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UNIVERSITY OF CAPE TOWN



Analysis of energy efficiency in South Africa's primary mineral industry: A focus on gold

Submitted to the University of Cape Town in fulfilment of
the requirements for the degree of Masters of Science in
Engineering

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ABSTRACT

Energy use is the human activity responsible for the majority of its greenhouse gas emissions. In 2010 the global energy-related emissions of carbon dioxide - the principal greenhouse gas - jumped by 5.3% from the previous year, to a record 30.4 gigatonnes (IEA 2011a). The International Energy Agency (2011) has projected that the world's primary energy demand could increase by 33% and that energy related CO₂ emissions will increase by 20% to 36.4 Gt between 2010 and 2035 (IEA 2011a). South Africa is one of the most energy intensive countries in the world, measured as GHG emissions per Gross Domestic Product produced. South Africa's energy intensiveness is a result of the energy intensive nature of a number of its key industries. The mineral industry is one such industry. It plays a crucial role in South Africa's economy and is the largest industry in its primary economic sector (Chamber of Mines 2010).

Energy efficiency has been identified as one of the cheapest and most effective measures to reduce energy consumption and its associated greenhouse gas emissions. The Long Term Mitigation Scenarios coordinated by the University of Cape Town's Energy Research Centre identified that South Africa's industrial sector had cumulatively the greatest potential to reduce its GHG emissions through improved energy efficiency, ahead of the commercial, residential or transport sectors (Winkler 2007). South Africa's continued reliance on unsustainable energy production, particularly coal, increases the need for maximising energy efficiency to mitigate resource consumption and the GHG emissions associated with the production and use of fossil fuel generated energy.

This project aims to identify and holistically evaluate the potential opportunities that exist for the reduction of energy and climate footprints of South Africa's gold industry sub-sector, with the aim of providing guidance to both government and industry for a path towards a more energy efficient industry with lower associated GHG emissions. To this end the thesis begins with a comprehensive review of the potential drivers, barriers and opportunities for increased EE and GHG emissions mitigation for the local minerals industry.

Opportunities for improved EE within industry and the mineral industry in particular were identified and grouped into two categories namely: effective management and technical opportunities. From the perspective of effective management, improved employee education and the implementation of an effective energy management plan were the two most significant opportunities to come out of literature. From a technical opportunities perspective, a large number of utility optimisation opportunities were identified for improved EE including; compressed air systems, ventilation and air-conditioning processes, utilising process heat, pumps and fans (motor systems). The key improvements for the extraction and beneficiation processes in mining included: improvements to rock comminution circuits, underground processing and robotic mining.

A case study was subsequently carried out on South Africa's three largest gold mining companies namely, AngloGold Ashanti, Harmony Gold and Gold Fields. This case study

was carried out in three parts viz. a background review of South Africa's gold sub-sector as a whole, a desktop study on the three companies; and a semi-structured interview and survey investigation conducted with employees of the three companies.

The background review revealed that South Africa's national gold production levels have fallen significantly over the last decade. This fall has not been in line with the global trends in gold production and as such South Africa's share of global gold production has fallen from 16.3% in 2000 to 7.9% in 2010. The main reason for the decline of South Africa's gold production is the near exhaustion of its Witwatersrand goldfields (Hartnady 2009). Other reasons for this decline in production include increasing wage costs and extensive mine safety stoppages.

The desktop study, of South Africa's three biggest gold mining companies, investigated the performance of each company in terms of its energy consumption and GHG emissions. Information for this study was sourced predominately from publicly available company reports. The findings of the desktop study showed that despite a consistently increasing gold price, average production of South Africa's three biggest gold mining companies had decreased by 30.2% between 2006 and 2010. The key reason for this drop in the reviewed companies gold production is the same physical challenges faced by South Africa's gold industry sub-sector as a whole (MBendi 2011, Hartnady 2009)). These challenges are a result of the depletion of South Africa's highest ore-grade and most accessible deposits, which has forced mines to mine deeper and lower grade ores. The ore-grade of the reviewed companies was down 21.9% between 2006 and 2010. The increased mining depths significantly affect the base energy load of deep underground mines from ventilation and the cooling and pumping of water, which are independent of production. The depletion of these deposits has left many mines nearing their end of life phase. The significant base loads of ventilation and the cooling and pumping of water stay relatively constant while throughput and production of the mines significantly decrease, resulting in a notable increase in energy and thus emission intensity. The above causes have resulted in a dramatic rise in energy and emission intensity of the reviewed companies operations, which rose on average 40.0% and 40.8% respectively, between 2006 and 2010,

The costs incurred due to increasing energy and GHG emissions intensities are compounded by the rapidly increasing cost of electricity and demands for higher wages by mine workers. The decline in production levels of South African gold mines is in the medium to long-term expected to continue, unless there is the unlikely discovery of a new reef. In the short-term with improvements to safety procedures and the increasing demand for gold, production levels may increase slightly (PWC 2010). It was observed that due to the number of mine closures, safety stoppages and EE improvements over the last five years, the total energy consumption of the reviewed companies has dropped marginally by 2.6% to 43696 TJ or 12138 GWh. Given that over 90% of GHG emissions from the mining companies reviewed are a direct result of electricity consumption, it was unsurprising that total GHG emissions and electricity consumption trends both stayed relatively similar. However, due to

the significant quantities of mine methane at one of the operations reviewed, total GHG emissions had increased by 6.8% in 2010. This supports similar findings made by Mudd(2010) for the global gold sub-sector.

The third section of the case study consisted of a questionnaire and survey investigation, which was carried out with energy and climate experts from the same companies reviewed in the desktop study. The aim of this investigation was to gain an industrial perspective on key energy efficiency opportunities, barriers hindering the uptake of opportunities, drivers promoting the uptake of opportunities and the key criteria used to evaluate potential opportunities.

In terms of energy efficiency opportunities, projects that were eligible for Eskom's Demand Side Management were rated by the interviewees as the most significant in terms of their ease of implementation and potential magnitude of energy savings. Localised cooling/ more efficient refrigeration, improved compressed air systems as well as the redesign of old over specified technologies were all practical technical EE opportunities in which the reviewed companies felt that they could make significant improvements to the EE of their operations. Companies also stressed the importance of improved employee education around energy issues as an administrative opportunity that could significantly improve the energy efficiency of their operations.

The key drivers promoting improved EE in the mineral industry at present included: The issue of energy security of the mines, the rapidly increasing electricity price which has drastically increased the proportion of the mines operating budget being spent on electricity, as well as the threat of a future carbon tax, which the industry appears to be taking seriously at present.

The key barriers hindering the uptake of more EE opportunities predominately revolved around cost issues, with the two biggest barriers identified during the interview and survey investigation being the direct cost of developing and implementing new EE technologies, and the uncertainty and risk with regards to the performance and reliability of new EE technologies. The companies' likelihood of investing in new technologies was further hampered by their aversion to prematurely retiring working technologies, which had typically been bought at a large capital expense. Another key area identified by the interviewees was a lack of skilled personnel to carry out the skilled work of identifying, evaluating, implementing and operating new EE opportunities.

The fact that at none of the companies reviewed there existed ring-fenced funding for EE projects means that EE opportunities must compete with a number of other potential projects for capital. This highlighted the need to understand how companies went about deciding on projects to invest in. The key decision-making criteria used to evaluate energy efficiency opportunities to come out of the interview and survey investigation were all very financially based and included: Accounting rate of return, Energy consumption reduction,

Payback period and Maintenance of projects. This focus on costs made it clear that EE project aggregators, which are typically either in-house energy experts or experts from outside energy services companies, must focus on projects with a high degree of eco-efficiency in order for them to be given the go ahead by industry at present.

It was concluded that organisations within the gold industry are taking the issue of energy efficiency seriously; this increased focus on energy efficiency within their organizations is predominately due to the increasing cost of electricity and the issues around energy security. The level of focus on energy efficiency within the industry is expected to rise with the rising price of electricity. Greenhouse gas emissions are not given anywhere near the attention that energy efficiency is given, with current greenhouse gas emissions savings typically just a spin off from energy saving projects.

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ACRONYMS

General text

AGA	AngloGold Ashanti
ARR	Accounting rate of return
C1	Company 1
C2	Company 2
C3	Company 3
CDM	Clean Development Mechanism
CER	Certified Emission Reductions
DSM	Demand-side management
EE	Energy Efficiency
EES	Energy Efficiency Strategy
EMP	Energy Management Plan
EU	European Union
GDP	Gross Domestic Product
GHG	Greenhouse gas
HPGR	High-pressure grinding roll
IRP	Integrated Resource Plan
I&AP	Interested and Affected party
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
KPI	Key Performance Indicator
LTMS	Long Term Mitigation Scenarios
NERSA	National Energy Regulator of South Africa
NGO	Non-Governmental Organization
OECD	Organization for Economic Co-operation and Development
PGMs	Platinum Group Metals
R&D	Research and Development
ROM	Run-of-mine
SABC	Semi-autogenous-ball milling-crushing
SAG	Semi-autogenous Grinding
SE	Standard error
USA	United States of America

Unit of measurement

bn	Billion
CO ₂	Carbon dioxide
CO _{2e}	Carbon dioxide equivalent
g	Gram-unit of mass (1g = 1000mg = 10 ⁻³ kg)
Gt	Gigatonne- unit of mass (1Gt = 1000Mt = 10 ⁻³ Tt)

GW	Gigawatt- unit of energy (1GW = 1000MW = 10^{-3} TW)
GWh	Giga Watt hour- unit of energy (1GWh = 1000 MWh = 10^{-3} TWh)
kg	Kilogram-unit of mass (1kg =1000g = 10^{-3} t)
kWh	Kilo Watt hour- unit of energy (1kWh = 1000 Wh = 10^{-3} MWh)
mm	Millimeter- unit of length (1mm = 1000 μ m = 10^{-3} m)
Moz	Million ounces- unit of mass
Mt	Megatonne- unit of mass (1Mt = 1000Kt = 10^{-3} Gt)
MW	Megawatt – unit of energy (1MW = 1000kW = 10^{-3} GW)
oz	(troy) Ounce- unit of mass (1oz t= 31.1035g)
t	Tonne- unit of mass (1t = 1000kg = 10^{-3} Mt)
TJ	Terajoule- unit of energy (1TJ = 1000GJ = 10^9 kJ)
W	Watt- unit of energy (1W = 10^{-3} kW)

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1 INTRODUCTION

Most experts agree that the global climate is affected by the observed increase in greenhouse gas (GHG) concentrations in the atmosphere caused by human activities (IPCC 2007). A GHG is any atmospheric gas that adds to the greenhouse effect by absorbing infrared radiation produced by solar warming in the Earth's surface. The burning of fossil fuels and organic matter to create energy is the human activity responsible for the majority of our GHG emissions. In 2010 the global energy-related emissions of carbon dioxide (CO₂) - the principal GHG - jumped by 5.3% to a record 30.4 gigatonnes (Gt) (IEA 2011a). Under the New Policies Scenario, one of the future scenarios explored by the International Energy Agency (IEA), the world's primary energy demand could increase by 33% between 2010 and 2035 and the energy related CO₂ emissions could increase by 20% to 36.4 Gt (IEA 2011a).

South Africa relies heavily on fossil fuels and in particular coal-fired energy as its primary supply of electricity (DoE 2010). In 2009 it was the world's 5th largest consumer of coal (U.S. EIA, 2009). South Africa's total 2009 CO₂ emissions from fuel combustion were 369.4 MtCO₂ with 295.4 MtCO₂ of those total emissions due to the combustion of coal (IEA 2011a). This figure excludes the quantities of coal used by Sasol. South Africa is also one of the most energy intensive countries in the world per GDP. South Africa's energy intensiveness is a result of the energy intensity nature of a number of its key industries. One of its most energy intensive industries is the mining industry which is the largest industry in its primary economic sector and plays a crucial role in South Africa's economy (Chamber of Mines 2010).

The focus of this thesis is on the energy efficiency of South Africa's primary mineral industry, with a specific emphasis on the gold sub-sector.

1.1 Background information and motivation for research

This section provides the background information and motivation for the research contained in this thesis, including the link between climate change and energy consumption, South African energy and emissions profiles, the impact of the mining industry on South Africa's energy and emissions profiles as well as the importance of Energy Efficiency (EE) in mitigating energy consumption in industry.

1.1.1 Link between climate change, greenhouse gas emissions and energy production

In 2007 the Inter-Governmental Panel on Climate Change (IPCC) released its Fourth Assessment Report on Climate Change, containing its most significant and recent findings. The IPCC concluded that "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread

melting of snow and ice, and rising global mean sea level” (IPCC 2007).The report provided a proposed explanation for observed global warming trends:-“Most of the observed increase in globally averaged temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic greenhouse gas concentrations”(IPCC 2007). The use of the term “very likely” indicates a greater than 90% probability, and as such its use indicates the broad acceptance by scientists of the link between GHG emissions and global climate change.

The significant increase in concentrations of key GHG emissions over the last 120 years are as a direct result of human activities(IPCC 2007). CO₂ concentrations have increased significantly over the last century, compared with the pre-industrial era in which the concentration stayed relatively constant. In 2005 concentrations of CO₂ were approximately 35% higher than in the mid-1880s (IEA 2011b). Anthropogenic GHG emissions accumulate in the atmosphere and produce a net warming of the earth by strengthening the natural “greenhouse effect”.

The human activity that produces by far the most GHG emissions is the use of energy. The production, transformation, handling and consumption of energy commodities accounts for approximately 65% of global GHG emissions (IEA 2011b). Thus the mitigation of GHG emissions resulting from fuel-based energy production and use is one of the best places to start to reduce global GHG emissions.

1.1.2 South Africa’s energy and GHG emissions profile

Along with other developing countries, South Africa is highly sensitive to the impacts of climate variability and change (RSA Government 2011). At the same time it is the 11th biggest emitter of GHGs worldwide and has one of the highest CO₂ emissions per GDP(IEA 2011b).

The significance of South Africa’s GHG emissions is a direct result of both South Africa’s energy intensiveness and its reliance on fossil fuels, particularly coal which was in 2010, responsible for approximately 90% of South Africa’s total electricity generation (DoE 2010). South Africa consumes approximately 40% of the total energy produced in Africa (DME 2004) and in 2008 consumed approximately 1552 TWh of total energy (U.S. EIA 2009). Data provided by a study in Japan (Suehiro 2007) clearly shows that compared with a number of signatory countries to the Convention on the Organisation for Economic Co-operation and Development (OECD), South Africa is one of the higher consumers of energy per GDP, this is indicated by Figure 1.

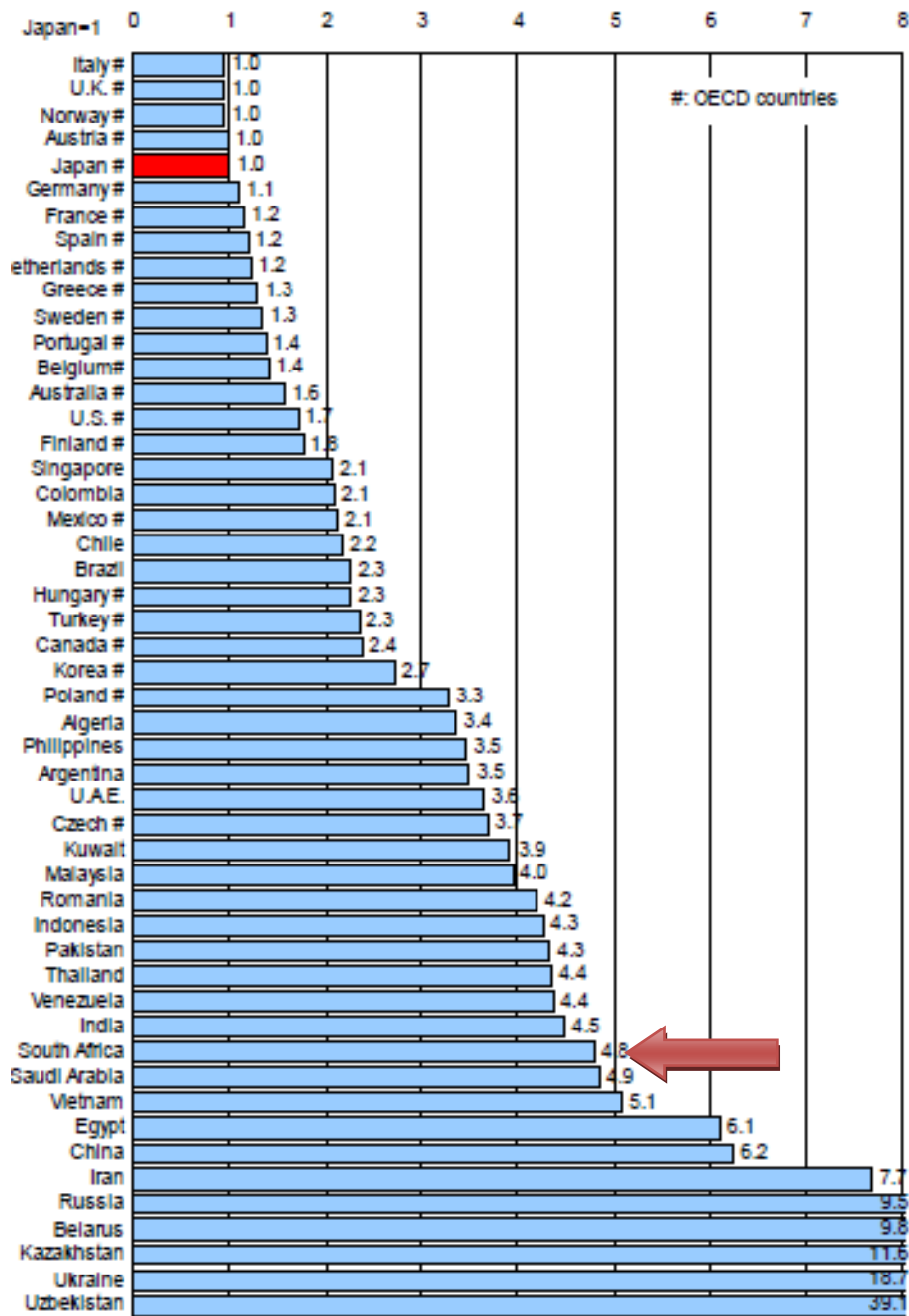


Figure 1: Energy Intensity of GDP as an index of Energy Conservation (Suehiro 2007)

Figure 1 indicates that South Africa is 4.8 times more energy intensive than best performing countries and uses two times more energy per GDP than other developing countries such as Brazil, Chile and Mexico.

In accordance with Kreuger (2009), one of the key reasons for South Africa's high energy intensiveness is its abundance of coal which has played a significant role in creating a situation in which historically South Africa's unit electricity prices were among the cheapest in the world.

However since 2009 significant increases in electricity costs of 24.8 % for 2010, 25.8 % for 2011 and 25.9 % for 2012 (NERSA 2010) have been put in place to pay for new power stations. The need for reinvestment in South Africa's primary supply has become clear since the electricity crisis of 2008 when electricity demand exceeded supply for the first time in South Africa's recent history. The investment programme has included returning three previously mothballed power stations to operation as well as commencement of the construction of two new coal fired power stations, Medupi and Kusile (Lawrence 2009). However the capacity of the new power stations will only be realised with their completion. Thus to gain a more immediate impact on the energy crisis, Eskom has adopted a number of aggressive programmes promoting residential, commercial and industrial EE. Eskom's most significant contribution to EE in the mineral industry is the demand-side management (DSM) funding programme which pays the full capital fee for eligible EE projects up to a benchmark figure (Visagie 2010).

1.1.3 Contribution of South Africa's mining industry to energy and GHG emissions profile

South Africa's historically low cost of energy has created an economic environment that has assisted the growth of energy intensive industries. One such industry is South Africa's mining industry. Figure 2 shows the significance of the mining industry on a national energy demand, identifying that - it consumes 7.5% of South Africa's total energy supply. However, due to the mineral industry's reliance on electricity from Eskom¹ for power this figure more than doubles to 18% of South Africa's total *electricity* market share (Subramoney et al 2009).

¹ Eskom is South Africa's national utility which operates the integrated high-voltage transmission system and has a practical monopoly on bulk electricity, supplying electricity directly to large industrial consumers (DoE 2012)

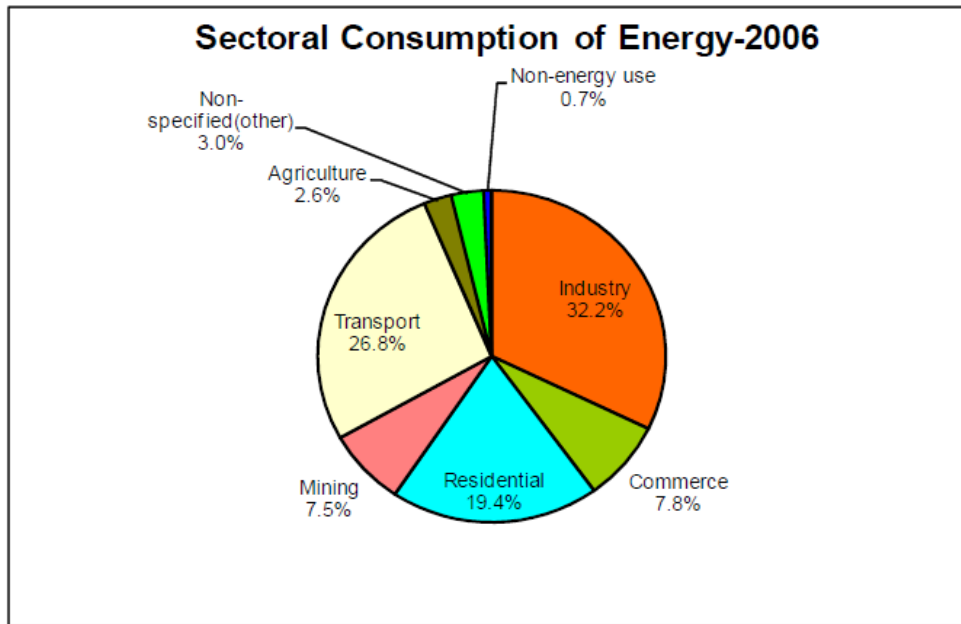


Figure 2:Sectoral consumption of energy 2006 (Subramoney et al 2009).

South Africa is one of the most geologically and mineral rich countries in the world. It possesses the largest known reserves of platinum group metals (PGMs), gold, chrome ore and vanadium. In terms of production statistics, South Africa is ranked 1st for; PGM's, ferrochromium, aluminosilicates, vanadium and vermiculite, 2nd for manganese, zirconium and titanium minerals production and 5th for gold (Chamber of Mines 2010, DMR 2010).

The mineral industry is the largest industry in the primary economic sector and as of 2009 directly contributed 8.8% and indirectly 19% of South Africa's GDP (Chamber of Mines 2010). Mining accounted for 9% of the total fixed investment and 13.3% of the total private sector investment (Chamber of Mines 2009). In 2009, South Africa's total mineral sales amounted to R241.3 billion and the mining industry employed just under 500,000 economically active South Africans paying them approximately R50 billion in wages as well as another R21 billion in taxes to the state (Chamber of Mines 2010).

South Africa's mineral industry is largely built on gold, coal, PGMs and diamond mining. Gold, coal and PGMs made up 71.2% of South Africa's total mineral sales in 2009 (Chamber of Mines 2010, Swart et al. 2007). South Africa was for many years the world's largest producer of gold, and as such gold has played a foundational role in creating South Africa's current economy. Although the national importance of gold has fallen somewhat over the last decade, it still accounts directly for 2.4% of South Africa's GDP, accounted for R49 billion in foreign currency earnings and employed 159 925 employees who earned R17.4 billion in wages (Chamber of Mines 2010).

The reason for the fall in South Africa's share of global production of gold to just 7.97%, in 2009 (Chamber of Mines 2010), is predominantly due to the depletion of its higher grade and most accessible deposits. According to figures from the US Geological Survey (2012), South

Africa's gold reserves are down to 6000t approximately 8.5% of the world's total reserves. A report by Hartnady (2009) estimates that South Africa's Witwatersrand goldfields are as much as 95% depleted. This has forced gold companies to close certain mines as well as mine deeper and lower grade ores. Forced safety shutdowns and significant increases in the cost of electricity have also affected the production levels of mines (AngloGold Ashanti 2010). The increased depth and lower grade of gold pose a significant challenge for the gold industry sub-sector in terms of reducing its energy consumption and associated GHG emissions.

1.1.4 Role of EE in reducing the energy and GHG emissions profile of industry

South Africa's historically cheap energy supply has meant that the issue of EE had been, until recently, largely ignored by industry (DME 2004). EE provides one of the cheapest and most effective ways of reducing GHG emissions (RSA Government 2011). South Africa's Long Term Mitigation Scenarios (LTMS) identified that the industrial sector had cumulatively the greatest potential to reduce its GHG emissions through improved EE, ahead of the commercial, residential or transport sectors (Winkler 2007). South Africa's continued reliance on unsustainable energy production, particularly coal, increases the need for maximised EE to mitigate resource consumption and GHG emissions associated with the production and use of fossil fuel generated energy. To this end the Energy Efficiency Strategy (EES) was officially adopted by South Africa in March 2005. The EES aims for the national reduction of energy usage of 12% by 2015 compared to a projected "business as usual" trend which is modelled on a projected annual increase of 2.8% economic growth (SECCP 2006)

1.2 Problem statement, objectives and research approach

The discussion presented in the previous section provides the motivation to identify possible ways in which the mineral industry and in particular the gold industry can improve its uptake of EE opportunities and thus reduce its energy consumption and GHG emissions.

1.2.1 Problem statement

The threat of climate change, energy shortages and the reliance on coal-fired energy as the primary source of electricity makes it critical to improve the EE of South Africa's more energy intensive industries, which includes the mineral industry. The depletion of a number of the most exploitable reserves and the resulting increase in mining depth and decrease in ore-grade, make improving the energy efficiency of South Africa's gold sub-sector particularly challenging.

1.2.2 Objectives and key questions

The overarching objective of this thesis is to analyse energy efficiency in South Africa's primary mineral industry, particularly the gold sub-sector, and thus be able to make suggestions for improving the uptake of EE opportunities.

The key questions that must be answered in order to achieve the above objectives are:

Generic mineral industry key questions:

- 1 What role does energy efficiency have to play in South Africa's mineral industry's response to climate change and energy shortages?
- 2 What opportunities exist for energy efficiency within the mineral industry?
- 3 What are the key drivers and barriers affecting the uptake of energy efficiency opportunities?

Gold industry specific key questions:

- 4 What is the gold industry's current performance with regards to energy consumption and GHG emissions?
- 5 What opportunities exist for energy efficiency within South Africa's gold sub-sector and what are the drivers and barriers affecting their uptake
- 6 What are the perspectives' of key decision makers within South Africa's gold-sub-sector on the available EE opportunities as well as the drivers and barriers affecting their uptake?
- 7 What steps can be taken to improve the uptake of EE opportunities within South Africa's gold sub-sector?

The approach to answering the above questions and thus achieving the overarching objective of this thesis is provided below.

1.2.3 Research approach and scope

This study was comprised of two main research components, namely a generic literature review and assessment (part 1), and a detailed case study of the gold industry in South Africa (part 2).

Part 1: The literature review and assessment aimed to provide background knowledge and consolidate existing knowledge on energy efficiency in South Africa's mining and mineral beneficiation industry with a view to addressing the first 3 generic industry key questions. More specifically this review set out to identify and assess potential drivers, barriers and opportunities for increased EE and mitigation of GHG emissions in the local minerals industry.

Part 2: The findings of the generic literature review formed the basis for the detailed case study of the gold sub-sector. This sub-sector was selected due to its national economic significance, and the extensive challenges it faces with respect to improving its energy efficiency, within the context of its declining ore reserve and grades.

This study was of the gold sub-sector only and did not include research into other sub-sectors of the mineral industry. The case study of the gold sub-sector was carried out in three tasks.

Firstly, an introduction to the sub-sector was provided in which the production and revenue trends, energy efficiency, energy breakdown and the specific energy challenge faced by the industry were explored. A desktop study of South Africa's three biggest gold mining companies was subsequently conducted. This comprised a review and analysis of energy and GHG emissions related performance data contained within publicly available company reports to address key question 4. This was followed by an interview and survey investigation with external consultants and in-house company representatives with a view to addressing key questions 5 and 6.

Finally, the understandings and information gained from these studies was used to make recommendations for the improved uptake of EE opportunities by the South African gold industry sub-sector, in an attempt to answer key question 7.

1.3 Thesis Layout

The approach to fulfilling the aims and scope of this study, as outlined in the previous subsection, is closely reflected in the thesis layout, as represented schematically in Figure 3.

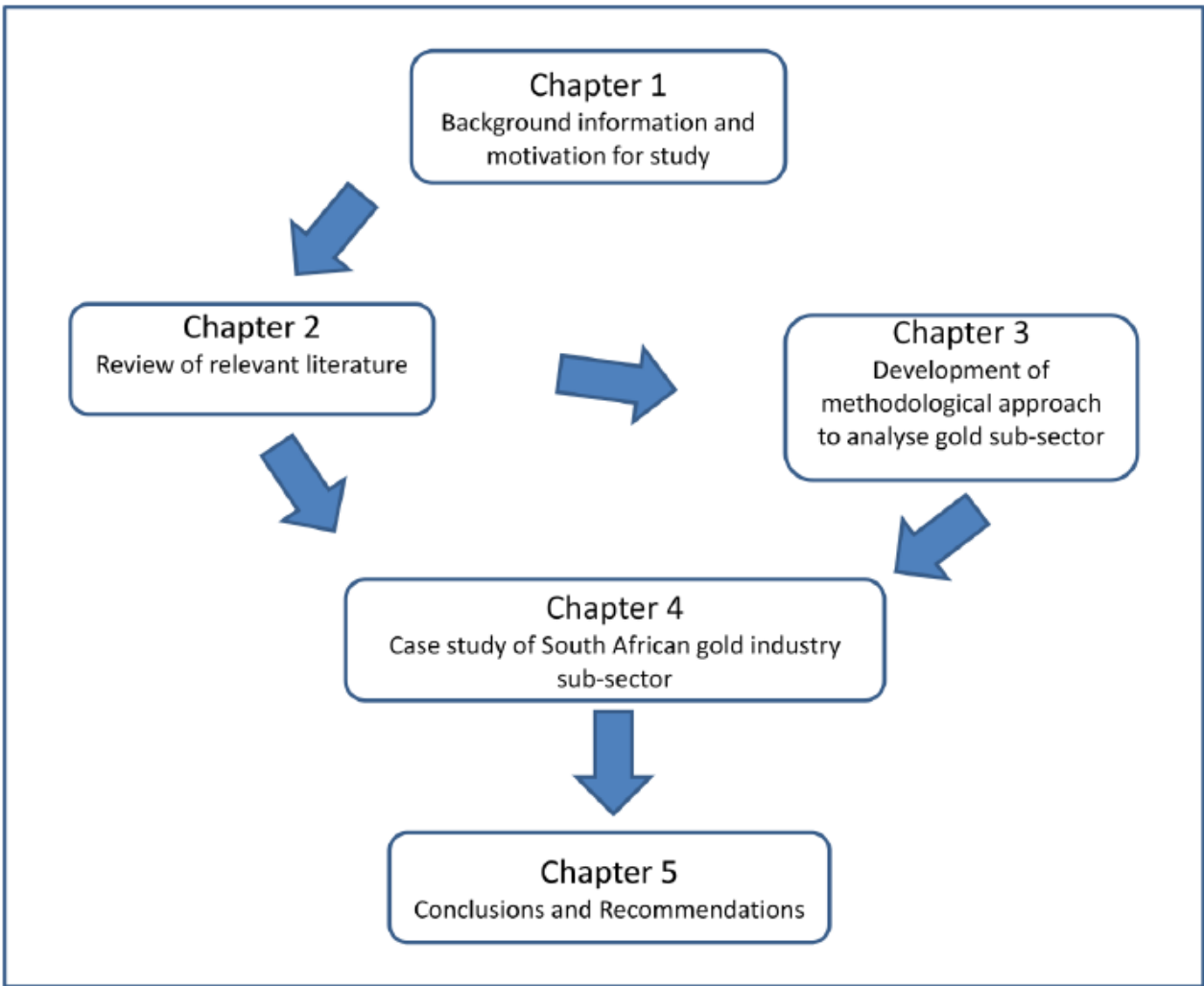


Figure 3: Schematic representation of the thesis structure

2 LITERATURE REVIEW

Chapter 1 provided the motivation to improve the EE of South Africa's primary minerals industry particularly its gold sub-sector. This chapter provides the background to responses to the need for mitigation of greenhouse gas emissions, as well as South Africa's energy crisis. It then explores the questions as to the role energy efficiency, specifically industrial energy efficiency, can play in mitigating greenhouse gas emissions, addressing the national energy crisis. It then focuses on energy efficiency in the mineral industry and answers the key questions around the existing opportunities for energy efficiency within South Africa's mineral industry as well as those surrounding the drivers and barriers affecting the uptake of EE opportunities within the mineral industry.

2.1 Greenhouse gas emissions and the energy crisis: International and national responses

Energy and greenhouse gas emission mitigation are both national and international issues with resource depletion and climate change driving the move to cleaner and more energy efficient energy production and usage. This section outlines global and national responses to the issue, and the potential role of EE in mitigation.

2.1.1 International mitigation pledges and commitments

Internationally there has been a shift towards more sustainable and "cleaner" energy. This shift has come about with the knowledge that a diverse energy supply is the best way to ensure a constant and secure supply of energy, and the awareness of the significant environmental impacts of a fossil fuel based energy sector (DME 1998).

One of the key international agreements target at reducing the global greenhouse gas emissions is the Kyoto Protocol, which was initially adopted in 1997 and came into force in 2005. Under the Protocol 37 developed nations (Annex 1 countries) committed to reducing GHG emissions by 5.2% by 2012 from 1990 levels (UN 1998). However the uncertainty beyond 2012 and the lack of a global agreement on targets and enabling policies have meant that the implementation of a more forceful response to GHG emissions has not been achieved (RSA Government 2010). The South African government recognition of the importance of a global effort to effectively reduce GHG emissions is reflected in the 2010 National Climate Change Response White Paper in which it is stated: "Stabilization of greenhouse gas concentrations in the atmosphere at a level that prevents dangerous anthropogenic interference with the climate system will require the efficient international implementation of an effective and binding global agreement on among others, greenhouse gas emissions reductions" (RSA Government 2011). Internationally it is the European Union (EU) who has led the way with regards to maximising energy efficiency and reducing GHG emissions. As of 2005 China and the USA used more than 500% and 50% respectively, more energy than EU to produce one unit of GDP (European Commission 2005). The EU

has agreed binding targets for a 5% reduction in GHG emissions by 2012 and implemented a carbon cap and trade scheme (UN 1998). The EU Commission has formulated a 2020 plan for a 20% reduction in emissions relative to 1994 levels, a 20% increase in energy efficiency, and a 20% increase in the uptake of renewable energy (RSA Government 2010).

2.1.2 Commitments and targets in South Africa

South Africa is a signatory to the United Nations Framework Convention on Climate Change as well as the Kyoto Protocol (UN 1998). The South African government has stated in the National Climate Change Response White Paper that an effective response to climate change requires national policy in order to ensure a coordinated, coherent, efficient and effective response to the global challenge of climate change (RSA Government 2011). In accordance with this White Paper, the government recognises that there will be costs associated with reductions in GHG emissions, but has stated that it considered these costs to be far less than the costs resulting from delaying action over global warming issues (RSA Government 2011).

Due to South Africa's status as a developing nation (Annex 2 country) under the Kyoto Protocol, it has of yet no international requirements for reducing its energy and GHG emissions. This status is likely to change post 2015. It has however committed to actions that would result in a 34% GHG emissions reduction relative to forecasted business as usual trends by 2020 and 42% by 2025. However, South Africa has stated that achieving these targets are subject to technical and financial support from developed countries (RSA Government 2011).

One of the key issues needing to be addressed in order to meet the above targets from a supply side is the extremely large quantity of associated emissions from electricity produced by Eskom's² coal fired power stations. In 2010 a total of 2246 Mt of CO₂ was released from the burning of coal (Eskom 2011). The Integrated Resource Plan (IRP) sets out South Africa's current plan for construction of additional energy generating capacity for the period 2010 to 2030. The Policy Adjusted plan detailed in the IRP, which is understood to be being pursued by South Africa at present, sets out the following targeted energy mix for South Africa by 2030 (these targets are in addition to all existing and committed power plants – including the 10 GW of committed coal power) (DoE 2010). This plan includes energy security and emission mitigation considerations that, if implemented, will considerably reduce the emission factor associated with electricity generation.

- 9.6 GW of nuclear
- 6.3 GW of coal
- 17.8 GW of renewable
- 8.9 GW of other generation sources

Figure 4 shows the IRP's targeted overall energy share per energy source by 2030.

² Eskom currently produces 95% of the total electricity produced in South Africa's (DoE 2012)

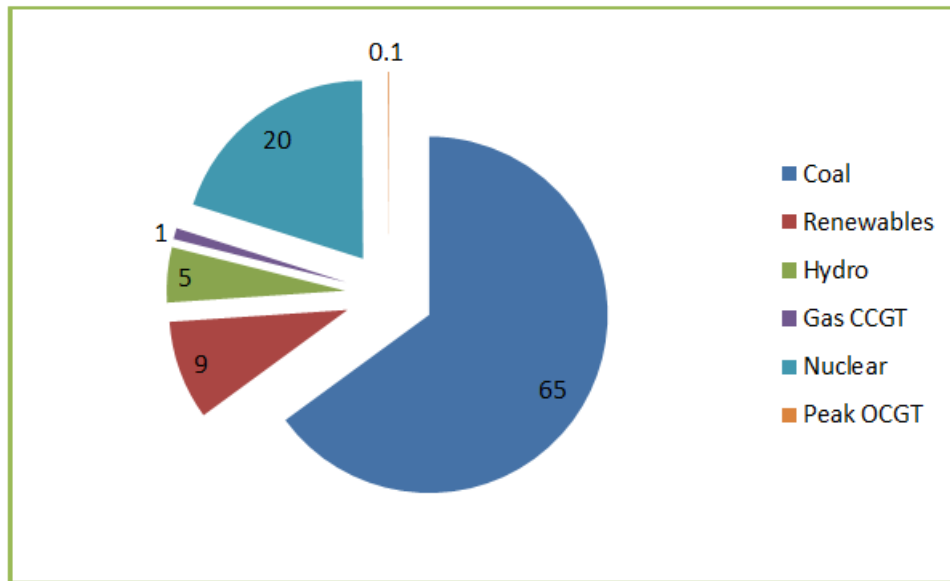


Figure 4: Targeted percentage energy share (by MWh) per source by 2030 (DoE 2010)

The above energy mix shows a 25% decrease from the current energy share provided from coal from approximately 90% down to 65% (DoE 2012). This decrease would lower the current electricity emission factor by approximately 20% and thus lower the emissions associated with electricity consumption by the mineral industry (DoE 2010, Letete et al undated).

2.1.3 Role EE has to play in South Africa's industry's response to climate change and energy shortages.

From a demand/industrial side, one of the cheapest and most effective ways of reducing GHG emissions is the effective implementation of improved EE measures (RSA Government 2011). Industrial energy efficiency can be simply explained as a reduction in demand for energy per unit of output produced (Winkler 2007). The LTMS identified the industrial sector as the sector to have the highest potential cumulative reduction in emissions from improved EE. The LTMS findings also showed industrial energy efficiency is a net negative cost mitigation action.

The Energy Efficiency Strategy (EES) was officially adopted by SA in March 2005. The EES aims for a national reduction of energy usage of 12% by 2015 compared to a projected "business as usual" trend. This trend is modelled on a projected annual increase of 2.8% economic growth (SECCP 2006). A proposed sector target of 15% has been set for industry and mining as a whole. These targets however rely on the voluntary participation of important role players in each sector, with no proposed penalties to be enforced on those who fail to meet the targets.

As illustrated in Table 1, the EES breaks down the 12% national target into sector specific targets. The "Potential Reduction" column of Table 1 indicates the perceived reduction

potential that could be achieved through improvements in energy efficiency up to international best practice standards.

Table 1: EES energy utilisation reduction targets (DME 2005)

Sector	Targeted Reductions	Potential Reduction
Industry & mining	15%	50%
Power generation	15%	*
Commercial & public buildings	15%	25%
Residential	10%	*
Transport	9%	*

The targeted 15% reduction for industry and mining is based on research which indicates the existence of potential energy savings of 11% through the use of low to medium-cost technical interventions, as well as an additional energy saving of between 5%-15% through no-cost and low-cost techniques of energy management and good housekeeping (DME 2008). The sub-sector target set specifically for the mining sector is a final energy demand reduction of 10% by 2015 (DME 2008)

2.2 Energy efficiency in South Africa

The previous section indicated the significance of South Africa's energy crisis, the international and national response to climate change as well as the potential of EE to help address these issues. This section focuses on national drivers for improved EE, as well as barriers and constraints hindering improved EE in South Africa towards answering the key question; what are the key drivers and barriers affecting the uptake of EE opportunities in South Africa's industry?

2.2.1 National drivers to reduce the energy consumption and associated GHG emissions of industry

The government has planned to use incentives and disincentives, through regulation and the use of economic and fiscal measures, to promote behaviour change that would support the transition to a low carbon society and economy, as well as provide support and help facilitate the GHG and energy intensity mitigation plans for the energy, transport and industrial sectors (DoE 2010).

Within South Africa's mineral industry high energy consumption and the associated GHG emissions lead to negative externalities. Without the use of external tools and policy the negative externalities generated as a by-product of a mining company's production is costless to that individual company. However these negative externalities have a significant

cost from a societal point of view. Instruments need to be applied to the industry to account for these negative externalities to avoid significant market failure (Cloete et al. 2010).

There are a number of instruments to reduce the energy consumption and associated GHG emissions of industry. These instruments can be classified into four general categories; pure regulation, instruments that use the market, instruments which create new markets and voluntary agreements (National Treasury 2006). All the instruments within each category have the potential to reduce energy consumption and associated GHG emissions, though they differ on the mechanisms used to achieve these reductions. Each instruments will typically use at least one of the following three mechanisms; price, quantity or technology (Cloete, Robb & Tyler 2010). Table 2 provides an overview of the different categories of instruments aiming to reduce energy and GHG emissions.

Table 2: Categorized instruments with a description on how they aim to reduce energy consumption and GHG emissions. Adapted from (Cloete et al. 2010).

Instrument category	Instrument name	Description	Mechanism to reduce emissions
Legislation and Regulation	Performance standard	Regulator sets some kind of target for the level of energy consumption and/ or emissions that producers must comply with or face penalties	Quantity
	Technology standards	Regulator determines minimum technological standards that producers must comply with or face penalties	Technology
	Information disclosure	Labelling requirements informs consumers about the carbon content of goods. This may lead to substitution towards less carbon-intensive goods.	Quantity/ Price
Existing markets	Taxes	A tax is set on emissions to force producers to internalise the full cost of their activities	Price
	Subsidies	Incentives are provided to subsidise the cost to producers of reducing energy consumption and/or GHG emissions or to encourage R&D in climate-friendly technologies. Subsidies can include public or private funding provided to science councils, universities etc. to advance research focused on GHG mitigation.	Price
New markets	Cap and trade schemes	A certain cap on emissions quantities is determined and producers then face a decision to reduce emissions internally, or purchase emission reduction permits from those able to beat their caps more cost effectively.	Quantity

Voluntary agreements	Voluntary commitments	Mitigation activities voluntarily agreed to by producers. Often used in the early stages of environmental policy consideration to aid adaptation before more stringent measures are introduced. Can include government-led initiatives such as consumer awareness campaigns.	Quantity/ Technology/ Price
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The above table gives a brief overview of the instruments available, below each instrument category and its available tools are explored in more detail.

Legislation and regulation

Legislation and regulation is a key driver for industry to improve its environmental performance (Priyantha et al. 2004). It should be noted that it is not a case of more legislation but more effective legislation that will bring about improved standards, protection of the environment and innovation (Coakley et al. 2007). The key role of legislation should be to create the right conditions for change to occur within industry. Legislation should not focus on specific technologies or standards as these can end up complicating and thus hindering environmental improvement within industry (Coakley et al. 2007).

It is critical that governments have long term and clear policies around environmental improvements; this allows companies to take longer term and better informed decisions when it comes to investing in new EE improvements (Priyantha et al. 2004). Companies financial forecasting can be significantly affected by key variables such as the cost of electricity or level of carbon tax, thus to reduce the financial risk associated with EE projects it is important that companies receive clear information on these and other key variables from government.

New legislation and regulation will not perform as it was designed to if it is not implemented and enforced correctly (Coakley et al. 2007). Therefore new policy should only be introduced once a practical and effective process to implement and enforce it has been agreed on.

There are typically two types of legislation and regulation that can be used within industry namely:

- *Restrictions, bans and standards:* i.e. emission and discharge rate standards. These policies set a base limit/standard that companies must adhere to or face legal and/or financial consequences. However these policies provide no incentive for companies to go beyond the set standards, and on their own may hinder further environmental improvement (Coakley et al. 2007).
- *Trade policy:* Trade policy can help the movement towards improved EE by negotiating favourable tariff treatment for merchandise on the basis of energy and carbon footprint of merchandise (European Commission 2005).

Existing markets

Using markets can be an effective way of influencing industry without the necessity of using hard and fast laws to force industries compliance. The key options for using markets to increase the uptake of EE opportunities in South Africa include:

Carbon Tax: The appropriate taxation of emissions provides continuous incentives for companies to decrease both their energy consumption and GHG emissions. By reducing their energy consumption companies can reduce both their operating energy costs as well as associated tax on emissions resulting from their energyconsumption (Barclay et al. 2008).

Increasing electricity price: Locally, in 2008 electricity demand exceeded electricity supply for the first time in South Africa's modern history, leading to load shedding throughout the country. This shortage of supply has forced the price per unit of electrical energy to increase dramatically with increases of 24.8% for 2010, 25.8% for 2011 and 25.9% for 2012 (NERSA 2010). The increase in electricity price has, over the last five years, almost doubled the percentage of the operating budget spent on electricity by mining companies, providing significant financial incentives for the companies to reduce their energy consumption.

Eskom demand side management (DSM) funding: The DSM funding by Eskom is currently one of the biggest drivers for the implementation of EE opportunities in the mineral industry. Table 3shows the budget and energy targets the DSM program aims to spend and meet

Table 3: Eskom DSM Budget and targets until 2013(Visagie 2010)

	Year	2011	2012	2013	Total
Funding	R 000mil	1239	1576	2477	5292
Demand Saving	MW	301	313	459	1073
Energy Saving	GWh	995	1280	1827	4102

As indicated in Table 4DSM funding is targeted at specific programs, with each program having a benchmark funding amount. Currently Eskom will pay 100% of the allocated benchmark per MW of electricity saved; any additional costs for the project must be covered by the company itself.

Table 4: Programs with benchmark funding(Visagie 2010)

Programmes	Funding offered
Lighting & HVAC	Up to R5.2million/MW
Hot Water	Up to R6.3million/MW
Demand Response	Up to R3.5million/MW
Compressed Air	Up to R4.4million/MW
Process Optimisation	Up to R5.2million/MW
Other	Up to R5.2million/MW

New markets

Another way to reduce energy and GHG emissions is to create new markets. The key potential instrument for this task in South Africa is the Clean Development Mechanism (CDM), which was developed under the Kyoto Protocol.

The CDM is a mechanism whereby a company from an Annex I country may purchase emission reductions credits which arise from projects located in non-Annex I countries. The carbon credits that are generated by a CDM project are termed Certified Emission Reductions (CERs), expressed in tonnes of CO₂ equivalent (tCO_{2e}) (Greiner et al. 2000).

In order for a project to generate CERs, it must provide proof of reduction in GHG emissions. It must also prove that its emission reductions are additional to any emission reduction that would occur in the absence of the CDM project. To do this it must undergo a rigorous process of documentation and approval by a variety of local and international stakeholders (UNEP 2007).

The uncertainty of what will happen post 2012 and the Kyoto Protocol and its impact to the value of CER's as well as the time and effort required to correctly follow the stringent CDM processes means that currently CDM projects from a mineral industry perspective are risky and difficult to implement.

Voluntary agreements

Voluntary targets are typically set through agreements reached within particular industries or between government and industry. Voluntary targets offer industry a good chance to improve their standing with government and play a significant role in their own target setting. Voluntary agreements can lead to setting of standards and prerequisites within industry which are typically established by industry formed councils or associations (Coakley et al. 2007).

Public pressures

Along with government and industry, the public also have the potential to drive change in industry. Organisational managers have recognised for a number of decades that congruency between an organisation's actions and the values of the relevant public are essential to an organisation's continued existence (Lindblom 1984).

Mining organisations run and create profit via the extraction and depletion of non-renewable natural mineral resources. They discharge considerable quantities of harmful waste and are exceedingly energy intensive. These issues raise a number of concerns over the sustainability of the mining industry from a social perspective (Jenkins & Yakovleva 2006).

The poor relationship between the mineral industry and the relevant public is beginning to generate significant pressure particularly from non-governmental organizations (NGO's) and local communities which is starting to have a significant impact on the mind-set and planning of mining companies (Jenkins & Yakovleva 2006). This pressure has enabled a number of companies to realise that environmental depletion protection and economic growth are not always in opposition (Mazurkiewicz 2005).

The importance companies place on creating a "greener image" particularly for overseas investors is increasing; this could potentially lead to increased expenditure on research and development (R&D) and the uptake of more EE projects. Alternatively this pressure may lead companies into "green-washing" their image and public reports (a process in which bold general statements and pictures are used to give a company a "greener" image without the company really improving its environmental performance).

2.2.2 Barriers and constraints to the uptake of energy efficiency opportunities

In this section significant factors from outside of the mineral industry with the ability to hinder the uptake of EE opportunities are identified and reviewed.

Uncertainty over the future pricing of electricity and carbon taxes

In whatever decision an organisation decides to take, no matter how in-depth and thorough the decision making process, there lies an element of uncertainty as to what exactly the future impacts of that decision will be (Kempener 2008). Thus all decisions contain some element of risk. According to Singh (1986), risk is a fundamental occurrence in bringing about innovation in a company. This is supported by Kempener (2008), who states that there is a typically a high level of uncertainty involved with the newness of innovation.

This inherent uncertainty around decisions made by companies particularly in areas of innovation, in which EE projects exist, is compounded by a lack of certainty about the future electricity prices. The official increases in electricity price have only been provided by NERSA until 2012 and although the price of electricity is expected to rise in South Africa

post 2012 the scale of increases are currently unknown(NERSA 2010). The government is also currently reviewing introducing a carbon tax or a cap and trade scheme, however it is unknown if or when one of these two measures will be implemented nor how severe the tax, or how low the cap would be if they were implemented.

These issues add significant uncertainties for companies trying to financially evaluate the feasibility of long term EE opportunities, thus potentially reducing the number of opportunities matching the financial hurdle rate set by each individual company. When uncertainties exist companies will typically follow the more conservative option when it comes to determining how heavily to invest in new EE projects.

Uncertainty and risk of new technology

There is a generally accepted proposition that new technology or technology innovation is characterized by a degree of uncertainty (Rosenberg 1996). When companies need to decide on a major facility investment they will typically face a dilemma if a new and superior process technology may be available in the near future. This new technology if successfully developed could leave their recent investment obsolete, making it in retrospect a poor investment, however waiting for a new technology to become available may result in lost profits in the interim(Gardner &Buzacott 1999).

There is a risk that an unproven technology may perform below its technical specifications, entirely fail or be incompatible with existing technologies, thus there is the risk and return trade off to be considered when evaluating projects when there is uncertainty around its reproducibility(Rosenberg 1996).

Lack of legislation or regulatory control

The South African government has of yet not imposed hard and fast targets on the South African mineral industry around the reduction of energy and GHG emissions. It has though set soft targets that rely on the voluntary participation of key industrial role players (DME 2008). This means that there is no real incentive for companies, other than reducing their operating costs and having a greener image, to reduce their energy or GHG emissions. This severely limits the number of new EE opportunities that mining companies will view as practical.

Access to external finance for process innovation

Banks typically lack knowledge of EE technologies, and consider such specialized knowledge outside of the scope of their operational interest. Existing procedural frameworks within banks vary and banks are reluctant to alter them. To be operated effectively, new lines of business must be compatible with existing systems. Major banks currently view EE projects as relatively small niche business and as of yet do not have experienced teams to effectively carry them out (Robert et al. 2008).This leads to a situation in which companies that can't fund new EE projects internally have difficulty gaining banks approvals for loans to

fund these projects, thus reducing the number of new EE projects being implemented (Robert et al. 2008). This typically complicated and long investment approval procedure makes it easier for companies to repair old inefficient technologies than purchase new efficient ones.

2.3 Energy efficiency opportunities in the local mining industry

Due to the lack of significant change within South Africa's mineral industry and thus the old age of a large proportion of mining equipment, it is suggested here that there exist significant opportunities to reduce the energy consumption and thus the associated GHG emissions of the industry. It has been demonstrated that improved energy-efficiency saves money, increases the reliability of operations and has a positive effect on productivity and competitiveness.

In this section identified EE opportunities for South Africa's mineral industry are split into three sections namely; Effective Management, Technical and Long term opportunities.

2.3.1 Effective management opportunities for improved EE

There is a wide range of possible opportunities available for improved EE, particularly for a mining organisation. It is thus critical for decision makers to prioritise EE programs. Barclay et al. (2008) gives three priority brackets from highest to lowest priority which industrial decision makers involved with EE should follow.

- Priority 1 – Quick wins with very short paybacks, mostly by optimising existing equipment and processes
- Priority 2 – Opportunities requiring some capital investment with medium term payback periods
- Priority 3 – High capital expenditure on long-term solutions which can cause significant change

Effective management opportunities fall within priority 1 opportunities. These management opportunities include improved employee education, incentive schemes, increased R&D expenditure, effective maintenance, improved layout of equipment as well as more efficient lighting and lighting control systems. The effective implementation of these management opportunities is one of the cheapest ways to improve the EE of an industrial facility. In order to implement an effective energy management plan (EMP) it is important that companies have the appropriate monitoring equipment to receive automatic, timely information, at a granularity that makes it easier to identify EE opportunities, reduce energy costs and better predict energy use during the processes of mineral beneficiation (Sterling 2009). For these energy indicators to be relevant to employees and the company they should be simultaneously: global, detailed by areas, relevant from the energy consumption point of view, representative of an area or process or important machine, allow for comparison and be linked to an instrumentation system ensuring the energy consumption measuring of an area (Maldonado 2005). Having an accurate baseline for the energy consumption of current

processes is crucial for making comparison with new EE technologies and thus evaluating the feasibility of upgrading.

Without an EMP, opportunities to reduce energy consumption may go unrecognised or may not be promoted and implemented due to organizational barriers (McKane et al. 2008). The implementation of an EMP has shown a potential to improve the energy efficiency of industrial systems by 20% (McKane 2007). This makes it critical that company leaders have the right motivation and skills to implement an EMP.

2.3.2 Technical opportunities for improved EE

The implementation of new and more efficient technologies as well as the optimizing of current technical systems is a key area in reducing the energy consumption of the mining industry.

Utilities

The technical systems that support industrial processes include; - compressed air, pumping, and fan systems (motor systems)-, steam systems, and process heating system (McKane et al. 2008). The LTMS identified the potential for improved EE for a variety of industrial technologies which are indicated Table 5 (Winkler 2007).

Table 5: Overall potential of industrial efficiency improvements, distinguishing technology efficiency and system savings (Winkler 2007)

	2015	2030	2050
Boilers and steam systems	10, 10%	16, 16%	20, 20%
Compressed air	7.5, 7.5%	16, 16%	20, 20%
Process heat	3%	4%	5%
HVAC	12%	18%	25%
HVAC with waste heat	0%	10%	30%
Lighting	30, 10%	70, 10%	75, 10%
Other motive	9%	11%	15%
Pumping, fans (process flow)	10%	25%	40%
Process cooling	5%	7%	10%

Note: Only one percentage is given when technology efficiency and systems savings are equivalent.

The EE in boilers and boiler house systems can be improved in a number of ways including; repairing water and steam leaks, recovering heat from flue gas and boiler blow-down whenever possible, taking the valve's off idle boilers to reduce radiation loss and ensuring adequate insulation of system.

Industrial compressed air systems are a technical area within industry in which significant EE opportunities exist. The energy consumption of a compressed air system can typically be reduced by 10-20% for a very low capital outlay (Energy Research Institute 2010). These EE savings can be achieved by regular maintenance to improve compression efficiency, air leakage or pressure variability. Leaks can cause significant wastage of energy up to 30% of compressors output. Between 80 and 93% of electrical energy consumed by an industrial air compressor is converted into heat. Thus a heat recovery unit can recover between 50-90% of waste heat and use it to heat air or water (Energy Research Institute 2010).

Savings in energy used for air-conditioning and ventilation, which are the biggest users of energy in underground mines (Natural Resources Canada, 2005), can be achieved through the application of frequency converters in the mine ventilation; this process has the potential total savings estimated amount to 35% (Maldonado 2005). Another option is to ensure that the system uses the free cooling effect of outside air when possible (Energy Research Institute 2010).

For energy saving for refrigeration it is important to have adequate monitoring equipment installed on the plant, ensure good and regular maintenance, utilise waste heat where possible and improve thermal insulation.

Motors systems and drives, as indicated by the above table, are another potential area in which significant technical opportunities for improving EE exist. Energy savings in these areas can be achieved by switching off motors when not needed, selecting correctly sized motors, the use of high efficiency motors when operating for long periods at high loads, the use of variable speed drives -particularly for instances where fan or pump loads vary- and ensuring motors run between 75% and full load as they are most efficient within those conditions (Energy Research Institute 2010). Table 6 shows an evaluation of high EE motors in the USA (Maldonado 2005).

Table 6: Total economic savings of installing per new efficient motor system(Maldonado 2005)

Type of benefit	Economic Savings (US\$/year)
Failure Reduction	430
Increased maintenance time span	175
Reduction of unproductive time due to predictive maintenance	135
Energy Savings	145

The results of the study show that energy savings are one of many savings resulting from the replacement of old inefficient motors with new efficient ones.

Table 6 indicates the importance of viewing the holistic benefits an EE opportunity may bring including; failure reduction, reduced maintenance and improved productivity.

There is also significant room to save energy in South African mines by optimizing the technical performance of the current processes. Improvement to the technical operational control during mineral concentration for primary and secondary crushing, tertiary and quaternary crushing, conventional milling, unitary milling, SAG milling and flotation can result in an estimated energy savings of between 12 and 14% (Maldonado 2005).

Power factor corrections can be made to optimize energy savings. Capacitors can be installed on low quantity inductive devices to offset the reactive power that they require. For facilities with high quantities of inductive devices, the automatic power-factor correction devices that sense demand for reactive power and then switch in banks of fixed capacitors to balance the inductive load should be used (Energy Research Institute 2010).

For EE improvements to be made in these utility systems, a number of specific technical improvements need to be made.

Cross-cutting technical energy efficiency opportunities

Table 7 shows a general technology list of cross-cutting energy efficiency opportunities for industry, giving the technologies general energy saving ability, stage of development, and

expected payback period³(Martin et al. 2000). This gives some indication of the multitude of available crosscutting technologies for improving the EE of the mineral industry.

Table 7: Summary of profiled emerging energy-efficient industrial technologies(Martin et al. 2000)

Emerging energy-efficient industrial technologies	Total Energy Savings	Other benefits	Suggested next step	Likelihood of success	Simple Payback (Years)
Hi-tech facilities HVAC	Medium	P	Dissemination	Medium	4
Advanced lighting technologies	High	P, Q, O	Dissemination.	Medium	1.3
Variable wall mining machine	Low	P, S	Demo	Low	10.6
Advance ASD designs	High	P, Q	R&D	High	1.1
Advanced compressor controls	Medium	P, Q	Dissemination.	Medium	0
Compressed air system management	High	P, Q	Dissemination.	Medium	0.4
Motor diagnostics	Low	P, Q	Dissemination. Demo	High	Immediate
Motor system optimization	High	P, Q	Dissemination. Train	Medium	1.5
Pump efficiency improvement	High	P, Q	Dissemination. Train	Medium	3
Switched reluctance motor	Medium	P, Q	R&D	Medium	7.4
Advanced lubricants	Medium	P, Q	Dissemination.	Medium	0.1
Anaerobic waste water treatment	Medium	O	Dissemination. Demo	High	0.8
High-efficiency/low	High	P	Dissemination. Demo	Medium	3.1

³Payback period here refers to the required time for the return of the investment of the opportunity to repay the sum of the original capital investment of the opportunity

NOx burners					
Membrane technology wastewater	High	P	Dissemination. R&D	High	4.7
Process integration (pinch)	High	P	Dissemination.	Medium	2.3
Sensors and controls	High	P, Q	Dissemination. , R&D, demo	High	2
Advanced CHP turbine systems	High	P, Q	Policies	High	6.9
Advanced reciprocating engines	High	P, Q, O	R&D, demo	Medium	8.3
Fuel cells	High	P, Q	Demo	Medium	58.6
Microturbines	High	P, Q, O	R&D, demo	Medium	Never

Notes

- 1) "High" could save more than 0.1% of manufacturing energy use by 2015, "medium" saves 0.01 to 0.1%, and "low" saves less than 0.01%.
- 2) "High" could save more than 1% of sector energy use by 2015, "medium" saves 0.1 to 1%, and "low" saves less than 0.1%.
- 3) "P"=productivity, "Q"=quality, "S"=safety, and "O"=other.

Extraction and beneficiation technologies and processes

Innovation in South Africa's mineral industry is vital if the industry is to be competitive in the global economy. As in other industries, competitive advantage can be gained through the development of new products, adoption and use of new technologies and improvements to industrial processes. One example where process innovation could lead to improved EE is Comminution.

Comminution

Comminution (the process in which particle size of the ore is progressively reduced by crushing and grinding) is extremely energy intensive and can use approximately 30- 40% of the total energy of a mining operations (Hilden, Powell 2008). In general in the mining and minerals processing industry, the comminution process remains inherently inefficient with approximately 85% of the energy input dissipated as heat, 12% attributed to mechanical loss and only 1% of the energy actually used in the size reduction of feed material (Alvarado et al. 1998).

Pokrajcic(2008) has carried out testing on two approaches that can be used in the design of comminution circuits for improved efficiency and a reduction in the total energy consumption. The first approach entailed a modified grinding strategy where efficient grinding equipment is used and techniques employed to decrease grinding media energy consumption. In the case study investigated by Pokrajcic (2008) for the beneficiation of a sample of rod mill discharge from Mount Isa in Queensland, Australia, a high pressure grinding rolls (HPGR) unit was used to generate a product distribution with a narrower size range. Ways to minimize the load in grinding mills as well as the use of autogenous grinding (AG) techniques to decrease indirect energy consumption were investigated.

The findings showed that the eco-efficient moderation of the existing semi-autogenous milling-crushing circuit prompted an improvement in the floatation performance by 2%, as well as a 35% reduction in direct energy saving and a 79% savings in indirect energy based on media and liner wear.

The second approach proposed by Pokrajcic (2008) entailed a more integrated and holistic selection of optimum target product size for a comminution circuit based on a better understanding and interpretation of mineral liberation data. The finding of this investigation showed a potential energy saving of approximately 66%, due to a rejection of approximately 50% of the liberated non-sulphide gangue (primarily coarse) at the head of the separation circuit before further grinding.

High pressure grinding rolls (HPGR) are widely considered more efficient than tumbling mills such as SAG mills. HPGR units have been installed in three different mines around the world – Cerro Verde: Copper mine (Peru), Mogolokwane: Platinum mine (South Africa) and Grasberg: Copper and gold mine (Indonesia) - and have been reported to have energy savings of approximately 19% over more conventional grinding routes (Hilden and Powell 2008).

Rock crushing is a processing area offering significant opportunities for reducing energy costs. Typically between 1 and 2 % of the total energy supplied to rock during comminution is effectively utilized for fracturing (Tromans & Meech 2002). Work is being done by Djordjevic, investigating the accumulation of thermal energy in rock, using an advanced thermal imaging camera. It is hoped that a better understanding of heat losses, will generate options for modification of operational and equipment parameters of comminution equipment to reduce heat losses and improve efficiency of rock crushing. Their results indicate that energy savings of up to 40% can be achieved through optimization of the applied pressure and modification of the feed size (Djordjevic 2008).

Another way to potentially reduce the energy consumption during mineral beneficiation is underground processing.

Underground processing

The idea behind underground processing is to pre-concentrate the ore underground as close as possible to the working areas, and just take the small proportion of ore containing valuable mineral to the surface, where it is then treated intensively. The advantages of conducting at least part of the processing phase of mineral beneficiation underground are numerous. It lowers reduction, hoisting and haulage due to lower tonnage, decreases the required size of surface plant capacity due to higher grade and removes the necessity for backfill to be produced on the surface and sent back underground (Hughes & Cormack 2008). Underground processing has the potential to reduce power consumption by 50% when compared with conventional milling power consumption (Hughes & Grigg 2008). However the deeper mines go the hotter the mines become, which then increases the energy requirement for ventilation and cooling. Thus a possible way to reduce the energy consumption of future mining great depths is to use robots instead of people to mine. This would take away the need for ventilation and cooling.

Robotic mining

The deeper mining companies need to go to access available mineral deposits the hotter the mining sites get, thus necessitating more advanced and expensive ventilation and cooling systems. Mines are investigating the idea of robotic mining which would remove the need for energy intensive processes such as ventilation and cooling as there would be no people down at the rock face (Paul 2010). This would significantly reduce the amount of energy required to work at extreme depths of up to 5 kilometres.

2.3.3 Identification of drivers for and constraints to the uptake of EE opportunities in the mineral industry

In this section the generic factors influencing the uptake and realisation of EE opportunities within the mineral industry, as opposed to factors outside the mineral industry explored in section 2.1.1, are identified and reviewed.

The effect of skills and technology development on the uptake of EE opportunities

Before an EE opportunity can be evaluated and implemented it must first be identified. EE opportunities are often ignored simply because industry is unaware that they exist (DME 2008). The first step in identifying opportunities is to conduct an onsite investigation. This process should include the benchmarking of all major onsite energy consuming components. These benchmarks can then be compared with new technologies and the theoretical optimal performance of the current system. Informed recommendation can then be made on which opportunities to evaluate further (Barclay et al. 2008).

A key driver for realizing the potential of available EE opportunities is thus higher in-house levels of independent quality technical support and information around new technologies. This support would go some way in overcoming a misconception frequently encountered in industry that EE will disrupt the production processes and that changes should only be made

when absolutely necessary (DME 2008). Effective implementation of improved technical support and information around new technologies would assist in increasing the rate at which the diffusion of new technologies occurs at in the mineral industry. Mineral companies must find the right balance between the deployment and diffusion of known, cost-competitive technologies for the near-term, and innovation and development of new technologies for the longer-term (Lazarus & Kartha 2009).

However the uncertainty over the compatibility between new cleaner technologies and existing technologies is an important consideration that mines need to make (Joint Research Centre 2004). Mineral processing companies have typically invested significant capital into their current production processes, which have significant life spans. There exists certainty in the performance of current technologies in mineral processing companies as the performance of these technologies would have been monitored and tracked. Thus management typically perceives there to be significant risk from changing the status quo of using known technologies with the unknown of new technologies (McKane et al. 2009). This adds to industry's apprehension about prematurely retiring capital.

Systems that support industrial processes typically are engineered for reliability rather than EE. EE technologies are often regarded as a luxury that industry can't afford during lean times (McKane et al. 2009). However it has been found that new EE technologies in industrial systems are typically more reliable and perform better than less efficient ones (McKane et al. 2009). Aside from improved skills, the uptake of EE opportunities can also be significantly affected by corporate policies and strategies.

Corporate policies and strategies

There are a number of processes that need to be in place to ensure a company's corporate framework is structured in a way that promotes EE including; commitment to EE from all levels of staff, improved communication between different levels and sectors of employees, incorporation of in-house training programs, running of regular awareness raising campaigns as well as giving incentives to employees who obtain energy reductions greater than the set targets according to chosen energy indicators (Barclay et al. 2008).

All these issues would typically fall within the scope of an effective Environmental Management Programme (EMP). For an EMP to be effective in mineral processing companies it is imperative that there is support and commitment from a corporate level, as it is typically from a corporate level that EE targets are set and the budget allocation dedicated for new projects decided on. An EMP exists to guide the internal implementation of activities undertaken to achieve energy saving targets. An effective EMP should include a status quo or baseline consumption of a facility's biggest consumers as well as effective monitoring to allow a high level of process control. Optimised process control is a prerequisite to improving efficiency and environmental performance in the mineral industry. Process control is the technological and managerial capacity to continuously adjust process conditions so as to

optimize overall performance. Achieving effective process control relies on the monitoring and processing of reliable, real-time information on operations and the capacity to adjust and maintain desired levels of performance (Warhurst & Bridge 1996). An effective EMP should also include the evaluation of EE measures considered, a description of the proposed EE measures, a time frame for the implementation of EE programmes and the expected results for the programmes (Maldonado 2005).

Once an EE opportunity is implemented it is important that the EMP provides programmes to continually train new employees and adapt the system to production change - otherwise the system will lose its initial efficiency gains over time (Maldonado 2005). Other barriers hindering an effective EMP include: poor communication among plants, limited finances and a lack of understanding on how to create support for an EE project (McKane et al. 2008).

Stakeholders in the minerals industry have divergent agendas and there is still a lack of knowledge about the environment, in particular relating to best practices (Dijkema et al. 2006). This lack of knowledge around environmental best practices is compounded by the fact that the success or failure of EE opportunities typically takes a number of years to accurately assess. This can make investors reluctant to tie-up financial resources in long-term EE projects (DME 2008). Normally EE opportunities are evaluated and implemented by a group of individuals, thus there is typically a lack of ownership of EE projects resulting in poor accountability for the measures implemented. The lack of knowledge and accountability of projects is made worse by the lack of adequate EE incentives which are usually insufficient to promote innovation, and don't reward individuals who promote and implement EE projects (Centre for Energy Efficiency 2001).

A key driver for EE from a corporate perspective is operational resilience and energy security. This has become apparent since the forced mine closures of 2007. Mines feel that by improving their EE and thus reducing their total energy consumption they will considerably reduce the likelihood that Eskom will need to shut down their operations. Another key issue driving corporate EE is the reputational benefits associated for companies that reduce their energy and GHG emissions. Particularly as investors from first world countries are becoming more and more concerned with the environmental performance of the companies they invest in. An increase in R&D expenditure has been shown to be an important driver for improved EE by the Joint Research Centre who found that there was a direct link between R&D expenditure and the rate of expenditure on environmental friendly technologies (McKane et al. 2008). A company's willingness to invest in potential drivers such as R&D is typically dependent on a number of financial factors.

Financial factors

A mining company's first priority, like any business, is to make a profit. Mining companies are typically owned by shareholders who invest in the mining company primarily because of the financial returns they believe they can make on their investments. The financial

performance of a mining company can be improved by increasing the competitive advantage and thus market share of the company, reducing the company's operating costs or bringing in outside funding. Thus a key area when evaluating a potential investment is the investment's effect on the financial performance of the company.

Electricity consumption, which is a significant operating expense for underground mining operations, is reduced by improved EE. The level of potential savings in operating expenses due to optimized EE is currently growing with significant increases in the electricity price. The ability of EE to reduce GHG emissions could potentially become an even more important method for mining companies to reduce their operating expenses with the potential introduction of a carbon tax (Robert et al. 2008).

Another financially related barrier to the uptake of EE opportunities is companies' aversion to being the first to develop and implement a new technology. Companies do not want to go through the expensive process of figuring out the best way of implementing new technologies. They would prefer to wait until a competitor has gone through the process and then learn from their mistakes without having to take the risk of the new technology failing. Inadequate awareness of the financial or qualitative benefits arising from EE programmes within mineral processing companies can considerably reduce the number of viable EE projects implemented.

Companies typically have limited capital available and a corporate mind-set leading to greater investment in new production capacities rather than EE. This leads to there being significant competition for capital between potential projects within mineral processing companies. There is also typically greater weight given to addressing upfront costs compared to recurring energy costs, especially if these costs are a small proportion of production costs. The difficulty EE projects have for obtaining funding is compounded by the fact that clear and proven financial benefits do not exist yet for many new technologies. There is thus an uncertainty of the exact savings in operating expenses that the new technologies will produce. This competition between projects makes it important to understand the decision process companies follow before approving a project, to identify what can be done to improve the chances of investments being made in EE projects.

Industrial decision-making

In general it is difficult to obtain and comprehend all of the information that is needed to make strategic decisions in a large organization (Quinn 1980). The strategic decision-making process typically requires contributions from people with a wide range of expertise and from numerous decision-making levels. This is particularly true for the mineral industry where the wide variety and large number of stakeholders as well as the necessity to consider a number of competing objectives, adds significantly to the complexity of the decision-making process. There is also uncertainty over future national and international responses to climate change and EE. This uncertainty is compounded by the risks associated with the performance of

new technologies. All these factors add to the challenges facing decision-makers in evaluating and selecting EE options.

Key issues for mineral industry specific decision making include: (Smith et al. 2006)

- The optimal scale of operations
- Technology selection and associated mining layouts
- The influence of existing asset base
- Identification of consequences for downstream recovery processes and other critical interfaces such as skills resourcing

The above list gives some indication of the complex nature of decision-making within South Africa's mineral industry.

For robust and well-informed decisions to be made, it is also important that a high level of scenario planning and strategy be put in place.

Smith identifies three scenarios that should be developed for a strategic mine operation plan(Smith et al. 2006).

- **Upside scenario**—this scenario should embrace a justifiably optimistic perspective on metal pricing and all relevant economic parameters
- **Downside scenario**—the alternate view to the upside scenario encompasses situations such as price or quantity depression resulting from reduced market demand, oversupply and/or substitution
- **Best estimate**—the best estimate scenario should reflect the most pragmatic view of the project

The evaluation of these different scenarios allows more prudent decision making, with decision outcomes viewed not just according to their predicted outcome but according to their best and worst outcomes as well.

On reviewing potential projects, key decision makers will typically evaluate the available projects according to key criteria including:(Musingwini 2009).

- Net present value of the project
- Maintenance
- Payback period
- Internal rate of return
- Uncertainty and risk

These and other important criteriasuch as: The availability and reliability of information onalternative technologies, energy consumption reduction and ease of implementation, are then combined into a single real discount rate which either meets the company's set "hurdle rate"⁴ or does not. Thus it is important that EE projects have a high degree of eco-

⁴ A hurdle rate is the minimum rate of return on a project a manager or company is willing to accept before starting the project.

efficiency⁵ in order to effectively compete with other projects for the available capital (Joint Research Centre 2004).

2.4 Summary

It is clear from the review of South Africa's response to climate change and the energy crisis that a national move towards more energy efficient technologies is occurring. The introduction of energy efficiency and GHG emissions as important indicators is beginning to change the expectations that both the public and government have for companies. This pressure and the introduction of voluntary targets, as well as the expected introduction of stringent legislation in the near future around energy consumption and GHG emissions, has forced industrial companies to explore new opportunities for improving their environmental performance.

Energy efficiency has been shown to be one of the most effective ways to reduce GHG emission, with a negative cost mitigation action and a potential to reduce the energy consumption of industry and mining by more than 15% by 2015.

The primary minerals industry faces a particularly difficult challenge in reducing its energy consumption given the decreasing ore-grades and increasing mining depths at a number of operations. However, an effective energy management plan aligned with demand side management funding and the rising electricity price are continuing to making EE projects more economically viable.

There exist a number of EE opportunities within the minerals industry. These include a number of effective management opportunities including; the implementation of an effective energy management plan, employee education, preventive maintenance, accurate energy monitoring systems and incentive schemes. Technical opportunities for improved EE include; optimizing motor systems, process heating systems, steam systems, a host of other cross-cutting issues. There also exists long term opportunities such as underground processing, HPGR mills and robotic mining.

Drivers to improve the uptake of EE opportunities with industry these include; regulatory control around energy consumption, GHG emissions and information disclosure technology standards; implementation of a carbon tax and or cap and trade scheme; and, financial incentives such as tax cuts and rebates on research and development of clean technologies. Despite these drivers, in order to notably improve the uptake of EE opportunities,

⁵Eco-efficiency is achieved through the delivery of "competitively priced goods and services that satisfy human needs and bring quality of life while progressively reducing environmental impacts of goods and resource intensity throughout the entire life-cycle to a level at least in line with the Earth's estimated carrying capacity" (WBCSD).

industry must overcome the barriers associated with the EE opportunities such as; the uncertainty over future pricing of electricity, the risk and uncertainty associated with new technologies as well as the typically large capital investment of new technologies.

Effective investment decision-making in the mineral industry is becoming an increasingly complex process. There are a number of stakeholders and objectives that the decision process for a new investment should consider. EE projects have to compete for a company's available capital with a number of other investment opportunities, thus the reduction in energy consumption and GHG emissions forms just two of a number of considerations that a decision-maker takes into account when evaluating possible projects.

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3 METHODOLOGY

The literature review and assessment in Chapter 2 highlighted the role of energy efficiency in reducing energy consumption and global warming, and identified potential drivers, barriers and opportunities for increased EE in the local minerals industry. Using the insights gained from this review as a basis, a more in-depth study has been conducted for the specific case of the gold sub-sector, with a view to answering the key research questions 4-7, as described in Chapter 1. This chapter describes the approach and methodology used to conduct this case study. This methodology can be summarised in terms of three main tasks, as illustrated diagrammatically in Figure 8, and detailed in Sections 3.1 to 3.2:

Task 1: A background investigation into South Africa's gold sub-sector to: provide a context for EE and CO₂ emissions in the industry; identify the existing opportunities, drivers and barriers for EE within the sub-sector; and evaluate what role energy efficiency, in the sub-sector, has to play in South Africa's mineral industry's response to climate change and energy shortages

Task 2: A desktop study of key South African gold mining companies, to evaluate the trends in performance as measured against key performance indicators (KPIs) and thus determine the performance with regards to energy consumption and GHG emissions, of both the individual companies and the sub-sector as a whole.

Task 3: An interview and survey investigation, involving key energy experts, on selected South African gold mining companies. This investigation was carried out to determine the perspective of key decision makers within South Africa's gold sub-sector on the available EE opportunities as well as the drivers and barriers affecting their uptake.

As demonstrated in Figure 5, each of these tasks has a number of outcomes.

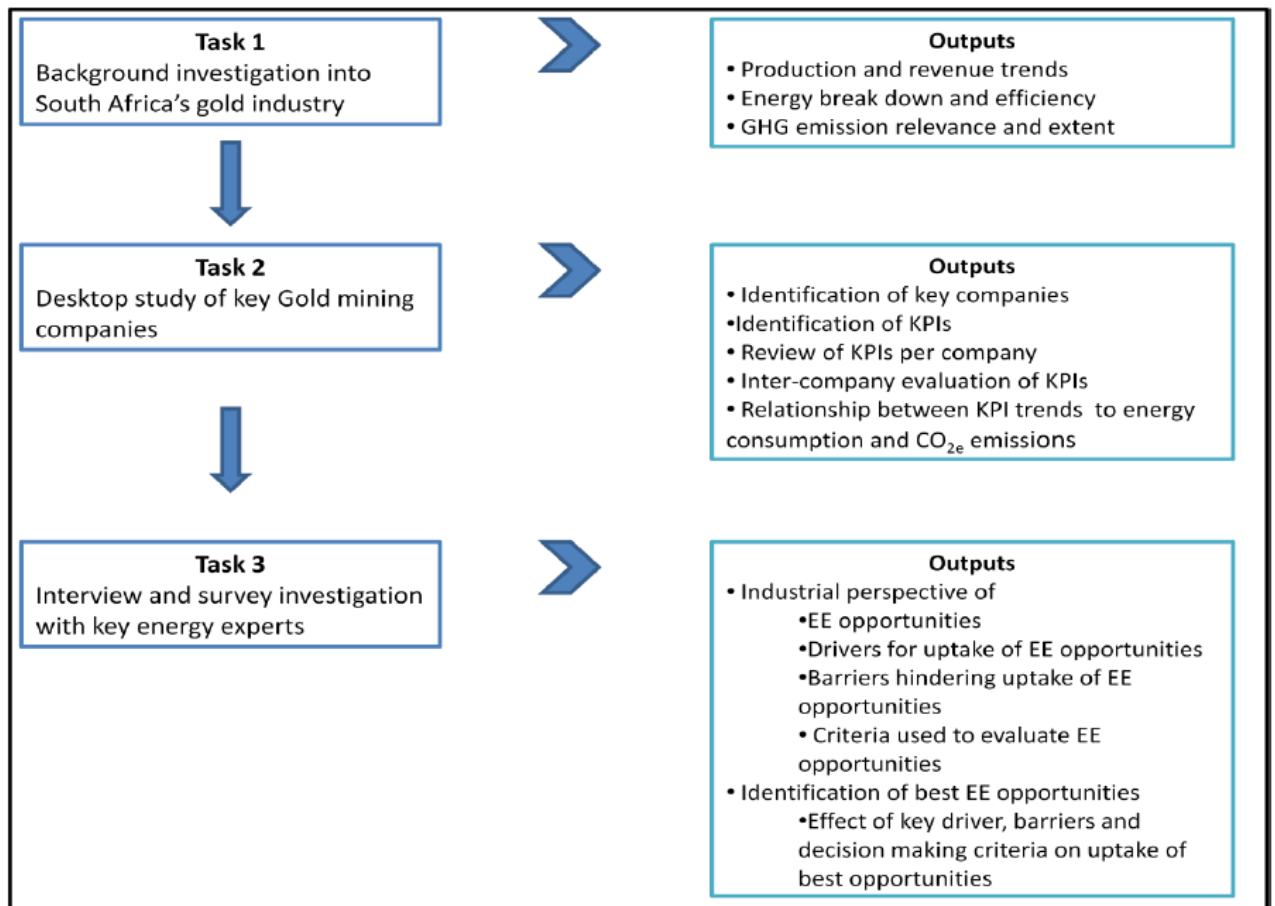


Figure 5: Generalised framework for analysing and evaluating the performance and importance of energy and GHG emissions within South Africa's gold industry

3.1 Task 1: Background research on South Africa's gold mining industry

A review of the gold industry was conducted to provide context to the case study. This review focused on the national significance of the sub-sector, international demand for the commodity, South Africa's reserves of the commodity as well as the key energy challenges faced by the sub-sector.

The outcomes of this review are presented in section 4.1 of the case study.

3.2 Task 2: Desktop study of key gold mining companies

To gain more specific insight in to the importance and performance of energy and GHG emissions in South Africa's gold industry, a desktop study on three of South Africa's major gold mining companies was conducted, namely, AngloGold Ashanti, Harmony Gold and Gold Fields. The South African operations of these three companies accounted for 85% of

the total gold produced in South African in 2010 (AngolGold Ashanti 2010, Gold Fields 2010 & Harmony Gold 2010a). It was due to the significance of their contribution to the South Africa's total gold production that these three companies where chosen to be reviewed.

The desktop study focussed on the energy consumption and GHG emissions associated with each company's South African operations. Key existing information and data was gathered from company reports from the internet, commercial databases and available project sources.

After reviewing the available data on each of the three companies, 8 key performance indicators (KPIs) were chosen to carry out the analysis of the energy and GHG emissions performance of the companies, namely:

- Total throughput (Mt)
- Total production of gold (oz)
- Ore-grade of the gold mined (g/t)
- Total energy consumption of operations (TJ)
- Total CO_{2e}emissions (ktCO_{2e})
- Energy intensity of throughput (TJ/Mt)
- Energy intensity of production(TJ/oz)
- Emission intensity of production (ktCO_{2e}/oz)

Explicit data for all the companies CO₂ emissions are not available pre 2006, thus it was decided to use 2006 as a base year, and review the change each year in each KPI from 2006 to 2010. This analysis was done on a company by company basis, before intercompany comparisons were made between the KPIs to establish trends specific to the gold sub-sector.

3.3 Task 3: Interview and survey investigation

Before the interview and survey investigation began an initial questionnaire and rating sheet was drawn up using findings from the literature review completed in Chapter 2 and the desktop study completed in Task 2.

The interview and survey investigation was conducted in two distinct phases.

Firstly, an initial round of semi-structured⁶interviews with key energy and miningexperts was completed. During this process people with in-depth knowledge of the mining industry in

⁶The objective of a semi-structured interview is to understand the respondent's point view rather than leading the interviewee towards preconceived choices. The interviewer may ask prepared questions or questions that occur to the interviewer at the time of the interview. (Zorn 2011)

general as well as the role of energy efficiency within in the industry were targeted. The aim of this initial process was to test out the effectiveness of the initial questionnaire and rating sheet, as well as to ask for input into from the interviewees on how the questionnaire and rating sheet could be improved for interview with experts from the gold mining companies..Interviews were conducted with the following people:

- The Mintek chief executive officer
- The industrial DSM funding expert for Eskom
- Mineral industry expert Prof Ray Shaw
- Anglo Americans head of Research and Development

The findings from the initial interviews were then used to create a 'final' rating sheet and questionnaire. The rating sheet was created to conduct a survey investigation of the selected companies from the gold sub-sector. The questionnaire was constructed to be used in the semi-structured interview process, as described in Section 3.3.1.

The people interviewed during this process included:

- Two environmental and energy experts from AngloGold Ashanti
- Two environmental and energy experts from Gold Fields
- Two environmental and energy experts from Harmony Gold

3.3.1 Semi-structured interview process

In accordance with the procedure adopted by Zorn (2001), the main objective of the semi-structured interviews was to understand the respondent's point of view rather than leading the interviewee towards preconceived choices. However, a set of possible questions, form of a questionnaire, was prepared in order to guide the interview process, as and where deemed necessary. These questions were aligned to the key research questions of the thesis, and related specifically to:

- Strategies, awareness levels and behaviour patterns around energy efficiency and global warming
- Drivers and constraints around the uptake of EE opportunities
- Identification and realization of EE opportunities
- Investment decision making within the company around EE opportunities

The extent to which specific questions were addressed during each interview was dependent on the knowledge area of the individual interviewee. Interviewees were also asked to nominate additional energy experts within the industry as potential candidates for the subsequent survey investigation (section 3.3.2)

The full questionnaire used for the semi structured interviews is provided in Appendix B1.

3.3.2 Survey investigation

The rating sheet, used in the survey investigation, first asked for the interviewee to rate their company's employees awareness, motivation and active engagement around EE and GHG mitigation. Next the interviewee was asked to specify which decisions - operational, tactical, or strategic- they were typically involved in making within the company.

The rest of the survey asked interviewees to rate the significance of the key factors, grouped into four categories, each category with a specific rating scale. The four categories were:

- EE opportunities
- Key drivers for improved uptake of EE opportunities
- Key barriers hindering the uptake of EE opportunities
- Criteria used for the evaluation of EE opportunities

At the end of each interview the interviewees were asked whether they would prefer their name and/or their company's name kept confidential.

For the full rating sheet, see Appendix B3.

3.3.3 Analysis of collected data and completion of case study

The data obtained through the interview and survey investigation was then used to complete the case study on South Africa's three biggest gold mining companies as seen in section 4.3.

The analysis of the data obtained was carried out on a section by section basis and followed the format used for the rating sheets:

- EE Opportunities
 - Ease of implementation
 - Magnitude of savings
- Key Drivers for improved uptake of EE opportunities
- Key Barriers hindering the uptake of EE opportunities
- Criteria used for the evaluation of EE opportunities

The review of each category followed a similar fashion. The average ratings of each company were determined, as well as the standard error⁷ (SE) for each rating:

$$SE = s/\sqrt{n}$$

Where:

s is the sample standard deviation, and

⁷The standard error was calculated to indicate the range of ratings given for a particular criterion.

n is the size of the sample.

The best and worst performing criteria for each category were identified with reasons and explanation given, when available, for their importance or lack thereof. The relationships between the key drivers, barriers and decision-making criteria with the overall best EE opportunities were then explored. For the raw data of responses to the rating sheets and full intercompany comparisons of ratings, see Appendices B3 and B4 respectively.

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4 CASE STUDY OF THE SOUTH AFRICAN GOLD INDUSTRY SUB-SECTOR

Energy efficiency in South Africa's mineral industry was evaluated in general in Chapter 2. This chapter focuses on the evaluation of South Africa's gold sub-sector and specifically on the performance of South Africa's biggest three gold mining companies namely, AngloGold Ashanti (AGA), Gold Fields, Harmony Gold.

4.1 Review and assessment of South Africa's gold industry sub-sector

South Africa's gold production and revenue trends are reviewed with key international comparisons made. The significance of energy and GHG emissions within South Africa's gold industry is also evaluated.

4.1.1 Production and revenue trends

South Africa has the world's second largest known reserves of gold (USGS 2012) and for many years was the world largest producer of gold. However over the last 40 years gold production has been on the decline (Hartnady 2009). The decline in South Africa's gold production is due to a complex mix of factors including but not limited to, the depletion of its best deposits, increasing electricity costs, labour strikes, ongoing electricity crisis (Chamber of Mines 2010) as well as safety stoppages (PWC 2010).

Table 8 shows South Africa's total gold production in comparison with world's global production from 2000 to 2010.

Table 8: South African percentage of the world's total gold production (Chamber of Mines 2011, Chamber of Mines 2010)

Year	SA fine gold production (metric tonnes)	Total world gold production (metric tonnes)	SA as % of world's total	South Africa's realized value R million
2000	428.0	2620.4	16.33	26,507
2001	393.5	2645.7	14.87	28,679
2002	395.2	2619.0	15.09	41,100
2003	375.8	2623.8	14.32	32,909
2004	342.0	2496.0	13.70	28,877
2005	297.3	2550.0	11.66	27,215
2006	275.1	2482.1	11.08	36,414
2007	254.7	2475.8	10.29	38,394
2008	217.6	2408.8	9.04	47,660
2009	204.9	2589.5	7.91	51,246
2010	191.4	2688.9	7.12	54,744

As can be seen in Table 8 South Africa's total gold production has more than halved since 2000, with its global contribution down 9.21%. This decline in production between 2000-2010 resulted in South Africa losing its status as the world's No. 1 gold producing nation in 2007 and has since fallen to 5th as of 2009 (DMR 2010).

Table 9 shows the average gold price in US\$/oz from 2006 to 2010. The values show that over the last 5 years the gold price has risen fairly dramatically.

Table 9: Annual gold price and rand dollar exchange rate (Gold Fields 2010)

Year	Gold price (US\$/oz)	Average (Rand/US\$) exchange	Gold price (R/oz)
2006	524	6.40	3357
2007	638	7.20	4591
2008	816	7.27	5929
2009	875	9.01	7883
2010	1085	7.58	8226

Despite the increasing gold price, increasing operating expenses have begun to erode the profitability in the industry (PWC 2010); however gold has continued to play a critical part in South Africa's economy. This is depicted by Table 8 which shows that the realized value of the gold industry has continued to increase and in 2010 was over R54 billion. In 2008 gold accounted for approximately 2.4% of South Africa's gross domestic product (GDP) and R48.5 billion in foreign currency earning (Chamber of Mines 2011). As of 2007 the gold industry sub-sector employed 169,057 people (DME 2008). In 2008 the industry invested R8.8 billion in capital expenditure, paid the state R3.7 billion in taxation and paid a dividends of R354 million to the investors of capital (Chamber of Mines 2011, Chamber of Mines 2009).

From Table 8 it is clear that rate of decline of South Africa's gold production far exceeds that of the world's gold production decline post 2001. Table 10 shows the comparison in total gold production from 2005 to 2009 of the world's top gold producing countries, the percentage change in production and each country's percentage contribution to the world's total gold production. It is clear that South Africa's decline in production is significantly more than that of Australia, USA or Canada and is in stark contrast to China's significant increase in production.

One of the key reasons for the decline in South Africa's total gold production is the exhaustion of the Witwaterstrand goldfields, with some estimates suggesting that only 5% remains (Hartnady 2009). The United States Geological Survey (USGS) currently approximates South Africa's total gold reserve at 6000 t (USGS 2011)

Table 10: Comparison of top gold producing countries(Chaize 2009, Johnson 2012)

	South Africa		Australia		USA		Canada		China	
Year	2005	2009	2005	2009	2005	2009	2005	2009	2005	2009
Total production (t)	297	204.9	263	227	262	216	118.5	95	240	314
Percentage of worlds production	11.8	7.7	10.4	8.6	10.2	8.1	4.7	3.6	9.7	11.8
Change in production 2005-2009 (%)	-31.01		-13.69		-17.56		-19.83		30.83	
Global position (2009)	4th		2nd		3rd		8th		1st	

South Africa's average energy costs compared with other major gold mining countries are high. A Canadian study, completed in 2005, compared the energy expenses for deep underground mines from the world's leading gold producing countries which possessed sufficient data for comparison. These producers were Canada, South Africa, the USA and Australia. Data for 27 South African mines was sourced. The result of the study can be seen in Table 11.

Table 11: Energy cost for gold production from leading gold producing countries, expressed in U.S dollars (Natural Resources Canada 2005)

Process	Canada	South Africa	USA	Australia	Gap in energy expense between highest and lowest (%)
Average Energy Cost per Tonne of Ore Hoisted* (1999 U.S. Dollars)	5.07	8.84	5.34	3.83	57
Average Energy Cost per Tonne of Ore Milled* (1999 U.S. Dollars)	4.83	7.08	6.16	3.5	51
Average Energy Cost per Troy Ounce of Gold Produced* (1999 U.S. Dollars)	22.12	33.54	12.01	19.34	64

Table 11 indicates that South Africa's underground gold mining industry has significantly higher energy costs than Canada, Australia or USA. South Africa has 50% higher energy costs than the best result per process, showing that there is significant scope in the gold industry to become more EE when compared with international best practices.

However, these figures do not take into account the significant depth, reaching almost 4 km below the surface (Anglogold Ashanti 2010), that South Africa mines operate at. Although completed over 5 years ago, the above results do however clearly indicate the significantly higher energy cost incurred for South Africa's gold mines. Given the significant drop in ore-grade and significant increases in electricity costs experienced by South African mines over the last 5 years, one would expect this gap to have grown even larger. The increasing electricity prices and mining depth, decreasing ore-grade and workers' demands for higher wages have significantly raised the operating expenses of South Africa's gold mines. (Norgate & Haque 2010).

Table 12 indicates the decrease in the yield of gold mined in South Africa from 1999 to 2010 as well as the associated decreases in throughput and production. The yield of gold mined in South Africa has gradually decreased since the 1970s (Chamber of Mines 2009). Note that the production data presented in Table 12 is lower than that of Table 8 as it only includes South Africa's biggest producers, whereas Table 8 includes all national gold production.

Table 12: Average ore-grade for gold production from South Africa's biggest producers (Chamber of Mines 2011, Chamber of Mines 2009)

Year	Ore milled metric tonnes 1 000	Production kilograms	Yield g/t
1999	86,552	399,489.62	4.62
2000	83,956	378,071.2	4.50
2001	82,962	342,551.9	4.13
2002	81,422	347,542.6	4.27
2003	68,215	311,257.8	4.56
2004	59,702	282,030.6	4.72
2005	49,609	255,290.4	5.15
2006	50,349	235,042.5	4.67
2007	53,257	219,223.1	4.12
2008	50,999	182,489.8	3.58
2009	65,545	170,298.2	3.29
2010	73,803	160,646.4	3.04

4.1.2 Energy breakdown and efficiency in gold mining

The key factors affecting the amount of energy used per ounce of gold are the depth at which mining is undertaken, the grade of the ore, the strip ratio (ratio of waste rock to ore) and whether it is mined underground or open-cast. In South Africa underground mining is the dominant form of gold mining due to the depth at which gold is typically found, between 100 - 2000m (Mudd 2007). With a lower ore-grade, more ore will need to be moved and more

energy used to produce the same amount of gold. Thus more energy is used for moving the rock, though more gold is not produced (Gold Fields 2010b).

The major energy consumers in South Africa’s deep underground mines are ventilation, air compression and refining (Tshiekedi 2009). Ventilation and the cooling and pumping of water consume approximately 48% of the total electricity consumed by deep underground mines. The cooling requirements of deep underground mines depend on the depth of the mine and increase significantly as the depth at which mining is undertaken increases. The average depth of ore mined in South Africa has increased over the past few years and as a result energy consumption per tonne mined has risen (Gold Fields 2009). Water pumping and ventilation form part of the baseline electricity consumption, as they are not dependent on production (Gold Fields 2010b). Figure 6 shows clearly how the energy consumption required to produce a unit of gold typically increases as the ore-grade decreases. These findings are from a global study carried out on gold mines (Mudd 2010).

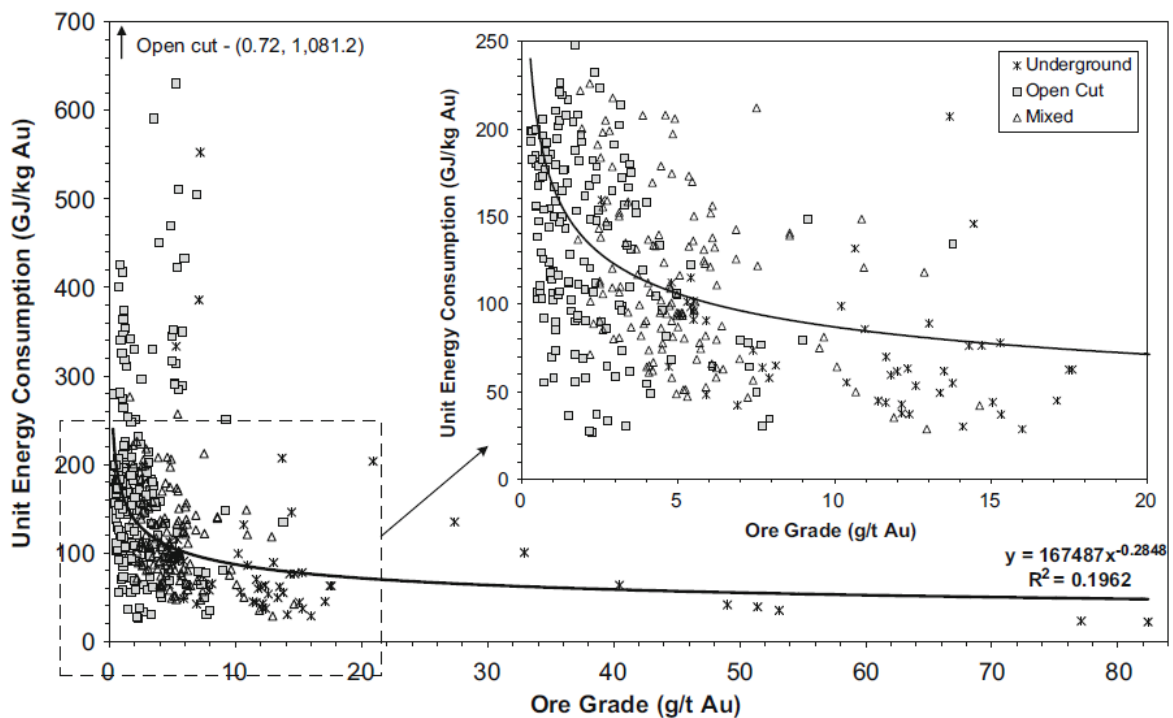


Figure 6: Energy Consumption vs. ore-grade of Gold (Mudd 2010)

Figure 6 shows a sharp increase in energy consumption once the ore-grade starts to get less than 4 g/t. South Africa’s average gold ore-grade for 2010 was 3.04 g/t (Chamber of Mines 2011). The increase in energy consumption of gold mines has been shown to cause an increase in mines total GHG emissions.

4.1.3 GHG emissions

There are two types of GHG emissions associated with gold mining in South Africa, direct and indirect emissions. The majority of direct (the so called “Scope 1” emissions) are those released during the burning of fossil fuels, predominately diesel to power on-site

equipment and vehicles. Indirect emissions are as a result of the emissions released during the generation of electricity which the mines buy from Eskom. Because of the historically cheap price of electricity, mines and particularly gold mines meet the majority of their energy requirements through the purchasing of electricity. Although the breakdown for the relationship between direct and indirect GHG emissions of all South Africa's gold mines is not available, the average figure for the 3 companies reviewed, which account for approximately 85% of all the gold produced in South Africa, is approximately 90% indirect and 10% direct (AngloGold Ashanti 2010, Gold Fields 2010a, Harmony 2010a). The high proportion of indirect GHG emissions means that there is a close link between mines electricity consumption and their total GHG emissions.

The geological make-up of the mine can't be changed and thus neither can the increasing energy consumption and associated emissions due to these conditions. Mining companies only control over the energy consumption of their mines is their ability to shut down mines and mine shafts, adjust the throughput and the efficiency of equipment.

Global work carried out on gold mines by Mudd (2010) established the linear relationship between energy consumption and GHG emissions in gold mining for differing power supplies, as indicated by Figure 7. The coal fired power supply shown in the red would be the most relevant from a South African gold sub-sectors perspective given its reliance on coal fired energy.

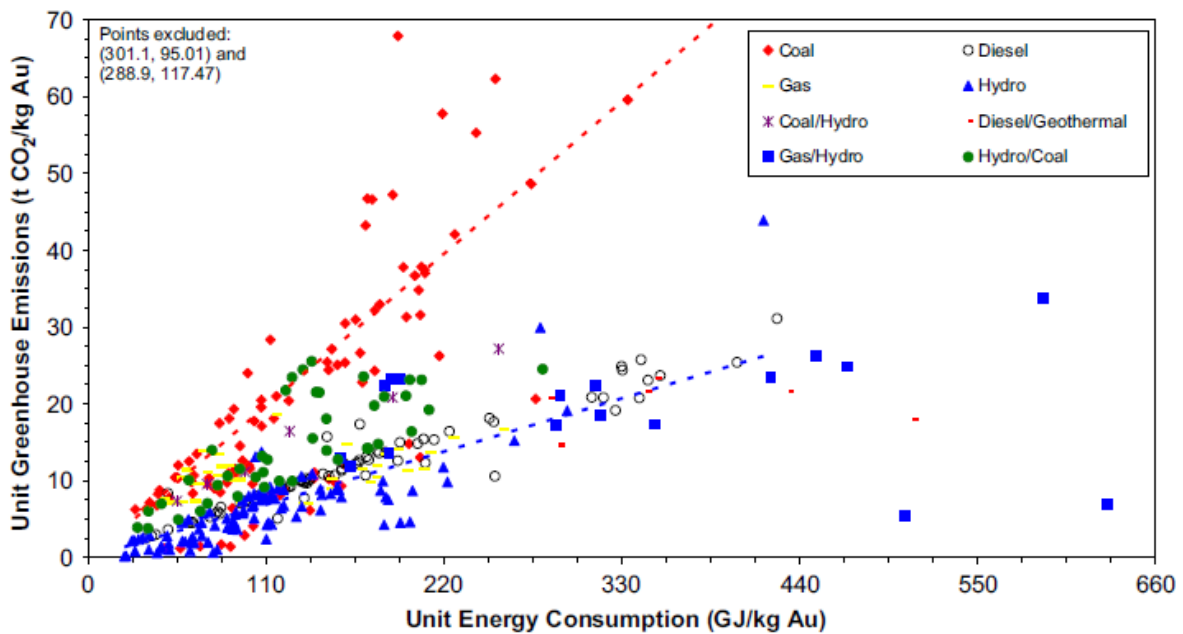


Figure 7: GHG emissions vs. Energy consumption for the production of gold (Mudd 2010)

As can be seen from Figure 7 mining that relies on coal as a primary electricity source has significantly the highest associated GHG emissions. The relationship between total GHG emissions and total energy consumption indicated by Figure 7, given the relationship between energy consumption and ore-grade, indicated by Figure 6, indicates that there

exists a relationship between ore-grade and GHG emissions. Mudd (2010) established this relationship for global gold mines; this relationship is indicated by Figure 8.

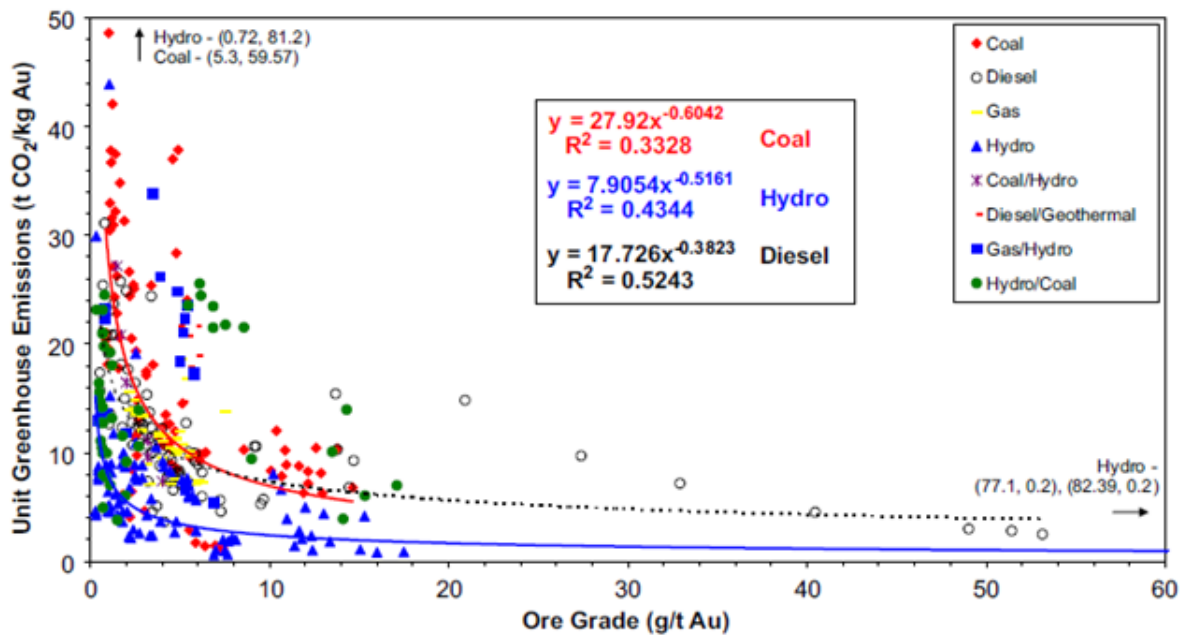


Figure 8: GHG emissions vs. Ore-grade of gold (Mudd 2010)

Figure 8 clearly shows that Mudd's study indicates that as ore-grade decreases the total GHG emissions emitted to produce a unit of gold increases. Again the red data from coal generated electricity would be the most useful from a South African perspective. This data shows a dramatic increase in GHG emissions per unit of gold produced as the ore-grade begins to drop below 4 g/t.

4.2 Desktop study of gold companies

The current context of South Africa's gold industry has been provided in Section 4.1. This section reviews selected information found in the public domain on three of South Africa's leading gold mining companies namely; AngloGold Ashanti, Harmony Gold and Gold Fields. The review compared the actual performance, in terms of energy consumption and GHG emissions, of each company over the last 5 years, with the aim of the review being to get a greater understanding of South Africa's gold industry's current performance with regards to energy consumption and GHG emissions.

4.2.1 Analysis of key performance indicators

Data for each of the three companies has been captured and analysed. The companies' total production of gold for 2010 of 5.084 million troy ounces (Moz) accounts for just over 85% of the total amount of gold produced by all South African mining operations of approximately 6 Moz (Chamber of Mines 2011). The data captured was then used to review the chosen KPIs dealing with EE and GHG emissions.

For the “Average” (average taken of the three companies KPI’s) and “Total” (addition of the three companies KPI’s) KPI information of the three reviewed companies, see appendix A1.

AngloGold Ashanti

AngloGold Ashanti’s (AGA’s) South African operations consist of six deep-level mines with the main working levels varying between 1500 and 3500m, and one open-pit mine (AngloGold Ashanti 2011). In 2010 these operations produced 1.78 Moz of gold and employed 35 660 people (AngloGold Ashanti 2010). The energy costs of AGA’s South African operation rose 33% between 2009 and 2010 and currently account for 18.7% of the company’s total operating cash costs. Table 13 shows the KPI data captured for AGA.

Table 13: KPIs for AngloGold Ashanti’s South African operations(AngloGold Ashanti 2010, AngloGold Ashanti 2009b, AngloGold Ashanti 2009a, AngloGold Ashanti 2007)

Year	2006	2007	2008	2009	2010
Total throughput (Mt)	11.03	10.36	9.48	8.72	8.85
Total production (000oz)	2554	2328	2099	1797	1784
Ore-grade (g/t)	7.20	6.99	6.89	6.41	6.27
Total energy consumption(TJ)	13,619	13,155	12,680	12,300	12,400
Total CO₂emissions(ktCO_{2e})	3554	3387	3381	3400	3420
Energy intensity of throughput (TJ/Mt)	1234	1270	1338	1411	1401
Energy intensity of production (GJ/oz)	5.33	5.65	6.04	6.84	6.95
Emission intensity (kt CO_{2e}/oz)	1.39	1.45	1.61	1.89	1.92

The percentage changes in the performance from 2006 of each KPI have been calculated and are indicated by Figure 9.

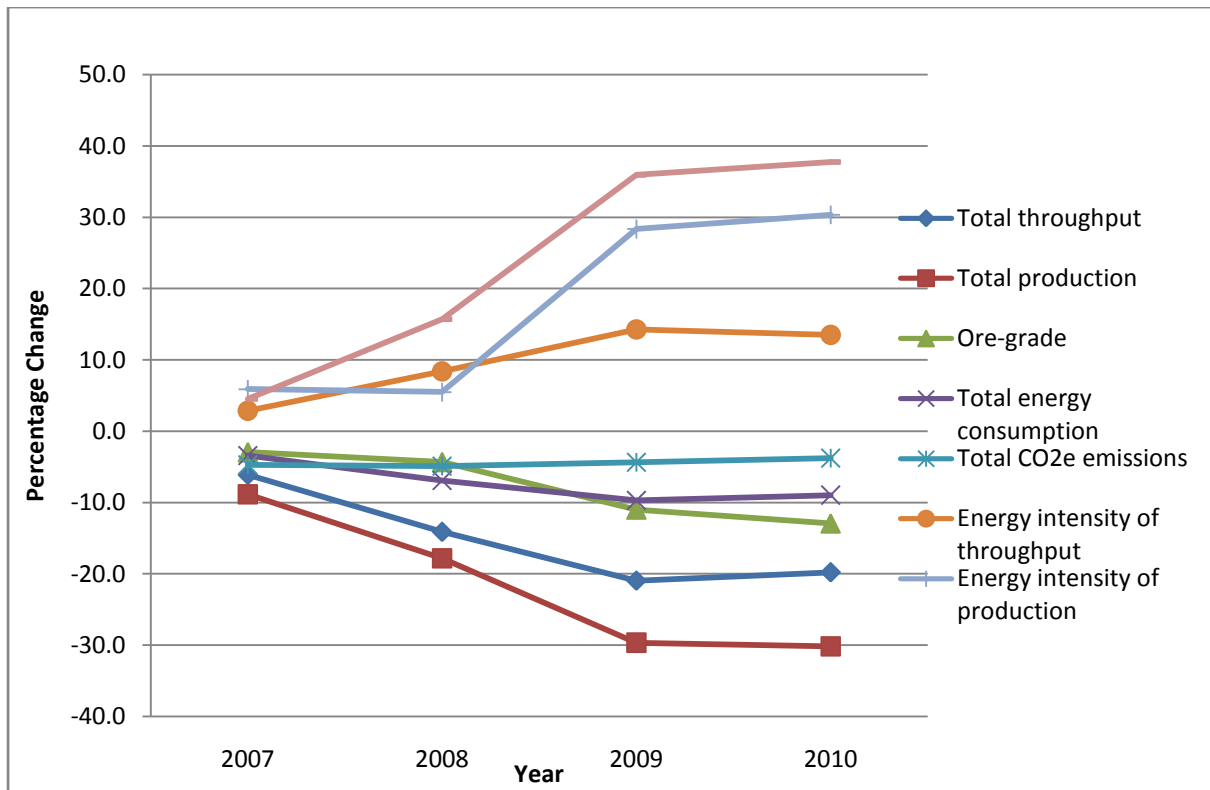


Figure 9: AngloGold Ashanti KPI comparison

As indicated by Figure 9 AGAs *totalthroughput* has fallen significantly over the last 5 years, down 19.8%. In 2009 a number of in-company and government enforced safety stoppages halted certain operations and caused severe disruption to the level of throughput achieved in that year. This situation has improved in 2010 as is indicated by the slight increase in throughput from 2009 to 2010.

In 2010 AGAs South African operations produced 39% of the AGA group's total gold production. 36% of the total 39% produced by AGAs South African production came from underground operations, the other 3% from the one surface operation (AngloGold Ashanti 2010). The *production* levels of its South African operations have however continued to decrease over the last 5 years and in 2010 production was 30.1% down from 2006 levels. This is as a largely as a result of decreasing throughput and falling yield. AGAs *yield* marginally decreased throughout the time period reviewed and in 2010 ended 12.9% below 2006 levels.

This reduction in AGAs throughput and total gold production was somewhat echoed by the *total energy consumption*, which dropped significantly by 9.7% from 2006 to 2008. Other reasons for the drop in total energy consumption besides decreasing production and throughput levels are the economic recession since 2008 as well as South Africa's electricity crisis which resulted in a forced mine shut down. The rate of decrease in total energy consumption decelerated from 2008, and in 2009 started to increase, with total energy consumption up 0.7% in 2010 from 2009.

The reduced energy consumption of the groups South African operations has also affected the group's *total GHG emissions*. This is because approximately 94% of all AGA's GHG emissions are indirect emissions as a result of electricity consumption. AGAs total GHG emissions dropped by 4.7% in 2007 and then remained relatively constant over the next 3 years, down 3.8% in 2010 below 2006 levels.

Given that the throughput has decreased more significantly than energy consumption the *energy intensity (TJ/Mt)* of the throughput has increased steadily over the last 5 years. This intensity peaked in 2009 at 14.3% above 2006 levels before slightly decreasing in 2010 to 13.5% above 2006 levels.

The dramatic drop in gold production of over 30% and the marginal drop in total energy consumption of around 9.0% has resulted a significant increase in the *energy intensity (GJ/oz)* of gold production of 30.3% above 2006 levels.

With energy and GHG emissions so closely related for AGA's South African operations, it is not surprising that the increase in energy intensity (TJ/oz) has been echoed by an increase in *emission intensity (TJ/oz)*. The emission intensity has increased each year with a particularly large increase in 2009 of 36% above 2006. This increase in emission intensity is a direct result of the significant decrease in gold production given the slight increase in total CO_{2e} emissions. In 2010 *emission intensity* was 37.8% up from 2006.

Harmony gold

Harmony is one of the world's ten largest gold mining companies and operates in South Africa and Papua New Guinea. It has ten underground and two surface operations in South Africa. Harmony's South African operations produced 1.37 Moz of gold in 2010 and employed approximately 40 000 people. Over 52% of Harmony's shareholders are from North America, the United Kingdom and Europe (Harmony Gold 2010a). Energy costs are rapidly increasing and as of 2009 accounted for 13% of the company's operating cost base of R7657 million (Harmony Gold 2009). Table 14 shows the KPI data captured for Harmony's South African operations.

Table 14: KPI's for Harmony Gold's South African operations(Harmony Gold 2009, Harmony Gold 2010b, Harmony Gold 2008)

Year	2006	2007	2008	2009	2010
Total throughput (Mt)	22.95	23.34	17.70	17.89	17.72
Total production (000oz)	2155	2109	1525	1461	1367
Ore-grade (g/t)	2.92	2.81	2.68	2.54	2.40
Total energy consumption(TJ)	14200	15700	14100	12400	13174
Total CO_{2e} emissions (ktCO_{2e})	5039	4810	4582	4183	4403
Energy intensity (TJ/Mt)	619	673	797	693	744
Energy intensity (GJ/oz)	6.59	7.44	9.25	8.49	9.64
Emission intensity (kt CO_{2e}/oz)	2.34	2.28	3.00	2.86	3.22

Figure 10 indicates the percentage change in performance from 2006 of the KPIs shown in Table 14.

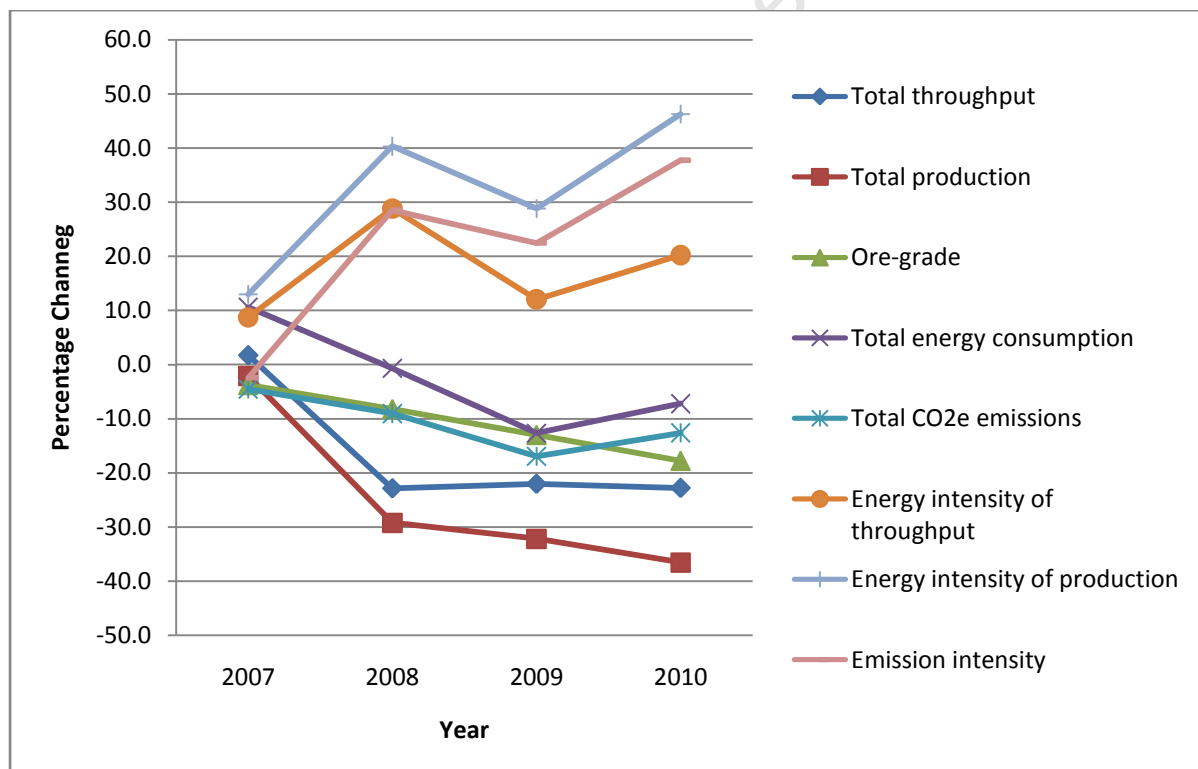


Figure 10: Harmony Gold KPI comparison

Harmony's *total throughput* has declined over the last five years, with a significant drop of 22.9% as of 2008, since then it has remained reasonably constant. The noteworthy drop in throughput in 2008 can be attributed to the closure of a number of unprofitable mines. Harmony has adopted a policy of closing unprofitable mines to ensure an adequate operating profit margin (Harmony Gold 2010a).

The *total production* of Harmony's South African operations has on average continually dropped since 2006 and in 2010 was 36.6% below 2006 levels. Internationally Harmony stated in their 2010 Carbon Disclosure Project report that it intends to increase production to 2.2 Moz by 2012 (Harmony Gold 2010b).

Harmony's *yield* has continually decreased since 2006 and in 2010 was down 17.8%. This decrease can be directly attributed to depletion of the company's best South African gold deposits. This is compounded by the fact that the company's efforts to identify a new asset in South Africa of sufficient value at a reasonable price have not been successful. The reason for Harmony's average ore-grade being significantly lower than either AGA or Gold Fields is because of the higher percentage of gold it obtains from surface operation. Surface operations have significantly lower yield value than underground operations. During 2010 the ore-grade for Harmony's surface operations was 0.41 g/t and for its underground operations was 4.54 g/t (Harmony Gold 2010a).

The decrease in Harmony's throughput has been somewhat shadowed by the company's *total energy consumption*. The total energy consumption for the company increased by 10% in 2007 before dropping back down to -0.7% in 2008, relative to 2006, due primarily to the radically reduced throughput of the company that year. Total energy consumption dropped down significantly to -12.7% in 2009 before increasing in 2010 back to -7.2% below 2006 levels.

As of 2009, 99% of Harmony CO_{2e} emissions were indirect emissions as a result of electricity purchased from Eskom (Harmony Gold 2009). Harmony's *total CO_{2e} emissions* decreased steadily in 2007 and 2008, before decreasing significantly in 2009 to -17% below its 2006 level. For the year ended June 2010 total CO_{2e} emissions ended -12.6% below 2006 levels.

With throughput decreasing by over 20% and energy consumption by just 7.2% the *energy intensity (TJ/Mt)* of throughput for Harmony's South African operations increased significantly. The biggest increase in energy intensity relative to 2006, of 28.8%, came in 2008 before going down to 20.8% in 2010, relative to 2006.

Harmony's *energy intensity* of production increased more rapidly than that of throughput. This is due to the greater decrease in production than throughput because of decreasing ore-grades. The energy intensity of production increased up to 40.3% in 2008 before coming down to 28.8% in 2009. Energy intensity then increased significantly again in 2010 up to a 46.3% above 2006 levels.

The close relationship between electricity consumption and GHG emissions at Harmony's South African operations has meant that *emission intensity* of production has followed a fairly

similar trend to the energy intensity (TJ/Mt) of production. The emission intensity increased by 28.5% in 2008 before coming down slightly from that level in 2009 before increasing again in 2010 to 37.7% more energy intensive than 2006.

Gold Fields

Gold Fields has four gold mining operations in South Africa as well as five international operations in West Africa, South America and Australasia. In 2010 the company's South African operations produced 1.9 Moz of gold, employed over 40 000 people with a total capital expenditure of R4.5 billion (Gold Fields 2010a). The company's global operating profit was up 10% from R11 462 million in 2009 to R12 573 million in 2010. This was despite the 14% increase in operating costs in the South African region due to increases in the electricity price and demands for higher wages (Gold Fields 2010a). Table 15 shows the data captured for the identified KPIs from Gold Fields four South African operations.

Table 15: KPIs for Gold Fields' South African operations (Gold Fields 2010a, Gold Fields 2009, Gold Fields 2008, Gold Fields 2007)

Year	2006	2007	2008	2009	2010
Total throughput (Mt)	14.10	14.96	14.52	13.76	14.32
Total production (000oz)	2752	2646	2419	2039	1933
Ore-grade (g/t)	6.07	5.50	5.18	4.61	4.20
Electricity consumption(TJ)	17,022	16,564	18,069	16,679	18,122
Total CO_{2e} emissions (ktCO_{2e})	4125	4079	4303	4054	4590
Energy intensity of throughput (TJ/Mt)	1207	1107	1244	1212	1266
Energy intensity of production(GJ/oz)	6.19	6.26	7.47	8.18	9.38
Emission intensity (kt CO_{2e}/oz)	1.50	1.54	1.78	1.99	2.37

Figure 11 shows the yearly percentage change in performance of Gold Fields' KPIs, presented in Table 15, using the 2006 results as a benchmark.

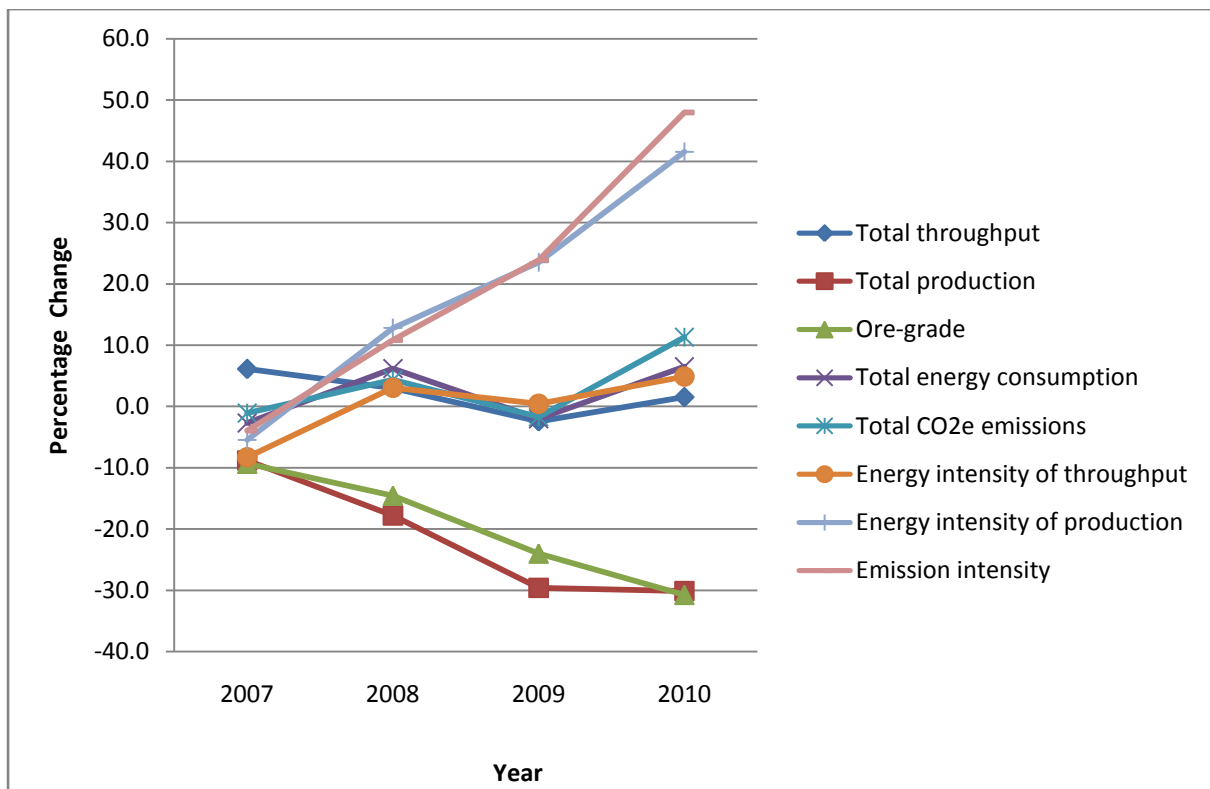


Figure 11: Gold Fields KPI comparison

The *total throughput* of Gold Fields' South African operations has remained reasonably constant over the review period. In 2010 total throughput ended 1.5% above 2006 levels. The constant throughput is not echoed by constant levels of gold production. *Total gold production* has continually dropped since 2006 with its 2010 levels of production 24.8% below 2006 levels. This drop in local production is in stark contrast to Gold Fields' five international operations which increased their combined production by 16% in 2010. The 5% decline in gold production from 2009 to 2010 of Gold Fields' South African operations has been attributed by the company to a number of protracted mine-wide safety closures at the company's Driefontein and Kloof gold mines, where production dropped 14% and 11% respectively. Another of Gold Fields' South African operation, South Deep, was acquired during the review period covered by this study in 2007. In 2010 the production of South Deep was up 52%, to 0.26 million ounces from 2009. Production for South Deep is only expected to be near its full capacity of between 0.75 and 0.80 million ounces by 2014.

Given the fairly constant throughput and the significant drop in production it is unsurprising that the *yield* of Gold Fields' South African operations has dropped significantly since 2006 and in 2010 was down by 30.8%.

The *total electricity consumption* for Gold Fields' South African operations has remained fairly constant over the review period with a slight decrease in 2009 before ending in 2010 6.5% above 2006 levels. 96% of Gold Fields' South African operations total energy requirements are met by electricity (Gold Fields 2010c).

The percentage of Gold Fields total CO_{2e} emissions being indirect is only 80%, this is substantially less than either AGA or Harmony. The discrepancy between Gold Fields and the other two companies is due to the significant amount of mine methane found in geological faults at Gold Fields' Beatrix mine. The mine methane is released when mining operations come into contact with faults containing methane, these direct emissions account for approximately 14% of Gold Fields South African operations total CO_{2e} emissions. Gold Fields' total CO_{2e} emissions have been up and down over the review period. 2009 was the low point with total CO_{2e} emissions down 1.7% and 2010 the high, with total CO_{2e} emissions 11.3% higher than 2006 levels.

Throughput and energy consumption remained fairly constant over the review period. This has resulted in the *energy intensity* of throughput also remaining reasonably constant. As of 2010 the energy intensity of throughput had only increased 4.9% above 2006 levels. The significant decrease in ore-grade resulting in a substantial decrease in gold production has resulted in the *energy intensity* of production increasing all the way to 2010, to 41.5% above 2006 levels.

The relationship between energy and GHG emissions for Gold Fields' South African operation was not as linear as the other 2 companies reviewed, due to the mine methane at the Beatrix operation. The *emission intensity* of production showed a very similar trend to the energy intensity of production. The emission intensity slightly decreased in 2007 before it increased significantly each year up to 2010 where it was 47.9% higher than 2006.

4.2.2 Inter-company evaluation of key performance indicators

In this section the performances of the three companies is compared for five KPIs. For graphed KPI comparisons see appendix A2.

Total throughput

It appears that typically the throughput of South African gold mines is on the decline; this is indicated by

Table 16. Two key reasons for the decrease in the throughput of the companies reviewed are the scaling back of mining operations and the closure of mine shafts. The 10% target reduction in energy consumption set by Eskom has encouraged the pace of both the scaling back of operations and closure of mine shafts. These issues have resulted in throughput for both AGAs and Harmony's operations falling by approximately 20% in the last 5 years.

Table 16: Comparison of percentage change in total throughput relative to 2006

	2007	2008	2009	2010
AGA	-6.1	-14.1	-21.0	-19.8
Harmony	1.7	-22.9	-22.1	-22.8
Gold Fields	6.1	3.0	-2.4	1.5
Average	1.2	-13.3	-16.1	-15.0

The only exception to this downward throughput trend found in this study was that of Gold Fields' South Deep mine. The rapid increase in throughput at Gold Fields' South Deep mine since 2007 has offset the reduction in throughput of its other 3 mines keeping Gold Fields overall throughput relatively constant since 2006.

Total production

Gold production has dropped significantly for all three companies every year except for Gold Fields who experienced a slight increase in 2007, the year in which it acquired its South Deep mine. Table 17 indicates the change in production from 2006 to 2010 for each company's South African operations.

Table 17: Comparison of percentage change in total gold production relative to 2006

	2007	2008	2009	2010
AGA	-8.8	-17.8	-29.6	-30.1
Harmony	-2.1	-29.2	-32.2	-36.6
Gold Fields	3.0	-5.9	-20.7	-24.8
Average	-2.7	-17.0	-27.2	-30.2

The average reduction in production of the three companies over the last five years of just over 30.2% is significant. The significance of this reduction is in line with the reduction of South Africa's national gold production, which is down more than 50% from 2000 levels. This fall in production has come despite a steadily increasing gold price over the last 10 years. The decrease in production levels is however not in line with global gold production which has decreased only marginally since 2001.

The average drop in production of between 2009 and 2010 of approximately 3 % is significantly less than the 10% of the previous 2 years. This is in line with the national gold study carried out by Price Waterhouse Coopers (2010) whose findings indicated that the improvements made in operating and safety performance as well as renewed investment in the gold industry should stabilize the gold supply and potentially add marginal growth in the medium term, although for the long term the decline in gold production is expected to continue (PWC 2010).

Yield

The key reason for the decline of South Africa's gold production is that the Witwatersrand goldfields are approximately 95% exhausted (Hartnandy 2009). The average ore-grades found in the deposits of the companies reviewed have all decreased significantly during the review period. Table 18 shows the percentage change to the average ore-grade values of the reviewed companies South African operations over the last 4 years.

Table 18: Comparison of percentage change in ore-grade relative to 2006

	2007	2008	2009	2010
AGA	-2.9	-4.3	-11.0	-12.9
Harmony	-3.8	-8.2	-13.0	-17.8
Gold Fields	-9.3	-14.6	-24.0	-30.8
Average	-6.0	-8.9	-16.2	-21.9

There is a constant and clear trend of decreasing ore-grades for all three companies South African operations, with an average decrease of -21.9% over the last 5 years (Chamber of Mines 2011). Without the unlikely discovery of a new reef in South Africa, the ore-grade of gold is expected to continue to decline.

Electricity consumption

Electricity consumption has remained fairly constant for all three companies reviewed with 2009 being the average low point with consumption falling to 7.7% below 2006 levels. All three companies showed increasing mining activities post 2009, with all their energy consumptions going up from 2009 to 2010. Table 19 shows the percentage change in total electricity consumptions for the companies' South African operations from 2007 to 2010.

Table 19: Comparison of percentage change in total electricity consumption relative to 2006

	2007	2008	2009	2010
AGA	-3.4	-6.9	-9.7	-9.0
Harmony	10.6	-0.7	-12.7	-7.2
Gold Fields	-2.7	6.2	-2.0	6.5
Average	1.3	-1.9	-7.7	-2.6

As mentioned previously, the companies reviewed have typically followed processes of scaling back of operations, closure of uneconomical mining operations and implementing a number of EE projects. This has resulted in an average reduction in total energy consumptions over the last 5 years. The ramping up of production at Gold Fields' South Deep mine accounts for the increased electricity consumption of Gold Fields' operations.

Total CO_{2e} emissions

The average CO_{2e} emissions of the three companies' South African operations have stayed fairly constant and in 2010 were 6.8% above 2006 levels. Table 20 indicates the average change in each company's total CO_{2e} emissions.

Table 20: Comparison of percentage change in total CO_{2e} emissions relative to 2006

	2007	2008	2009	2010
AGA	-4.7	-4.9	-4.3	-3.8
Harmony	-4.5	-9.1	-17.0	-12.6
Gold Fields	-1.1	4.3	-1.7	11.3
Average	-0.6	2.2	-8.5	6.8

The total CO_{2e} emissions of AGA and Harmony have dropped slightly since 2006; this is predominately due to decreases in the energy consumptions of their South African operations. Over 95% of both companies total CO_{2e} emissions are as a result of electricity consumption. The two key reasons the significant difference in the change in total CO_{2e} emissions between Gold Fields and the other two companies with its 11.3% increase in 2010, is due to the increased energy consumption at its South Deep mine and because of the mine methane found at its Beatrix mine.

4.2.3 Relationship of KPI trends to energy consumption and CO_{2e} emissions

The three companies' total production of gold for 2010 accounted for approximately 85% of South Africa's total gold production for that year (Chamber of Mines 2011). Thus, the average performance of the KPIs of the three reviewed companies shown in Figure 12 gives a good indication of not just the performance of the three companies but of South Africa's gold industry as a whole.

Figure 12 paints a particular negative image of gold mining in South Africa, with energy intensity (TJ/oz), emission intensity of production (TJ/oz), energy intensity of throughput (TJ/Mt) and total CO_{2e} emissions all on the increase, while total throughput, total production and ore-grade are all on the decline. The only positive indicator from the mines perspective is total electricity consumption, which has marginally decreased.

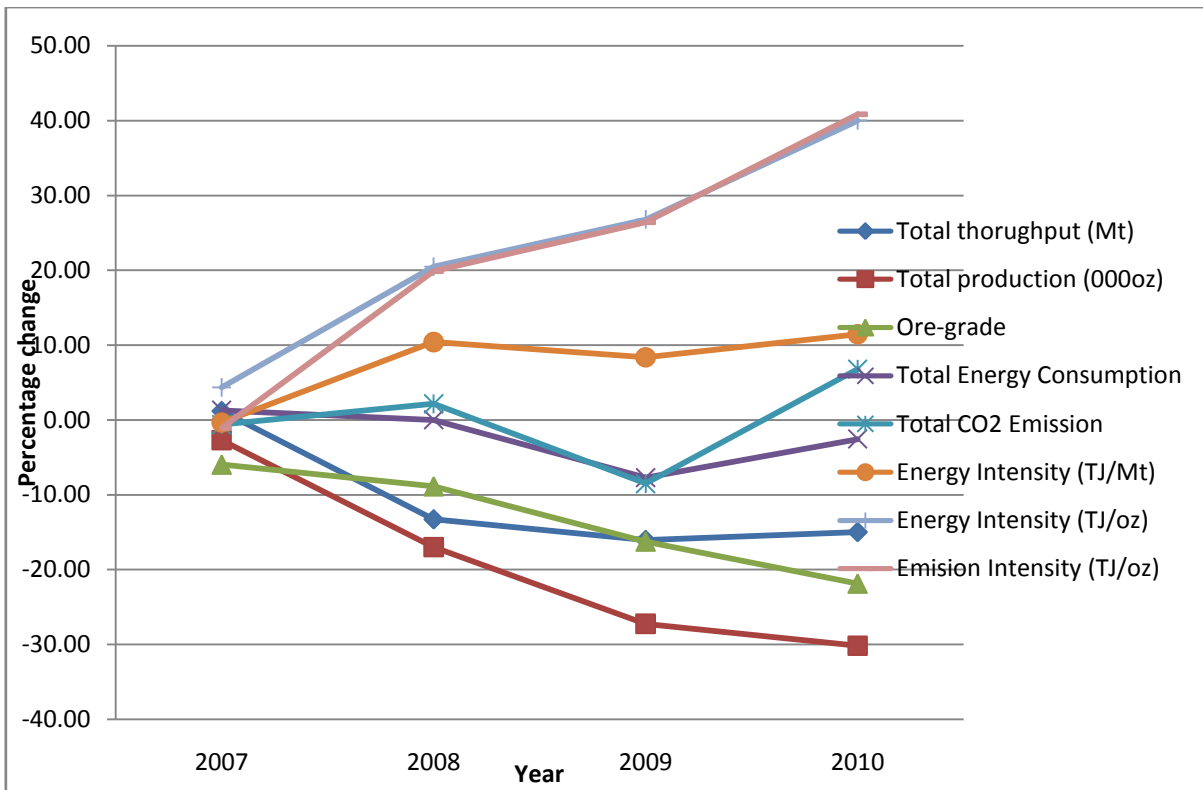


Figure 12: Average KPIs for the reviewed companies

The significant reduction in both throughput and production has not been reflected by an equivalent reduction in energy consumption. In 2010, as seen in Table 21, the average throughput and production levels fell 15% and 30% respectively, while the total energy consumption dropped just 2.6%.

Table 21: Percentage change in key energy performance indicators relative to 2006

Indicator	2007	2008	2009	2010
Total throughput	1.2	-13.3	-16.1	-15.0
Total production	-2.7	-17.0	-27.2	-30.2
Total energy consumption	1.3	0.0	-7.7	-2.6

The key reason for this discrepancy between energy consumption and the other two KPIs is because of the number of deep underground mines which are nearing their end of their lives. When a deep underground mine nears the end of its life the throughput and gold production of those mines falls significantly while the base energy consumption for major energy components such as ventilation and cooling remain relatively constant, as they are not linked to production (AngloGold Ashanti 2010).

The difference in the rate of change between throughput and production compared with energy consumption has resulted in significant increases in the both energy intensities of both throughput and production. The higher rate of change of the energy intensity of production over throughput is a result of the decreasing ore-grade of the throughput.

Table 22: Percentage change in key performance indicators relative to 2006

Indicator	2007	2008	2009	2010
Energy intensity of throughput	-0.35	10.42	8.37	11.46
Energy intensity of production	4.35	20.47	26.78	40.00
Emission intensity	-1.08	19.86	26.41	40.82

The trends of both the total CO_{2e} emissions and emission intensity are predominately as a result of the energy situation explained above, given the almost direct relationship between energy consumption and GHG emissions of gold mines reviewed. The only significant divergence between these two KPIs should be due to the methane released out of geological faults at Gold Fields' Beatrix gold mines, any other significant discrepancies are as a result of incorrect energy or CO_{2e} emissions auditing or changing auditing standards.

The total energy and climate footprints of the industry have stayed fairly constant over the last five years. 2010 saw a slight decrease of 7.2% for total energy consumption and a slight increase in total GHG emissions of 6.8%.

4.3 Interview and survey investigation

A synthesis of the responses given to the rating sheets, as well as relevant information obtained through semi-structured interviews with key employees and the desktop study of the three reviewed companies has been completed in this section. This synthesis follows the structure used in the rating sheet and considers opportunities, drivers, barriers and decision-making criteria relating to EE opportunities within South Africa's gold industry sub-sector. This section shows clearly the key opportunities that exist for energy efficiency within South Africa's gold sub-sector, the drivers and barriers affecting their uptake and what the perspectives' of key decision makers within South Africa's gold-sub-sector are on the available EE opportunities as well as the drivers and barriers affecting their uptake.

For the questionnaire checklist, rating sheet and all interviewees' individual responses to the rating sheets see appendices B1, B2 and B3 respectively.

4.3.1 Opportunities for EE improvement

There currently exist a number of implementable opportunities for South Africa's gold mining companies to improve their EE. The views of key decision makers on identified EE opportunities are presented and explored below.

Ease of implementation of key opportunities

Table 23 shows the 11 opportunities with the highest overall average ratings for their perceived ease of implementation as well as the standard error (SE) of the ratings

Table 23: Opportunities with the highest ease of implementation rating

Opportunity	Company 1	Company 2	Company 3	Average	Standard error
Projects that are eligible for Eskom DSM financing	3.0	5.0	3.5	3.8	0.37
Maintenance	3.0	4.0	4.5	3.8	0.31
Energy efficient lighting: low energy bulbs/ natural lighting	4.0	3.0	4.0	3.7	0.42
Re-design of old technologies (optimization)	3.3	4.0	3.5	3.6	0.37
Utilization of more energy efficient mining equipment (e.g. HPGR mills)	3.0	4.0	3.5	3.5	0.36
Improved pumping system	3.3	4.0	3.0	3.4	0.29
Optimizing the use of process heat, maximizing combustion efficiency, utilizing waste heat and streamlining processes	2.7	4.0	3.5	3.4	0.51
Localized cooling and more Efficient Refrigeration	2.3	4.0	3.5	3.3	0.44
More efficient ventilation system	2.3	4.0	3.5	3.3	0.49
Better instruments and sensors allowing greater control over comminution and classification processes	3.3	3.0	3.5	3.3	0.36
Employee incentives schemes	2.0	4.0	4.0	3.3	0.49

The highest average rating for *ease of implementation* was given to *projects eligible for DSM funding*. Given the significance of *capital expenditure*(see barriers results 4.3.3) as a barrier to the uptake of EE as well as the intense competition for capital between opportunities it is clear why the DSM funding program which provides up to a 100% of the initial capital expenditure for a project, up to the relevant benchmark figure, is considered such an important opportunity. This funding has made a huge difference in making a number of two to three year payback periods projects eligible for implementation. Feedback from the semi-structured interview process would indicate that energy experts from the reviewed companies are predominately focusing on these short return DSM funded projects, before considering doing bigger and longer-term EE projects.

The next highest ratings for the ease of implementation were given to improved *maintenance* and adopting more *efficient lights*. Both these opportunities are widely renowned as easy

opportunities to implement. Neither requires any significant risk from the companies' perspective with the estimations of their expected performance typically very accurate.

The reviewed companies all had comprehensive and effective tools monitoring the energy consumption of their operations. The second by second and disaggregated nature of this energy feedback allows energy experts to identify any old technologies that are underperforming and thus in need of maintenance work or replacing. The replacement of old over designed technologies with more suitably sized and efficient *redesigned technologies* is typically hindered by the capital costs involved as well as the life expectancy of the mine. The risk that production may at some future stage exceed the capacity of the smaller sized new technology is another factor.

Improving the efficiency of *mining equipment* was identified by all three companies as an easy way to reduce energy consumption. The overall rating of 3.5 suggests that HPGR technology is not far away from being ready for greater dissemination into the gold mining sub-sector.

Improved pumping systems were given an average rating of 3.4 for its ease of implementation. The importance of this rating was recognised by all but one of the interviews, its low SE of 0.29 indicates this. This process involves replacing old inefficient pumps with new correctly sized and more efficient pumps. The main barriers to this option include the capital expense of the new pumps, a short life expectancy of the mine at which the pumps operate and a resistance to reducing the safety factor of the pumps.

A high percentage, over 80%, of energy used during the comminution process is dissipated as heat, this significant quantity of energy can be used to power other stages of the beneficiation process, the average rating of 3.4 given to *optimizing the use of process heat* suggests that effectively using this and other waste heat can be carried out by gold mining companies with only some small effort. There is however some uncertainty around this rating which received ratings ranging from 1 to 5 and thus it has a high SE of 0.49.

The distance water needs to cover to cool South Africa's deep underground mines is a serious issue. The significant distances cooling water must travel if only a single centralised pumping system is used makes the opportunity of implementing *localised pumping systems* an EE one. The fact that no new technology would be required to switch to smaller localised pumping systems from a centralized large pumping system is reflected by the average rating of 3.3 given to this opportunity in terms of its ease of implementation.

The leakage and inefficiency of the current *compressed air systems* in the deep underground gold mines was one of the key issues raised by the interviewees. The ease in implementing a more efficient ventilation system was given an average rating of 3.3.

Better instruments and sensors allowing more accurate monitoring was stressed as key to firstly identify areas for the uptake of EE opportunities and then to determine the return on investment on the new opportunity once implemented, this opportunity received varying ratings from 2 to 5. All interviewees found this to be an important opportunity though some gave it a low rating as they felt it was unnecessary for their company who they felt already had effective instruments and sensors in place.

Using incentive schemes is an opportunity in which only one company is practising - C3. C3 gave this opportunity a rating of 4 for its ease of implementation. C1 who is not giving incentives to employees who reduce energy consumption gave this an ease of implementation of 2. The fact that the only company who has implemented this opportunity gave it such a high rating would suggest that C1's perspective of the difficulty in implementing this opportunity is uninformed and that it is in fact an opportunity which can easily be introduced into a company.

Table 24 shows the seven opportunities that on average got the lowest ratings for their perceived ease of implementation.

Table 24: Most difficult opportunities to implement

Opportunity	Company 1	Company 2	Company 3	Average	Standard error
Underground processing	1.0	2.0	2.5	1.8	0.46
Improvement in the tools for analyzing mineral deposits: Models sensors and instrumentation	1.7	2.0	2.5	2.1	0.22
On-site generation of energy	1.7	2.0	3.5	2.4	0.49
HPGR mills	1.3	2.0	4.0	2.4	0.55
Projects potential to obtain carbon finance and eligibility for carbon credits trading. (CDM)	1.7	4.0	2.0	2.6	0.47
Change to management structure (e.g. employing specialists etc)	2.0	3.0	3.0	2.7	0.26
Research and Development	2.0	2.0	4.0	2.7	0.43

The opportunity rated as the most difficult to implement was *underground processing*. This view was shared by all three companies. There is still significant uncertainty around the actual energy saving benefits of underground processing. Underground processing

reduces the energy required for haulage but increases the heat in the mine shafts which will increase the energy required for ventilation and cooling. Most of the interviewees stated in the semi-structured interview that they felt underground processing was something that would definitely not be implemented within the next ten years.

By *improving the tools that analyse mineral deposits*, gold mining companies could save significant amounts of energy by targeting only the sections of the ore deposits containing high percentages of gold mineral and ignoring large sections of waste rock. The low rating for this opportunity shows that the procedure to effectively analyse mineral deposits is a difficult one and that there is significant scope for improvement in this area. This low rating was consistently agreed by all interviews thus the low SE for this opportunity of 0.22.

The main issue for gold mining companies at present with respect to *on-site generation of electricity* is that currently they cannot generate electricity as cost effectively as they can buy it from Eskom.

The cost of replacing existing grinders with *HPGR mills*, as well as the interruption that this process would cause to the throughput of a mine, makes it a difficult opportunity to implement. The capacity of HPGR grinders is significantly less than other ordinary grinders and they produce different amounts of fines to other grinders (Hidden & Powell 2008), these issues create uncertainty as to how HPGR mills will perform if used to completely replace the current grinders. The high SE of 0.55 for this rating is a result of the relatively higher ratings given by two corporate interviews.

CDM projects are being explored by all three companies with a number of projects in the pipeline and a few already successfully completed. However, the stringency and inflexibility of the procedures required to successfully implement a CDM project was an issue brought up by all three companies who felt a number of potential CDM projects were not being realised due to difficulty of the process.

The low ratings given to the two opportunities dealing with *research and development (R & D)* are surprising, particularly the *increase in R & D expenditure* with all 3 companies spending less than 0.5% of their operating budgets on R & D. A major breakthrough in *R & D* in the gold mining industry has not been forthcoming in the last number of decades, which could explain the low rating for this opportunity. The fact that all the companies reviewed are spending less 0.5% of their operating budget on R & D suggests that it would not take much effort to increase the R & D programs followed by each company.

Changing the *management structure* to promote better EE was an issue that was suggested by a few of the interviewees. It was also felt that more teams of energy specialists would generate greater energy savings. The average rating of 2.7 is fairly moderate, although it should be noted that the rating was given by the key personnel making up the current energy

management structure and thus would not be inclined to highlight a lack of skills within their teams.

Magnitude of savings of EE opportunities

Interviewees were asked to rate EE opportunities in terms of their potential magnitude of energy savings. Table 25 shows the ratings per company as well as average of all three companies for the *magnitude of energy savings* potential for the twenty-eight identified opportunities.

Table 25: Opportunities with the highest rating for their Magnitude of energy savings

Opportunity	Company 1	Company 2	Company 3	Average	Standard error
Localized cooling and more efficient refrigeration	4.7	5	4	4.6	0.22
Employee education	4.0	5	4.5	4.5	0.21
Projects eligible for Eskom DSM financing	3.3	5	4.5	4.3	0.37
Re-design of old technologies (optimization)	3.0	5	4.5	4.2	0.48
More efficient ventilation system	3.7	5	4	4.2	0.68
Reduction in quantities of material coming into comminution by improved ore sorting or heap leaching of ROM ores	3.7	4	4	3.9	0.17
Employee incentives schemes	3.3	4	4.5	3.9	0.48
Improved pumping system	3.0	5	3.5	3.8	0.56

The opportunity currently viewed by the energy experts as having the biggest energy saving potential is *localized cooling and more efficient refrigeration*. The distance's coolants must travel in deep underground mines, if run from a central cooling station tend to be extremely far, which dramatically affects the effectiveness of the system. The importance of this opportunity was stressed during the majority of the semi-structured interviews, making it clear there was significant room to improve the efficiency of their current cooling systems, which are run from large centralized cooling plants. Literature on South African industry indicates a general industrial potential to improve EE through process cooling by 7% (Winkler 2007). This process is particularly critical to deep underground mines and thus the

potential EE improvement for underground mining would likely exceed the general industrial saving predicted by literature.

The average rating of 4.5 given to *employee education* for its magnitude of energy saving potential is surprising when considering how much of the total energy consumption in gold mining is consumed by heavy machinery. However energy savings due to improved energy management, in which employee education plays a key role, has shown a potential to improve energy efficiency of industrial systems by 20% (McKane 2007). This high rating also indicates the importance the energy manager's place on the effective operation of heavy machinery. Employees operate and control most of the energy intensive machinery within the mine. The interviewees all agreed on the potential magnitude of saving of this opportunity, thus the low SE of 0.21.

Adequate *ventilation* is a non-negotiable due to health concerns in deep underground mines. The inefficiency of current ventilation systems especially around compressed air issues is indicated by the opportunity's high rating of 4.2. Literature on South African industry indicates a general industrial potential to improve EE through improved compressed air systems by between 10 to 20% (Winkler 2007, Energy Research Institute 2010). Not all the interviewees agreed over the magnitude of the potential energy savings still left through improvement of compressed air systems, thus the high SE of 0.68.

The importance of *incentive schemes* has been underutilised by two of the companies reviewed, with only one of the three companies offering any financial incentives to employees who actively reduce the company's energy and GHG emissions. This is potentially a key area for the companies to pursue if they want to get employee buy in to EE initiatives and thus make educating employees and the implementation of an effective EMP an easier proposition.

The current *pumping systems* of the reviewed mines are typically oversized; this is due to large safety factors and overestimation for the predicted throughput of the mine when the systems were put in many years ago. This has created an opportunity for the companies to significantly reduce the energy consumption of their pumping systems by replacing their big oversized inefficient systems with smaller accurately sized efficient ones. The findings from LTMS indicated that EE of pumping systems could be improved by approximately 25% by 2030 (Winkler 2007). The high SE of 0.56 is a result of some interviewees feeling that their company had already explored this opportunity adequately and thus there is little scope for further improvements.

Table 26 shows the six opportunities viewed to have the smallest potential to save energy

Table 26: Opportunities with the smallest potential to reduce energy consumption

Opportunity	Company 1	Company 2	Company 3	Average	Standard error
On-site generation of energy	1.7	2	2	1.9	0.54
Energy efficient lighting: low energy bulbs/ natural lighting	1.3	2	2.5	1.9	0.48
Improvement in the tools for analysing mineral deposits: Models sensors and instrumentation	3.0	2	3.5	2.8	0.45
Maintenance	3.0	2	3.5	2.8	0.52
Better instruments and sensors allowing greater control over comminution and classification processes	3.3	3	2.5	2.9	0.45
Projects potential to obtain carbon finance and eligibility for carbon credits trading. (e.g. CDM)	2.7	4	2.5	3.1	0.37

The problem of *onsite generation* being more expensive for gold mining companies than purchasing electricity from Eskom has been mentioned. After the semi-structured interviews, it was clear that South Africa's gold mining companies do not currently view on-site generation as a workable solution. Though with the electricity price continuing to rise and issues around the security of mines energy supply in doubt, on-site generation may well be an opportunity that becomes more attractive to South Africa gold mining companies in the future. The high standard error of 0.54 is a result of a few corporate interviewees giving this opportunity a significantly higher rating than the technical interviewees.

Underground mining is extremely energy intensive due to its comminution, cooling and ventilation processes. Thus although the EE of lighting systems themselves can typically be improved by over 60% in industry in South African (Maldonado 2005), this saving is relatively small when compared to the mines total energy consumption. All the interviewees agreed on the low magnitude of energy saving potential from EE lighting.

The magnitude of energy saving potentials for the *improvement in the tools for analysing mineral deposits* and *effective maintenance* are not totally agreed on by the three companies with SEs 0.45 of and 0.52 respectively. C1 and C3 both rated these opportunities as 3 and

3.5 respectively which indicates a moderate to significant energy saving, while C2 rates them both as a 2, indicating only a small energy saving. This could indicate that either C2 sees that these opportunities, if effectively implemented, would have little effect on the overall energy consumption of their operations or that these opportunities have been explored by the company adequately already and thus further savings would be minimal.

Better instruments and sensors allowing greater control over comminution and classification processes were given an average rating of 2.9, indicating that they had a moderate potential to save energy. This rating was however emphasized by a number of outside experts as key to reducing the energy consumption of the mines by improving the yield factor of the mines and thus reducing the throughput.

The *potential of carbon financing* to reduce energy consumption was rated as 3.1 showing that this opportunity has a moderate potential to save energy.

4.3.2 Drivers for the uptake of EE opportunities

A number of drivers promoting the uptake of EE exist for South Africa's gold mining sub-sector. These drivers include financial, managerial and legislative drivers. The perspectives from the interviewed experts on a list of thirteen key identified drivers for the uptake of EE opportunities are evaluated below. The description given for a rating of three was that it had moderate potential to drive change and for a rating of 4 was for an opportunity that had significant potential to drive change. Table 27 shows the drivers that the interviewees on average rated as the most important

Table 27: Most effective drivers for improved uptake of EE opportunities

Driver	Company 1	Company 2	Company 3	Average	Standard error
Operational resilience/ energy security	4.3	4.5	5.0	4.6	0.27
Increase in electricity price	4.0	4.5	5.0	4.5	0.26
Reduce exposure to carbon tax and potential emissions trading schemes	3.4	4.5	4.5	4.1	0.33
Increase in fuel price	3.6	3.5	5.0	4.0	0.31
Tax rebates or incentives	3.6	4.0	3.0	3.5	0.22
Reputational benefits	3.0	3.0	4.0	3.3	0.31

The top five rated drivers are financial in nature or closely linked to financial performance. This highlights the importance that saving operating costs has for driving the uptake of EE opportunities within South Africa's gold industry sub-sector. The feedback from the interviews indicated that currently in the gold industry, EE was seen almost entirely as just a way to reduce operating expenses.

From the responses obtained, *operational resilience and energy security* appears to currently be the biggest driver for gold mining companies to improve their uptake of EE opportunities with an aggregate rating of 4.6. The fear of forced mine closure is a very real one in South Africa with just such an occurrence happening in 2008. This forced closure due a shortage of energy reportedly costing the industry an estimated R12 bn rand in revenue (Chamber of Mines 2009).

Typically, over 90% of energy for South Africa's gold mines comes from Eskom. C1, C2 and C3 report that electricity consumption accounts for 99%, 98% and 96% respectively of their total energy consumption of their South African operations (AngloGold Ashanti 2010, Gold Fields 2010a, Harmony Gold 2009). The rapidly increasing electricity price has in general close to doubled the proportion of the operating budget being spent on electricity, for the companies reviewed over the last 5 years, to between 11% and 18%. With the electricity price set to increase next year and probably again in 2013 by approximately 25% a year, the operating cost spent on electricity can be expected to increase accordingly. Thus, it is no surprise that a key driver for increased EE opportunity uptake is the *increasing electricity price*.

It is clear that the reviewed companies are taking the potential introduction of a *carbon tax or emission trading scheme* very seriously, with an average rating 4.1 having been given to this driver. The driver's high rating may be influenced by the review of the Kyoto protocol in 2012 and the uncertainty of South Africa's responsibilities and response post this review.

The *increase in fuel price* was given an average rating of 4.0. Given the low proportion of fuel-generated energy the mining companies use, this high rating is slightly surprising. C1 and C2 rated this driver as 3.6 and 3.5 respectively, indicating a moderate importance. It was C3's rating of 5 which pushed this overall rating up. Internationally fuel accounts for 19% of C3's scope 1 and 2 emissions, this international perspective as well as the slightly higher local percentages of fuel driven energy usage of C3 may be the main reason for its employees rating the *increase in fuel price* driver so highly.

The potential for companies to receive some form of *tax rebate* or other incentive for improving their EE also seems to be a significant driver with an average rating of 3.5. This opportunity was unanimously rated as important by all the interviewees, thus the low SE of 0.22.

The importance of the *reputation benefits* their companies could potentially receive for reducing their energy and climate footprints because was particularly stressed by C3. This is likely due to the high percentage of C3 owned by investors from Annex 1 countries. The interviewees mentioned that overseas shareholders and in some cases potential investors were evaluating both the environmental and financial performance of companies, not just the financial which had been the case in the past.

While the interviewees recognised the importance of the above drivers, there were other drivers on the rating sheet, which were not as highly recognised by the interviewees. These drivers are shown in Table 28.

Table 28: Least significant drivers for improved uptake of EE opportunities

Driver	Company 1	Company 2	Company 3	Average	Standard error
Exclusivity rights to self-pioneered new technologies	1.5	2.5	1.0	1.7	0.38
Pressure from up or downstream business partners	1.3	3.5	1.5	2.1	0.55
I&AP pressure (NGOs, local committees etc)	1.8	3.0	2.5	2.4	0.53
High levels of technical support & information around new technologies	3.0	2.5	2.5	2.7	0.37
Competitive advantage/increase in market share	1.5	3.0	3.5	2.7	0.53

Unlike the table of key drivers, which included financial orientated drivers, Table 28 has drivers that are predominately not linked directly to financial performance.

Exclusivity rights to self-pioneered new technologies is clearly a driver that is not important to the gold sub-sector at present. C2 rates this driver a 2.5 which although is significantly higher than the ratings given by C1 and C3 it is still the lowest rating given by C2. C2's average rating of 3.5 is the highest given to the drivers and goes some way to explain the higher rating given to this unimportant driver. The low importance for this driver is predominately due to the fact that gold companies do not set the price of gold and thus there is little competition between the companies.

The low rating given to *pressure from up or downstream business partners* is apparent with South Africa's biggest gold mining companies not having any up or downstream business partners with gold being typically sold directly to banks. This driver's high SE of 0.55 is a result of a few technical interviewees giving a relatively higher rating for this driver.

I & AP pressure was rated between insignificant and small by C1 and C3. This is to be expected given the low community attention been placed on EE within the gold sub-sector as opposed to other environmental issues such as water pollution etc. C2 rated the driver between moderate and significant. There seems to be no plausible reason for this higher rating by C2 except the employee's inclination to give the drivers relatively higher rating than the other 2 companies.

High levels of technical support & information around new technologies was a driver which appears industry is not investing much value to. This can create a situation in which companies possess a low level of awareness around EE and other environmental concerns which has been cited as a direct barrier to EE technologies (Faiers&Neame 2006). Improvement in this driver would decrease the risk and uncertainty associated with new technology. Improving this driver has also been shown to increase the speed of dissemination for new technologies.

Competitive advantage/increase in market share, was given a low rating by C1. Though C2 rated it as a 3 it was still one of the company's five least significant drivers. These ratings would again suggest that there is little competition in South Africa's gold sub-sector. The rating of 3.5 by C3 is somewhat interesting showing a slightly more competitive mindset from the employees from C3, though this rating is only just above the C3's average of 3.3 and as such still is not viewed as a significant driver. The companies' differing opinions over this driver resulted in a high SE of 0.53.

4.3.3 Barriers hindering the uptake of EE opportunities

Twelve key barriers to the uptake of EE opportunities were identified during the literature review and desktop study processes. The interviewees' perspectives on these barriers are evaluated below.

Table 29 shows the five barriers given the highest rating for their potential to hinder the uptake of EE opportunities.

Table 29: Most significant barriers hindering the uptake of EE opportunities

Barrier	Company 1	Company 2	Company 3	Average	Standard error
Direct cost of developing and implementing new technologies	4.5	4	4	4.2	0.25
Perceived risks associated with new technologies	3.8	3.5	3.5	3.6	0.18
Lock in effect of old technologies/ Premature retirement of capital	3.3	2.5	4	3.3	0.41
Shortage of skills	2.3	2.5	3.5	2.8	0.46
Uncertainty over the benefits of new technologies	2.5	3.5	2	2.7	0.50

The actual size of the *direct capital cost required to implement new technologies* was bought up as an issue by all three companies and has significantly the highest rating of any of the identified barriers hindering the uptake of EE opportunities. New technologies are typically untested at an industrial level. This creates uncertainty in terms of their reliability and level of performance (Rosenberg 1996). This adds significant risk in spending the required capital for new technologies as opposed to older proven technologies. Thus it is not surprising that 3 of the barriers relating to these issues are found in the top 5. The very low standard error of 0.18 for the *perceived risks associated with new technologies* indicates that all three companies see the risk involved with new technologies as a key barrier.

As mentioned major mining equipment typically has an extremely high capital expenditure, thus mines are unlikely to replace an item of equipment that is working and even if there is a much more EE alternative to the equipment. This unwillingness to *prematurely retire working capital* means that new mining equipment is typically adopted only when old equipment comes to end of its life. The premature retirement of capital is also affected by the life span of the operations with companies even more unlikely to invest in new equipment with a mine nearing the end of its life.

Although all the mines reviewed had specialists that dealt with energy issues, there was a feeling among certain employees that more teams of specialists and/or more extensive teams would significantly increase the uptake of EE opportunities. Though on the whole

which is indicated by the low rating of 2.8 the employees interviewed felt that the current level and quantity of skilled energy professionals within their companies were adequate.

The high risk associated with new technologies is as a result of the size of the capital investment and the lack of data and the uncertainty around the performance of new technologies. The *uncertainties over the benefits of new technologies* surround the unproven nature and lack of information on new technologies. The uncertainty over the benefits of a new technology would depend on the particular technology in question; this goes some way to explaining the high SE of 0.50 for this barrier. The fact that this barrier is so highly rated while the driver *high levels of technical support & information around new technologies* was in the bottom given a low rating of 2.7, is somewhat conflicting.

Table 30 shows the barriers that the interviewees rated as having the least effect on the uptake of EE opportunities.

Table 30: Least significant barriers hindering the uptake of EE opportunities

Barrier	Company 1	Company 2	Company 3	Average	Standard error
Banks policy around the financing of process innovation	1.8	2	2.5	2.1	0.42
Innovation too easy to copy	1.5	2.5	2.5	2.2	0.38
Inadequate data and information to motivate/ support change	1.0	3	2.5	2.2	0.44
Lack of corporate commitment (Low level of environmental awareness)	1.0	3	3	2.3	0.50
Lack of top-down support and incentives	1.3	3	3	2.4	0.44

C1's average rating of 2.0 was significantly lower than the other companies and this tendency of the C1 employees to downplay the identified barriers is evident in the above table with each barrier receiving its lowest rating from C1.

As previously mentioned the ability of all three companies to finance the majority of new projects in-house makes the bank's *policy around financing of process innovation* insignificant to their choice of which project to implement. This however is not true for smaller companies in the gold sub-sector and the mineral industry in general, where banks strict policy for lending money for an EE project having considerable impact on a projects potential to be implemented (Robert et al. 2008)

The low rating of 2.2 given to *innovation too easy to copy*, again highlights the lack of competition between the major gold mining companies in South Africa.

The particular low ratings to the bottom three barriers namely; *inadequate data and information, lack of corporate commitment and lack of top-down support and incentives* from C1 is due to the interviewees belief that these barriers have been adequately addressed by the company already, not that these were not important barriers. The ratings given by C2 and C3 indicate that while these barriers fall into the bottom 5 they are still worth investigating. The divergence of these ratings has resulted in high SE's for these barriers of 0.44, 0.50 and 0.44 respectively.

4.3.4 Investment decision making criteria

Seventeen criteria were identified to form part of the investment decision making process around the uptake of EE opportunities. The average rating given per criteria was 3.8. A rating of 3 represents criteria with a moderate level of importance while a rating of 4 represents criteria of significant importance.

This high overall rating of 3.8 out of 5 shows the significance the seventeen criteria have in determining whether an identified opportunity gets the go ahead or not. Table 31 shows the six highest rated parameters.

Table 31: Key investment decision-making criteria

Criteria	Company 1	Company 2	Company 3	Average	Standard error
Energy consumption reductions	4.3	4.5	4.5	4.4	0.20
Payback Period	4.3	4.0	4.5	4.3	0.30
Maintenance of project	4.0	5.0	4.0	4.3	0.34
Accounting rate of return (ARR)	4.0	4.0	4.5	4.2	0.31
Availability and reliability of data and information on current performance	4.0	4.0	4.5	4.2	0.26
Availability and reliability of data and information on alternative technologies/equipment	4.0	4.0	4.5	4.2	0.26

The fact the ratings have been obtained by the energy experts of the reviewed companies and concern EE opportunities, the importance given to *energy consumption reductions* is to be expected. The uniformity of the ratings is indicated by the low SE of 0.20.

A short *payback period* of approximately 3 years appears to be a non-negotiable when companies review an EE opportunity. There seems to be a mandate in the gold mining industry at present given to all energy professionals to target these 'low hanging' EE opportunities before evaluating and implementing the longer term EE opportunities. The targeting of these projects may also occur as projects with DSM funding are the typically the only current EE projects able to meet the companies required hurdle rates.

The *maintenance* of the project was defined as operating/running costs for the project. It would appear that projects that require little or no maintenance i.e. processes that have less wear and tear thus low running costs are significantly preferred to projects that have high running costs.

The *accounting rate of return* (ARR) is the standard way companies rank opportunities; it gives the percentage return companies can expect on their investment and is the key criteria on deciding whether or not a project will get implemented. In the gold mining sub-sector a projects ARR must meet or exceed the set hurdle rate before it is given funding.

The last two parameters focus specifically on information. Before any changes can be made to improve EE within a mining operation it is critical to be able to give an accurate benchmark for energy consumption of the current equipment. This information is crucial to be able to firstly identify the need to improve the system and secondary a prerequisite for

Eskom DSM funding. The more data and testing that have been done around the performance of new opportunities the better. Good research can significantly reduce the risk and uncertainty involved with the implementation of new technology.

The lowest rating given to any of the indicators was 3.4. Both *eligibility for carbon credits* and *discounted payback periods* received this rating.

4.4 Synthesis of findings

The desktop review of South Africa's three largest gold mining companies showed the average trends of the three companies to have a close relationship to the national trends over the five year period between 2006 and 2010. The detail of the information for the desktop study was limited by the detail of energy and greenhouse gas information presented in the reviewed companies reports.

From the desktop study it was observed that due to the number of mine closures, safety stoppages and EE improvements over the last 5 years, the total energy consumption of the reviewed companies has marginally dropped by 2.6% to 43696 TJ or 12138 GWh. Currently electricity consumption accounts for between 11% and 18% of the operating expenses of the reviewed companies. Improving the EE of their operations is considered the best way of reducing this operating expense.

Given that over 90% of GHG emissions from the mining companies reviewed are a direct result of electricity consumption, it was unsurprising that total GHG emissions and electricity consumption trends both stayed relatively similar over the review period, however due to the mine methane at one of the operation reviewed GHG emissions had increased by 2010 while energy consumption had decreased. The degree of awareness and concern around GHG emissions is minimal in the industry with interviewees stating that it was Eskom's responsibility to reduce the associated GHG emissions of their companies' electricity consumption. This could possibly change with an improved CDM program or the implementation of a carbon tax.

South Africa's national gold production levels have fallen significantly over the last decade. South Africa's total nation production levels dropped 30.5%, from 2006 to 2010, to 191.8 tonnes or 6000 oz. This significant drop in production comes despite gold trading at an all-time high against the US dollar. This fall has not been in line with the global trends in gold production and as such, South Africa's share of global gold production has fall from 16.3% in 2000 to 7.9% in 2010. Mine closures and safety stoppages have resulted in total throughput at the mines of the reviewed companies decreasing from 2006 to 2010 by 15% to a total of 40.9 Mt. The decreasing throughput has been compounded by rapidly declining ore-grades at the mines of the reviewed companies – down 21.9% to 4.36 g/oz – which has resulted in a significant drop in gold production from 2006 of 30.2% to 5084 oz in 2010. The fall in gold

production is result of the depletion of South Africa's highest ore-grade and most accessible deposits that has forced mines to mine deeper and lower grade ores.

The deeper and lower grade ore has affected the energy and emission intensity of South Africa's gold mines. In 2010, the energy intensity of throughput of the reviewed mines was up 11.4%, energy intensity of gold production was up 40.0% and emission intensity of gold production up 40.8% from 2006 levels. The increase in energy and emission intensity due to decreasing ore-grades as well as the linear relationship between the in energy and emission intensity of gold production found in this study is in line with the findings of Mudd (2010) for the global gold industry.

The decreasing ore-grade and increasing operating costs experienced by most South African gold operations are resulting in the multi-national mining companies closing local South African mines and instead investing in mines in other countries with better prospects of generating profit. This will continue to have detrimental impacts on unemployment statistics as well as the companies' capital investments in South Africa. Though the total energy consumption of the industry can thus be expected to decline with the continued decline in production. The EE of the mines will most likely continue to rise given the physical challenges mentioned above (PWC 2010).

The findings from the interview and survey investigation shed light on a number of key EE opportunities as well as the factors driving and hindering the uptake of these opportunities. Table 32 shows the overall best opportunities when the two criteria used to rate EE opportunities are combined.

Table 32: Overall best opportunities

Opportunity	Ease of implementation	Magnitude of savings	Average
Projects eligible for Eskom DSM financing	3.8	4.3	4.1
Localized cooling and more efficient refrigeration	3.1	4.6	3.8
Redesign of old over specified technologies	3.4	4.2	3.8
Employee education	3.1	4.5	3.8
More efficient ventilation (compressed air)	2.9	4.2	3.6
Employee incentive schemes	3.3	3.9	3.6
Improved pumping system	3.4	3.8	3.6

According to the findings from the survey investigation, the four highest rated opportunities all have high magnitudes of energy savings. This high magnitude of energy savings makes the following drivers, which are all closely linked to energy savings, particularly relevant to the top four opportunities, these drivers being; the *increase in electricity price, operational resilience / energy security* as well as *reduced exposure to carbon tax and potential emission trading schemes*. All three of these drivers have been rated as being of high importance by the interviewees of this study. Opportunities with high magnitudes of energy savings will also receive high ratings for the decision-making criterion *energy consumption reduction*, which was the criterion given the highest rating in this study.

Aside from *projects eligibility for Eskom DSM financing*, none of the other top opportunities have an ease of implementation of above 3.4. Key to improving a projects ease of implementation is improvement in the skill of employees, information on current performance as well as the availability and reliability of data and information on alternative technologies/equipment.

Eligibility for Eskom DSM financing got the highest overall rating as an EE opportunity of 4.1. The feedback from the semi-structured interviews indicated the importance of the DSM funding, it could be suggested that the DSM funding is a prerequisite for a brown-fields EE project to get the go ahead. From the side of decision making criteria the *eligibility for Eskom DSM financing* achieved an average rating of 4.0. Eskom's funding which pays up to 100% of the projects cost up to the set benchmark figures significantly impacts on other decision making criteria used to evaluate a potential EE project. With DSM funding the payback period of a project would be significantly reduced, while the internal rate of return of the project will be significantly increased.

The magnitude of its energy saving makes *localized cooling and more efficient refrigeration* an extremely important opportunity. The key barriers hindering the uptake of this opportunity include lock in effect of old technologies/ premature retirement of capital and the direct cost of developing and implementing new technologies. The significance of these barriers is reflected in the low average rating given to the ease of implementation for this opportunity of 3.1. The reliability and availability of energy data and information allowing the effective comparison to be made between the current centralized systems with localised systems would be critical to this opportunity's potential implementation, as this data would significantly affect the opportunity's payback period and accounting rate of return.

Redesign of old over specified technologies achieved an overall rating of 3.8. The key barriers hindering the uptake of this opportunity include: the direct cost of developing and implementing new technologies, the life span of the particular operation as well as the lock in effect of old technologies/ premature retirement of capital. There should be limited risk and uncertainty involved with adopting more efficient and accurately sized technologies. One of the specific key opportunities in this regard would be the improvement of the mines current pumping systems which got an overall rating of 3.6. The potential to reduce energy consumption by replacing *old over-designed technologies* (e.g. motor systems operating pumps and fans) with new redesigned technologies has been suggested at 25% by literature (Winkler 2007). The energy savings of new energy efficient motor systems should not be viewed in isolation but in conjunction with the other benefits of new energy efficient motors such as failure reduction, reduced maintenance and improved productivity (Maldonado 2005)

Employee education also received an overall rating of 3.8. Its moderate rating for its ease of implementation could be significantly overcome by the implementation of an employee incentive scheme. The impact that the use of an incentive scheme has on improving the ease of implementation of employee education is clear with C2, who is the only company employing an incentive scheme, giving the ease of implementation of employee education a rating of 4. While the average ease of implementation for an *incentive scheme* was rated as 3.3, it was only C1 who gave this opportunity a low rating of 2. Both C2 and C3 both gave ease of implementation of this opportunity a rating of 4. The importance of an energy management plan and employee education has been indicated by literature to have the potential for improving the EE of an organization by up to 20% (McKane et al. 2008, McKane 2007).

More efficient ventilation / compressed air systems achieved an overall rating of 3.6. This opportunity had the lowest rating for its ease of implementation of any of the highest overall rated opportunities. The key barriers hindering the uptake of this opportunity would be the perceived risk associated with new technologies, lock in effect of old technologies / premature retirement of capital as well as the direct cost of developing and implementing new technologies. The potential to improve the EE of South Africa's industrial compressed

air systems has been stated in literature to be between 10% and 20% (Winkler 2007, Energy Research Institute 2010). The significant quantity of energy used for ventilation was brought up by the interviewees from all the reviewed companies. However, this opportunity only received an average rating of 3.3. This low rating comes despite literature identifying potential energy savings of up to 35% for air-conditioning and ventilation in the mining industry (Maldonado 2005).

The companies' reviewed also had a low regard for underground processing with it given an average opportunity rating of 2.4. Literature has estimated that underground processing could use 50% less energy than conventional above ground processing (Hughes & Grigg 2008). However, two of the independent technology experts interviewed in this thesis were not convinced by the energy savings potential of underground processing and stressed that there was significant uncertainty about energy increases that would be required for cooling and ventilating due to the heat generated by underground processing.

Although not making up one of the top rated opportunities with only a rating of 2.8, improved comminution technologies such as *HPGR* mills have reported energy savings of approximately 19% over more conventional grinding systems (Hidden & Powell 2008). This would indicate that the reviewed companies should invest more resources into investigating the feasibility of *HPGR* mills.

A number of key barriers were identified that need to be overcome to improve the uptake of EE from an industrial perspective. The *direct cost of developing and implementing new technologies* was rated the highest barrier hindering the uptake of EE opportunities. This barrier was also stressed in literature (McKinsey & Company 2009, Sawin & Moomaw 2009). The reasons given by the interviewees for its significance as a barrier included; competition for capital and the mandate they had to target short payback period projects. The focus on short payback period projects for EE projects is not just confined to the mineral industry but is prevalent in industry as a whole (Aryndel et al. 2011).

The *perceived risks of new technologies* are a result of uncertainties in the information and performance of new technologies and are in line with the findings from literature (Gardner & Buzacott 1999, Rosenberg 1996). Possible ways to overcome this barrier would be to increase the levels of information and support around new technologies, through increased R&D expenditure and more effective technology standards.

The mineral industry's averseness to *pre-maturely retire capital* was identified by reviewed companies to be a significant barrier hindering the uptake of new EE technology, this matches finding in the literature (Energy Research Centre 2007). This is a particular significant barrier in the gold mining industry due to the upfront cost of new technologies together with the short life expectancies of a number of mines. This can make the payback period of the new technology longer than the life expectancy of the mine. Key ways for

reducing the effect of this barrier would be more detailed information on the new potential technology, accurate estimations for the life of mines, and outside funding or tax reduction to reduce the direct cost of new technologies thus shortening their payback periods.

A *shortage of skills* was identified by the interviewees as one of the key barriers hindering the uptake of EE opportunities. This is due to the specific nature of the skills required to effectively identify, evaluate and implement EE opportunities. Key ways to overcome this barrier include, improved internal capacity building within mining companies through employee education, the outsourcing of work to skilled energy service companies and the hiring of more skilled personnel.

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5 CONCLUSIONS AND RECOMMENDATIONS

Electricity shortages, the threat of climate change and the reliance on coal fired energy as the primary source of electricity have significantly increased the need for improved energy efficiency in South Africa's more energy intensive industries. One such industry is the minerals industry, which consumes 18% of South Africa's electricity (more than 90% of which is fossil-fuel based) and 7.5% of the country's total energy supply. Decreasing ore-grades and increasing mine depths, within the context of declining ore reserves and growing socio-political and economic constraints, make improving the energy efficiency of South Africa's gold sub-sector particularly challenging.

It is this challenge that this thesis addresses, by identifying and evaluating potential opportunities for the reduction of energy and climate footprints in South Africa's minerals industry and the gold industry sub-sector in particular. More specifically, this research thesis set out to answer the following research questions:

Generic mineral industry key questions:

- 1 What role does energy efficiency have to play in South Africa's mineral industry's response to climate change and energy shortages?
- 2 What opportunities exist for energy efficiency within the mineral industry?
- 3 What are the key drivers and barriers affecting the uptake of energy efficiency opportunities?

Gold industry specific key questions:

- 4 What is the gold industry's current performance with regards to energy consumption and GHG emissions?
- 5 What opportunities exist for energy efficiency within South Africa's gold sub-sector and what are the drivers and barriers affecting their uptake?
- 6 What are the perspectives of key decision makers within South Africa's gold-sub-sector on the available EE opportunities as well as the drivers and barriers affecting their uptake?
- 7 What steps can be taken to improve the uptake of EE opportunities within South Africa's gold sub-sector?

This chapter highlights the key findings of this study and makes recommendations in terms of the way forward.

5.1 Summary of key findings

This study was comprised of two main research components, namely (i) a holistic and generic literature review and assessment to provide background knowledge and consolidate existing knowledge on energy efficiency in South Africa's mining and minerals beneficiation industry; and (ii) a detailed case study of the gold industry in South Africa. The key findings of these two tasks are summarised in Sections 5.1.1 and 5.1.2.

5.1.1 Potential drivers, barriers and opportunities for increased EE and GHG emissions mitigation in the local minerals industry

The literature review and assessment, presented in Chapter 2, addressed the first three key questions of this research study, by highlighting the role of energy efficiency in reducing energy consumption and global warming, and identifying potential drivers, barriers and opportunities for increased EE in the local minerals industry.

The results of this review demonstrated that the minerals industry is one of South Africa's most energy intensive industries. The need for the implementation of improved energy efficiency within South Africa's minerals industry has been recognised by policy makers and industry alike. This is due to its cost effectiveness in reducing GHG emissions, the rapidly increasing electricity price and the extent of its potential energy savings. Research suggests that the industry can reduce its GHG emission by well over 15% within the next decade from improved EE.

From a management perspective the key opportunities identified for improving industrial EE include: improved employee education, incentive schemes, increased R&D expenditure, effective maintenance, improved layout of equipment, and more efficient lighting and lighting control systems. The above opportunities should all form part of an effective energy management plan, the implementation of which has been shown to improve the energy efficiency of industrial systems by up to 20%.

Optimisation of compressed air systems provided one of the key opportunities for reducing the energy consumption associated with utilities. Energy reduction of up to 10 to 20% can be achieved at low capital costs by regular maintenance to improve compression efficiency, air leakage or pressure variability. Further energy savings can be achieved by recovering heat from air compressors. The EE of ventilation and air-conditioning processes, which have been shown to be the biggest user of energy in deep underground mines, can be improved by up to 35% through the application of frequency converters. The EE of process cooling or refrigeration can be improved through thermal insulation and regular maintenance. The EE of pumping and fans (motor systems) can also typically be improved by switching off motors when not needed, selecting correctly sized motors, using high efficiency motors when operating for long periods at high loads, and/or using variable speed drives.

Various EE opportunities were identified for the mineral extraction and beneficiation phases. HPGR mills have demonstrated the potential to reduce energy consumption by 19% over more conventional grinding routes. Improvements in the selection of target product size for comminution circuits have shown the potential to improve its EE by up to 66% when 50% of the circuit feed material was removed for further size reduction. Underground processing indicated a potential energy saving of up to 50% when compared to the power consumption of conventional milling methods due to energy savings through reduced hoisting and

haulage, because of lower tonnage and a decrease of the required size of the surface plant capacity, as a result of higher ore-grades.

The key mechanisms with the potential to drive EE within South Africa's industry are Eskom's Demand Side Management (DSM) funding and Clean Development Mechanism (CDM) projects. Eskom's DSM funding pays 100% of the capital cost for a brown-fields EE project, up to the relevant benchmark figure which is between R3.5-R6.5 million/MW depending on which program the opportunity falls under. CDM projects however require a high level of skill and significant time periods for successful implementation. Other potential mechanisms identified include a carbon tax, voluntary industrial agreements, increased public pressure and 'green' trade policy.

The key barriers found to be hindering the uptake of EE opportunities of South Africa's mineral industry in general included; the capital cost of developing and implementing new technologies, the uncertainty around the performance of new EE technologies, the uncertainty over the future pricing of electricity, a lack of legislation and regulatory control as well as limited access to external financing for process innovation.

5.1.2 Case study of the South African gold industry sub-sector

The gold case study was conducted in three parts. Firstly a background review was conducted to provide context to the study. A desktop study was subsequently conducted to evaluate the energy related performance of South Africa's three largest gold mining companies, AngloGold Ashanti, Harmony Gold and Gold Fields, thereby answering the 4th key research question of this study. This was followed by an interview and survey investigation with external consultants and in-house company representatives on the available EE opportunities as well as the drivers and barriers affecting their uptake from an industrial perspective (key research questions 5 and 6).

Improving the EE of South Africa's local gold sub-sector is particularly challenging due to the sunset nature of the industry. The depletion of gold ore reserves has implications in terms of the life of specific operations and the industry as a whole. The situation is exasperated by the declining grades and accessibility, which are resulting in increasing costs, deeper mines and higher energy consumptions. Operations of particular relevance to energy consumption by the gold mining industry are ventilation, air compression and refining.

The desktop study, carried out on South Africa's three largest gold mining companies, confirmed that the throughput and production levels of the companies have declined significantly over the last five years, on average by 15% and 30.2% respectively. These significant decreases have resulted in a slight decrease in energy consumption by 2.5%. The energy intensity of throughput and production have however increased significantly by approximately 12% and 40% respectively.

Interviews and surveys with key industry-based employees provided an indication of the overall highest rated EE opportunities (rated in terms of their potential energy saving and their ease of implementation). The highest rated EE opportunity was *projects eligible for Eskom Demand Side Management (DSM) funding*. The DSM funding process has been very successful in the mineral industry and particularly in the gold sub-sector with AngloGold Ashanti being the largest industrial user of DSM funding as of 2010. Other highly rated EE opportunities included: localised cooling/more efficient refrigeration, redesign of old over-specified technologies, the implementation of an energy management plan, employee education and training, and improved compressed air systems.

The key drivers promoting the uptake of above EE opportunities were the increasing cost of electricity, the gold sub-sectors' concern over energy security and the increasing cost of fuel. Other drivers that the gold sub-sector felt had the potential to significantly promote the uptake of EE opportunities would be reducing their exposure to a carbon tax as well as tax rebates or incentives.

The key barriers hindering the uptake of EE opportunities were typically cost based with the *direct cost of developing and implementing new EE technologies* rated the highest. The high capital cost and possible disruptions to production caused by replacing old technology with new more efficient technology as well as the low life expectancy of many of the countries' gold mines, have made companies averse to replacing technologies before they reach the end of their life, causing a lock-in effect of old technologies. Thus there is contest between the need for new equipment and the lock in effect of old technologies, making it a crucial area in which the right management will result in the uptake of more EE opportunities.

This lock in effect of old technologies is compounded by the perceived risks associated with the performance of new EE technologies. Another key barrier hindering the uptake of EE opportunities is a shortage of skilled personal to identify, evaluate, implement and run new EE projects. These barriers are thus the key barriers that industry, government and other stakeholders need to overcome if they wish to promote the uptake of EE opportunities in industry.

The number of stakeholders and competing objectives have made investment decision-making in the mineral industry a complex process. The fact that no ring-fenced funds exist in the reviewed companies -specifically for EE projects - means that EE efficiency projects must compete with other potential capital investment projects. The key decision-making criteria used to evaluate EE opportunities to come out of the survey investigation are: energy consumption reduction, payback period, the cost of maintenance of the project and the accounting rate of return. All four of these top rated decision-making criteria focus on the cost benefits of a project and emphasise that it is typically the project showing the best economic return that get the go ahead in South Africa's gold sub-sector. Thus EE project aggregators should ensure that they focus on EE projects that have a high degree of eco-

efficiency and therefore satisfy all of the above criteria, to give the potential EE project the best chance for obtaining funding.

5.1.3 Concluding Remarks

Finally this thesis concludes that organisations within South Africa's gold sub-sector are taking the issue of energy efficiency seriously. This increased focus on energy efficiency within their organisations is predominately due to the increasing cost of electricity and the issues around energy security. The level of focus on energy efficiency within the industry is expected to rise with the rising price of electricity, better structured CDM opportunities and the likely introduction of some form of carbon tax. The identified drivers are expected to become stronger over the next decade and as such will continue to make new EE opportunities more attractive to the mineral industry. However on the down side, gold mining companies are still reluctant to invest in more energy efficient technologies. This is particularly true for technologies that have high capital costs and long pay-back periods, due to the limited life expectancy of many operations for the gold sector and the high aversion to risk within the industry as a whole.

The introduction of a carbon tax and CDM opportunities better structured for the mineral industry, will as go a long way in increasing the attention placed on greenhouse gas emissions, which are currently not given anywhere near the attention that energy efficiency is given within South Africa's gold sub-sector. Currently reductions in greenhouse gas emissions typically arise as a spin-off from energy saving projects.

5.2 Recommendations

This section addresses the final key research question of this thesis by making recommendations on what steps can be implemented to improve the uptake of EE opportunities by South Africa's gold sub-sector; how further study should address some of the shortcomings and limitations of this study; as well as where this study could be expanded on.

5.2.1 Suggestions to improve the uptake of EE opportunities in industry

This thesis suggests that further academic research be conducted around the quantitative understanding of potential energy savings that could be realised through implementation of the EE opportunities identified by this thesis. Given the emphasis on cost recovery and risk aversion of the gold sub-sector, such a study should include a more quantitative analysis of associated financial implications both in the short and longer term, within the context of the different decision-making scenarios discussed in the literature review. This would, in turn, require a more quantitative analysis of future energy costs-both direct and indirect. Studies such as these should be targeted firstly at opportunities that have been identified in the

general literature but not widely recognised or exploited within the industry. Such opportunities include underground mining and the use of HPGR mills.

Another potential opportunity that was stressed in the literature but not viewed in a good light by industry was that of CDM project. For CDM opportunities to be better utilised, either the mines need to have more specialists evaluating and implementing the projects or the stringent procedures that mining companies must follow in order to be awarded this funding must be altered.

An area which industry should investigate is the EE saving potential of employee incentives schemes for improved energy performance. Only one of the three reviewed companies used employee incentives schemes for improved energy performance. This company gave significantly higher ratings than the other two companies for employee buy-in to energy efficiency as well as ease of implementation of employee education around energy issues.

Nationally it is crucial that the government sets out concrete long-term plans with regards to; the future cost of electricity, likelihood and severity of a carbon tax, as well as any other legislation or regulations dealing with energy and/or GHG emissions. This will enable industry to conduct effective scenario planning for the future feasibility of potential EE projects. A significantly higher future electricity cost and/or severe carbon tax could markedly affect which EE opportunities are financially feasible for mining companies to implement.

5.2.2 Recommendations for further study

The industrial perspective of South Africa's three major gold mining companies with regards to EE opportunities, drivers and barriers has been clearly established by this work. However, additional studies in this area would increase the confidence in and usefulness of the approach developed within this thesis.

The limited number of energy experts located and interviewed within each company was found to be one of the major limiting factors in terms of the certainty of the outcomes of the interview and survey process. The identification of additional in-house energy experts, both on a corporate and operational level, will provide a more holistic view of industries' perspective on EE issues. This would also allow comparisons to be made between the perspectives of different levels of decision-makers around energy and climate issues within organisations.

The fact that only the three largest gold mining companies in South Africa were used for the case study limits the usefulness of this thesis mainly to large industrial organisations that can finance the majority of their capital investment projects in-house. Therefore it is recommended that similar work be carried out to analyse EE in smaller mining companies. A

comparison of this study would improve the understanding of where large and small mining companies differ and where they are similar in terms of EE opportunities.

Given the direct relationship between electricity consumption and GHG emissions, it is recommended that a study into potential of reducing the GHG emissions for the local minerals industry by using alternative (non-fossil fuel based) sources for generating electricity be investigated.

Finally it is recommended that the approach and methodologies adopted in this particular study be extended to other sub-sectors of the South African minerals industry, including PGMs, diamond and coal. Such studies can serve to guide the development and implementation of EE interventions, as well as legislative policies and regulation

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APPENDICES

Appendix A: Results from Desktop study

A1: Key Performance Indicators of the reviewed companies

Table 33: Average results for KPI of AGA, Harmony and Gold Fields

Averages	2006	2007	2008	2009	2010
Total throughput (Mt)	16.03	16.22	13.90	13.46	13.63
Total energy consumption (TJ)	14947.00	15139.67	14949.67	13793.00	14565.33
Total production (000oz)	2487.00	2361.00	2014.33	1765.67	1694.67
Energy intensity (GJ/Mt)	1020.03	1016.47	1126.28	1105.37	1136.91
Energy intensity (GJ/oz)	6.04	6.45	7.45	7.84	8.65
Total CO _{2e} emissions (ktCO _{2e})	4239.23	4213.23	4331.03	3879.04	4527.56
Emission efficiency (Kt CO _{2e} /oz)	1.74	1.76	2.13	2.25	2.50
Ore-grade	5.53	5.16	5.12	4.65	4.36

Table 34: Total KPIs from the sum of AGA, Harmony and Gold Fields

Totals	2006	2007	2008	2009	2010
Total throughput (Mt)	48.09	48.67	41.70	40.37	40.88
Total energy consumption (TJ)	44841.00	45419.00	44849.00	41379.00	43696.00
Total production (000oz)	7461.00	7083.00	6043.00	5297.00	5084.00
Energy intensity (GJ/Mt)	3060.08	3049.42	3378.85	3316.10	3410.72
Energy intensity (GJ/oz)	6.04	6.45	7.45	7.84	8.65
Total CO _{2e} emissions (ktCO _{2e})	12717.69	12639.70	12993.09	11637.13	13582.68
Emission efficiency (Kt CO _{2e} /oz)	1.74	1.76	2.13	2.25	2.50
Ore-grade	5.53	5.16	5.12	4.65	4.36

Table 35: Percentage change in KPIs from 2006 levels

AngloGold Ashanti				
	2007	2008	2009	2010
Total throughput (Mt)	-6.1	-14.1	-21.0	-19.8
Total production (000oz)	-8.8	-17.8	-29.6	-30.1
Ore-grade (g/t)	-2.9	-4.3	-11.0	-12.9
Total energy consumption(TJ)	-3.4	-6.9	-9.7	-9.0

Total CO_{2e} emissions (ktCO_{2e})	-4.7	-4.9	-4.3	-3.8
Energy intensity (TJ/Mt)	2.9	8.4	14.3	13.5
Energy intensity (TJ/oz)	5.9	5.5	28.4	30.3
Emission intensity (TJ/oz)	4.6	15.7	36.0	37.8
Harmony				
	2007	2008	2009	2010
Total throughput (Mt)	1.7	-22.9	-22.1	-22.8
Total production (000oz)	-2.1	-29.2	-32.2	-36.6
Ore-grade (g/t)	-3.8	-8.2	-13.0	-17.8
Total energy consumption(TJ)	10.6	-0.7	-12.7	-7.2
Total CO_{2e} emissions (ktCO_{2e})	-4.5	-9.1	-17.0	-12.6
Energy intensity (TJ/Mt)	8.7	28.8	12.0	20.2
Energy intensity (TJ/oz)	13.0	40.3	28.8	46.3
Emission intensity (ktCO_{2e}/oz)	-2.5	28.5	22.5	37.7
Gold Fields				
	2007	2008	2009	2010
Total throughput (Mt)	6.1	3.0	-2.4	1.5
Total production (000oz)	-8.8	-17.8	-29.6	-30.1
Ore-grade 0g/t)	-9.3	-14.6	-24.0	-30.8
Total energy consumption (TJ)	-2.7	6.2	-2.0	6.5
Total CO_{2e}emissions (KtCO_{2e})	-1.1	4.3	-1.7	11.3
Energy intensity (TJ/Mt)	-8.3	3.1	0.4	4.9
Energy intensity (TJ/oz)	-5.5	12.8	23.5	41.5
Emission intensity (ktCO_{2e}/oz)	-4.0	10.8	23.9	47.9

A2: Comparative percentage changes in Key Performance Indicators of the reviewed companies

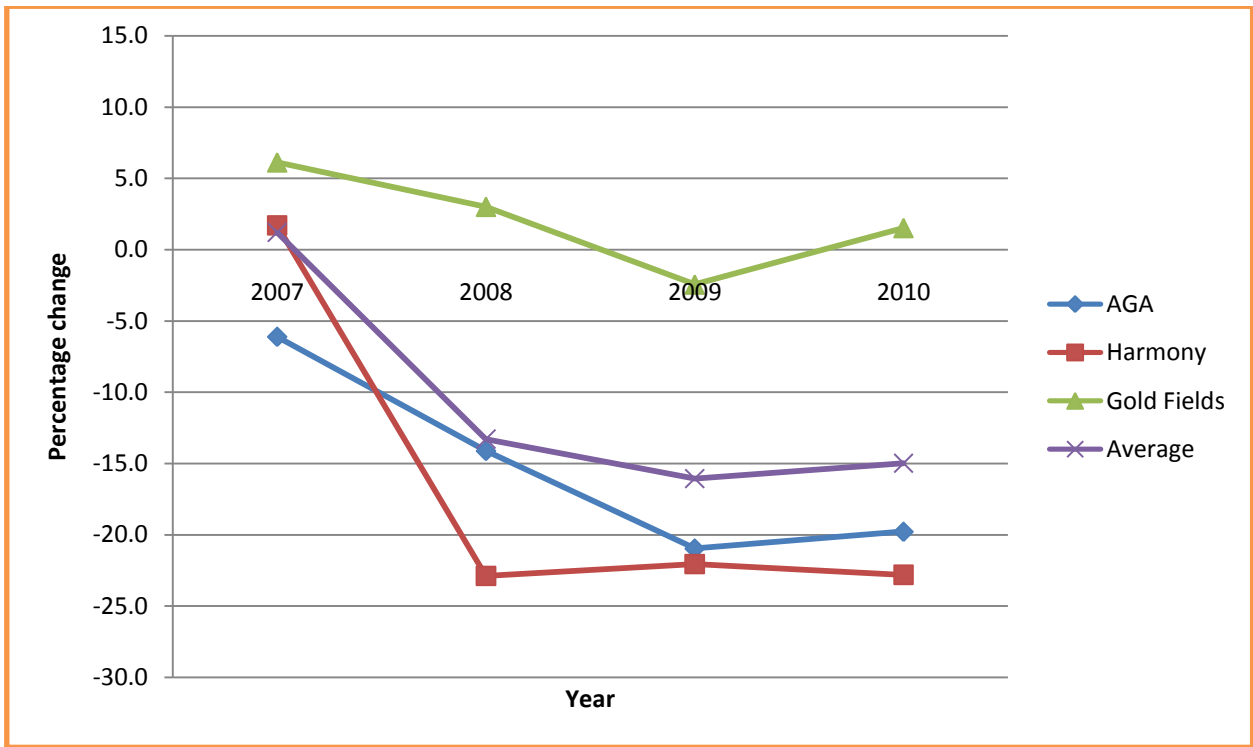


Figure 13: Percentage change in throughput

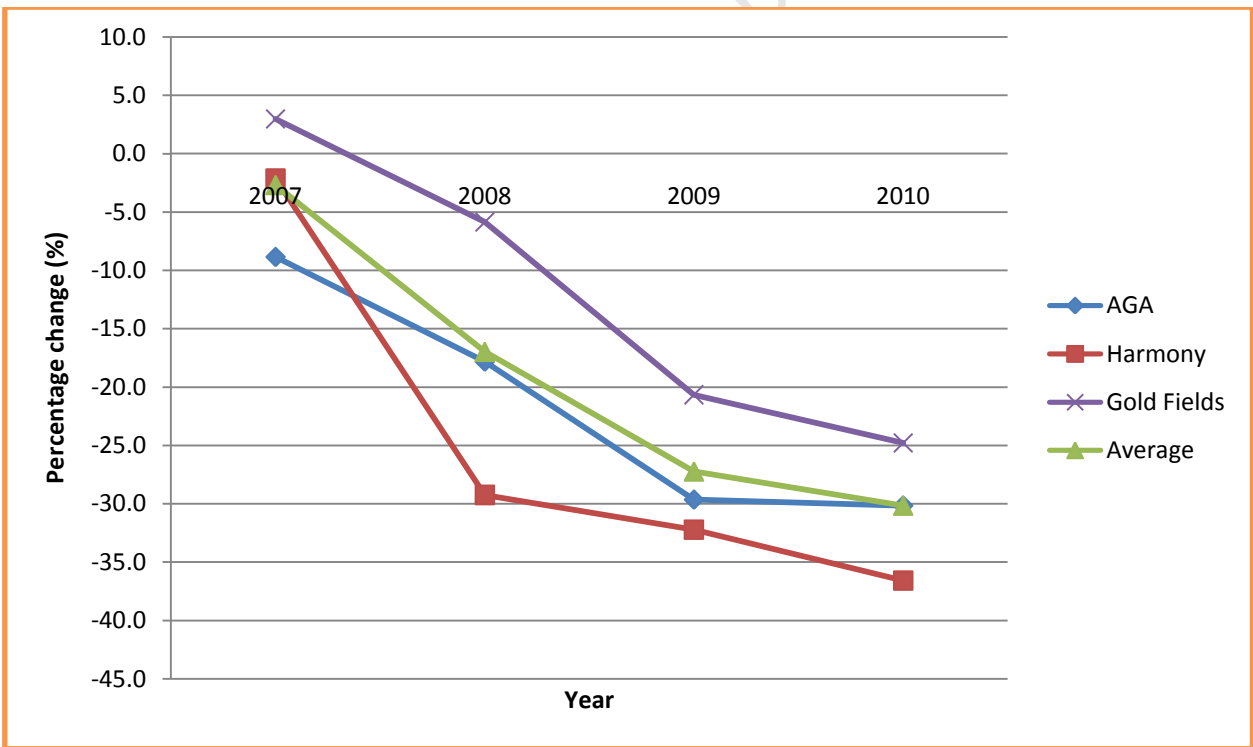


Figure 14: Percentage change in total gold production

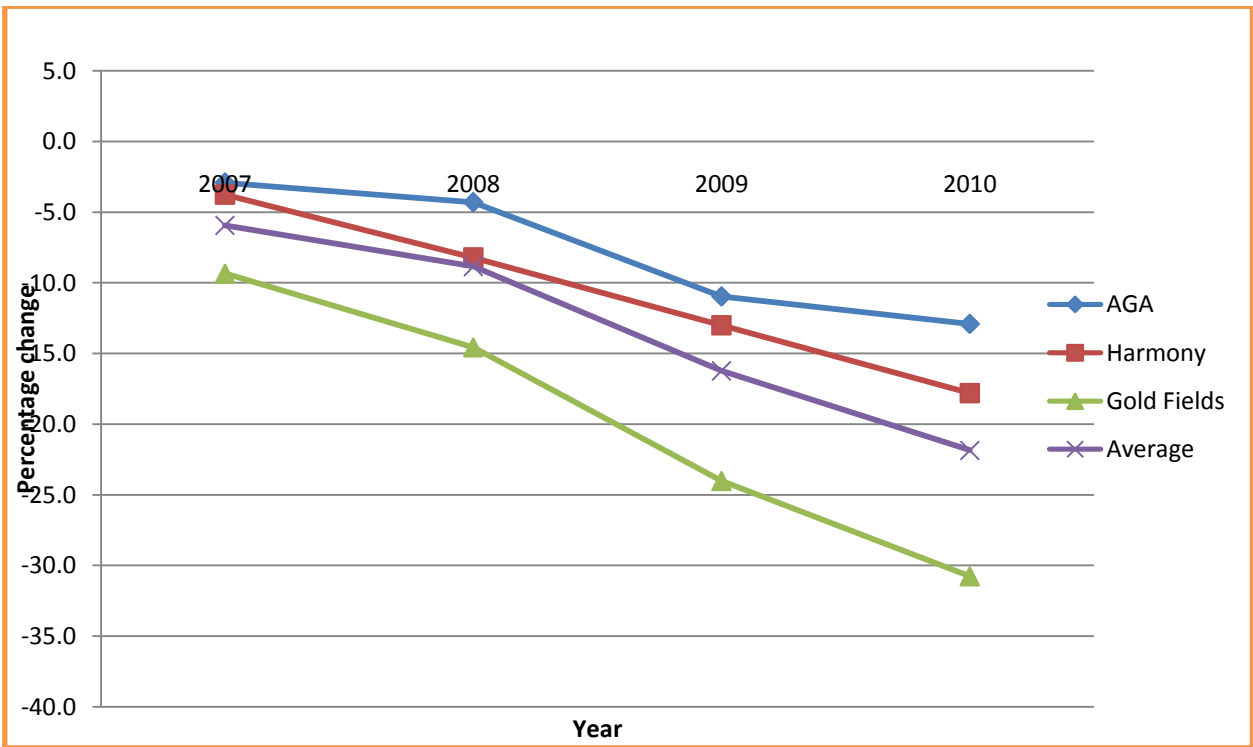


Figure 15: Percentage change in yield



Figure 16: Percentage change in total energy consumption

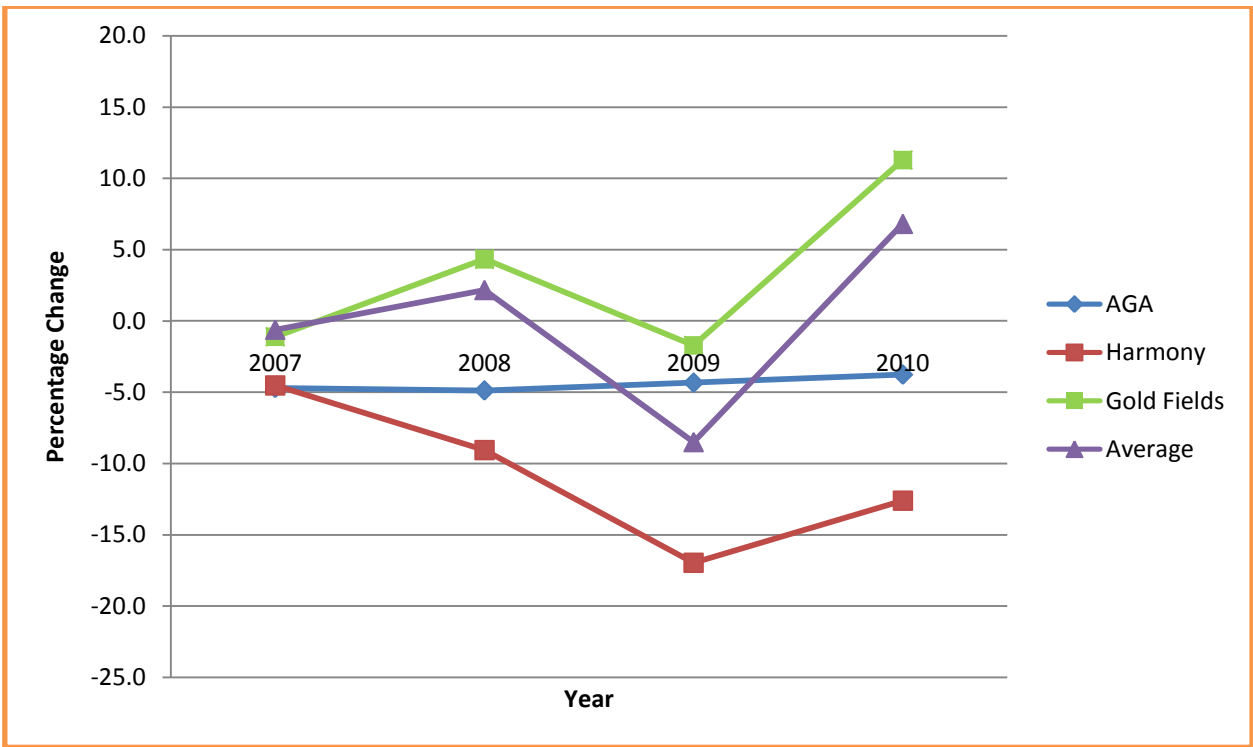


Figure 17: Percentage change in total GHG emissions

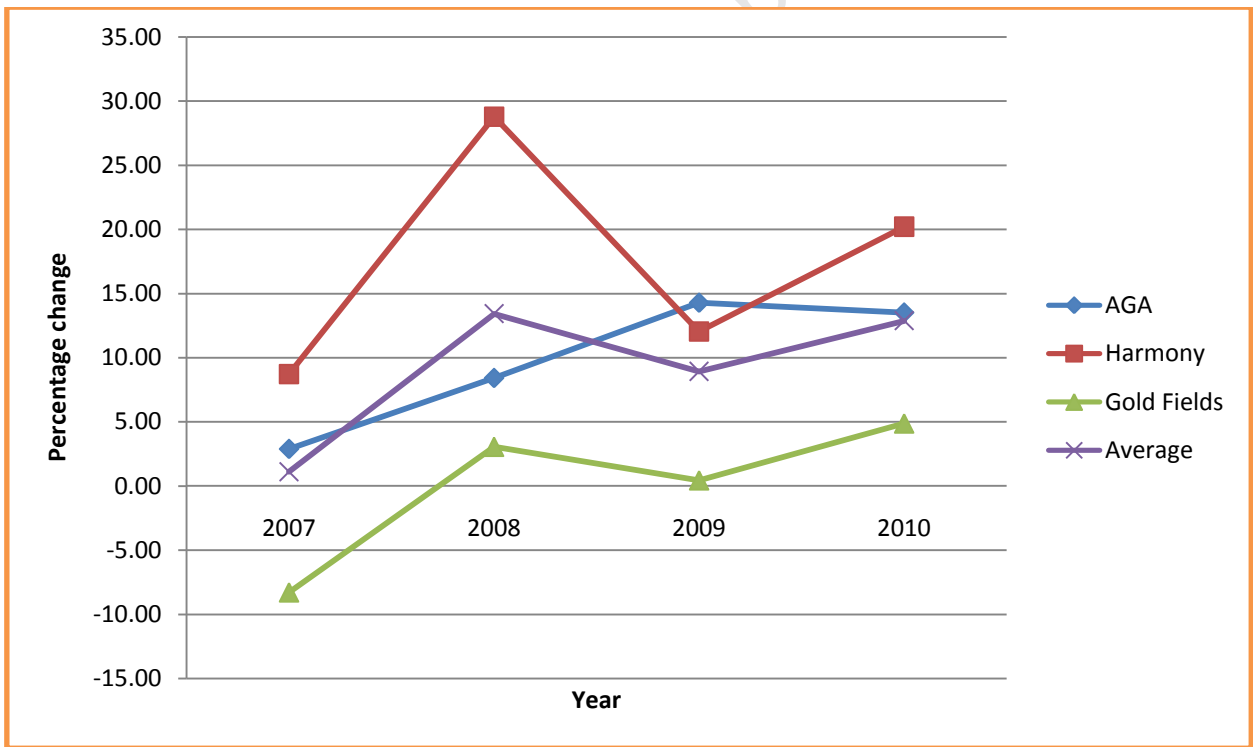


Figure 18: Percentage change in energy intensity of throughput

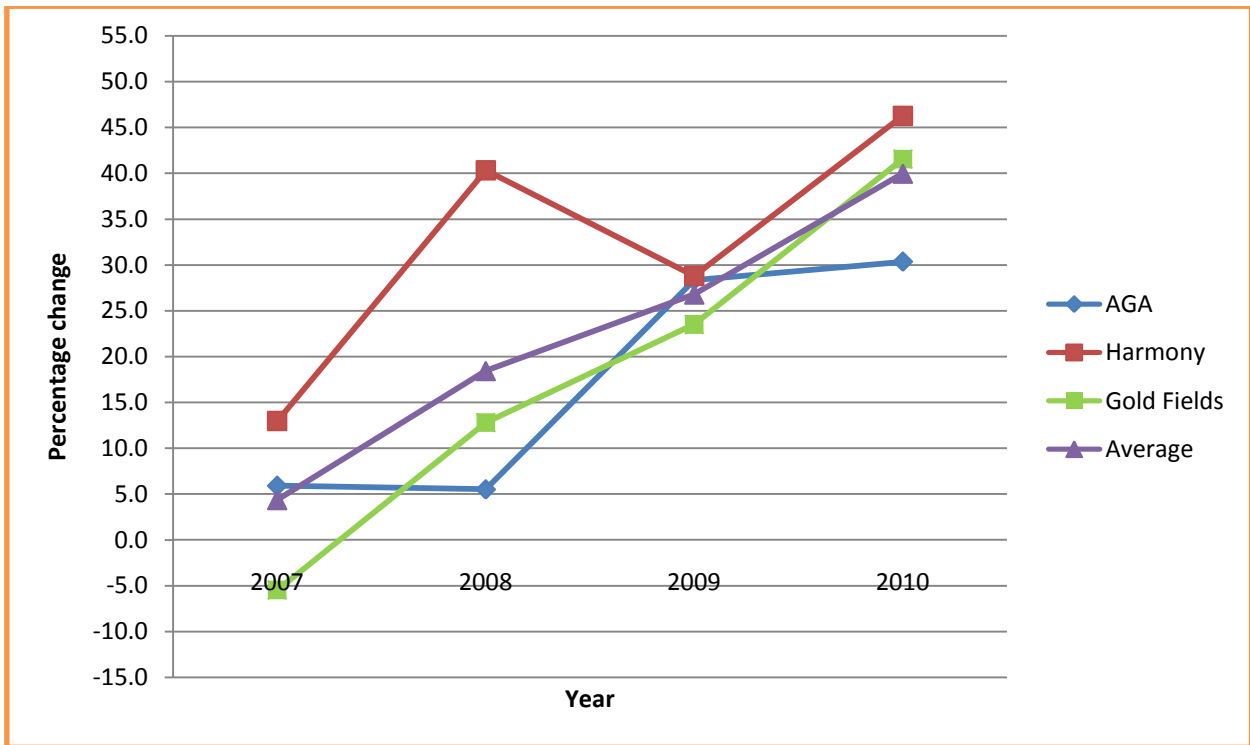


Figure 19: Percentage change in energy intensity of production

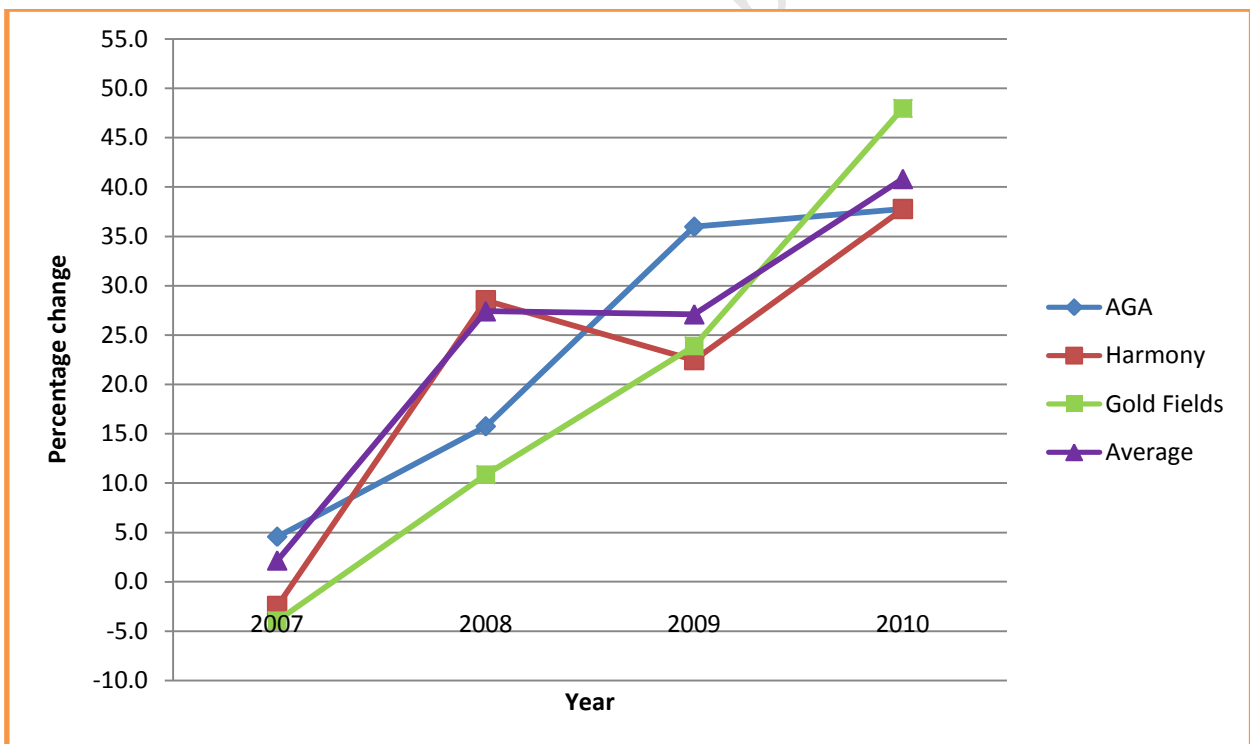


Figure 20: Percentage change in emission intensity of production

Appendix B: Questionnaire, rating sheet and raw survey data.

B1: Questionnaire checklist for semi-structured interviews

Personal Information:

- What is your position within the organization?
- What are your typical job functions and responsibilities?
- Are you currently involved in the area of energy efficiency/ climate change and if so, to what is your involvement?

Strategies, awareness levels and behaviour patterns around energy efficiency and global warming:

- How does your organization view its energy management process with respect to industry as a whole?
 - Trendsetter, leader, follower etc.
- Are there any employees who have energy management and/or climate change related issues as the major component of their job descriptions or key performance indicators? If so, please elaborate
 - With whom does the final responsibility for EE lie within your organization?
- Does your organization have a strategy for engaging with suppliers on their GHG emissions and the impacts of climate change on their business?
- Have there been or are there any planned programs to increase employee awareness around EE and GHG mitigation opportunities within your organization?
 - If so, can you please describe these programs?
- Does your organization have any internal targets regarding EE and GHG emissions?
 - What are those targets?
 - How is the organization tracking towards achieving them
- Do you know what percentage of operating costs can be attributed to energy consumption each year/month?
 - What is the amount
- Is there a list of energy efficiency projects which have been considered, implemented or rejected
 - When was it last updates
 - Would it be possible to receive a copy
- What do you see as your possible path going forward regarding EE within your organization

Driver for and constraints to the improved energy and climate profile:

- Do current and/or anticipated regulatory requirements related to climate change present significant risks to your company?
- Can you identify any significant risks related to energy and associated carbon emissions, for you organization?
 - If so, do you have any mitigation or adaptation plans in place?

- Describe the ways in which the identified risks could affect your business and your value chain.
- Describe any actions the company has taken or plans to take to manage or adapt to the risks that have been identified, including the cost of those actions.
- What do you believe the likelihood is of the implementation of some form of regulatory requirements related to climate change?
 - Do you think it would force any major changes to the way your company operates?
 - Have you made any plans for that eventuality?
- Do current and/or anticipated regulatory requirements related to climate change present significant opportunities for your company?
- Do you engage with policy makers on possible responses to climate change including taxation, regulation and carbon trading?

Identification and realization of opportunities:

- What do you see as your organization biggest opportunities to (i) reduce energy consumption and (ii) decrease GHG emission?
- Up until now what are the most significant adoptions/innovations that have been implemented around energy efficiency at you organization (Last 5-10 years)?
- Describe any action the company has taken or plans to take to exploit the opportunities that have been identified
 - The process to ensure the investment needed to take actions is available?
- Describe your company's process for identifying significant risks and/or opportunities from climate change and assessing the degree to which they could affect your business, including the financial implications?

Investment Decision Making Within Company

- How does your organization go about completing the following?
 - Identifying of potential EE opportunities
 - Project definition and screening
 - Analysis and acceptance of EE projects
 - Implementation of approved EE projects
 - Monitoring and post audit of implemented EE projects
- What are the key parameters you take into account when reviewing an EE opportunity?
- What is your capital limit when it comes to making decisions?
- What processes do you follow to get the go ahead for an EE project?
- Do you compile all the variables of project into one running cost?
- What life cycle/system boundary do you look at when reviewing new equipment ?
 - Do you take into account indirect emissions?

Documentation

- Do you have any case studies conducted by your business around EE or GHG emission?
- Do you have any examples of any decision heuristics used by your company to evaluate an EE project?
 - Case study

- Do you have any lists of potential EE opportunities?

Closing of interview

- Who else should I be speaking to?
 - Within your company
 - Industry organizations
 - Within other organizations
- Is there anything else you would like to add regarding the subjects breached?

B2: Rating sheet

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Forward:

All information from this interview will be aggregated with information obtained from other reports and interviews conducted with a number of players within the industry. Any explicit information about yourself or your company will only be included with your express permission.

Name:

Position:

Company Name:

Employee awareness

- How would you rate the awareness levels, and behavior patterns around energy efficiency and global warming within your companies' management?

Employees'	EE (/5)	GHG (/5)
Awareness		
Motivation/enthusiasm		
Active engagement		

- Ratings:
 - 0: None evident
 - 1: Very low level
 - 2: Low level
 - 3: Moderate level
 - 4: High levels
 - 5: Extremely high levels

- **Decision level that you most typically deal with**

Decision level	Tick one box
Operational	
Tactical	
Strategic	

Drivers for the uptake of EE opportunities

- **What do you consider to be the biggest drivers for improving EE and/or reducing GHG emissions within your organization?**

Driver	Rating (/5)
Tax rebates or incentives	
High levels of technical support & information around new technologies	
Exclusivity rights to self-pioneered new technologies	
Increase in electricity price	
Increase in fuel price	
I&AP pressure (NGOs, local committees etc)	
Pressure from up or downstream business partners	
Reputational benefits	
Reduce exposure to carbon tax and potential emissions trading schemes	
Operational resilience/ energy security	
Generation of carbon credits	
Outside funding for the investigation of new EE projects	
Competitive advantage/increase in market share	
Other Specify:	
Other Specify:	

- **Ratings**
 - 0: Not considered a driver for change

- 1: Insignificant driver for change
- 2: Small potential to drive change
- 3: Moderate potential to drive change
- 4: Significant potential to drive change
- 5: Critical to driving change

Barriers hindering the uptake of EE opportunities

- **What do you consider to be the biggest barriers to the implementation of effective measures to improve EE and/or reduce GHG emission within your company?**

Barriers	Rating (/5)
Perceived risks associated with new technologies	
Innovation too easy to copy	
Shortage of skills	
Banks policy around the financing of process innovation	
Uncertainty over the benefits of new technologies	
Lock in effect of old technologies/ Premature retirement of capital	
Direct cost of developing and implementing new technologies	
Lack of corporate commitment (Low level of environmental awareness)	
Lack of top-down support and incentives	
Insufficient external financial incentives	
Lack of legislation or regulatory control	
Inadequate data and information to motivate/ support change	
Lack of available time to adequately review opportunities	
Other Specify:	

- **Ratings**
 - 0: Not considered a barrier to change
 - 1: Insignificant barrier to change
 - 2: Small barrier to change
 - 3: Moderate barrier to change
 - 4: Significant barrier to change

- 5: Critical barrier to change

Opportunities of improved EE

- **What do you consider to be the biggest opportunities for improving E and/or reducing GHG emission reductions within your company/the-gold sector?**
 - Note: Rating should be viewed for their generic value not for the value that they could add to business at present.

Opportunity	Ease of implementation (/5)	Magnitude of savings (/5)
Effective Management/Administration		
Employee education		
Incentives schemes		
Change to management structure (e.g. employing specialists etc)		
Increase in R&D expenditure		
Maintenance		
Group transport facilities		
Energy efficient lighting: low energy bulbs/ natural lighting		
Other Specify:		
Technical		
More efficient plant equipment and utilities (fans etc)		
Improvement in the tools for analyzing mineral deposits: Models sensors and instrumentation		
Better instruments and sensors allowing greater control over comminution and classification processes		
Metallurgical separation research and development activities		
Optimizing the use of process heat, maximizing combustion efficiency, utilizing waste heat and streamlining processes		
Elimination of process steps		

Improve efficiency of machinery reducing particle size (HPGR)		
Reduction in quantities of material coming into comminution by improved ore sorting or heap leaching of ROM ores		
Optimization of fragmentation process		
Localized cooling and more Efficient Refrigeration		
More efficient ventilation system		
Improved pumping system		
Over design of old technologies (optimization)		
Avoiding haulage through in-situ or underground processing		
Other Specify:		
Other Specify:		
Long term		
On-site generation of energy		
Reducing direct process emissions (air conditioning)		
Underground processing		
HPGR		
R & D development		
Other Specify:		
Financial		
Projects Eligibility for Eskom DSM financing		
Projects potential to obtain carbon finance and eligibility for carbon credits trading. (CDM)		
Other Specify:		
Other Specify:		
Other Specify:		

- Ratings: Ease of implementation/ Magnitude of energy savings
 - 0: Impossible to implement/ No energy savings
 - 1: Very Difficult to implement/ Insignificant energy saving
 - 2: Difficult to implement / Small energy saving
 - 3: Reasonable to implement/ Moderate energy saving
 - 4: Easy to implement/ Significant energy saving
 - 5: Very easy to implement / Critical energy saving

Criteria used to evaluate EE opportunities

- **Please rate the below parameters used to assess energy or climate footprint reduction opportunities?**

Criterion	Rating (/5)
Availability and Reliability of data and information on current performance	
Availability and Reliability of data and information on alternative technologies/equipment	
Payback Period	
Accounting rate of return (ARR)	
Capital cost required for the implementation of the project	
Internal rate of return (IRR)	
Net present value (NPV)	
Discounted Payback periods (DPP)	
Energy consumption reductions	
GHG emission reductions	
Potential to obtain carbon finance	
Ease of implementation	
Eligibility for generation of carbon credits	
Uncertainty and Risk	
Eligibility for Eskom DSM financing	
Maintenance of project	
Time needed to effectively review opportunity	
Other Specify:	
Other Specify:	

- Ratings:
 - 0: Irrelevant parameter
 - 1: Parameter has an insignificant level of importance
 - 2: Parameter has a low level of importance
 - 3: Parameter has a moderate level of importance
 - 4: Parameter has a significant level of importance
 - 5: Parameter is of critical importance

B3: Raw data from rating sheets

	Company 1				Company 2		Company 3	
Drivers	I1A	I2A	I2A	I4A	I1B	I2B	I1C	I2C
Tax rebates or incentives	4	4.5	3	3	4	4	3	3
High levels of technical support & information around new technologies	5	3	2	2	3	2	3	2
Exclusivity rights to self pioneered new technologies	0	3	1	2	3	2	1	1
Increase in electricity price	3	4	4	5	4	5	5	5
Increase in fuel price	3	4.5	4	3	4	3	5	5
I&AP pressure (NGOs, local committees etc)	0	4	1	2	3	3	1	4
Pressure from up or downstream business partners	0	3	1	1	2	5	1	2
Reputational benefits	2	4	3	3	3	3	5	3
Reduce exposure to carbon tax and potential emissions trading schemes	2	4	3.5	4	4	5	5	4
Operational resilience/ Energy security	5	3	4	5	4	5	5	5
Generation of carbon credits	2	3	2	2		3	4	3
Outside funding for the investigation of new EE projects	4	3	4	1	3	4	1	4
Competitive advantage/increase in market share	1	3	2	0	3	3	5	2
Barriers	I1A	I2A	I2A	I4A	I1B	I2B	I1C	I2C
Perceived risks associated with new technologies	3	4	4	4	3	4	4	3
Innovation too easy to copy	0	3	1	2	2	3	3	2

Shortage of skills	0	3	2	4	2	3	4	3
Banks policy around the financing of process innovation	0	3	2	2	2	2	1	4
Uncertainty over the benefits of new technologies	1	4	2	3	2	5	1	3
Lock in effect of old technologies/ Premature retirement of capital	1	4	4	4	2	3	4	4
Direct cost of developing and implementing new technologies	5	4	4	5	3	5	4	4
Lack of corporate commitment (Low level of environmental awareness)	0	3	1	0	3	3	3	3
Lack of top-down support and incentives	0	1	1	3	3	3	3	3
Insufficient external financial incentives	0	3	3	2	3	2	3	3
Lack of legislation or regulatory control	0	4	2	1	3	NA	4	2
Inadequate data and information to motivate/ support change	0	2	1	1	2	4	3	2
Lack of available time to adequately review opportunities		2				4	2	4
Opportunity	I1A	I2A	I2A	I4A	I1B	I2B	I1C	I2C
Ease of implementation								
Effective Management/Administration								
Employee education	3	1	1		3	4	5	2
Incentives schemes	2	1	3		3	4	5	3
Change to management structure (e.g. employing specialists etc)	NA	2	4		3	3	3	3
Increase in R&D expenditure	3	3	3		3	2	5	2
Maintenance	3	3	3			4	5	4
Group transport facilities	3	3	2		3	2	4	3
Energy efficient lighting: low energy bulbs/ natural lighting	5	5	2		3	3	4	4
Other Specify:								
Technical								

More efficient plant equipment and utilities (fans etc)	3	1	3		3	3	4	2
Improvement in the tools for analyzing mineral deposits: Models sensors and instrumentation		2	3		3	2	3	2
Better instruments and sensors allowing greater control over comminution and classification processes	5	2	3		3	3	4	3
Metallurgical separation research and development activities	4	2	1		3	4	3	3
Optimizing the use of process heat, maximizing combustion efficiency, utilizing waste heat and streamlining processes	5	1	2		3	4	4	3
Elimination of process steps	3	2	2		3	3	4	2
Improve efficiency of machinery reducing particle size (HPGR)	4	2	3		3	4	4	3
Reduction in quantities of material coming into comminution by improved ore sorting or heap leaching of ROM ores	4	2	1		3	4	4	2
Optimization of fragmentation process	4	1	2		3	3	5	3
Localized cooling and more Efficient Refrigeration	4	1	2		3	4	4	3
More efficient ventilation system	3	1	3		3	4	5	2
Improved pumping system	4	3	3		3	4	4	2
Over design of old technologies (optimization)	4	3	3		3	4	5	2
Avoiding haulage through in-situ or underground processing	4	1	2		3	2	4	1
Long term								
On-site generation of energy	1	3	1			2	4	3
Reducing direct process emissions (air conditioning)	NA	4	1			4	4	

Underground processing	1	1	1		3	2	4	1
HPGR	2	1	1			2	4	
R & D development	3	2	1		3	2	4	
Other Specify:								
Financial								
Projects Eligibility for Eskom DSM financing	4	3	2		3	5	4	3
Projects potential to obtain carbon finance and eligibility for carbon credits trading. (CDM)	1	3	1		3	4	3	1
Opportunities	I1A	I2A	I2A	I4A	I1B	I2B	I1C	I2C
Magnitude of savings								
Effective Management/Administration								
Employee education	4	4	4			5	5	4
Incentives schemes	5	2	3			4	5	4
Change to management structure (e.g. employing specialists etc)		3	1			4	5	3
Increase in R&D expenditure	3	3	3			3	5	4
Maintenance	4	3	2			2	5	2
Group transport facilities	3	3	2			4	4	2
Energy efficient lighting: low energy bulbs/ natural lighting	1	1	2			2	4	1
Technical								
More efficient plant equipment and utilities (fans etc)	5	3	2			3	5	4
Improvement in the tools for analyzing mineral deposits: Models sensors and instrumentation		4	2			2	3	4
Better instruments and sensors allowing greater control over comminution and classification processes	3	5	2			3	3	2
Metallurgical separation research and development activities	3	4	4			4	3	1

Optimizing the use of process heat, maximizing combustion efficiency, utilizing waste heat and streamlining processes	4	5	2			4	4	1
Elimination of process steps	5	3	3			3	4	1
Improve efficiency of machinery reducing particle size (HPGR)	3	2	2			4	4	2
Reduction in quantities of material coming into comminution by improved ore sorting or heap leaching of ROM ores	3	4	4			4	4	4
Optimization of fragmentation process	4	3	3			3	5	2
Localized cooling and more Efficient Refrigeration	5	5	4			5	4	4
More efficient ventilation system	5	5	1			5	5	3
Improved pumping system	4	4	1			5	4	3
Over design of old technologies (optimization)	3	4	2			5	5	4
Avoiding haulage through in-situ or underground processing	4	4	4			2	4	3
Long term								
On-site generation of energy	1	2	2			2	4	0
Reducing direct process emissions (air conditioning)		1	2			4	4	
Underground processing	5	3	3			2	4	2
HPGR	3	4	3			2	4	
R & D development	3	4	2			2	4	
Other Specify:								
Financial								
Projects Eligibility for Eskom DSM financing	4	3	3			5	5	4
Projects potential to obtain carbon finance and eligibility for carbon credits trading. (CDM)	3	3	2			4	2	3
Criteria	I1A	I2A	I2A	I4A	I1B	I2B	I1C	I2C

Availability and Reliability of data and information on current performance	5	3	4	4		4	5	4
Availability and Reliability of data and information on alternative technologies/equipment	5	3	4	4		4	5	4
Payback Period	5	5	3	4		5	5	4
Accounting rate of return (ARR)	5		3	4		4	5	4
Capital cost required for the implementation of the project	5	3	4	5		4	4	4
Internal rate of return (IRR)	5	4	4	5		4	3	4
Net present value (NPV)	5	4	3	5		4	4	4
Discounted Payback periods (DPP)	5	4		4		4	2	4
Energy consumption reductions	5	4	4	4		5	5	4
GHG emission reductions	3	4	2	3		4	5	3
Potential to obtain carbon finance	3	3	2	2		4	5	3
Ease of implementation	5	3	5	5		3	3	4
Eligibility for generation of carbon credits	3	4	3	3		4	3	3
Uncertainty and Risk	5	5	4	4		4	1	4
Eligibility for Eskom DSM financing	4	3	4	5		5	4	3
Maintenance of project	5	3	4	4		5	5	3
Related impacts such as Water Usage	4	4	4	3			4	3
Time needed to effectively review opportunity		3				5		