provides an overview of all the initiatives to the user. The analysis starts in May 2016 when the first initiative was implemented, and ends in September 2018, the month when this analysis was done. The cumulative actual power reduction (or impact) and the target power reduction are shown on the left y-axis. The cumulative cost saving is shown on the right y-axis.

Figure 4.4 shows the following regarding the energy savings: For the first 12 months until April 2017, the initiatives consistently underperformed against the cumulative target and the impact steadily increased, especially from October 2016. From May 2017, the initiatives started to perform better with the gap between the target and impact stabilising and even slightly decreasing over the next 12 months. From June 2018, the gap started to decrease even more, which could be attributed to new, overperforming initiatives being implemented in this period. On average over the whole period, power was reduced by 14.8 MW per month.

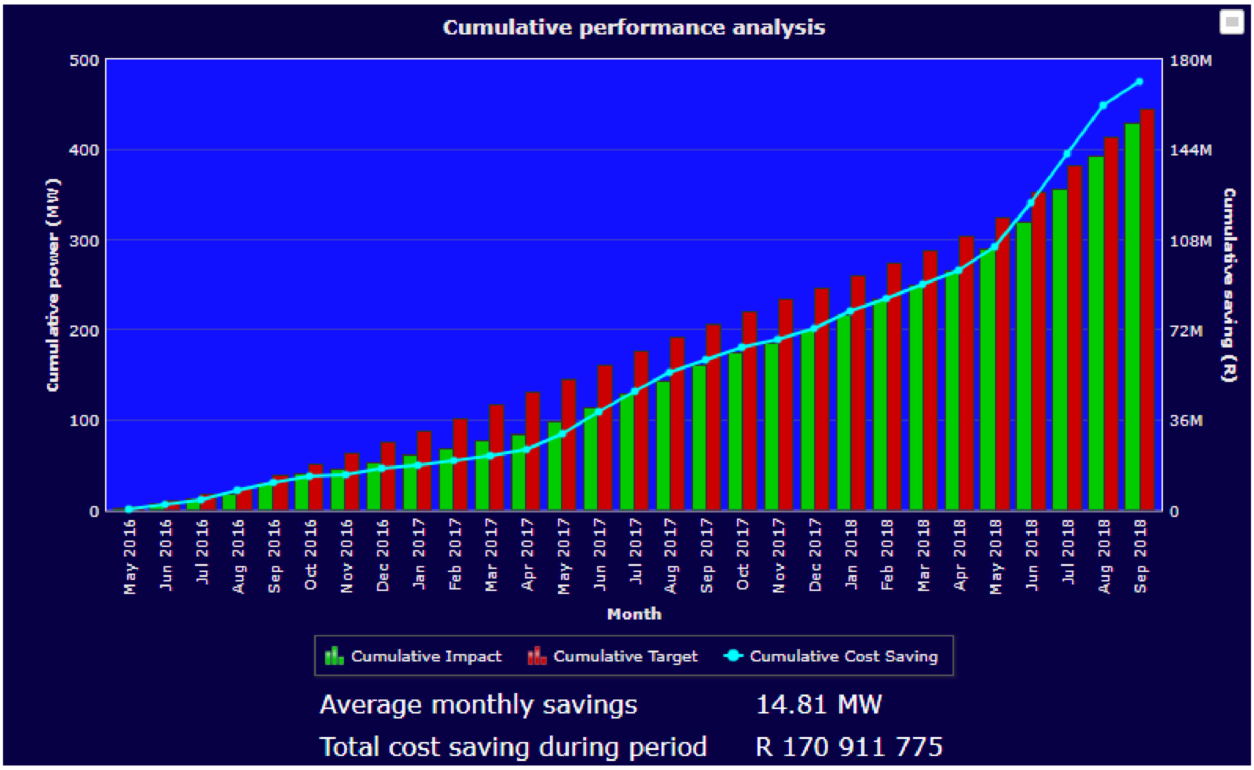

Figure 4.4: *Case study 3 – Cumulative performance analysis*

In terms of cost-savings, Figure 4.4 shows the following: The cost savings were fairly consistent each month for the first year with a slight downturn from October 2016, which correlates with the decrease in energy performance mentioned in the previous paragraph. From May 2017 until August 2017, there was a significant increase in cost savings, which is attributed to the better performing initiatives as well as the increase in electricity cost during the winter months. The winter months referred to here are every year from June to August as defined by the utility company and winter-peak periods are three times more expensive than peak periods in non-winter months.

Another sharp increase in cumulative cost savings is observed from June 2018 to August 2018, which again correlates with the increased winter tariffs and the implementation of the new, overperforming initiatives mentioned in an earlier paragraph. The high tariffs during the peak months make it essential for all initiatives to be well maintained and working optimally during these periods. The total cumulative cost saving during this analysis period is close to R170 million. More than 51% of these savings were achieved in the peak winter months, even though only 31% of the months in this period were winter months.

4.4 Discussion

A need for a generic efficiency initiative performance monitoring system was identified in literature. The system developed in this study aids energy personnel to manage the performance of their energy initiatives. They have a collection of visualisations and reports available to analyse initiative performance via the web application. The system was implemented on a relatively large-scale operation.

The proposed system achieves the need to aid in environmentally friendly and sustainable development identified by Watson *et al.* [1]. The generic nature of the system allows it to be used for various efficiency projects as illustrated in the results across both energy and water. However, the system is not limited to those areas and could be expanded to cover air quality, water pollution reduction as well as any other measurable environmental impact. The system could further be improved by incorporating Big Data and Internet of Things techniques and concepts, which have shown promise in managing natural resource usage and sustainable development [37, 51, 71]. These Big Data techniques could provide enhanced insight into usage patterns and wastages, which could be used as indications of savings opportunities [37, 51, 71].

Further advancement of the system could focus on incorporating further non-energy or indirect cost benefits that efficiency initiatives realise [36, 72, 73]. This could aid in the wider adoption of environmentally sustainable production by initially focusing on the direct financial benefit for the industries involved. Another additional benefit is that the system could work closely with environmental management systems such as those described by the ISO 14001 standard [74,75]. Implementing an efficiency monitoring system could increase the uptake of direct environmental management by first targeting improvements to the bottom line of the mining industry.

However, this study did identify some shortcomings. From the survey mentioned in Article 3, concerns were raised whether the results generated by the system are verifiable. Since it is possible to manually verify the calculations based on the data in the database, the real concern here is the reliability of field data collected from various sources. This is a major concern for most systems relying on external data sources. There is therefore scope to perform some data quality checks to ensure that the data is usable for the analysis. Such data quality analysis could be automated based on existing M&V and data quality techniques as developed by Goosen [76].

Furthermore, while the system was implemented and used successfully at numerous mining sites, the results are limited to the South African deep mining industry. Further study would be required to determine if the same or a similar approach could be used in other industrial sectors such as manufacturing, steel-making or the cement industry.

Chapter 5

Conclusion

5.1 Summary of work

This study set out to develop and implement an EMIS for industries that can be adapted to specific tariff structures. The first step was to establish the need for such a system. The need for a scalable system to be implemented in industry with real-world results was apparent from literature. Investigating the vast amounts of data processed and analysed automatically by the system highlights the need for such a system, as the process would be labour intensive without it. The data investigation showed that the two mining groups where this system was implemented process more than 56 000 electricity bill data points and 9.3 million efficiency initiative data points annually.

It is important to have a broad understanding of a company's energy usage in order to manage and improve energy efficiency effectively. An Energy Map will help to visualise the overall change in energy consumption. High-level energy information is freely available in the form of monthly electricity bills provided by utility companies. Although valuable data is available, it becomes overwhelming for large-scale industries to extract and analyse all the information. An integral part of the EMIS is the automatic extraction, organisation and analysis of bill data.

The bill analysis tool allows users to identify potential savings initiatives. For example, time-of-use data highlights areas where load-shifting or peak-clipping initiatives could be implemented to reduce the amount of energy consumed during more expensive peak periods. The maximum demand analysis could identify opportunities for reducing the notified maximum demand and the associated costs thereof without risking penalties for exceeding maximum demand. On the other hand, the reactive power tool identifies the risk of a low power factor, which could be penalised during winter months.

Companies can reduce energy consumption and increase their operational efficiency by implementing energy efficiency initiatives. However, to maintain the optimal performance of an initiative, it should be monitored continuously. This requires large amounts of data to be processed and analysed on a regular basis. Although commercial systems exist that are able to monitor system performance, none of these systems provides initiative performance monitoring integrated with bill analysis. A need was identified for a system to monitor the performance of efficiency initiatives automatically. Such a system was developed as part of the larger EMIS.

The efficiency initiative monitoring system was implemented on a large-scale mining operation. Several case studies were analysed to illustrate the use of the system. The first case study examined the performance of a load-shifting project. The system helped to identify underperformance early in the month, which was rectified quickly. However, it still took several days to recover the monthly cumulative performance, which illustrates the importance of daily monitoring.

Another case study of the initiative monitoring system illustrated cumulative performance analysis of all initiatives for a mining group. This analysis enables the user to determine whether the holistic performance of the initiatives is improving or deteriorating. Over the 29-month case-study period, the initiatives achieved an average power reduction of 14.81 MW and a total electricity cost saving of R170 million.

The objective of this study was achieved by developing and implementing an EMIS for industries in South Africa. The system aids industries to manage energy efficiency effectively by automating the data collection, translation and storage processes. Energy personnel are able to analyse the data effectively to extract meaningful information and identify potential opportunities for improving energy efficiency, and monitor the performance of implemented initiatives.

5.2 Shortcomings and future research

Apart from the basic improvements to the bill analysis system mentioned in Section 3.5, there are a few research areas that could be explored further. For example, expanding the capabilities of the system to analyse bills for other sources such as coal, gas and diesel. Although electricity is a major energy source in most industries, creating awareness about the consumption of other sources will ultimately help to consume them more efficiently.

As mentioned in Section 3.5, using bill data to forecast energy cost and usage is a valuable tool, which will further improve awareness and potentially aid in the planning of energy intensive operations. A similar tool was mentioned by Rodrigues *et al.*, which would be a good starting point for this research [59]. Finally, the bill analysis system could be expanded to be compatible with the tariff structures of other countries as well. Currently it is limited to South Africa.

In terms of the efficiency initiative performance monitoring system, the most prominent concern from the survey was regarding the reliability of the results - specifically the accuracy of the raw field data collected from using instrumentation. To improve the credibility of the results, research could be conducted regarding automated data quality checking and data quality quantification [76].

To further improve performance monitoring, the feedback cycle could be tightened by analysing data more regularly (for example, every 30 minutes). Relevant personnel would then be notified immediately if a baseline is exceeded and could act faster to minimise any negative energy or financial impact.

As mentioned in Section 4.4, the generic nature of the system allows it to be used for various initiatives for both energy and water. However, the system could easily be expanded to cover air quality, water pollution reduction as well as any other measurable environmental impact. The system could further aid other environmental management systems described by the ISO 14001 standard [74, 75]

Finally, with the vast amounts of data available in the system, the techniques and concepts of Big Data and Internet of Things could be incorporated to manage natural resource usage and sustainable development [37, 51, 71]. These techniques could help to identify savings opportunities by providing additional insight into usage patterns and wastages.

References

[1] R. T. Watson, M. C. Boudreau, and A. J. Chen, "Information systems and environmentally sustainable development: Energy informatics and new directions for the IS community," *Management Information Systems Quarterly*, vol. 34, no. 1, pp. 23–38, 2010.

[2] P. Goosen, J. A. Swanepoel, and J. N. du Plessis, "The need for a comprehensive energy management information system for industries," *South African Journal of Industrial Engineering*, vol. 27, no. 3, pp. 1–11, 2016.

[3] Department of Energy, "2016 South African energy prices statistics," Department of Energy, Pretoria, South Africa, Tech. Rep., 2016.

[4] Department of Energy, "2017 South African energy prices statistics," Department of Energy, Pretoria, South Africa, Tech. Rep., 2017.

[5] M. Pusnik, F. Al-Mansour, B. Sucic, and A. F. Gubina, "Gap analysis of industrial energy management systems in Slovenia," *Energy*, vol. 108, pp. 41–49, 2016.

[6] P. N. Neingo and T. Tholana, "Trends in productivity in the South African gold mining industry," *Journal of the Southern African Institute of Mining and Metallurgy*, vol. 116, pp. 283–290, 2016.

[7] M. Benedetti, V. Cesarotti, and V. Introna, "From energy targets setting to energy-aware operations control and back: An advanced methodology for energy efficient manufacturing," *Journal of Cleaner Production*, vol. 167, pp. 1518–1533, 2017.

[8] J. C. Jordaan, "An estimation of the impact of the 2012 platinum-sector strike on the South African economy," *South African Journal of Economic and Management Sciences*, vol. 19, no. 2, pp. 302–320, 2016.

[9] Mine Health and Safety Council, "Mine Health and Safety Act 29 of 1996 and Regulations," Johannesburg, South Africa, 1996.

[10] O. Ogunnowo and S. Joshua, "Xenophobic attacks in South Africa and Nigeria's foreign policy: Rethinking Nigeria's Afro-centric foreign policy posture," *Covenant University Journal of Politics and International Affair*, vol. 7, no. 1, 2019.

[11] M. D. Seke, "The impact of the proposed nationalisation of South African mines on employment in the platinum sector," Ph.D. dissertation, University of Pretoria, 2013.

[12] S. du Plessis, "Nationalising South African mines: Back to a prosperous future, or down a rabbit hole?" in *Presidential Address Presented at the Biennial Conference of the Economic Society of South Africa*, 2011, pp. 5–7.

[13] Republic of South Africa, "Act No. 15 of 2019: Carbon Tax Act," Cape Town, South Africa, 2019.

[14] L. Dong, X. Tong, X. Li, J. Zhou, S. Wang, and B. Liu, "Some developments and new insights of environmental problems and deep mining strategy for cleaner production in mines," *Journal of Cleaner Production*, vol. 210, pp. 1562–1578, 2019.

[15] J. A. Bohlmann and R. Inglesi-Lotz, "Analysing the South African residential sector's energy profile," *Renewable and Sustainable Energy Reviews*, vol. 96, pp. 240–252, 2018.

[16] C. Burger and A. Jansen, "Increasing block tariff structures as a water subsidy mechanism in South Africa: An exploratory analysis," *Development Southern Africa*, vol. 31, no. 4, pp. 553–562, 2014.

[17] W. Schoeman, H. Brand, and J. Vosloo, "A DSM approach for water usage and electricity costs on water distribution networks," in *Proceedings of the Conference on the Industrial and Commercial Use of Energy, ICUE*, 2016, pp. 191–199.

[18] Sibanye-Stillwater, "Integrated annual report 2017," Roodepoort, South Africa, pp. 109–110, 2017.

[19] G. E. du Plessis, D. C. Arndt, and E. H. Mathews, "The development and integrated simulation of a variable water flow energy saving strategy for deep-mine cooling systems," *Sustainable Energy Technologies and Assessments*, vol. 10, pp. 71 – 78, 2015.

[20] H. J. van Antwerpen and G. P. Greyvenstein, "Use of turbines for simultaneous pressure regulation and recovery in secondary cooling water systems in deep mines," *Energy Conversion and Management*, vol. 46, no. 4, pp. 563–575, 2005.

[21] J. Vosloo, L. Liebenberg, and D. Velleman, "Case study: Energy savings for a deep-mine water reticulation system," *Applied Energy*, vol. 92, pp. 328–335, 2012.

[22] J. A. Crawford, H. P. R. Joubert, M. J. Mathews, and M. Kleingeld, "Optimised dynamic control philosophy for improved performance of mine cooling systems," *Applied Thermal Engineering*, vol. 150, pp. 50–60, 2019.

[23] J. N. du Plessis, "Development of a supervisory system for maintaining the performance of remote energy management systems," Ph.D. thesis, North-West University, 2014.

[24] A. L. Meek, "A systems engineering approach to improve the measurement and verification process of energy services companies," Master's dissertation, North-West University, 2013.

[25] H. J. Groenewald, "A performance-centered maintenance strategy for industrial DSM projects," Ph.D. thesis, North-West University, 2015.

[26] S. Backlund, P. Thollander, J. Palm, and M. Ottosson, "Extending the energy efficiency gap," *Energy Policy*, vol. 51, pp. 392–396, 2012.

[27] M. Schulze, H. Nehler, M. Ottosson, and P. Thollander, "Energy management in industry: A systematic review of previous findings and an integrative conceptual framework," *Journal of Cleaner Production*, vol. 112, pp. 3692–3708, 2016.

[28] C. Cooremans and A. Schönenberger, "Energy management: A key driver of energy-efficiency investment?" *Journal of Cleaner Production*, vol. 230, pp. 264–275, 2019.

[29] A. Lawrence, T. Nehler, E. Andersson, M. Karlsson, and P. Thollander, "Drivers, barriers and success factors for energy management in the Swedish pulp and paper industry," *Journal of Cleaner Production*, vol. 223, pp. 67–82, 2019.

[30] E. A. Abdelaziz, R. Saidur, and S. Mekhilef, "A review on energy saving strategies in industrial sector," *Renewable and Sustainable Energy Reviews*, vol. 15, no. 1, pp. 150–168, 2011.

[31] International Organization for Standardization, "ISO 50001:2018 Energy management systems," 2018. [Online]. Available: https://www.iso.org

[32] M. Levesque, D. Millar, and J. Paraszczak, "Energy and mining: The home truths," *Journal of Cleaner Production*, vol. 84, pp. 233–255, 2014.

[33] B. Gopalakrishnan, K. Ramamoorthy, E. Crowe, S. Chaudhari, and H. Latif, "A structured approach for facilitating the implementation of ISO 50001 standard in the manufacturing sector," *Sustainable Energy Technologies and Assessments*, vol. 7, pp. 154–165, 2014.

[34] H. Kanneganti, B. Gopalakrishnan, E. Crowe, O. Al-Shebeeb, T. Yelamanchi, A. Nimbarte, K. Currie, and A. Abolhassani, "Specification of energy assessment methodologies to satisfy ISO 50001 energy management standard," *Sustainable Energy Technologies and Assessments*, vol. 23, pp. 121–135, 2017.

[35] S. A. Ates and N. M. Durakbasa, "Evaluation of corporate energy management practices of energy intensive industries in Turkey," *Energy*, vol. 45, no. 1, pp. 81–91, 2012.

[36] A. McKane, P. Therkelsen, A. Scodel, P. Rao, A. Aghajanzadeh, S. Hirzel, R. Zhang, R. Prem, A. Fossa, A. M. Lazarevska, M. Matteini, B. Schreck, F. Allard, N. Villegal Alcántar, K. Steyn, E. Hürdoğan, T. Björkman, and J. O'Sullivan, "Predicting the quantifiable impacts of ISO 50001 on climate change mitigation," *Energy Policy*, vol. 107, pp. 278–288, 2017.

[37] K. Zhou, C. Fu, and S. Yang, "Big data driven smart energy management: From big data to big insights," *Renewable and Sustainable Energy Reviews*, vol. 56, pp. 215–225, 2016.

[38] M. Parvizimosaed, F. Farmani, H. Monsef, and A. Rahimi-Kian, "A multi-stage smart energy management system under multiple uncertainties: A data mining approach," *Renewable Energy*, vol. 102, pp. 178–189, 2017.

[39] K. Jia, G. Guo, J. Xiao, H. Zhou, Z. Wang, and G. He, "Data compression approach for the home energy management system," *Applied Energy*, vol. 247, pp. 643–656, 2019.

[40] K. Zhou and S. Yang, "Smart energy management," *Comprehensive Energy Systems*, vol. 5, pp. 423–456, 2018.

[41] P. Goosen, M. J. Mathews, and J. C. Vosloo, "Automated electricity bill analysis in South Africa," *South African Journal of Industrial Engineering*, vol. 28, no. 3, pp. 66–77, 2017.

[42] P. Thollander and M. Ottosson, "Energy management practices in Swedish energy-intensive industries," *Journal of Cleaner Production*, vol. 18, no. 12, pp. 1125–1133, 2010.

[43] L. Sivill, J. Manninen, I. Hippinen, and P. Ahtila, "Success factors of energy management in energy-intensive industries: Development priority of energy performance measurement," *International Journal of Energy Research*, vol. 37, no. 8, pp. 936–951, 2013.

[44] M. T. Solnørdal and L. Foss, "Closing the energy efficiency gap: A systematic review of empirical articles on drivers to energy efficiency in manufacturing firms," *Industrial Energy Efficiency*, vol. 11, no. 3, 2018.

[45] A. Trianni, E. Cagno, M. Bertolotti, P. Thollander, and E. Andersson, "Energy management: A practice-based assessment model," *Applied Energy*, vol. 235, pp. 1614–1636, 2019.

[46] C. McMahon and A. Ball, "Information systems challenges for through-life engineering," *Procedia CIRP*, vol. 11, pp. 1–7, 2013.

[47] B. Swords, E. Coyle, and B. Norton, "An enterprise energy-information system," *Applied Energy*, vol. 85, no. 1, pp. 61–69, 2008.

[48] B. Sucic, F. Al-Mansour, M. Pusnik, and T. Vuk, "Context sensitive production planning and energy management approach in energy intensive industries," *Energy*, vol. 108, pp. 63–73, 2016.

[49] D. Velázquez, R. González-Falcón, L. Pérez-Lombard, L. Marina Gallego, I. Monedero, and F. Biscarri, "Development of an energy management system for a naphtha reforming plant: A data mining approach," *Energy Conversion and Management*, vol. 67, pp. 217–225, 2013.

[50] L. Martirano, L. Borghi, F. Bua, L. Cristaldi, G. Grigis, C. Lavecchia, M. Liziero, L. Mongioví, E. Nastri, and E. Tironi, "Energy management information systems for energy efficiency," in *2018 IEEE International Conference on Environment and Electrical Engineering and 2018 IEEE Industrial and Commercial Power Systems Europe (EEEIC/I&CPS Europe)*, 2018, pp. 1–7.

[51] J. Herman, H. Herman, M. J. Mathews, and J. C. Vosloo, "Using big data for insights into sustainable energy consumption in industrial and mining sectors," *Journal of Cleaner Production*, vol. 197, pp. 1352–1364, 2018.

[52] P. Robison, M. Sengupta, and D. Rauch, "Intelligent energy industrial systems 4.0," *IT Professional*, vol. 17, no. 3, pp. 17–24, 2015.

[53] A. Teke, O. Timur, and K. Çağatay Bayındır, "Development and testing of an energy saving tool: Suitability analysis with case study," *International Journal of Electrical Power & Energy Systems*, vol. 77, pp. 59–69, 2016.

[54] J. Brühl, G. Smith, and M. Visser, "Simple is good: Redesigning utility bills to reduce complexity and increase understanding," *Utilities Policy*, vol. 60, p. 100934, 2019.

[55] D. Eryilmaz and S. Gafford, "Can a daily electricity bill unlock energy efficiency? Evidence from Texas," *The Electricity Journal*, vol. 31, no. 3, pp. 7–11, 2018.

[56] Y. Geng, W. Ji, B. Lin, J. Hong, and Y. Zhu, "Building energy performance diagnosis using energy bills and weather data," *Energy and Buildings*, vol. 172, pp. 181–191, 2018.

[57] C. Yan, S. Wang, and F. Xiao, "A simplified energy performance assessment method for existing buildings based on energy bill disaggregation," *Energy and Buildings*, vol. 55, pp. 563–574, 2012.

[58] C. Yan, S. Wang, F. Xiao, and D. Gao, "A multi-level energy performance diagnosis method for energy information poor buildings," *Energy*, vol. 83, pp. 189–203, 2015.

[59] A. Rodrigues, L. Martinuzzo, F. M. Varejao, V. E. Silva Souza, and T. Oliveira-Santos, “Reducing power companies billing costs via empirical bayes and seasonality remover,” *Engineering Applications of Artificial Intelligence*, vol. 81, pp. 387–396, 2019.

[60] P. Goosen, R. Pelzer, and H. J. du Plessis, “A method for accurate electricity budget cost calculations for a deep mine,” in *Proceedings of the Conference on the Industrial and Commercial Use of Energy, ICUE*, 2015, pp. 155–160.

[61] P. Goosen, R. Pelzer, and G. Bolt, “Efficient monitoring of mine compressed air savings,” in *Proceedings of the Conference on the Industrial and Commercial Use of Energy, ICUE*, 2013.

[62] W. Booysen, “Measurement and verification of industrial DSM projects,” Ph.D. thesis, North-West University, 2014.

[63] B. Jovanović and J. Filipović, “ISO 50001 standard-based energy management maturity model – proposal and validation in industry,” *Journal of Cleaner Production*, vol. 112, pp. 2744–2755, 2016.

[64] S. Hu, F. Liu, Y. He, and T. Hu, “An on-line approach for energy efficiency monitoring of machine tools,” *Journal of Cleaner Production*, vol. 27, pp. 133–140, 2012.

[65] M.-T. Ke, C.-H. Yeh, and C.-J. Su, “Cloud computing platform for real-time measurement and verification of energy performance,” *Applied Energy*, vol. 188, pp. 497–507, 2017.

[66] M. Wei, S. H. Hong, and M. Alam, “An IoT-based energy-management platform for industrial facilities,” *Applied Energy*, vol. 164, pp. 607–619, 2016.

[67] R. Ilsen, H. Meissner, and J. C. Aurich, “Optimizing energy consumption in a decentralized manufacturing system,” *Journal of Computing and Information Science in Engineering*, vol. 17, no. 2, pp. 21 006–21 007, 2017.

[68] E. Zampou, S. Plitsos, A. Karagiannaki, and I. Mourtos, “Towards a framework for energy-aware information systems in manufacturing,” *Computers in Industry*, vol. 65, no. 3, pp. 419–433, 2014.

[69] G. May, B. Stahl, M. Taisch, and D. Kiritsis, “Energy management in manufacturing: From literature review to a conceptual framework,” *Journal of Cleaner Production*, vol. 167, pp. 1464–1489, 2017.

[70] J. J. Cárdenas, L. Romeral, A. Garcia, and F. Andrade, “Load forecasting framework of electricity consumptions for an intelligent energy management system in the user-side,” *Expert Systems with Applications*, vol. 39, no. 5, pp. 5557–5565, 2012.

[71] F. Shrouf and G. Miragliotta, “Energy management based on Internet of Things: Practices and framework for adoption in production management,” *Journal of Cleaner Production*, vol. 100, pp. 235–246, 2015.

[72] A. Aghajanzadeh, P. Therkelsen, P. Rao, and A. McKane, “Global impact estimation of ISO 50001 energy management system for industrial and service sectors,” Lawrence Berkeley National Laboratory, Tech. Rep., 2016.

[73] A. J. H. Nel, J. C. Vosloo, and M. J. Mathews, “Financial model for energy efficiency projects in the mining industry,” *Energy*, vol. 163, pp. 546–554, 2018.

[74] L. Shen, K. Muduli, and A. Barve, "Developing a sustainable development framework in the context of mining industries: AHP approach," *Resources Policy*, vol. 46, pp. 15–26, 2015.

[75] J. A. Oliveira, O. J. Oliveira, A. R. Ometto, A. S. Ferraudo, and M. H. Salgado, "Environmental management system ISO 14001 factors for promoting the adoption of cleaner production practices," *Journal of Cleaner Production*, vol. 133, pp. 1384–1394, 2016.

[76] A. E. Goosen, "A system to analyse industrial data quality," Master's dissertation, North-West University, 2018.

Appendices

A. Co-author statements

I, Dr. J.A. Swanepoel, hereby provides consent that the article listed below (1), may be used as part of P. Goosen's Ph.D thesis.

Signature: ____________ Date: 01/11/2019

I, Dr. J.N. du Plessis, hereby provides consent that the article listed below (1), may be used as part of P. Goosen's Ph.D thesis.

Signature: ____________ Date: 2019-11-04

I, Dr. M.J. Mathews, hereby provides consent that the articles listed below (2 and 3), may be used as part of P. Goosen's Ph.D thesis.

Signature: ____________ Date: 2019-11-05

I, Dr. J.C. Vosloo, hereby provides consent that the articles listed below (2 and 3), may be used as part of P. Goosen's Ph.D thesis.

Signature: ____________ Date: 2019-11-04

List of articles:

1. P. Goosen, J. A. Swanepoel, and J. N. du Plessis, "The need for a comprehensive energy management information system for industries," *South African Journal of Industrial Engineering*, vol. 27, no. 3, pp. 1–11, 2016.
2. P. Goosen, M. J. Mathews, and J. C. Vosloo, "Automated electricity bill analysis in South Africa," *South African Journal of Industrial Engineering*, vol. 28, no. 3, pp. 66–77, 2017.
3. P. Goosen, M. J. Mathews, and J. C. Vosloo, "Generic efficiency initiative monitoring system," *Computers in Industry*, 2019. (Under review)

B. Article 1 – The need for an EMIS

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THE NEED FOR A COMPREHENSIVE ENERGY MANAGEMENT INFORMATION SYSTEM FOR INDUSTRIES[#]

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ABSTRACT

Electricity costs in South Africa are increasing rapidly, and the funding hurdle rates for energy conservation incentives are decreasing. Therefore, with rising international competition and increasing operational costs, marginal industries need to focus on energy management strategies where larger savings can be achieved with lower capital expenditure. This paper sketches the need for a comprehensive energy management information system (EMIS). Common industrial energy management pitfalls are identified and energy conservation incentives are outlined. New focus points that improve client awareness and in turn improve the sustainability of energy management interventions are also highlighted. However, benefitting from energy incentives is becoming more complex. Therefore, many clients do not benefit from these incentives unless specialised Energy Service Companies (ESCos) are employed. ESCos, however, require large amounts of data to manage clients' energy effectively. Herein lies the need for a comprehensive EMIS that aids ESCos and their clients with the energy management process. An EMIS was developed and implemented for several industries in South Africa. Data is automatically collected, processed, analysed, and presented on a daily basis. A case study investigates the exorbitant amounts of data and reports that are managed automatically, which further highlights the need for a comprehensive EMIS.

OPSOMMING

Die koste van elektrisiteit in Suid-Afrika neem vinnig toe en die befondsing struikelblok vir energiebesparing innovasie is besig om weg te kwyn. Met die toenemende internasionale mededinging en bedryfskostes moet marginale industrieë fokus op energiebestuur-strategieë wat groter besparings kan bewerkstellig met laer kapitaalbesteding. Hierdie artikel skets die behoefte vir 'n omvattende energiebestuur inligtingstelsel. Algemene industriële energiebestuur slaggate word geïdentifiseer en energiebesparings-insentiewe word uiteengesit. Nuwe fokuspunte wat kliënt-bewustheid verbeter en dus die volhoubaarheid van energiebestuur verbeter word uitgelig. Om voordeel te trek uit energiebesparings-insentiewe word meer kompleks en baie kliënte trek nie voordeel daaruit tensy daar van energiediensmaatskappye gebruik gemaak word nie. Energiediensmaatskappye benodig egter groot hoeveelhede data om hul kliënte se energie doeltreffend te bestuur. Die behoefte lê dus in 'n alomvattende energiebestuur inligtingstelsel wat energiediensmaatskappye en hul kliënte kan bystaan. So 'n inligtingstelsel is ontwikkel en geïmplementeer by verskeie industrieë in Suid-Afrika. Data word outonoom bymekaargemaak, geprosesseer, geanaliseer en voorgehou op 'n daaglikse basis. 'n Gevallestudie ondersoek die buitensporige data volumes en verslae wat outonoom genereer word. Dit beklemtoon die behoefte vir 'n alomvattende energiebestuur inligtingstelsel.

1 INTRODUCTION

South African electricity tariffs and international non-renewable energy costs are increasing at a rapid rate [1]. These trends highlight the need for competitive, energy-intensive industries to reduce energy cost [2]. An international drive for improved energy efficiency is incentivising and regulating industrial, commercial, and residential areas to reduce their energy consumption. The improvement of energy efficiency in all these sectors, however, remains a slow and expensive process [2]. Improving energy efficiency requires the updating, replacement, or addition of new, more effective devices, infrastructure, or control systems. However, these interventions are expensive, with both lengthy payback periods and extended periods of time needed to install or implement them [3].

In energy-strapped environments, like South Africa, incentive and rebate programmes provide crucial financial and legislatorial assistance to the industrial, commercial, and residential sectors [4]. This provides the required support to the demand side of the South African electricity network to reduce demand and improve energy efficiency [5]. However, with an aging generation infrastructure, the South African electricity utility, Eskom, and the National Energy Regulator of South Africa, NERSA, are shifting focus away from these programmes, in order to increase profits and finance new infrastructure. The impact of this shift is apparent in the decreasing incentive hurdle rates and changes in legislation, which make it increasingly difficult for the demand side to reduce energy consumption.

Although the demand side needs to reduce energy consumption, interventions and energy efficiency improvements need to be self-funded, which remains difficult in marginal and highly competitive environments. Effective management and an altered focus in industry can provide a stepping stone to reduce energy cost, and so doing, provide the needed financial flexibility to implement additional, more costly energy efficiency improvements (as seen in Figure 1) [6].

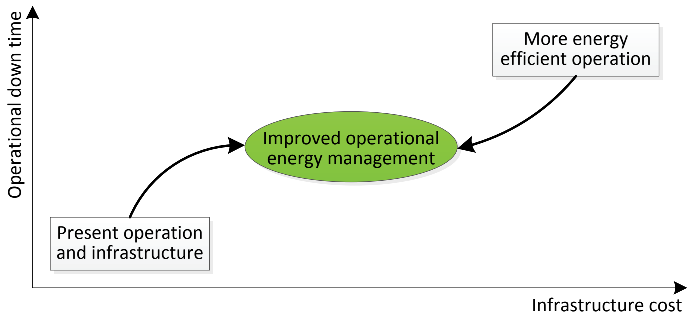

Figure 1: Improving energy efficiency by applying better operational energy management

Industry is aware of opportunities for more energy-efficient operation, but the high infrastructure cost and the risk of operational down-time weighs against the potential benefits. The installation of more energy efficient equipment is expensive and requires extended down-time. Hurdle rates of energy efficiency incentives are also decreasing and becoming more complex. Improved energy management reduces this cost and risk, but also requires experience to ensure a successful outcome. Addressing these common pitfalls in energy management assists clients to manage operations and alter procedures to decrease energy costs. An Energy Service Company (ESCo) typically holds this expertise and actively employs tools to assist with data processing and reporting, in order to achieve efficient energy management.

Based on the above arguments, the following sections of this paper will:

- address common pitfalls that inhibit consumers from achieving maximum energy cost-saving potential;
- summarise the regulations, legislations, and incentives available to clients in order to improve their energy efficiency;
- propose a more structured energy management strategy;
- describe a comprehensive energy management information system (EMIS) employed by an ESCo to assist them with the energy management of large energy consumers; and
- analyse results of an EMIS data investigation to accentuate its need further.

2 COMMON PITFALLS

A few common pitfalls are found in industrial or commercial energy management. These pitfalls often prevent the demand side from achieving all possible savings from existing circumstances, including: time-of-use (TOU) pricing, new incentives, new legislation, and new programmes.

2.1 Isolated focus or lack of focus

Personnel or individuals often focus either on specific tasks at hand or on too many tasks at once. Key performance indicators from different sectors generally align personnel outcomes and personnel drive with specific areas of focus. These areas of focus include production targets, production rate targets, component reliability, component availability, or in some cases, energy efficiency. Aligning the personnel drive with specific focus areas works well to motivate these individuals to achieve optimised solutions; however, the areas are sometimes misaligned with larger ideals, which results in the overall targets not being met. Additionally, if personnel focus is unclear, or if there are too many focus areas for individuals with a lot of different responsibilities, some areas, especially energy management, are often inadequately executed or overlooked entirely.

2.2 Poor integrated management

As discussed in Section 2.1, personnel are structured into specific areas of focus, such as maintenance, production, operations, and support. However, energy management, as a multi-disciplinary field, requires the collaboration of multiple departments. Most often, the different departments are isolated and collaborate only in a crisis or under forced circumstances. This phenomenon usually goes unnoticed and reduces the amount of energy savings that is achieved.

2.3 Lack of communication and outdated systems

Older systems and infrastructure limit the amount of information that can be used to analyse present energy performance. Energy management is therefore restricted in these circumstances, as feedback or reporting does not indicate where possible improvements can be made. Integrated reporting and communication is thus essential in order to set out and quantify possible energy consumption and energy cost improvements. Referring back to Section 2.1, some personnel will also increase energy consumption in order to achieve other key performance indications. However, the increase in energy consumption or cost is not reported on and often remains unnoticed and unimproved.

2.4 Outdated procedures

Energy management is a fluctuating and dynamic environment. New infrastructure, procedures, and best practices are updated and improved frequently. New incentives and programmes are also developed on a constant basis. However, most personnel remain focused on other fields or remain isolated in their specific work environment without learning or taking note of newer, more effective procedures. More experienced personnel also tend to remain reluctant to alter present procedures because these procedures are tried and tested. However, noting and applying new standards, procedures, and best practices as they develop remains crucial in the energy sector.

3 REGULATION, LEGISLATION, AND INCENTIVES

Legislation and regulation provides a framework in which energy management can take place. This regulatory structure also provides the guidelines for the development of policies and standards that are used in the energy sector. Different funding and rebate incentives are also available to promote the compliance and regulation of the energy sector. Regulation, legislation, and policies pertaining to South African and international energy management are summarised in Table 1.

Energy consumers in South Africa are motivated by both government and NERSA to improve energy efficiency and reduce energy cost with multiple different incentives. These incentives include infrastructure funding, tax rebate incentives, environmental levies, and carbon taxation. The different incentives and rebates are summarised in Table 2. However, applying for and implementing these different incentives remains a complex task, and the incentives fluctuate in availability and hurdle rate on a frequent basis. This fluctuation also makes it increasingly difficult for clients and some ESCos to implement and benefit from these incentives.

Table 1: Legislation, regulation, and policies in South Africa [5]

Regulation	
1	Electricity Regulation Act (2006)
2	Electricity Regulation Act – Std. for Reticulation (2008)
3	National Energy Act (2008)
4	National Energy Act – Allowances for EE Savings (2011)
5	Electricity Regulations IRP (2011)
6	Revision of Regulatory Rules for EE & DSM (2010)
7	Advanced Metering Infrastructure - R&C Consumers (2008)
Policy	
1	SANS 10400XA DTI (Promulgated Nov 2011)
2	SANS 50001 and 50010

Table 2: Energy efficiency incentives in South Africa [5, 7]

EE Incentives and rebate	
1	Environmental Levy on Non-Renewable Electricity - Eskom (2009)
2	Section 12L of the Income Tax Act, Act No. 58 of 1962
3	MYPD Funding for DSM Programme – Eskom (2011-2013)
Industrial – DTI	
1	Section 12I of the Income Tax Act, Act No. 58 of 1962
South African Revenue Services	
1	Carbon Dioxide Vehicle Emissions Levy (2011)
2	Carbon Tax Discussion Paper, National Treasury, (2010)
3	Carbon Emissions Tax in the National Budget Review (2012)

Eskom has been experiencing a notable electricity production shortfall since 2008. In addition, an uneven demand profile showcases increased demand pressure during morning and evening peaks. As a result, different TOU tariff structures are used to reduce peak demand in the South African electricity market [1]. The aim of these TOU tariff structures is to provide incentives for the demand side to shift consumption to less-constrained times of the working week. As a result of the demand side's response to this TOU tariff implementation, the South African electricity demand has changed and relieved some of the pressure from the electricity supply.

However, the demand increased to such an extent in 2015 that the altered demand profile once again placed strain on supply in peak periods. Integrated demand management projects previously assisted clients in achieving larger benefits from the correct use of these TOU structures; however, with decreasing hurdle rates and increasing market pressure, these projects are becoming more difficult to implement [6]. Large potential for improvement still remains in the South African demand profile. A lot of opportunities for TOU cost savings are unused by the demand side. The onus of achieving this benefit, however, is shifting away from specific Eskom-funded projects to client-managed and client-initiated load profile improvement.

Different support and demand-side management (DSM) programmes have been developed and made available for both clients and ESCos. These programmes have been implemented by different institutions including Eskom, the South African Department of Energy, and other facets of government. A summary of present incentive programmes and energy efficiency support and development programmes is given in Table 3.

Legislation, regulation, and incentives are often complex and are also updated on a frequent basis. In many cases, specialised personnel are required to assist the demand side to navigate the complex routes and corridors that energy legislation and regulation entail. Benefitting from incentives is also becoming more complex. The National Cleaner Production Centre (NCPC) of South Africa conducts free energy audits and, through its Industrial Energy Efficiency (IEE) project, makes recommendations regarding resource efficiency and cost-saving opportunities [4, 7]. However, sustaining project savings and improvements is difficult without proper maintenance [8]. As a result, many consumers do not use or benefit from these incentives unless specialised ESCos are employed.

Table 3: Energy efficiency programmes in South Africa [5, 7]

Department of Energy (DoE) and Eskom – existing	
1	IDM: ESCo Model; Performance Contracting; SP, SO, SWH Rebate & CFL Mass Rollout
2	PCP, ECS & Electricity Growth Management
3	Municipal EE with National Treasury and DPW
4	NEEA with BUSA and NBI / EELN (DoE)
5	Signatory Kyoto Protocol for CDM. DNA resides within the DoE
6	EE monitoring & performance in 5 municipalities
7	Awareness-raising programmes
Under consideration or development	
1	Standards and Labelling for selected residential appliances
2	Extended awareness raising programmes
Other government	
1	Building & Measurement Standards: SANS 204, 10400XA, 50001 and 50010
2	Free Energy Audits conducted by NCPC
3	Manufacturing Competitiveness Enhancement Programme (MCEP)
4	Green Energy Efficiency Fund (GEEF)
5	Green Building Council of South Africa (GBCSA)
6	New Vehicle Emissions Excise Tax
Under consideration or development	
1	Develop EE auditor accreditation (DTI)

4 STRUCTURED ENERGY MANAGEMENT

One of the key elements of sustainable projects remains personnel focus. Personnel focus can be maintained by quantifying key deliverables or key performance indicators. Revising these key performance indicators will improve both the awareness and sustainability of energy management interventions. It will also motivate personnel to creatively apply personal experience to energy management and improve possible savings.

For example, the cement industry monitors several different key performance indicators to ensure optimal operation. The performance indicator aimed at improving energy efficiency is the amount of energy consumed per ton of product produced (kWh/t on electricity equipment and MJ/t on other energy-intensive equipment). These performance indicators motivate personnel to operate the cement production equipment at optimal efficiency; however, they do not indicate how well the operational personnel use TOU tariff structures. Adding a key performance indicator that describes the cost intensity per ton produced ((energy cost)/t) will therefore motivate personnel to align operational idle time with more expensive TOU tariff periods.

A second step is to create a platform for communication between different departments of the business. For example, in the cement industry, combining the expertise of the production, maintenance, and operational personnel on a frequent basis to address the interdisciplinary issue of energy management will improve possible savings. Dedicated energy management personnel are employed by many different industries. However, these personnel generally only form a consulting wing of the company. The executive powers of the site at hand and the personnel at the considered site still execute all operational tasks, during which the energy management personnel consult, sometimes in a very ineffective manner. The premise for energy cost improvement thus lies on frequent communication between the different departments and direct executive consulting by energy management personnel. Doing this ensures that all personnel and operational tasks maintain the focus on energy cost and energy efficiency.

The number of dedicated energy management personnel, however, is limited. Large numbers of possible projects and constantly changing legislation and incentive platforms limit the impact that these dedicated personnel members have on industry-wide energy efficiency and energy cost improvement. In industry, there remains a need for active, effective, and focused consulting by ESCos. To manage the energy use of clients effectively, however, an ESCo must have the necessary tools in place that will aid with the organisation and analysis of energy-related data.

The ISO 50001 standard for energy management is based on a continual improvement model to help organisations manage their energy efficiency by means of an energy management system [9, 10]. However, the continuous nature of the standard requires increasingly more measurements and analysis of data. Consequently, this data should be managed by an automated and integrated system that provides personnel with the most essential energy information.

5 COMPREHENSIVE ENERGY MANAGEMENT INFORMATION SYSTEM

The need was established for an energy management information system (EMIS) that contains the correct information and allows for interpretation of this information in a way that assists industry to benefit from or comply with energy management standards, incentives, legislation, and regulation.

5.1 Data collection process

Data required for effective energy management is received in various formats from various sources. The range of data formats includes energy invoices, 30-minute interval data from External Metering Companies (EMCs), and two-minute interval data from the client's Supervisory Control and Data Acquisition (SCADA) system. Figure 2 shows a flow diagram of the EMIS. All data is processed into a generic format, and processed data is stored in a database. Data is retrieved from the database to be analysed and to generate useful energy information. Reports are compiled with the energy information, which can also be viewed on online dashboards.

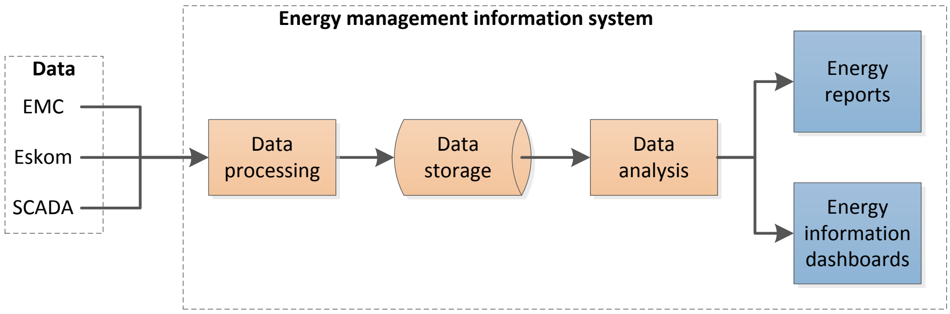

Figure 2: Data flow diagram of the EMIS

5.2 Bills (risks and opportunities)

A starting point for such a system is to import information from electricity bills. This information allows for monthly budgeting and the identification of areas for optimisation. Opportunities that can by identified include notified maximum demand adjustments and time-of-use optimisation. These verified electricity consumption figures can also be used to assess the future risk of carbon taxation, electricity cost inflation, and excessive reactive power readings. There are a number of dashboards that show energy information; some of these dashboards are explained in more detail in Table 4.

Table 4: Energy bill dashboards

	Dashboard	*Description*
Electricity Coal Gas Diesel	Costs	Summary of energy cost for financial year. Energy bill breakdown. Monthly energy cost compared with budget. Energy cost breakdown by user.
	Consumption	Summary of energy consumption for financial year. Monthly energy consumption compared with budget. Energy consumption breakdown by user.
	Account detail	Individual bill information is broken down into operations detail and compared against budgets.
Risks	Carbon tax risk	Carbon tax at a rate of ZAR 120/ton CO2e will be implemented and pose a big financial risk.
	Electricity cost inflation risk	Tariff increases are still the biggest risk factor and are forecasted according to MYPD3 publications.

6

	Dashboard	*Description*
	Reactive power risk	Reactive power is currently only charged during the winter. Eskom plans on charging clients for the whole year. The cost impact on individual operations is forecasted here.
Opportunities	Time-of-use (TOU) opportunities	The electricity consumption breakdown is compared with the electricity cost breakdown to highlight and quantify the importance of demand-side management.
	Maximum demand	Savings opportunities for updating the notified maximum demand at specific points-of-delivery are quantified.
	DSM opportunities	Projects qualifying for DSM funding are listed with their MW savings and ROI based on Eskom-IDM benchmarks.
	Reactive power opportunities	Power factor correction savings are quantified.
Savings	Savings achieved	An executive summary showing the cost savings achieved for the previous month.

5.3 System detail

To improve the resolution of monthly monitoring, electricity consumption data can be obtained on a daily basis from Programmable Logic Controllers (PLC), SCADA systems, historian systems, and metering databases. At this resolution, automated data collection is required to ensure data continuity. This data could typically consist of half-hourly data that forms daily profiles that can be compared with target profiles, in order to provide a daily target for energy management personnel. After obtaining access to electricity data from diverse data sources, it was realised that data for other energy types such as coal, gas, and diesel are also available on similar sources.

There are two main dashboards for system details: monthly system detail and daily system detail. The monthly dashboard shows a yearly overview of each system's monthly energy performance. The daily dashboard shows a weekly overview of each system's daily energy performance. More detail for each view is available, showing average energy consumption profiles for the selected month or day.

5.4 Projects

In extension to this system-related data, the performance of specific energy projects or DSM initiatives can also be measured by comparing the actual performance to the baseline constructed before the intervention. Performance calculations can be tailored according to the specific DSM strategy, such as a load-shifting, energy efficiency, or peak-clipping strategy. This performance assessment calculation can be compared with the findings of the measurement and verification (M&V) team appointed to assess the performance of the project.

Similar to the systems detail mentioned in Section 5.3, there are two main dashboards for projects: monthly project detail and daily project detail. The monthly dashboard shows a yearly overview of each project's monthly energy performance. The daily dashboard shows a weekly overview of each project's daily energy performance. More detail for each view is available, showing average energy consumption profiles for the selected month or day.

On a daily basis, issues related to a project's performance — for example, data loss — is automatically marked and the relevant ESCo project engineer is notified by email. The engineer can then investigate the issue further and resolve the issue, if possible. The engineering manager is also notified of any unresolved issues.

5.5 Environmental

With access to data on energy consumption that includes electricity, coal, gas, and diesel, a single energy management information platform can also assist with annual environmental reporting. Additional information not automatically obtained can be inserted by environmental personnel in order to produce a complete environmental report without excessive data processing.

Table 5: Environmental dashboards

Dashboard	*Description*
Materials	Summary of materials used or produced per operation. For example, rock mined, waste rock recycled, coal used, LPG used, diesel used, hydraulic oil used, explosives used, etc.
Energy	Summary of energy used. For example, electrical energy, fossil fuels, renewable energy, and energy used in travel.
Water	Summary of water consumption. For example, water use for primary activity, potable water, non-potable water, surface water, ground water, and water recycled in process.
Land	Summary of land area. For example, land under mine charge, land distributed for mining activities, land rehabilitated, and land available for rehabilitation.
Effluent	Summary of effluent. For example, effluent to disposal facility, surface water quality check, adverse biophysical environmental impact on surface water, groundwater quality check, etc.
Waste	Summary of waste management. For example, accumulated tailings, accumulated waste rock, hazardous waste to landfill, hazardous waste to incineration, scrap steel, etc.
Emissions	Summary of Scope 1 and Scope 2 emissions, as well as carbon tax.
Incidents	List of environmental incidents reported each year.

5.6 Custom views

The luxury of access to an extensive set of data prompts user specific reporting or analysis. A specific view that allows users to create customised energy information dashboards provides a comprehensive solution. The underlying framework for the customised views are generic, but users can specify which charts, tables, and other information they want to analyse. Multiple users can access a specific view, or a view can be limited to a specific user.

5.7 Document management

The EMIS also aids the ESCo and clients to manage documentation related to their energy use effectively. Adhering to the ISO 50001 standard requires much documentation about energy policies, energy reviews, energy baselines, energy performance indicators, and action plans. Benefitting from incentive programmes like tax rebates (Section 12L of the Income Tax Act) also requires stringent traceability of M&V documentation. A generic document control manager is therefore a helpful tool.

To aid with navigating through the documents, they are linked to specific systems in the operational structure of a client group, as well as a predefined document structure. Documents can further be filtered by years and labels linked to each document. Finally, a user can also search for specific key words to find documents. This functionality displays documents with these key words in the document name, ordered by relevance.

6 RESULTS OF AN EMIS DATA INVESTIGATION

The EMIS is implemented for a number of industrial client groups in South Africa. These implementations include several mining groups, cement groups, and a steel manufacturer. Data is collected from various sources automatically on a daily basis. Each point of measurement or data object is referred to as a ‘tag’. For example, the energy consumption of a compressor is measured and stored in a tag. A tag has a specific resolution at which data is stored. High-resolution tags are processed into 48-samples per day. Other tags have much lower resolutions — for example, daily production totals and monthly electricity bill charges.

Figure 3 shows the number of tags extracted from energy bills for five client groups, as well as the number of data points that these tags can have over a year. These tags have a monthly resolution, since clients are invoiced on a monthly basis. Each point of delivery has several tags and each site can have multiple points of delivery. Figure 3 shows that the electricity bills for a client group with a large number of sites, like Mine Group A, can produce more than 2,300 tags and more than 28,000 data points per year.

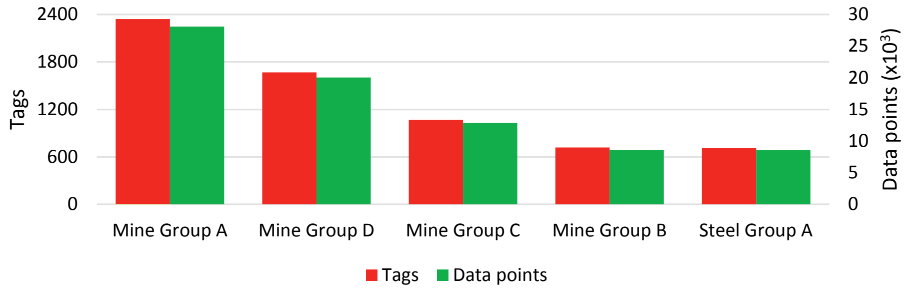

Figure 3: Number of bill tags and yearly data points per client group

Figure 4 shows the number of 48-sample system tags used for five client groups. In some cases, these tags can have relatively low-level detail; for example, the electricity consumption of an individual pump. Depending on the detail level, a client group can easily have more than 200 high-resolution data tags. Collecting this amount of data on a daily basis without a comprehensive system will be a daunting task. Figure 4 also shows the total number of data points that the tags will have if extrapolated over a year.

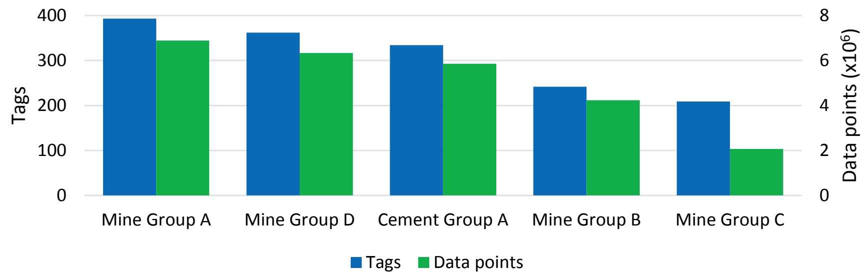

Figure 4: Number of system tags and yearly data points per client group

Having all these data points is pointless if they are not analysed further and presented as valuable information. On a daily basis, the EMIS automatically sends out more than 40 energy performance reports to more than 90 recipients; that is over 14,600 reports per year. ESCo and client personnel are also able to access this data through the web application.

At the moment, the level of system detail is limited to the energy consumption of individual equipment units — for example, a pump or compressor unit. If, however, the ESCo wants to do condition monitoring on each unit, then more measurements are required. For example, basic condition monitoring on a large mine de-watering pump requires about ten measurements; these pump measurements include power, flow, suction pressure, discharge pressure, vibration, temperature, etc.

However, for more advanced condition monitoring on well-equipped pumps, more than 45 individual measurements are available. This will have a tremendous effect on the number of data points that should be analysed, considering that a single mineshaft can have more than 25 de-watering pumps. Even if this data is aggregated to 48-samples per day, these 25 pumps will add almost 19 million additional data points per year. Figure 5 illustrates the relation between the current setup (one measurement per pump) for the 25 pumps and the potential setup if all 45 pump tags are used.

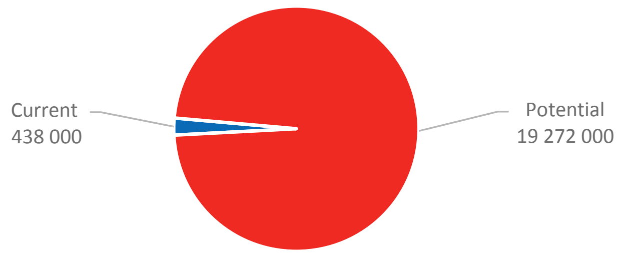

Figure 5: Current and potential number of yearly data points for 25 pumps

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The above-mentioned scenario only shows the tip of the iceberg for a mineshaft. The mineshaft has 25 large de-watering pumps, but there is a lot of other equipment that can also benefit from condition monitoring. Examples of such equipment include fridge plants, winders, bulk air coolers, compressors, etc. However, a mining group like Mine Group A has more than 15 mineshafts, as well as a number of processing plants. Therefore, it will be impossible to manage this large amount of data without a comprehensive EMIS.

7 CONCLUSION

Complex incentive programmes and reducing rebate hurdle rates are extending the gap between present operation and the installation of more energy-efficient equipment. However, the large potential for energy cost savings, via improved operational and energy management, presents the opportunity to bridge the same gap. Common pitfalls in energy management strategies, however, limit the application of improved operations and energy management. It also limits the ability of energy managers to use available incentives to reach energy management goals. Small shifts in key performance indicators and improved communication will both improve awareness and reverse the impact of these pitfalls. Reducing energy costs also allows the demand side to implement self-funded energy improvement measures.

A comprehensive EMIS is vital to support any energy management effort. The amount and resolution of data from diverse data sources poses the risk of overwhelming energy management personnel to a point where efficient energy management is not possible. A single platform is required to retrieve, analyse, store, and represent data in a way that assists energy managers to identify potential areas for optimisation, and assist personnel to reap the maximum benefits of adherence to regulation, legislation and incentives.

REFERENCES

[1] **Abdelaziz, E.A., Saidur, R. and Mekhilef, S.** 2011. A review on energy saving strategies in industrial sector. *Renewwable and Sustainable Energy Reviews,* 15(1), pp. 150-168.

[2] **Dong, C., Huang, G.H., Cai, Y.P. and Liu, Y.** 2013. Robust planning of energy management systems with environmental and constraint-conservative considerations under multiple uncertainties. *Energy Conversion and Management,* 65, pp. 471-486.

[3] **Swanepoel, J.A., Mathews, E.H., Vosloo, J.C. and Liebenberg, L.** 2014. Integrated energy optimisation for the cement industry: A case study perspective. *Energy Conversion and Management,* 78, pp. 765-775.

[4] **Budge, M., Booysen, W. and Vosloo, J.C.** 2015. Simplifying the process of identifying viable industrial energy efficiency incentives. *2015 International Conference on the Industrial and Commercial Use of Energy (ICUE).*

[5] **Department of Energy and SANEDI.** 2012. *South African energy efficiency high level policy map.* October.

[6] **Trollip, H., Butler, A., Burton, J., Caetano, T. and Godinho, C.** 2014. Energy security in South Africa. *Mitigation Action Plans & Scenarios,* No. 17.

[7] **Bolt, G.D., Vosloo, J.C. and Pelzer, R.** 2014. Strategies for energy efficiency funding in the absence of industrial Eskom-IDM support. *2014 International Conference on the Industrial and Commercial Use of Energy (ICUE),* Cape Town

[8] **Groenwald, H.J., van Rensburg, J.F. and Marais, J.H.** 2014. Business case for industrial DSM maintenance. *2014 International Conference on the Industrial and Commercial Use of Energy (ICUE),* Cape Town.

[9] **Fiedler, T. and Mircea, P.M.** 2012. Energy management systems according to the ISO 50001 standard — Challenges and benefits. *2012 International Conference on Applied and Theoretical Electricity (ICATE),* Craiova.

[10] **van Heerden, M., Kleingeld, M. and Vosloo, J.C.** 2015. Improving DSM project implementation and sustainability through ISO standards. *2015 International Conference on the Industrial and Commercial Use of Energy (ICUE),* Cape Town.

ACRONYMS AND ABBREVIATIONS

BUSA	Business Unity South Africa
CDM	Carbon Development Mechanism
CO2e	Equivalent carbon dioxide emissions
DoE	Department of Energy
DNA	Designated National Authority
DPW	Department of Public Works
DSM	Demand Side Management
DTI	Department of Trade and Industry
EE	Energy Efficiency
EELN	Energy Efficiency Leadership Network
EMC	External Metering Companies
EMIS	Energy Management Information System
ESCo	Energy Services Companies
GBCSA	Green Building Council of South Africa
GEEF	Green Energy Efficiency Fund
IDM	Integrated Demand Management
IRP	Integrated Resource Management

M&V	Measurement and Verification
MCEP	Manufacturing Competitiveness Enhancement Programme
MYPD	Multi-Year Price Determination
NBI	National Business Initiative
NCPC	National Cleaner Production Centre
NEEA	National Energy Efficiency Accord
NERSA	National Energy Regulator of South Africa
PLC	Programmable Logic Unit
R&C	Residential and Commercial
ROI	Return On Investment
SCADA	Supervisory Control and Data Acquisition
SO	Standard Offer
SP	Standard Product
SWH	Solar Water Heating
TOU	Time-Of-Use
ZAR	South African Rand

C. Article 2 – Automated electricity bill analysis

Title:	Automated electricity bill analysis in South Africa
Journal submitted:	South African Journal of Industrial Engineering (SAJIE)
Status of article:	Published
Journal guidelines:	See Appendix E

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AUTOMATED ELECTRICITY BILL ANALYSIS IN SOUTH AFRICA

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ABSTRACT

The ever-increasing cost of energy puts industries under pressure. Industries are forced to monitor their energy consumption and to manage energy more efficiently and responsibly. Some industrial companies have multiple operations spread out over a wide area, making it logistically difficult to get a holistic view of the company's energy performance. Valuable information is freely available in the form of electricity bills. However, to benefit from the information in the bills, the data should be extracted and analysed, which is a time-consuming process. In this paper, a need for an automated centralised system that extracts and analyses electricity data from bills was identified. The methodology for extracting, organising, and presenting the electricity bill information is explained in detail. The system is implemented for a gold mining company, and the results are interpreted and discussed. It was found that the system is beneficial for companies with many operations. As the number of operations increases, the value of automated bill analysis increases.

OPSOMMING

Die kostes verbonde aan elektrisiteit in Suid-Afrika neem vinnig toe en die befondsingshekkie vir energiebesparinginsentiewe verminder. Daarom, met die toenemende internasionale mededinging en operasionele kostes, moet marginale industrieë fokus op energiebestuurstrategieë waar groot besparings met klein kapitaalbestedings verwesenlik kan word. 'n Behoefte aan 'n omvattende energiebestuur informasiestelsel word uiteengesit in hierdie artikel. Energiebestuur slaggate word uitgelig en energiebesparinginsentiewe word bespreek. Nuwe fokuspunte wat kliëntbewustheid verbeter en gevolglik die volhoubaarheid van energiebestuuringrypings verhoog word ook uitgelig. Om voordeel te trek uit energiebesparings word egter meer ingewikkeld en gevolglik ly baie kliënte daaronder, behalwe as hulle industriekenners betrek. Hierdie industriekenners vereis egter groot hoeveelhede data om 'n kliënt se energie effektief te bestuur. Daarin lê die noodsaak vir 'n omvattende energiebestuur informasiestelsel. So 'n energiebestuur informasiestelsel is ontwikkel en geïmplementeer vir verskeie industrieë in Suid-Afrika. Data is outomaties ingesamel, geprosesseer, analiseer en voorgehou op 'n daaglikse basis. 'n Gevallestudie ondersoek die enorme hoeveelheid data en verslae wat outomaties bestuur word. Dit beklemtoon die behoefte aan 'n omvattende energiebestuur informasiestelsel.

1 INTRODUCTION

Energy is expensive around the world; and in South Africa, electricity prices have increased dramatically in the last decade [1–4]. This has placed considerable pressure on industries to monitor their electricity consumption and implement initiatives to reduce their electricity costs [4–6].

Effective energy management requires comprehensive monitoring of energy consumption. Therefore, energy should be measured at as many nodes as possible, to determine which consumers are using energy inefficiently. However, to measure the electricity consumption at each node requires expensive additional infrastructure, if it is not already installed. Fortunately, high level electricity data is freely available in the form of electricity bills (invoices). Electricity bills contain a lot of information that can provide valuable insights to assist with energy management efforts [7].

Electricity bills, as a feedback instrument, are a form of indirect feedback, as it is only available some time after the energy has been consumed. The energy savings potential for indirect feedback is consequently not as large as direct feedback, if it is readily available. Darby investigated studies on indirect feedback that showed that domestic consumers can save up to 19 per cent on their electricity bill, using indirect feedback [8]. Although savings levels were not as high as for direct feedback, indirect feedback has been shown to increase the interest and awareness of consumers [8].

The problem for large electricity consumers is that bills are sent to the finance department. The actual electricity consumers on the ground do not always get a view, or any other detail, of their consumption. Therefore consumers do not necessarily grasp the cost implications of their actions. When energy information is available, awareness increases. Furthermore, a substantial amount of additional information is included in the bills, which might be of no interest to the finance department, but which can offer valuable insights to the consumer, engineer, or manager on the ground. Consumers also rarely see a holistic view of the company's electricity consumption, which could give them a better understanding of how their actions affect the company.

Large energy consumers, unlike most typical energy users, face an additional challenge — the scale of their operations, with most large energy users having multiple points-of-delivery (POD) where electricity is provided to the user. This complicates the bill analysis of these consumers by increasing the factors that must be considered. Therefore, a system that automatically analyses the electricity data on a company-wide scale is needed.

As stated, valuable insight can be gained from the information provided in electricity bills. The aim of this work is to develop a method to analyse electricity bills automatically, and provide information from which insights can be gained, to reduce electricity consumption and cost.

2 METHOD

The method explained here is for the electricity bills issued by Eskom, the main electricity supplier in South Africa. Many large industries in South Africa receive electricity bills directly from Eskom. Each bill has one account number and one or more premise numbers for each measuring point or point-of-delivery (POD). Essentially, several PODs can be grouped together in one account. In an Eskom bill, there is also a summary page containing the total energy and cost data for the account (sum of all PODs), and one page for each POD containing more detailed electricity consumption information. While this method is specific to Eskom bills, the underlying method can be applied to bills issued by any electricity supplier.

The process is divided into the following main steps:

1. Data retrieval
2. Data linking and organisation
3. Data analysis and presentation

2.1 Data retrieval

The data retrieval process is automated, from receiving the bills from Eskom to extracting data from each bill and storing it in a centralised database.

<u>Document collection</u>
Original PDF documents (bills) are emailed directly from Eskom to a designated mailbox. If the method is used for multiple clients, each client group will have their own email address to which their electricity bills are sent. An energy management information system (EMIS) monitors the mailboxes for new data in five-minute intervals. If an email containing a bill is found, the bill is downloaded to a predefined folder, to extract the text within the PDF, before the next step is taken.

Data extraction

The PDF text is processed using regular expression patterns to find and extract detailed information. A ‘regular expression’, in computer science, is a sequence of symbols and characters expressing a string or pattern to be searched for within a longer piece of text. All billing items are extracted as single data points with identifying characteristics. (The different types of data will be discussed in detail in section 2.2.) Overall, it is possible to have more than 45 different parameters that could be captured from different PODs with different tariff structures. A typical POD on a Megaflex tariff structure has about 36 different parameters available over a 12-month period.

Data storage

Each data point (referred to as a ‘data tag’) is stored in a centralised relational database. Each tag has identifying characteristics linked to it. For example, each tag will be linked to the specific POD and specific data type, such as total energy cost, peak energy cost, and off-peak energy cost.

2.2 Data linking and organisation

To analyse the electricity data in a better way, it is organised into a logical structure. Figure 1 below shows an example of how the electricity bills are organised. Each POD is referred to as a system (level 3). Each account (level 2) is also referred to as a system, and is the sum of all the underlying systems (or PODs). Finally, all the systems can be grouped to get a ‘top’ system, which represents the entire client group (level 1).

As mentioned earlier, each tag is linked to the specific POD and specific data type. For example, in Figure 1, the tag with the name ‘POD A1 Admin charge’ is linked to the data type ‘Admin charge (R)’ and to the corresponding system ‘POD A1’. This way it will be easy to cross-reference the values of a specific data type for all the PODs.

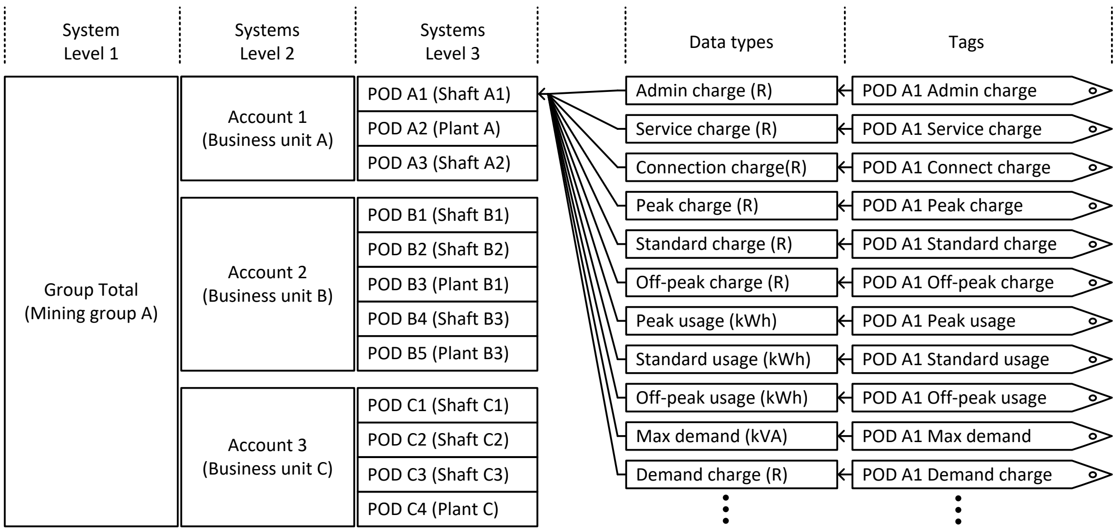

Figure 1: Structural example of data linking and organisation

Each system also has an alias by which it is better known. For example, in Figure 1, POD A1 is better known as ‘Shaft A1’. It sometimes happens that the name of a mine or shaft is changed; but these name changes are not always updated at Eskom. The system therefore allows for name changes, making it easier to understand what data is presented.

2.3 Data analysis and presentation

After the data has been collected and organised, it is analysed and presented in a meaningful way. This section describes the methods used to analyse and present the data. The way data is organised, as shown in Figure 1, makes it possible to analyse the electricity cost and usage for the entire group, each account individually, as well as each POD individually. This is valuable because different shafts, plants, or factories within the same group can now be benchmarked and their electricity costs and consumption compared.

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2.3.1 Monthly electricity costs and usage

The actual electricity cost and usage data are compared with a cost and usage budget. Equation 1 shows how the value of a specific parameter x (for example, total electricity cost) for a specific month m is calculated for an account. In the equation, POD_{mxi} indicates the value of parameter x for POD i in the electricity bill for month m. Consequently, Equation 2 shows how the value of a parameter for the entire group is calculated.

$$Acc_{mx} = \sum_{i=1}^{p} POD_{mxi} \qquad \textbf{Equation 1}$$

$$Grp_{mx} = \sum_{i=1}^{a} Acc_{mxi} \qquad \textbf{Equation 2}$$

$m = month\ index$
$x = parameter\ index$
$p = number\ of\ PODs\ in\ an\ account\ (Acc)$
$a = number\ of\ accounts\ in\ the\ group\ (Grp)$

The budget is usually determined beforehand by the client. (How it is calculated is not part of this study.) The actual and budget data are displayed for a 12-month period giving an overview of monthly performance. An example of this is given in section 3.1.

2.3.2 Electricity cost and usage breakdown by consumer

Electricity cost and usage per consumer is calculated and compared. The comparison can be done on the top level, giving the cost and usage breakdown of all the accounts. Equation 1 (above) is used to calculate the values for each account. The comparison can also be done on the account level, giving the breakdown of the PODs of the selected account. The proportional costs and usages are displayed in pie-charts, making it possible to identify any outliers. If there is a large difference between the proportional cost and the usage of a specific consumer, it may warrant further investigation. An example of this is given in section 3.2.

2.3.3 Electricity charges breakdown

Detailed electricity charges for a 12-month period are analysed. On the account level, Equation 1 is used to calculate the total of each charge parameter for each month in the 12-month period. The total of the parameter for the 12-month period is simply the sum of all the months. Similarly, on the group level, Equation 2 is used to calculate the total of each charge parameter. A 12-month period is used for this analysis, as not all the different charges are applicable every month. Potential opportunities to reduce costs can be identified by looking holistically at all the charges. An example of this is given in section 3.3.

2.3.4 Electricity cost inflation

Potential electricity cost inflation for the next five financial years is calculated and displayed. In recent years, Eskom has increased electricity tariffs every year on 1 April. The confirmed average increase for each year is stored in the database. The estimated annual increases for the next five years are determined by calculating the average confirmed increase over the previous five years.

Table 1 shows an example of future electricity cost inflation. The electricity cost for the last complete financial year is calculated. In this example, the actual cost for the 2016 financial year is R1 000 000. For 2017, the inflated cost is calculated by increasing the actual cost for 2016 by the confirmed 2.2 per cent for 2017. The inflated costs for the years that follow are calculated by increasing the inflated cost of the previous year by an estimated 8.06 per cent. In this example, the electricity cost in the 2022 financial year will be more than 50 per cent higher than in the 2016 financial year.

The way the data is organised (shown in Figure 1) makes it possible to analyse the electricity cost inflation for the entire group, for each individual account, and for each POD. An example of this is given in section 3.4.

Table 1: Calculation example of future electricity cost inflation

Financial year	*Actual cost*	*Cost increase*	*Inflated cost*
2016	R 1 000 000	-	-
2017	-	2.20%*	R 1 022 000
2018	-	8.06%**	R 1 104 373
2019	-	8.06%	R 1 193 386
2020	-	8.06%	R 1 289 573
2021	-	8.06%	R 1 393 512
2022	-	8.06%	R 1 505 829
* Confirmed electricity cost increase ** Average of last five confirmed increases (2013-2017)			

2.3.5 Time-of-use breakdown

Electricity cost and usage for each time-of-use period are compared. The time-of-use consumption data is displayed for each month, which makes it possible to identify opportunities for tariff optimisation strategies by implementing load-shifting initiatives. A normalised electricity usage value is also calculated for electricity usage for each time-of-use period. This is done to understand better the time-of-use breakdown of the total energy used during each month. The peak time-of-use period in the high season is weekdays between 6am-9am and 5pm-7pm. During low season, the peak time-of-use period is weekdays between 7am-10am and 6pm-8pm. Around 14 per cent of the hours in a year fall in this peak time-of-use period. Therefore, if the peak energy used during a month is more than 14 per cent of the total energy used, there is probably potential to improve the time-of-use energy consumption.

To calculate this value, the proportion of hours in a year for each time-of-use period is first calculated. For the peak and standard periods, the proportions are around 14 per cent and 36 per cent respectively. Thereafter, the proportional monthly energy (PME) for the month can be calculated for each time-of-use period, using Equation 3. Time-of-use cost data is also displayed for each month, together with the sum of all the other charges. By using Equation 1 and Equation 2, it is possible to analyse the time-of-use breakdowns for the entire group, for each individual account, and for each POD. An example of this is given in section 3.5.

$$PME_{ti} = E_i \times H_t \qquad \textbf{Equation 3}$$

$t = time\text{-}of\text{-}use\ period\ (Peak/Standard/Off\text{-}peak)$
$E_i = total\ active\ energy\ for\ month\ i\ (kWh)$
$H_t = yearly\ proportion\ of\ hours\ for\ period\ t\ (\%)$
$PME_{ti} = Proportional\ Monthly\ Energy\ for\ month\ i, period\ t\ (kWh)$

2.3.6 Maximum demand

The maximum demand information can be used to identify potential risks or opportunities. If the margin between the measured maximum demand and the notified maximum demand becomes small, the consumer runs the risk of exceeding the notified maximum demand and thus paying additional charges. In contrast, the maximum demand information can also identify potential opportunities to reduce the cost of the notified maximum demand. If the margin between the notified maximum demand and the measured maximum demand remains constantly large, the consumer can consider lowering the notified maximum demand to reduce these costs.

The average notified maximum demand and measured maximum demand are calculated for a 12-month period. With these values, the average margin is calculated as a percentage, shown in Equation 4 below. The measured maximum demand and notified maximum demand are also displayed for those 12 months. If the margin is relatively constant, the consumer can consider lowering the maximum demand to save costs.

$$MD_{margin} = \left(1 - \frac{\sum_{i=1}^{12} MD_i}{\sum_{i=1}^{12} NMD_i}\right) \times 100 \qquad \textbf{Equation 4}$$

$MD_i = measured\ maximum\ demand\ for\ month\ i\ (kVA)$
$NMD_i = notified\ maximum\ demand\ for\ month\ i\ (kVA)$

2.3.7 Reactive power and power factor

Consumers are only charged during the peak and standard periods of the high season for reactive energy consumption. This charge is only applicable if the reactive energy during a 30-minute period is more than 30 per cent of the active energy, which implies a power factor below 0.96 [3]. Reactive energy can be reduced by installing power factor correction systems (capacitor banks). It is therefore imperative that these systems work correctly during the high season months.

The excess reactive energy consumed during a billing period is, however, only available in the electricity bill during the high-season period when the charge applies. Fortunately, the actual reactive energy for each time-of-use period is available in every electricity bill; the same applies to the active energy for each time-of-use period, which means that the average power factor for each billing period can be calculated. Equation 7, used for calculating the power factor, is derived from Equation 5 and Equation 6. The active, reactive, and apparent powers in the equations can be replaced with the active, reactive, and apparent energies, because they are measured over the same period.

$$pf = \frac{P}{S} \qquad \textbf{Equation 5}$$

$$S^2 = P^2 + Q^2 \qquad \textbf{Equation 6}$$

$$\therefore pf = \frac{P}{\sqrt{P^2 + Q^2}} \qquad \textbf{Equation 7}$$

$pf = power\ factor$
$P = active\ power\ (kW)$
$S = apparent\ power\ (kVA)$
$Q = reactive\ power\ (kvar)$

3 RESULTS

The method was implemented at a South African gold mine. The mine has 45 PODs divided into seven accounts, each of which is sent to a designated email address every month. The EMIS downloads these emails and extracts the data using regular expressions. The data is stored in a centralised database as tags, which are linked to systems, as described in Section 2.2. The sections that follow show some of the data that is available on the EMIS and that can be used by energy management personnel to make informed decisions.

3.1 Electricity costs and usage

Figure 2 shows a monthly electricity cost comparison for the entire group. The values of all the underlying PODs are summed to generate the information in this figure. The figure also displays the budgeted electricity cost for each month. It is therefore possible to track the electricity costs for the entire mining group, compared with the monthly electricity budget. As seen from Figure 2, the months of April to June show a large reduction in electricity cost compared with the budget. This can indicate that less energy than expected was consumed, or that a higher electricity tariff increase was expected for April 2017, or a combination of both.

Figure 3 shows the monthly electricity usage comparison for the entire group. The values of all the underlying PODs are summed to generate the information in this figure. The figure also displays the budgeted electricity usages for each month. It is therefore possible to track the electricity usage for the entire mining group compared with the monthly electricity budgets. As seen from Figure 3, the months of March to June show a large reduction in electricity usage compared with the budget. Comparing Figure 3 and Figure 2, it can be argued that a higher electricity tariff increase was expected from April 2017, compared with the actual average increase of 2.2 per cent. Future budgets can now be adapted with the actual increase that was given, to ensure accuracy.

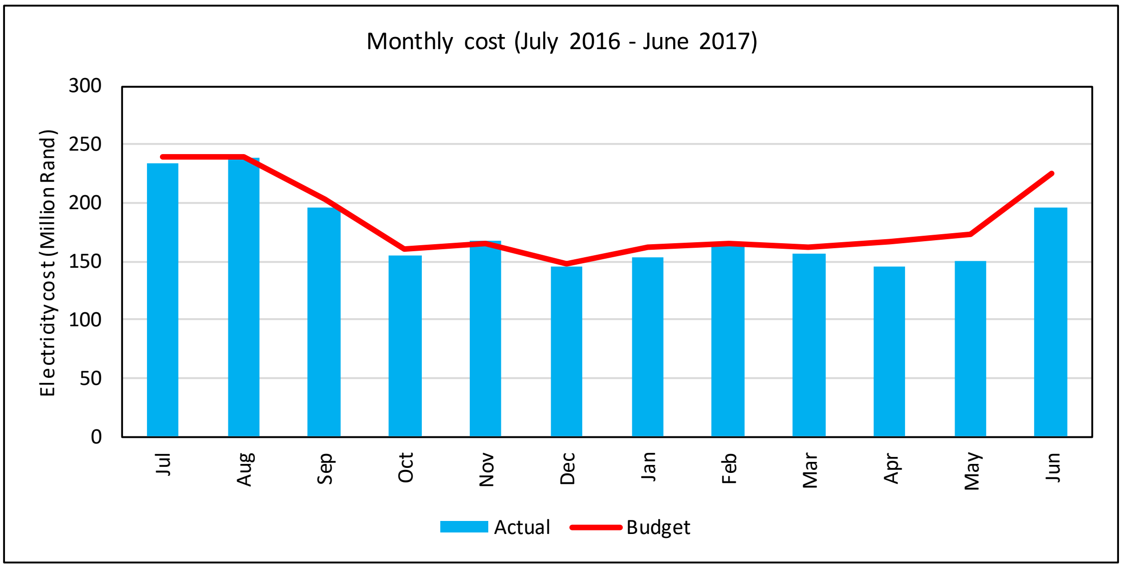

Figure 2: Monthly electricity cost comparison

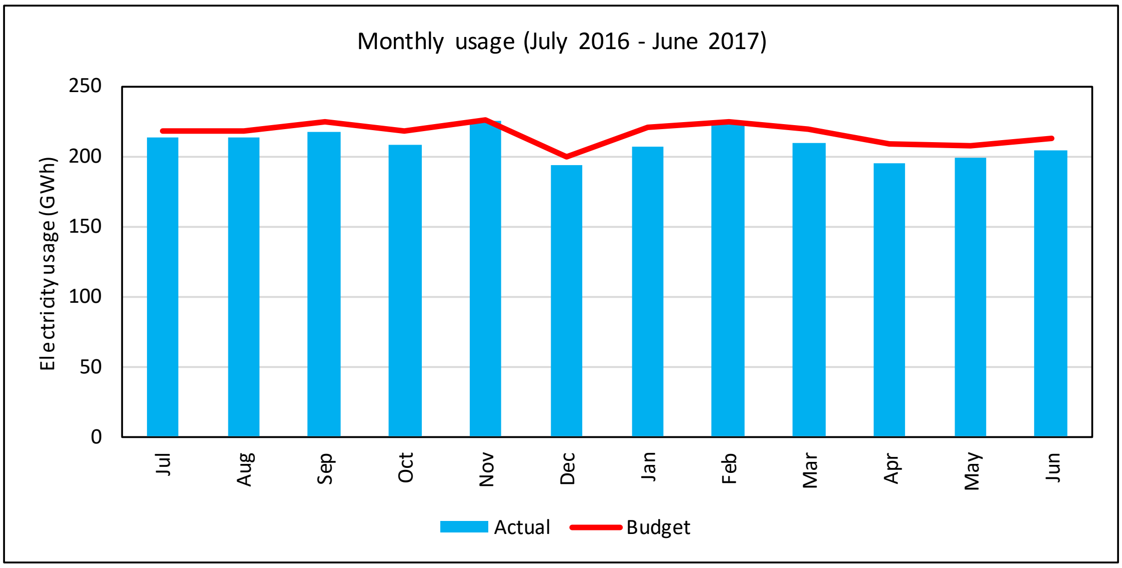

Figure 3: Monthly electricity usage comparison

3.2 Electricity cost and usage breakdown by consumer

Figure 4 shows the electricity cost and usage breakdown of all the accounts over a 12-month period. From this figure, it is easy to identify which consumer has the highest electricity cost and who consumes the most electricity. In this example, the electricity cost and usage of the accounts correlate relatively well — meaning the more electricity consumed, the higher the electricity cost. This figure will make it possible to identify a system that consumes proportionately less or more energy than the electricity cost. This is possible due to the consumer being on a time-of-use tariff structure that allows different energy pricing at different times of the day. The results from Figure 4 indicate that the business units are making similar use of their time-of-use tariff structures. Section 3.5 will show how it is possible to investigate whether this is the best use of the tariff structure.

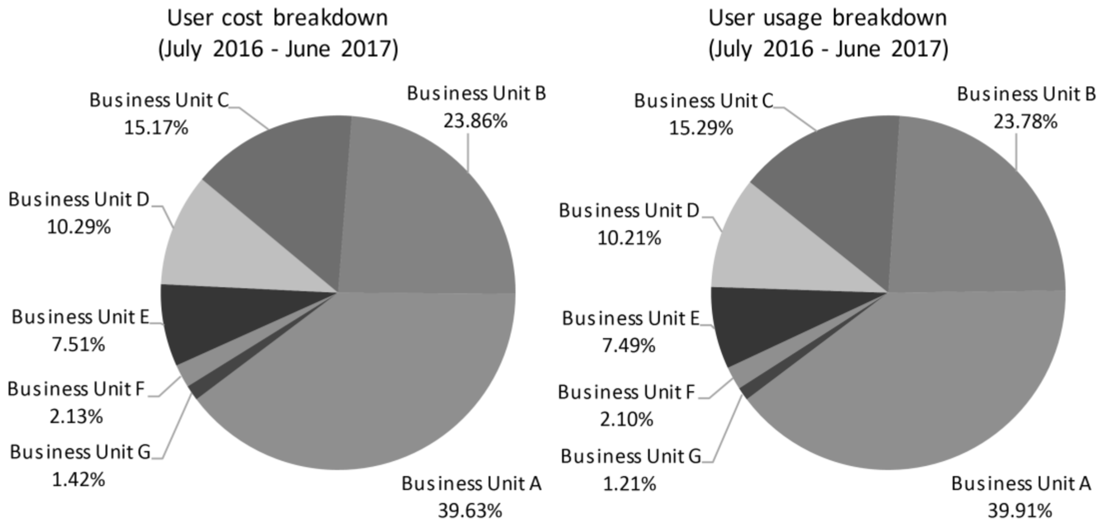

Figure 4: Electricity cost and usage breakdown per consumer

3.3 Electricity charges breakdown

Figure 5 shows a breakdown of all the electricity charges for a 12-month period for the entire group. The values of all the underlying PODs are summed to generate the information in this figure. From this figure, it is apparent that the active energy costs are about 75 per cent of the total electricity cost. It is also interesting to note that the cost of electricity during peak hours in the high season is higher than in the low season, even though there are only three months in the high season and nine months in the low season. This indicates to the energy manager that there is still potential for cost savings by implementing load shifting initiatives, to move electricity usage out of the peak periods, especially during the winter months.

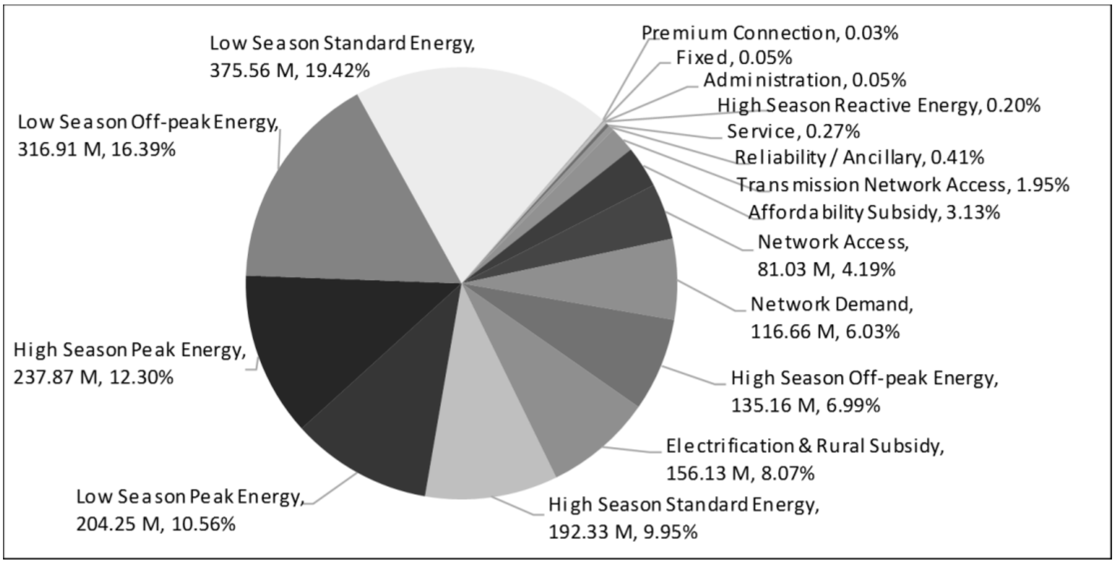

Figure 5: Electricity charges breakdown for a 12-month period

3.4 Electricity cost inflation

Figure 6 shows what effect electricity cost inflation will have on the annual electricity cost of the mining group. Using the 2016 financial year as a base, the inflation for subsequent years is calculated. For 2017, the cost inflation of 2.2 per cent is already approved. The cost inflation for the next five years is estimated by calculating the average electricity cost inflation of the last five known annual increases. In this case, this is 8.06 per cent. The figure shows that the mining group's electricity costs will increase from about R2 billion in 2016 to R3 billion in 2022. This can be used to determine electricity budgets for the future.

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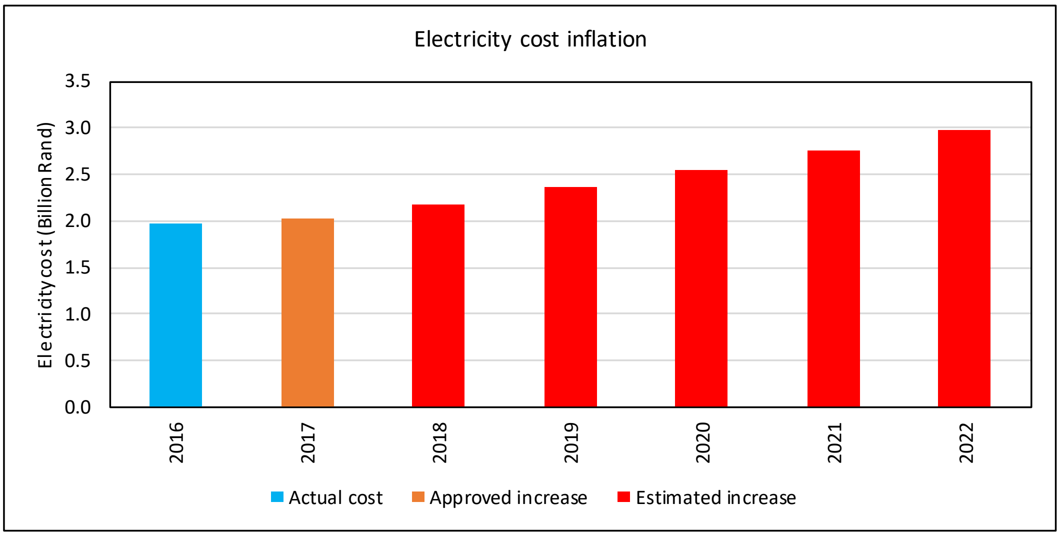

Figure 6: Electricity cost inflation estimated for next five years (see online version for colour image)

3.5 Time-of-use breakdown

Figure 7 shows the monthly usage time-of-use breakdown for an individual POD. As explained in section 2.3.5, the proportion of hours in a year for each time-of-use period is calculated. For the selected period in these figures (May 2016 – April 2017), the peak and standard proportions are 14.3 per cent and 36.2 per cent respectively. Using Equation 3, the proportional monthly energy (PME) for the peak and standard periods is calculated for each month, and is displayed in Figure 7. As seen in the figure, the actual peak energy usage for August, September, and October is very close to the PME, which can indicate poor performance of existing load shifting initiatives. November and February might look better compared with the peak PME, but this is marred by the high amount of total energy consumed. April is the best performing month, with low total consumption and better performance of PME. These results indicate that there is potential scope for energy cost optimisation by using less energy during peak periods.

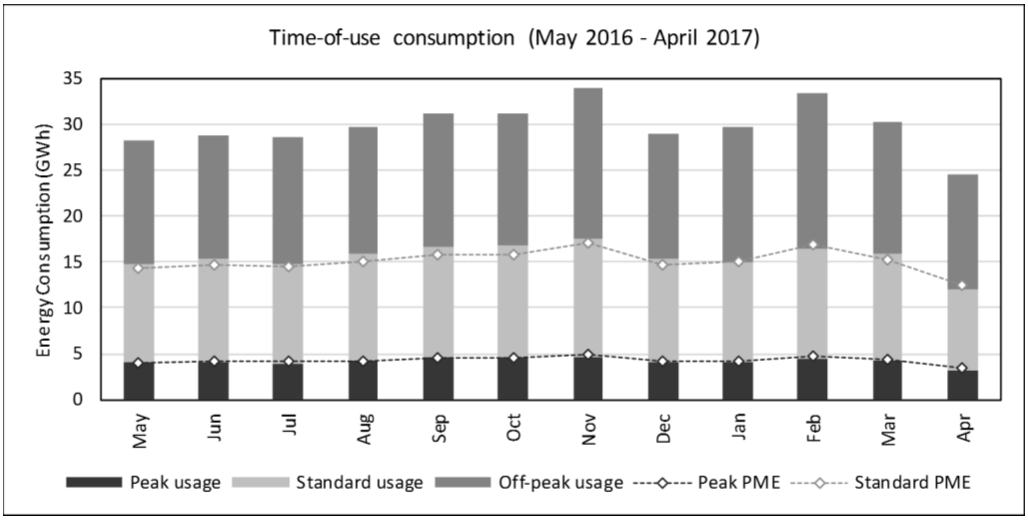

Figure 7: Electricity usage time-of-use breakdown

Figure 8 shows the electricity cost time-of-use breakdown for the same POD and period as in Figure 7. As expected, the peak periods in the high season months (June – August) are much more expensive and have a large effect on the total electricity costs for these months. June is lower than the other high season months, as its billing period includes days in the low season month of May. Similarly, September is higher than other low season months as its billing period includes days in the high season month of August. The cost effect of the improved time-of-use in April is also clearly visible in this figure.

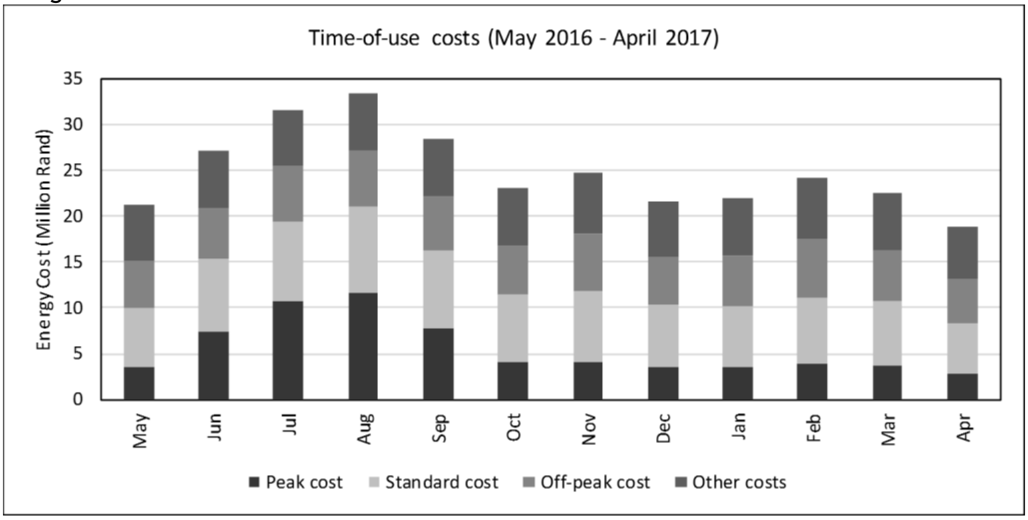

Figure 8: Electricity cost time-of-use breakdown

3.6 Maximum demand

Figure 9 shows the notified maximum demand and actual maximum demand figures for a 12-month period, compared with the costs related to the notified maximum demand of an individual POD. On 1 April 2015, the electricity tariffs increased, with a concomitant increase in demand costs. For this POD, the costs in April are lower than in May, as the April billing period was from 21 March to 18 April and so was charged at two different rates. If there is a large difference between the notified and the measured maximum demand, there is potential scope to decrease costs by decreasing the notified demand. Conversely, if there is very little difference between the notified and the measured demand, this indicates that there is a risk of exceeding the notified demand and paying a penalty. This risk can then be mitigated by increasing the notified demand and/or reducing the measured maximum demand.

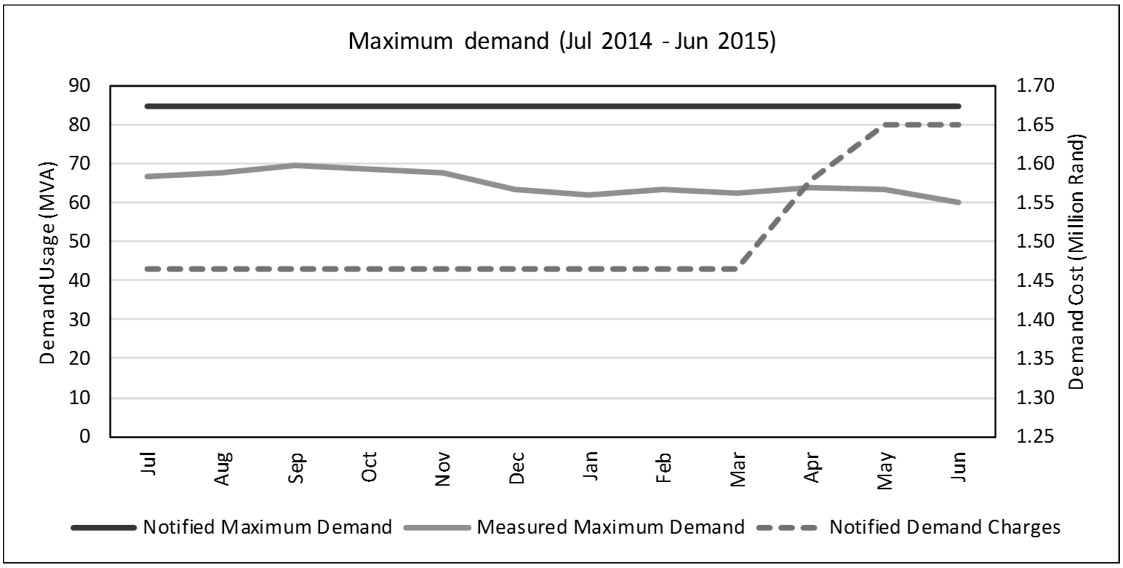

Figure 9: Notified maximum demand vs measured maximum demand

For the first six months, up to December 2014, the notified maximum demand for the mine was 84.66 MVA, while the average measured demand was 67.12 MVA. This means that there was a 'safety' margin of 20.7 per cent (17.54 MVA). For the last six months, from January 2015, the average measured maximum demand was 62.45 MVA, which means a margin of 26.2 per cent (22.21 MVA). If the notified maximum demand is reduced to 72 MVA (13.3 per cent margin), it will reduce the

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demand costs from R1.65 million in June 2015 by R246 743 per month. That is an annual cost saving of R2.96 million.

3.7 Reactive power

As mentioned in the method, consumers are only charged during peak and standard periods in the high season for reactive energy consumption. Figure 10 shows the average power factor per time-of-use period of an individual POD. The average costs of R132 687 (blue line), charged during the high-season months (June – August), are also displayed on the secondary axis. The dramatic decline in the average power factor from February is important to note in this example. This large decline will have an adverse effect on the reactive energy charges in the upcoming high season starting in June 2017.

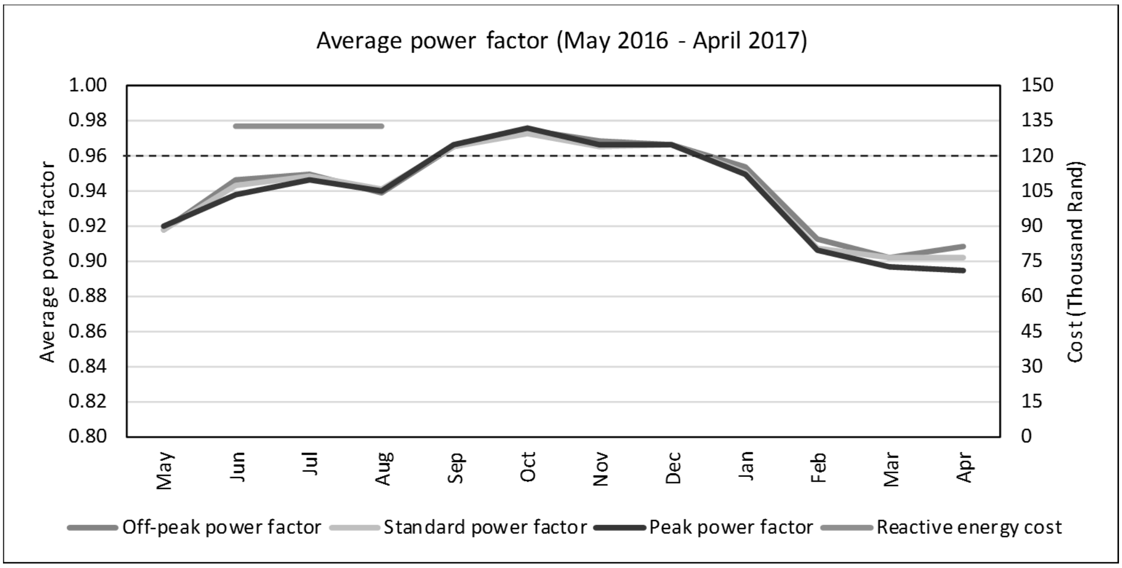

Figure 10: Average power factor per time-of-use period

3.8 Discussion

As seen from the results, various insights can be gained by analysing data gathered from electricity bills. Automated electricity bill analysis can easily be used as a tool to increase cost awareness. The consumers can see how their actions and decisions impact the consumption and costs involved, not only for a specific POD, but also for the entire company. Furthermore, automation can help minimise typical inaccuracies found in manual processes. However, automated bill analysis is only likely to be beneficial once there are multiple PODs and the analysis becomes more complex. As the number of PODs increases, the value of automated bill analysis also increases, due to the time that would be required to analyse the bills manually.

A few recommendations can be made about the analysis and presentation of data. The electricity cost inflation analysis can be adapted to use data from the previous 12 months, instead of the previous financial year. This way, the inflation risk will update every month as new electricity bills are processed. For the time-of-use analysis, the exact number of hours for each time-of-use period in a month should be used to calculate the monthly proportional energy, which will improve the accuracy of this analysis. Finally, an estimated cost risk for reactive power can be calculated and presented, based on the average power factor.

4 CONCLUSION

Increasing electricity prices puts a lot of strain on the profitability of industries in South Africa. This makes effective energy management vital for the survival of these industries. Although detailed energy measurements are ideal for energy management, a lot of information that is available in monthly electricity bills is also valuable for energy management. Some companies have large numbers of points-of-delivery, which makes it difficult to analyse all the data in the electricity bills. A need was therefore identified for an automated system that analyses electricity bills on a monthly basis.

A method was developed for an automated system to collect the electricity bills from the electricity utility company for various consumers. The data from these electricity bills was extracted using regular expression patterns. The data was then organised to enable the users of this system to extract valuable insights from the information provided, at various levels of the organisation. This is especially valuable for companies with numerous points-of-delivery. Analyses are done on various types of data found in an electricity bill, including total cost and usage, reactive energy, maximum demand, and time-of-use.

The system was implemented for a gold mining group with 45 different points-of-delivery. From the resulting data, various insights were gained. For example, the company's risk due to further electricity cost inflation is roughly R1 billion in 2022. A specific mine shaft can reduce the cost of notified maximum demand by as much as R2.96 million per year. The same shaft is also at risk of an increase in reactive energy charges in the high season, due to a dramatic decline in the power factor.

ACKNOWLEDGEMENT

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REFERENCES

[1] **Goosen, P.**, **Swanepoel, J.A.** and **du Plessis, J.N.** 2016. The need for a comprehensive energy management information system for industries, *South African J. Ind. Eng.*, 27(3), pp. 1–11.

[2] **Van der Zee, L.F.**, **Pelzer, R.** and **Bolt, G.** 2014. Quantification of optimal electricity cost risk reduction for a South African gold mining company, in *Proceedings of the Conference on the Industrial and Commercial Use of Energy, ICUE*, pp. 1–9.

[3] **Goosen, P.**, **Pelzer, R.** and **du Plessis, H.J.** 2015. A method for accurate electricity budget cost calculations for a deep mine, in *Proceedings of the Conference on the Industrial and Commercial Use of Energy, ICUE*, pp. 155-160.

[4] **Bredenkamp, J.I.G.**, **Schutte, A.J.** and **van Rensburg, J.F.** 2015. Challenges faced during implementation of a compressed air energy savings project on a gold mine, in *Proceedings of the Conference on the Industrial and Commercial Use of Energy, ICUE*, pp. 23-29.

[5] **Engles, J.**, **van Jaarsveld, S.** and **van Heerden, S.W.** 2016. Cost effective control of a platinum mine cooling system using combined DSM strategies, in *Proceedings of the Conference on the Industrial and Commercial Use of Energy, ICUE*, pp. 128-132.

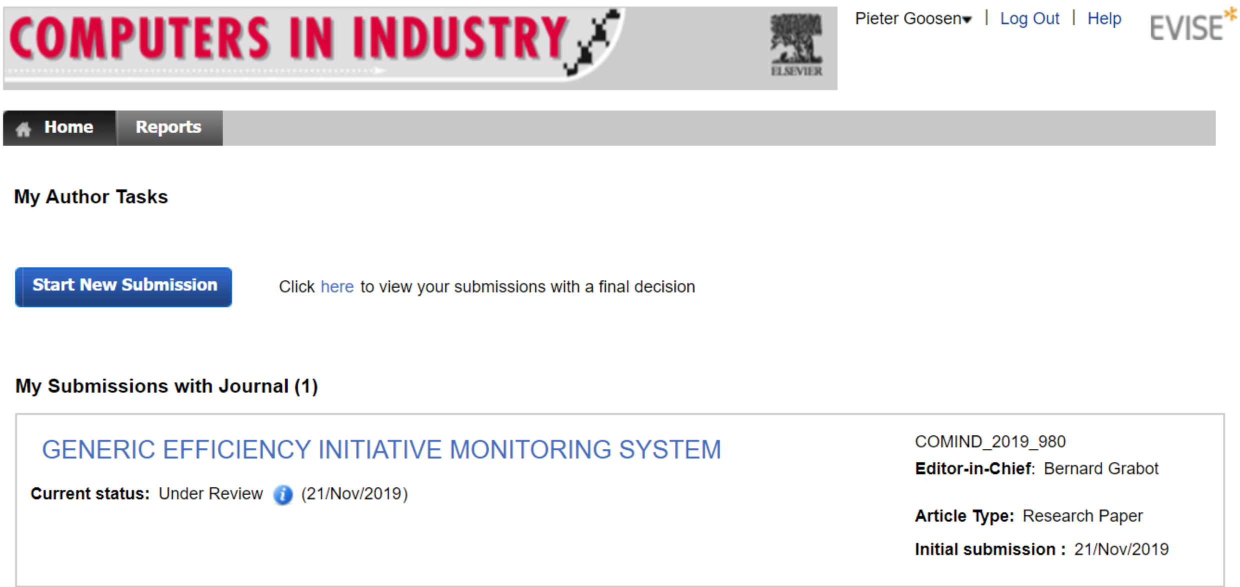
[6] **Deysel, J.A.**, **Kleingeld, M.** and **Kriel, C.J.R.** 2015. DSM strategies to reduce electricity costs on platinum mines, in *Proceedings of the Conference on the Industrial and Commercial Use of Energy, ICUE,* pp. 89-96.

[7] **Moran, A.**, **Fuertes, J.J.**, **Dominguez, M.**, **Prada, M.A.**, **Alonso, S.** and **Barrientos, P.** 2013. Analysis of electricity bills using visual continuous maps, *Neural Comput. Appl.*, 23(3–4), pp. 645–655.

[8] **Darby, S.** 2000. Making it obvious: Designing feedback into energy consumption, in *Energy Efficiency in Household Appliances and Lighting*, pp. 685-696.

D. Article 3 – Generic efficiency initiative monitoring system

Title:	Generic efficiency initiative monitoring system
Journal submitted:	Computers in Industry
Status of article:	Under review
Journal guidelines:	See Appendix F



GENERIC EFFICIENCY INITIATIVE MONITORING SYSTEM

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ABSTRACT

The mining industry is striving to become more efficient amongst increasingly difficult economic conditions. This has become evident in the uptake of more energy and water efficiency initiatives and projects to save on the costs and limit their environmental impact. However, these efficiency initiatives have been shown to reduce in effectiveness over time if there are no overarching management strategies and systems in place to manage them. This study showed the need for a generic system to monitor various types of efficiency initiatives. A system was designed based on the ISO strategic framework of Plan-Do-Check-Act which ensures that the management and sustainability of initiatives are emphasised. The system consists of three major components, a data management system, an efficiency initiative monitoring system and a graphical user interface for end users. The system was implemented on 24 different mining sites and 81 different efficiency initiatives were recorded. The system showed positive performance in terms of its capability to monitor a large array of efficiency initiatives with minimal setup time. Survey results of users confirmed that the user experience was intuitive and that users felt the system was generic in the ability to setup and configure various types of efficiency initiatives. There was some concern regarding the verification of data, which could be addressed by conducting data checks and validation based on existing techniques. In conclusion, the system is a unique starting point to manage various efficiency initiatives which will be critical for the mining industry to continue to be sustainable.

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1. INTRODUCTION

Industries need to operate efficiently to stay competitive. In recent years the operational costs of the mining industry in South Africa have increased as mining depths have started exceeding 3km underground [1, 2]. This means that mines are losing their competitiveness. A study by Neingo [3], identified various challenges for South African gold mines, including: instability of commodity prices, declining ore grades, depth of mines, labour issues, environmental-, social- and political issues and increased production costs. The major production costs are labour, energy and water, accounting for more than 50% of the operating expenses of a typical gold mine [2, 4, 5]. Furthermore, the intensive use of natural resources in terms of energy and water also has a significant negative environmental impact [5].

The direct cost of these resources has also been growing substantially. Energy costs in South Africa have increased rapidly in recent years [6–8]. Since the electricity crisis in 2008, South Africa's electricity tariffs have increased 6 times more than the consumer price index over the same period [9]. Water usage by South Africa's largest gold mining company was in excess of 54 ML water of which 18 ML was purchased municipal drinking water at a cost of $23.6 million[1] [10]. In South Africa, as in many countries, water is a scarce resource and becoming more so [11, 12]. From an environmental and financial point of view, it is important to use water sparingly.

To address these issues mines and mining groups implement efficiency initiatives [2, 13–16]. An efficiency initiative, for the scope of this study, can be defined as an intervention to improve the efficiency of a system or operation focusing on water or electricity. These initiatives are often implemented and maintained by 3rd party efficiency services companies (ESCo's) [8]. In many cases the performance of these initiatives, however, deteriorates over time due to lack of monitoring and the initiatives not being maintained [17, 18]. Groenewald [17] showed that up to 70% of this deterioration could be mitigated by using performance-centered maintenance strategies based on the ISO 50001's plan-do-check-act (PDCA) cycle. Watson *et al.* [19] further highlights this concern in terms of the lack of uptake of information systems in environmentally sustainable development and illustrates the need for frameworks and information systems to aid mines with monitoring efficiency initiatives.

Various studies have addressed some of the underlying concerns regarding the monitoring and maintenance of energy projects [8, 20–22] and a few have addressed some concerns regarding water efficiency initiatives [12]. There are no studies however which offer a solution for the monitoring and maintenance of both energy and water efficiency initiatives concurrently. In order to determine the scope and need for this study a literature review was conducted to determine what form such a generic efficiency monitoring system should take in order to be effective.

Schulze *et al.* [20] did a systematic review of 44 journal publications on industrial energy management. From this comprehensive study, they developed a framework for integrative energy management. Similar to the proven plan-do-check-act cycle of ISO 50001 [2], their framework contains a feedback loop that enables continuous improvement. The feedback loop for continuous improvement is therefore an important aspect of maintaining savings initiatives.

A major part of the feedback loop is "checking", which includes: data collection, monitoring and reporting [21]. Therein lies the need for an automated information system to monitor the performance of efficiency initiatives. Such a system will make the maintenance of initiatives more efficient and sustainable. Literature describes numerous information systems which have been developed for different aspects of energy usage in industry. These systems vary from very specific applications such as on-line energy efficiency monitoring of machine tools [23] and real-time measurement and verification (M&V) [24] to energy platforms for entire industrial facilities [22].

The on-line approach proposed by Hu *et al.* [23] collects measurements automatically and monitors the real-time efficiency of machine tools although it does not have a historical database for in depth analysis nor is it adaptable to other uses. The real-time M&V solution of Ke *et al.* [24] tracks historical data and can be monitored via a web application, however it does not support reporting functionality required to complete the feedback loop identified by Shulze *et al.* [20].

More generic energy information systems such as the internet-of-things (IOT) based energy management platform described by Wei *et al.* [22] or the simulations of decentralised manufacturing (similar in complexity to mining) proposed by Ilsen *et al.* [25] are compelling but lack real-world implementation as well as the ability to develop, target and track specific efficiency initiatives. Zampou *et al.* [26] introduced a generic framework for energy-aware information systems in manufacturing based on the fundamental principles or energy monitoring and energy-aware analytics. These core principles could benefit the mining industry if implemented correctly.

The unique challenges facing the mining industry in terms of depth and complexity also provide substantial opportunity in the sense that installed equipment can have large rated capacities [15, 27] with a large mining group using up to 6 TWh of energy annually [10]. Therefore, small efficiency improvements can have drastic energy reduction benefits. This highlights the importance and relevance of energy information systems for sustainable development in the mining sector [19]. For example, a previous study presented a system that can

[1] US Dollar – Average exchange rate of 12.29 ZAR per USD (Jan. – Jun. 2018)

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efficiently monitor the performance of Demand Side Management projects on mines [18]. This system was very specific to a certain project type, however, and not generic nor adaptable to any other type of efficiency initiative. A reporting and monitoring system exists which can be used to gain insights into sustainable energy consumption in the industrial and mining sectors [28]. However, this system has not been developed to track efficiency initiatives and thus does not complete the feedback loop described by Shulze *et al.* [20].

Based on the limitations of existing systems in literature, a need exists for a generic system to monitor various types of energy efficiency initiatives. Such a system would be the start to remedying the concerns highlighted by Watson et al. in terms of the lack of uptake of information systems for sustainable production. Such an information system should automate the monitoring and performance tracking of efficiency initiatives to complete the feedback loop of the ISO 50001 PDCA cycle consistently, accurately and reliably. This will aid managers to continuously improve the performance of the efficiency initiative.

2. METHOD

Figure 1 shows a simplified diagram of the efficiency initiative monitoring system (EIMS). It forms part of a larger collection of hosted web services. An existing SQL database stores measured data as well as configuration data of the efficiency initiatives. Users interact with the system via a web graphical user interface (GUI). In the following sections, the components of Figure 1 is explained.

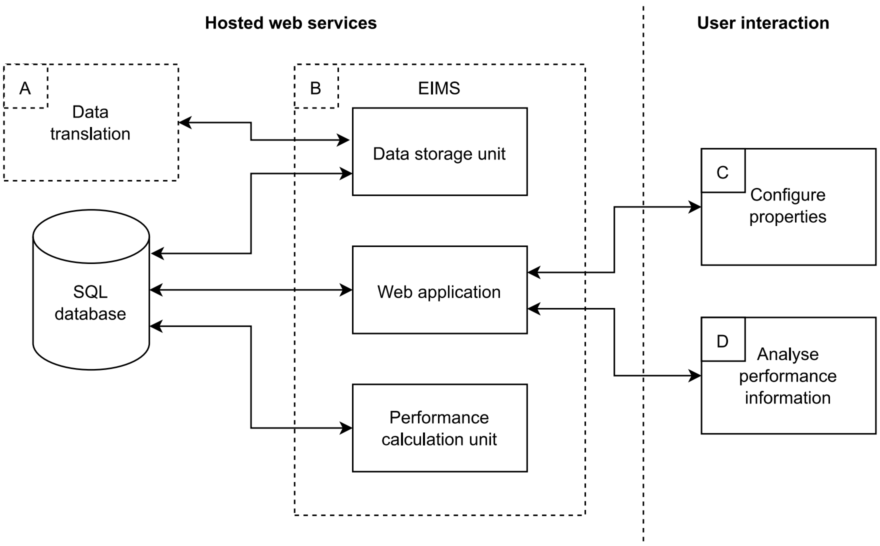

Figure 1: Simplified diagram of the efficiency initiative monitoring system

Data translation

The data translation unit (block A) processes data from various sources, usually with different data formats. The detail of the data translation unit is not in the scope of this study and is only summarised here. Each point of measurement or data object is referred to as a 'tag'. The tags in each data source are set up according to the file format of the source and the resolution of the data. It is then translated into a standard format, before it is sent to the data storage unit of the EIMS.

Data storage unit

Block B illustrates different components of the EIMS. Data received from the data translation unit is processed and stored in the relational SQL database. The storage unit also verifies the amount of data points per day of the received tags. This verification of information is used to easily identify missing data and indicate it to the user during analysis.

Configuration of properties

Users configure the properties of initiatives via the web application. The initiatives are designed to be as generic as possible. Various types of initiatives can be monitored with this system, provided it has a baseline (or budget) before the inception of the initiative and a target saving to achieve. Targets can either be positive or negative, meaning it can either reduce the baseline consumption by the target amount or exceed the baseline by a target amount.

3

Figure 2 shows a simplified illustration of the database design. The *Initiative* table is the core table storing the most basic information, for example the initiative name, description, start date and end date. The *Property* table links with a foreign key (fk) to the *Initiative* table, forming the composite primary key with the property type field. Various properties of an initiative are stored in this table, including the type of initiative and the stage of the initiative. If a specific property type changes, for example the stage of the initiative, a new entry is made in the property table. The start date of the new property automatically signifies the end date of the previous property for that specific property type.

The *Target* and *Baseline* tables work similar to the property table, in terms of start and end dates. It is linked to an initiative in the *Initiative* table with a foreign key. It contains a start date, and optional season and day-of-the-week fields. Targets and baselines can either be constant for the whole year and each day of the week or customised for specific months of the year and days of the week. Energy neutral scaling of baselines can be done automatically. Alternatively, if targets or baselines needs to be customised further, it can be done by importing custom data into tags, and not use the *Target* and *Baseline* tables.

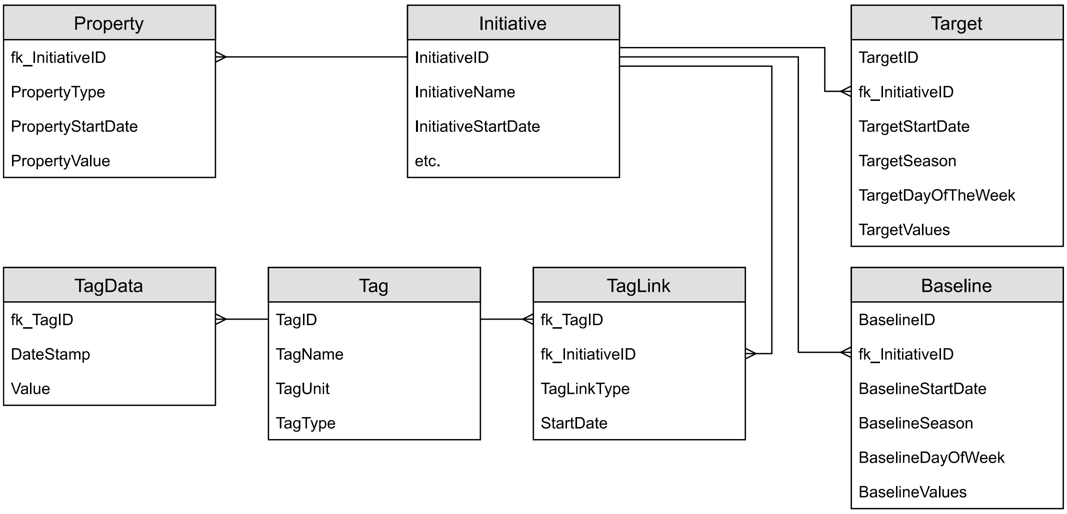

Figure 2: Database design (simplified)

As mentioned earlier, 'tags' represent data objects, for example, the energy consumption of a pump. Information regarding the pump tag is stored in the *Tag* table. For example, it will have a name 'Level 20 Pump 2 Power', a unit 'kWh' and a type which indicates the resolution of the data. Energy consumption tags typically have a resolution of 48 samples per day, that is, a single average value every 30 minutes. The values of each tag are stored in the *TagData* table. Each value is identified by the foreign key tag ID, and a time stamp field. These two fields form the composite primary key of the *TagDate* table. Initiatives are linked to tags via the *TagLink* table.

Performance calculations

The performance calculation unit is executed at set time intervals, for example every five minutes. Figure 3 shows a flow diagram of the performance calculation unit. It starts by collecting a list of initiatives from the database and iterating through each. For each initiative, information of its tags is collected from the database. The tags of each initiative are checked to see if it received new data since the last time the performance calculations have been performed.

If any tag of an initiative has new data, it is added to a processing queue together with the dates to process. The queue is a convenient step that enables manual processing. If a user wants to recalculate the performance of an initiative, the initiative is added to the queue. The steps to check for new data since last processed is bypassed by adding the initiative directly to the queue.

After all initiatives with new data have been added to the queue, the process steps through the elements in the queue to calculate the performance of each initiative. The properties and tag information of the initiative is collected from the database. Thereafter, the relevant tag data is collected for the dates to be processed. For each date the performance of the initiative is then calculated, and the results stored in database.

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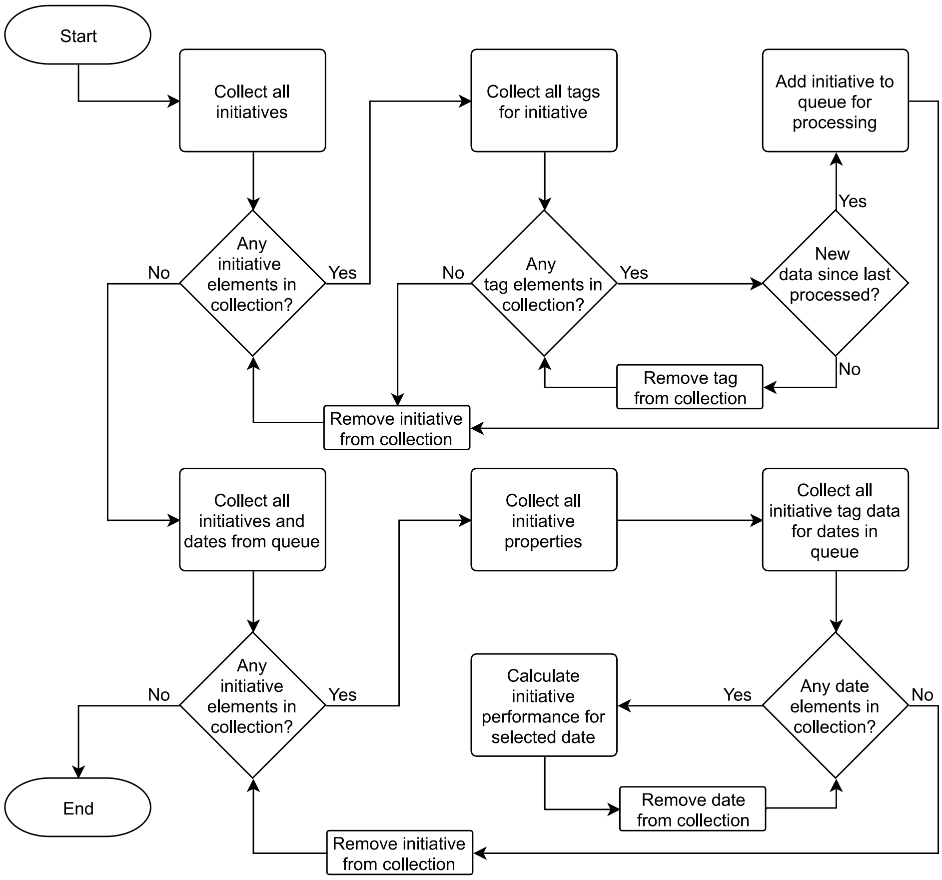

Figure 3: Performance calculation flow diagram

<u>Performance analysis</u>

Users can analyse the performance of efficiency initiatives on the web application. Various types of data visualisations are available which are listed below and explained in more detail in section 3. On a daily basis the performance of the initiatives is monitored by ESCo engineers. ESCo clients also have access to the system to monitor the initiatives implemented by the ESCo. The visualisations make it easier to get a holistic and detailed view of the efficiency initiatives.

Available types of visualisations:

- Monthly performance overview of all initiatives
- Daily performance overview of all initiatives (Figure 5)
- Daily performance detail for an individual initiative (Figure 6)
- Monthly performance detail for an individual initiative (Figure 7 and Figure 8)
- Cumulative performance analysis of all or individual initiatives (Figure 9)

The web application allows users to automatically create daily or monthly reports of the efficiency initiatives. Figure 4 shows an example of a monthly report. Depending on the remuneration agreement between the ESCo and the client, the performance of the initiative is agreed upon and signed off by both parties. The monthly report contains the necessary information for sign off.

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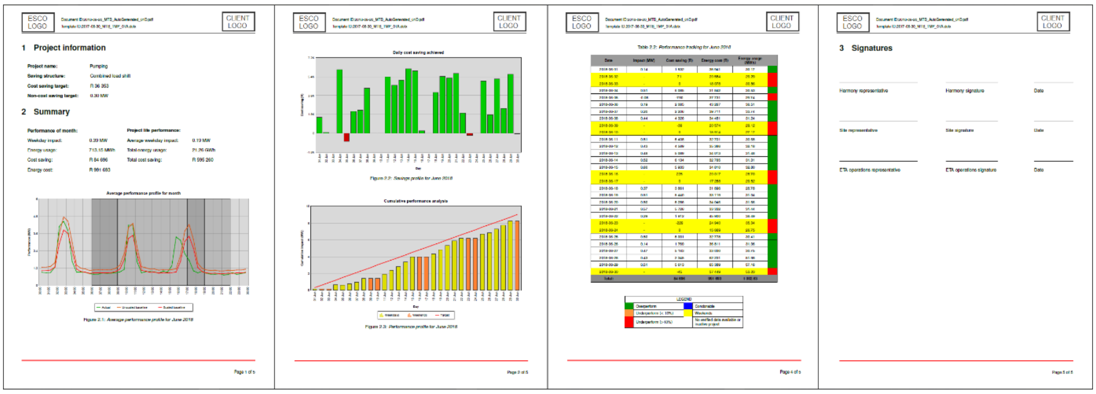

Figure 4: Monthly report

3. RESULTS

3.1 System verification

The system was implemented by an ESCo on a variety of client sites (24 sites, 81 initiatives). Client and ESCo personnel can analyse the performance of initiatives via the web application. Users are given access to specific sites and can only analyse the performance of those sites. Figure 5 shows an example of the daily performance overview accessible by a user. The performance of each initiative is indicated by colours. Green for over-performance, red for under-performance and orange for under-performance of less than 10%. Data-loss is either indicated in grey if no data is available for the entire day, or blue, if only some data points are missing for the day.

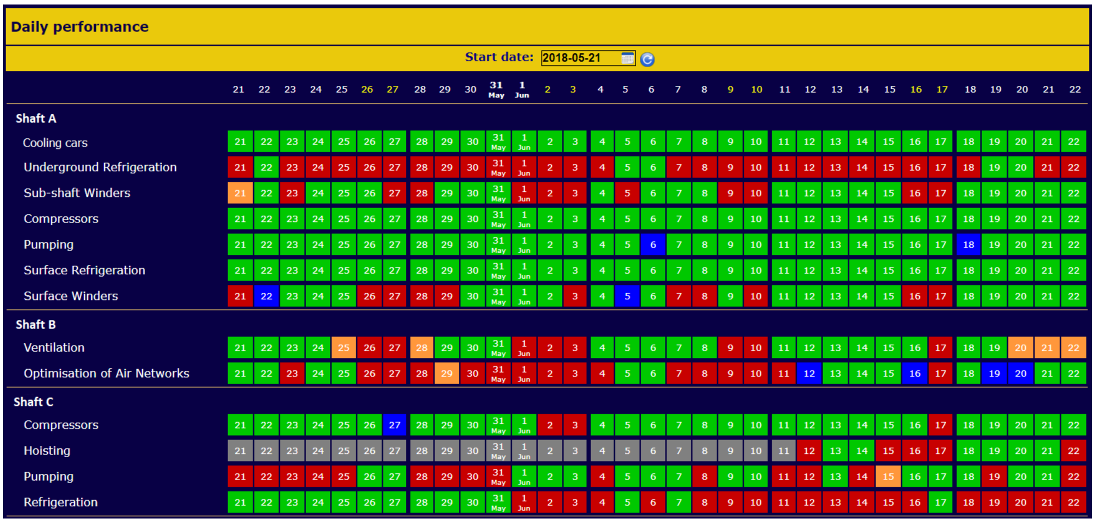

Figure 5: Daily performance overview of all initiatives accessible by a user

The user can further assess the detailed performance of a single day for a specific initiative. Figure 6 shows an example of this detailed performance analysis. In this example the initiative has a cost saving target of $2302 per day, but an actual cost saving of only $2212 was achieved. The non-cost saving target in this case implies an average electricity power reduction of 1 MW, but an actual average impact of only 0.91 MW was achieved. The performance of initiatives can also be viewed on a monthly basis and an example is shown later in Figure 7.

6

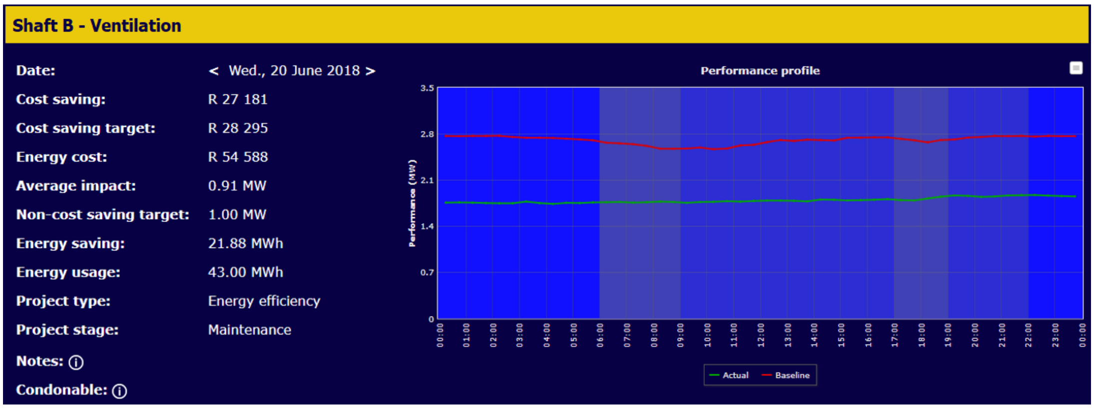

Figure 6: Performance detail for a single day

3.2 Case study 1 - Load shift initiative

The first case study is a load shift initiative on a mine pumping system. The goal of this type of initiative is to shift electrical load from the more expensive peak periods, to the less expensive off-peak and standard periods. The peak period of the applicable tariff for June 2018, was 6 and 3.3 times more expensive than the off-peak and standard periods, respectively.

An electrical baseline, a peak-load reduction target as well as a monthly cost saving target were established and agreed upon by all parties before the initiative was implemented. The baseline is adjusted according to the actual daily energy consumption, also known as energy neutral scaling. Equation 1 and Equation 2 are used to calculate the scaled energy neutral baseline.

The baseline scaling is used to ensure that comparisons can be drawn. For instance, baseline scaling takes into account various factors which might have resulted in an overall increase or decrease in energy usage, but in a more efficient manner. For example, more energy may have been used but much greater production achieved and thus the energy intensity (kWh/tonne) decreased. The system can make use of any numerical scaling method desired by the user and the same can be done for water efficiency projects.

$$f = \frac{\sum_{i=1}^{n} A_i}{\sum_{i=1}^{n} B_i} \qquad \textbf{Equation 1}$$

$$S_i = f \cdot B_i \qquad \textbf{Equation 2}$$

$f = scaling\ factor$
$n = number\ of\ data\ points$
$B = baseline\ energy\ profile$
$A = actual\ energy\ profile$
$S = scaled\ baseline\ energy\ profile$

Figure 7 shows the monthly performance summary of this initiative for June 2018. The initiative in this case study has a combined load shift, non-cost savings target, of 0.3 MW. This implies an average power reduction of 0.3 MW during the morning (06:00–09:00) and evening (17:00–19:00) peak periods. This target is only applicable for weekdays, because there are no peak periods over weekends.

As seen from the profile chart (top right) in Figure 7, the electricity load is shifted between one and two hours earlier from the evening peak period. This resulted in a combined power reduction of 0.39 MW in peak hours for June 2018. By shifting load to less expensive periods, an electricity cost saving is achieved. The initiative has a \$2958 monthly cost saving target, and achieved a total cost saving of \$6891 in June 2018.

The monthly view in Figure 7 also shows daily performance tracking for the selected month. In the bottom left chart in Figure 7, the daily cost saving is shown. Only one weekday (5 June) had a negative cost impact. The other weekdays in general over performed well which resulted in the monthly cost saving of \$6891. When examining the cumulative performance chart (bottom right of Figure 7), the negative impact of 5 June is also visible.

7

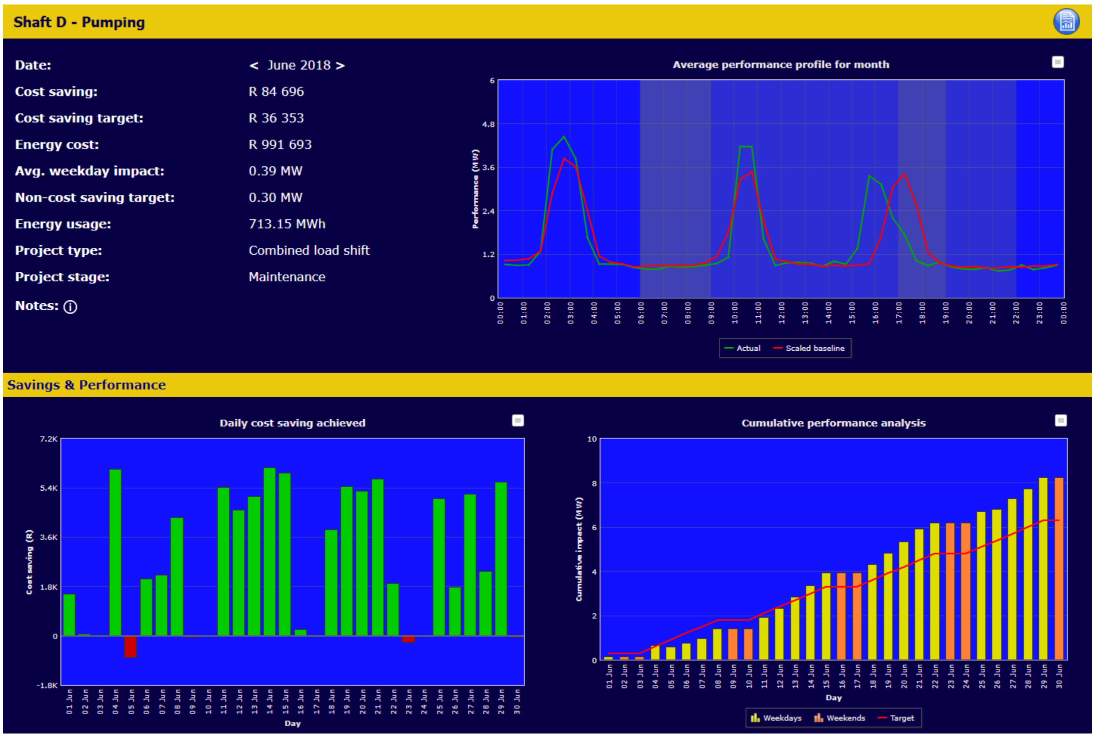

Figure 7: Case study 1 - Monthly performance detail

3.3 Case study 2 – Energy efficiency initiative

The second case study is an energy efficiency initiative on a mine compressed air system. The goal of this type of initiative is to reduce energy consumption throughout the day and in the process also save electricity costs. It is however not advisable to prohibit the mine from obtaining their production goals. Therefore, compressed air supply would not be altered during the drilling hours (08:30-14:00), but only non-drilling hours. The baseline is adjusted energy neutral, similar to the first case study, but only for the drilling hours. To calculate the scaled baseline, Equation 1 is adjusted to only use the drilling hours for both the actual and baseline profiles to determine the scaling factor. The scaled baseline is then calculated with Equation 2.

Figure 8 shows the monthly performance summary of case study 2 for June 2018. The initiative in this case study has an average energy efficiency target of 0.9 MW. This target is applicable for each day of the week. As seen from the average performance profile chart (top right) in Figure 8, the initiative is able to reduce compressed air supply for two hours before the drilling period and again after the drilling period. This results in an average power reduction of 0.58 MW, which is 35.6% below target.

The initiative has a monthly cost saving target of $23 406 and achieved an actual electricity cost saving of $50 317, which is 115% above target. Because the cost and non-cost saving targets are applicable for both weekdays and weekends, the daily cost saving chart (bottom left of Figure 8) and the cumulative performance chart (bottom right of Figure 8) correlate well. The cost savings target is more conservative than the impact target of 0.9 MW, which is why the initiative achieves the cost target but not the impact target. Further, the cost savings are more significant on weekdays, because of higher weekday electricity tariffs.

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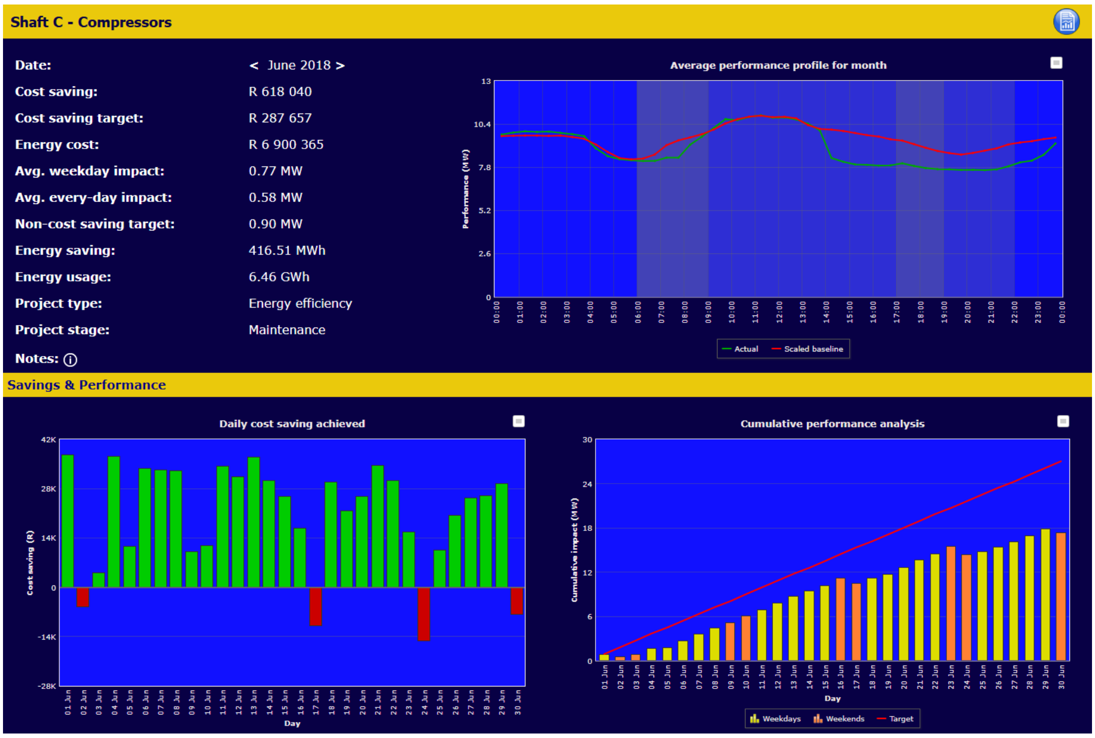

Figure 8: Case study 2 - Monthly performance detail

3.4 Case study 3 - Cumulative performance tracking

In this case study, the cumulative performance of a collection of electricity efficiency initiatives is tracked. Figure 9 shows a cumulative performance analysis chart of the efficiency initiatives. On the primary y-axis are the cumulative impact (MW power reduced) and cumulative target, and on the secondary y-axis the cumulative cost savings. On the x-axis are the months since the first initiative in the collection was implemented. This chart allows the user an overview of the performance of all the initiatives.

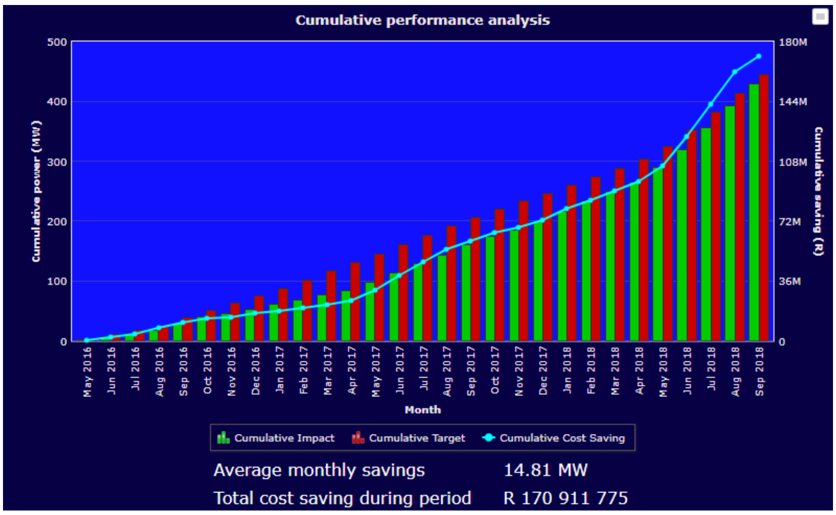

Figure 9: Cumulative performance analysis

From the chart in Figure 9, it can be observed that the gap between the impact and the target increased significantly between October 2016, until April 2017. Since May 2017, the gap between the cumulative impact and cumulative target has steadily been decreasing. This means that collectively these initiatives have been over achieving their targets since May 2017.

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Another important observation from the chart in Figure 9, is the increased cost savings during the electricity peak periods of June, July and August. In South Africa, electricity is much more expensive during these colder months due to increased demand. Therefore, it is important that load shifting initiatives (similar to case study 1) are well maintained and ready to perform optimally during these expensive periods. In this example, more than 51% ($7 174 393) of the total cost savings were achieved during the peak months, although only 31% of the months in this period are peak months.

3.5 Case study 4 - Water efficiency initiative

In the final case study, a water efficiency initiative on a gold mine is investigated. The objective of this initiative is to balance the amount of water in the water reticulation system, without having to dump any excess water. Water in the system increases either by fissure water entering from underground, or potable water purchased from the local municipality.

Figure 10 shows the monthly performance detail for April 2018. The monitoring of the dumped water was started in August 2017 and an average of 122 ML of water was dumped during the first eight months. After careful planning, the system was rebalanced by dumping more than 264 ML of water from 14 April to 18 April. This major rebalance in April was necessary to keep the system balanced for longer. In the months following April 2018, no water has been dumped. By monitoring this initiative automatically, it is possible earlier detect water dumping and remedy the situation as early as possible.

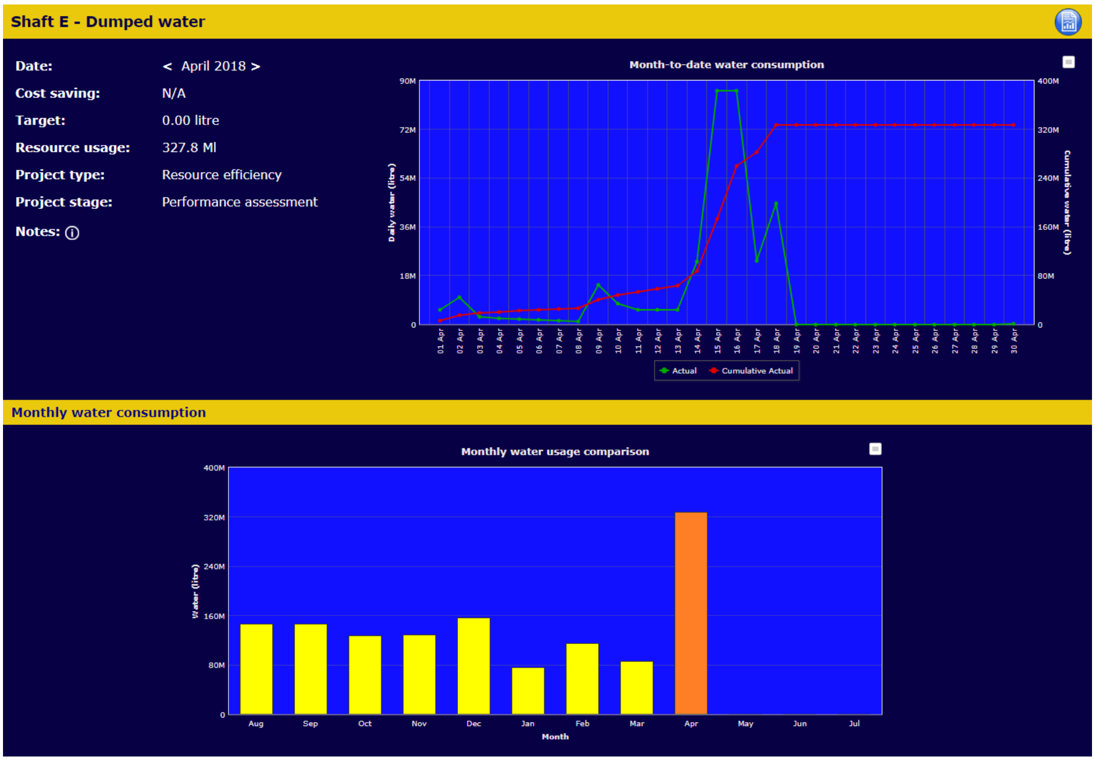

Figure 10: Case study 4 - Monthly performance detail

3.6 Survey results

In order to validate the system, a survey was conducted on the typical users of the system at the ESCo. Participants included high level management, as well as project engineers concerned with the day-to-day monitoring and configuration of the initiatives. The survey was divided into three sections namely, configuration, analysis and overall impression.

Participants who are responsible for configuring initiatives on the platform, all agreed that the interface is user-friendly, and that the features and configuration options are sufficient to set up efficiency initiatives. On average they use the configuration interface 0.7 times a week.

In terms of the performance analysis platform, participants use the platform 1.8 times per week on average. They all agreed that the system enables them to efficiently monitor and track the performance of various

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initiatives. The also agreed that the performance results are accurate and provides sufficient detail for efficient monitoring of initiatives. However, 22% of participants did not agree that the results are verifiable.

Overall, participants were satisfied with the functionality of the system. All participants agreed that the system addresses a performance monitoring need and helps them to work more efficiently. However, only 89% of participants agreed that the system is generic. Further, 11% of participants experienced stability issues with the system.

4. DISCUSSION

The generic efficiency initiative monitoring system makes it easy for project engineers to manage the performance of the initiatives they are responsible for. The web application provides a variety of different visualisations to analyse the performance of initiatives. Performance reports can be generated from the web application which can be signed off by relevant stakeholders. Based on results of the survey, participants were overall satisfied with the system and agreed that it addressed their needs regarding performance monitoring.

The proposed system achieves the need to aid in environmentally friendly and sustainable development identified by Watson *et al* [19]. The generic nature of the system allows it to be used for various efficiency projects as illustrated in the results across both energy and water. However, the system is not limited to those areas and could be expanded to cover air quality, water pollution reduction as well as any other measurable environmental impact. The system could be further improved by incorporating big data and Internet of Things techniques and concepts which have shown promise in managing natural resource usage and sustainable development [28–30]. These big data techniques could provide enhanced insight into usage patterns and wastages which could be used as indications of savings opportunities [28–30].

Further advancement of the system could focus on incorporating further non-energy or indirect cost benefits which efficiency initiatives realise [31–33]. This could aid in the wider adoption of environmentally sustainable production by initially focusing on the direct financial benefit for the industries involved. There is also the additional benefit that the system could closely work with environmental management systems such as those described by the ISO 14001 standard [34, 35]. This means that implementation of an efficiency monitoring system could increase the uptake of direct environmental management by first targeting improvements to the bottom line of the mining industry.

There were however some shortcomings identified in this study. From the survey, concerns were raised whether the results generated by the system are verifiable. Since it is possible to manually verify the calculations based on the data in the database, the real concern here is the reliability of field data collected from various sources. This is a major concern for most systems relying on external data sources. There is therefore scope to perform some data quality checks to ensure the data is usable for the analysis. Such data quality analysis can be automated based on existing M&V and data quality techniques.

Furthermore, while the system was successfully implemented and used at numerous mining sites, the results are limited to the South African deep mining industry. Further study would be required to determine if the same or a similar approach could be used in other industrial sectors such as manufacturing, steel making or the cement industry.

5. CONCLUSION

The significant price increases faced by mining companies in South Africa have placed substantial focus on the reduction of costs, specifically in terms of their consumption of natural resources such as water and energy. The consumption of these natural resources is an integral part of mining and thus efficiency initiatives are pursued in order to reduce their cost impact. However, literature has showed that without monitoring these initiatives their performance deteriorates over time. Therein lies the need for a generic efficiency initiative monitoring system.

In this study, the development of an efficiency initiative monitoring system was described where data is automatically collected, processed and stored in a database. Initiatives are configured via a web application. The performance of the initiatives is calculated automatically. Project managers can then analyse the performance via various visualisations on the web application. Performance reports can be generated to be signed off by relevant stakeholders. Four case studies are discussed to illustrate how the performance of initiatives can be tracked and monitored. Ultimately the study was successful in developing a generic initiative monitoring system which can be used in the mining industry to monitor efficiency initiatives in order to drive sustainable development.

6. ACKNOWLEDGEMENTS

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7. BIBLIOGRAPHY

[1] **Ruffini, A.** 2008. South Africa's deep level gold mines attend to key infrastructure, *E&MJ-ENGINEERING AND MINING JOURNAL*, vol. 209, no. 7. pp. 84–86.

[2] **Bredenkamp, J. I. G.**, **Mathews, M. J.**, and **Vosloo, J. C.** 2016. An integrated energy management strategy for the deep-level gold mining industry, in *Proceedings of the Conference on the Industrial and Commercial Use of Energy, ICUE*, pp. 133–139.

[3] **Neingo, P. N.** and **Tholana, T.** 2016. Trends in productivity in the South African gold mining industry, *J. South. African Inst. Min. Metall.*, vol. 116, pp. 283–290.

[4] **Lane, A.**, **Guzek, J.**, and **van Antwerpen, W.** 2015. Tough choices facing the South African mining industry, *Journal of the Southern African Institute of Mining and Metallurgy*, vol. 115. scieloza, pp. 471-479.

[5] **Dong, L.**, **Tong, X.**, **Li, X.**, **Zhou, J.**, **Wang, S.**, and **Liu, B.** 2019. Some developments and new insights of environmental problems and deep mining strategy for cleaner production in mines, *J. Clean. Prod.*, vol. 210, pp. 1562–1578.

[6] **Bohlmann, J. A.** and **Inglesi-Lotz, R.** 2018. Analysing the South African residential sector's energy profile, *Renew. Sustain. Energy Rev.*, vol. 96, pp. 240–252.

[7] **Goosen, P.**, **Mathews, M. J.**, and **Vosloo, J. C.** 2017. Automated electricity bill analysis in South Africa, *South African J. Ind. Eng.*, vol. 28, no. 3, pp. 66–77.

[8] **Goosen, P.**, **Swanepoel, J. A.**, and **du Plessis, J. N.** 2016. The need for a comprehensive energy management information system for industries, *South African J. Ind. Eng.*, vol. 27, no. 3, pp. 1–11.

[9] **Breytenbach, W. J. J.**, **Brand, H. G.**, and **Marais, J. H.** 2017. Framework for operational changes to reduce electricity costs in the South African steel industry, in *Proceedings of the Conference on the Industrial and Commercial Use of Energy, ICUE*, pp. 1–8.

[10] **Sibanye-Stillwater** 2017. Integrated Annual Report 2017. Roodepoort, South Africa, pp. 109–110.

[11] **Burger, C.** and **Jansen, A.** 2014. Increasing Block Tariff structures as a water subsidy mechanism in South Africa: An exploratory analysis, *Dev. South. Afr.*, vol. 31, no. 4, pp. 553–562.

[12] **Schoeman, W.**, **Brand, H.**, and **Vosloo, J.** 2016. A DSM approach for water usage and electricity costs on water distribution networks, in *Proceedings of the Conference on the Industrial and Commercial Use of Energy, ICUE*, pp. 191–199.

[13] **Du Plessis, G. E.**, **Arndt, D. C.**, and **Mathews, E. H.** 2015. The development and integrated simulation of a variable water flow energy saving strategy for deep-mine cooling systems, *Sustain. Energy Technol. Assessments*, vol. 10, pp. 71–78.

[14] **van Antwerpen, H. J.** and **Greyvenstein, G. P.** Mar. 2005. Use of turbines for simultaneous pressure regulation and recovery in secondary cooling water systems in deep mines, *Energy Convers. Manag.*, vol. 46, no. 4, pp. 563–575.

[15] **Vosloo, J.**, **Liebenberg, L.**, and **Velleman, D.** 2012. Case study: Energy savings for a deep-mine water reticulation system, *Appl. Energy*, vol. 92, pp. 328–335.

[16] **Crawford, J. A.**, **Joubert, H. P. R.**, **Mathews, M. J.**, and **Kleingeld, M.** 2019. Optimised dynamic control philosophy for improved performance of mine cooling systems, *Appl. Therm. Eng.*, vol. 150, pp. 50–60.

[17] **Groenewald, H. J.**, **Kleingeld, M.**, and **Vosloo, J. C.** 2015. A performance-centred maintenance strategy for industrial DSM projects, in *Proceedings of the Conference on the Industrial and Commercial Use of Energy, ICUE*, pp. 50-53.

[18] **Goosen, P.**, **Pelzer, R.**, and **Bolt, G.** 2013. Efficient monitoring of mine compressed air savings, in *Proceedings of the Conference on the Industrial and Commercial Use of Energy, ICUE*.

[19] **Watson, R. T.**, **Boudreau, M. C.**, and **Chen, A. J.** 2010. Information Systems and Environmentally Sustainable Development: Energy Informatics and New Directions for the IS Community, *Manag. Inf. Syst. Q.*, vol. 34, no. 1, pp. 23–38.

[20] **Schulze, M.**, **Nehler, H.**, **Ottosson, M.**, and **Thollander, P.** 2016. Energy management in industry - A systematic review of previous findings and an integrative conceptual framework, *J. Clean. Prod.*, vol. 112, pp. 3692–3708.

[21] **Jovanović, B.** and **Filipović, J.** 2016. ISO 50001 standard-based energy management maturity model-proposal and validation in industry, *J. Clean. Prod.*, vol. 112, pp. 2744–2755.

[22] **Wei, M.**, **Hong, S. H.**, and **Alam, M.** 2016. An IoT-based energy-management platform for industrial facilities, *Appl. Energy*, vol. 164, pp. 607–619.

[23] **Hu, S.**, **Liu, F.**, **He, Y.**, and **Hu, T.** 2012. An on-line approach for energy efficiency monitoring of machine tools, *J. Clean. Prod.*, vol. 27, pp. 133–140.

[24] **Ke, M.-T.**, **Yeh, C.-H.**, and **Su, C.-J.** 2017. Cloud computing platform for real-time measurement and verification of energy performance, *Appl. Energy*, vol. 188, pp. 497–507.

[25] **Ilsen, R.**, **Meissner, H.**, and **Aurich, J. C.** Feb. 2017. Optimizing Energy Consumption in a Decentralized Manufacturing System, *J. Comput. Inf. Sci. Eng.*, vol. 17, no. 2, pp. 21006–21007.

[26] **Zampou, E.**, **Plitsos, S.**, **Karagiannaki, A.**, and **Mourtos, I.** 2014. Towards a framework for energy-aware information systems in manufacturing, *Comput. Ind.*, vol. 65, no. 3, pp. 419–433.

[27] **Liebenberg, L.**, **Velleman, D. H.**, and **Booysen, W.** 2012. A simple demand-side management solution for a typical compressed-air system at a South African gold mine, *J. Energy South. Africa*, vol. 23, no. 2, pp. 20–29.

[28] **Herman, J.**, **Herman, H.**, **Mathews, M. J.**, and **Vosloo, J. C.** Oct. 2018. Using big data for insights into sustainable energy consumption in industrial and mining sectors, *J. Clean. Prod.*, vol. 197, pp. 1352-1364.

[29] **Zhou, K.**, **Fu, C.**, and **Yang, S.** 2016. Big data driven smart energy management: From big data to big insights, *Renew. Sustain. Energy Rev.*, vol. 56, pp. 215–225.

[30] **Shrouf, F.** and **Miragliotta, G.** 2015. Energy management based on Internet of Things: practices and framework for adoption in production management, *J. Clean. Prod.*, vol. 100, pp. 235–246.

[31] **McKane, A.** et al. 2017. Predicting the quantifiable impacts of ISO 50001 on climate change mitigation, *Energy Policy*, vol. 107, pp. 278–288.

[32] **Aghajanzadeh, A.**, **Therkelsen, P.**, **Rao, P.**, and **McKane, A.** 2016. Global Impact Estimation of ISO 50001 Energy Management System for Industrial and Service Sectors.

[33] **Nel, A. J. H.**, **Vosloo, J. C.**, and **Mathews, M. J.** 2018. Financial model for energy efficiency projects in the mining industry, *Energy*, vol. 163, pp. 546–554.

[34] **Shen, L.**, **Muduli, K.**, and **Barve, A.** 2015. Developing a sustainable development framework in the context of mining industries: AHP approach, *Resour. Policy*, vol. 46, pp. 15–26.

[35] **Oliveira, J. A.**, **Oliveira, O. J.**, **Ometto, A. R.**, **Ferraudo, A. S.**, and **Salgado, M. H.** 2016. Environmental Management System ISO 14001 factors for promoting the adoption of Cleaner Production practices, *J. Clean. Prod.*, vol. 133, pp. 1384–1394.

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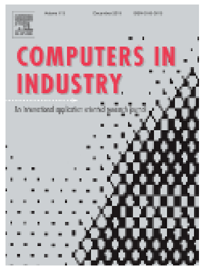

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