The use of 4IR technology in accelerating net zero transition in the South African mining industry

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A research report submitted to the Faculty of Commerce, Law and Management, University of the Witwatersrand, in partial fulfilment of the requirements for the degree of Master of Management in the field of Digital Business

Johannesburg, 2024

ABSTRACT

This quantitative study aimed to assess the impact of fourth industrial revolution (4IR) technology adoption on the ability of South African mining companies to accelerate their transition to net zero, focusing specifically on the reduction of greenhouse gas (GHG) emissions. There has been an urgent need to research the nature of association, and if so, the impact of such association between rate of adoption of 4IR technology's ability to accelerate net zero transition, given the new challenges in the South African mining sector in the wake of the phase 2 carbon tax regime.

Through a comprehensive survey, desktop analysis and subsequent statistical analysis involving multiple mining entities across South Africa, this study investigated the direct and indirect relationships between 4IR technology maturity and the efficacy of GHG emission reduction strategies, thereby accelerating net zero transition.

The study revealed a complex relationship between 4IR maturity and GHG emissions, moderated by organisations' access to financial and skill resources. Contrary to expectations, no significant direct indirect linear relationship was found between aspects of 4IR maturity and GHG emissions. The research suggests a moderate, statistically insignificant negative association, which becomes more pronounced and statistically significant when considering organisations' financial status and employee size.

The study was conducted using a cross-sectional method using a non-experimental approach and focused on establishing the corelation between two key variables namely, 4IR maturity and acceleration of net zero transition through GHG reduction. The causality of these two variables was not investigated. The study was undertaken by choosing a sample which was representative of the JSE listed mining companies. Hence extended population of global mining organisation needs to consider specific regional considerations before generalising the findings.

By emphasising the crucial relationship between technological innovation and climate change mitigation, these findings not only advance our understanding of technology's role in environmental sustainability within the mining sector, but also provide useful information to industry stakeholders, policymakers, and sustainability strategists. This work offers a fundamental structure for subsequent investigations and tactical planning with the objective of harnessing 4IR developments to promote a more ecologically conscious and sustainable mining sector in South Africa.

KEYWORDS

4th Industrial Revolution (4IR) Technologies, Net Zero, Net Zero Transition, Quantitively, 2050 Net Zero Goal, Mining, South Africa

DECLARATION

I, Ramaprasad Deepak Belur, declare that this research report is my own work except as indicated in the references and acknowledgements. It is submitted in partial fulfilment of the requirements for the degree of Master of Management in the field of Digital Business at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in this or any other university.

Name: Ramaprasad Deepak Belur Signature:

Signed at Kyalami, South Africa

On the …………22nd…………….. day of ………May ………… 2024…..

DEDICATION

I dedicate this research to my wife and daughter, who were my support system though the ups and downs of this process. To my buddy Coco who was next to me (literally) and was witness to every word that went into this report. To MMDB WhatsApp research support group, without them it would have been impossible to reach this juncture in my research journey. Lastly, to all the miners who work tirelessly for South Africa’s economic progress.

ACKNOWLEDGEMENTS

I wish to acknowledge and thank all representatives of the mining sector who willingly participated in this study.

I further would like to acknowledge and thank my supervisor Prof Gregory Lee for his support, guidance and mentorship during my research journey.

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LIST OF ACRONYMS

4IR	4th Industrial Revolution
AI	Artificial Intelligence
BAU	Business as Usual
CFA	Confirmatory factor analysis
CoV	Coefficient of variance
CO_2	Carbon dioxide
CH_4	Methane
DEFF	Department of Environment, Forestry and Fisheries
DV	Dependent variable
EFA	Exploratory factor analysis
EBITA	Earnings before interest, taxes and amortisation
GDP	Gross domestic product
GHG	Greenhouse gas
GRI	Global Reporting Initiative
H_2O	Water vapour
HFCs	Hydrofluorocarbons
IoT	Internet of things
IV	Independent variable
JSE	Johannesburg Stock Exchange
NDC	Nationally Determined Contributions
PAF	Principal axis factoring

RBV	Resource-based view
SAMERDI	South African Mining Extraction Research, Development and Innovation
SEM	Structural equation model
SDG	Sustainable Development Goal
TAM	Technology acceptance model
TOE	Technology-organisation-environment framework
VDMI	Verband Deutscher Maschinen – und Anlagenbau

CHAPTER 1. INTRODUCTION

1.1 Statement of purpose

This research investigated whether there was an association between pace of 4th Industrial Revolution (4IR) technology and the ability of mining organisations to achieve net zero transition at an accelerated pace, to meet the 2050 net zero goal, in a South African context. Figure 1.1 illustrates the possible association.

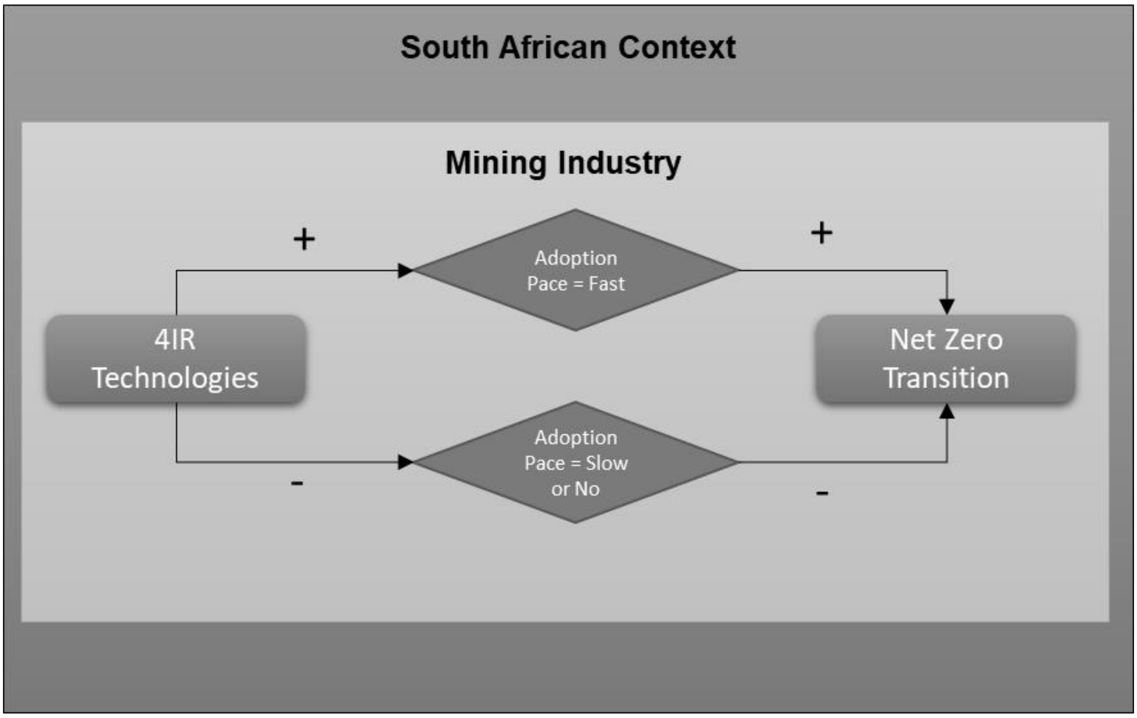

Figure 1.1. Statement of purpose

The association between the pace of 4IR technology adoption with the ability of mines to reach their net zero goals at an accelerated pace was studied with the intention of understanding firstly if there is any direct association, and if yes, the nature and extent of the association.

1.2 Background of the study

Most emerging country economies depend heavily on the energy-intensive mining industry to create jobs and increase gross domestic product (GDP) (Immink et al., 2018).

In the South African economy mining contributes R480.9 billion to the country's GDP which is 8.7% of the overall South African GDP, contributes R78.1 billion in taxes, and directly employs 458 954 people within the industry. The overall value of the production in 2021 exceeded R1 trillion for the first time (Minerals Council of South Africa, 2022).

As highlighted by (Immink et al., 2018), mining consumes a lot of energy during the beginning stages of development and for the duration of a mine operations. There are two key energy sources in a mining operational context, namely, liquid fuel and grid electricity. In open-cast mine operations liquid fuel (diesel) serves as the primary energy carrier, whereas grid electricity serves as the primary energy source in underground mine operations. These energy sources are employed for vital support functions such staff movement, cooling, water circulation, and air and water heating in addition to direct production and ore transportation.

Given the fact that mining is a highly polluting industry along with energy producing industries and manufacturing, there is an increased need for close monitoring of greenhouse gas (GHG) emissions and impact on the climate and environment thereof. The Paris Agreement was based on the trajectory of global decarbonisation comprising forecasts of country-specific GHG emissions (Okereke & Coventry, 2016). This resulted in setting up of decarbonisation goals across all member countries that collectively formed the net zero goal to be achieved by 2050.

The Paris Agreement resulted in 197 nations committing themselves to keeping global warming far below 2 °C and working to keep it at 1.5 °C (Fankhauser et al., 2022). In order to reduce the risk of irreversible climate tipping points, the 1.5 °C ambition entails limiting any temperature excess to 1.5 °C or less, and returning to pre-industrial levels as quickly as practicable. In order to do that, GHG emissions must decrease by half by 2030 from a baseline of 2020 and reach almost zero by 2050. At the same time, it is imperative to quickly scale up natural carbon sinks and removal technologies (Zhongming, Linong, Xiaona, Wangqiang, & Wei, 2020).

Net zero is not only a scientific concept of a pre-determined target as represented above, but is also considered to be a framework for understanding and measuring global action against climate change.

Net zero demands operationalisation across numerous social, political, and economic sectors. A successful implementation of net zero could be thwarted by a number of political, economic, legal, and behavioural difficulties as well as multiple ethical judgements, social concerns, political interests, fairness elements, economic considerations, and technological transitions (Fankhauser et al., 2022).

In a research paper titled “The meaning of net zero and how to get it right” (Fankhauser et al., 2022), the authors identified seven attributes of net zero to use as a frame of reference towards climate action (Figure 1.2).

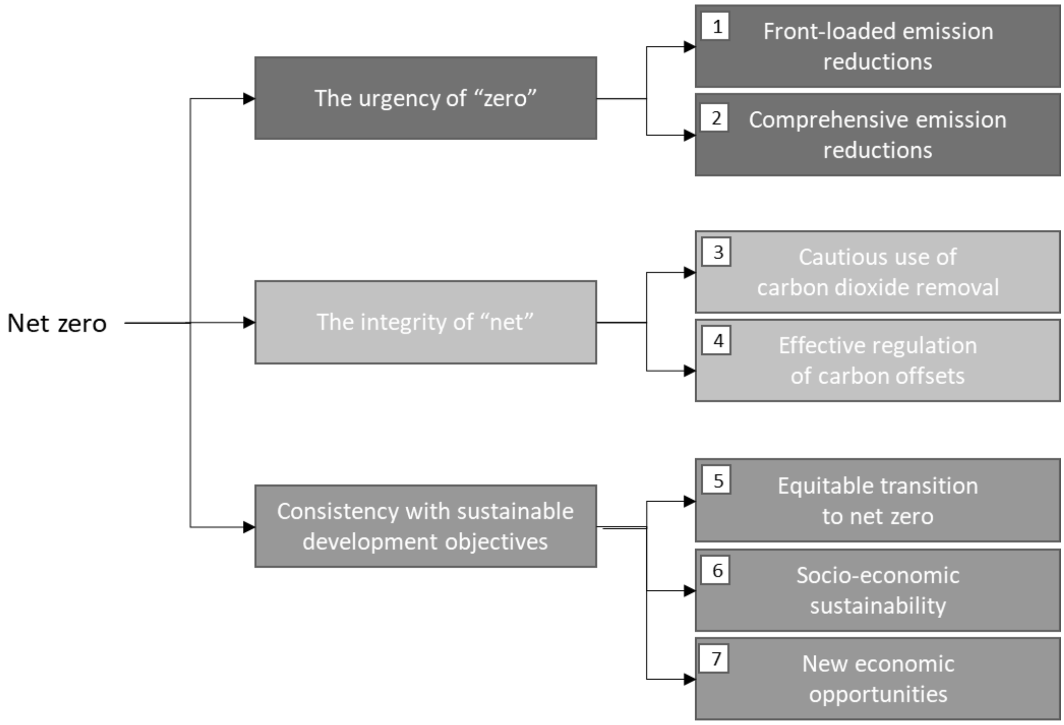

Figure 1.2: Attributes of net zero as a frame of reference
Source: (Fankhauser et al., 2022)

Decarbonisation of the mining industry in South Africa is strongly related to the mining companies' energy consumption habits and energy goals. A Deloitte study conducted for Eskom found that manufacturing and the mining sector together account for nearly 60% of the country's electricity usage, while contributing just around 22% of the GDP (Zulu, Pretorius, & Van Der Lingen, 2021).

China's provincial panel data from 2011 to 2019 examined the mechanism and influence of the digital economy on the reduction of carbon emissions reported that: 1) the development of the digital economy has a significant spatial spillover effect on the reduction of carbon emissions; and 2) the digital economy influences carbon emission reduction both directly and indirectly. This means that the digital economy might indirectly influence the decrease of carbon emissions through changes to the energy structure (Li et al., 2021).

Asongu, Le Roux and Biekpe (2018) used the generalised method of moments to measure samples with panel data for 44 African countries from 2000 to 2012 and discovered that information and communications technology (ICT) penetration in the sample countries had a positive impact on carbon emissions while its squared term had a negative impact. This finding supports the idea that reducing carbon emissions was made possible by greater ICT penetration.

Using multiple panel regression and other measurement techniques, Wang, Chen, Ramsey and Hewings (2021) studied the effect and mechanism of digital technology innovation and technology spillover on carbon emission intensity. According to the study, digital technology encouraged green development and decreased the intensity of carbon emissions.

The emergence of 4IR and accompanying technologies pose a major opportunity for mining organisations globally, specifically from a net zero and sustainability perspective, by: enabling and accelerating changes to energy consumption, promoting energy transition, enhancing operational efficiencies though automation, enabling insights for effective planning, and developing robust reporting and compliance frameworks to support accurate reporting regarding GHG emissions and other key sustainability parameters.

4IR technologies included artificial intelligence (AI), machine learning (ML), big data, internet of things (IoT), robotics, blockchain, etc., that enable cyber physical systems to interact with one another to increase productivity, reliability and growth.

According to Combes, Nassiry, Fitzgerald and Moussa (2017), the digital economy is a new type of economic growth that uses data resources as the primary factor in production, digital technology innovation as the primary drive behind it, and digital platforms like contemporary information networks and digital infrastructure as the major carriers.

Digital transformation/4IR is described from the perspective of the South African mining industry as technical advancements that blur the boundaries between the physical, digital, and biological domains. It fundamentally merges big data, cloud computing, robots, artificial intelligence-based systems, additive manufacturing, and cyber-physical systems and IoT (Van der Woude, 2019; Zulu et al., 2021).

From a South African mining perspective, digital transformation using 4IR technologies can help address some of the major issues the industry is currently dealing with, such as high operating costs, safety concerns, declining profitability, regulatory requirements, mounting pressure to meet sustainability goals, and depleting high-grade reserves.

Bearing in mind the above context, this research explored whether there is an association between the rate of 4IR technology adoption and the ability of mining sector to meet the 2050 net zero goal within the South African context, and, if so, the nature of the association.

Mining is a significant contributor to South Africa's economy, but the country faces a number of particular difficulties, including high unemployment rates, worker union resistance to adopting new technologies, a reliance on coal for a significant portion of its energy needs, a high rate of corruption, and a widening digital divide. This makes South Africa a unique and interesting case study as most of the outlined factors have a direct or indirect impact on the ability of the South African mining sector to meet the net zero goal as agreed to in the Paris Agreement.

1.3 Research problem

The mining industry in South Africa is facing a plethora of challenges due to increasing operational costs and decreasing profits. This is further complicated by unpredictable global demand for ores in the face of the Russia – Ukraine war and economic recession that is impacting major importers of the ores, such as America, Europe and China.

The new GHG emission reporting laws in South Africa are in line with voluntary reporting standards like the Global Reporting Initiative (GRI) or the Carbon Disclosure Project (Immink et al., 2018). These laws, along with the introduction of phase 2 of the carbon tax regime with no clear tax-free allowance, will have a materially negative impact on an already constrained sector.

However, there are significant opportunities for emissions reduction in this industry which can be achieved by either lowering energy demand or implementing energy efficiency programmes. This is because the decarbonisation of the mining industry in South Africa is closely related to the energy consumption patterns and energy targets of the mining companies (Imminket al., 2018).

4IR technologies have been found to have an overall positive impact on mining organisations sustainability initiatives as found in the seminal works listed in Table 1.1. These works provide a global as well as local South African perspective on 4IR technology adoption and the impact of technology transformation on sustainable mining.

Table 1.1: List of seminal work undertaken on impact of 4IR technologies of sustainable mining

Seminal Work Title	Authors	Year of Publication	Citation
Digital Transformation in Asset-intensive Businesses: Lessons Learned from the Metals and Mining Industry	Gao, Hakanen, Töytäri, & Rajala	2019	(Gao, Hakanen, Töytäri, & Rajala, 2019)
Canada as the Trailblazers in Net-Zero Carbon Mining	Zhang, Tunc, & Steyn	2023	(Zhang, Tunc, & Steyn, 2023)
Placing the South African mining sector in the context of a circular economy transition	Khan, Nontso, Magweregwede, Godfrey, & Sereme	2021	(Khan, Nontso, Magweregwede, Godfrey, & Sereme, 2021)
Technological and Intellectual Transition to Mining 4.0: A Review	Zhironkina & Zhironkin	2023	(Zhironkina & Zhironkin, 2023)

Artificial intelligence enabled efficient power generation and emissions reduction underpinning net-zero goal from the coal-based power plants	Ashraf, Uddin, Ahmad, Jamil, Tariq, Shahzad, et al.	2022	(Ashraf et al., 2022)
Effects of digital economy on carbon emission reduction: new evidence from China	Yi, Liu, Sheng, & Wen	2022	(Yi, Liu, Sheng, & Wen, 2022)
Weathering the 'perfect storm' facing the mining sector	Singh	2017	(Singh, 2017)
Effects of Digital Transformation on Environmental Governance of Mining Enterprises: Evidence from China	Xu, Chen, & Dai	2022	(Xu, Chen, & Dai, 2022)
Sustainable development in mining companies in South Africa	Sorensen	2012	(Sorensen, 2012)
Does enterprise digital transformation contribute to the carbon emission reduction? Micro-level evidence from China	Shang, Raza, Huo, Shahzad, & Zhao	2023	(Shang, Raza, Huo, Shahzad, & Zhao, 2023)

Notwithstanding the above cited research which has been undertaken in the context of overall sustainability, there is a paucity of work undertaken to study the association of 4IR technology directly and/or indirectly on net zero transition within a South African mining context. Even though there are independent point of views and thought-leadership pieces available exploring the correlation, there is a gap in studies based on a robust theoretically grounded model.

Second, there is an urgent need to research the nature of association, and if so, the impact of such association between rate of adoption of 4IR technology's ability to accelerate net zero transition, given the new challenges in the South African mining sector and the context of the phase 2 carbon tax regime.

This research adds to the already existing independent but vast body of knowledge on the topic of the impact of 4IR technology adoption on mining and net zero transition in mining by studying the possibility of an association with, and if so, the nature and extent of this association, between 4IR technology adoption on ability to accelerate net zero transition in a South African mining context.

1.4 Research questions

Based on the research topic and research context outlined in the above sections, the research question is formulated as follows:

> ***Is there a direct and/or indirect association between 4IR technology adoption and the ability of South African mining organisations to meet the net zero transition goals at an accelerated pace?***

This research aimed to postulate a model that can study whether there is an association, and if so, the impact that 4IR technology adoption has on net zero transition for mines. The current study drew upon Johannesburg Stock Exchange (JSE) listed South African mining companies, as these companies have the best opportunity to apply and benefit from the model.

The research question was further refined into a set of sub-questions that were addressed as part of this study:

i. What is the level of 4IR technology adoption and maturity within the mining sector?

ii. What are the GHG emission trends within the mining sector in South Africa?
iii. What are the impacts of these 4IR initiatives in accelerating the ability of mines to reduce the GHG emissions?

1.5 Rationale

Globally, resource extraction and processing are to blame for 50% of climate impacts, 90% of water stress, and 90% of biodiversity loss. In order to solve a number of worldwide social concerns, we must change the way we generate and utilise resources (Khan et al., 2021). This makes the impact on climate a critical discussion from a mining context. A strategy that can hasten South African miners' journey to net zero is essential given the significance of climate action and the relevance of the mining industry in the country's economy.

The South African mining industry, which is battling the Decarbonisation Act and worldwide sustainability targets, must employ digital transformation/4IR technological initiatives to address environmental sustainability challenges (Zulu et al., 2021). Considering that there is a substantiative knowledge base of seminal research available since 2002 to date that establishes a good empirical base to understand the impact of 4IR technologies on mining in general, and considering that, to some extent, these studies have been extended to cover the impact on sustainable mining, this research aimed to grow this body of knowledge by establishing a correlation between these two vastly important and well researched areas of the knowledge base.

1.5.1 *Theoretical Significance*

The study seeks to achieve the following theoretical significance:

- To advance the body of knowledge, a theoretically sound framework based on exploratory factor analysis and a mediated regression statistical model was developed to examine the relationship between the adoption of 4IR technology and accelerated net zero transition in the context of South African mining.
- Based on this research, if a correlation is found and its nature is investigated between the adoption rate of 4IR technology and a speedier transition to net zero in the context of South African mining, it will contribute to the body of knowledge already in existence.

1.5.2 *Empirical Significance*

The study sought to achieve the following empirical significance:

- Adoption of a digital maturity framework to understand the level of 4IR technology adoption in identified mines.
- Investigation of the steps taken by identified mines towards their net zero goal and towards reduction of GHG emissions.
- The deduction of inferences based on the model to establish the type of corelation between 4IR technology adoption and net zero transition.
- Testing of the model developed to study the association between rate of 4IR technology adoption and accelerated net zero transition within a South African mining context.

Though there is a relatively good body of knowledge in the academic literature for the period 2010 to 2023 on the impact of 4IR technology in mining (~5,280 search results on Google Scholar) and net zero transition in mining (~32,500 search results on Google Scholar), there is a limited body of knowledge correlating these two concepts (~ 872 search results on Google Scholar). This body of knowledge further narrows when limited to the South African context (~391 search results on Google Scholar).

By contrast a Google search provides 33 900 search results for the topic "Impact of 4IR technologies on net zero transition in mining in South Africa" which is dominated by thought leadership contributions from climate actions groups, regulators and mining organisations themselves.

This shows the importance and relevance of this research topic in the South African mining context, and is of global relevance given the limited amount of time left for mining organisations to progress towards their 2030 net zero goal of halving the GHG emissions and the final 2050 goal of complete net zero transition.

Hence, establishing the corelation between 4IR technologies with ability of mining organisations to accelerate their net zero transition is not only an interesting topic for research, but also a necessary topic for the South African mining sector.

1.6 Delimitations of the study

The study is delimited to the following:

i. There are many aspects to global climate actions; the focus of this research is limited to net zero transition and GHG emissions.
ii. 4IR technologies impact mining in many ways; the focus of this research is limited to the impact from a next zero transition and GHG emissions perspective.
iii. Impact of 4IR technologies on the identified mining organisations are studied at a specific point in time and not on a retrospective basis.
iv. Net zero transition has many other socio-economic ramifications related to job losses through automation, revenue losses though non-compliance, enterprise development programmes, etc. However, the focus of this study is limited to the correlation of 4IR technology adoption on mining

organisations' ability to accelerate net zero transition and does not cover the socio-economic ramification of net zero transition as such.

v. The study is limited to the sample size of mining organisations that are listed on the JSE.

vi. The study is limited to a South African geographic context even though literature from a global perspective is reviewed.

1.7 Definition of terms

This study covers the following key terms that are defined below.

1.7.1 *Net zero*

According to Fankhauser et al. (2022), with the Paris Agreement's peak temperature goals as a common connection, climate ambition is increasingly defined as a particular target date for achieving net zero emissions. The net zero targets cover over two-thirds of world emissions and a somewhat greater percentage of global gross domestic product.

1.7.2 *Greenhouse gases (GHGs)*

GHGs (primarily carbon dioxide, nitrous oxide, methane, and water vapour) trap heat from the sun and cause the earth's temperature to rise. The Earth would not be able to support the majority of life forms without greenhouse gases. However, in the last century, the amount of GHGs in the earth's atmosphere has increased significantly, mostly as a result of the burning of fossil fuels like oil, coal, and gas. Scientific research unequivocally demonstrates that the rise in GHGs is substantially to blame for the planet's rising surface temperature (Burley & Haslam, 2008).

1.7.3 *4th Industrial Revolution (4IR)*

A new era of sophisticated technological breakthroughs is being introduced by 4IR. In addition to block chain technology and the IoT, other factors powering the transformation include machine learning and artificial intelligence. Automation is becoming more and more popular in the mining industry, especially to address issues with challenging working conditions, subpar deposits, and other issues with productivity and efficiency along the value chain (Hongoro et al., 2021)

From the perspective of the mining sector in South Africa, digital transformation (4IR) is characterised as technology advancements that cause the distinctions between the physical, digital, and biological domains to become increasingly fuzzy. It fundamentally combines cyber-physical systems, the IoT, big data, cloud computing, robotics, AI-based systems, and additive manufacturing (Van der Woude, 2019; Zulu et al., 2021).

4IR in the context of mining technology mainly refers to the use of cutting-edge digital technologies applied to mining techniques. The industry is employing a high-tech strategy to radically modify the way that machines and people interact to produce goods and services. The IoT, big data analytics, cloud, 3D printing, robots, artificial intelligence (AI), machine learning, and 5G technology have all been highlighted as the essential technologies of 4IR (Hongoro et al., 2021).

1.8 Assumptions

This study makes the following assumptions:

i. Mining companies in South Africa are aware of the regulatory compliance regarding net zero transition and are taking steps to meet the net zero goals.

ii. The GRI or Carbon Disclosure Project guidelines are being followed by mining corporations when reporting their GHG emissions.

iii. All JSE listed mining organisations follow reliable financial and sustainability related reporting and disclosure.

iv. A gap exists in the body of knowledge and literature between theory and application.

v. Representatives of mining organisations are skilled enough and are capable of assessing their organisations' 4IR maturity and adoption.

1.9 Chapter outline

Table 1.2 provides an outline of chapters and their content.

Table 1.2: Chapter outline

Chapter 2	Literature review and theoretical framework	This chapter is a critical review of the scholarly articles relevant to the research topic as outlined in section 1.1 and which propose possible answers to the research questions outlined in section 1.4. This chapter looks at building the relevant analytical frameworks required to build the possible hypotheses or propositions related to the research topic.
Chapter 3	Research methodology	This chapter outlines the methodology that was followed to address the hypotheses and propositions that were formulated in the literature review, including data collection methods employed, sampling techniques used, research instruments adopted, data analysis strategies used and quality assurance.
Chapter 4	Presentation of results and findings	This chapter summarises the key results and findings for each of the research questions outlined in section 1.4.

Chapter 5	Discussion of the results and findings	This chapter corelates the results and findings from Chapter 4 to validate the relevance of the developed model of corelation between 4IR technology adoption and accelerated net zero transition and discusses the merits of this corelation for the mining industry in South Africa.
Chapter 6	Conclusions and recommendations	This chapter validates or negates the hypotheses and propositions formulated in Chapter 3 and provides detailed recommendations regarding correlation between 4IR technology adoption and accelerated net zero transition for industry experts, other researchers, police makers and mining organisations.

CHAPTER 2. LITERATURE REVIEW AND THEORETICAL FRAMEWORK

2.1 Introduction

According to Khan et al. (2021), one of the main sources of GHGs in South Africa and around the world is the mining sector. GHG emissions are mostly produced by coal mining and its related power utilities. One percent of the world's emissions come from South Africa, which is rated as the 12th greatest contributor. The mining industry is responsible for 15% of South Africa's GHG emissions.

In addition to the negative effects on the environment caused by the mining industry, the country runs the risk of experiencing a shortage of investment, which might have a disastrous effect on the employment rates in the mining industry. This position is made much more difficult by the mining industry's pursuit of complex ore bodies that are mined at greater depths with old infrastructure, leading to serious safety problems and significantly increasing the cost of operations. As a result, there is a greater emphasis on gaining access to dependable energy, improving the quality of resources, and making the switch to carbon neutrality.

The present issues facing the mining industry need to be addressed, including national goals for a fair transition to a low-carbon economy. We have a strategy to handle some of these issues thanks to the circular economy. To promote economic growth and generate alternative employment opportunities, policies and incentives must be developed and put into place to encourage circularity in the mining sector (Khan et al., 2021).

More new age metals and minerals will be needed, not fewer, if the world is to make the transition to a low-carbon future in order to prevent our planet from warming by more than 1.5 °C above pre-industrial levels. Energy, electric vehicles and robots of the emerging future require large volumes of metals and minerals such as copper, cobalt, platinum, chrome, manganese and lithium (Khan et al., 2021), but the traditional take-make-dispose approach will jeopardise future socio-economic development.

Traditionally mining has not previously been associated with a circular economy vision, but 4IR presents opportunities for mining to play a part in South Africa transitioning to a circular economy with low carbon emissions (Harvey, 2019).

4IR technologies can aid miners to harvest the metals and minerals needed to advance towards a circular economy while being environmentally conscientious. More and more value chains are now digitally integrated as a result of the growth and development of digital technologies such as blockchain, 3D printing, the IoT, 5G, cloud computing, automation and robots, artificial intelligence, and data analysis (Wang et al., 2021). In Germany, Finland, and Spain, non-invasive mineral exploration technologies are being tested (Harvey, 2019).

According to Wang et al. (2021), three factors should be considered when discussing the role of digital technology innovation in reducing carbon emission intensity: increasing non-fossil energy consumption, improving energy efficiencies, and optimising the industrial structure.

Based on the aforementioned context, it is clear that the mining industry in South Africa needs to make the transition to an environmentally benign circular method as soon as possible. Even if the sector has made tremendous progress towards achieving net zero carbon emissions and shifting to a circular economy, adopting technology from the 4IR will help to speed up this transition. This literature study explores the present level of knowledge about the use of 4IR technologies to quicken the mining transition to net zero in South Africa.

2.2 Definition of topic or background discussion

This study looks at establishing a possible relationship between two key topics. The first topic that is central to this study is the concept of 4IR technologies. The second topic that forms the foundation concept for this study is the need and ability of the mining sector to transition to net zero GHG emission in alignment with the agreements various countries have signed as part of the Paris Agreement (Fankhauser et al., 2022).

4IR is enabling new dimensions of technology innovation and value chain automation driven by technologies such as machine learning and artificial intelligence, complimented with cloud, IoT, robotics, block chain, 3D printing, metaverse, edge computing, 5G technologies and emerging developments in quantum computing.

In Africa and South Africa in particular, mining companies are in a state of flux trying to contribute to socio-economic diversification and managing typical sectoral challenges of degrading ore quality, aging infrastructure, minerals price volatility, geo-political environment, labour relations, safety, and increasing operational and production costs.

The advent of 4IR presents a distinct set of challenges for the mining industry, chief among them being the need to strike a balance between issues of productivity, safety, sustainability, and profitability on the one hand, and the safety and accessibility of employment on the other. Both opportunities and hazards are present in this situation.

Despite the 4IR's emergence, the mining industries of various nations are still undergoing varying degrees of technological transformation in order to embrace and adapt to advancements in this field (Hongoro et al., 2021). This emphasises how crucial it is to comprehend the degree of technological maturity and technology deployment in the mining business. Based on research it is possible to evaluate not only the current state of technology development, but also the difficulties and repercussions of implementing new technology in the mining industry.

The next section provides a history of industrial revolutions in order to better understand the significance of 4IR technology, as illustrated in Figure 2.1.

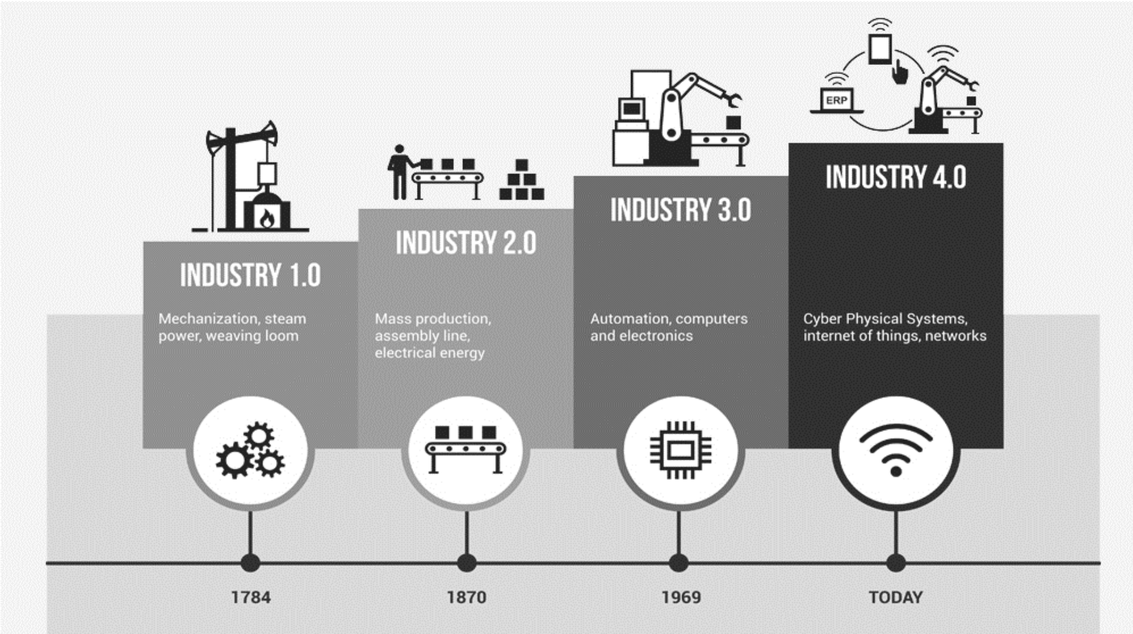

Figure 2.1: Industrial revolutions leading to the 4IR
Source: https://blogs.sw.siemens.com (2021)

Table 2.1: Industry revolutions leading to the 4IR

First Industrial Revolution	Mechanised the methods of manufacturing and used steam as the main energy source. The utilisation of steam power, which boosted the demand for coal, was a key discovery of the time (Hongoro et al., 2021).
Second Industrial Revolution	The era of mass production and industrialisation. The significant discovery of the era was the invention of production of electricity and the assembly line. The late 19th-century mineral discoveries in Southern Africa resulted in profound social transformation. These developments drove industrialisation in South Africa (Hongoro et al., 2021).
Third Industrial Revolution	Phase of automation driven by semi-conductor industry and characterised by electronics (Hongoro et al., 2021)
Fourth Industrial Revolution	The fourth industrial revolution is enabling new dimensions of technology innovation and value chain automation driven by technologies such as machine learning and artificial intelligence, complimented with cloud, IoT, robotics, block chain, 3D printing, metaverse,

	edge computing, 5G technologies and emerging developments in quantum computing.

Today, climate ambition is most often defined as a precise deadline for achieving net-zero emissions, usually related to the Paris Agreement's peak temperature goals. Net zero targets have already been reached for about two-thirds of world emissions and a somewhat greater percentage of the global gross domestic product (Fankhauser et al., 2022).

According to the Intergovernmental Panel on Climate Change (IPCC), net zero emissions will be achieved when anthropogenic removal of greenhouse gases from the atmosphere over a predetermined period balance anthropogenic emissions of greenhouse gases into the atmosphere. The determination of net-zero emissions when many greenhouse gases are involved depends on the climatic measure selected to compare emissions of various gases (such as global warming potential, global temperature change potential, and others, as well as the chosen time horizon) (Loveday, Morrison, & Martin, 2022).

A related concept that we need to understand while researching net zero is GHGs. The following is the IPCC definition for GHGs: In the spectrum of terrestrial radiation released by the Earth's surface, the atmosphere itself, and clouds, there are gaseous components known as greenhouse gases that absorb and emit radiation at particular wavelengths. The greenhouse effect results from this quality. The main GHGs in the Earth's atmosphere are water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), and ozone (O_3). In addition, the Montreal Protocol regulates a number of GHGs in the atmosphere that are solely the product of human activity, including halocarbons and other compounds containing chlorine and bromine. The Kyoto Protocol addresses the GHGs sulphur hexafluoride (SF_6), hydrofluorocarbons (HFCs), and perfluorocarbons in addition to CO_2, N_2O, and CH_4 (PFCs) (Loveday et al., 2022).

Net zero as a concept was initially used in 1957 in physics articles about electric fields. The use of the term net zero continued to be used as a concept in physics for the new few decades until 1991 when for the first time zero net carbon emission was used in relation to the use of biomass fuels. The phrase "climate-relevant net zero" first appeared in print in 2001, once more in connection with the burning of biomass (Loveday et al., 2022).

Outside the literature review of academic articles, when researching net zero in the climate action related websites a media article written in 2019 was found in Climate House News (Darby, 2019) that discusses a group of 30 women, including attorneys, diplomats, financiers, and activists, who met in a Scottish country estate mansion to talk about the collapse of the 2009 Copenhagen Conference of the Parties meeting. According to the article the focused group questioned the term "net" in net zero. They thought the term masked various loop-holes and provide too much wiggle room. But they also agreed that the term "net zero" brought sufficient clarity to the issue of climate action that was previously lacking and hence adopted the concept and promoted the same within their network around the world (Figure 2.2).

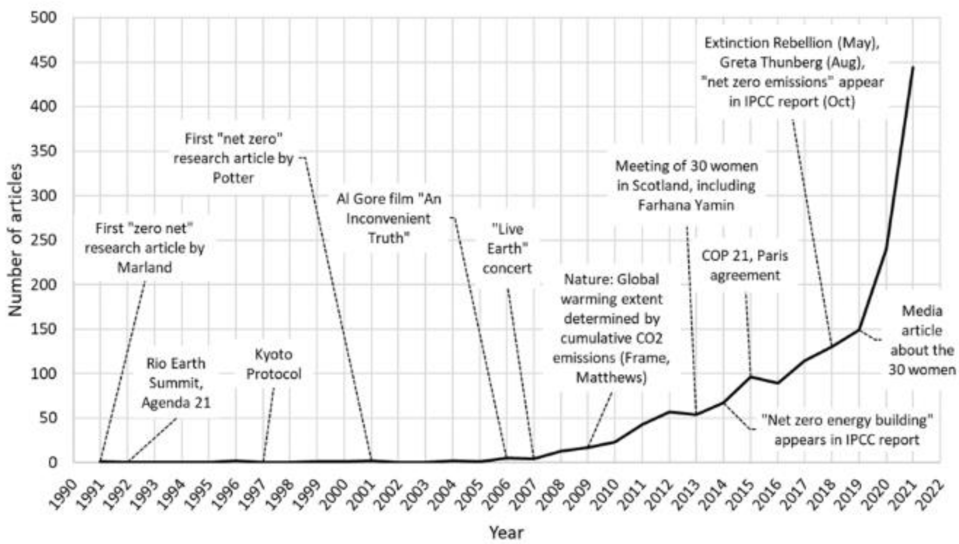

Figure 2.2: A timeline with pertinent historical occurrences and the frequency of research articles using the terms "net zero" or "zero net" in the title, abstract, or keywords
Source: (Loveday et al., 2022)

As discussed in section 1.2 of this research paper, Fankhauser et al. (2022) identified various gaps in the adoption of net zero targets and listed the following seven characteristics to establish net zero as a reliable framework for tackling climate change:

Attribute 1: Front-loaded emission reductions: Economic model simulations have revealed that the most cost-effective strategy to meet a particular temperature target is to front-load climate action with long-term planning spanning several years (Fankhauser et al., 2022).

Attribute 2: A thorough approach to reducing emissions: Net zero means tackling all emissions. Even though there has been traction in terms of clean energy transition, and electric vehicles, there are 'harder-to-treat' sectors such as mining, logistics and transport, aviation, agriculture and heavy industries that need to increase the pace of net zero transition.

Attribute 3: Careful removal of carbon dioxide: Different levels of residual emissions and various types of offsetting removals via carbon sinks can be used to get to net zero. It is important to strike a balance between efforts to reduce carbon emissions on the one hand, and scaling up removal on the other hand, through geological storage or other more sophisticated methods such soil carbon sequestration, ocean alkalinisation, and mineralisation. For these emerging removal alternatives to be safe and effective, more research is required.

Attribute 4: Effective regulation of carbon offsets: Worldwide standards and frameworks that can control and produce this global balance are required, because relatively few countries and organisations are able to accomplish the balance between residual emissions and elimination in sinks.

Attribute 5: Fair implementation of net zero: This has been a long-standing challenge in terms of effective climate action. Fairness is necessary regarding how the burden of meeting global net zero targets are shared between developed and developing economies. These equity and fairness guardrails are key to ensure collective buy-in resulting in real change and action with global impact.

Attribute 6: Adherence to more general socio-ecological goals: Instead of simply focusing on specific goals like carbon storage, there is a need to pursue broader goals with the whole range of ecosystem services interwoven in broader strategies for socio-ecological sustainability.

Attribute 7: Pursuit of new economic opportunities: Even though net zero is now viewed as a zero-sum game, a successful net zero strategy may eventually lead to economic prospects. Innovations that produce zero carbon can start a positive cycle of investment, rejuvenation, and growth (Fankhauser et al., 2022).

2.3 Is there a direct and/or indirect association between 4IR technology adoption and the ability of South African mining organisations to meet the net zero transition goals at an accelerated pace?

2.3.1 *What is the level of 4IR technology adoption and maturity within the mining sector in South Africa?*

Industry 4.0 was a term coined in Germany to define the fourth industrial revolution (Bartodziej, 2017). According to Maisiri and van Dyk (2019) the 4IR has three distinct features that differentiates it from Industry 3.0, namely:

a. The exponential pace at with technology is evolving
b. The breadth and dept of technology advancement, and
c. The extent of impact across the entire system

We have embarked on the era of 4IR which has the potential to increase the progress and development made in the 3rd industrial revolution exponentially. 4IR is much more than the application of ICT to achieve automation in the production process, but a complete digitisation of manufacturing operations with the application of cyber-physical systems that are capable of self-cognition, optimisation, and customisation (Gillward, 2019)

According to (Singh, 2017) The South African Mining Extraction, Research, Development and Innovation (SAMERDI) strategy was developed by the Council for Scientific and Industrial Research (CSIR) in November 2014. The core focus areas of the SAMERDI strategy were as follows:

- Modernisation of current mining operations
- Mechanised drilling and blasting
- Non-explosive rock breaking
- Advanced ore body knowledge
- Real-time information management systems
- Human factor

The role of 4IR technologies has been identified as critical to achieve the key objectives of the SAMERDI strategy specifically in the areas of ore processing, reducing energy consumption, increasing connectivity, mechanised drilling and blasting, and real-time analytics.

a. *Impact of 4IR technologies*

Review of the academic research to understand the impact of 4IR technologies on sustainability reveals that 4IR technologies can have a major impact in helping countries meet their Sustainability Development Goals (SDGs). Combes et al. (2017) claim that 4IR technologies can increase the possibilities for emissions reduction in infrastructure-intensive industries (including energy and transportation) where long-term investment decisions have already been taken (Combes et al., 2017).

More than 100 countries state that they require international help for technology development and transfer in order to implement their Nationally Determined Contributions (NDCs) in relation to the SDGs (Combes et al., 2017).

As the 4IR technologies mature and combine with one another, they will disrupt and transform industries by displacing incumbent technologies and changing existing business models. This transformation will reduce the investment barriers and create opportunities for new entrants who will disrupt the status quo by having even more ambitious emissions reductions towards a sustainable future. Cost and revenue improvements of between 15% and 20% might be anticipated with the 4IR, according to a McKinsey analysis (Goodman, Rajagopaul, & Cassim, 2019).

When such disruptions cut across resource intensive industries such as transport, energy, mining, manufacturing and agriculture, we will start seeing a multiplier effect across value chains in terms of sustainable climate action.

A notable illustration of the aforementioned effect is the most recent breakthroughs in the field of renewable energy. By lowering costs and raising production, technology innovation in renewable energy technologies (such as wind, solar, and batteries) has changed the potential and influence of these renewable energy sources. As a result, numerous energy-intensive sectors have adopted renewable energy projects on a big scale, which has decreased demand for dirty electricity and sped up the energy transition in those sectors. This has resulted in the decoupling of greenhouse gas emissions from economic growth.

Although 4IR technology has the ability to alter and mould an entirely new appearance for certain industry sectors, it is necessary to be aware of the potential social and economic upheavals that its development and application may cause. The impacts of technology disruption can have far reaching social and political impact in terms of employment, social inclusion and inequalities. Such high impact transformation invariably creates winners and losers; how developing countries in particular deal with such impacts will decide the rate and depth of transformative impact 4IR technologies have on those countries.

Understanding the readiness to adopt and leverage 4IR is fundamental for the industry sectors to leverage value from digital transformation. An exploratory study conducted by Maisiri and van Dyk (2019) discovered substantial gaps in South African organisations' use of 4IR. They came to the conclusion that a substantial portion of the analysed organisations lacked a current strategy, which is what propels the adoption of 4IR. The study found that there are difficulties because not all equipment infrastructure supports 4IR, but in many cases equipment functionality can be upgraded to fulfil 4IR criteria. The exploratory investigation revealed that there are pockets of 4IR expertise in South Africa. According to this exploratory study, South African industry might be classified as partially developing and partially emerging in the field of digital transformation (Maisiri & van Dyk, 2019).

b. ***4IR in the mining context***

The mining sector in South Africa is a contested area, and the manner, speed, and degree of adoption of 4IR technology will depend on the political dynamics (Ndlovu, Ngwane, & Mongae, 2022).

The dominating factors in the mining industry are labour unions and political settlements, and the economic rents this industry produces have raised the position of its key participants in the political system.

Due to the aforementioned constraints, 4IR technology uptake in South Africa's mines has generally been slow. The deep and challenging geology of the nation's mines and the relatively high cost of modernisation are further factors in the slow adoption rate.

Four major characteristics that characterise the mining industry's digital transformation are highlighted in a white paper by the World Economic Forum (WEF) (World Economic Forum, 2017) (Figure 2.3).

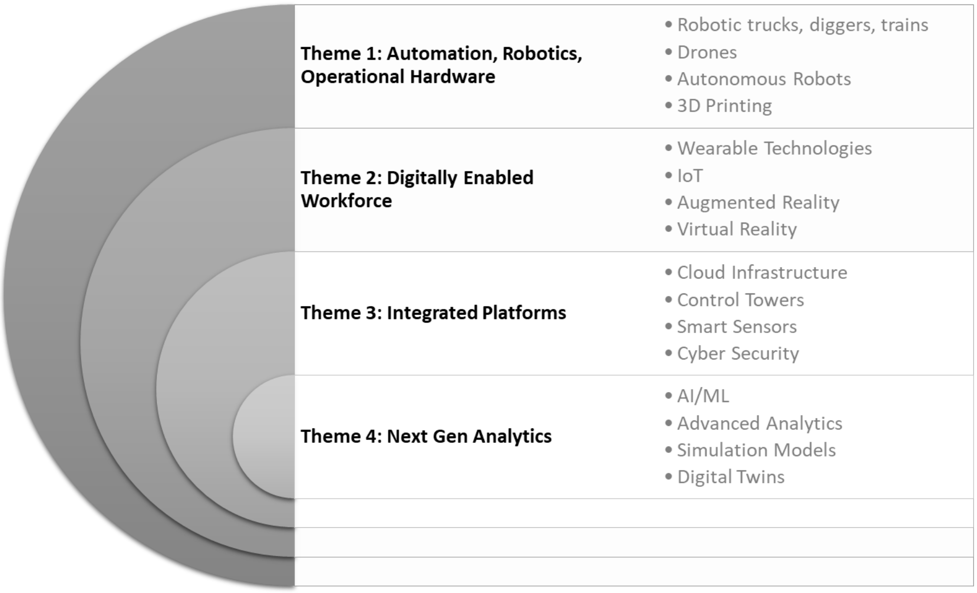

Figure 2.3: Illustration from Initiatives for Digital Transformation: A WEF White Paper
Source: (Forum, 2017)

The South African mining industry has been experiencing stagnation for a decade. In real terms the value has declined by 4% between 2007 and 2017 (Goodman et al., 2019). The key contributors towards this decline have been increasing ore complexity, degrading infrastructure, increasing cost of electricity, lack of cost competitiveness, volatility in price and currency and the country's economic outlook.

A survey Goodman et al., 2019 shows that mining industry is a laggard when it comes to digital maturity and South Africa is among the countries with slowest adoption rates in terms of technology transformation (Figure 2.4).

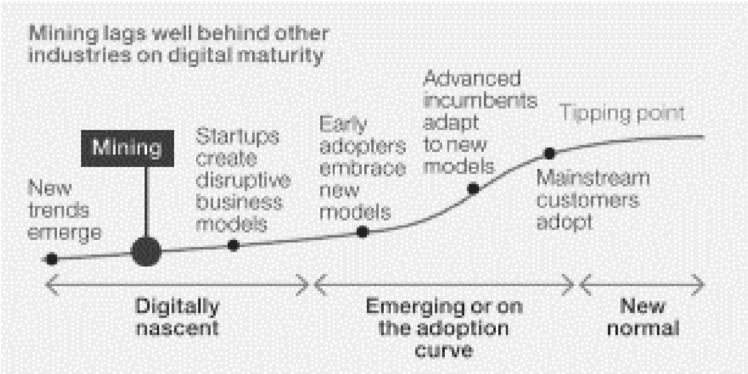

Figure 2.4: Digital maturity index for mining
Source: (Goodman et al., 2019)

Digital initiatives can drive major improvements across all South African mines (Figure 2.5). Enablement of frontline technologies can increase worker productivity, safety and asset management while reducing the cost of operations and increasing efficiencies. Data driven decision making technologies can enable optimised mine planning, reduce operating costs, increase plant throughput, and reduce equipment down times.

Exhibit 5

Digital initiatives could drive significant improvements across all types of South African mines

Relevant | Partially applicable | Not applicable

	How digital can improve operations	Examples of impact cases applicable to South African Mines	Relevant for (mining method)[1]: Underground Conv	Underground Mechanized	Open cast	Plant	Potential impact on margin
A. Enable frontline with technology	Increase worker safety and productivity	Drone technology can shorten surveying time, improve accuracy and enable access to restricted areas	Partially applicable	Partially applicable	Relevant	Not applicable	1-3
	Improve performance management and help workers to do their job better	Connected mobile and AR[2] devices (e.g. smart helmets) can improve maintenance productivity and performance management by providing real-time access to guides / work plans	Partially applicable	Relevant	Relevant	Relevant	
	Improve equipment maintenance and reduce costs	Internet of Things (sensors) can better monitor equipment condition to reduce maintenance demand and consumable cost	Partially applicable	Relevant	Relevant	Relevant	
B. Data-driven decision making	Optimize mine planning	AA[3] can optimise mine planning by reflecting dynamic medium /long-term views, linked to processing and logistics capacities	Relevant	Relevant	Relevant	Not applicable	6-12
	Reduce operating costs	Equipment on-board computing data can improve fleet productivity and reduce cost by enabling routing, reducing idle times and fuel consumption	Not applicable	Partially applicable	Relevant	Not applicable	
	Improve plant throughput and yield	Applying AA in the plant can increase throughput and yield by optimizing process parameters	Not applicable	Not applicable	Not applicable	Relevant	
	Avoid equipment downtime	Applying statistical analysis can reduce down-time and maintenance costs by enabling maintenance only when necessary and optimising scheduling	Partially applicable	Relevant	Relevant	Relevant	
		Total potential from digital for SA Mining					7-15

1 Conv = conventional; UG = underground; Plant = processing plant

2 Augmented Reality

3 Advanced Analytics

SOURCE: Expert interviews; McKinsey Digital opportunity in mining - Top down assessment; Press search

Figure 2.5: Exhibit from McKinsey report outlining the impact of technology initiatives on South African mines
Source: McKinsey and Company (2019)

A study by (Ndlovu et al., 2022) shows that while 69% of South African miners recognise the value of digital transformation and have invested in some task-related innovations, the majority of their initiatives are still in the planning stages.

Stepping outside of academic research and searching for digital initiatives undertaken by JSE listed mining companies reveals some interesting developments, such as the first fully digital mines in the form of Exarro's Belfast Coal Mine, Anglo American's conceptual Future Smart Mining™ aimed at creating an integrated platform embedding advanced technologies to impact environmental sustainability, and Kumba Iron Ore's initiatives to implement technologies to extend the lifespan of its mines. Even though these examples standout, it is clear that most of the transformation initiatives are narrowly focused or still in their conceptual stages.

Policy-makers, development planners and other stakeholders play a key role in shaping whether 4IR can be harnessed to help their countries achieve their NDCs (Combes et al., 2017).

The review of academic literature and extended research of various integrated reports from key mining establishments of South Africa reveal that the mining sector in South Africa is in general a laggard in terms of technology adoption, and 4IR technologies are still in their nascent stages of adoption at scale.

2.3.2 *What are the GHG emission trends within the mining sector in South Africa?*

There is a global agreement to cut GHG emissions resulting from the Paris climate change summit in 2015, however there are no explicit, legally-binding instructions regarding the crucial stages and policy measures that must be implemented to accomplish the decarbonisation goals. Each nation is allowed to select and design its own decarbonisation path.

a. ***Understanding GHG***

In the management of GHG emissions, the "carbon footprint" component is acknowledged as a significant and relevant indication of GHG. In general, the term "carbon footprint" refers only to the emission of CO_2 and CH_4. The full range of Kyoto's "basket" GHGs, including CO_2, CH_4, N_2, sulphur hexafluoride, hydrofluorocarbons, and perfluorocarbons, is sometimes required, though. The common terminology used to refer to this statistic outside of academic literature is "GHG inventory" (Turner et al., 2012).

The GHG Protocol Corporate Accounting and Reporting Standard (World Resources Insitute, 2004) is widely adopted in South Africa by businesses and organisations (Immink et al., 2018).

Growth without constraints depicts the trajectory on which a nation's GHG projections would increase if no restrictions were placed on carbon emissions or any other cause. This is referred to as "business as usual" (BAU) and is used as the foundation for modelling a country's long-term mitigation scenarios (Winkler, Hughes, Marquard, Haw, & Merven, 2011).

Since these nations are still developing and must increase their GHG emissions in order to meet the socioeconomic requirements of their population, developing nations like South Africa declare their promises to act on mitigation in relative terms. Relative to a set base year, the emissions must increase less quickly than they would have under a growth without constraints scenario. This is referred to as “deviation below BAU” (Winkler et al., 2011). On the other hand, rich nations are anticipated to cut emissions significantly. The SDG objective of "leaving no one behind" and the idea of "fair transition" are both supported by this notion.

b. *GHG in the context of South African mining*

South Africa has a carbon-intensive economy because coal is burned to produce more than 70% of the nation's energy, which has led to a carbon-intensive energy sector. Despite recurring blackouts since 2008 and a widening disparity between supply and demand, energy demand has been rising. It should come as no surprise that South Africa's energy sector is the main driver of the country's GHG emissions, accounting for 80% of total emissions in 2017 and 97% of the GHG increase between 2000 and 2017. South Africa has the 12th-highest CO_2 emissions in the world in 2020, making up 1.3% of all emissions worldwide, with the mining industry contributing 15% of those emissions (Khan et al., 2021).

A Deloitte research study conducted for Eskom found that manufacturing and the mining sector together account for nearly 60% of the country's electricity usage, while contributing only about 22% of the GDP (Zulu et al., 2021). The transportation industry, which receives 98% of its energy from petroleum products, is the third largest contributor of GHG emissions after the mining and manufacturing sectors. Energy and trade are heavily reliant on the South African mining industry; therefore, disclosure and laws must be carefully crafted to keep the nation competitive (Winkler et al., 2010).

Based on the above, Immink et al. (2018) conclude that decarbonisation targets for South African mining sector should be closely linked to energy consumption patterns and energy targets of the mining companies.

Given the pressure from international environmental bodied, investor community and government, the mining sector is under tremendous pressure to accelerate decarbonisation and reduce GHG emissions through various methods of emission reduction and removal.

c. ***South African GHG trends***

South African emission trends as compared to the BAU base-line show a downward trend since 2010 across all types of GHG emission as shown in analysis of GHG emission between 2000 – 2020 as part of South African Carbon Inventory assessment by the Department of Environment, Forest and Fisheries (DEFF) (Figure 2.6).

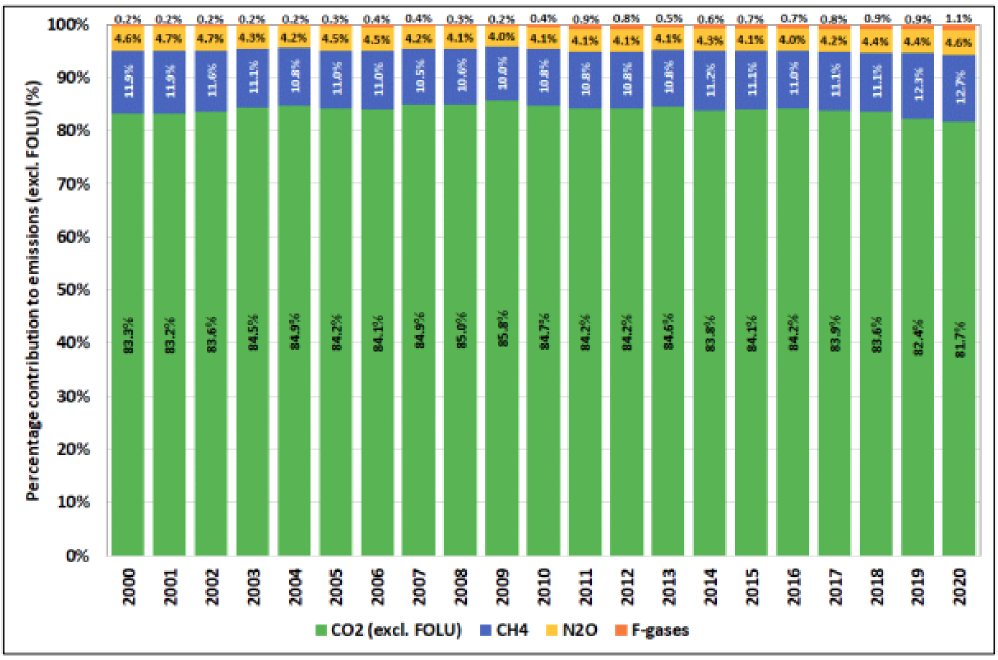

Figure 2.6: Percentages of each gas's contributions to South Africa's emissions from 2000 and 2020

Source: Department of Forestry,, Fisheries and the Environment (2022)

The above trend as compared to the BAU baseline from 2009 to 2018 also shows a downward trend as per the data published by Minerals Council South Africa (2022) (Figure 2.7). The analysis of the GHG emission trends clearly outline that given the current economic situation and increasing risk of extended electricity outages, South Africa is well on its way to meeting its Paris Agreement commitments.

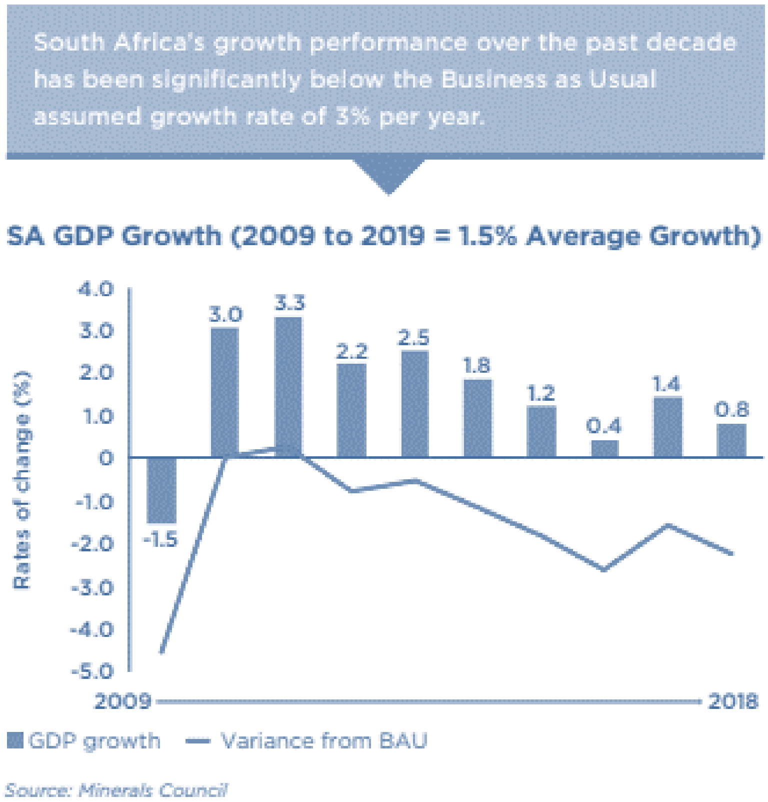

Figure 2.7: South African GPD growth vs variance from BAU
Source: Minerals Council South Africa (2022)

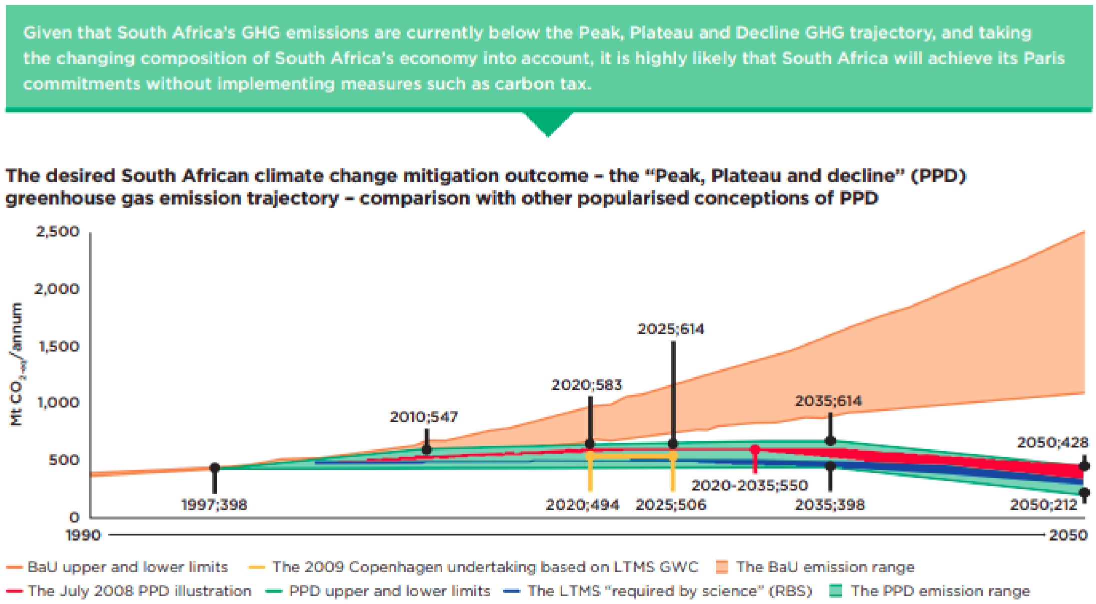

Figure 2.8: South African GHG emission trend and projections
Source: Minerals Council South Africa (2022)

Review of non-academic sources such as climateactiontracker.org, carbonbrief.org, climate-transparency.org, etc. reveals that, even though South Africa is well on course to meet its Paris Agreement commitments, the actual commitment itself is classified as insufficient as the policies and actions are only geared towards < 3 °C reduction in temperatures vis-a-vie the global ambition of < 1.5 °C. The current trajectory of NDC targets is classified as almost sufficient as it is geared towards a < 2 °C reduction in temperature (Figures 2.8 and 2.9).

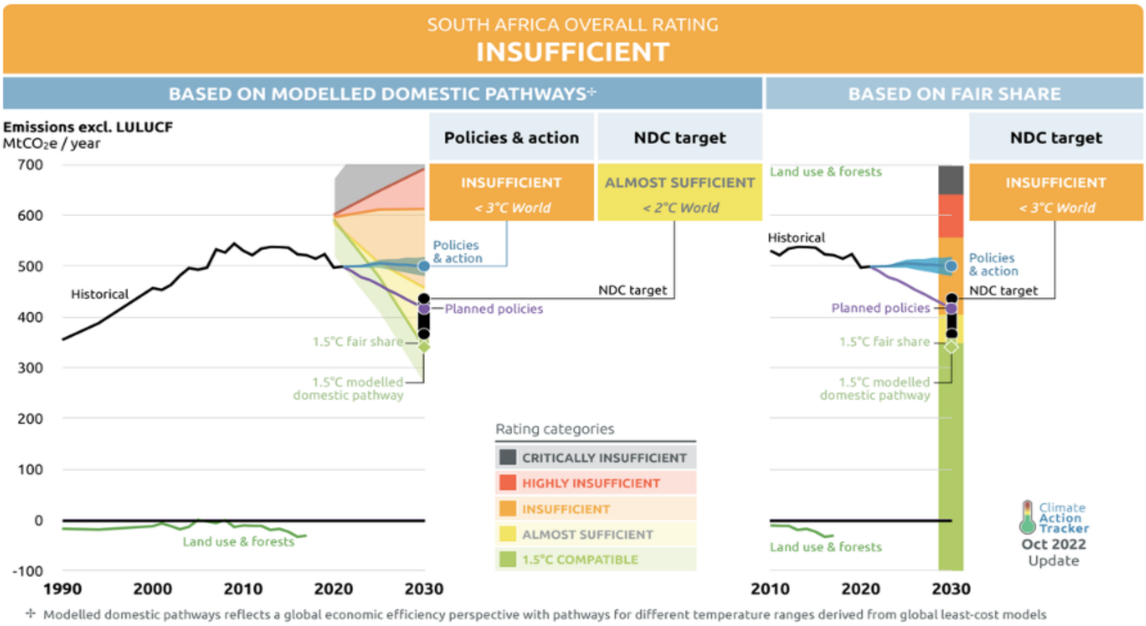

Figure 2.9: South Africa overall rating
Source: Climate Action Tracker (2023)

Based on the above review of various academic and non-academic literature we can safely conclude that mining sector is the largest consumer of electricity in South Africa. This makes the mining sector a major contributor to the country's GHG emissions. In general, the GHG trajectory of South Africa is well under the BAU baseline, but this is more likely due to the constrained economic conditions and rolling blackouts the country is experiencing since 2008 and less likely due to specific climate action measures taken by mining organisations.

Hence there is an urgent need for mines in South Africa to start looking at reducing GHG emissions through key measures such as energy transition, operational optimisation, and electrification of fleet. This will ensure investor confidence is retained and enable mines to attract the required level of investments to continue operations while securing employment for the large labour force the mining sector employs.

2.3.3 *What are the impacts of these 4IR initiatives in accelerating the ability of mines to reduce the GHG emissions?*

The researcher presented a detailed literature review on the topics of 4IR and GHG emissions in the earlier sections. Now we turn towards the relationship between 4IR initiatives and ability of mining organisations to reduce GHG emission as a result of specific 4IR initiatives.

Raheem, Tiwari and Balsalobre-Lorente (2020) used the pooled mean group estimator to determine that digital technology has a favourable impact on carbon emissions for the G7 nations. Park, Meng and Baloch (2018) used panel data from the European Union for the years 2001 through 2014 to demonstrate a substantial positive association between internet usage and carbon emissions.

However, Arshad, Robaina and Botelho (2020) asserted that the development of digital technology is not environmentally favourable in both developing and developed nations.

Wang et al. (2021) suggested that the absorptive capacity of organisations directly influences innovation performance, arising from their examination of numerous academic studies focused on the relationship between digital technology innovation and carbon emissions. They also drew the conclusion that poor nations' failure to successfully employ technology to reduce emissions may be due to a lack of capacity to absorb digital technology innovation and a lack of utilisation of green technologies.

Furthermore, a small number of studies have found that the inability of digital technology innovation to reduce carbon emissions is primarily due to the failure of these studies to take into account the ability of digital technology related emissions abatement potential to reduce emissions in other sectors, including the power, mining, energy, agricultural, transport, and service sectors.

a. *Impact of 4IR on reduction of carbon intensity*

Digital technology innovation with a combination of various 4IR technologies can assist in reduction of carbon intensity in the following ways:

a. Increase non-fossil energy consumption through better non-fossil energy generation technology innovation
b. Improve energy efficiencies
c. Optimise industry structures
d. Increasing corporate governance via increased visibility
e. Reduce information asymmetry and interaction cost between mining enterprise and stake holders
f. Enhance enterprise information sharing and knowledge integration abilities

Many researchers have also considered the negative impacts of technology innovation on carbon intensity of developing countries. Development of information technology in its self is an energy intensive process and when viewed in isolation can itself lead to increasing GHG emissions.

Despite not being an "environmentally benign industry" itself, Wang et al. (2021) note that the information industry has lowered carbon emission intensity through cross-industry and cross-border technology empowerment. Overall, the influence of digital technology innovation and technological spillover reduces the intensity of carbon emission at a national level (Wang et al., 2021).

Further investigation into the disruptive potential of 4IR technologies in the mining industry reveals increasingly extreme use cases that forge a non-alternative course for the development of mineral resource complexes. Zhironkina and Zhironkin (2023) posit that the Mining 4.0 platform combines digital technology with automated and autonomous equipment as a means of addressing challenges that the resource sector currently faces with regard to social and environmental issues as well as production and economic issues within mining operations (Figure 2.10).

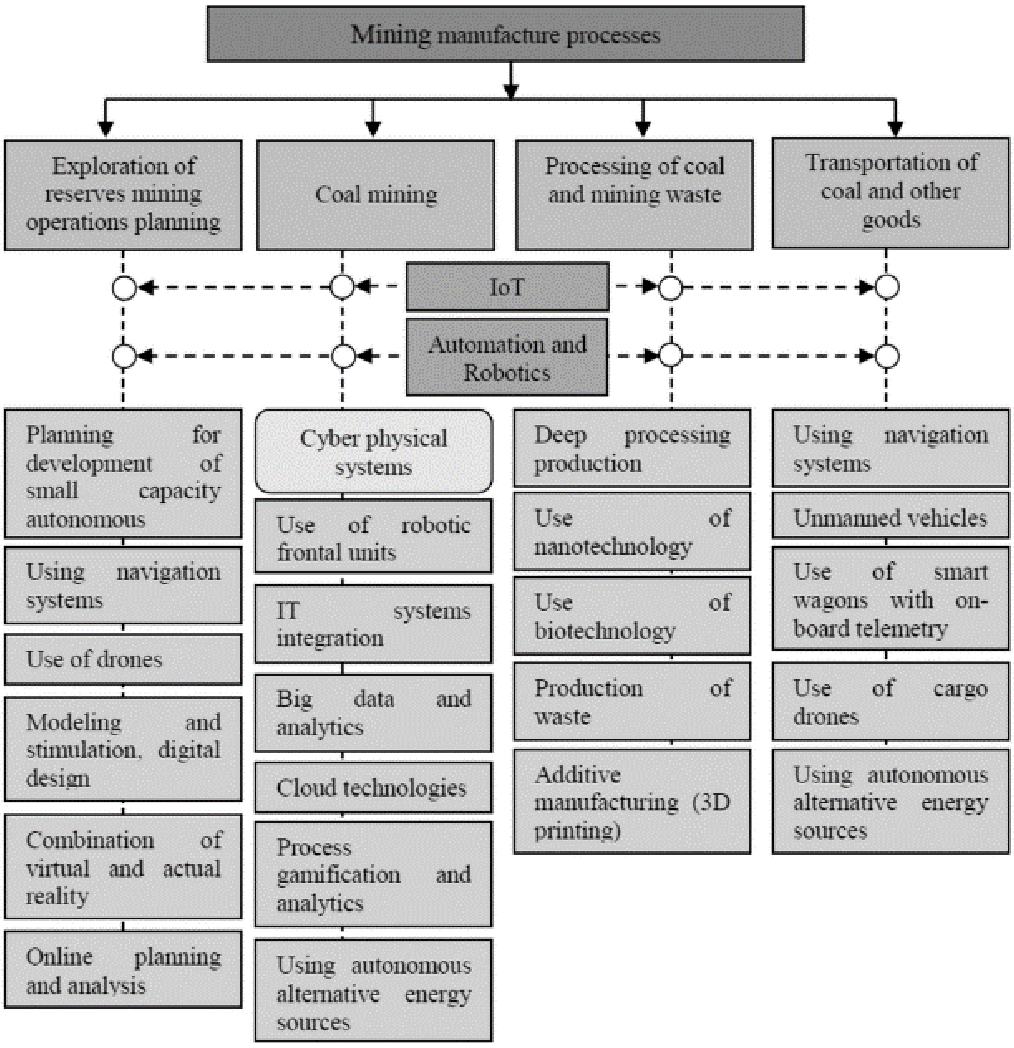

Figure 2.10: Industry 4.0’s core components and mining industry segments
Source: (Zhironkina & Zhironkin (2023)

The researcher concludes that 4IR technologies and digital transformation can play a critical role in accelerating the net zero transition by directly contributing to reducing carbon intensity in the mining industry based on the study of many academic publications.

2.4 Analytical framework

Technology advancements related to 4IR are creating disruptive changes to value chains across the globe. The impact of 4IR adoption is widely felt at a country, industry and organisation level with the degree of impact and the ramifications of the changes being different at different levels. The pace at which 4IR technologies are reshaping our future is exponential and adaption of 4IR is unavoidable for survival and competitiveness.

The effects of 4IR are already being felt in the mining sector, and the introduction of platforms like Mining 4.0, which was covered in the section before this one, is evidence of these effects. Although the adoption of Industry 4.0 technology, systems, and processes has advanced noticeably in industrialised nations, there remains doubt over the readiness of businesses and industries in emerging nations, including South Africa (Maisiri & van Dyk, 2019).

The ability of 4IR to help the mining sector to pivot to a circular economic model, away from a traditional and linear take-make-dispose approach, has been researched extensively and there is empirical proof of the positive impact 4IR technologies can have on the ability of mining organisations to progress their SDGs and net zero ambitions.

2.4.1 *Theoretical framework*

Academic research has demonstrated that businesses that disregard disruptive technology developments do so at their peril because they run the risk of being overtaken by rivals who adopt the technology first since they will be able to leverage and differentiate dramatically in a shorter period of time (Gillward, 2019). This is also true regarding the impact of technology implementation (or lack thereof) on organisations' SDGs and net zero ambitions.

Many theories and models with a strong academic foundation can help explain what motivates technology adoption in organisations. Perceived utility and ease of use are two important elements that affect end users' acceptance of technology, according to the technology acceptance model (TAM).

While TAM offers an individual view on how people adopt technology, other frameworks, including the technology-organisation-environment (TOE) framework expand on TAM to offer an organisational perspective. According to TOE, the technological context, organisational context, and environmental context all have an impact on how a firm absorbs and applies technological advancements (Depietro, Wiarda, & Fleischer, 1990).

The term "organisational context" refers to the features and assets of an organisation, such as its size, level of centralisation, level of formalisation, managerial structure, human resources, quantity of slack resources, and connections between employees. The macroeconomic climate, the firm's competitors, the size and structure of the industry, and the regulatory environment are all part of the environmental context (Gillward, 2019) (Figure 2.11).

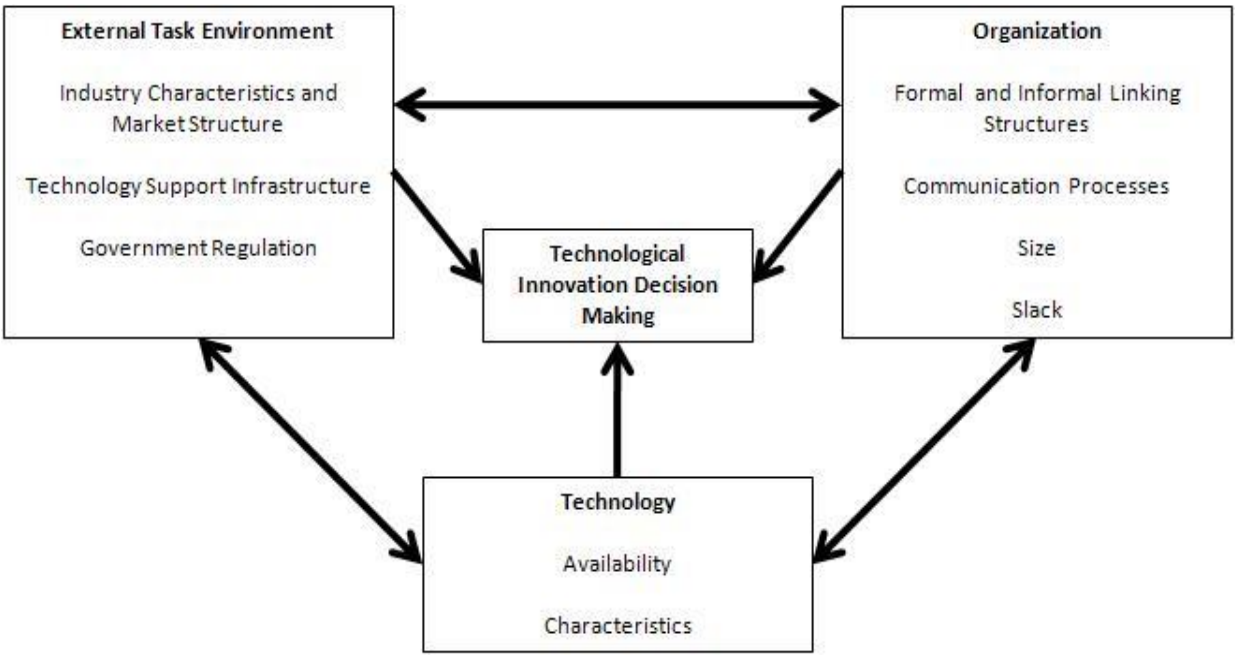

Figure 2.11: TOE framework
Source: Gillward 2019

Other theories such as the task-technology fit and the resource-based view (RBV) framework provide additional context to the TOE framework, and outline the ability of 4IR technologies to integrate, build and reconfigure internal and external competencies to address the dynamically changing landscape of mining in lieu of the urgent changes required to meet the carbon intensity reduction goals.

Based on the above, the researcher decided that the best theoretical framework to test the proposed hypothesis would be a combination of two frameworks: the TOE framework and the RBV framework. By combining the TOE framework and the RBV framework, we can analyse how the 4IR maturity of mining organisations influences their ability to reduce GHG emissions and accelerate the net-zero transition. The TOE framework helps capture the broader contextual factors, while the RBV framework focuses on the internal resources and capabilities of organisations.

The TOE framework focuses on the interplay between technological factors, organisational factors, and environmental factors. The 4IR maturity of mining organisations represents the technological factor, their ability to accelerate the net-zero transition represents the environmental factor, and their organisational structure and practices represent the organisational factor. By examining these three dimensions, the TOE framework helps analyse the potential relationship between 4IR maturity and the ability to reduce GHG emissions.

The RBV framework, on the other hand, emphasises the strategic resources and dynamic capabilities of organisations. In this case, we consider 4IR technologies, knowledge, data management systems, and other relevant resources as strategic assets that can give mining organisations a competitive advantage in driving the net-zero transition and reducing GHG emissions. By assessing the availability and effective utilisation of these resources within mining organisations, we can gain insights into their potential to accelerate the net zero transition.

As an outcome of the theoretical review of the above models and framework, the researcher decided to choose the Impulse Foundation of Verband Deutscher

Maschinen- und Anlagenbau (adjusted for the purposes of this research) as a tool to conduct a quantitative study as this model addresses all the factors outlined in the theoretical framework and provides the required empirical grounding to assess the 4IR maturity of the South African mining sector. Desktop analysis of the sustainability reports and financial statements of all the main listed mining organisations in South Africa will then be added to this in order to better understand the trends in GHG emissions and create a framework for testing the formulated hypotheses.

2.4.2 *Conceptual framework*

The current research adds to this pre-existing body of knowledge by creating a framework that mining organisations can use to study the impact of 4IR technologies on their ability to accelerate net zero transition.

Figure 2.12 shows a conceptual model of the research study.

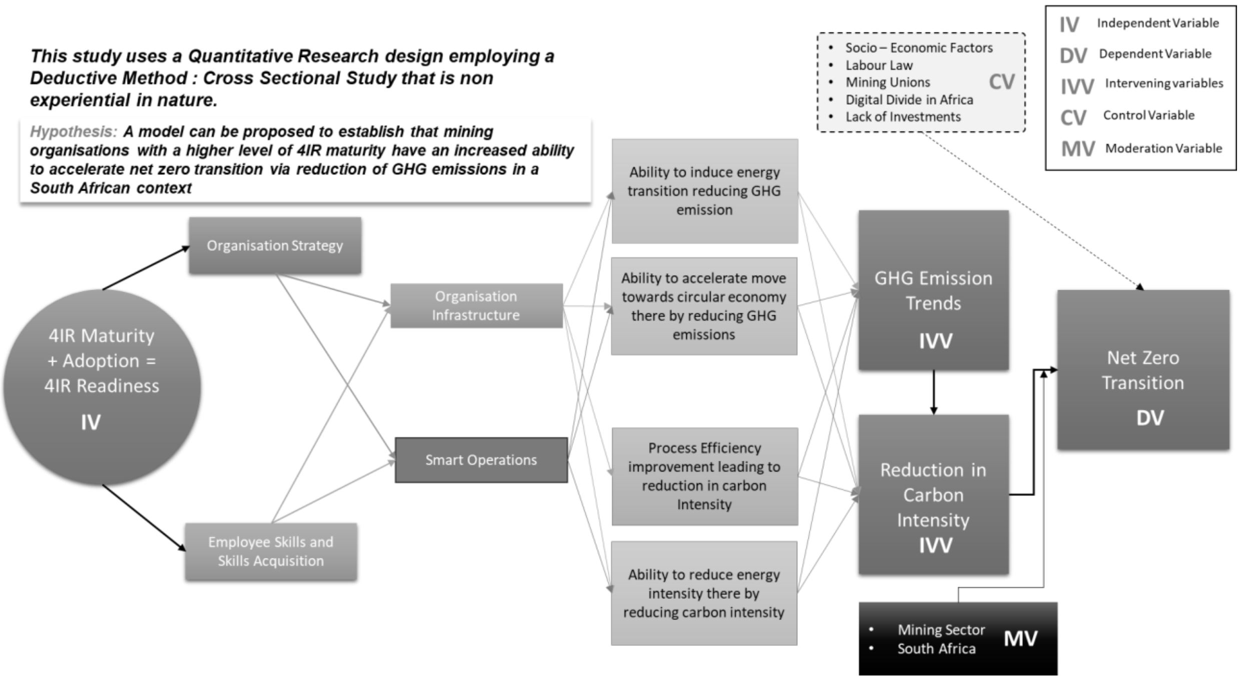

Figure 2.12: Research conceptual approach

In order to achieve the above, a step-by-step approach was followed.

a. *Step 1*

To examine the current 4IR maturity of South African mining organisations, including evaluating 43 JSE listed base material companies, a quantitative study using modified quantitative criteria compiled by the Impulse Foundation of Verband Deutscher Maschinen- und Anlagenbau (VDMA) was conducted (Figure 2.13).

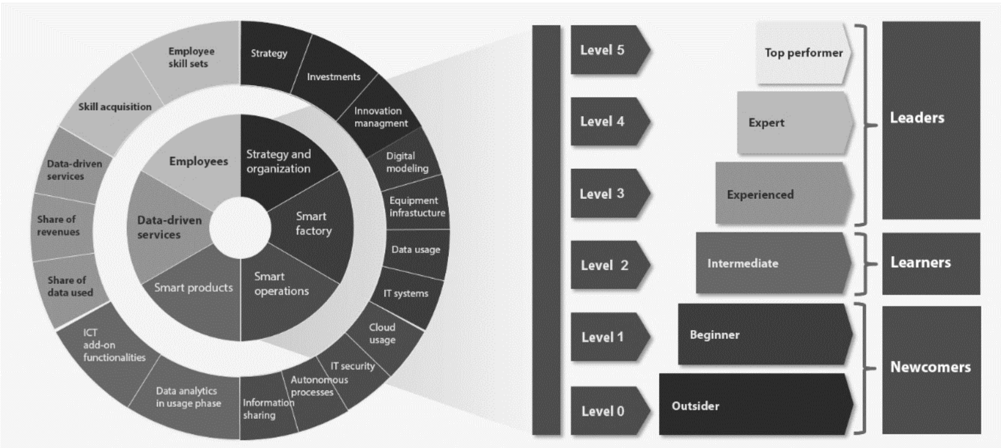

Figure 2.13: Adoption of IMPULS Industry4.0 Readiness Online Self-check for business framework

Source: Industrie 4.0-Readiness-Check (industrie40-readiness.de)

The VDMA survey uses six dimensions to understand the industry 4.0 readiness and maturity and uses a weighted average score to map the readiness factor to a six-level maturity scale to identify the 4IR maturity level of the organisation. Table 2.2 shows the weighted score of the six dimensions.

Table 2.2: VDMA dimensions and weighted scores

Dimensions	Weighted Score
Organisational strategy	25%
Organisation Infrastructure	24%
Smart operations	33%
Employees	18%

Table 2.3 shows the readiness levels of the VDMA model.

Table 2.3: VDMA Industry 4.0 maturity categories

Readiness Levels	Criteria
Level 0: Outsider	0
Level 1: Beginner	0 < Points </= 50
Level 2: Intermediate	50 < Points </= 90
Level 3: Experienced	90 < Points </= 120
Level 4: Expert	120 < Points </= 145
Level 5: Top performer	145 < Points </= 160

Researchers use and recommend the Industry 4.0 readiness assessment by VDMA as being a well-researched instrument to conduct exploratory Industry 4.0 maturity evaluations (Maisiri & van Dyk, 2019).

Therefore, the VDMA evaluation method was selected from the existing and available Industry 4.0 readiness assessment tools to carry out this research. Permission to use the VDMA questionnaire for research purposes was obtained in accordance with good ethical practice (Appendix A).

b. *Step 2*

Desktop assessment of GHG emissions data published by 19 Johannesburg Stock Exchange listed base material companies as per GRI reporting standards, to establish the trends of GHG emission for the five years from 2018 to 2022.

c. *Step 3*

Correlation of key findings to establish the relationship between 4IR maturity and adoption to impact on GHG reduction and net zero transition was studied using two propositions. Firstly, establishing the retained factors from the VDMA model. Secondly, using a mediated regression model to establish the relationship between identified dependent and independent variables.

Based on the above study the main hypothesis along with identified sub hypothesis will be tested.

2.5 Conclusion

Understanding how 4IR technologies can have an impact on the GHG emission and carbon intensity of mining organisations was the major goal of the literature review. Establishing the nature of the relationship between 4IR maturity and its impact on an organisation's transition to net zero is a key goal.

To understand the nature of the above relationship, the researcher first started by understanding the meaning of 4IR and its related technologies. After this the impact and relevance of 4IR technologies was studied from a South African mining perspective. Various point of views on the adoption of 4IR within the mining sector were reviewed along with understanding the maturity levels of 4IR adoption within the mining sector in South Africa.

Secondly the researcher reviewed the meaning of net zero transition in terms of carbon intensity and GHG emissions. Standard frameworks for understanding carbon inventory, BAU base and models of variance to this base in terms of carbon intensity were reviewed. These concepts were applied in a South African mining context and key viewpoints regarding GHG emissions and its impact on mining were explored to form a point of view that was grounded in theoretical evidence.

Lastly, various academic research works from 2010 till 2023 were reviewed to establish a possible relationship between 4IR technology maturity and adoption on the ability of mining organisations to reduce their GHG emissions and accelerate their net zero transition. As an outcome of the detailed literature review the researcher formulated the alternate hypothesis and sub-hypotheses in section 2.5.1.

2.5.1 *Hypothesis*

A model can be proposed to establish that mining organisations with a higher level of 4IR maturity have an increased ability to accelerate net zero transition via reduction of GHG emissions in a South African context.

Mining organisations with higher levels of 4IR maturity (m1) have GHG emission levels of (e1) and mining organisations with lower levels of 4IR maturity (m2) have GHG emission levels of (e2).

The hypothesis states **when m1 > m2 then e1 < e2**

The above overall hypothesis was further distilled into the sub-hypotheses listed in Table 2.4.

Table 2.4. List of sub-hypotheses

H1	Mining organisations with a higher level of focus on Organisation Strategy aspects of 4IR maturity are associated with lower GHG emissions.
H2	Mining organisations with a higher level of focus on Organisation Infrastructure aspects of 4IR maturity are associated with lower GHG emissions.
H3	Mining organisations with a higher level of focus on Smart Operations aspects of 4IR maturity are associated with lower GHG emissions.
H4	Mining organisations with a higher level of focus on Employee Skills acquisition aspects of 4IR maturity are associated with lower GHG emissions.

Ha	Larger mining organisations with higher headcount have better means of reaching higher 4IR maturity and hence are able to more effectively reach lower GHG emissions.
Hb	Mining organisation with favourable EBITA position are more proactive in reaching higher 4IR maturity and hence can more effectively reach lower GHG emissions.
Hc	Mining organisation with a favourable revenue position are more proactive in reaching higher 4IR maturity and hence are able to more effectively reach lower GHG emissions.

CHAPTER 3. RESEARCH METHODOLOGY

The research study has thus far examined the impact of 4IR technologies on the mining industry and the urgent need for the mining industry to uphold its decarbonisation commitments in accordance with South Africa's Paris Agreement commitments even though these are deemed to be insufficient in and of themselves to meet the global ambition of 1.5 °C temperature reduction.

The literature review identified the possible relationship between the adoption rate and maturity of 4IR technology and the ability of the mining industry to fast track the transition towards net zero by accelerating the reduction in GHG emissions. The review also identified gaps in existing research in terms of availability of an academically grounded framework to establish the extent and nature of this relationship.

Therefore, development of a reliable academically grounded framework for establishing the relationship between rate of 4IR technology adoption with the ability to accelerate net zero transition contributes significantly to the existing body of knowledge and enables mining organisations to invest effectively to achieve their net zero ambition. Given the limited amount of time available to meet the 2030 and 2050 commitments, development of such as framework could become a key enabler towards accelerated net zero transition for various developing economies.

The identified method of research is anchored on the TOE and RBV framework and looks at establishing the 4IR adoption and maturity of the South African mining sector by using the IMPULS Industrie 4.0 Readiness Online Self-check for business framework as a quantitative assessment tool. A desk-top analysis of published GHG emission data will be used to assess the GHG emission trends, while a desk-top analysis of integrated reports published by identified sample mining companies in South Africa will be used to study the recent interventions undertaken by these companies to reduce GHG emissions.

A key outcome of the above process was the establishment of a correlation framework using 4IR maturity and rate of GHG emissions to establish the type of relationship between these two variables using multiple statistical models.

This section will provide the details of the research strategy adopted to test the hypotheses that were formulated as a result of literature review. Furthermore, this section details the approach taken towards selection of sample, collection and analysis of data, while outlining the limitations and problems of the chosen strategy.

3.1 Research approach

The author considered a quantitative research approach for undertaking this study as quantitative researchers measure precise variables and test hypotheses that are linked to a general causal explanation (Plonsey & Barr 2007). The hypotheses seek to derive a correlational explanation by comparing a dependent variable with an independent variable, while considering the impact of various intervening and moderation variables; a quantitative approach lends itself to analysis of hard data of this nature. Quantitative analysis ensures objective measurement of variables such as 4IR maturity, GHG emissions, and the ability to accelerate net zero transition though statistical modelling and analyses to effectively test the formulated hypotheses.

A quantitative design further allows for generalisation of findings to a broader population of mining organisations, making the research model replicable by other researchers to build on the body of knowledge created in this research. Lastly it is the author's view that a quantitative design allows for rigorous examination of the relationship between 4IR maturity, net zero transition, and GHG emissions reduction, providing quantitative insights that can inform decision-making and policy development.

Given that this study sought to establish correlations between dependent and independent variables, while considering multiple other intervening and moderation variables, the author used descriptive analysis to summarise and explore the impact of this collected data on the larger population from which the sample was drawn. In addition, exploratory factor analysis (EFA) was conducted to understand and retain the required variables from the data collected during this study around 4IR maturity.

EFA is a statistical technique used to uncover the underlying structure of a relatively large set of variables. EFA is used for identifying the number and nature of latent variables which explain patterns of correlations among the observed variables. By applying this model to VDMA indicators the author explored the underlying structure of 4IR maturity and identified the latent factors or dimensions related to the VDMA model's framework.

Considering the small sample size, a linear and robust regression analysis was conducted on the retained variables from EFA in order to develop a model to study the complex relationship between GHG emission and 4IR maturity in the presence of moderators such as organisations' revenue, earnings before interest, taxes and amortisation (EBITA) and headcount. Lastly, a moderated regression analysis was conducted to understand the impact of moderation variables on the complex relationship between 4IR maturity and GHG emissions. This tailored framework allowed for the examination of the direct impact of 4IR maturity on GHG emissions while accounting for the influence of significant organisational factors. It provided a structured approach to analyse complex relationships between the variables and refine hypotheses where required.

Furthermore, given that the author formulated a hypothesis based on a detailed literature review of existing academic body of knowledge in the areas of 4IR maturity, net zero transition and GHG emissions, the author chose a deductive method for the study. Deductive reasoning involves moving from general principles or theories to specific hypotheses and testing them through empirical observation or data collection.

By employing a deductive method, the author was able to structure the study around theoretical frameworks (such as the TOE and RBV frameworks mentioned earlier) that guided the development of the research model and hypotheses. This approach enabled the author to use existing knowledge and theories as a foundation for the study, increasing the theoretical grounding and credibility of the research.

Given that the study sought to establish a correlational relationship between 4IR maturity, net zero transition, and GHG emissions reduction, within mining organisations, the researcher chose a non-experimental cross-sectional study design for undertaking this study. A cross-sectional study allows for gathering data at a specific point in time while providing a snapshot of variables of interest. This approach enables assessment of current state of the variables of interest and their relationship.

Lastly, given the limited amount of time and resources available, it was imperative to choose a research design that is cost-effective and more efficient. This research design was suitable to collect data from multiple organisations within a specific time frame.

The overall research approach that was used in this study is summarised in the Figure 3.1.

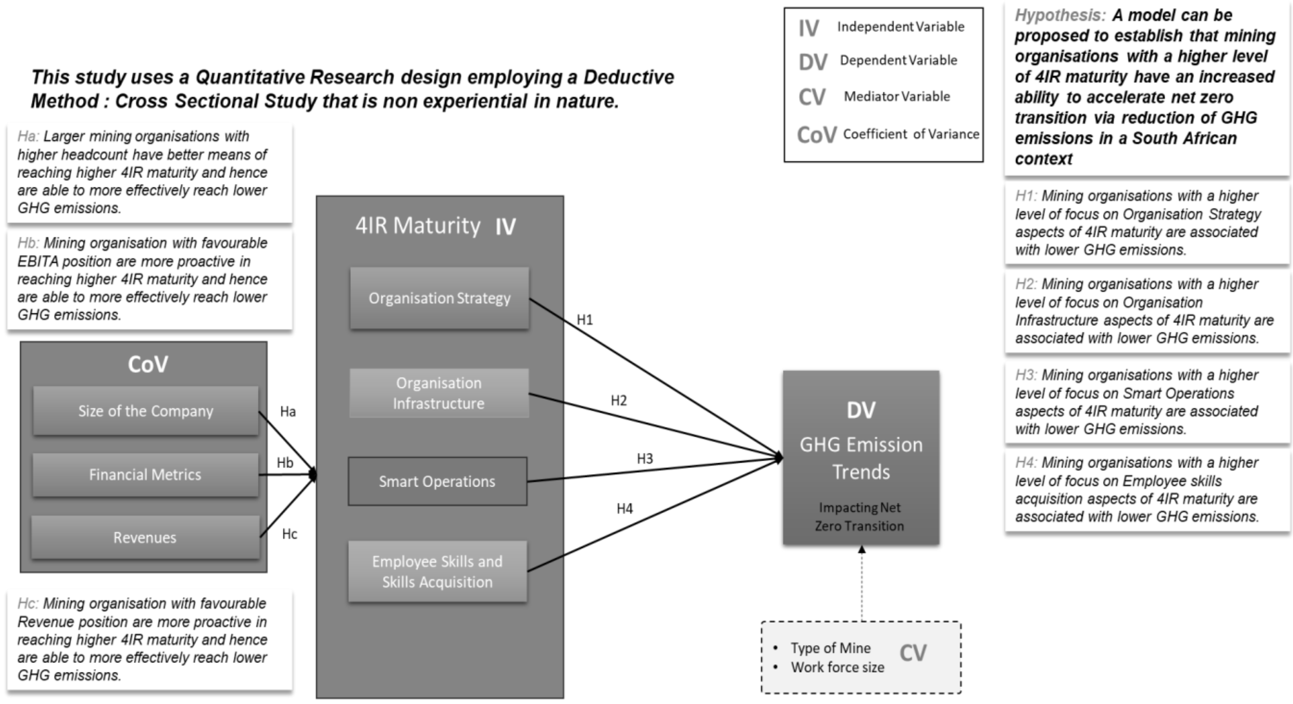

Figure 3.1: Research approach summary

The key assumptions of the research approach were as follows:

a. The research will be undertaken based on a current snap shot view of the identified population to establish corelation between the variables of interest as the scope of this study is to understand the corelation between 4IR maturity and net zero transition, given the limited time available to conclude the research. For a more robust understanding of causality between the variables of interest a longitudinal or experimental designs could be explored in future research.

b. The research assumes that the identified sample of mining organisations follow the required regulations and reporting frameworks to publish their GHG emissions data and trends. Furthermore, the design assumes that this information is publicly available as stipulated by the GRI reporting standards that were discussed in earlier sections.

c. The research design assumes that given the market coverage and revenue contribution of the identified sample of Johannesburg Stock Exchange listed mining organisations, the findings are generalisable across the South African mining industry. Use of a quantitative design further ensures generalisability.

3.2 Research design

The main research question "is there a direct and/or indirect association between 4IR technology adoption and the ability of South African mining organisations to meet the net zero transition goals at an accelerated pace?" called for two main aspects to be explored in greater detail. The two aspects were:

- What is the level of 4IR technology adoption and maturity within the mining sector?
- What are the GHG emission trends within the mining sector in South Africa?

By evaluating the South African mining sector's preparation for 4IR industry, it is possible to fully comprehend the level of 4IR technology acceptance and maturity. As a result, the author chose to apply VDMA's 4IR readiness assessment. Researchers have used and recommended the Industry 4.0 readiness assessment by VDMA as a well-researched instrument to conduct exploratory 4IR readiness evaluations (Maisiri & van Dyk, 2019).

The VDMA framework and concepts of indicators as applied by Siemens (Maisiri & van Dyk, 2019) are shown in Table 3.1.

Table 3.1: Industry 4.0 readiness assessment

Category	Sub-category	Indicator
Organisational Strategy	Industry 4.0 strategy implementation	• Status of implementing a strategy • Compatibility of the strategy with the overall organisational strategy
	Organisational investments	• Extent of committed and planned investment in Industry 4.0

	Systematic technology and innovation management	• Extent of with systematic technology and innovation management implementations.
	Industry 4.0 technologies	• Number of technologies in use
Organisational Infrastructure	Equipment functionalities	• Number of technologies in use • IT use level for machine system control • How frequently machine-to-machine communication is used • Interoperability of machines on a scale
	Equipment functionality adaptability	• Amount of M2M communication usage • Interoperability of machines on a scale
	Digital modelling	• Machine data lifecycle
	Systems, and interface to leading system	• Number of leading interfaces across systems in use
Smart Operations	Cross-departmental information sharing	• Extent of cross-departmental information sharing • Extent of external integrated cross-departmental information sharing
	Autonomous functionality	• Autonomous workpiece guides • Ability to enable Real-time response from autonomous industrial processes
	IT solutions	• IT organisation • Level of security solution implementation • Cloud service usage
Employees	Industry 4.0 skills	• Existing skill levels

A 4IR readiness score was calculated per identified mining organisation using descriptive statistics based on the aforementioned indicators and responses that were gathered across all identified areas of the 4IR readiness assessment, as it was thought to be a necessary data analysis approach when dealing with convenience sampling data (Maisiri & van Dyk, 2019).

The GHG emissions trends were calculated by analysis of the GHG emissions data presented by the sample mining organisations in their respective sustainability and financial reports. Given the relatively small size of the identified sample of mining organisations selected for the study, the desk top analysis was conducted manually to establish the GHG emission trends and carbon intensity for the identified organisations.

An EFA for 4IR maturity variables was conducted using statistical tool SAS and SPSS to identify the loadings, cross-loadings or unique relationships and decide on key factors to be retained from the VDMA model.

Lastly, a linear and robust regression along with moderation regression was conducted to develop a model to study the complex relationship of independent variables (4IR maturity factors) on dependent variable (GHG emission reduction leading to accelerated net zero transition) through one or more mediating variables (such as revenue, EBITA and headcount).

As outlined above the overall study design was based on survey (VDMA Industry 4.0 readiness tool) and documentary analysis method by establishing a coding scheme to identify GHG emission trends, specific initiatives related to net zero transition, and indicators of GHG emissions reduction. In the context of this study, where we aimed to examine the relationship between 4IR maturity, net zero transition, and GHG emissions reduction in mining organisations, documentary analysis was valuable as it involved the systematic examination of sustainability reports and financial reports related to the mining organisations under study.

Advantages of using the adopted approach were as follows:

i. **Enhanced data richness:** Incorporating documentary analysis allowed for a deeper exploration of the research topic by providing a more comprehensive understanding of the phenomena under investigation.
ii. **Contextualization of quantitative findings:** Documentary analysis helped to contextualise quantitative data by allowing for a more nuanced understanding of the relationships between variables.
iii. **Triangulation of data:** This approach enabled data triangulation, by incorporating findings from different data sources. Triangulation increases the validity and reliability of the research by strengthening the evidence base and reducing the potential biases associated with a single data source.

Despite these advantages, there were some limitations and challenges associated with this research approach:

i. **Subjectivity and bias:** Documentary analysis involves interpretation, and authors subjective judgements may influence the coding and analysis process.
ii. **Limited generalisability:** The findings from documentary analysis are often specific to the documents and organisations under study. The generalizability of the findings to a larger population may be limited.

Overall, the adopted approach offers valuable insights and a more comprehensive understanding of the research topic.

3.3 Data collection methods

The data collection methods used to answer the research questions are shown in Table 3.2.

Table 3.2: Data collection method description

Research Questions	Data Collection Method	Justification
What is the level of 4IR technology adoption and maturity within the mining sector?	Questionnaire method using VDMA Industry 4.0 readiness tool • Minimum 1 per identified mining organisation • Maximum 2 per identified mining organisation	The VDMA Industry 4.0 readiness self-assessment tool provides a standardised framework for assessing an organisation's level of readiness for Industry 4.0. By using this tool, the author ensured consistency in data collection across different mining organisations, making comparisons and analyses more reliable. Furthermore, this tool has been used in other academic research in a South African context such as "Industry 4.0 Readiness Assessment for South African Industries" (Maisiri & van Dyk, 2019) and in the global context in studies such as "A maturity model for assessing Industry 4.0 readiness and maturity of manufacturing enterprises" (Schumacher, Erol, & Sihn, 2016) and has proven to provide reliable results. Administrating the tool to more than one individual in the identified organisation helped to eliminate individual bias and ensure capture of a cross sectional view across the sample population.
What are the GHG emission trends within	Documentary analysis through collecting and	All the identified mining organisations publish specific data related to GHG emission and

the mining sector in South Africa?	analysing all the sustainability reports and integrated financial statements of identified mining organisations.	initiatives undertaken to reduce GHG emission and accelerate move towards net zero in their respective sustainability and financial reports as per King committee and GRI requirements. Hence, analysis of these documents provided reliable information regarding GHG emission trends and key initiatives to reduce emissions. Extracting relevant data and information using a pre-established coding scheme enabled the author to gain insights into the research question while cross validating the information gathered using the VDMA tool.

3.4 Population and sample

3.4.1 *Population*

The population of this study was all the mines in developing countries comparable to the characteristics of mining sector of South Africa that possess similar scale of mining operation, ore bodies, ore composition and are faced by similar complexities of mining operations like in South Africa.

3.4.2 *Sample and sampling method*

The author used a non-probability sampling method keeping in mind the market capitalisation of the identified population. Given that the South African mining sector is dominated by few major players who contribute more than 95% of revenues, it was suitable to use this approach where each member of the population does not have a known chance to be included in the study.

Specifically, the author used purposive sampling, where the author selects participants based on specific criteria or judgement, rather than relying on random selection. In this case, the author purposively selected JSE listed mining companies based on their market capitalisation and contribution towards overall mining sector revenues. JSE listed companies were readily available for the study and were mandated by regulation to report accurately on GHG emissions following specific reporting standards.

The sample frame for this research based on the above outline sampling approach comprised 19 out of 38 JSE listed mining organisations with a combined market capitalisation of more than 95% of the overall mining sector revenues in South Africa. Below is the list of identified organisations:

1. BHP Group Limited
2. Glencore plc
3. Anglo American plc
4. Anglo American Platinum Ltd
5. Gold Fields Limited
6. South32 Limited
7. Anglogold Ashanti
8. Impala Platinum Holdings Limited
9. Sibanye Stillwater Limited
10. Exxaro Resources Limited
11. Northam Platinum Holdings Limited
12. Harmony Gold Mining Company
13. African Rainbow Minerals
14. Thungela Resources Limited
15. DRDGOLD Limited
16. Pan African Resources plc
17. Tharisa plc
18. Wescoal Holdings Limited
19. Kumba Iron Ore

As per research conducted by PwC (2022) the total market capitalisation of the mining sector was R1 303bn of which the top ten mining companies contributed approximately R1 212bn. Hence the identified population represented the vast majority of industry players within the South African mining context.

Based on the above sample frame, the author intended to generate the quantum of responses shown in Table 3.3.

Table 3.3: Number of questionnaires / documents and respondent profile

Data collection mechanism	**Number of responses / documents**	**Respondent profile**
Questionnaire response	Maximum: **38** responses Minimum: **19** responses	Respondents needed to be part of the mining operations group and in roles such as Mine Engineer and Operations Managers in organisations identified.
Documents for analysis	Sustainability reports: **19** Integrated financial reports: **19**	Not applicable

3.5 The research instrument

The research instrument used in this study was the Industrie 4.0 Readiness self-assessment tool from Impulse Foundation of Verband Deutscher Maschinen- und Anlagenbau (VDMA) with some modifications to suite the study objectives. This instrument was used to assess the level of 4IR technology adoption and maturity within the identified population.

The self-assessment tool was built across six dimensions with varied weightage. The tool was modified to four dimensions and each of these four dimensions were identified as a cog in the 4IR readiness wheel which play a key role in helping organisations reach the desired level of maturity.

Based on the responses each organisation in the sample was classified into the levels of 4.0 readiness as listed in Table 3.4.

Table 3.4: Industry 4.0 Readiness Assessment for South African Industries as the basis for the industry 4.0 readiness categories

Readiness Levels	Description	Criteria
Level 0: Outsider	• Industry 4.0 is either unknown and unimportant, or no criteria is met.	0
Level 1: Beginner	• Pilot projects for Industry 4.0, focused investments. • Future needs are partially met by infrastructure. • Few areas contain skills.	0 < Points </= 50
Level 2: Intermediate	• Industry 4.0 integration into business strategy. • Investments across a number of notable sectors. • Partial automation of data collecting. • Some areas have the necessary skills to undertake Industry 4.0.	50 < Points </= 90
Level 3: Experienced	• Strategy created. • Investments in wide range of areas. • There may be upgradeable infrastructure. • Information technology systems are secure.	90 < Points </= 120

Level 4: Expert	• Utilising the Industry 4.0 strategy. • Investment success practically throughout the entire organisation • Massive volumes of data are automatically gathered and used for optimisation. • The goods come with optional information technology features.	120 < Points </= 145
Level 5: Top performer	• Implementation of the Industry 4.0 strategy and progress monitoring. • Infrastructure investments made as part of Industry 4.0 meet all standards set out by this technology.	145 < Points </= 160

Source: (Maisiri & van Dyk, 2019)

After making the necessary adjustments, the questionnaire instrument included 34 items in total, of which 23 had scoring weights with the remaining 11 being utilised for information gathering (Table 3.5).

Table 3.5: Structure of the instrument used

Section	Title	Coverage	Number of Questions
Section 1	General questions	General inquiries are intended to elicit information from respondents such as the type of industry, the size of the organisation, and revenues.	3
Section 2	Organisation Strategy	Questions that aim to gather data on the current implementation status of Industry 4.0, tracking of the	5

		initiatives, types of technologies implemented, current and future outlook.	
Section 3	Use of 4.0 in Sustainability	Questions on use of 4.0 technologies to support sustainability initiatives were asked to gather data regarding the organisations' intention to use technology to become more sustainable.	3
Section 4	Organisation Infrastructure	Questions that gather information on the degree of equipment infrastructure adaptability to Industry 4.0 functional needs, including the digital factory model, that provide a link between the real world and the virtual world.	4
Section 5	Smart Operations	Questions that gather data on the concept of vertical and horizontal integration, distributed control, autonomous / automatic response, information security and cloud adoption.	6
Section 6	Employees	Employee-related questions that aimed to understand the availability of staff talents for digital transformation.	3

The VDMA instrument provided a standardised framework for assessing 4IR readiness while ensuring consistency in data collection and allowed for comparisons across different mining organisations.

The VDMA instrument has undergone rigorous development, testing, and validation, enhancing its validity and reliability as a measurement tool. Using such a validated instrument increased the credibility of the study's findings. This is validated further by various local and global academic studies that adopted this tool for their studies (Maisiri & van Dyk, 2019; Schumacher et al., 2016).

The VDMA instrument covers various dimensions of 4IR readiness, including technological capabilities, organisational culture, and strategic alignment. This comprehensive assessment allowed for a holistic understanding of mining organisations' readiness for 4IR, enabling more robust analyses and insights.

The VDMA instrument is specifically designed for assessing 4IR readiness in industrial contexts. As mining organisations are part of the industrial sector, the instrument's relevance to this study's focus enhances its applicability and practicality in evaluating the mining industry's maturity and adoptability of 4IR.

However, there are potential disadvantages or limitations associated with using the VDMA 4.0 Industrie Readiness instrument.

The VDMA instrument was developed within a specific context and for specific regions. Hence the tool was modified to address the unique characteristics and challenges of the mining industry in the South African context.

While the VDMA instrument provides a comprehensive assessment of 4IR maturity and adoption, it is not able to capture the essence of net zero transition and GHG emission reduction. Hence a second method of document analysis was used to analyse the sustainability reports and financial statements of the populations to ensure comprehensiveness of this study.

The VDMA instrument typically relies on self-assessment by the organisations being evaluated, which could have led to subjectivity and potential biases. Therefore, this instrument was administered to more than one mining operations member of the organisations within the sample which helped to eliminate individual bias.

3.6 Procedure for data collection

Data was collected using the two mechanisms outlined in Table 3.6.

Table 3.6: Data collection methods

Data Collection Instrument	Data Collection Method
Altered VDMA Instrument	• The instrument was loaded on a secure data collection website. • Respondents in the identified population were identified based on the mining operations position they held within the organisation. • An initial introductory email was sent out introducing them to the study and asking if they were willing to participate in the study. • Once their expression of willingness was received, a call was scheduled (either face-to-face meeting or via e-meeting on Microsoft Teams) to further explain the objectives of the study and walk through the instrument used. • Lastly, a final email was sent to the respondents that agreed to participate with a consent form and a secured link to the instrument where the respondents were able to complete the instrument via a web interface and the data was automatically stored into a back-end database for analysis.
Document Analysis	• Sustainability reports and integrated financial reports for FY 2022 were downloaded manually by visiting the company websites of the sample. • The downloaded documents were securely stored as per the folder structure: ○ This PC/Documents/MMDB/Research Methodology/Document

	Analysis/<<Organisation name>>/Sustainability reports o This PC/Documents/MMDB/Research Methodology/Document Analysis/<<Organisation name>>/Integrated financial reports o This PC/Documents/MMDB/Research Methodology/Document Analysis/GHG inventory report • The documents were analysed based on a pre-established coding scheme and relevant data was extracted. • The extracted data was inserted into the same data base where the data from VDMA instrument were stored, for analysis.

The above approach provided a secure and safe way to collect, manage and analyse data, and was easy for the respondents to understand and use the instrument to respond effectively.

3.7 Data analysis strategies and interpretation

Data analysis was divided into two phases. Phase 1 of the data analysis constituted analysis of the data gathered from respondents through the use of the VDMA instrument.

A descriptive analysis model was used to summarise and describe the main features of the collected dataset of 4IR maturity of the identified sample population.

This was followed by EFA to uncover the number of latent variables and study the pattern of correlations. This was also used to identify factor loading and prioritise the factors of VDMA model to be retained for further analysis.

The following steps were followed to undertake this analysis:

- Descriptive analysis was conducted on data collected per question on the VDMA questionnaire.
- Principle component analysis was conducted to extract factors from the data that was required for further analysis.
- Correlation matrix based on the variables of interest was calculated.
- Initial factor loading was conducted while consulting the VDMA readiness model.
- Factors were extracted iteratively.
- Factor structure was refined by evaluation of the factor loadings, communalities, and uniqueness estimates.
- Overall model fitment was evaluated using fit indices specific to EFA.

After completion of EFA the retained factors along with the dependent variables and identified moderation variables were subjected to a Pearson correlation coefficients analysis, which is a type of simple statistics modelling used to compute correlation coefficients that measure the strength and direction of the relationship between variables.

In summary, the output indicates that most of the variables have a moderate to significant relationship with other identified variables in the model as represented in Table 3.7.

Table 3.7: Correlation matrix

Variable Name	GHG Emissions	OS	OI	SO	ES	Rev	Headcount	EBITA
GHG Emissions	1.000	-0.443	0.087	0.088	-0.007	0.844	0.691	0.856
OS		1.000	0.081	-0.084	0.316	-0.372	-0.256	-0.432
OI			1.000	0.860	0.603	0.088	0.082	0.164
SO				1.000	0.614	0.079	0.084	0.148
ES					1.000	-0.006	0.165	-0.017
Rev						1.000	0.639	0.942
Headcount							1.000	0.615
EBITA								1.000

- GHG emissions has a moderate to low negative correlation to organisational strategy and employee skill suggesting that GHG emissions decreases as the organisational strategy and employee skills around 4IR technologies matures.

- GHG emissions show a low positive correlation with organisational infrastructure and smart operation suggesting that there could be a small increase in GHG emissions of an organisation as these two aspects of 4IR maturity increases.

- GHG emissions show a strong positive correlation with revenue, EBITA and headcount aspects of an organisation suggesting that as the organisation size in terms of these parameters increase there is good chance that the organisation's GHG emissions will increase.

In Phase 2 the factors retained from the VDMA model were combined with the GHG emission data that were extracted using the document analysis of sustainability reports and financial statements and the overall GHG emission for each organisation to test the identified hypothesis and sub-hypothesis identified as part of this research objectives.

To establish a correlation between the digital maturity of the organisation (measured using the VDMA 4.0 Industrie Readiness instrument) and GHG emission trends (analysed through document analysis of financial statements and sustainability reports), linear regression, robust regression followed by moderated regression was used to develop a model to study the complex relationship between the variables.

The model captured the hypothesised relationships between the independent variable (4IR Maturity) and the dependent variable (GHG Emissions), considering the influence of moderators.

Dependent Variable=$\beta 0 + \beta 1 \times \mathrm{IV1} + \beta 2 \times \mathrm{IV2} + \cdots + \beta n \times \mathrm{IV}n + \varepsilon$

Where:

- β_0 is the intercept,
- $\beta_1, \beta_2, \ldots, \beta_n$ are the coefficients of the independent variables (IV1,IV2,…, IV_{n}),
- ε represents the error term.

This formula allows us to predict the value of the dependent variable dv based on the values of the independent variables IV_1, IV_2, IV_3, IV_4. The error term ε accounts for the variation in dv that the model does not explain.

A robust regression was further conducted by estimating the coefficients (β) in a way that reduces the influence of outliers.

Lastly, a moderated regression was conducted using specific interaction terms, as defined in Table 3.8.

Table 3.8: List of interaction variables

Interaction Term	Composition
OSxRev	iv_1(OS) x rev
OSxHC	iv_1 (OS) x headcount
OSxEBITA	iv_1 (OS) x ebita
OIxRev	iv_2 (OI) x rev
OIxHC	iv_2 (OI) x headcount
OIxEBITA	iv_2 (OI) x ebita
SOxRev	iv_3 (SO) x rev
SOxHC=	iv_3 (SO) x headcount
SOxEBITA	iv_3 (SO) x ebita
ESxRev	iv_4 (ES) x rev
ESxHC	iv_4 (ES) x headcount
ESxEBITA	iv_4 (ES) x ebita

Using the moderated regression formula incorporating the interaction term, the moderation impact of 4IR factor → GHG emission relationship was studied as follows:

$$Dv = \beta 0 + \beta 1 \times IV1 + \beta 2 \times IV2 + \beta 3 \times IV3 + \beta 4 \times IV4 + \beta 5 \times (moderator) + \beta 6 \times (moderator) + \beta 7 \times (interaction\ term) + \varepsilon$$

The proposed model allowed for the examination of the complex relationship between 4IR maturity on GHG emissions while accounting for the influence of significant organisational factors.

3.8 Possible limitations of the study

The study had the following limitations:

- The study was conducted using a cross-sectional method and focused on establishing the corelation between two key variables namely, 4IR maturity and acceleration of net zero transition through GHG reduction. The causality of these two variables was not studied because it was considered to be outside the scope of this study, leaving an opportunity for further longitudinal studies to establish casualty.
- The study was undertaken by choosing a sample which was representative of the JSE listed mining companies using a non-probability sampling method. Hence the ability to generalise the findings to an extended population of global mining organisations is limited as specific regional considerations need to be factored in before generalising.
- Due to limitations of cost and time, a non-experimental approach was adopted in this study, hence the causality between the variables of interested was not established leaving scope for further more rigorous experimental studies in this field.
- Given that VDMA is a self-assessment tool completed by operations managers and mine managers within the organisation of the identified population, there was scope for bias. Even though every effort was made to eliminate bias, this cannot be completely assured and hence forms a limitation of this study.
- Specific impacts of labour laws, socio-economic factors, labour unions, changing landscape of regulatory framework and other macro factors were not considered during this study as each of these were deemed to be large enough areas to constitute individual topics for further research.

3.9 Quality assurance

The validity and reliability, with external validity in this study are essential as it affects the reliability of the model. In this respect a tried and tested research strategy was used, appealing to the concept of reliability rather than validity or external validity. Hence the research approach was anchored in the use of an established VDMA instrument and reliable statistical models with required statistical tests such as fit indices specific to EFA and ordinary least squares regression as regression analysis techniques.

The data collection and analysis was conducted using state-of-the-art statistical tools, thereby eliminating aspects of human error and ensuring end-to-end auditability and traceability.

The critical question is whether the formulated statistical model can be trusted over any other possible models and approach. As highlighted in the research approach section, the overall research design was well thought through bearing in mind the research questions and variables of interest.

Furthermore, use of well-established research instruments ensured reliability of the input data and data triangulation using document analysis further adds to the possible accuracy of the proposed model. Steps taken to avoid respondent bias, by using multiple respondents per organisation in the identified sample, improved data reliability.

Given the fact that the identified sample constituted organisations that contribute to almost 95% of overall market capitalisation of the South African mining industry, the proposed approach sought to increase validity and generalisability in the South African and growth markets context.

Clear acknowledgement of gaps of the study laid down clear boundaries for the study and therefore; the limitations of this research have been addressed alongside the methods used to minimise potential criticisms.

3.9.1 *External validity*

The proposed study approach used non-probability sampling with JSE listed mining organisations as the population. Given that these companies constitute

95% of the overall market capitalisation of the South African mining industry, and seconded by the fact that smaller non-JSE listed mining organisations are very small mining operations that do not publish reliable data on 4IR maturity and GHG emissions, the findings of this research can be generalised to the South African mining sector.

Mining operations have region specific nuances and GHG regulations vary from country to country, but South Africa has some of the world's best mining operations with varied levels of complexities, so the findings of this study can be applied to all growth economies that have a similar size of mining operations to South Africa, given that they have comparable complexities in terms of ore composition, ore bodies, mining operations and other socio-economic factors like South Africa.

3.9.2 *Internal validity*

Given that the data was collected from a panel of respondents who contribute a majority of revenue share (~95% market share) to the South African mining industry, the findings or the study can be accepted as valid in a South African mining context.

Direct inputs from mine operators of leading South African mining organisations, use of well-established and proven research instruments, and employment of multiple data triangulation and statistical significance testing techniques ensured that the research hypotheses were thoroughly tested so the findings are valid for South African miners.

3.9.3 *Reliability*

Reliability in this context

- Firstly, refers to whether the data collected is reliable and free of respondent bias.

- Secondly, refers to whether the developed statistical model is robust enough to test the hypothesis and establish corelation between variables of interest.

The research approach and identified statistical models increased the reliability of the data by using well-established research instruments that had been previously used in the South African context, which increases confidence in the data gathered. Data triangulation using document analysis and testing of statistical outcomes with hypothesis testing increases robustness and reliability of the employed statistical model.

3.10 Ethical considerations

This is a low-risk study as the proposed research instruments are well accepted in the industry and do not intend to cause harm or present radical views that could result in adverse outcomes. In addition, signed consent was obtained before the administration of the research instrument to the identified respondents.

All data captured will remain anonymous and confidential. No personal data was collected, analysed or stored. Organisation identities are known to the researcher only. Further details can be obtained in the WBS Ethics Clearance Application in Appendix F.

CHAPTER 4. PRESENTATION OF RESULTS / FINDINGS

This chapter presents the results of the quantitative analysis of data obtained as a result of the research approach that was outlined in Chapter 3. Firstly, the 4IR maturity was assessed using the modified VDMA survey tool; the 4IR maturity was established across four key areas namely, organisational strategy, organisational infrastructure, smart operations, and employee skills. Secondly, a corelation was established between 4IR maturity and GHG emission trends and thirdly, a corelation was established between organisation size, location, and financial metrics regarding the 4IR maturity levels of the mines that were part of the research sample set.

4.1 Introduction

Initial findings based on descriptive analysis of the 4IR maturity survey data and GHG emissions trends are presented as the first step of the analysis, followed by outputs of exploratory factor analysis. These steps interpret and summarise the collected data along with establishing the underlying relationships and associations between various variables. The outputs of exploratory factor analysis in terms of identify retained factors is also presented.

Confirmatory factor analysis and moderated regression analysis examined the complex relationship of independent variables (4IR Maturity factors) on the dependent variable (GHG Emission reduction) leading to accelerated net zero transition) through one or more moderating variables (such as revenue, EBITA and headcount).

Outputs of the above statistical analysis lead to validation of the identified hypotheses which are the focus areas of this research study. The survey questions generated data regarding 4IR maturity. The desktop analysis identified the GHG emission trends and other moderating factors such as organisation size, organisation location and financial metrics such as EBITA. The results are laid out per identified hypothesis.

4.2 Results: Descriptive analysis of survey results – 4IR maturity of mining organisation in South Africa

Based on the demographics of the respondents, 60% of the responses were from companies that do mining and 36% of the responses were from companies that do both mining and metals processing, while 4% of respondents did not respond to this question (Figure 4.1).

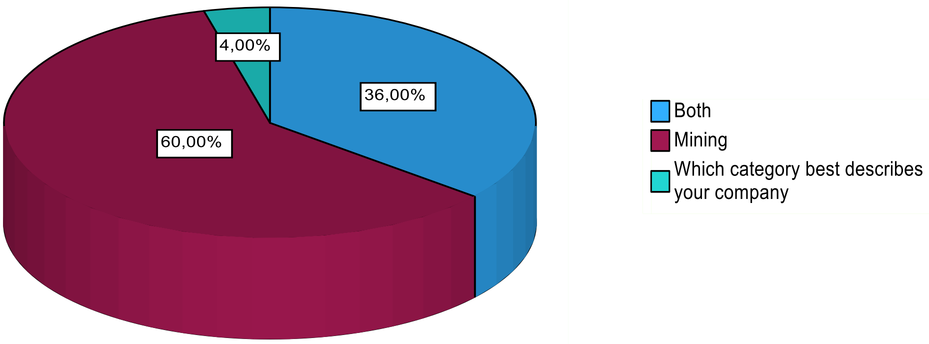

Figure 4.1: Respondent category

Most of the responses (40%) were from mining organisations that employed more than 10 000 employees, whereas medium sized miners with between 5 000 to 6 000 employees, along with small mines employing less than 1 000 employees, each accounted for 12% of the responses (Figure 4.2).

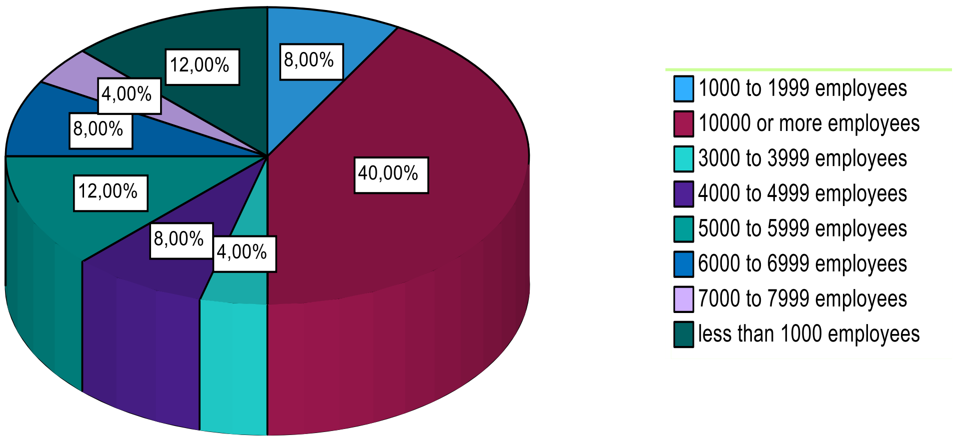

Figure 4.2: Size of respondent company

Table 4.2 shows that the overall 4IR maturity of the key mining organisations in South Africa is mainly in the intermediate or experienced category.

Table 4.1: 4IR maturity summary

Mine	Mining Resource	4IR Maturity Ranking	Maturity Ranking
Miner 1	Minerals & Metals	3	Experienced
Miner 2	Minerals & Metals	2	Intermediate
Miner 3	Minerals & Metals	3	Experienced
Miner 4	Metal	1	Beginner
Miner 5	Metal	2	Intermediate
Miner 5	Metal	3	Experienced
Miner 6	Minerals & Metals	2	Intermediate
Miner 7	Metal	3	Experienced
Miner 8	Metal	2	Intermediate
Miner 10	Metal	2	Intermediate
Miner 11	Minerals	3	Experienced
Miner 13	Minerals & Metals	3	Experienced
Miner 14	Minerals	3	Experienced
Miner 15	Metal	3	Experienced
Miner 17	Metal	2	Intermediate
Miner 18	Metal	1	Beginner
Miner 19	Metal	2	Intermediate

4.2.1 *Organisational Strategy*

Based on the analysis of responses, 52% of respondents report that they have either implemented a relevant 4IR strategy for their organisation or are in the process of implementing one. Further, 26% of respondents reported that they have launched pilot initiatives around 4IR adoption. Only 22% of the respondents reported that they were still either in the strategy development stage or have a strategy formulated but have not yet implemented it.

From the above responses it is clear that most of the organisations in the South African mining sector have identified 4IR technology adoption as a key strategic imperative and have taken steps towards 4IR adoption. This sentiment is further reinforced because 70% of respondents indicated that they are tracking the implementation status of 4IR technologies using a system of indicators.

In terms of 4IR technologies adopted, machine-to-machine communications and real time location systems were the most common, while big data and mobile device adoption were less common (Figure 4.3).

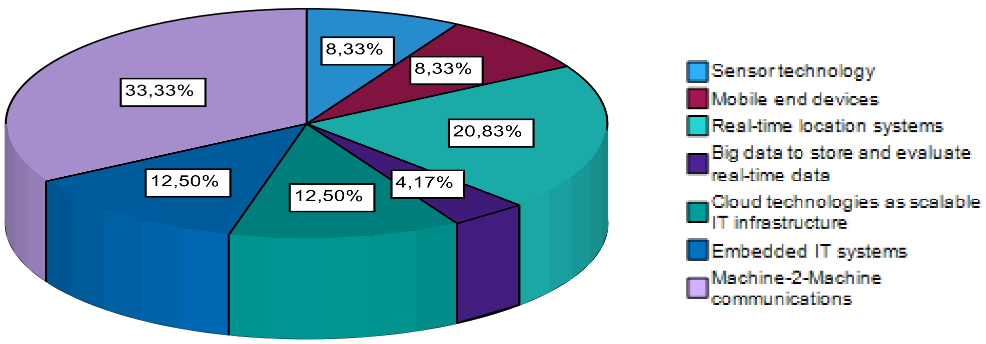

Figure 4.3: 4IR technology adoption

Most mining organisations indicated that they were investing in 4IR technologies for improving production, manufacturing, and the research and development aspects of the business along with improving their internal information technology capabilities. Adoption of 4IR technologies in sales, logistics and procurement aspects of the business were lagging behind.

An interesting observation around use of 4IR technologies to assist in meeting sustainability goals is that 42% of respondents reported that they have considered this while the majority of 54% reported that they are still only planning to consider this.

Respondents reported that they are using or considering the use of 4IR technologies in areas of safety, health, carbon emissions reporting, training, remote operations, water circularity, production optimisation, digital twins, green energy, as well as feasibility studies around hydrogen and waste management aspects to meet their sustainability goals.

4.2.2 *Organisation Infrastructure*

Based on the responses, 64% of the respondents reported that their organisation could, to some extent, control machines through IT, 60% of the respondents agreed that they have implemented machine-to-machine communication and 68% agreed that there is interoperability to some extent between their systems. Only 8% to 16% agreed that they have full control of machines through IT and have fully implemented communication and interoperability.

In terms of a digital model of mines, a staggering 75% of the respondents reported that they are collecting machine and processing data during production related activities in order to create a data foundation to build a digital model. Only a small number of respondents (12%) reported that they are not collecting any machine or processing data.

Most of the respondents agreed that they were predominantly collecting data related to manufacturing throughputs, equipment capacity utilisation and inventory. Positioning data, production residues and error quota data was also being collected. Based on the responses it looks like most organisations are still lacking data collection in the areas of employee utilisation, overall equipment utilisation and transition times.

Based on the data collected, 25% of the respondents agreed that they were using the collected data to increase transparency across the production process, while 16% of respondents were using it for predictive maintenance and optimisation of resource consumption (Figure 4.4).

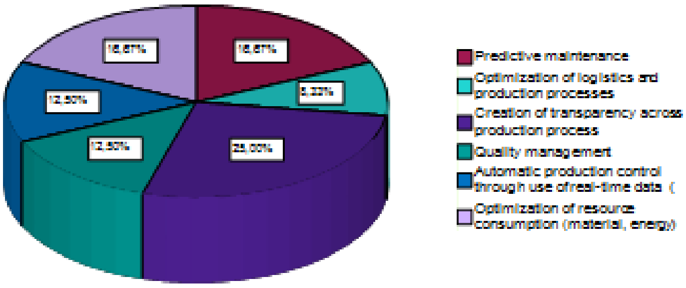

Figure 4.4: Data use cases

Based on the responses it can be further inferred that adoption of the production planning systems, supply chain management systems and enterprise resource planning systems were high, while manufacturing execution systems, machine data collection systems and computer aided design systems were medium. Adoption of product lifecycle management systems and product data management systems seemed low.

4.2.3 *Smart Operations*

Vertical and horizontal integration of IT systems and production and manufacturing systems seemed high, while for logistics, sales and financial accounting systems it seemed medium. Vertical and horizontal integration seems to be low in systems used for research and development and purchasing with more than 50% of the respondents suggesting that they do not have such integration in place.

Implementation of autonomous production and operation systems has been one of the key focus areas of digital mining and 4IR technologies have been identified as being most suitable for this purpose. When respondents were asked to comment on the ability of their organisation's production systems to operate autonomously through the production process, the largest group of 45% reported that they do not have autonomous production processes, 35% reported that they have either piloted or implemented some autonomous processes, and only 16% reported that they have implemented autonomous process across the full production value chain.

When considering autonomous responses to changes in production conditions, 37% reported that they have not implemented autonomous or automatic responses, 37% that they have implemented it in selected areas, 17% that they were piloting such systems, and only 8% reported they had implemented such controls across the production value chain (Figure 4.5).

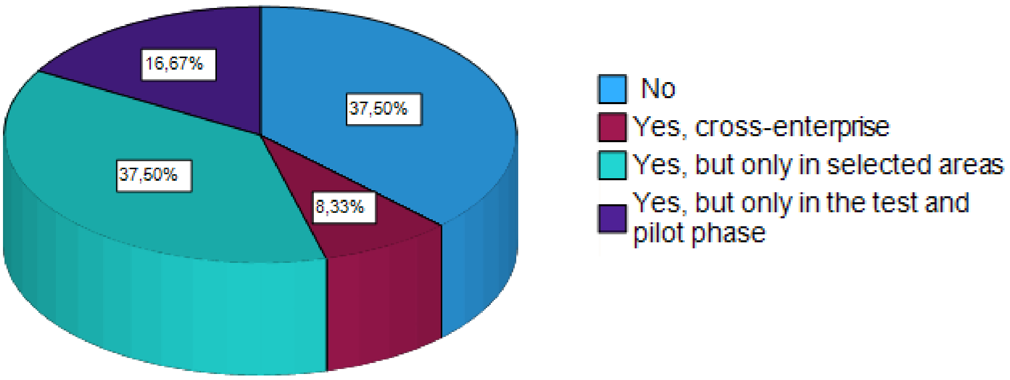

Figure 4.5: Autonomous responses summary

Given the importance of cloud adoption and information security, questions were posed regarding the structure of organisations' technology support teams and their security posture. Most of the respondents (62%) reported that they use service providers to support their systems, with only 29% of respondents reporting that they have a central IT department.

In terms of implementation of adequate information security systems, the majority of the respondents (75% to 80%) had implemented or were in the process of implementing solutions around data security, cloud security and network security. A very small portion of respondents suggested solutions were planned but not implemented (8% to 12%).

Regarding cloud adoption, the vast majority of respondents (75%) indicated that they were either in the process of installing cloud-based data analysis and storage, cloud-based applications, or they had already done so. Only 15% of the respondents said they were still planning to install a cloud solution, and 10% of respondents said that the cloud was irrelevant for their company.

Analysis of the data reveals that IT solutions are highly adopted in the areas of integration, self-service reporting, and monitoring, and less so in the domains of object information, automatic identification, and location, technology adoption was mediocre. Information technology solutions in the domains of help systems and product memory were lacking.

4.2.4 *Employee Skills*

In terms of skills coverage, a very low percentage of respondents felt they had sufficient skills coverage in the areas of IT infrastructure (29%), automation technologies (29%), data analytics (16%), data security (25%), assistance systems (37%) and collaboration software (29%). The majority of respondents reported that skills coverage across all the above aspects were non-existent or inadequate.

Most of the respondents (83%) reported that they were making efforts to acquire or upskill resources in the above areas, while only 17% of respondents reported that they had no plans for upskilling or acquiring skills (Figures 4.6).

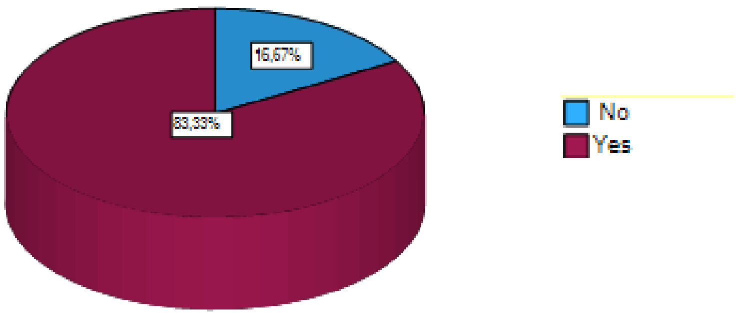

Figure 4.6: Skills acquisition

Based on detailed descriptive analysis of the survey responses, it was noted that most organisations performed better in Organisational Strategy and Smart Operations factors of the 4IR maturity and performed slightly less well in the Organisational Infrastructure and Employee Skills factors of 4IR maturity (Figures 4.7 and 4.8).

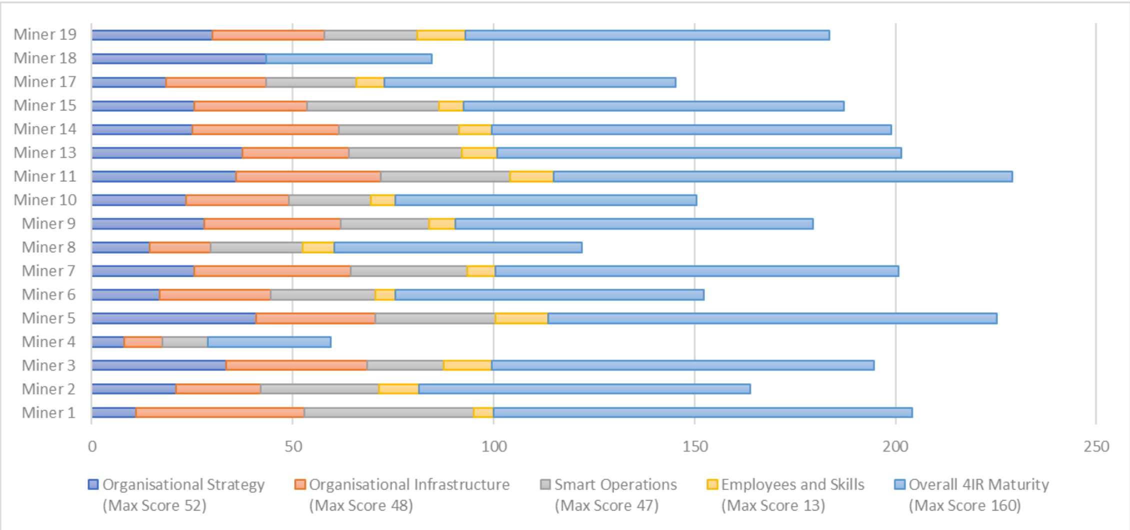

Figure 4.7: 4IR maturity by factors

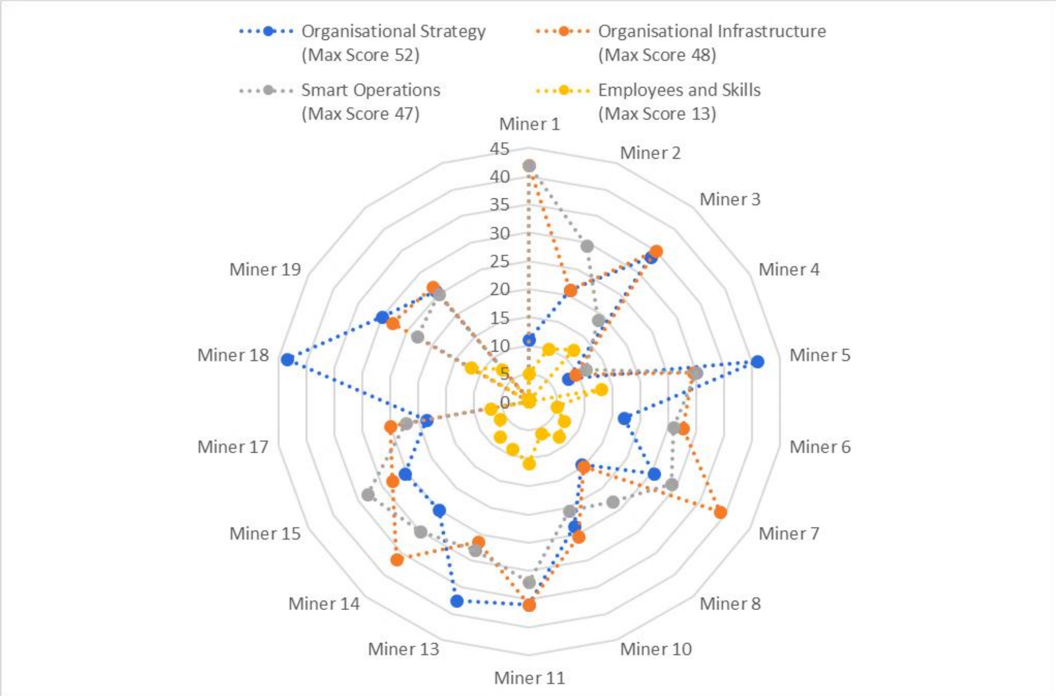

Figure 4.8: 4IR maturity by factors summary

Further analysis revealed that, in contrast to minerals miners and miners who mine both metals and minerals, miners in the metals sector have a higher 4IR Maturity (Figure 4.9).

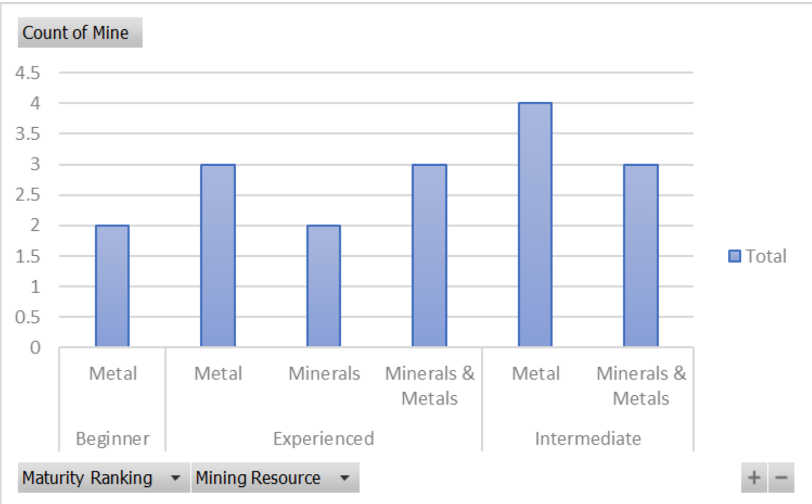

Figure 4.9: 4IR maturity by respondent group

4.3 Results: Descriptive analysis – GHG emission trends for identified sample mining organisations

Based on the descriptive analysis of the GHG emission data collected via a desktop analysis of integrated financial reports and sustainability reports of the identified mining organisations for financial years 2018 till 2022, the findings are summarised in Figure 4.10.

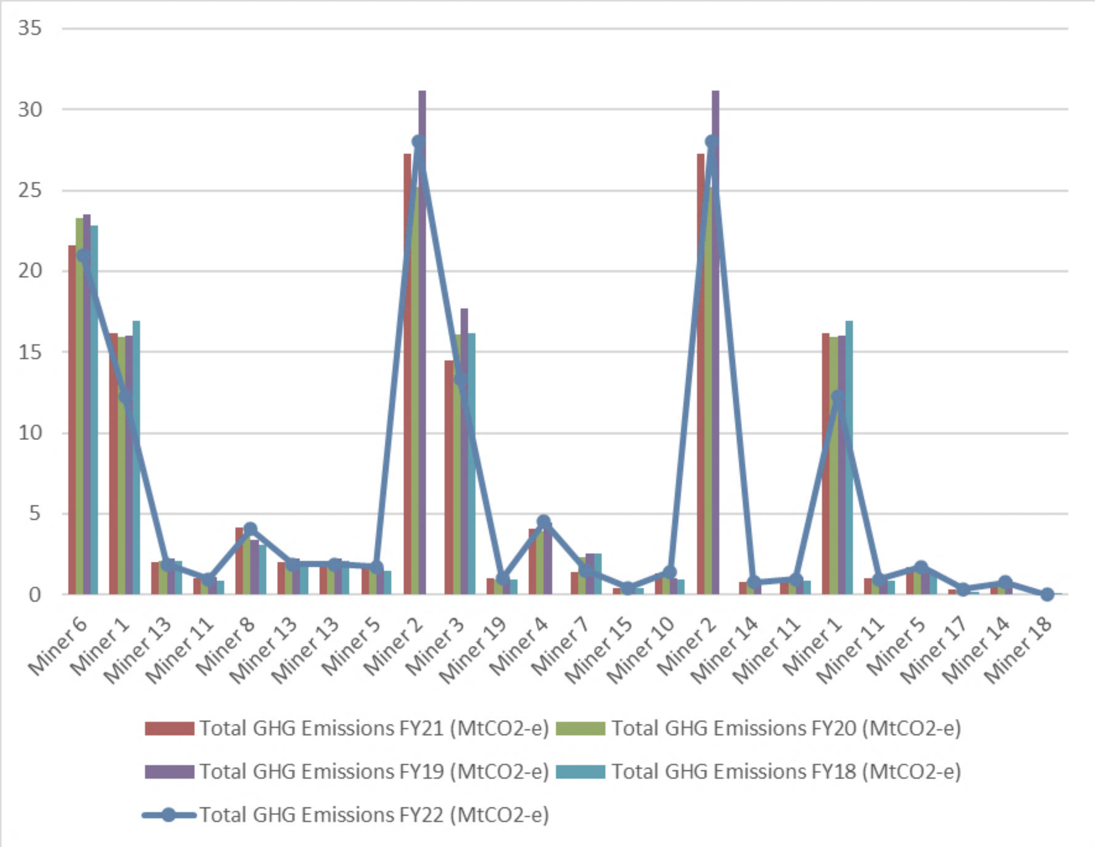

Figure 4.10: GHG emission trends

Figure 26 shows that in most cases there has been a steady decrease in GHG emissions with only a few smaller miners being outliers in this trend.

When analysing carbon intensity, which is an indicator of the amount of carbon (in the form of CO_2 emissions or equivalent greenhouse gases) emitted per unit of mineral or metal extracted, the trend was similar. Carbon intensity was noted to be on a downward trend in line with the declining trend of the GHG emissions (Figure 4.11).

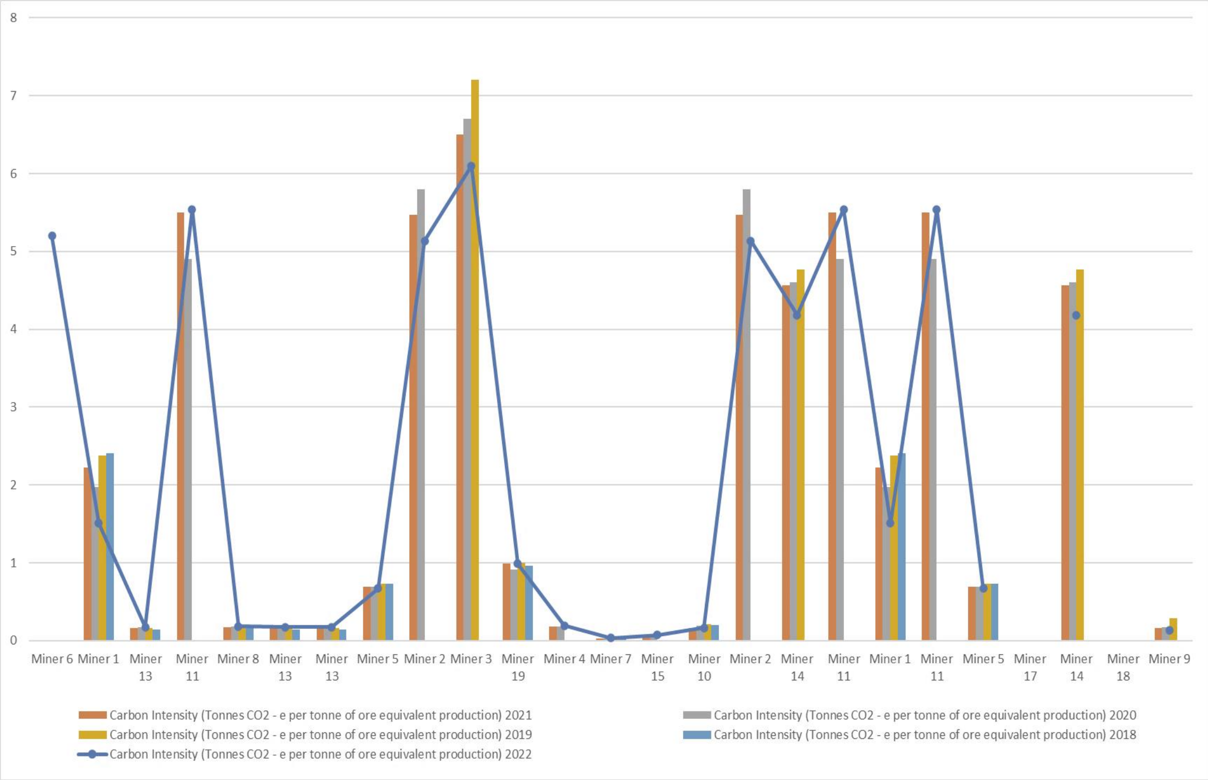

Figure 4.11: Carbon intensity trend

4.4 Results: Factor analysis – establishing the relationships between factors and factor retention

4.4.1 *Exploratory factor analysis*

As the first step in factor analysis an EFA was performed on data collected by the 4IR maturity survey using the modified VDMA self-assessment tool so as to understand the relationship between various variables identified by descriptive analysis across all the survey variables.

Using a primary axis factoring extraction with a promax rotation method—an oblique rotation that permits the factors to be correlated—factor loading was initially carried out across all variables found in the survey questions in order to extract a factor loading matrix (Table 4.2).

Table 4.2: Rotated factor pattern for 4IR maturity items

Questions	Factors			
	OI	ES	SO	OS
Adaptability of equipment infrastructure	0.935			
Digital model of mine	0.924			
Machine and process data collection	0.848			
Extent of machinery, processes and product data collection	0.683			
Digital mining systems in use	0.652			
Use of digital mine data	0.549			
Interface to leading and lagging systems in digital mine	0.507			
Equipment infrastructure deployment	0.400			
Skills Assessment – IT infrastructure		0.894		
Skills Assessment – automation technologies		0.770		
Skills Assessment – data analytics		0.755		
Skills Assessment – data security		0.641		
Skills Assessment – assistance systems		0.634		
Skills Assessment – collaboration systems		0.629		
Skill development plans current		0.529		
Skill development plans future		0.511		
Integrated cross-departmental information sharing – research and development			0.476	
Integrated cross-departmental information sharing – production and manufacturing			0.871	
Integrated cross-departmental information sharing – IT			0.739	

Use cases for autonomous production			0.679	
Use cases for autonomous response			0.660	
Internal IT organisation structure			0.594	
Security systems implementation			0.585	
Cloud services implementation			0.546	
Cloud security implementation			0.491	
Functions of information and communication systems			0.470	
4IR technologies used in the organisation				0.848
Implementation status of 4IR strategy				0.623
Investments in 4IR technologies				0.621
Systematic technology and innovation management				0.589
4IR technologies to meet sustainability goals				0.585

Based on questions that were loading to specific factors, four factors were identified as summarised in Table 4.3.

Table 4.3: Factors to 4IR maturity linkage

Factors	**4IR Maturity Areas**
Factor 1	Organisational Strategy
Factor 2	Organisation Infrastructure
Factor 3	Smart Operations
Factor 4	Employee Skills

The four factors together explain approximately half of the total variance in the dataset, which suggests that these factors capture important dimensions within the data. However, the results also show that over 50% of the variance is due to other factors not captured by these four.

Based on visual observation of the eigenvalue plots it is evident that the first four factors have eigenvalues significantly higher than the rest, suggesting that these are the main factors that should be retained for further analysis. This analysis further confirms the factor loadings that predominantly loaded to four factors.

To further understand the relationship between the independent variables a correlation matrix was computed using Pearson correlation coefficients (Table4.4).

Table 4.4: Correlations of factors

Name	OS	OI	SO	ES
Organisational Strategy (OS)	1	0.08079	-0.08355	0.31636
Organisational Infrastructure (OI)		1	0.85972	0.60299
Smart Operations (SO)			1	0.61406
Employee Skills (ES)				1

Based on the above correlation heatmap the following relationships between independent variables were inferred:

- Organisational strategy has a very low correlation to organisational infrastructure, smart operations and employee skills aspect of the 4IR maturity.
- Organisational infrastructure has a strong effect on smart operations and low effect on employee skills.
- Smart operation has a moderate correlation with employee skills.

In conclusion, the correlations suggest that the components retrieved appear to assess distinct constructs with a certain amount of overlap.

A linear regression model using SAS PROC REG was conducted to check model fitment and the diagnostic plots were analysed. The goodness of fit of the suggested model to the dataset was tested using the R-square and RMSE test for exact fit (Table 4.5).

Table 4.5: Test of goodness of fit

Fit index	Score for linear regression
Root MSE	0.41905
Dependent Mean	1.44340
Coeff Var	29.03221
R-Square	0.7899
Adj R-Sq	0.6980

Note: *** DF = 7, F value = 8.59, Pr >F = 0.0002.

The F-value is 8.59, which is a measure of the overall significance of the model. A very small p-value (Pr > F) of 0.0002 suggests that the model is statistically significant. The R-squared value of 0.7899 suggests that the model explains about 78.99% of the variability in the dependent variable.

Table 4.6: Parameter estimates regression outputs

Variable	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1.44340	0.08554	16.87	<.0001
OS	-0.00889	0.01178	-0.75	0.4616
OI	0.00090353	0.01701	0.05	0.9583
SO	-0.00392	0.02002	-0.20	0.8474
ES	0.00453	0.03558	0.13	0.9003
Rev	0.01180	0.01854	0.64	0.5334
Headcount	0.01762	0.01157	1.52	0.1474
EBITA	0.03565	0.02981	1.20	0.2491

As seen in Table4.6, none of the predictors are statistically significant at the conventional 0.05 alpha level, as indicated by their p-values.

In summary, analysis of the diagnostic plots suggest that the model fits the data reasonably well. While the overall model is statistically significant, none of the individual predictors show a significant association with the dependent variable at the 0.05 level. This could mean that while the predictors together explain a significant portion of the variance in the dependent variable, their individual effects are not strong enough to be statistically significant.

Further robust regression was performed using SAS PROC ROBUSTREG while removing the variable EBITA from the regression model as it was identified to be non-significant and interfering with the factor revenue. This analysis was done to reduce the impacts of outliers in the identified dataset.

The intercept was found to be highly significant with an estimate of 1.3770. The independent variables of 4IR maturity factors were not statistically significant with high p-values as compared to the conventional 0.05 threshold as found in the linear regression model in the previous step. Revenue and headcount were seen to become statistically significant predictors with positive associations with the GHG emissions, as show in Table 4.7.

Table 4.7: Parameter estimates robust regression outputs

Parameter	Estimate	Standard Error	95% Confidence Limits		Chi-Square	Pr > ChiSq
Intercept	1.3770	0.0540	1.2712	1.4827	651.38	<.0001
OS	-0.0042	0.0072	-0.0183	0.0099	0.34	0.5578
OI	-0.0003	0.0104	-0.0206	0.0200	0.00	0.9787
SO	-0.0016	0.0125	-0.0260	0.0229	0.02	0.8982
ES	0.0017	0.0216	-0.0407	0.0441	0.01	0.9379
Rev	0.0319	0.0050	0.0221	0.0418	40.57	<.0001
Headcount	0.0252	0.0074	0.0107	0.0398	11.54	0.0007
Scale	0.3444					

A small proportion (4.17%) of the data points were identified as outliers based on the cutoff of 3, which is a common threshold in robust regression. The model was found to explain 67.32% of the variability in GHG emissions with a low AICR and BICR as outlined in Table 4.8.

Table 4.8: Goodness of fit results

Fit index	Score for robust regression
R-Square	0.6732
AICR	15.7837

Fit index	Score for robust regression
BICR	33.6218
Deviance	1.3494

In conclusion, the robust regression model seems to fit the data reasonably well, explaining a significant portion of the variance in the dependent variables; revenue and headcount are identified as significant predictors, while the other variables are not significant. The diagnostics suggest the model is robust and has a good fit based on the R-squared value.

4.5 Results: Moderated regression – to explain the relationship between 4IR maturity factors and GHG emission in the presence of moderators

The final set of tests regards moderations of the impact of 4IR factors on GHG emission by size of the organisation considering revenue, headcount and EBITA as the organisation size factors.

It would have been optimal to moderate using SEM or, at least, undertake mediated moderation analysis (Baron & Kenny, 1986). However, the sample size does not offer the required power for such tests. Therefore, the moderations are tested individually per main relationship, using the classic interaction method of Baron and Kenny (1986).

Since linear regression and robust regression established that 4IR maturity factors have a weak to moderate relationship with GHG emissions of the organisation, this was the relationship focus with organisation revenue, EBITA and headcount moderation variables to study the impact of these moderators on the main relationship (Table 4.9).

Table 4.9: Summary of moderations

Main relationship	Moderator	Overall finding
4IR factor organisational strategy → GHG emissions	Revenue	No statistically significant moderation
4IR factor organisational strategy → GHG emissions	EBITA	No statistically significant moderation
4IR factor organisational strategy → GHG emissions	Headcount	Significant moderation *(β=.0014, p=.0078)*
4IR factor organisational infrastructure → GHG emissions	Revenue	No statistically significant moderation
4IR factor organisational infrastructure → GHG emissions	EBITA	No statistically significant moderation
4IR factor organisational infrastructure → GHG emissions	Headcount	No statistically significant moderation
4IR factor smart operations → GHG emissions	Revenue	No statistically significant moderation
4IR factor smart operations → GHG emissions	EBITA	Significant negative moderation *(β=-.0045, p<.0001)*
4IR factor smart operations → GHG emissions	Headcount	Possible negative moderation *(β = -.0008, p < .123).*
4IR factor employee skills → GHG emissions	Revenue	No statistically significant moderation
4IR factor employee skills → GHG emissions	EBITA	No statistically significant moderation
4IR factor employee skills → GHG emissions	Headcount	Significant negative moderation *(β=-.0044, p=.0076)*

4.5.1 *Headcount as a moderator of 4IR factor organisational strategy → GHG emissions*

The moderation effect of headcount on the organisational strategy → GHG emissions relationship is illustrated in Figure4.12. This figure shows that for smaller organisations with lower headcounts, the impact of organisation strategy on GHG emissions is associated with a negative effect where GHG emissions reduce as the organisation strategy around 4IR matures. On the other hand, for larger organisations with higher headcount the effect seems to be opposite where the GHG emissions actually increase as the organisation strategy around 4IR technologies matures. For organisations of medium headcount size, headcount does not seem to have a major influence on the organisational strategy → GHG emission relationship.

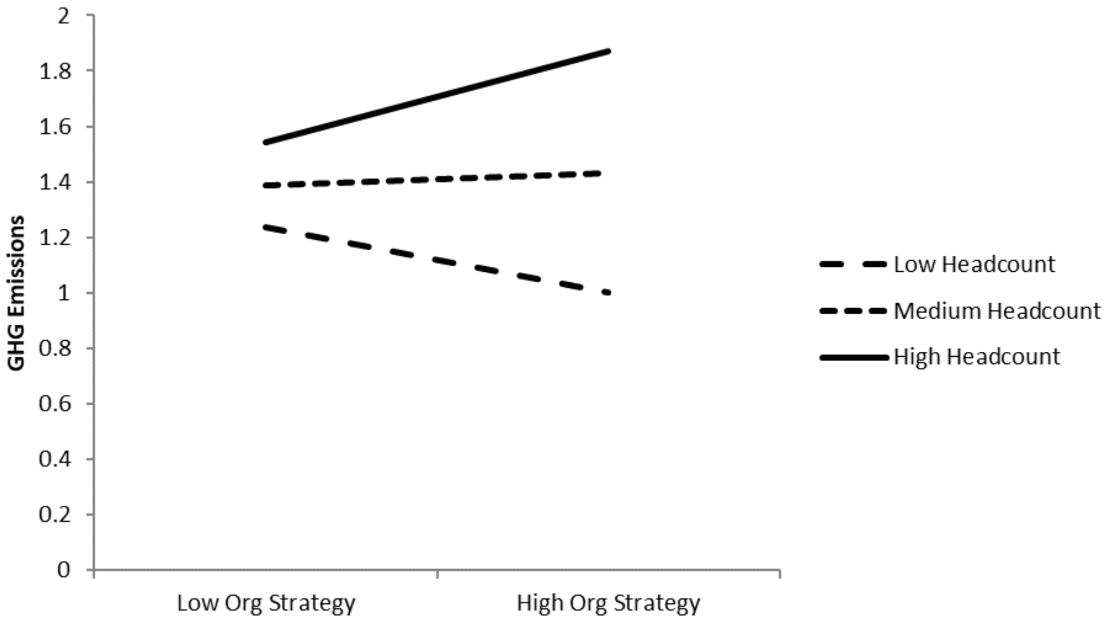

Figure 4.12: Headcount moderating organisational strategy → GHG emissions relationship

4.5.2 *EBITA as a moderator of 4IR factor smart operations → GHG emissions*

The moderation effect of EBITA on smart operations → GHG emissions relationship is illustrated in Figure 4.13. The figure shows that for smaller organisations with lower EBITA position, the impact of smart operations on GHG emissions is not really significant. On the other hand, for larger and medium sized organisations with higher EBITA the effect seems to be profound and negative with a steep decrease of GHG emission as the maturity around smart operations increases, showing an accelerated possibility of GHG reduction.

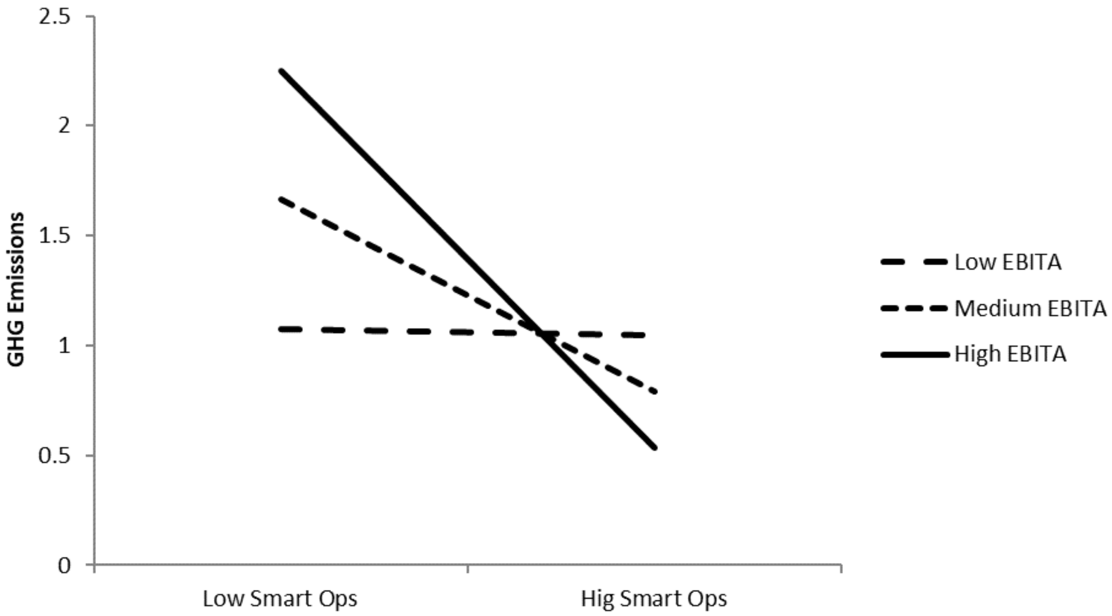

Figure 4.13: EBITA moderating smart operations → GHG emissions relationship

4.5.3 *Headcount as a moderator of 4IR factor smart operations → GHG emissions*

The moderation effect of headcount on smart operations → GHG emissions relationship is illustrated in Figure 4.14. The figure shows that for smaller organisations with lower headcounts, the impact of smart operations on GHG emissions is moderately positive showing that GHG emissions of organisations actually increase as the smart operations aspect of 4IR technology aspects mature. This trend is slightly less significant but consistent with the earlier observation for medium sized organisations. On the other hand, for larger organisations with larger headcounts the effect seems to be strong and negative with a decrease of GHG emission as the maturity around smart operations increases within the organisation.

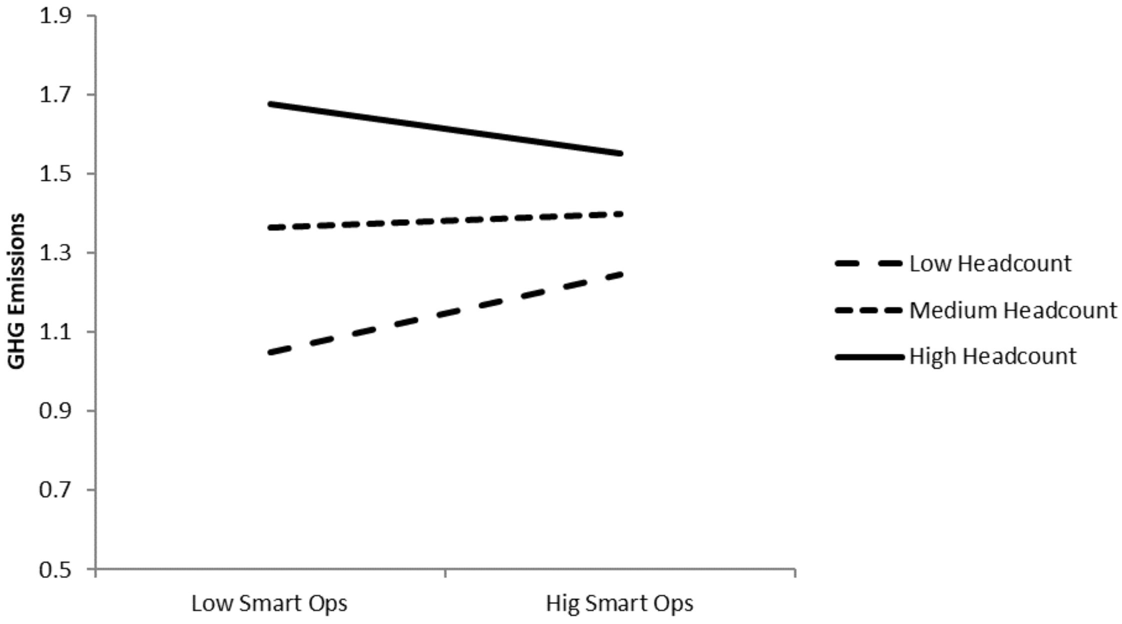

Figure 4.14: Headcount moderating smart operations → GHG emissions relationship

4.5.4 *Headcount as a moderator of 4IR factor employee skills → GHG emissions*

The moderation effect of headcount on employee skills → GHG emissions relationship is illustrated in Figure 4.15. This figure shows that for smaller organisations with lower headcounts, the impact of smart operation on GHG emissions is moderately positive meaning that GHG emissions of organisations actually increase as the employee skills aspect of 4IR technology aspects mature. This trend is a slightly less significant but reversed with the earlier observation for medium sized organisations. On the other hand, for larger organisations with larger headcounts the effect seems to be strong and negative with a profound decrease of GHG emission as the maturity around employee skills improves within the organisation.

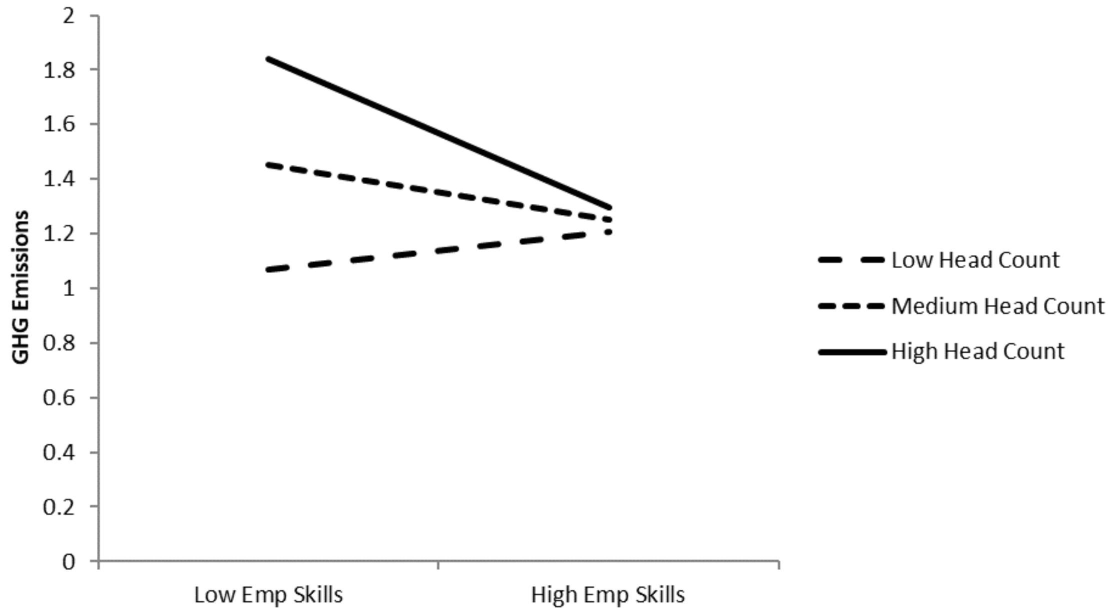

Figure 4.15: Headcount moderating smart operations → GHG emissions relationship

4.6 Summary of the results/findings

a) 4IR maturity in the sample of organisations considered for this study in the South African mining context is identified to be between intermediate and experienced levels of maturity.
b) Rate of GHG emissions in the sample of organisations considered for this study in the South African mining context seems to be on a declining trend with a few outliers related to smaller miners.
c) Identified independent variables for 4IR maturity loaded into four factors with Organisational Strategy, Organisational Infrastructure, Smart Operations and Employee Skills and loading on their respective factors named OS, OI, SO, and ES.

d) Positive correlations of factor analysis suggest that the components retrieved appear to assess distinct constructs with a certain amount of overlap.
e) Pearson correlations output indicates that most of the variables have a significant relationship with other identified variables in the model.
f) Based on the above finding all four factors were considered for further analysis.
g) Linear regression and robust regression analysis suggests a good model fitment explaining a significant portion of the variance in the dependent variables. Revenue and headcount are identified as significant predictors, while the other independent variables are not significant in their own.
h) As a last step in the analysis, a moderated regression analysis was conducted to establish the impact of relationship of 4IR maturity factors on GHG emissions in the presence of moderators. Variables identified as moderators in the theoretical framework (i.e. Revenue, EBITA and Headcount) were used as mediator variables in this analysis.
    - It was found that statistical significance between 4IR maturity variables and GHG emissions in many cases became statistically significant while moderated by revenue, EBITA or headcount and the relationship gravitated towards a negative relationship.
    - Moderation effect of headcount on organisational strategy → GHG emission made this relationship statistically significant with negative correlation in larger organisations.
    - Moderation effect of EBITA on smart operations → GHG emissions made this relationship statistically significant with steep negative correlation in medium and larger organisations.
    - Moderation effect of headcount on smart operations → GHG emissions made this relationship statistically significant with negative correlation in larger organisations.
    - Moderation effect of headcount on employee skills → GHG emissions made this relationship statistically significant with negative correlation in medium to larger organisations.

CHAPTER 5. DISCUSSION OF THE RESULTS OR FINDINGS

The main contribution of this paper is a theoretically grounded model to test the direct and/or indirect association between 4IR technology adoption and the ability of South African mining organisations to meet the net zero transition goals through reduction of their overall GHG emissions at an accelerated pace. The model involves understanding of current levels of 4IR maturity of the mining sector in South Africa and establishment of GHG emissions trends of the mining organisation. It then leverages a qualitative analysis process to explain the nature and extent of relationship between 4IR maturity and GHG emission trends. The model is anchored on the TOE framework and the RBV framework.

5.1 Introduction

This chapter discusses the key outcomes and findings of the developed analytical model in relation to the literature that was reviewed in Chapter 2. Furthermore, the author explains the findings per hypotheses while linking the outcomes to either prove or disprove each hypothesis.

5.2 Demographic profile of respondents

As discussed in the research methodology, the respondents for the survey were purposively chosen to be representative of mine operations and engineering teams so as to be able to gather data that was a true reflection of the day-to-day mining reality. A total of 19 out of 34 JSE listed mines were studied as part of the desktop research and 4IR maturity survey to understand their respective 4IR maturity and GHG emission trends, representing 95% of South African mining sector revenue (Verhaeghe, 2023). The sample size used in this study in terms of number of respondents and companies considered was comparable to similar studies conducted by Maisiri and van Dyk (2019) and Bittighofer, 2018).

5.3 Discussion pertaining to 4IR maturity of the South African mining sector

Today's business environment is dynamic and moving at a radical pace of change within the context of a high level of uncertainty; this provides both major opportunities and key challenges to the global mining industry (Lazarenko, Garafonova, Marhasova, & Tkalenko, 2021). As per the document "Ten insights into 4IR and ESG" published by the Minerals Council South Africa, 56% of the mining organisations are at the level of digital follower maturity level, while 36% are reaching the maturity levels of digital innovators. This is an improvement compared to 69% as digital followers and 13% as digital innovators in 2020 (Verhaeghe, 2023).

As outlined by Zhironkina and Zhironkin (2023), Mining 4.0 with the values and concepts of Industry 4.0 is perceived to be bringing "end-to-end" innovations with deep digitalisation of mining operations in the next decade. Mitchell, 2021) identifies the top 10 risks and opportunities for metals and mining sector, writing that digital effectiveness is one of the key risks for mining organisations.

Based on the findings of the 4IR survey using the VDMA framework, this study has also found that 4IR maturity in the South African mining sector is moving from an intermediate to an experienced level with organisations performing better in the Organisational Strategy and Smart Operations aspects of 4IR maturity while lagging slightly behind on the Organisational Infrastructure and Employee Skills aspects.

5.4 Discussion pertaining to GHG emission trends of the South African mining sector

According to Nwaila et al., 2022) the 4IR is playing a role as a strategic determinant of sustainability, competitiveness and success in the modern mining sector. Su et al., 2021) state that use of energy and energy intensity and CO_2

emissions are corelated in a positive direction, which means that an increase in energy usage invariably results in higher GHG emissions. Dalhammar and Richter (2019) are of the view that developing countries have not been able to focus on environmental and climate change goals given the competing socio-economic challenges these countries are faced with.

Based on the desktop analysis of sustainability reports and integrated financial reports of the sampled mining organisations in South Africa, it can be inferred that most of the large mining organisations are showing a declining trend in GHG emissions both from a Scope 1 and Scope 2 perspective. Scope 3 emissions are in general showing a slower rate of increase compared to previous years. The reduction in Scope 1 and 2 emissions is mainly attributed to the push towards using renewable sources of energy and optimisation of operational efficiencies. Smaller mining organisations are still showing a slight increase in the Scope 1, 2 and 3 GHG emission trends, but the carbon intensity is slowing down compared to previous years.

Su et al. (2021) suggest that GDP has been statistically shown to have a negative impact on GHG emission in the BRICS region. This effect is evident in the findings of this research as well, and is attributed to slightly increasing Scope 3 emission trends.

5.5 Discussion pertaining to Hypothesis H1

Hypothesis H1 proposed that mining organisations with a higher level of focus on Organisation Strategy aspects of 4IR maturity are associated with lower GHG emissions. This concurs with a PwC report which suggests that 4IR technologies have the ability to deliver a unit of output with lower units of energy (Herweijer, 2017).

Digital innovations should be viewed as endeavours that encompass all facets of business which necessitates a fundamental shift in a company's vision, values, strategy, business model, planning and operational processes and workflows, as well as organisational capabilities. The purpose of these innovations is to provide a fully integrated and automated mining value chain (Lazarenko et al., 2021). In their study of organisational strategy in the context of 4IR readiness in South African companies, Gillward (2019) found companies to be in a foundation phase. The current study found that South African mining organisations have improved their organisation strategy aspect of 4IR maturity and are performing at intermediate to experienced levels compared to the findings of the study by Gillward. This finding aligns with the findings of Maisiri and van Dyk, 2019) where the authors found that 80% of their respondents' organisations were in the 'developing' category in terms or organisation strategy in the 4IR context.

Based on the analysis conducted in the analytical model developed for this study, it is noted that there is a moderate relationship that is not statistically significant between the organisation strategy aspect of 4IR maturity and ability of organisations to accelerate reduction in GHG emissions. As understood from the 4IR maturity survey most organisation in the South African mining sector have progressed work on 4IR strategy and some are in the implementation phase. Hence it is understandable that the impact of organisation strategy from a 4IR perspective is still to be felt and the benefits still to be measured regarding ability to reduce GHG emissions.

5.6 Discussion pertaining to Hypothesis H2

Hypothesis H2 proposed that mining organisations with a higher level of focus on Organisation Infrastructure aspects of 4IR maturity are associated with lower GHG emissions. The findings of the current study concur with those of a similar study conducted by Maisiri and van Dyk (2019) who found that a number of organisations in South Africa experience significant challenges in the area of organisation infrastructure that support 4IR requirements. The current study identified that organisations were performing at an intermediate level in terms of the organisation infrastructure dimension of 4IR maturity.

Yang, Wang, Deng and Xiang (2023) studied the impact of digital transformation on an enterprise's carbon intensity, concluding that the relationship between carbon emission and digital transformation could be non-linear.

Analysis conducted as per the analytical model developed for this study found no direct or indirect linear relationship between organisation infrastructure and ability of the organisation to reduce their GHG emissions. A slight positive relationship was noted which was deemed statistically not significant. This finding is in line with Shang et al.'s (2023) literature review in which they identified that there could be a non-linear relationship between digital transformation and enterprise environment performance and that excessive digital transformation may make enterprises bear greater environmental burden.

5.7 Discussion pertaining to Hypothesis H3

Hypothesis H3 proposed that mining organisations with a higher level of focus on the Smart Operations aspects of 4IR maturity are associated with lower GHG emissions.

Technological competitiveness of an organisation is significantly affected by it's capabilities in technology, innovation and science (de Almeida, Augusto de Jesus Pacheco, Caten and Jung, 2021). Research conducted by Maisiri and van Dyk (2019) on a comparable sample to the sample in this research study found that 50% of the respondent were in the developing category for smart operation which suggests that companies in South Africa are having challenges with seamless integration of physical and virtual worlds.

Even though the performance of smart operations has improved to intermediate and experienced levels as per the 4IR maturity survey conducted in this research, the impacts of the same is still felt on the sustainable operations side of things. In line with these findings, analysis conducted as per the analytical model developed for this study noted no direct or indirect linear relationship between smart operations and ability of an organisation to reduce their GHG emissions.

A slight negative relationship was noted that was deemed statistically not significant. This finding is in line with the literature review of Shang et al. (2023) in which they noted that there could be a non-linear relationship between digital transformation and enterprise environment performance, and that excessive digital transformation may make enterprises bear greater environmental burden.

5.8 Discussion pertaining to Hypothesis H4

Hypothesis H4 proposed that mining organisations with a higher level of focus on employee skills acquisition aspects of 4IR maturity are associated with lower GHG emissions.

The 4IR maturity survey outcomes in this research found that the majority of organisations in the sample set indicated that they are in the 'experienced' category when it comes to employee skills and this finding corroborates the findings of Maisiri and van Dyk (2019) with a similar sample. However, the findings of this study differ from those of Gillward (2019) and Dewa et al. (2018) which both concluded that infrastructure and talent acquisition were a major challenge to 4IR adoption in South Africa. They stated that the majority of South African executives were not confident of their organisation's preparedness to fully exploit 4IR technologies. The survey outcomes suggest that this situation has improved dramatically from 2019 till now, but the impact of these improvements is yet to be felt in terms of transition to sustainable mining practices.

In line with the above findings from the existing body of knowledge, analysis conducted as per the analytical model developed for this study noted that there was no direct or indirect linear relationship between employee skills and the ability of an organisation to reduce their GHG emissions.

A slight negative relationship was noted that was deemed statistically not significant. This finding is in line with that of Shang et al. (2023) who note from their literature review that there could be a non-linear relationship between digital transformation and enterprise environment performance, and that excessive digital transformation may make enterprises bear greater environmental burden.

5.9 Discussion pertaining to Hypothesis Ha

Hypothesis Ha proposed that larger mining organisations with a higher headcount have better means of reaching higher 4IR maturity and hence are able to more effectively reach lower GHG emissions.

According to Leopold, Ratcheva, Zahidi and Samans (2017) countries in Africa are not yet prepared for the disruption and opportunities 4IR brings to the current jobs and skills. Gillward (2019) notes that South Africa has been experiencing massive skills shortage in specialised technology areas that are required for 4IR adoption.

South Africa is currently ranked 67th globally in terms of global competitiveness (Schwab, 2018); one of the contributing factors identified is low technology adoption, access to internet, digital skills and critical thinking skills. Based on the above, and given that most companies struggle with finding the required skills for 4IR adoption in South Africa even though the situation has improved since 2019 as shown in the current 4IR maturity survey, there is still a long way to go before headcount aspects of a company can have a direct corelation to the 4IR maturity of the company.

Contrary to above sentiments, a moderation regression analysis conducted as per the analytical model developed for this study noted that headcount acted as a significant moderator between the complex relationship of 4IR maturity and GHG emissions with a negative correlation. In the presence of this moderator the relationship became statistically significant for smart operations and employee skills aspects of 4IR maturity, showing a moderate to strongly negative correlation for medium to large organisations. This indicates that organisation headcount is material in interventions aimed at modifying the 4IR maturity or GHG emission factors of the organisation. Large organisations need to develop skills in the 4IR space to strengthen their ability to accelerate net zero transition in the South African mining context.

From an organisation strategy perspective, an opposite effect was noted for medium to large organisations that tend to agree with the findings of the literature reviews above. The results show a positive correlation between organisation strategy and GHG emission for large organisations, which indicates that there could be a risk of increased GHG emission as the organisation strategy regarding 4IR adoption matures in large mining organisation. Interestingly this trend is reversed for smaller mining organisations. This indicates that the scale of 4IR strategy adoption becomes prominent when considering its impact on GHG emissions.

Hence, organisations need to focus on developing employee skills in the 4IR space as a key enabler towards net zero transition. There is a need to concentrate on development of green skills (Ramli, Rasul, & Affandi, 2018) which are a set of sustainable development skills. Large mining organisations need to be mindful of the increased GHG emission due to deployment of 4IR technologies at scale and need to ensure mitigating measures are in place to address such an increase in GHG emissions.

5.10 Discussion pertaining to Hypothesis Hb

Hypothesis Hb proposed that mining organisations with a favourable EBITA position are more proactive in reaching higher 4IR maturity and hence can more effectively reach lower GHG emissions.

Mining in South Africa faces unique financial, socio-economic and operational challenges. Singh (2017) writes that the South African mining industry is facing challenges in attracting foreign direct investments, mining of existing orebodies is becoming extremely complex, commodity price fluctuations is posing a major threat, and new policy regimes around carbon taxes and sustainability is adding more strain to the already constrained bottom-line.

Moderated regression analysis conducted as per the analytical model developed for this study noted that organisations' EBITA position had a strong impact on the GHG emissions of the organisation and as a moderator had a strong moderation effect on the 4IR maturity→ GHG emission relationship of the organisation.

This effect was significant for the smart operations aspect of the 4IR maturity factor and ability of organisation to leverage smart operations to reduce GHG emissions. The impact was profound for large organisations indicating that large organisations can use this as a factor to accelerate their net zero transition.

Thus, mining organisations with strong EBITA position can leverage the smart operations factor of 4IR maturity to reduce GHG emissions and should look to invest in 4IR technologies in this area.

5.11 Discussion pertaining to Hypothesis Hc

Hypothesis Hc proposed that mining organisations with a favourable revenue position are more proactive in reaching higher 4IR maturity and hence are able to more effectively reach lower GHG emissions.

As outlined in the discission of Hb, the mining industry in South Africa is facing critical challenges that are constraining their revenues and profitability. In the face of these challenges the focus of mining organisations is on increasing throughput and operational efficiencies. Implementation of technology in mining has been a gradual process (Hongoro et al., 2021), and 4IR technologies are slowly being adopted in these mines.

Given the constraints on revenue and slow rate of technology adoption, regression analysis conducted as per the analytical model developed for this study noted that no direct or indirect correlations were identified between organisation revenue position and 4IR maturity of the organisation.

However, a strong relationship was identified when using organisation revenue as a moderator in the relationship between 4IR maturity factors and ability of organisations to reduce GHG emissions, which indicates that the role of organisation revenue is material in interventions aimed at modifying the 4IR maturity or GHG emission factors of the organisation. This suggests organisations with strong balance sheet need to look at increasing their 4IR technology adoption to start seeing the benefits on operational efficiencies, energy transition and reduction of carbon emissions.

5.12 Conclusion

Based on the above findings we can conclude that all four 4IR maturity factors do not have a statistically significant linear relationship with organisations' ability to accelerate reduction in GHG emissions and thereby accelerate their journey towards net zero. They only exhibit a moderate negative effect on GHG emissions.

It is further concluded that organisation headcount, revenue position and EBITA position play a moderating role in making the complex relationship between 4IR maturity and an organisation's ability to accelerate net zero transition statistically significant, indicating organisations with a larger headcount and stronger revenue and EBITA positions can use 4IR strategies and technologies to make strategic decisions in relation to net zero roadmaps.

CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

This research aimed at postulating a model that can study the nature of the association between 4IR maturity and net zero transition for mines. The research model chose 19 of the 34 JSE listed South African mining companies as the sample population.

The main objectives of this study were to answer the following questions:

I. What is the level of 4IR technology adoption and maturity within the mining sector?
II. What are the GHG emission trends within the mining sector in South Africa?
III. What are the impacts of these 4IR initiatives in accelerating the ability of mines to reduce the GHG emissions?

6.2 Conclusions regarding research Question I

Lazarenko et al. (2021) assert in their research study that the digital transformation process is a crucial element driving the mining industry's growth. By utilising the most recent technological developments to enhance operational procedures and guarantee strategic competitiveness while lowering risks and boosting corporate performance, digitalisation has emerged as a business necessity. Based on the survey results published in The Future of Jobs Survey (World Economic Forum, 2020), it is anticipated that the mining and metals industry will use digital technologies at a faster rate.

Maisiri and van Dyk (2019) used a similar 4IR maturity model as this study on a similar sample and identified that organisations in the mining sector were in the beginner (34%) and intermediate levels (47%). A study conducted by PwC and the Minerals Council South Africa in 2022 (Verhaeghe, 2023) found that 56% of respondents in the mining sector were in the digital follower category and 36% were in the digital innovator category.

The findings of this research are aligned to the above findings but we found that more organisations in the mining sector are now in the intermediate to intermediate level (44%) and experienced level (44%), with only 11% of the sample in the beginner level. This shows that the mining industry is increasingly embracing 4IR technologies to address their current and future challenges.

6.3 Conclusions regarding research Question II

In order to make the transition to a low-carbon future, more minerals and metals will be needed, not fewer, according to Harvey (2019). Green industrialisation integrates the extraction of raw materials with new global value chains (Altenburg & Rodrik, 2017) which will enable countries such as South Africa to use its natural resources to fuel 4IR (Schwab, 2017).

South Africa has a large value chain opportunity to exploit its endowment in minerals and metals to restructure its economy (Valiani, 2018), given that the future is renewable energy, robots, and electric vehicles, and that the country mines the majority of the minerals or metals required for this transition (Harvey, 2019).

Based on the above it is clear that South Africa has the potential to become a key player in 4IR metal and minerals exploration. Considering this, Harvey (2019) asserts that a low-carbon mining sector can be quickly adopted by the mining industry by means of well-managed and efficient vertical and horizontal links.

The Renewables 2017 Global Status Report (REN21, 2017) notes that over the previous three years there was a decline in carbon dioxide emissions related to energy. This was caused by a mix of rising renewable energy use, decreasing coal consumption, and advances in energy efficiency. The findings of this research tends to agree with the above report in terms of overall GHG emissions trends. We noted a roughly 15% decline over all in Scope 1 and Scope 2 GHG emissions across the sample set, with the exception of a few outliers where an upward trend in terms of GHG emissions was noted. Scope 3 emissions reduced by approximately 8% from reported 2021 figures, showing similar declining trends. Similar trends were noticed when looking at carbon intensity that reduced roughly 6% from the 2021 reported figures.

The above findings show that the South African mining industry is making a conscious effort to become a low-carbon sector mainly focusing on energy transition from fossil fuel to renewable energy sources. Much still remains to be done in terms of Scope 2 and Scope 3 reductions by leveraging 4IR technologies to bring about value chain improvements in terms of GHG emission reduction.

6.4 Conclusions regarding research question III

Current research shows that the relationship between 4IR maturity and GHG emissions is a complex one, and depends on the rate of technology adoption across the full value chain which involves structural changes within the current mining ecosystem with both vertical and horizontal integration.

According to RBV, the foundation of enterprise innovation is an organisation's ability to access a wealth of resources. The availability of corporate finance resources may have a direct impact on businesses' efforts to reduce their emissions and use less energy. Testing the impact of financial resource abundance on firms' digital transformation is therefore crucial (Yang et al., 2023). As per the above argument it is also important to test the ability of an organisation to access employee capacity and skills. The key question then becomes if an organisation has an abundance of resources in terms of finance and skills, will they be in a better position to reduce their GHG emission?

Research published by (Yang et al., 2023) concluded that an enterprise's carbon emission intensity can be considerably decreased by digitisation, and the influence exhibits a "marginal increase" feature. The authors' conclusion is noteworthy as it suggests that there are three pathways through which the beneficial effect of digitalisation on carbon emission intensity can be moderated: financial constraints, green technology innovation, and knowledge asymmetry.

In contrast to these findings this research concluded that there is no direct or indirect linear relationship between organisational strategy, organisational infrastructure, smart operations and employee skills aspects of 4IR maturity with the ability of an organisation to accelerate net zero transition. But the relationship dynamics changed when effects of the moderate variables were considered, indicating that for medium to large mining organisations the negative association between aspects of 4IR maturity on GHG emissions was statistically significant. This impact was amplified considerably when the RBV of organisations were considered and the organisations' financial position (revenue and EBITA) along with headcount were used as moderation factors. This finding tends to agree with the findings about RBV by Yang et al. (2023).

6.5 Recommendations

The findings of this study suggests that mining organisations that are sizeable in terms of revenue, EBITA and headcount, need to focus on ensuring they improve their 4IR maturity across the value chain of their operations to have an accelerated effect on reduction of GHG emissions. While formulating strategies it is important for executives making key decisions to assess all possible implications of available 4IR technologies considering the fast-growing developments that are taking place in the 4IR technology space.

Furthermore, mining specific research and regulatory organisations such as CSIR, the Minerals Council South Africa and the Department of Mineral Resources need to play the role of catalysts to fast track technology adoption and demonstrate stewardship and leadership in terms of pushing the boundaries with mining organisations to enable robust strategy formulations.

The South African government will have to play the role of regulator and effective policy maker in order to monitor and facilitate progress in terms of structural transition of the mining sector and ensure it is fair and just in all aspects. Government will also need to play a pivotal role in ensuring vertical and horizontal integration within the mining sector to create sufficient employment opportunities for the labour force that will be displaced in this process.

Abundance of 4IR related minerals and metals in South Africa provides a massive opportunity to create many additional employment opportunities while transitioning into a more circular and environmentally conscious mining economy.

6.6 Suggestions for further research

Given the importance of net zero transition and the complex nature of the relationship between 4IR maturity / adoption and the ability of an organisation to accelerate their net zero ambition, there is plenty of scope for further research in this space to mature the existing body of knowledge. Below are a few suggestions for further research:

- Conduct more detailed research on each identified aspect of 4IR maturity and study its independent impact on environmental parameters by considering a larger population size to understand all facets of this complex relationship.
- Given that this research did not include studying the causality of 4IR maturity on ability of organisations to reduce GHG emission, there is scope for further research to study the causality of this complex relationship.
- Development of a mining industry specific 4IR maturity model that looks at embedding the concept of circularity and sustainable mining practices at the epicentre of the maturity model.

- Research can be conducted to develop a 4IR strategy template that can act as a guiding framework towards accelerating sustainable mining practice in developing economies such as South Africa.
- Development of a scientific model to accurately predict the impact of various types of 4IR technology adoption on the GHG emission trends as a scenario planning tool for the mining industry to assist in effective investment decision making around 4IR investments

Table 6.1: Consistency table: research questions, propositions, data collection and data analysis

RQ #	Research Question or Objective	hyp #	Hypothesis	Data collection detail	Data analysis method
1	Is there a direct and/or indirect association between 4IR technology adoption and the ability of South African mining organisations to meet the net zero transition goals at an accelerated pace?	1	A model can be proposed to establish that mining organisations with a higher level of 4IR maturity have an increased ability to accelerate net zero transition via reduction of GHG emissions in a South African context.	Adapted version of VDMA 4.0 Industrie Readiness Self-assessment tool Document analysis of financial statements, sustainability reports and carbon inventory	Quantitative analysis using: • Exploratory factor analysis: principal axis factoring (PAF) Quantitative analysis using: • Mediated regression method
1.1	What is the level of 4IR technology adoption and maturity within the mining sector?	1.1	Mining organisations with a higher level of focus on strategy and organisation aspects of 4IR maturity have an increased ability to accelerate net zero	Adapted version of VDMA 4.0 Industrie Readiness Self-assessment tool	Quantitative analysis using: • Exploratory factor analysis: principal

RQ #	Research Question or Objective	hyp #	Hypothesis	Data collection detail	Data analysis method
			transition via reduction of GHG emissions.		axis factoring (PAF)
		1.2	Mining organisations with a higher level of focus on smart operation aspects of 4IR maturity have an increased ability to accelerate net zero transition via reduction of GHG emissions	Adopted version of VDMA 4.0 Industrie Readiness Self-assessment tool	Quantitative analysis using: • Exploratory factor analysis: principal axis factoring (PAF)
		1.3	Mining organisations with a higher level of focus on smart product aspects of 4IR maturity have an increased ability to accelerate net zero transition via reduction of GHG emissions	Adapted version of VDMA 4.0 Industrie Readiness Self-assessment tool	Quantitative analysis using: • Exploratory factor analysis: principal axis factoring (PAF)
		1.4	Mining organisations with a higher level of focus on data driven services aspects of 4IR maturity have an increased ability to accelerate net zero	Adapted version of VDMA 4.0 Industrie Readiness Self-assessment tool	Quantitative analysis using: • Exploratory factor analysis: principal axis factoring (PAF)

RQ #	Research Question or Objective	hyp #	Hypothesis	Data collection detail	Data analysis method
			transition via reduction of GHG emissions		
		1.5	Mining organisations with a higher level of focus on employee skills acquisition aspects of 4IR maturity have an increased ability to accelerate net zero transition via reduction of GHG emissions	Adapted version of VDMA 4.0 Industrie Readiness Self-assessment tool	Quantitative analysis using: • Exploratory factor analysis: principal axis factoring (PAF)
		1a	Larger mining organisations have better means of reaching higher 4IR maturity and hence are able to more effectively reach lower GHG emissions.	Document analysis of financial statements, sustainability reports and carbon inventory	Document analysis using pre agreed coding and data extraction patterns

RQ #	Research Question or Objective	hyp #	Hypothesis	Data collection detail	Data analysis method
		1b	Mining organisations with favourable EBITA positions are more proactive in reaching higher 4IR maturity and hence are able to more effectively reach lower GHG emissions.	Document analysis of financial statements, sustainability reports and carbon inventory	Document analysis using pre agreed coding and data extraction patterns
		1c	Multi-national mining organisations have better access to 4IR technologies globally and are able to reach higher 4IR maturity and hence are able to more effectively reach lower GHG emissions.	Document analysis of financial statements, sustainability reports and carbon inventory	Document analysis using pre-agreed coding and data extraction patterns
1.2	What are the GHG emission trends within the mining sector in South Africa?			Sustainability reports of organisations in the identified population Integrated financial reports of	Document analysis using pre-agreed coding and data extraction patterns

RQ #	Research Question or Objective	hyp #	Hypothesis	Data collection detail	Data analysis method
				organisations in the identified population Carbon inventory published by DEFF	
1.3	What are the impacts of these 4IR initiatives in accelerating the ability of mines to reduce the GHG emissions?				Quantitative analysis using • Mediated regression method

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Appendix A: Research Tool

4IR_Readiness_and
_Maturity_Survey (1).

Approval from VDMA to use the research instrument:

Johannes Gernandt <Johannes.Gernandt@vdma.org>
to Karl, Henry, me

Dear Mr Belur,
We, the VDMA IMPULS Foundation, commissioned the study at the time. You are welcome to use the study and also the tool for your work.
However, we cannot answer any questions about the content of the study. For this, you would have to contact the study's recipient, the IW Cologne, directly.

Good luck with your work, best regards
Johannes Gernandt

Viele Grüße
Dr. Johannes Gernandt
Leiter Competence Center Wirtschaftspolitische Grundsatzfragen
Referent in der Hauptgeschäftsführung
Geschäftsführender Vorstand der IMPULS-Stiftung

VDMA e.V.
Hauptgeschäftsführung
IMPULS-Stiftung

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E-Mail johannes.gernandt@vdma.org
Internet vdma.org

Der VDMA im Web Multimedia | Datenschutz

Vereinsregister beim Amtsgericht Frankfurt am Main, Nr. VR4278

Appendix B: Participant Information Sheet

Participant Information Sheet (PIS)

University of the Witwatersrand,
Wits Business School
T: +27 11 717 3626

Good day,

My name is Ramaprasad Deepak Belur. I am a Masters in Management of Digital Business (MMDB) student in Wits Business School at the University of the Witwatersrand, Johannesburg. My supervisor is Prof. Gregory Lee. I am conducting a research study about possibility of accelerating net zero transition in South African mining through 4th Industrial Revolution (4IR) technology adoption. The study title is "A quantitative study into accelerating net zero transition in South African mining through 4IR technology adoption".

I am inviting you to take part in answering a questionnaire called Industrie 4.0 Readiness Self-Assessment Check developed by Impulse Foundation of Verband Deutscher Maschinen- und Anlagenbau (VDMA) in Germany and which has been adopted for this study with some minor changes. If you decide to take part, your participation in this research study will last about thirty (30) minutes. The research activity will take place via an online website at a time convenient to you between 1st Sep 2023 till 30Th Sep 2023.

With your permission, I would like to store the responses provided electronically into a secured data base which will be used to perform statistical analysis on the data collected. This data will be stored in this data base on a secured drive for 10 years from the date of publication of research report that will be developed as an outcome of this study and deleted after 10 years. Only the researcher will have access to the data along with other researchers who intend to continue further research on this topic, given that you authorize the sharing of data.

During the research activity, no personal information about you will be collected or stored, only general information about your organisation including name of the organisation, size in terms of revenue and employees, type of commodity mined, etc will be collected.

The research activity will be confidential and anonymous. When I share the results of the research study, I will not include your name or anything else that could identify you. With your permission, other researchers may use the data collected from this research study, but your name and any personal information will not be used or passed on.

If you decide to take part in the research study, it should be because you want to volunteer. You do not have to take part. You can stop being in the study at any time. You do not have to answer any questions if you do not want to. You will not get any direct benefits if you choose to join the research study. You will not lose any services, benefits or rights you would normally have if you decide not to join. Taking part in the research study will not cost you anything. You will not be paid for being in this research study.

The risks for this research study are no more than what happens in everyday life.

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This research study will be written up as a research report. The report will be available on the university library website. If you would like to receive a summary of this report, I will be happy to send it to you.

If you have any questions during or afterwards about this research study, feel free to contact me or my supervisor on the details listed below. If you have any concerns or complaints about the ethical procedures of this research study, you are welcome to contact the University Human Research Ethics Committee (Non-Medical), telephone +27(0) 11 717 1408, email hrecnon-medical@wits.ac.za.

Yours sincerely,

Ramaprasad Deepak Belur
Mobile: +27 (079) 884 3769
Email: 2622456@students.wits.ac.za

Supervisor:

Prof Gregory Lee
Mobile: +27 11 717 3626
Email: Gregory.Lee@wits.ac.za

Appendix C: Supervisor endorsement

Gregory Lee
to me

Hi, happy for you to submit your proposal

Gregory Lee
Associate Professor | Wits Business School

E : Gregory.Lee@wits.ac.za
T : +27 11 717 3626
W : www.wbs.ac.za

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2 St Davids Place, Parktown,
Johannesburg

Appendix D: Completed Ethics Application Form

WBS REC Ethics
Application form V2

Appendix E: Ethics Clearance

Ethics Clearance -
Deepak Belur Ramap

Graduate School of Business Administration
University of the Witwatersrand, Johannesburg

Wits Business School

Wits Business School Ethics Committee
Constituted under the University Human Research Ethics Committee (Non-Medical)

Ethics Clearance Certificate

Ethics protocol number:	WBS/DB2622456/623

This certificate is only valid with a legitimate ethics protocol number and signed by the Researcher (below)

This certificate is only valid if accompanied by formal permission from the relevant stakeholder(s).

Project title	The use of 4IR technology in accelerating the net zero transition in the South African mining industry
Investigator / Researcher	Mr Ramaprasad Deepak Belur
Nature of Project	MM (Digital Business)
Decision of the Committee	Approved, provided stakeholders and participants are guaranteed anonymity and confidentiality.
Issue Date of Certificate	25 08 2023
Expiry date	Date of submission of the project / research report
Chairperson	Dr Pius Oba ☎ +27 11 717 3976 +27 82 733 6587 pius.oba@wits.ac.za

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Declaration by Researcher

One copy must be signed by the Researcher and returned to the Chairperson of the Wits Business School Ethics Committee.

I fully understand the conditions under which I am authorized to carry out the abovementioned research and I guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I undertake to resubmit the protocol to the Committee.

	31/08/2023
Signature	Date:

Appendix F: Completed first submission checklist

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

WITS FACULTY OF COMMERCE, LAW & MANAGEMENT

THESIS/DISSERTATION/RESEARCH REPORT – FIRST SUBMISSION CHECKLIST FORM *(for Examination)*

Name of Candidate:	**Ramaprasad Deepak Belur**	
Person/Student Number:	**2622456**	
Qualification:	**Master in Management of Digital Business (MMDB)**	
Title:	**The use of 4IR technology in accelerating the net zero transition in the South African mining industry**	
Supervisor(s):	**Prof. Gregory Lee**	
Contact Details:	**Cell number(s): 0798843769**	**Email: {2622456@students.wits.ac.za}**

FIRST SUBMISSION CHECKLIST *(for Examination)*

Student to send:	**Electronic copy of research** *(Hard copy may be required upon request from the examiner)* **** WBS students are required to submit in MS Word format. All other schools must submit in PDF format. ****	X
	Full Turn-it-in Report *(signed by Supervisor)* **** For WBS Masters – this report does not require the Supervisor's approval ****	X
	Confirmation of Ethics *(Clearance/Waiver certificate or declaration)*	X
	Overall Supervisor Evaluation form *(MBA candidates ONLY)*	
Supervisor to send:	**University Clearance Certificate** *(Supervisor to complete and send directly to Faculty)*	X
	Supervisor's Report *(Supervisor to complete and send directly to Faculty)*	X
Faculty to check on:	Approved title and supervisor(s)	
	Approved examiners	
	Registration status *(students must be registered during the examination period)*	

Please send your research submission to the correct email:

- {HYPERLINK "mailto:" \l "Fac-MBAsubmissions@wits.ac.za"} – for **MBA (ARP)** research submissions
- {HYPERLINK "mailto:Veli.Mongwe@wits.ac.za"} – for PhD and Full Research Masters students **belonging to WBS**
- {HYPERLINK "mailto:" \l "Fac-MMsubmissions@wits.ac.za"} – for MM research submissions **belonging to WBS and WSG**
- {HYPERLINK "mailto:Nasreen.Abdulla@wits.ac.za"} – for PhD and Full Research Masters students **belonging to WSG**
- {HYPERLINK "mailto:Tshepo.Mohlakoane@wits.ac.za"} – for all research types **belonging to Commerce and Law (SEF, SBS, SOA and SOL)**

Please Note:

- *Outstanding fees must be cleared to enable Awaiting Examiner's registration.*
- *Incomplete submissions will NOT be prioritised.*
- *There may be a delay in the examination process where the research has been accepted by Faculty without approved examiners.*
- *If you submit by end-February, you are more likely to graduate in July.*
- *While Faculty will do all that is possible to streamline the research examination process, graduation is NOT guaranteed for any student.*
- *WBS submissions must undergo internal academic quality checks before the exam process may begin.*