Examining the technologies and practices that can help SA mining industries meet carbon blueprint reductions

Applied Research Project Proposal

submitted by

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2. INTRODUCTION

2.1. Introduction

Mining has always been regarded as a black sheep due to its legacies of environmental accidents, pollution, and safety incidents. However, for economies to grow, they need energy and energy requires metals to generate, transmit and store power. These metals are mostly sourced from mining and so as the world changes to cleaner and greener energy options, it is only fitting that mining equipment also becomes more environmentally friendly and keep up with the times.

Heavy mining equipment such as ultra class dumptrucks and face shovels have 2-3MW diesel engines which can easily burn hundreds of litres of diesel per hour (Komatsu, 2022). Diesel has been the fuel of choice for many years due to its developed supply chains, ease of storage, high energy density and reliable engines. High fuel consumptions coupled with increasing fuel prices and deepening mines means that in addition to increasing expenses and pressure from environmental organisations, South African mines are becoming more and more carbon intensive.

In December of 2015, at the 21st Conference of the Parties (COP21) to the United Nations Framework Convention on Climate Change (UNFCCC) held in Paris, an international treaty on climate change was adopted by 195 parties. This treaty also known as the Paris agreement was a landmark agreement since this was the first legally binding treaty aimed at fighting climate change (United Nations Climate Change, 2015). The Paris agreement covered many items but these are some of the most crucial ones; Long-term temperature goals with the aim of restricting global temperature increases to below 2 degrees Celsius or even further to 1.5 degrees Celsius; National Adaptation Plans which outlines plans and actions for different nations based on their needs and priorities; Finance, technology and capacity-building support that addresses developed countries providing financial assistance to less endowed countries for adaption and accelerating technology development.

Many major mining houses have already made several Environmental, Social, and Governance (ESG) commitments. Anglo American has committed to reduce net greenhouse gas (GHG) emissions by 30% and improve energy efficiency by 30% by the year 2030 (Anglo American, 2022). BHP has also committed to reduce operational GHG emissions by 30% from its 2020 levels by the year 2030 and by 2050 achieve net zero GHG emissions (BHP, 2022).

Whilst these targets are received with much optimism from stakeholders, the roadmap to achieving them is not very clear. This paper focuses on investigating the different technologies available which are best suited to meet these targets whilst considering the tough environment that South African mines operate in to ensure that selected technologies can be adopted successfully.

2.2. The research problem statement

Most mining companies have committed to reducing GHG emissions by 30% from its 2020 levels by the year 2030 and by 2050 to achieve net zero GHG emissions. Burning of coal to generate electricity is one of the largest contributors to carbon emissions and as part of the change to a sustainable future along with much pressure from investors, many global mining organisations have started divesting their coal assets. A good example is the unbundling and the sale of Anglo Americans coal assets in the form of Thungela Resources.

Opencast mines make use of Heavy Mining Equipment (HME) such as drill rigs for drilling holes needed for blasting, dozers which pushes and clears earth, excavators and shovels which are used to load blasted material and dumptrucks which haul material to processing plants. Support equipment such as light duty vehicles (LDV’s), graders, telehandlers, cranes and tractor loader backhoe’s (TLB’s) are a few examples of other mobile equipment used on mines. Diesel has dominated as the most commonly used fuel for heavy mining equipment and support equipment due to its high energy density, proven engines and well-developed supply chains. In recent years, diesel costs have doubled in addition to rapidly rising carbon tax levies. There is also enormous pressure from environmental organisations and governments to decarbonise which has largely reduced the popularity of diesel. It is estimated by Mckinsey and Company that about 40 to 50% of Carbon emissions from mines come from diesel driven equipment.

Greenhouse gases (GHG) are gases that trap heat in the atmosphere and include Carbon dioxide (CO_2), Methane (CH_4), Nitrous oxide (N_2O) and other Fluorinated gases. Carbon dioxide is the biggest contributor and makes up 84.8% of total GHG emissions. The energy sector was responsible for 79.1% of total GHG emissions in South Africa in 2017, total GHG emissions have increased by 22.8% over the past 17 years. (Department of Environment, Forestry and Fisheries, 2020). Scope 1 are direct emissions such as emissions from diesel driven equipment, Scope 2 are indirect emissions from the consumption of purchased energy whilst Scope 3 are indirect emissions from upstream and downstream activities such as travelling, waste and purchased goods (Sustain Life, 2021). The mining industry in South Africa is energy intensive and hence has a major influence on all 3 scopes of emissions.

Mining companies have often been criticised for been very reactive in dealing with ESG matters which stands for Environmental, Social, and Governance but recently ESG has become a vital part of most listed companies' annual reports and one can anticipate that this will soon become a mandatory requirement for all publicly listed companies. However, ESG set outs criteria and standards for investors who are socially conscious and may have varying measurables. Therefore, many mining companies choose to use the 17 Sustainable Development Goals (SDG's) that were laid out in 2015 by the United Nations (Lexis Nexis, 2021). For example, Kumba Iron Ore which operates two open cast iron ore mines in Northern Cape publishes an annual sustainably report of which it measures itself against all 17 SDG's. Some of the key SDG's include community development and education programmes, women in mining integration, employee training and development, water management plans, zero waste to landfill drive, and achieving carbon neutrality by 2040 (Kumba Iron Ore Limited , 2021).

In addition to achieving ESG and SDG targets mentioned earlier, mines will have to adapt to remain competitive, especially in South Africa where mining input costs have been steadily increasing (approximately 10% in 2021) over the past years (Minerals Council South Africa, 2022). Eskom tariffs have increased by approximately 400% (PWC, 2021) in past decade, significantly higher than inflation in the same period whilst diesel prices have approximately doubled in the past decade. Labour costs have been driven higher by above inflation increases due to industrial action and attempts to undo historical injustices. Carbon taxes along with other levies and safety stoppages are adding to the miner's problems hence causing investors to look elsewhere for more feasible assets with better returns on investments. Finance Minister Enoch Godongwana announced in February 2022 that the carbon tax in South Africa will increase to R144 per tonne of carbon dioxide equivalent (CO_2e) and is expected to increase to $20/t by the year 2026 and $30/t in 2030 with expectations of further taxes to be passed to customers in 2025 by the countries energy provider Eskom which makes use of coal primarily to generate electricity.

Hydrogen fuel cells can be hugely beneficial to South Africa Platinum group metals (PGM's) producers in that the platinum which is used for the chemical reaction within the fuel cell to create electricity, is mined in South Africa and South Africa also have the largest reserves in the world (Minerals Council South Africa, 2022). Fuel cells produce electricity and water as a by-product instead of carbon emissions and is more efficient than internal combustion engines. Companies such as Nikola and Toyota are already gaining market share by introducing such vehicles. Palladium is also used extensively for catalytic convertors in exhausts which has caused its price to rise rapidly in recent years. Electric cars which make use of nickel-manganese-cobalt batteries are poised to take over the motor industry with companies like Tesla having huge market capitalisation due to this. South Africa has 4.7% of nickel and 28.9% of Manganese reserves in the world (Minerals Council South Africa, 2022). Adopting these technologies to heavy mining equipment means that in addition to increase in the demand for minerals which are mined, carbon footprints are also reduced and they should also add to the bottom line by reducing energy costs once the correct economies of scale are reached.

Whilst there might be several advancements in technology, South African mines have often struggled to integrate and adopt new technologies. Understanding the reasons for these failures and using it to inform future implementation is critical to ensuring success and realising intended value. Although not mining related, a good example of poor adoption and implementation would be the famous “E-tolls” system that was rolled out in Gauteng.

South Africa’s mining industry is falling behind the rest of the world as new deposits are being mined at lower costs closer to the surface and thus South African mines will have to make sure the change to green energy is successfully implemented to prevent further loss of market share.

2.3. The research purpose (aim and objectives) statement

With the demand for metals increasing, an industry which may have been seen to be in its sunset, may be able to get a new lease on life. The current energy transition to which is further fuelled by sanctions on Russia due to their invasion of Ukraine makes use of renewables such as Photovoltaic (PV) cells, wind turbines, compressors, electric motors, fuel cells and batteries, all of which require raw materials for production. According to a report from the World Bank titled “Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition”, demands for minerals especially those needed for energy storage such as cobalt, lithium and graphite are expected to increase by approximately 500% when using 2018 as a base. Demand for other minerals such as copper and aluminium which are needed for PV cells production as well as wind turbines which already make extensive use of steel and chromium are expected to rise substantially (World Bank Group, 2020).

However, for South Africa to take advantage of the anticipated increase in demand for minerals, major issues need to be addressed such as developing and retaining the correct skills, adding enabling infrastructure and repairing existing infrastructure, streamlining processes to allow exploration and accessibility to mining rights, promoting new technology and local beneficiation, increasing energy and water efficiencies whilst changing to cleaner and renewable energy sources, as well as ensuring that legislation is up to date and provides the value that it was intended for.

The objective of this research covers only a small portion of the issues highlighted above. It aims to identify the challenges that need to be addressed from an operational perspective in order to adopt technological advancements to meet "SDG 13 - Take urgent action to combat climate change and its impact" (Lexis Nexis, 2021), where most mining companies set out to reduce greenhouse gas (GHG) emissions by 30% by the year 2030.

2.4. The research questions as well as where applicable accompanying research hypotheses or research propositions

2.4.1. Question 1:

Null hypothesis: There will be no changes in driving power for the next generation of heavy mining equipment.

Research hypothesis (directional or non-directional): What will power the next generation of heavy mining equipment to achieve blueprint carbon reductions?

Alternative hypothesis: The next generation of mining equipment will move from diesel to hydrogen, electric or hybrid.

Proposition: The new generation of mining equipment will make use of green energy such as hydrogen or electricity generated from renewable sources to achieve GHG reduction targets.

2.4.2. Question 2:

Null hypothesis: South African mining is slow to adopt new technology for Heavy Mining Equipment.

Research hypothesis (directional or non-directional): Is South Africa ready to accept the disruption and change to adapt new technology for Heavy Mining Equipment?

Alternative hypothesis: Many South African mines are driving change and adapting new technology.

Proposition: South African mines are slow to develop and adapt new technology, government strategy, regulations and mining culture needs to be revised to promote innovation and skills development.

2.5. Research Significance

Many failures of new technology are often not related to the actual technology but more due to the way in which it has been planned, implemented and controlled or poorly engineered work systems (Macfarlane, 2001).

“Examining the technologies and practices that can help SA mining industries meet carbon blueprint reductions” will help identify operational issues associated with implementation of new technologies such as the workforce’s appetite for change, reducing risks such as sabotage from employees who may associate the new technology with job losses such as a diesel mechanic who might be replaced with an auto-electrician if dumptrucks diesel engines are replaced with electric motors and understanding the current skill level of the workforce and gaps that should be filled. Learnings from the research will be used to inform change management methodologies and reduce financial risk to mining companies.

The research will also help assess what technology is deemed to be the best suited for different operations based on their technical maturity as there are a range of different technological advancements available to achieve reduction in GHG emissions even though some might still be in the development phases.

2.6. Delimitations and assumptions of the research study

The research is based on South African mining companies and the results of the research might not be applicable to other countries especially due to their skill levels, political climate and difference in governance.

One of the major assumptions of the study is that the sample population is knowledgeable about advancements in technology for heavy mining equipment and have managed such equipment including the associated maintenance staff during their careers. They should also be well versed with their company's decarbonisation efforts and targets unless there are none in place.

The research is based at middle management levels i.e. those who understand the organisation and its goals as well as have relevant practical and in depth knowledge of operations. This should give a balanced response to questions since senior employees might drive change while junior employees might oppose change.

South Africa's mining history is known for its poor safety statistics of which many accidents have occurred due to poor change management and poor training of employees. The mining legislation therefore is very rigid and is known to have been written in blood which may lead to individuals fearing change and not embracing new technology which may lead to accidents or incidents that can cause production stoppages, disciplinary action or even prosecution. Therefore some employees may prefer tried and tested technologies which are deemed to be the safer option.

The sample population is relatively small due to time and resource constraints which may affect confidence and reliability of the results.

3. APPLICATION OF PRIOR RESEARCH

3.1. Literature Review

3.1.1. Technological advancements for Heavy Mining Equipment

There are several different types of power units been developed and trialled for heavy mining equipment which makes uses of alternative fuels, diesel engine advancements, hybrids which uses a combination of diesel and electric as well fully electrified drives (Leonida, 2022). In addition to major OEM's developing these power units, some mining organisations have taken it upon themselves to lead the way for technology development especially since there is often shared value in doing so. Many of the metals needed for the technological advancements are often mined by these organisations.

Rolls Royce through its MTU brand envisages developing a hybrid system which couples a battery pack to a diesel engine and uses a dynamic charging system to recuperate energy when braking and travelling downhill which is stored in the battery pack. This technology is readily available and has already been implemented on trains with diesel savings of approximately 25%. The company also has a hydrogen fuel cell demonstration at its factory and plans to deliver hydrogen fuel cell trucks in 2025 whilst it also explores burning of hydrogen in typical internal combustion engines which may be available from as soon as 2023. They also plan to release in 2023 engines that can operate on sustainable fuels such as 2nd generation biofuels and e-diesel which are climate neutral (Rolls Royce, 2022).

Anglo American announced their pilot for Zero emission haulage solution which retrofits an ultra-class diesel dumptruck with a 2MW hybrid hydrogen fuel cell and battery power unit. The fuel cell combines hydrogen and oxygen using platinum as a catalyst to produce electricity with water been the only emission. Regenerative braking produces energy when trucks are travelling downhill, this energy is then used to charge onboard batteries which is redeployed when required such as when travelling uphill. In addition to this they have also built an electrolyser plant to produce hydrogen from water, along with refuelling and storage facilities. Whilst there is still much development needed, Anglo American plans to retrofit 40 trucks at its Mogalakwena mine and then roll out the technology to the rest of its opencast mines which could realise a reduction of 80% of scope 1 emissions for those sites (Anglo American, 2022).

Battery technology such as that employed by Tesla has many benefits such as high efficiencies since there are not as many losses during charging as compared to diesel engines and hydrogen fuel cells which have major mechanical loses such as friction, heat and compression. However, the current energy density of batteries would require too much volume to power an ultra-class dumptruck, adding excessive weight thus reducing payloads and would also require frequent charging or swop out of batteries. Fast charging has the capability to reduce charging times for a Tesla 100kWh (kilowatt hour) battery from 7 hours with a 22kW 3phase charger to 30 min with a 250kW DC supercharger (Electric Vehicle Database, 2022). Rough calculations for a typical 2000kW dumptruck at 60% average load would require approximately 1200kWh and would require 14400kWh for a 12-hour shift which equates to 144 of 100kWh battery packs. If a 100kWh battery pack weights 625kg and has a volume of 0.4m^3 (Weight of Stuff, 2022), this would add approximately 90 tons to the weight of a dumptruck but more importantly require 57.6m^3 of additional space. To put this into perspective, a Komatsu 930E ultra class dumptruck with 2014 kW gross power has an empty vehicle weight (EVW) of 231 tons, of which the engine weighs in at about 9 tons and the fuel tank has a volume of approximately 6m^3 (Komatsu, 2022). In addition to the extra weight, structure and volume required for battery power, this would come at a massive cost. Assuming a price of $150/kWh (Lambert, 2020), a 14400kWh battery pack would cost a whopping $2,160,000. However, as battery technology develops, there is no doubt that cost and volume will decrease while energy density increases thus making it a very attractive option to power heavy mining equipment.

Hitachi Construction Machinery on the other hand have been supplying diesel electric trains since the 1980’s. First Quantum Minerals, Kansanshi copper mine in Zambia makes use of Hitachi dump trucks enabled with a trolley system which was commissioned in 2016. During normal or conventional mode, the diesel engine drives an alternator which generates electric power to drive electric wheel motors. The dump trucks also make use of overhead trolley lines that supply electrical power via a pantograph system (very similar to that used on electric trains) for majority of the steep incline out of the opencast pit which is the most fuel intensive part of the trip as the trucks are normally fully laden at this point. Fuel burn rates are reduced by 90% while running on power from overhead trolley lines. Trucks also speed up whilst receiving power from the overhead trolley line, since it operates at a higher voltage, which reduces cycle time and increases productivity (Hitachi Construction Machinery, 2022). Hitachi is working with several battery and charger suppliers to develop energy storage and transfer options as current battery technologies only allow 1 – 3 hours of storage onboard and lengthy charging cycles (Leonida, 2022).

Cummins provides fully integrated natural gas engine of which the largest produces about 475 hp, although the technology is well developed for stationary operations, this engine will be underrated for most mobile heavy mining equipment requirements (Canada's Oil Sands Innovation Alliance, 2019). Liquified Natural Gas (LNG) can also be used to substitute diesel by doing engine air intake modifications to accommodate dual fuel technologies such as those provided by Gaseous Fuel System (GFS) Corp. and since no changes are made to the internals of the engine, it can still run fully on diesel only. Although natural gas burns cleaner than diesel with substantially less pollutant emissions, it only provides 10% less GHG emissions when compared to diesel (Castillo, López, Escobar, Ríos, & Quirama, 2022). Therefore, the advantages of natural gas may not be as ambitious as those needed to achieve net zero emissions.

Caterpillar (CAT) has partnered with several major mining houses such as BHP, Rio Tinto, Newmont and Teck Resources to supply Zero Emission dump trucks (Leonida, 2022). Whilst there is no indication of the preferred technology, Caterpillars 2021 sustainability report mentions multiple power solutions with development in five key areas namely, lower-carbon intensity fuels such as hydrotreated vegetable oil (HVO), hydrogen fuel cells, electrification such as the trolley assist system, battery stored power such as fully powered battery driven machines and microgrids that allow multiple sources of energy such as renewables and battery storage (Caterpillar, 2021). Autonomous mining which is gaining much traction can help reduce fuel consumption and increase production. According to a study conducted, autonomous trucks used 11% less fuel and improved productivity by 11% as well with several other benefits such as improved safety and tyre wear (Leonida, 2022). During Caterpillars 2022 Investor Day much anticipated information was shared with regards to their timelines for zero emission battery electric haul trucks development and rollout. Haul trucks are the key focus area as they are responsible for 60-80% of scope 1 emissions on a mine. The bold timeline anticipates having prototypes running later in 2022 to evaluate technical feasibility, in 2024 to send learner units to minesites for technology and product evaluation as well as process development, in 2025 to have several trucks in operation so that fleet dynamics can be enhanced along with understanding of infrastructure requirements and by 2027 to commence with full production (International Mining, 2022).

Most mining companies have committed to reduce GHG emissions by 30% by the year 2030 and it is clear that a lot of development is in place to decarbonise heavy mining equipment which are responsible for most scope 1 emissions. With mining houses like Anglo American developing inhouse hydrogen hybrid equipment and other mines like BHP and Newmont signing deals with Caterpillar who are developing fully electric systems or hybrids it is clear that change is imminent, and that renewable energy will be needed in most cases to charge batteries or produce and compress hydrogen. Other factors such as available resources, geographic location, infrastructure, capital intensity and taxes will also significantly influence decisions.

Hybrid vehicles weather hydrogen, diesel or trolley assist which makes use of energy recovery using battery storage should pave the way to rapid development of highly efficient battery storage and ultra-fast charging for heavy mining equipment whilst shrinking the size of internal combustion engines or fuel cells. Therefore, many of the technologies mentioned above might be part of the journey to net zero.

3.1.1. Alternative Fuels

Alternative fuels can also be used to reduce GHG emissions with some of them been capable to work with current infrastructure, processes and internal combustion engines.

Hydrogen, which is the most abundant element in the universe, has been around for a long time as a fuel since it is normally used as rocket fuel due to its high energy density which ranges from 120 to 142 MJ/kg. Diesel has an energy density of 45.6 MJ/kg however has a volumetric energy density of 38,552 MJ/m^3 whereas hydrogen is only 12.79 MJ/m^3 at 1 atm (The Engineering Toolbox, 2022). Therefore, hydrogen needs to be compressed to high pressures or liquified in order to store enough onboard to prevent frequent refuelling which is a highly energy intensive process.

E-diesel may provide a solution to hydrogens poor volumetric efficiencies. Audi has partnered with Energiedienst Holding AG and Ineratec GmbH to develop a power to liquid plant in Laufenberg, Switzerland where they will make synthetic fuel from excess hydropower. The process makes use of electricity generated from hydropower to electrolyse water into hydrogen and oxygen, oxygen is released to atmosphere whilst the hydrogen is chemically reacted with carbon dioxide obtained from the atmosphere or other sustainable sources such as waste gases to form compounds of long chain hydrocarbons. The last step involves separation into waxes and e-diesel which is compatible with existing diesel engines, supply chains and infrastructure and Audi claims it is almost carbon neutral. Audi have also been investigating other environment friendly fuels such as e-gasoline and e-gas (Audi MediaCentre, 2017).

Biodiesel which is made from animal fats, vegetables, non-edible plant matter or biomass has an energy density similar to that of diesel at approximately 38-45 MJ/kg. First generation biofuel is made of wheat, corn, vegetable oils, sugar and other food crops but may threaten food supply whereas second generation biofuel is made from non-edible or waste products such as non-edible vegetables, lignocellulose feedstock and waste oils which is more sustainable. Hydrotreated vegetable oil (HVO) is a type of second-generation biodiesel that makes use of vegetable oils, soybean oil, sunflower oil, rapeseed oil or animal fat. Biodiesel can reduce up to 78% of pollutant emissions, however it often is blended due its high viscosity (H.Stancina, H.Mikulcic, X.Wang, & N.Duic, 2020).

There are various climate friendly alternative fuels that are been researched and developed. Ammonia (NH_3), Methanol, Dimethyl ether (DME) and Ethanol are other examples of this (H.Stancina, H.Mikulcic, X.Wang, & N.Duic, 2020). Whether in liquid, compressed or modified form, Hydrogen is gaining massive popularity due to it abundance, energy density when compressed or liquified and zero emissions.

3.1.2. Technology implementation and adoption

Technological advancements in mining may be introduced to improve safety or increase productivity and output. According to Jordaan & Hendriks (2009), technology has three of four human components, knowledge, know why and know-how, with the last being equipment. In the mining industry technology cannot be used to improve the product any further, the focus is to try and improve the process, reduce costs, reduce waste, and improve safety by automating dangerous tasks.

When trying to process change by introducing new technology, mining companies need to appoint the correct people in management to be the champions in the change management process. These champions must recognise the intangible human technology elements: knowledge, know why and know-how available in the organisation and align them with the introduction of the new technology in order to ensure a more successful process, adoption and outcome of the new equipment introduction. The mining champions need to be people who have the vision and belief that the new technology will add value to the company. They must have the ability to make decisions and must have long exposure to a particular mine site (Jordaan & Hendriks, 2009).

When choosing suppliers or providers of technology, equipment and maintenance, some companies prefer to use the services of only one service provider. There are pros and cons to this, with the pros being the availability of knowledge and expertise and the con being dependency on this particular company. Some more experienced mining sites may however choose to have a mix of suppliers which may better cater for their more specific needs as opposed to a generic technology solution. Today many OEM's have the ability to develop new technology based on the request by mining companies (Jordaan & Hendriks, 2009). Now, although this can be done mining companies need to weigh out the teething problems that could come with this new technology. Will the implementation and the problems associated with it outweigh the proposed benefits? Will the equipment be readily accepted by its human capital and are they in a position to use the new technology to the best of its ability? A decision needs to be made on whether to steer forward or to make the most of the existing systems.

The implementation of new technology can be successful or can collapse and this may have nothing to do with the technology itself but rather on how well it is managed and how well it is received and adopted by the workforce of the company. The outcomes of technological advancements must be measurable and needs the buy-in of all involved from top management to the skilled operators who will using it on a daily basis. New technology means news systems and different ways of doing things which essentially means there is going to be change coming. As with most things that cause change comes the resistance to change. Resistance to change is what could lead to the failure of the new technology being implemented and utilised to its full capacity. Such resistance could surface due to people doubting management's intentions and the fear of job losses (Macfarlane, 2001).

Those involved in the new changes need to understand the need for the changes and recognise how it will benefit not only the company but their own skill levels as well. Some success factors include a common vision, an involved workforce and quantified benefits (Macfarlane, 2001).

A winning change model which has worked for South Africa is the "Wheel of Change" (Malherbe, 1993). The Wheel of Change has eight stages in the change management process and has no ending, it be restarted at any given stage as required by the process. Stage 1 - Vision: There must be a sense of shared and common vision among all those who are involved in the process. Stage 2 – Team Change: Here again all stakeholders need to agree in terms of the value of the change and undertake to adopt the changes. New skill sets may also be required at this stage to ensure effective operation of the new technology. Stage 3- Work Cycles: New technology could require new work structures especially if the new technology is on large scale with a lot of capital investment. Stage 4 – Task Listing: Here we look at the current workforce. How big or small it is, what levels of skills are available and what improvements may be required to enable success. Stage 5 – Structure: With more complex technology comes the need for higher levels of skills and organisations may require more structures for example more support structures for the new work methods or a higher engineering component. Stage 6 – Systems: Many systems may also need to be reassessed or introduced such as new maintenance systems or emergency procedures. Stage 7 – People: People are the most important part of the change process and the successful implementation and operation of the new technology. The workforce needs to be evaluated in-terms of skills available to ensure that the technology will be able to fit in. Stage 8 – Culture: This is the re-evaluation of the process in order to determine any pitfalls and to measure the proposed benefits of the new implementations.

Other factors that influence people's intentions of adopting technology can be found in the TRA, TAM and Roger's Diffusion of Innovation theories (Rogers, 2003).The Theory of Reasoned Action (TRA) (Ajzen & Fishbein, 1980) reflects on how people's behaviour is affected by their attitudes and their perception of the benefits the changes as well as the acceptable social norms surrounding the changes (Feng, 2012).The Technology Acceptance Model (TAM), originally based on Ajzen and Fishbein's (TRA) theory, was first proposed by Davis (Davis, 1986). This model explores the acceptance of technology from a more inherent perception rather than external factors (Feng, 2012).

Lastly the Adoption, Innovation and Diffusion Theory. The Diffusion of Innovation (DOI) Model (Rogers, 2003) argues that the characteristics of the innovation will primarily determine how the innovation is adopted. The five attributes include: relative advantage, compatibility, complexity, observability and trialability (Feng, 2012).

The successful implementation and adoption of any new technology will also require new competencies and skills sets. Skiba (2020) focuses on training at a training sector level which would be the likes of technicians and transportation workers. Training will also need to include training from a safety perspective. The emerging need for new energy sources also requires measures to ensure that the risks associated with it are managed correctly. New technology may require new skills but may also make way for the introduction of new job roles in the industry. For instance, a Hydrogen vehicle electrician would need to have specialist knowledge in hydrogen vehicles as compared to a normal motor electrician. In the same way industry will develop the need for more Fuel Cell Fabrication and Testing Technicians or a Hydrogen Pipeline Construction worker for example (Skiba, 2020).

The new means of energy will also bring with it new hazards, these may present themselves in storage and transportation. Leaks, dispersion and flammability may be new points of concern. This will increase the need for people in technical, engineering and professional roles to be trained in these aspects of concern (Skiba, 2020). New energy properties and behaviours will need to be understood. Training will need to encompass health and safety aspects, first aid procedures and emergency response policies and procedures.

A look at only the introduction of the use of hydrogen alone will require knowledge in the following areas, hydrogen safety, hydrogen fires, hydrogen explosions and hydrogen ignition. The user will also need to understand the basic concepts surrounding hydrogen such as thermodynamics, chemical kinetics and fluid dynamics. Safety aspects will also differentiate among the different work roles and hydrogen systems in place (Skiba, 2020). Guidelines for training new skills may include relevant industry standards, regulations, health and safety requirements, risk control, environmental control and sustainable energy principles (Molkov & Dahoe, 2007). New skill sets may need to be developed for hazard identification, quality checks and protective measures .

Competence is defined as “the ability to perform activities within an occupation; to function as expected for employment; and the ability to do a job under a variety of conditions, including the ability to cope with contingencies” (Trinder, 2008). Competence is of extreme importance and is critical to the safety of the workers and the systems the industry employs.

The mining industry when implementing new methods of energy will require roles and skills specific to its sector. Multiple new roles that may be introduced in the forthcoming years to supplement the demand for more sustainable energy. Some of these may be of particular interest to the mining sector such as a Hydrogen fuel cell system technician, Hydrogen fuel transporter, Hydrogen fuelling station operator and a Hydrogen energy engineer (Bezdek, 2019).

Mining companies will therefore need to identify the new roles that will be required with the introduction, maintenance and control of the new system and find methods in line with regulations, health, safety and industry standards to train and impart new skills or advance existing skills of its workforce, and those involved with the new technology and energy methods.

Jordaan & Hendriks (2009) states that technology is useful in that it is able to help improve processes, reduce costs, reduce waste, and improve safety by automating dangerous tasks. Although technology has so many benefits its implementation may still collapse according to author Macfarlane (2001) and the reason for this this is because of the resistance to change which is often caused when the workforce mistrusts management’s intentions and the fear of job losses that the new technology could bring. The fears may also lead to the workforce sabotaging the implementation of the new technology and not utilising it to its full capacity. Macfarlane (2001) also shares similar views, in that the outcomes of technological advancements needs the buy-in of all involved from top management to the skilled operators who will using it on a daily basis and that change needs to be understood and encouraged in order to prevent being sabotaged by workforce who may feel threatened by it.

Theory of Reasoned Action (TRA) reinforces how external factors such as acceptable social norms affect people's perception of the benefits of change (Ajzen & Fishbein, 1980), whereas the Technology Acceptance Model (TAM), proposes that inherent perception is the deciding factor in accepting or rejecting change (Feng, 2012). The Adoption, Innovation and Diffusion Theory (Rogers, 2003) on the other hand argues that the characteristics of the innovation itself will determine how it may be adopted by its stakeholders.

Jordaan & Hendriks (2009) notes the importance of correct people in management to implement the change management process, transitioning new technology, choosing the correct providers, suppliers, and OEM strategy. Malherbe (1993) similarly, to Jordaan & Hendriks (2009) states in Stage 7 of the Wheel of Change, that people are the most important part of the change process.

Malherbe (1993) further adds that workforces need to be evaluated in-terms of skills available to ensure that the technology will be able to fit in. Skiba (2020) also recommends that workforces need to be evaluated and that gaps must be identified. According to Skiba (2020) this is important so that management can identify new competencies that are required and work towards training these new skills and competencies line with regulations pertaining to health, safety, and industry standards taking into account any new hazards that may also be identified.

4. DATA COLLECTION AND ANALYSIS

4.1. Data Collection

4.1.1. Research Approach

Selection of the right climate friendly technology for heavy mining equipment may give both the manufacturer and the company who implements them first a major advantage especially if the technology carries patents. Once the technology is proven and implemented successfully, many smaller operations will follow suit, especially those that don't have the capital to invest in their own expensive research and development. Demand will be high due to the massive incremental tax levies and hence equipment can be sold at a premium. Since major original equipment manufacturers (OEM's) such as CAT, Komatsu, Hitachi, Terex, Volvo, Liebherr, GE, Cummins, Rolls Royce and many others are all in a race to develop zero emission heavy mining equipment, most OEM's are not willing to share intellectual property. Since most of the technology is in development, prototype or test phases, technologies cannot be directly compared on a technical basis accurately. Therefore, data will be collected from mining operations who are trialling, developing or investigated new technologies for heavy mining equipment and this data will be used to conduct quantitative research.

Therefore, the approach is to understand the factors that influence choices from the customers point of view as well as challenges that might be faced during implementation.

4.1.2. Research Design

A cross sectional design also known as a survey design (Bryman, 2012) will be used for this research as it employs more than one case across organisations and commodities, will occur over a single point in time when all technology advancements in heavy mining equipment to reduce GHG emissions are relatively new, data will need to be quantifiable so that variation can be measured and comparison of variables will allow patterns of association.

4.1.3. Population And Sample

Ideally the target population is middle to senior management at mining operations since more junior employees may not be fully versed with the roadmaps associated with reaching net zero emissions and carbon neutrality. These should be qualified professionals' such as engineers, mine managers, general managers or strategic/specialist personnel associated with technological advancements for HME. This should also span across commodities with opencast mines such as Platinum, Diamonds, Iron ore, Gold and Coal as well as mining regions such as Mpumalanga, Northwest, Gauteng, Limpopo and Northern Cape. Many mining operations in South Africa are predominantly deep level shafts which use conventional mining methods and have a much smaller scope 1 carbon footprint as compared to opencast mines with HME and hence these will not be included in the target population.

The companies sampled are all well-established mining organisations who have GHG reduction and carbon neutrality targets. Samples per commodity of Platinum, Diamonds, Iron ore, Gold and Coal should be obtained as well as from diversified miners who mines multiple commodities. This will ensure that results are not skewed by a single organisations carbon footprint initiative. There are 45 publicly listed companies on the Johannesburg Stock Exchange (JSE) which fall in the Industrial Metals and Mining sector and the Precious Metals and Mining sector. Of the 45 companies, only 14 have opencast cast mines which make use of Heavy Mining Equipment in South Africa. Please refer to Appendices II for the full list of companies. There is also minimal value in sampling too many participants from the same organisation as the strategies will the same for the whole organisation as they are normally driven from the top down, hence there will be a maximum of 2 participants per company.

8 publicly listed companies were approached of which 6 participated. A relatively small sample was used due to time constraints and limited amount of large opencast mines in South Africa. The was a total of 9 participants who had

a minimum 5 years of experience with the management of personnel and HME. Hence, the sampling was purposive (Bryman, 2012) where the samples were selected to meet the purpose of the research and also have enough variety to be useful.

4.1.4. Data Collection

Data will be collected by completion of a research questionnaire (Appendix I) that is shared using a link from the Qualtrics XM platform. The questionnaires are developed to understand the individual's position and seniority in the organisation as well as their preferences to climate friendly HME and possible gaps that would have to be addressed to ensure its success. Data will also need to be structured so that it can be quantifiable.

Emails were sent to participants from the 17th of January 2023 with follow up emails sent as reminders. The last participant completed the survey on the 27th of January 2023. 9 of 13 (69%) participants who were approached, completed the survey.

4.1.5. Data Analysis

Questions will be setup allow for multivariate analysis for adoption and technically inclined questions using software package IBM SPSS for data analysis. Ordinal scales was used for screening data such as age, qualification and position. Interval scales was used to measure timelines for adoption and the Likert scale was used to assess skills, attitudes and perceptions for patterns of association.

4.1.6. Validity

The questionnaire has been designed to capture adequate data to answer questions 1 and 2 sufficiently by using Likert, Ordinal, Interval, Categorical and Proficiency scales. All scales selected are well developed and should provide valid data with regards to choose of technology for Heavy Mining Equipment, timelines for trials and implementation as well as preferred suppliers. Since adoption is very specific to individual experiences, most scales chosen here are Likert, Interval and Proficiency related. Whilst some scales are qualitative in nature, they can be converted into quantitative data for quantitative analysis.

Construct validity methods will be used in conjunction with correlations to link variables that are associated with each other for technology selections and adoption confidence. Linear regressions will then be conducted using intervals for adoption and technology selections as the dependant variables. A series of Chi-squared tests will also be performed for association.

4.1.6. Reliability

Since the target population is very focused to professional personnel in the mining industry especially since this a confidential field and the sample population is relatively small, it may be hard to reproduce these results. The study is also time sensitive since as technologies develop, adoption will be very different. However, strong positive correlations will be used to prove reliability along with evaluations of covariance and significance.

4.1.7. Limitations

The sample does not cover the entire South African mining industry and hence the findings may not be applicable to all mines. Mines sampled are mostly large mining organisations which are listed on the Johannesburg Stock Exchange (JSE), Australian Stock Exchange (ASX) and/or the London Stock Exchange (FTSE) and hence the research might not be an accurate reflection of smaller companies especially those who do not have the funds to trial new technologies and prefer tried and tested equipment. The research mainly focuses on opencast mining which predominantly uses HME for mining, whereas many South African mines are traditional underground mines using shafts and locomotives which don’t have large scope 1 GHG emissions.

Even though the survey participants were carefully selected to span several organisations and commodities, most large opencast operations in South Africa are still run by a select few major international mining companies.

4.2. Data Analysis

4.2.1. Introduction

In this section we will attempt to address the hypothesis identified within Chapter 1. This shall be done via the results that we have obtained via our data collection instrument as well as the accompanying inferential statistics.

First, we will examine the various associations for our first hypothesis which looks at the possible changes in driving power for the next generation of heavy mining equipment.

Next, we run the required analysis regarding our next hypothesis which addresses whether South African mining is slow to adopt new technology for Heavy Mining Equipment.

Lastly, we summarise and conclude the findings from the preceding analysis.

The demographics collected aligns well with expectations for a cross sectional design targeting middle to senior management at mining companies who have a minimum 5 years of experience with the management of personnel and HME. All 9 participants are senior management or higher, have a minimum qualification of a Bachelor's degree or Bachelor of Technology (BTech), 5 of whom have a master's degree and all of whom have more than the required minimum 5 years of experience.

4.2.2. Analysing whether there will be changes in driving power for the next generation of heavy mining equipment.

The hypothesis for this section has been restated as follows:

H0: There will be no changes in driving power for the next generation of heavy mining equipment.

H1: There could be possible changes in driving power for the next generation of heavy mining equipment.

Due to the nature and limitations of the current data from our data collection instrument, we thought that a series of Chi-squared tests would be sufficient as most of the variables our nominal. The variables related in addressing the hypothesis has been as stated below:

Table 1: Associations Tested

Association	Variable 1	Variable 2
Technology Vs GHC Targets	Technology	GHC Targets
Skills Required Vs Technology	Skills Required	Technology
GHG Emissions Targets Policy Vs Technology	GHG Emissions Targets	Technology

4.2.2.1 Testing the association between GHG emissions reduction year targets and type of technologies

Table 2: Type of Technology Investigated and Year to reduce GHG emissions targets

Count

		What technology is being investigated by your company to reduce scope 1 GHG emissions from heavy mining equipment?				
		Diesel Electric Hybrid	Hydrogen (FCEV)	Fully Electric Battery	Other	Total
By which year does your company target to reach 30% reduction in GHG emissions?	by 2030	0	5	2	0	7
	by 2040	1	0	0	0	1
	No target	0	0	0	1	1
Total		1	5	2	1	9

As seen in Table 2 above, the greatest count according to the tabulation was of that between the year 2030 as well as Hydrogen (FCEV). The Chi-squared results from our analysis is depicted below:

Table 3: Chi-square tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	18.000[a]	6	.006
Likelihood Ratio	12.307	6	.055
Linear-by-Linear Association	2.790	1	.095
N of Valid Cases	9		

a. 12 cells (100.0%) have expected count less than 5. The minimum expected count is .11.

The null hypothesis for this specific test is that there is no association between the type of technology investigated as well as the year for GHG emission to be reduced by 30%.

When analysing the results from our Chi-Squared Test in Table 3, we obtained a significant result ($\chi^2(6) = 18.000$, $p = .006$). We can therefore reject our null hypothesis and conclude that there is an association between our two variables. Based on this result there is also evidence to believe that any changes that happen within these targets, this will most likely affect the associated technology that is aligned with the target. Furthermore, it should be noted that expected counts refer to the projected frequencies when the null hypothesis is true. This will be the case of all Chi-squared tests within this chapter.

Moreover, when analysing figure 1 below, we see that the association primarily lies with Hydrogen and Fully electric technologies by the year 2030.

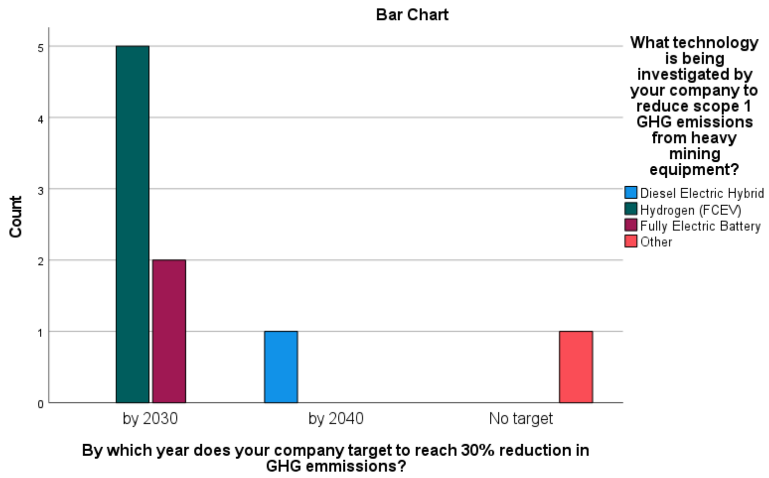

Figure 1: Cross Tabulation 1

4.2.2.2. Testing the association between type of technologies and skill development requirements

Table 4: Type of technologies and skill development requirements

		What technology is being investigated by your company to reduce scope 1 GHG emissions from heavy mining equipment?				
		Diesel Electric Hybrid	Hydrogen (FCEV)	Fully Electric Battery	Other	Total
What skills need to be developed the most to enable successful implementation of the chosen technology?	Electrical	0	1	0	0	1
	Control & Instrumentation	0	2	1	1	4
	Operators	0	1	0	0	1
	Specialists	1	1	1	0	3
Total		1	5	2	1	9

As seen in Table 4 above, Hydrogen (FCEV) and Electrical Control and Instrumentation showed the greatest count (2). As expected, Diesel Electric Hybrids show no counts for Electrical Control and Instrumentation as well as operators.

Table 5: Chi-square tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	4.875[a]	9	.845
Likelihood Ratio	5.774	9	.762
Linear-by-Linear Association	1.097	1	.295
N of Valid Cases	9		

a. 16 cells (100.0%) have expected count less than 5. The minimum expected count is .11.

The null hypothesis is that there is no association in terms of the skills to be developed as well as the type of technology. Based om the results of 5 Above, we fail to reject our null hypothesis and conclude that there is no association between the type of technology to be investigated as well as the skill to be developed. Figure 2 below provides a graph regarding the results of our earlier identified cross tabulation.

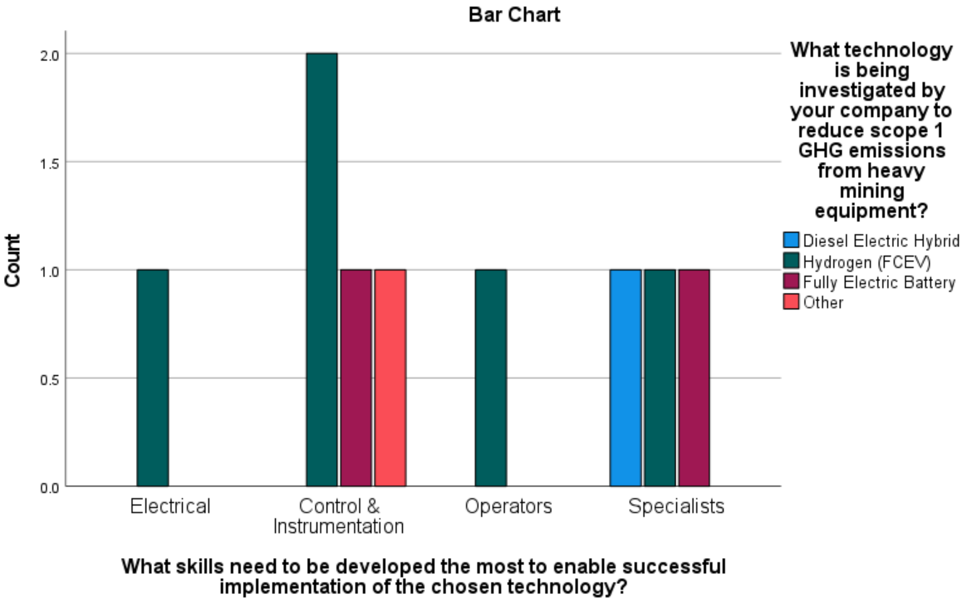

Figure 2: Cross tabulation 2

4.2.2.3 Testing the association between technologies investigated and commodity produced

Table 6: Commodity vs technology investigated

Count

		What technology is being investigated by your company to reduce scope 1 GHG emissions from heavy mining equipment?				
		Diesel Electric Hybrid	Hydrogen (FCEV)	Fully Electric Battery	Other	Total
What commodity does your company produce?	Gold	0	0	1	0	1
	PGM's	0	1	0	0	1
	Coal	0	0	1	0	1
	Iron Ore	0	2	0	0	2
	Diamonds	1	1	0	0	2
	Multiple	0	1	0	0	1
	Other	0	0	0	1	1
Total		1	5	2	1	9

As seen in Table 6 above, Hydrogen (FCEV) and Iron Ore produced the greatest count (2). Most other values within our cross tabulation produced a value of 1.

Table 7: Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	21.600[a]	18	.250
Likelihood Ratio	17.910	18	.462
Linear-by-Linear Association	.141	1	.708
N of Valid Cases	9		

a. 28 cells (100.0%) have expected count less than 5. The minimum expected count is .11.

The null hypothesis is that there is no association regarding the relationship between commodity produced and the technology investigated. Based on the results of 7 above, we fail to reject our null hypothesis and conclude that there is no association between the type of technology to be investigated and the commodity produced. Figure 3 below provides a graph regarding the results of our earlier identified cross tabulation.

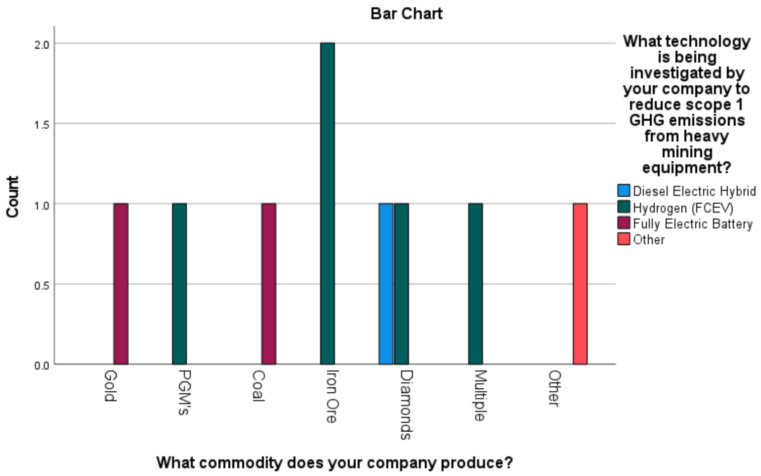

Figure 3: Cross Tabulation 3

4.2.2.4 Testing the Association between Technology Investigated and OEM

Table 8: Type of Technologies and OEM

		What original equipment manufacturer currently has the largest fleet on your mine/s?			
		CAT	Komatsu	Other	Total
What technology is being investigated by your company to reduce scope 1 GHG	Diesel Electric Hybrid	1	0	0	1
	Hydrogen (FCEV)	0	5	0	5
	Fully Electric Battery	0	1	1	2

emissions from heavy mining equipment?	Other	0	0	1	1
Total		1	6	2	9

Table 8 above shows that, Hydrogen (FCEV) and Komatsu had the biggest count (5) according to the crosstabulation.

Table 9: Chi-square tests

		df	Asymptotic Significance (2-sided)
Pearson Chi-Square	15.000[a]	6	.020
Likelihood Ratio	12.504	6	.052
Linear-by-Linear Association	4.912	1	.027
N of Valid Cases	9		

a. 12 cells (100.0%) have expected count less than 5. The minimum expected count is .11.

The null hypothesis is that there is no association between OEM and technology to be investigated. When looking at Table 9 above, we obtained a statistically significant result ($\chi^2(6) = 15.000$, $p = .020$). We can therefore reject our null hypothesis and conclude that there is an association between the type of OEM as well as the type of technology to be investigated.

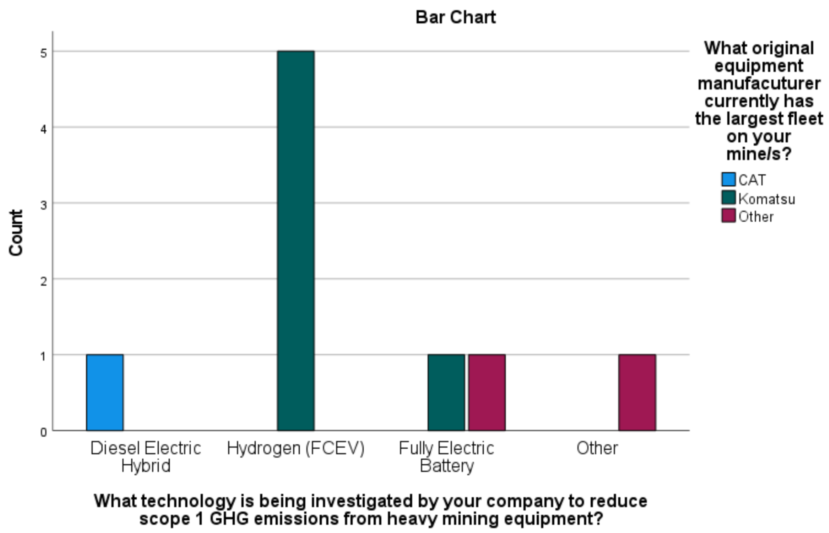

Figure 4: Technology investigated and OEM

4.2.3. Analysing whether South Africa is slow to adopt new technology for heavy mining equipment.

In this section we decided to run an independent samples Kruskal Wallis Test to test whether there is a significant difference between the year in which companies to aim to reduce GHG emissions according to a technology adoption scale. The null hypothesis is South African mining is slow to adopt new technology for Heavy Mining Equipment. First, we will compile the required statistics to test whether our technology adoption scale is reliable. Then we will perform the required inferential statistics to observe whether we will accept or reject the identified null hypothesis.

4.2.3.1 Reliability Statistics

Table 10: Reliability Statistics – Technology Adoption Scale

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.679	.667	3

Table 10 above shows that the Technology adoption scale is statistically reliable as we obtain a value that is greater than .65. Although most existing literature specifies a result of .70 is required, Salkind (2017) has stated that a value greater than .65 is acceptable. The scale was computed by using questions 21, 22, and 24 within our scale. In order to use the scale for the following analysis we then computed a technology adoption variable by averaging the responses of the questions utilised.

4.2.3.2. Kruskal-Wallis Test Results

Table 11: Hypothesis Test Summary

	Null Hypothesis	Test	Sig.[a,b]	Decision
1	The null hypothesis is South African mining is slow to adopt new technology for Heavy Mining Equipment	Independent-Samples Kruskal-Wallis Test	.116	Retain the null hypothesis.

a. The significance level is .050.

b. Asymptotic significance is displayed.

Table 12: Independent-Samples Kruskal-Wallis Test Summary

Total N	9
Test Statistic	4.303[a]
Degree Of Freedom	2
Asymptotic Sig.(2-sided test)	.116

a. The test statistic is adjusted for ties.

Table 11 and 12 above shows the results from our Kruskal-Wallis Test results. The null hypothesis has also been stated within Table 11. Based on these results we can therefore accept our null hypothesis. Key assumptions about the Independent-Samples Kruskal-Wallis Test include:

- The distribution is not that of a normal distribution.
- That the predictors are independent.

4.2.4. Analysing whether technology adoption differs based on the type of technology to be investigated

For this section we wanted to establish whether technology adoption differs based on the type of technology to be investigated. For this will assume that our data is normally distributed based on the sample size which is far less than 30. Moreover, the inferential statistic technique to be employed is the one-way ANOVA since our independent variable consists of more than 2 groups. The null hypothesis is many South African mines are not driving change and adapting new technology. The dependent variable is our technology adoption scale computed in section 4.2.3.1. above while our independent variable is the type of technology to be investigated. The results are as follows:

4.2.4.1. Descriptive Statistics

Table 13: Descriptive Statistics - Technology Adoption Scale

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean Lower Bound	95% Confidence Interval for Mean Upper Bound	Minimum	Maximum
Diesel Electric Hybrid	1	6.5000	.	.	.	.	6.50	6.50
Hydrogen (FCEV)	5	5.6000	.43461	.19437	5.0604	6.1396	5.00	6.00
Fully Electric Battery	2	5.0833	.58926	.41667	-.2109	10.3776	4.67	5.50
Other	1	3.6667	.	.	.	.	3.67	3.67
Total	9	5.3704	.84483	.28161	4.7210	6.0198	3.67	6.50

Table 13 above depicts the descriptive statistics concerning our one-way ANOVA. We see that Diesel Electric Hybrid produced the highest mean (M = 6.5000, SD =N/A). Note that standard deviation values are not applicable based on the size of the sample size. Furthermore, Fully Electric Battery produced the highest standard deviation (M = 5.0833, SD =.41667).

4.2.4.2. Testing of the assumption of equal variances between groups

Table 14: Tests of homogeneity of variances

		Levene Statistic	df1	df2	Sig.
Tech Transformation Scale	Based on Mean	.226	1	5	.654
	Based on Median	.223	1	5	.657
	Based on Median and with adjusted df	.223	1	4.000	.661
	Based on trimmed mean	.229	1	5	.653

Table 14 tests whether our independent variable displays an equal variance amongst groups. This null hypothesis for this particular test is that there is an equal variance amongst our groups within the independent variable. Due to the statistically insignificant result, we will therefore accept the null hypothesis and conclude that the variance between our groups is indeed equal (F(5) = .226, p = .6554).

4.2.4.3. One-Way ANOVA results

Table 15: Technology Adoption Scale

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4.607	3	1.536	6.963	.031
Within Groups	1.103	5	.221		
Total	5.710	8			

Table 15 evaluate the results from our one-Way ANOVA. We obtain a statistically significant result (F(3,5) = 6.963, p = .031). We can therefore reject our null hypothesis since the mean is statistically significant for at least one of our groups in the independent variable. We therefore conclude that many South African mines are driving change and adapting new technology.

4.2.5. Closing of Presentation of the Findings

The purpose of this chapter was to summarise the findings derived from our data collection instrument. Since we only have 9 observations, this poses a serious limitation on the results. Moreover, due to the type of data being nominal, it is quite difficult to obtain more meaningful results and run more comprehensive tests.

However, we ran a series of chi-squared tests to evaluate possible associations that between the type of technology investigated as well as GHG Targets, skills developed and OEMs. Moreover, we also tested for an association between type of technology as well as the commodity produced. It was found that there was a significant association with GHG targets and OEMs. All other association proved to be statistically insignificant.

We then ran a nonparametric test in the form of a independent samples Kruskal Wallis test to test for a difference in GHG year targets by a newly computed technology adoption scale. It was found that there was no difference according to the year which we can therefore infer that technology adoption is quite slow.

Lastly, we used the same technology adoption scale to test for differences in technology to be investigated. This was done to determine if South African mining companies are slow to adopt new technologies. We obtained a statistically significant result, and we could therefore infer that mining companies aren’t slow in terms of adapting new technologies.

The results will now be used as part of the discussion section within the next section.

4.3. Discussion

4.3.1. Analysing whether there will be changes in driving power for the next generation of heavy mining equipment.

4.3.1.1. Testing the association between GHG emissions reduction year targets and type of technologies

Most companies are targeting a 30% reduction in GHG emissions by 2030. This is in line with "SDG 13 - Take urgent action to combat climate change and its impact" that was laid out in 2015 by the United Nations (Lexis Nexis, 2021). It is also not a surprise that Hydrogen Fuel Cell Electric Vehicles (FCEV) has the highest count as this technology is already developed to a point where road cars have been rolled out and heavy mining equipment is in the trial phases in addition to having zero GHG emissions.

There are also 2 counts of fully battery electric heavy mining equipment. FCEV requires hydrogen at high pressure or liquified hydrogen which is energy intensive and hence fully battery electric heavy mining equipment has a major advantage over FCEV's due to it high energy efficiency. However, fully battery electric heavy mining equipment are not as far developed as FCEV's and require large battery packs to store the large amounts of energy needed and have long charging periods.

Although "none" which means there is no change in technology from Diesel engines was an answer option, the fact that no participant selected this option means that there is a drive for changes in driving power for the next generation of heavy mining equipment in South Africa and this aligns well with the rejection of the null hypothesis as mentioned in section 4.2.2.1.

4.3.1.2. Testing the association between type of technologies and skill development

Whilst hydrogen FCEV once again had the highest count of skills needed to be developed for successful implementation with control and instrumentation having a count of 2, there is no association between the type of technology to be investigated and the skills that need to be developed. This is evident by the spread of answers for skills needed between electrical, control and instrumentation, operators and specialists. Hence, it can be deduced that all of these skills need to be developed. The question should have rather allowed the participant to rank in order of priority the skills development needed for successful implementation rather than only a single selection.

It can be seen however that across all the types of technology investigated that Control and Instrumentation Technicians as well as Specialists have the highest counts. This reasons well considering that all technologies investigated have complex control systems to manage conversion of diesel, hydrogen and/or regenerative power to drive or retard electric wheel motors whilst monitoring and controlling several other systems.

The Wheel of Change (Malherbe, 1993) identifies people as the most important part of the change process whereby the workforce has to be evaluated for existing skills to identify new skills that must be developed in order to ensure successful implementation and operation of the new technology it is fitting that all these existing skills for HME are identified as developmental areas.

4.3.1.3 Testing the association between technologies investigated and commodity produced

There are several reasons why the inferred statistics show there is no association between Technologies Investigated and Commodity Produced. Participants were chosen across several commodities and several companies so that the results are not biased towards a single company or technology with no more than 2 participants per commodity or company.

However, it is clear to see that Hydrogen (FCEV) has the highest count of 5 (55%) across all commodities. Considering South Africa is a platinum rich nation having the largest reserves in the world (Minerals Council South Africa, 2022) and platinum is a catalyst needed for hydrogen fuel cells to produce electricity, it is fitting that this technology is been developed or trialed more than other types of technology in South Africa.

Most large opencast mines which was the target population of the survey may be affiliated to a larger organizations in some form or shape. Anglo American as an example has major shareholding in Anglo American Platinum, Kumba Iron Ore, De Beers and has recently unbundled Thungela Resources who produces thermal coal (Anglo American, 2022) and operate many of the largest opencast mines in South Africa. They have recently unveiled their Hydrogen Fuel Cell Truck at their Mogalakwena mine (Leonida, 2022) with plans to roll it out across their mines which may influence the selection of FCEV's in this survey.

Most gold mines in South Africa are deep level shafts which make use of conventional mining methods. However, when one drives through Johannesburg it can be seen that many tailings storage facilities are been remined to extract the remaining gold thanks to developments in technology and high gold prices. This provides a compelling case for fully battery electric heavy mining equipment as trucks often climb these storage facilities empty and return downhill fully loaded thus generating more power than what is consumed when travelling down the ramps which could explain the technology selection.

Whilst there might be strong associations between companies and technology investigations or trials, this could not be shared due to confidentiality reasons.

4.3.1.4. Testing the Association between Technology Investigated and OEM

From 4.2.2.4. it can seen that there is a statistically significant association between Komatsu and Hydrogen fuel cell technology for heavy mining equipment. Komatsu is also the largest supplier of trucks (6 of 9 samples) to the mines that have participated in the survey.

Cummins and Komatsu recently announced that they will be collaborating to advance the development of mining haul trucks with zero emissions whereby Cummins will provide hydrogen fuel cells, electrolysers for the production of hydrogen and batteries with Komatsu providing expertise in mining equipment design. The range is expected to be available by 2030 (Cummins, 2022).

Komatsu is also developing a power agnostic truck capable of running on various different sources of power such as trolley lines, batteries, hydrogen and diesel electric hybrid in a bid to reduce carbon emissions by 50% from the production and use of its equipment by the year 2030 (Cummins, 2022).

Komatsu’s large market share in South Africa, partnerships with major power product manufacturers and innovativeness has put Komatsu in the lead in terms of the findings of this research.

4.3.2. Analysing whether South Africa is slow to adopt new technology for heavy mining equipment.

The null hypothesis which states that “South African mining is slow to adopt new technology for Heavy Mining Equipment” was retained after generating a reliable scale in 4.2.3.1. for technology adoption by averaging the responses to questions 21,22 and 24 shown below and then conducting a Kruskal-Wallis test with the year in which companies target to reach 30% reduction in GHG emissions (Question 8).

- 21) In general, has engineering skill levels increased over the past 5 years at your organisation/mine?

- 22) Would you promote technologies that are more complex but provide efficiency advantages and GHG reductions?
- 24) Do you believe your engineering team supports new technology?

7 of the 9 samples (78%) indicated that they would achieve the 30% reduction by 2030, with 1 in 2040 and 1 with no target date. This is indeed slow adoption, especially since this includes scope 1, 2 and 3 emissions with the technology needed for scope 2 reductions in the form of solar photovoltaic (PV), wind and hydropower readily available.

The energy crisis in South Africa means that several mining companies are short of supply of electricity which means that most new renewable sources of energy are being used to fill the gap created by Eskom. Whilst this helps reduce scope 2 GHG emissions, this means that companies are spending large amounts of capital to stabilise their power supply which leaves less resources for technology development with regards to reductions in scope 1 emissions. The energy crisis has become so severe in South Africa, such that many companies including Eskom need to run diesel generators to keep production going, which is contrary to most companies' climate change plans to reduce scope 1 and 2 GHG emissions.

In summary this means that mining companies capital allocation will be more focused on scope 2 reductions and power stability rather than scope 1 emissions from heavy mining equipment unless companies like Eskom or other Independent Power Producers are able to provide the much-needed transition to renewable energy and fill the gap in supply of power. All responses to question 17 showed very little confidence in Eskom when participants were asked if they believe Eskom can provide stable power supply which would be needed for electric trucks.

The mining industry in South Africa is governed mainly by the Mines Health and Safety Act (Act No. 29 of 1996), Mineral and Petroleum Resources Development (Act 28 of 2002) and the National Environmental Management Act (Act No. 107 Of 1998). Many permits and licenses are needed in terms of these acts to develop and construct new facilities, such as Environmental Impact

Assessments (EIA), permits for the storage of high-pressure gases, registration with the National Electricity Regulator of South Africa (NERSA) and so on. Many of these permitting and registration processes are manual, complicated and tedious, evident in the responses to question 23 “Do you believe current legislation and governance enables technology development?” as shown in figure 5 below, thus slowing down development and construction.

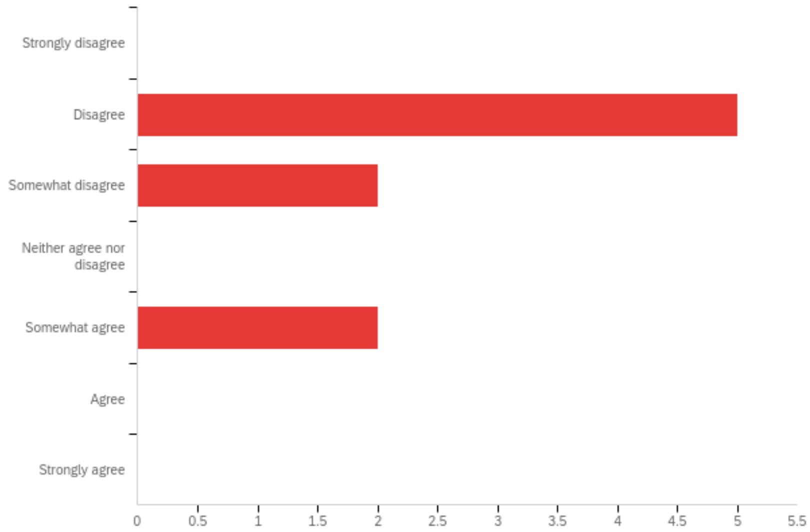

Figure 5: Responses to Q23

4.3.3. Analysing whether technology adoption differs based on the type of technology to be investigated.

From section 4.2.4 we concluded that many South African mines are driving change and adopting new technology. This is evident from the responses to question 9 which stated, “What technology is being investigated by your company to reduce scope 1 GHG emissions from heavy mining equipment?”. Whilst “none” was one of the options, no participants had selected this option.

Looking more into the detail of the responses to question 22 “Would you promote technologies that are more complex but provide efficiency advantages and GHG reductions?” and question 24 “Do you believe your engineering team supports new technology?” shows that most participants are receptive to adoption of new technologies and have teams that will most support the initiatives irregardless of the technology selected.

Much publicity of battery electric vehicles received from the likes of Tesla as well as one of its founders, Elon Musk, have already laid much of the foundations for changing people's mindsets towards new technologies such as battery electric vehicles and hydrogen. One could easily argue that most people would say that hydrogen is too dangerous and charging batteries would not be feasible a few years back, however it is clear to see from the survey that this is not the case in the South African mining industry.

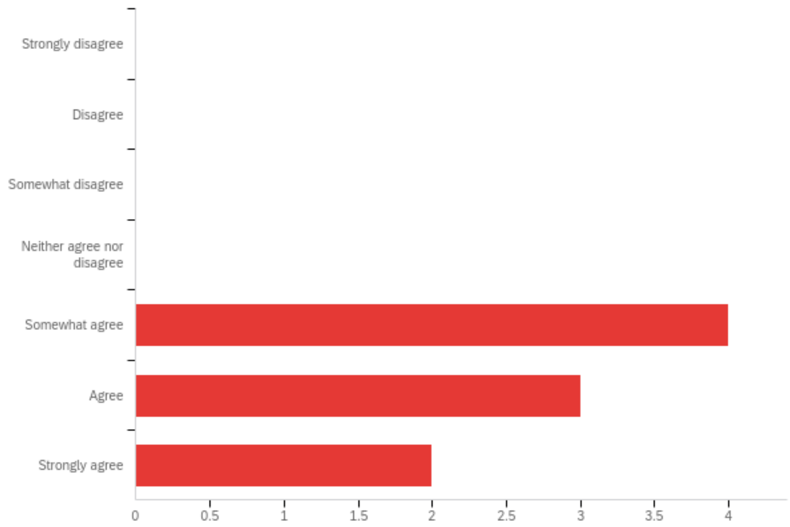

Figure 6: Responses to Q22 "Would you promote technologies that are more complex but provide efficiency advantages and GHG reductions?"

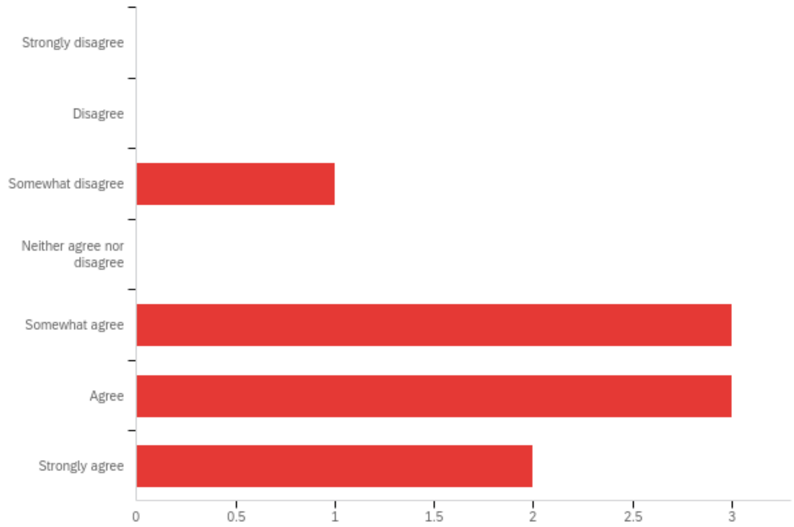

Figure 7: Response to Q24 "Do you believe your engineering team supports new technology?"

5. Recommendations and Conclusions

5.1. Recommendations for future research

Various data types were collected in this survey along with several different scales. Therefore, testing for associations between responses and conducting multivariate analysis often yielded insignificant results. Due to the nature of the topic and limited participants, a qualitative research method such as a one-on-one interview may have been more applicable, however participants would have to be assured that they will always remain anonymous otherwise there might be a lack of participation.

The scope of this research covered technology selections for reductions in carbon emissions and adoption of technology for opencast mines in South Africa. Considering that most South African opencast mines are reaching the end of their lifespans or are underground mines, this target population should be varied to reach a larger population and thus provide more reliable statistical results. For example, only covering Scope 1 reductions would focus on all diesel driven mining equipment and generators as well as fugitive emissions, and Scope 2 would cover all indirect emissions from power generation thus opening up the survey to underground and opencast mines, hence providing a larger sample population.

Data collection for a topic where participants are busy professionals in management roles and need to be headhunted should not be underestimated. Whilst the sample size for this survey was relatively small, finding the correct participants and persuading them to participate in the survey was a time-consuming effort. The survey data for this research was collected over a period of 1 month however, one should allocate atleast 2 months for data collection for research of this nature in order to secure more samples of the right quality.

5.2. Recommendations for technology development

Anglo American seems to be leading the way in South Africa for technology development and partnerships to reduce their carbon footprints. There is room for synergies between companies such as Anglo-American Platinum, Sibanye Stillwater, Tharisa Minerals, Impala Platinum, Royal Bafokeng Platinum and Northam Platinum which are all major PGM producing, publicly listed companies. Should Hydrogen fuel cell technology gain traction, all companies mentioned above would be major benefactors due to the use of platinum as a catalyst in the fuel cell. Considering that one of the main markets for platinum and palladium is catalytic converters which reduces the pollutive emissions from internal combustion engines to less harmful emissions will no longer be needed if fully electric battery vehicles become the driving power of choice, PGM producers should be doing all they can to ensure the success of FCEV's.

The synergy could be in the form of group funding, sharing of knowledge and information, developing supply chains, sharing of skills, trials of different technologies, etc. Testing and trials can also be split across the mines in different sections such as underground mining equipment, opencast mining equipment, light duty vehicles, bulk handling equipment such as trains or tipper trucks, refuelling/charging techniques, storage and transfer facilities, use of different suppliers or original equipment manufacturers (OEM's) and so on and so forth. By doing this, costs and risks are also split across organisations and development is fast-tracked.

Several large original equipment manufacturers (OEM's) for heavy mining equipment and prime movers believe that hydrogen technology will be used to bridge the gap while battery technology improves to a point where the battery energy density and charging cycles enable it to run for a complete production shift without reducing payloads. Diesel electric hybrids will enable massive power efficiency gains by using energy recovered from regeneration with excess energy stored in batteries which reduces diesel consumption and hence reduces GHG emissions. Hydrogen fuel cell vehicles also employ batteries for the use and storage of regenerative energy. This clearly paints a bright picture for the advancement and use of batteries no matter which technology is selected and is comparable to the development seen in light duty vehicles.

OEM's such as Komatsu, Caterpillar, Sandvik, Hitachi and Liebherr are all competing to deliver reduced or zero GHG emission mining equipment first. Drive created from investors, environmental organisations, governments, the United Nations (UN) and other climate change organisations will give massive first mover advantage to the OEM which can deliver a safe, reliable and practical product to market and possibly the OEM will gain a large amount of market share due to this. We can therefore expect rapid technology development and trials from all major OEM's in the next few years leading up to 2030. Many mining companies in South Africa who don't have the capital to invest in expensive development and trials will be eagerly awaiting OEM's to release these new products.

5.3. Recommendations for policy makers

The South African Revenue Services (SARS) currently collects carbon taxes via the Carbon Tax Act (Act 15 of 2019) per tonne of carbon dioxide equivalent and per litre of petrol or diesel. These are expected to increase gradually until 2030 and then rapidly to 2050. An incentive to mining companies to speed up technology development and adaption would be to offset some of technological development costs with tax rebates. This would help provide some capital funding relief for smaller mining companies and for those companies that have a negative investor sentiment towards South Africa. It will be mutually beneficial if these mines remain operational.

The Department of Mineral Resources (DMR) often releases guidelines for governing of Mines health and safety. Similar guidelines should be developed for the safe usage of hydrogen, batteries, charging stations, hybrid equipment, trolley lines and other new technologies to ensure that legislation is not behind the curve and holding up mainstream rollout. The same logic should be applied to developing and approving South African National Standards (SANS) especially since other standards authorities such as the International Organization for Standardization (ISO) have already done so in many cases.

South Africa ranked 84 out of 190 countries according to the 2019 ease of doing business report (The World Bank Group, 2019). Some of the major items identified in the report was the slow turnaround time for approvals of site development plans and building plans by the relevant authorities or municipalities. Obtaining environmental permits, water use licenses and other permits such as those needed for the storage of gas from various departments may take several months with some cases dragging on for years. The government can help speed up licensing and permitting by first streamlining procedures, then automating these processes and integrating them across the required authorities. Time limits for the different phases or approvals should also be enforced to ensure faster turnaround times. Current systems are counterproductive in achieving technology development.

5.4. Recommendations for skills development to ensure successful implementation

From question 21 “In general, has engineering skill levels increased over the past 5 years at your organisation/mine?” there are 5 responses disagreeing which shows that engineering skills levels are a concern and declining. Broadly speaking all skill levels are currently a concern at mining operations. It is therefore of utmost importance that mines start developing the skills needed the ensure smooth transition to the selected technologies as soon as a clear direction has been set for the desired technology.

This can be done by by either equipping existing auto-electricians, diesel mechanics and technicians with the additional knowledge and training required or developing specialists that cover all of these fields for a specific type of technology or piece of equipment. This transition needs to be managed carefully to ensure that employees do not fear losing their jobs if the new technology is successful or they might purposely cause it to fail. Several projects have failed in the past due to poor change management and stakeholder engagement. The use of OEM technicians and specialists often comes at a premium and can lead to significant delays or production losses if they are not permanently located onsite.

There may also be new skill requirements which may include the likes of battery technicians who service, repair and change battery cells, hydrogen refuelling operators who are trained in operating high pressure hydrogen equipment needed for refuelling trucks, fuel cell technicians who are able service and repair fuel cells and so on and so forth.

5.5. Recommendations for transparency

Whilst most publicly listed South African mining organisations have pledges in place to reduce GHG gases emissions by 30 to 50% by 2030, achieve carbon neutrality by 2040 and net zero GHG emissions by 2050, very few show how they plan on meeting carbon blueprint reductions. Companies should publish detailed roadmaps on how reductions in GHG emissions will be practically achieved together with the governance that is or will be instituted to ensure compliance.

5.6. Conclusion

The calls for change to greener and cleaner energy are becoming louder and louder with massive penalties in place for those who do not heed to the callings. From this research there is obviously a big appetite for the use of Hydrogen to achieve this in South Africa which aligns well with South Africa’s massive platinum metals endowment and hydrogens high energy density for industrial heavy-duty applications such as mining. Hydrogen production and logistics chain is highly energy intensive and inefficient due to the power needed for electrolysis, compression, liquefaction, cooling and refuelling and thus it may not be the best selection for an industry and country that is currently facing an energy crisis. Whilst there is a major drive for fully battery electric heavy mining equipment due to its high efficiencies and ease of use, this technology is not as well developed as hydrogen fuel cells are and may take 5 to 10 years before it is ready for mainstream rollout. There will also be a restriction of the speed of rollout of battery electric equipment based on the availability of resources needed to manufacturer batteries. Other technologies such as overhead trolley lines, alternative fuels such as natural gas, alcohols and biofuels as well as diesel electric hybrid offer several advantages in the short term but do not provide a complete and universal solution for the mining industries decarbonisation efforts.

South Africa's mining industry developments and trials of green technologies for heavy mining equipment has only touched the tip of the iceberg with Anglo Americans Hydrogen Fuel Cell Dumptruck being the only practical example thus far. Whilst there is positive sentiment around the adoption of these technologies, there is little tangible evidence to show how most mining companies plan to achieve this.

Australia's Fortescue Metals Group which is one of the world's biggest producers of iron ore, together with their green energy and technology division Fortescue Future Industries plans to be the world leader in the mining industry with regards to reducing their GHG emissions and hence producing green iron ore. They plan on achieving carbon neutrality by 2030 (Scope 1 and Scope 2) and reaching net zero emissions by 2040 (Fortescue Metals Group, 2023) which is 10 years ahead of all its South African counterparts. In 2021, Fortescue designed and built the first hydrogen fuel cell powered dump truck. In 2022 they also announced a strategic partnership with major mining equipment OEM, Liebherr and the acquisition of Williams Advanced Engineering (WAE) who are focused on developing green technologies. In January of 2023, WAE delivered a whopping 1.4MWh battery pack to be used in jointly developed Fortescue and Liebherr battery electric, zero-emission mining dump truck with energy regeneration. In addition to being the largest battery pack of its kind, it also has fast charging capability which can charge the battery pack in 30 minutes (Fortescue Metals Group, 2023).

South African mining companies' current targets mean they are planning to be about 10 years behind the industry leaders for mining emissions reductions. In order to understand this, it is important to also understand the climate that

South African mining companies operate in. State owned logistic’s company Transnet is failing to transport bulk commodities such as coal and iron ore out of the country for export at contracted capacities whilst state owned Eskom cannot supply the electricity needed for mining organisations to produce at full capacity whereas in the past they were able to supply cheap energy generated mainly from coal. This is simply due to corruption, poor leadership and lack of maintenance. It is therefore of utmost importance for mining organisations to develop partnerships or plough capital themselves into energy and transport and whilst doing so, choose technologies that are climate friendly and sustainable. This should not be seen as doom and gloom but rather as an opportunity for the mining sector to vertically integrate and for others in the private sectors to invest in stable revenue generating assets, especially since there will be increased demand for green metals and minerals from mining sector whilst the world transitions to low carbon.

South African mines also faces a critical skills shortage with a large dependence on OEM’s as well a brain drain due to globalisation and people who are looking for lands with better promise. The introduction of new technologies and systems in South Africa have often failed due to poor implementation and skills development. Skills attraction, development and retention in the short term is therefore a key success factor for the implementation of decarbonisation strategies in the medium term, not only in the mining industry but for all industries in South Africa. Practices for implementation is expected to be slow now due to the countries outlook and technology development standings but will gain traction as these technologies come to fruition.

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APPENDICES

Appendix I – Questionnaire

No.	Question	A	B	C	D	E	F	G	H	I	J
1	Which age group do you belong to?	20 to 25 years	26 to 30 years	31 to 35 years	36 to 40 years	41 to 45 years	46 to 50 years	50+ years			
2	What is your highest qualification?	None	Trade/ Higher Certificate	Diploma	Bachelors Degree / Btech	Honours Degree	Masters	PhD			
3	What is your current position in your organisation?	Supervisor/Team Leader	Junior Management	Middle Management	Senior Management	Top Level Management	Board of Directors	Majority Shareholders			
4	How many years of experience do you have using heavy mining equipment?	1-5 years	6-10 years	10-15 years	16-20 years	21 to 25 years	26 to 30 years	30+ years			
5	What commodity does your company produce?	Gold	PGM's	Coal	Iron Ore	Diamonds	Multiple	Other			
6	Where is your company located?	Gauteng	Mpumalanga	Limpopo	Free State	North West	Northern Cape	Kwa Zulu Natal	Eastern Cape	Western Cape	Multiple
7	Has your company adopted a policy to reduce GHG emissions?	Yes	No	In progress							
8	By which year does your company target to reach 30% reduction in GHG emissions?	Achieved	by 2025	by 2030	by 2040	by 2050	2050 +	No target			
9	What technology is being investigated by your company to reduce scope 1 GHG emissions from heavy mining equipment?	None	Diesel Electric Hybrid	Trolley Assist	Hydrogen (FCEV)	Fully Electric Battery	Alternative Fuels	Other			
10	When will your company start to use the technology?	Currently in use	1 year	2 years	3 years	4 years	5 years	6 + years			
11	Is your company using or planning to use alternative fuels other than Diesel? If so, which type?	None	Hydrogen	Alcohols	Bio-Diesel	Natural Gas	E-Diesel	Other			
12	How many dump trucks are in your fleet for your mine or at your companies biggest mine?	1 to 10	11 to 20	21 to 30	31 to 40	40 to 50	50 to 60	60 +			
13	What original equipment manufacturer currently has the largest fleet on your mine/s?	CAT	Komatsu	Hitachi	Volvo	Terex	Liebherr	Other			
14	Has your company partnered with any original equipment manufacturer for development of mining equipment to reduce GHG's? If so, which one?	CAT	Komatsu	Hitachi	Volvo	Terex	Liebherr	None /Other			
15	What type of renewables is your company planning to implement the most?	Solar PV	Wind	Hydropower	Tidal	Geothermal	Bioenergy	None /Other			
16	What percentage of renewables will be a part of the 2030 plan?	None	1 to 20%	21 to 40%	41 to 60%	61 to 80%	81 to 100 %	Eskom/Grid only			
17	Do you believe that Eskom can provide stable power supply that would be needed for electric trucks ?	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree			

18	By which year does your company target to reach zero scope 1 emissions (direct emissions from owned or controlled sources)?	Achieved	by 2025	by 2030	by 2040	by 2050	2050 +	No target				
19	By which year does your company target to reach zero scope 2 emissions (indirect emissions from the generation of purchased energy)?	Achieved	by 2025	by 2030	by 2040	by 2050	2050 +	No target				
20	By which year does your company target to reach carbon neutrality?	Achieved	by 2025	by 2030	by 2040	by 2050	2050 +	No target				
21	In general, has engineering skill levels increased over the past 5 years at your organisation/mine?	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree				
22	Would you promote technologies that are more complex but provide efficiency advantages and GHG reductions?	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree				
23	Do you believe current legislation and governance enables technology development?	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree				
24	Do you believe your engineering team supports new technology?	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree				
25	What is the engineering availability of your current dumptruck fleet/s?	1 to 15%	16 to 30%	31 to 45%	46 to 60%	61 to 75%	76 to 90%	90+ %				
26	What would you rate the skill level of your current heavy mining equipment maintenance team?	Not yet Competent	Beginner	Advanced Beginner	Competent	Proficient	Advanced	Expert				
27	Approximately what percentage of maintenance is done by original equipment manufacturers?	None	1 to 19%	20 to 39%	40 to 59%	60 to 79%	80-99%	All				
28	Approximately what percentage of repairs/breakdowns is done by original equipment manufacturers?	None	1 to 19%	20 to 39%	40 to 59%	60 to 79%	80-99%	All				
29	What skills need to be developed the most to enable successful implementation of the chosen technology?	Electrical	Control & Instrumentation	Mechanical	Operators	Specialists	Gas	Other				

Appendix II – JSE Listed Mining Companies

No.	Publicly Listed on the JSE2	Opencast Mines in Portfolio	South African Mines	Commodities
1	African Rainbow Minerals Ltd.	Yes	Yes	Diversified
2	Afrimat Ltd.	Yes	Yes	Diversified
3	Alphamin Resources Corp.	No	No	Tin
4	Anglo American Platinum Ltd.	Yes	Yes	Platinum
5	AngloGold Ashanti Ltd.	Yes	No	Gold
6	Anglo American plc	Yes	Yes	Diversified
7	ArcelorMittal South Africa Ltd.	No	No	None
8	BHP Group Ltd.	Yes	No	Diversified
9	Chrometco Ltd. (s)	No	Yes	Chrome
10	Copper 360 Ltd.	No	No	Copper
11	DRDGOLD Ltd.	No	No	Gold
12	Eastern Platinum Ltd.	No	Yes	Platinum
13	Efora Energy Ltd. (s)	No	No	Oil
14	Europa Metals Ltd.	No	No	Zinc & Silver
15	Exxaro Resources Ltd.	Yes	Yes	Coal
16	Gemfields Group Ltd.	Yes	No	Emeralds/Rubies
17	Gold Fields Ltd.	No	Yes	Gold
18	Glencore plc	Yes	Yes	Diversified
19	Harmony Gold Mining Company Ltd.	Yes	Yes	Gold
20	Hulamin Ltd.	No	No	Aluminium
21	Impala Platinum Holdings Ltd.	No	Yes	Platinum
22	Insimbi Industrial Holdings Ltd.	No	No	Metals
23	Jubilee Metals Group Plc	No	No	Diversified
24	Kibo Energy PLC	No	No	Energy
25	Kore Potash plc	Yes	No	Potash
26	Kumba Iron Ore Ltd.	Yes	Yes	Iron Ore
27	Master Drilling Group Ltd.	No	No	Drilling
28	MC Mining Ltd.	No	Yes	Coal
29	Merafe Resources Ltd.	Yes	Yes	Chrome
30	Northam Platinum Holdings Ltd.	No	Yes	Platinum
31	Oando plc	No	No	Energy
32	Orion Minerals Ltd.	No	Yes (Development)	Copper
33	Pan African Resources PLC	No	Yes	Gold
34	Randgold & Exploration Co Ltd.	No	No	Gold
35	Royal Bafokeng Platinum Ltd.	No	Yes	Platinum
36	Resource Generation Ltd. (s)	Yes	Yes (Development)	Coal
37	Salungano Group Ltd.	Yes	Yes	Coal
38	Sable Exploration and Mining Ltd.	No	No	None
39	Sibanye Stillwater Ltd.	Yes	Yes	Diversified
40	Southern Palladium Ltd.	No	Yes (Development)	Palladium
41	South32 Ltd.	Yes	Yes	Diversified

42	Tharisa plc	Yes	Yes	Platinum
43	Thungela Resources Ltd.	Yes	Yes	Coal
44	Union Atlantic Minerals Ltd. (s)	No	No	Silver
45	Wesizwe Platinum Ltd.	No	Yes	Platinum