

# CHAPTER 1



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*“The only way of finding the limits of the possible is by going beyond them into the impossible.” – Arthur C. Clarke*

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<sup>1</sup> Photo taken by HVACI personnel near Welkom in the Free State, South Africa.

# 1 INTRODUCTION AND BACKGROUND

## 1.1 Energy consumption trends

### 1.1.1 Global energy

The last two hundred years have witnessed an incredible increase in energy usage worldwide [1]. One of the main reasons for this increase is the continuous growth of the global human population. The global population growth and the increase in energy needs are strongly linked [2]. The global population reached a frightening number of seven billion individuals in 2011 with projected population estimates of ten billion by the end of this century [3]. If this projection holds, the world's population would have grown more than tenfold (from eight hundred million to ten billion people) between 1800 and 2100 [3].

The human population is very dependent on the earth's resources for electricity generation. Electricity is paramount to the basic needs of the modern day human being and is essential for achieving global economic sustainability [4]. However, electricity generation requires natural resources such as fossil fuels and other non-renewable resources. Unfortunately, these resources are becoming scarcer and more expensive and with the escalating impact of greenhouse gas ( $\text{CO}_2$ ) emissions, alternative electricity generation methods will have to be considered [5].

Figure 1 illustrates the global electricity generation projection using primary energy resources. According to this projection, the global net electricity generation will increase with 87% from 18.8-trillion kilowatt hour (kWh) in 2007 to 35.2-trillion kWh in 2035 [6]. Figure 1 also indicates that fossil fuels form a major part of the projected electricity generation. Considering carbon dioxide ( $\text{CO}_2$ ) gas emissions produced by burning fossil fuels, the world is facing a dilemma in the electricity generation sector.

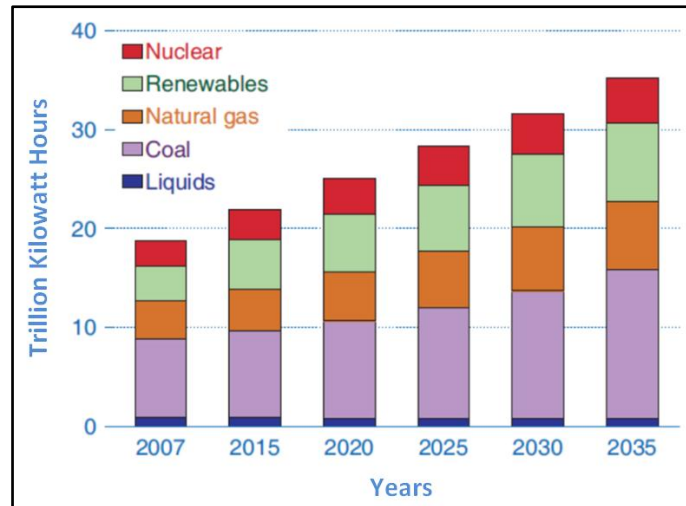


Figure 1: World net electricity generation by fuel (2007 – 2035) [6]

Renewable energy sources seem to be the upcoming workable solution for electricity generation. If electricity demand was only supplied by renewable sources it would allow for a sustainable future [7]. This is very promising, but unfortunately the renewable share of world electricity generation is projected to only increase from 18% in 2007 to 23% in 2035 [6]. This contributes only a fraction of the projected global net electricity generation increase of 87% mentioned in the previous paragraph.

The continuous rapid increase in energy usage has caused major concerns around the world. These concerns include the availability of finance, energy management, economic development and sustaining the global energy reserve margin. The continuous growth in human population, availability of non-renewable energy resources and the negative environmental effect of CO<sup>2</sup> gas emissions created a need for alternative electricity generation approaches. These problems have not only caused electricity providers to reconsider their generation methods, but also created a major need for consumers to utilise electricity more efficiently.

### 1.1.2 Energy in South Africa

South Africa is considered one of the more advanced emerging economies of the world [8]. As mentioned in the previous section, energy plays a crucial role in a country's economic sustainability and development. Energy, in particular electricity production, has been and still is, one of the contributing factors to the social and economic development of South Africa [9]. It is therefore vital to manage energy sources and electricity production in such a manner that it will provide for a sustainable economic future.

## Electricity crisis

During early 2008, Eskom (the state-owned electricity supplier in South Africa) was forced to introduce load shedding to decrease the total electricity demand during peak demand periods. Domestic and industrial electricity users had to endure blackouts across the country. It was argued that the electricity shortfall could partially be attributed to local lack of planning and decision making and possibly therefore, a lack of energy research [10].

During the early 1990s, the then South African Department of Minerals and Energy developed an Integrated National Electrification Programme (INEP) to electrify the majority of South African households. The focus was especially on underdeveloped rural areas. Prior to implementing this programme only about a third of all households were connected to the electricity grid [11]. By 2001, this figure increased to about two-thirds of all households [11].

Through the INEP more than 3.4 million households were connected between 1994 and 2001. The programme continued with the intent to electrify 300 000 homes annually [11]. Up to 2009, approximately 4.9 million new households have been connected to the electricity grid, totalling 9.25 million households [12].

The aim of the INEP was not just to electrify new households, but also to electrify schools and medical clinics in previously disadvantaged rural areas. By 2007/2008, 163 clinics and approximately 5 000 schools were electrified since 2001 [12]. Figure 2 represents the increase in newly electrified households from the start of the INEP in 1994 to the end of 2008.

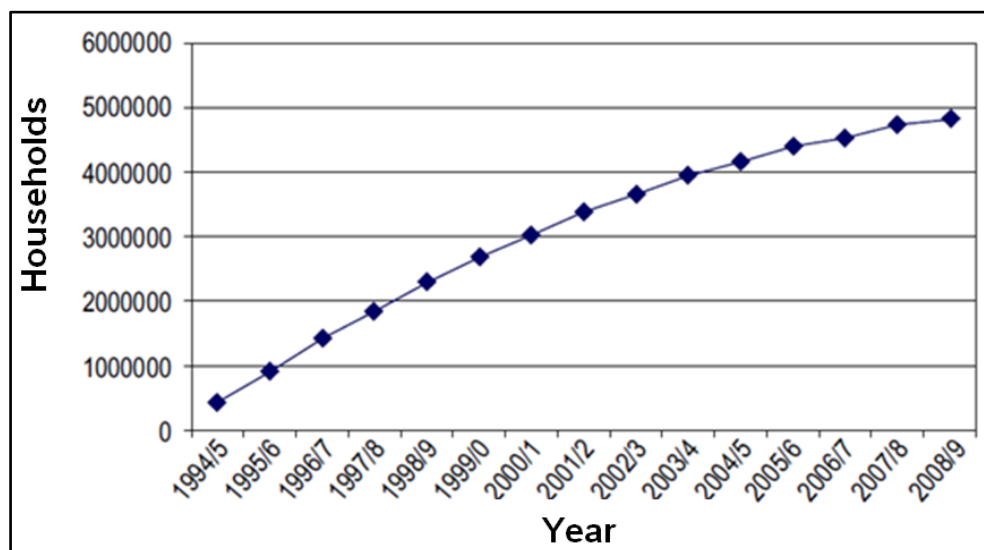


Figure 2: Newly electrified South African households from 1994 to 2008 [12]

The INEP initiative created a vast amount of jobs and exposed thousands of learners to new educational technologies [12]. Approximately 33 000 jobs were created from 2001 to 2008 and 6 900 students were thoroughly trained between 2005 and 2008 [12]. Together with South Africa's general economic growth, this initiative substantially contributed to the large increase in electricity demand. South Africa's electricity reserve margin declined from 25% in 2001 to between 8% and 10% in 2007. The global benchmark for safe operation is 15% [13].

Figure 3 depicts the projected electricity crisis in 2007/2008 when the maximum demand forecast exceeded Eskom's maximum supply capacity. From this figure it can be seen that since 2001 no provision was made for the rapid increase in electricity demand. A Cabinet decision was made during 1998 to restrict Eskom increasing their generation capacity [14]. Eskom was only allowed to refurbish and recommission current plants in storage [14]. However, the electricity demand was much higher than expected. One has therefore no other choice than to assume this dilemma was due to a lack of monitoring, analysing and decision making in the electricity generation sector.

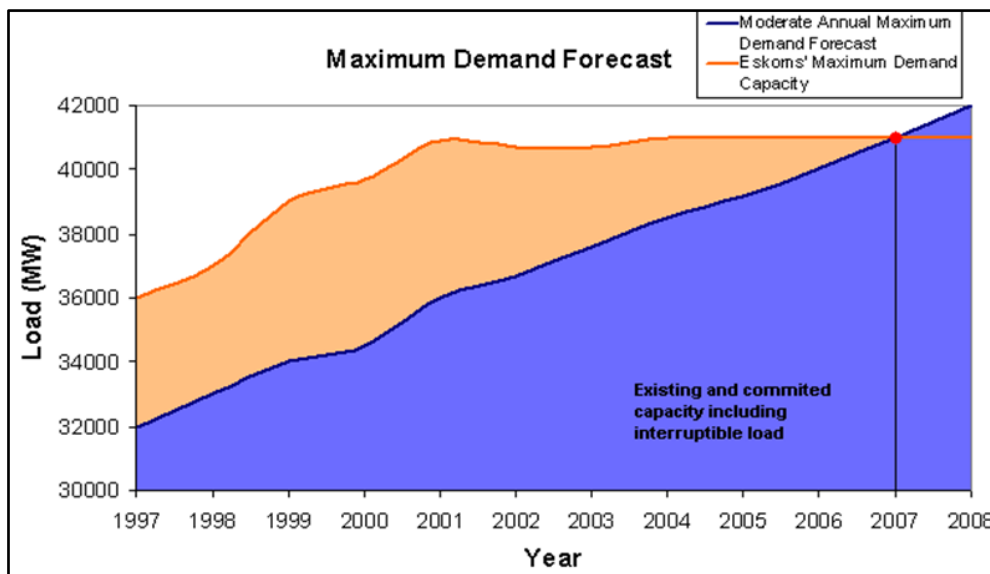


Figure 3: Eskom's maximum supply capacity and maximum demand forecast [15]

The electricity crisis forced Eskom to escalate supply side management (SSM) initiatives to increase its electricity supply capacity. These initiatives included refurbishing outdated power stations, as well as constructing new power stations and wind-generated turbines. It is predicted that several of these initiatives will only be completed by 2018/2019 [16]. Meanwhile, Eskom had to ramp up existing demand side management (DSM) strategies to reduce the electricity demand during peak demand periods.

DSM initiatives contributed to a major increase in Eskom’s electricity supply margin during peak demand periods. The contribution was so large that since April 2008 no load shedding has occurred [16]. Figure 4 displays the increasing amount of power saved due to the implementation of DSM initiatives. It is clear from this figure that major demand savings occurred from 2008 onwards; these increased almost linearly up to 2012.

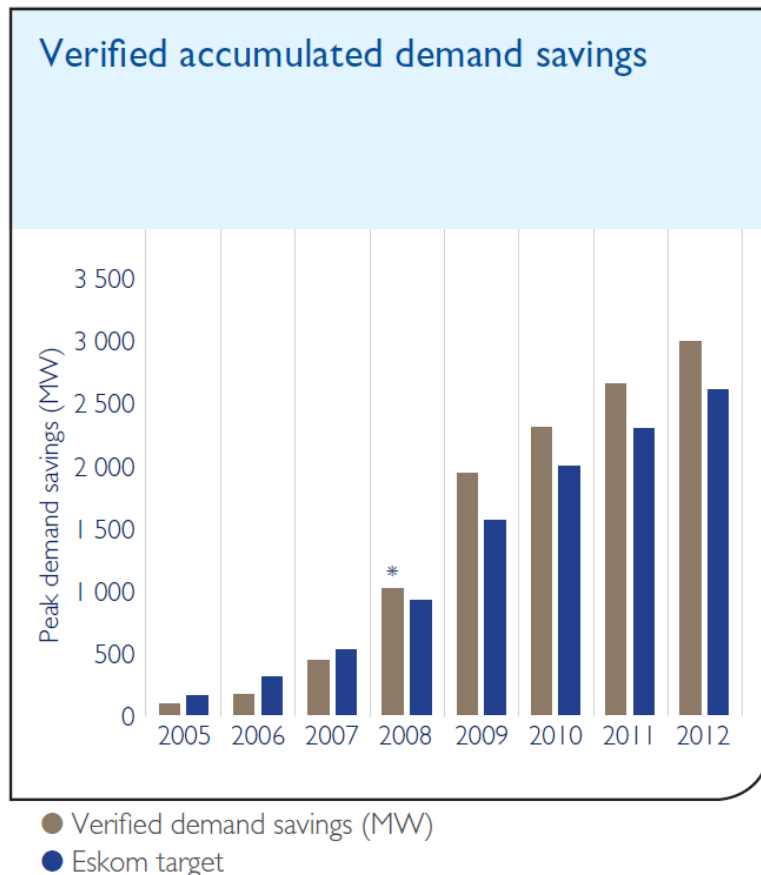


Figure 4: Verified electricity savings through DSM initiatives [16]

It is very important for Eskom to maintain the demand savings until the predicted completion date of their SSM initiatives. The demand savings will not only help to sustain a sufficient electricity supply margin, but will also allow for sustainable economic growth, which is very important for a developing country such as South Africa. It is therefore important for Eskom to continue implementing DSM strategies to reduce the electricity demand of their major energy consumers.

### South Africa’s major electricity consumers

Historically, electrical energy demand in South Africa has been dominated by heavy industry and mining [9]. These industries have determined the economic and energy structure of the

country for many years [9]. According to the 2012 Eskom Annual Report, heavy industry and mining sectors contributed to approximately 40% of total South African electricity sales. Figure 5 represents Eskom’s electricity sales in gigawatt hour (GWh) to various South African electricity consumers for 2011/2012.

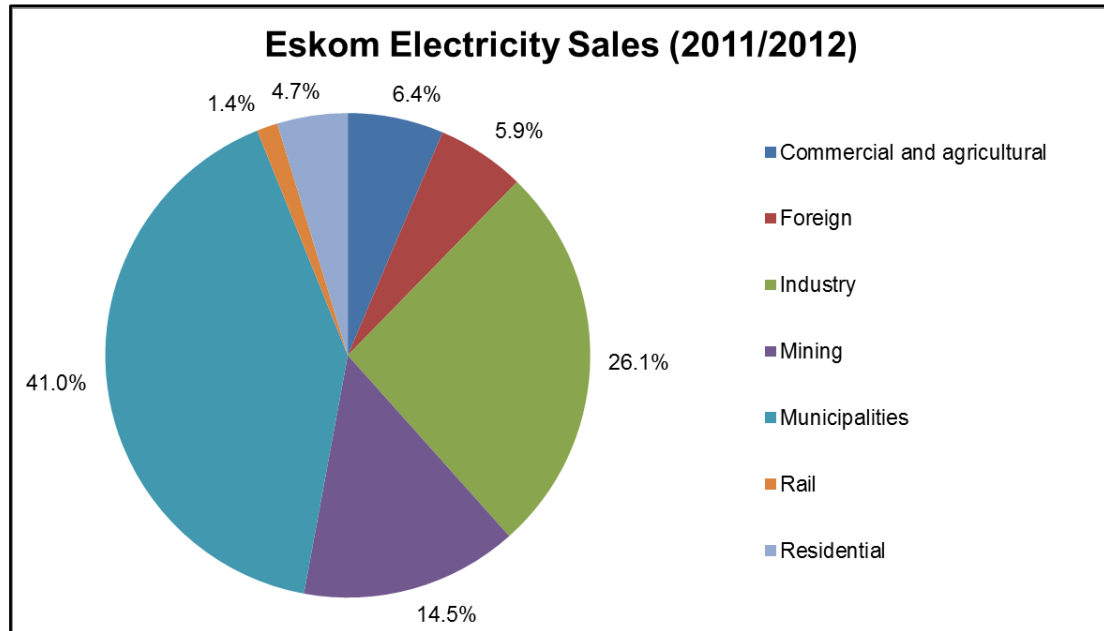


Figure 5: Eskom’s direct electricity sales for 2011/2012 [16]

From Figure 5 it can be seen that mining consumed approximately 14.5% of the total national electricity consumption. This is almost 50% of the total electricity consumed by heavy industry and mining sectors. Therefore, due to their high electricity consumption, mines offer several opportunities for the implementation of DSM strategies.

According to Howells, compressed air generation and machine drives are the main electricity consumers of a typical mine. Machine drives is the leading consumer using 45% of the total electricity, while compressed air generation is the second highest consumer using 20% of the total electricity [17]. However, at some mines compressed air consumes up to 50% of the total electricity consumption [18].

Compressed air generation is regarded as one of the most expensive and most inefficient means of energy distribution in mining operations [19]. It is estimated that only 19% of the total power used by a centrifugal compressor can be converted into usable work. The other 81% is lost in the form of heat, which is generated by a compressor, and other losses [20], [21].

The mines' high electrical demand and the inefficient manner in which electrical energy is converted into compressed air create major opportunities for DSM. High demand savings are made possible by optimising inefficient mine compressed air systems. It is claimed that by improving a compressed air system the financial costs spent on electricity bills could be reduced by approximately 20% to 50% [20], [22]. However, in South Africa it is estimated that effective compressed air management could account for 25% of Eskom's DSM savings [19]. These savings directly contribute towards a more reliable and more sustainable electricity supply margin.

South Africa is one of the developing countries with major growth in the industrial and private sectors [23]. It is important that Eskom provides sufficient power to sustain this growth. Therefore, there is a requirement for Eskom to sustain the demand savings obtained through optimising mining compressed air systems. The following section describes the background on mining compressed air systems.

## **1.2 Mining compressed air systems**

### **1.2.1 Background**

Mining in South Africa originated in the late 1800s starting with diamond mining in the Kimberley area. Since then the mining industry in South Africa has grown rapidly and South Africa became known as the country with the richest mining reserves in the world [24]. During the past decades, mining shafts were constructed on rich mineral fields to extract the valuable minerals, particular gold and platinum, which are encased in hard rock several kilometres underground. Today, many of these mines have already been decommissioned due to decreased production and profit concerns as the high concentration ore bodies have been extracted.

The process of constructing new mines still continues today. From inception, it takes between eight and thirteen years to bring a new gold mine into production [24]. The average lifespan of a mine is between ten and thirty-five years, depending on the ore deposits [24]. Some of the existing shafts today date back to the 1950s. According to Scheepers, the age of a South African mine is estimated by investigating the mine's compressors. Table 1 gives a list of compressors with their installation dates at various South African mines, providing an indication of the age of these mines [24].

<b>Age of South African Mines</b>				
<b>Mine</b>	<b>Compressor Type</b>	<b>Installation Year</b>	<b>Compressor Age in 2011 (Years)</b>	<b>Mine Status</b>
Tshepong	Sulzer	1985	26	Mining
	Sulzer	1985	26	
	Sulzer	1985	26	
	Sulzer	1985	26	
Bambanani East #	BB	1962	49	Shaft pillar mining
	GHH	1974	37	
	Sulzer	1981	30	
Masimong 2#	Marthinusen & Coutts	1950	61	Gold plant
Masimong 3#	Sulzer	1974	37	Backup for Masimong 5#
Masimong 4#	Hitachi	1981	30	Mining
Masimong 5#	Sulzer	1985	26	Mining
	Sulzer	1985	26	

Table 1: Age of South African mines using the age of the mine's compressors<sup>2</sup>

Scheepers compiled the information during 2011. The investigation was performed by inspecting the mines' compressors and consulting relevant mine personnel [24]. It is evident from Table 1 that some of these mines are much older than forty years. Mines older than twenty five years can already be regarded as old mines [24]. Therefore, these mines can be classified as old South African mines that are using old and inefficient equipment [24].

During the development of a new mine, especially gold and platinum mines, it is essential to incorporate a cooling, dewatering and compressed air system in the design. These systems enable miners to work at exceptional depths, as the ore containing the valuable minerals is deep underground. All the mines mentioned in Table 1 already have these essential systems incorporated in their design. For the purposes of this study, the compressed air part of the system will be discussed.

### 1.2.2 Typical mining compressed air systems

A mine compressed air system consists of one or several compressors connected to an air reticulation network. Some systems include multiple shafts and processing plants with compressor groups (clustered in compressor houses) located at various locations. Shafts and plants are all interconnected via an air reticulation network. This type of compressed air system is also referred to as a compressed air network. Figure 6 and Figure 7 are simplified examples of different compressed air systems in the mining industry.

<sup>2</sup> Shafts are indicated by the # symbol.

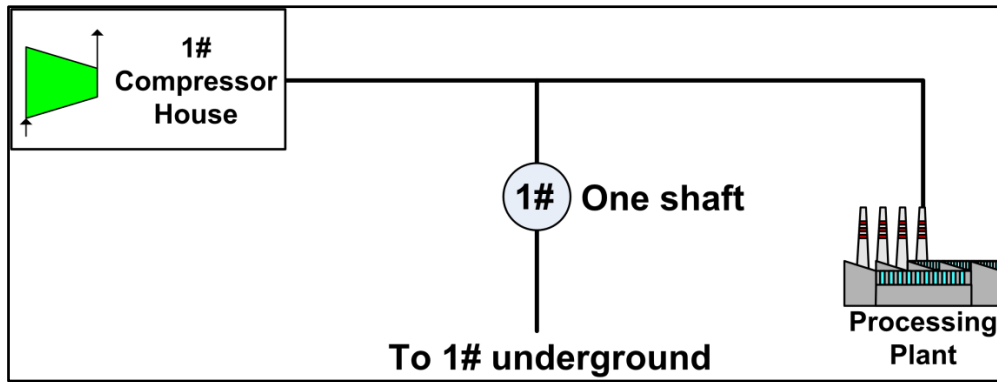


Figure 6: Stand-alone compressed air system

Figure 6 is an example of a compressed air system comprising a shaft, a processing plant and a compressor house. The compressor house may contain one or many compressors. The number of, and installed capacity (supply capacity) of the compressors, depend on the forecasted air requirements of the mine [25]. It is possible for this system to have a tap-off point for a mechanical workshop, which uses compressed air for pneumatic mechanical equipment, for example grinders, drills and saws. The processing plant may also be absent.

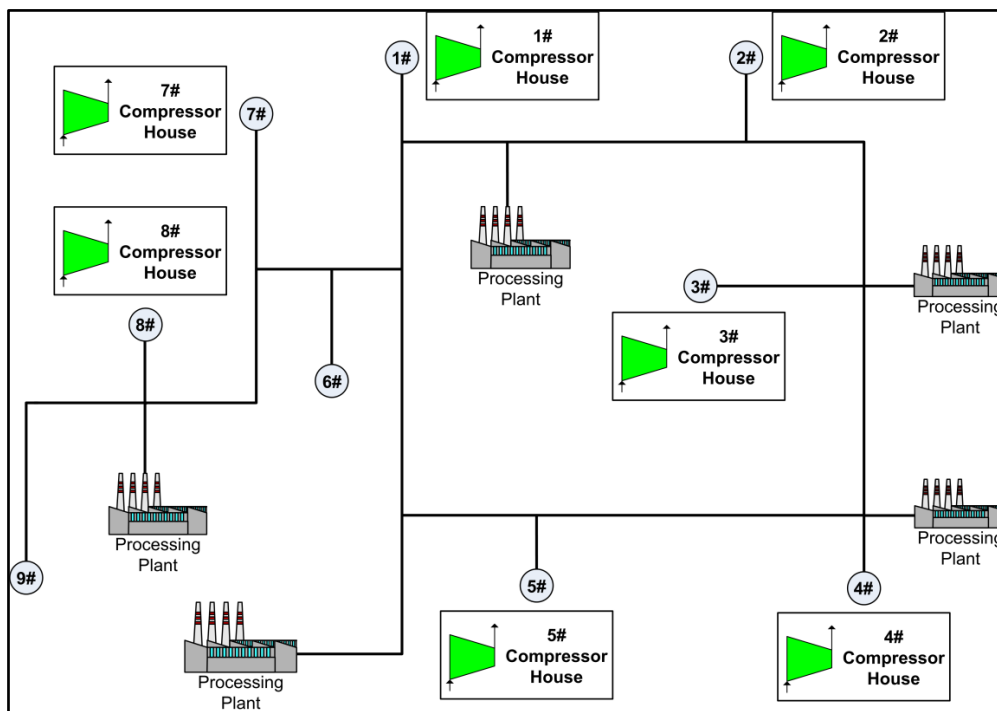


Figure 7: Complex compressed air system (compressed air network)

Figure 7 is an example of a compressed air system comprising many shafts, processing plants and compressor houses. All three components are interconnected via an intricate pipe (reticulation) network. The diameter of the pipe network typically range between 150 and

700 mm and can reach a total length of up to 40 km [26]. The compressed air network in this example contains nine shafts, five processing plants and seven compressor houses. Each compressor house may contain one or many compressors. The compressed air network relies on these compressors to satisfy the compressed air demand.

Compressors are the most essential part of mining compressed air systems and they are usually located on a mine's surface. The compressors are used to generate compressed air as mines rely on compressed air for most of their operations [18], [27]. Today, the centrifugal compressor is the most commonly used compressor type in the mining industry. Older mines still make use of mechanical piston compressors, but in most cases these have been replaced by centrifugal compressors [27].

### **1.2.3 Compressed air consumers**

#### **Preamble**

The majority of South African mines still make use of pneumatic equipment for their mining operations. This is because most of the mines already have compressed air infrastructure installed [18]. However, the cost involved in inefficient compressed air generation has forced mining companies to seek alternative approaches to reduce air consumption of mining equipment. At some mines, pneumatic equipment has been replaced with hydro powered and electrical equipment.

The equipment replacement strategy is a very costly and time-consuming operation [18]. The strategy is not widely implemented due to production and time constraints [18]. Consequently, mines continue to use pneumatic equipment for their operations. Mining compressed air consumers at a typical South African mine can be categorised in three categories, namely: surface, underground and unregulated consumers.

#### **Surface consumers**

Typical surface consumers are processing plants, workshops and pneumatic equipment such as air cylinders. Processing plants are the main consumers at gold and platinum mines. The processing plants are usually located near the shafts [28].

## **Underground consumers**

Compressed air is used by a wide variety of underground consumers on a deep-level mine. Apart from the already installed compressed air infrastructure, the majority of mines make use of pneumatic equipment due to its safety, reliability and ease of use [26], [29]. Pneumatic equipment such as rock drills, ore loaders and loading boxes are just a few of the consumers in underground mining applications. Pneumatic drills are the main consumers, especially during peak-drilling periods in deep-level mining [28].

## **Unregulated consumers**

Compressed air demand is also highly affected by artificial demand, where compressed air is consumed by unregulated users [24]. These unregulated users include leaks on pipe networks, open-ended pipes (used for cooling and ventilation) and illegal mining activities.

## **Interpretation of the consumers**

The power used by a mine's compressors is directly proportional to the compressed air demand of the consumers [26], [30]. The higher the demand, the higher the power consumption will be. There are a large number of compressed air consumers at a typical mine. These consumers do not necessarily operate efficiently and considering the additional load from unregulated consumers, mining compressed air networks offer major DSM potential.

## **1.3 DSM potential on compressed air networks**

Over the years, energy saving companies (ESCOs) have implemented a wide variety of energy saving initiatives on South African mining compressed air systems. These initiatives had a major contribution to maintaining a sustainable electricity supply margin. The initiatives also ensured cost savings on electricity bills of large consumers such as the mining industry.

According to Snyman, energy saving initiatives on mining compressed air networks can be divided into two categories. In the first category the supply efficiency of the mine is increased and in the second category the demand is reduced [22]. The supply efficiency is improved by matching supply with demand and utilising correct compressor sizes according to the demand of the end-users. Reducing the demand is achieved by managing the air consumption of the end-users. Fixing air leaks also contributes to reducing demand.

Schroeder also states that optimised control on mining compressed air networks can be divided into the same aforementioned two categories. Supply-side control is achieved through inlet guide vane (IGV) control, load sharing and correct compressor selection [27]. The main technique in controlling the demand side is with surface and underground control valves [27]. Control valves are used to regulate local network pressures [27].

Small modifications on compressed air networks can result in large energy savings with short payback periods [29]. These small modifications include controlling pressure set points, reducing leaks, using smaller compressors, reducing demand and increasing compressor efficiencies. Figure 8 illustrates the different modifications and their contributions to electrical energy savings in a compressed air network [29].

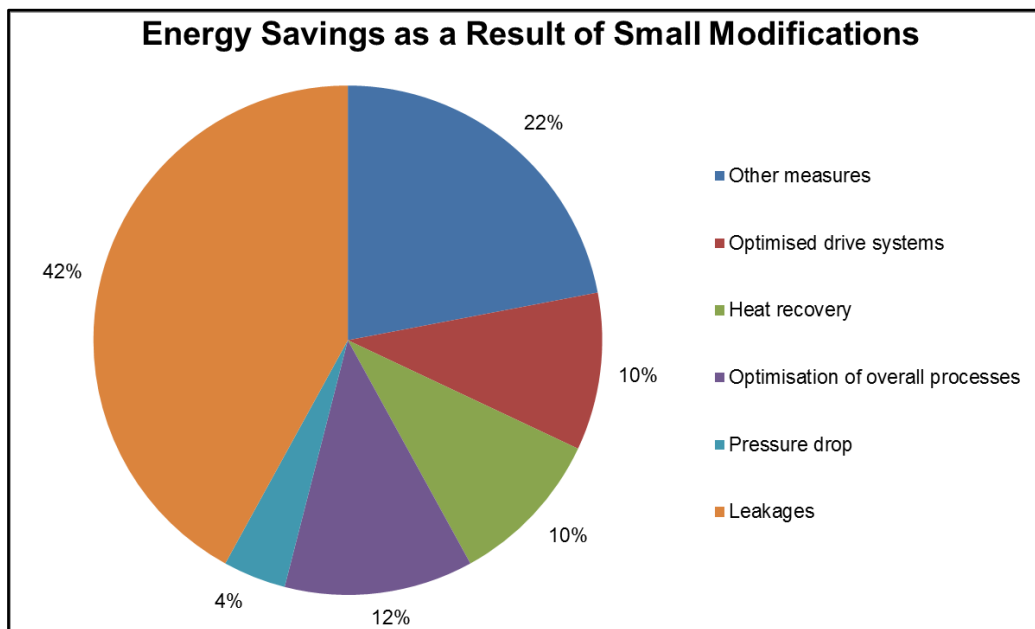


Figure 8: Small modifications for compressed air energy savings

All research conducted highlighted the same methods to optimise the operation of mining compressed networks. However, Shanghai, Hongbo and McKane discuss an additional strategy. The authors describe an optimisation strategy based on the reconfiguration of a tobacco plant's compressed air system. The system consisted of two sub-systems, each with its own compressed air supply source [20]. An oversupply of compressed air was supplied to both systems at all times [20]. The system was optimised by joining the sub-systems and using one compressor to supply the entire system [20].

It is evident from the presented research that many energy savings initiatives with major DSM potential are available. Optimising the operation of a small compressed air system

(tobacco plant) has also been researched. However, research on the physical reconfiguration of mining compressed air networks is scarce.

## 1.4 Problem statement

The continuous increase in global human population and the decrease in availability of energy resources are forcing consumers to utilise electricity more efficiently. DSM initiatives have been implemented in South Africa to sustain the electricity supply margin and enable sustainable economic growth. DSM initiatives, especially on high electricity consumers such as mining compressed air systems, must be maintained until Eskom has increased their supply capacity.

A wide variety of DSM initiatives are implemented on South African mining compressed air networks. The physical reconfiguration of mining compressed air networks is not widely implemented. Due to their age and their configuration, some of these networks are very inefficient. Mining companies generally only focus on maintaining the compressed air networks. The possibility of reconfiguring the networks for improved performance and possible cost savings is overlooked.

This study will investigate the feasibility of reconfiguring mining compressed air networks to generate cost savings. Cost savings do not exclusively refer to financial savings on electricity bills, but also include implementation cost payback and total savings over the lifespan of mines. Furthermore, cost savings can refer to the reduction in excessive maintenance costs.

## 1.5 Outline of the study

**Chapter 1** provides a background on global and South African energy consumption trends. Mining compressed air networks, as one of South Africa's major electricity consumers, is discussed. The DSM potential on compressed air systems is stated. Finally, the objective of the study is formulated.

**Chapter 2** investigates basic mining operations and compressed air requirements on South African gold mines. Existing technologies used to improve compressed air network efficiencies are discussed. The fundamental calculations used to evaluate and characterise a compressed air network are researched. The use of simulation models as an aid is also discussed. Lastly, the implementation of two similar reconfiguration projects is evaluated.

In **Chapter 3** a strategy is developed to reconfigure mining compressed air networks for possible cost savings. The information gathered in Chapter 2 is used as an aid during the strategy development.

In **Chapter 4** the developed strategy is implemented on the compressed air networks of two South African gold mines. In particular, the strategy is used to determine the viability (cost savings) of interconnecting two shafts and relocating a baseload compressor from an abandoned shaft to a fully productive shaft.

**Chapter 5** concludes the investigation into the possibility of reconfiguring mining compressed air networks for cost savings. Future recommendations for further studies are also stated.