Constraints leading to the resistance in the adoption of Industry 5.0 in mining sustainability transitions

23023504

A research project submitted to the Gordon Institute of Business Science, University of Pretoria, in partial fulfilment of the requirements for the degree of Master of Philosophy Corporate Strategy.

25 November 2024

ABSTRACT

The mining industry is undergoing a significant transformation driven by the advent of Industry 5.0 technologies, which emphasise human-centric approaches, sustainability, and resilience. This study investigates the implications of Industry 5.0 technologies for sustainable practices within the mining sector, particularly in the context of South Africa. The background of this research highlights the pressing need for the mining industry to adapt to new technological advancements to enhance operational efficiency, reduce environmental impact, and address the skills gap prevalent in the workforce. Despite the potential benefits, the industry faces substantial barriers to the adoption of these technologies, including financial constraints, resistance to change, and a lack of adequate training programs. The problem statement of this study centres on understanding the factors that hinder the adoption of Industry 5.0 technologies in the mining sector and identifying strategies to overcome these challenges. The research aims to explore the barriers to technology adoption, assess the role of upskilling and training in facilitating this transition, and develop a conceptual framework that integrates the findings into a coherent narrative that can guide future research and practice.

To achieve these objectives, a qualitative research methodology was employed, utilising semi-structured interviews with 13 participants, including mining professionals, consultants, and technology providers. The findings reveal that while there is a growing awareness of the benefits of Industry 5.0 technologies, significant barriers remain. Financial considerations were identified as a primary obstacle, alongside a cultural reluctance to embrace change and a lack of adequate training programs. The study emphasises the importance of fostering a culture of innovation and continuous learning to bridge the skills gap and facilitate the adoption of new technologies. The output of the conceptual framework, illustrates the interconnections between the identified themes and subthemes, providing a structured approach to understanding the complexities of technology adoption in the mining sector. This research contributes to the existing body of knowledge by offering fresh insights into the dynamics of Industry 5.0 technology adoption in mining, particularly in developing countries. It lays the groundwork for future research by identifying key areas for exploration, such as the role of policy interventions and financial incentives in promoting sustainable practices. Additionally, the study promotes continuous dialogue within the academic community and industry stakeholders, highlighting the need for collaborative efforts to address the challenges faced in the transition towards more sustainable mining practices.

Keywords: Industry 5.0, mining, technology adoption, sustainability transitions

DECLARATION

I declare that this research project is my own work. It is submitted in partial fulfilment of the requirements for the degree of Master of Philosophy Corporate Strategy at the Gordon Institute of Business Science, University of Pretoria. It has not been submitted before for any degree or examination in any other university. I further declare that I have obtained the necessary authorisation and consent to carry out this research.

25 November 2024

ACRONYMS

AI	Artificial Intelligence
AR	Augmented Reality
CBA	Cost-benefit analysis
CSR	Corporate Social Responsibility
EIA	Environmental Impact Assessment
I.4.0	Industry 4.0
I.5.0	Industry 5.0
IoT	Internet of Things
MC	Mining Consultant
ME	Mining Executive
PPP	Public-private partnership
RFID	radio-frequency identification
ROI	Return on Investment
SDG	Sustainable Development Goal
TBL	Triple Bottom Line
TS	Technical Supplier
UN	United Nations
VR	Virtual Reality

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

CHAPTER 1: INTRODUCTION

1.1 Background to the research problem

The mining industry has traditionally been reluctant to embrace new technologies (Dehran, 2018). However, this is changing with a growing emphasis on digital transformation and advanced technologies (Clausen & Sörensen, 2022; Dehran, 2018; Littleboy et al., 2019; Sánchez & Hartlieb, 2020). The industry now recognises the importance of digitalisation for competitiveness and adapting to market dynamics, with a focus on real-time process optimisation (Dehran, 2018).

This transition to digital metamorphosis involves not only the adoption of contemporary innovations but also the reconfiguration of the mining industry. This transition to digital metamorphosis involves not only the adoption of contemporary innovations but also the reconfiguration of the mining industry's operational framework. As this study delves deeper into the specific technologies being adopted, it becomes evident how automation, remote-controlled operations, and artificial intelligence (AI) are pivotal in enhancing productivity, reducing costs, and improving environmental efficiency (Sánchez & Hartlieb, 2020).

Technologies such as automation, remote-controlled operations, and AI are seen as key to enhancing productivity, reducing costs, and improving environmental efficiency (Sánchez & Hartlieb, 2020). Despite these benefits, the industry's adoption of these technologies faces challenges due to its historical reluctance and the perceived risks of disrupting established processes (Dehran, 2018; Sánchez & Hartlieb, 2020). Nonetheless, there is a growing need to invest in technological innovation to remain competitive.

As the mining industry progresses, Industry 5.0 signifies a pivotal shift towards a more human-centred approach. This revolution emphasises technology breakthroughs and underscores the partnership between humans and robots to create sustainable and resilient industrial operations.

Industry 5.0 represents a major evolution, focusing on a human-centric approach that integrates collaborative robots and AI (Clausen & Sörensen, 2022). The goal of Industry 5.0 is to create sustainable and resilient industrial processes that enhance safety and health (Mineral Council of South Africa, 2021). Central to this is the concept of 'Zero Harm,' which aims to minimise the risk of injury or harm in the workplace (De Jager, 2018). Industry 5.0 technologies improve information flow and sharing using sensors, radio-frequency identification (RFID), the Internet of Things (IoT), blockchain, cloud computing, big data analytics, AI, machine learning, simulations, and automation with robots and drones (Greco et al., 2021). The European Commission developed Industry 5.0 to promote collaboration between humans and robots, balancing ecological, social, and economic development (Asif et al., 2023). Moreover, the European Union (EU) supports Industry 5.0 initiatives to foster sustainable, human-centred businesses (European Commission [EC], 2021).

Building on the principles of Industry 5.0, innovative industrial technologies are also aligned with the United Nations Sustainable Development Goal (SDG) 9, which focuses on industry, innovation, and infrastructure. These technologies assist mining companies in reducing costs, minimising environmental impact, increasing output, and enhancing mineral extraction (Mining Review Africa, 2023).

Industry 5.0 rectifies the deficiencies of Industry 4.0., which focused on technical advancements but often neglected the human component (Asif et al., 2023). While Industry 4.0 improved productivity and efficiency, its social implications were limited. Industry 5.0 seeks to restore social, environmental, and economic balance through responsible governance, emphasising sustainability and digital advancement. Given these advancements and challenges, it is crucial to transform unsustainable and declining trends in the mining sector. Modern mining, with its potential for safer work conditions and increased efficiency, is key to reversing the industry's decline (Lumandi & Nyasha, 2024). However, Industry 4.0 has shown issues such as AI-related job displacement, environmental degradation, and lack of adaptability to global changes (Ghobakhloo et al., 2023). In response, the EU proposed Industry 5.0 to prioritise human needs and create robust, sustainable manufacturing techniques (EC, 2021).

Notwithstanding the potential achievements of Industry 5.0, the mining sector encounters substantial obstacles in the use of these technologies. These constraints highlight the need for a strategic approach to overcome barriers and fully leverage the potential of Industry 5.0.

The mining industry in South Africa, historically at the forefront of technological advancements, faces constraints in adopting both Industry 4.0 and 5.0 technologies, which promise to enhance operational efficiency, sustainability, and workforce optimisation. Central to Industry 4.0 in mining are automation, robotics, and connected systems, which improve productivity, reduce energy consumption, and enhance safety (Jämsä-Jounela, 2019). Advanced analytics and decision-support systems further optimise processes and strategic decisions (Jämsä-Jounela, 2019). However, the full potential of Industry 5.0 remains untapped due to barriers such as resistance to change, high capital investments, and the need for skilled personnel.

Addressing these difficulties requires a holistic approach that includes both technological and organisational components. Through the investment in automation and digitalisation technologies, alongside the cultivation of a culture of innovation and constant development, the mining industry may adeptly surmount these obstacles. A comprehensive grasp of the mining value chain and the cohesive integration of technologies are essential for effective execution. The sector must also address the increasing demand for sustainable practices. Industry 5.0 technologies can enable carbon-neutral or carbon-negative operations via autonomous systems, renewable energy integration, and sophisticated data analytics, thus diminishing the environmental impact and promoting long-term sustainability.

Therefore, researching the constraints and costs associated with implementing Industry 5.0 technologies can reveal both challenges and opportunities leading to the reluctance to adopt Industry 5.0 technologies. This research illuminated the economic, environmental, and social implications, such as job displacement, the need for new skills, and the broader impact on communities dependent on mining.

1.2 Research problem

The world faces multiple issues because of the current degree of industrialisation, known as the Triple Bottom Line (TBL). These challenges include ecological risks, climate change, and the abuse of non-renewable natural resources. According to Enang et al. (2023), Industry 5.0 technologies promise to advance from Industry 4.0 toward a sustainable transition that satisfies a company's social, environmental, and economic obligations. Furthermore, a company's TBL—its performance in the economy, society, and environment—can be improved by using innovative technology (Jayashree et al., 2021; Tate & Bals, 2018). As such, Chaudhuri et al. (2024) discovered that implementing new technologies enhances social, competitive, and financial performance, all of which have an impact on organisational success.

Despite these advantages, the mining sector has a record of adopting new technologies slowly (PriceWaterhouseCoopers (PWC), 2023). Calzada-Olvera and Lizuka (2023) note that significant barriers exist to technical advancement and modernisation in the mining sector. However, not much is known about the reluctance to adopt Industry 5.0 new technologies in sustainability transitions in the mining industry as the industrial revolution continues to progress and change, especially the factors contributing to resistance to embracing and adopting new Industry 5.0 technologies (Ivanov, 2023). Thus, the primary goal of this research was to examine the reasons behind the underutilisation of Industry 5.0 technologies in the sustainability transitions of the mining sector, with a particular emphasis on South African mining enterprises.

1.3 Research questions

The aim of this study was to address the gap identified by Ivanovic (2023) regarding the adoption of Industry 5.0 technology, its impact on sustainability, and the necessity to collect empirical data to identify specific opportunities and challenges faced by different industries. It was essential to contextualise Industry 5.0 as a distinct paradigm and clarify its relationship with Industry 4.0. Research resolved the ambiguities surrounding Industry 5.0, emphasising whether it supplements and extends Industry 4.0 rather than replacing it.

Furthermore, in the preceding industrial revolutions (1-4), the majority of prior studies (Calzada Olvera & Iizuka, 2024; Gault, 2018; Horváth & Szabó, 2019; Jahanmir & Cavadas, 2018; Molina, 2018; Navarro, 2018; van Oorschot et al., 2018; Yun & Lee, 2015) concentrated on obstacles to the implementation of novel technologies. This study sought to address the existing vacuum in the literature and enhance the current academic discourse about the development and transformation of industries in the context of the fifth industrial revolution, emphasising the attainment of increased sustainability (Asif et al., 2023; Chaudhuri et al., 2024).

1.3.1 Primary research question

The primary research question was: "Why do organisations remain reluctant to implement Industry 5.0 technologies in mining operations?"

1.3.2 Secondary research questions

The four sub-questions designed to direct the study and aid in addressing the primary question are:

i. How do constraints impact the adoption of Industry 5.0 technologies in mining sustainability transitions?
ii. How can strategies be employed to overcome these constraints and promote Industry 5.0 technology adoption?
iii. How do Industry 5.0 technologies contribute to sustainable mining practices?
iv. What is the understanding of Industry 5.0 technologies and their adoption reluctant outcomes amongst mining professionals?

1.4 Research aims

The purpose of this research was twofold: first, it was to provide fresh insights and improve understanding of the elements that lead to mining firms' reluctance to adopt Industry 5.0 new technologies. The study also sought to systematically explore the constraints/costs and interactions associated with the adoption of new technologies in the context of Industry 5.0. Secondly, by examining strategies to eliminate constraints/costs to Industry 5.0 new technology adoption and demonstrating how Industry 5.0 technologies support sustainable mining practices, the research sought to offer options to get over these limitations.

1.5 Research contribution

1.5.1 Business relevance

This research aimed to assist management in the mining industry in improving the acquisition of new technologies to facilitate the transition to sustainability. Mine management would become aware of the key issues hindering the successful adoption of Industry 5.0 technologies and gain insights into how these technologies can support sustainable mining practices. Additionally, exploring strategies to overcome obstacles to the adoption of Industry 5.0 technologies would be beneficial for strategic planning in mining management. This is particularly important for non-listed mining companies that collaborate with listed companies, and for listed companies that are required to make Environmental and Social Governance (ESG) disclosures.

This report holds significant business implications, particularly regarding the mining industry's transition to sustainability via the implementation of Industry 5.0 technology. As mining firms encounter heightened scrutiny from stakeholders concerning their ESG practices, comprehending the obstacles to technology adoption is essential for successful management and strategic planning. This research provides a comprehensive understanding of the challenges in integrating Industry 5.0 technologies in mining management. It emphasises the need to align technology adoption with sustainable practices, fostering a corporate culture that prioritises sustainability. Additionally, the research contributes to sustainable resource management by providing empirical evidence and theoretical insights, aiding mining companies to transition and promote responsible practices.

This study's business relevance is its capacity to provide mining management with the knowledge and strategies essential for navigating technology adoption complexities, improving sustainability initiatives, and achieving long-term success in a competitive and environmentally aware market.

1.5.2 Theoretical relevance

This study enhances and validates the existing body of knowledge regarding the constraints on adopting Industry 5.0 technologies in the transition to sustainable mining. It illuminates the issues that hinder the adoption of these technologies for sustainability and transition within mines. The research also highlights the challenges the mining sector faces in implementing Industry 5.0 technology, particularly in achieving the TBL, which has slowed the adoption of these technologies. Additionally, the study offers new perspectives on how Industry 5.0 technologies support environmentally friendly mining methods. By exploring the underutilisation of Industry 5.0 technologies in the mining sector, especially in South Africa, the research aims to fill critical gaps in existing literature and advance theoretical frameworks.

The research examined Industry 5.0, a novel industrial revolution that amalgamates human intelligence with innovative technologies, including AI, robotics, and the IoT. It enhances previous frameworks by integrating socio-technical factors, offering a holistic perspective on the utilisation of these technologies to attain sustainable results in the mining industry. The research delineates obstacles to adoption within South Africa's mining industry, pinpointing organisational, economic, environmental, social, regulatory, and procedural impediments. The study produced empirical evidence through qualitative interviews with industry professionals, thereby supporting and contesting existing theories.

Furthermore, the study contributes to the discourse on sustainable mining practices, focusing on how advanced technologies can facilitate transitions toward more sustainable practices. It also lays the groundwork for future research by identifying key areas for further exploration and promoting continuous dialogue within the academic community.

1.6 Scope of research

The study's theoretical focus was on adoption barriers and new technologies of Industry 5.0. The literature on innovation adoption models and sustainability as they relate to transitions are incorporated. The literature also covered the techniques needed to address the barriers to the adoption of new technologies, as well as the limits that affect the TBL of economic, social, and environmental concerns of the sustainability transition and Industry 5.0.

Purposive sampling was used to determine the research's physical scope to draw the study border. The experts engaged in the supply chain process of South African mining purchases of new technologies are specified by the inclusion criteria. Developed nations and other industries have been the subject of several prior studies. Thus, to investigate the barriers to the adoption of Industry 5.0 new technologies, the emphasis of this study is on the mining industry in South Africa.

1.7 Outline of research report

The research report consists of seven chapters. Chapter 1 introduces the research and provides a background to the research problem. It states the business and theoretical relevance, research objectives and aims, research contribution, and research scope. Chapter 2 is a comprehensive literature review consisting of seven sections that cover all four research questions and their key constructs. Chapter 3 is the research question and sub-research questions summarised review as guided by the literature gaps. Chapter 4 is the research methodology chapter that highlights the choice of methodology made and the justification for the appropriateness of the choices that guide the research process. Chapter 5 presents the findings and Chapter 6 discusses the findings. Chapter 7 concludes the study, presenting the conclusions and suggesting recommendations.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter presents a comprehensive review of the literature, focusing on theoretical and empirical findings related to Industry 5.0 and the adoption of new technologies. It explores how these technologies facilitate sustainability transitions and identifies the constraining factors that hinder their adoption. Additionally, the chapter discusses strategies for overcoming these barriers and managing the associated costs and highlights current debates. Table 1 provides a roadmap of the literature reviewed.

Table 1. Literature Chapter Roadmap

Headings	2.2 Industry 5.0 new technologies	2.3 Constraints/costs to Industry 5.0 new technology adoption	2.4 How Industry 5.0 contributes to sustainable mining practices	2.5 Strategies to mediate/overcome the constraints to Industry 5.0 adoption
Sub-headings	2.2.1 Industry 5.0 technological evolution	2.3.1 Economic constraints/costs to Industry 5.0 technology adoption	2.4.1 Economic benefits	2.5.1 Economic benefits
Sub-headings	2.2.2 Industry 5.0 definitions	2.3.2 Environmental constraints/costs to Industry 5.0 technology adoption	2.4.2 Perceived environmental benefits	2.5.2 Environmental benefits
Sub-headings	2.2.3 Industry 5.0 types of technologies	2.3.3 Social constraints/costs to Industry 5.0 technology adoption	2.4.3 Perceived social costs	2.5.3 Social benefits
Sub-headings	2.2.4 Industry 5.0 and Triple Bottom Line			
Sub-headings	2.2.5 Industry 5.0 and sustainability transitions			
Sub-headings	2.2.6 Industry 5.0 technology adoption and mining			
	2.2.7 Reluctance	2.6 Research	Gaps	

	outcomes in adopting Industry 5.0 technologies			
		2.7 Conceptual	Framework	
		2.8 Conclusion		

To compile a robust body of literature on Industry 5.0 technologies and their implications for sustainability in the mining sector, a systematic search was conducted using five reputable academic databases: Google Scholar, Scopus, Web of Science, Elsevier, and Core. The search focused on articles published recently published and ensured access to high-quality research. Keywords and phrases such as “new technology adoption,” “Industry 5.0,” and “mining sustainability transitions” were employed to target the core themes of the research. Only peer-reviewed articles, including empirical studies, theoretical frameworks, and literature reviews, were included. Non-peer-reviewed articles and those older than 10 years were excluded to maintain the integrity of the literature review. A quality assessment was performed to filter out non-quality journals, ensuring that the research is grounded in high-quality, peer-reviewed sources. This systematic approach provides a solid foundation for further exploration and analysis.

2.2 Understanding the evolution of Industry 5.0 and its new technologies for sustainability

Building on the methodology, this section delves into the conceptualisation debates surrounding Industry 5.0, a relatively new concept for both scholars and industry professionals. The discussions encompass the evolution and definitions of Industry 5.0, highlighting the differences between Industry 4.0 and Industry 5.0. Key topics include the TBL, new technology adoption, types of technologies, transition aspects, and their application in the mining industry. Additionally, the reluctance outcomes to the adoption of Industry 5.0 technologies are discussed as found in the literature. By examining these elements, this section endeavours to provide a comprehensive understanding of how Industry 5.0 technologies can drive sustainability transitions in the mining sector.

2.2.1 Industry 5.0 new technologies evolution

Businesses across all industries are evolving due to the adoption of new technologies and emerging disruptive threats (Ceipek et al., 2021; Roblek et al., 2021). Theories by Kondratieff (1928) and Schumpeter (1932) on disruptive innovations and business cycles can be applied to analyse Industry 5.0 technologies. Schumpeter posits that new goods, production processes, and organisational structures drive economic progress through innovation and entrepreneurship, leading to economic growth but also a decline in existing companies, industries, and technologies (Asif et al., 2023).

The industrial landscape has undergone significant transformations marked by technological advancements. These industrial revolutions are global transformative events driven by the interaction between people and technology, leading to new economic, social, and political values and ways of thinking, acting, and existing (Roblek et al., 2021). Humans have always used technology to achieve higher productivity and better living conditions. Technology, driven by industrial revolutions, involves modifying nature to meet needs and includes hardware, software, skills, information, and procedures (Aheleroff et al., 2022; Asif et al., 2023).

Five major transformational events have been identified in the Industrial Revolution narrative (Aheleroff et al., 2022). Figure 1 shows these major industrial transformations.

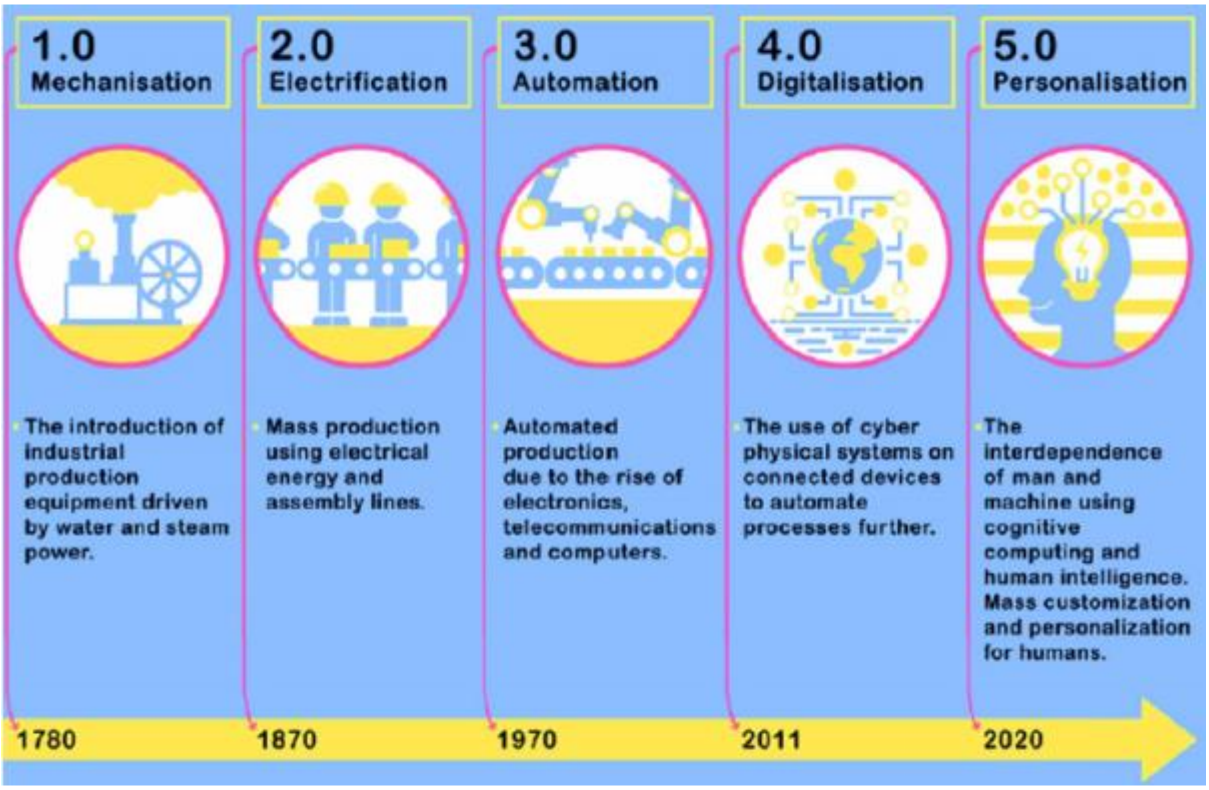

Figure 1. Timeline of the industrial revolution

Source: Aheleroff et al. (2022, p.12)

The first industrial revolution in the 18th century introduced agriculture, transportation, and factory machinery. The second one, in the early 20th century, brought mass production powered by electricity (Liao et al., 2018). The third, in the mid-1970s, saw the widespread use of electronics and IT in factories (Liao et al., 2018; Sonia & Lakonawa, 2021). In this decade there is the Fourth Industrial Revolution, or Industry 4.0, characterised by the IoT and digital transformation (Afolalu et al., 2021; Sonia & Lakonawa, 2021). Notably, this revolution came with the potential to significantly impact manufacturing, service delivery, and daily life (Sonia & Lakonawa, 2021).

Finally, the fifth industrial revolution introduces emerging digital technologies like AI, machine learning, IoT, additive manufacturing, edge and cloud computing, sophisticated robotics, and big data analytics (Aheleroff et al., 2022). However, these technologies are disrupting industries by altering employment, reducing costs, boosting sustainability, and changing industry functions (Calzada-Olvera & Iizuka, 2023; Greco et al., 2021). Nonetheless, researchers and decision-makers are keen on understanding the factors influencing the adoption of these technologies (Roberts et al., 2021).

Moreover, Industry 5.0 enhances information sharing through sensors, RFID, and IoT; enables decentralised transactions via blockchain; processes large data volumes with cloud computing and big data analytics; supports intelligent decision-making with machine learning and AI; and automates processes using drones and robotics (Horváth & Szabó, 2019). Industry 5.0 builds on Industry 4.0 to provide resilience, sustainability, and human-centric benefits (Asif et al., 2023; Pillai et al., 2021). In addition, whilst emphasising human-machine collaboration, Industry 5.0 ensures personalisation and trust among stakeholders, aligning with a holistic approach to business practices (Ahmed et al., 2023; Shakeel et al., 2020).

The next section reviews the definitions of Industry 5.0 by various researchers to understand the differentiating features of Industry 5.0 and I.4.0 technologies.

2.2.2 Industrial 5.0 definitions and focus

The term “Industry 5.0” emphasises a human-centric, resilient, and sustainable approach (Carayannis et al., 2024; Mukherjee et al., 2023; Sharma et al., 2024). It prioritises human needs in production, enhances resilience by minimising disruptions, and focuses on sustainability by reducing energy consumption and promoting resource reuse (Mukherjee et al., 2023).

Ivanov (2023) defines Industry 5.0 as a governance agenda driven by societal needs, highlighting technology-led digital transformation for sustainability. Rožanec et al. (2023)

suggest transitioning from Industry 4.0’s automation to Industry 5.0 to create new value through human capital. This shows varying perspectives, with some focusing on sustainability and others on human-centricity, sustainability, and resilience. Figure 2 summarises the main contrasting features of Industry 5.0 and I.4.0.

	Industry 4.0	Industry 5.0
Objective	• Smart manufacturing (smart mass production, smart products, smart working, smart supply-chain), • System(s) optimization.	• Sustainability, • Environmental stewardship, • Human-Centricity, • Social benefit.
Systemic Approaches	• Real-time data monitoring, • Integrated chain that follows through end of life-cycle phases.	• Utilization of technology ethically to advance human values and needs, • Socio-centric technological decisions, • 6R methodology and logistics efficiency design principles.
Human Factors	• Human Reliability, • Human-computer interaction, • Repetitive movements.	• Employee safety and management, • Learning/training for employees.
Enabling Technologies and Concepts	• Cloud Computing, • Internet of Things, • Big Data and Analytics, • Cyber Security, • Digitization (simulation, digital twins, artificial intelligence, augmented, virtual, or mixed technology), • Automation (advanced robotics, remote monitoring, autonomous robots, machine-to-machine communication), • Cyber-physical systems, • Horizontal and Vertical Integration (PLC, Supervisory Control and Data Acquisition (SCADA), Manufacturing Execution System (MES), Enterprise Resource Planning (ERP)), • Additive Manufacturing.	• Cloud Computing, • Internet Of Things, • Big Data and Analytics, • Cyber Security, • Digitization (simulation, digital twins, artificial intelligence, augmented, virtual, or mixed technology), • Human-machine-interaction, • Multi-lingual speech and gesture recognition, • Tracking technologies for mental and physical occupational strain, • Collaborative Robots, • Bio-Inspired safety and support Equipment, • Decision support systems, • Smart Grids, • Predictive maintenance.
Environmental Implications	• Systems are economic, • Waste prevention per data analytics, additive manufacturing, and optimized systems, • Increased material consumption, • Increased energy usage, • Extended product life cycle.	• Waste prevention and recycling, • Renewable Energy sources, • Energy-efficient data storage, transmission, and analysis, • Smart and energy-autonomous sensors.

Figure 2. Contrast of Industry 4.0 and Industry 5.0

Source: Pillai et al. (2021)

Figure 2 above shows that Industry 5.0 extends Industry 4.0, differing in objectives, systems approach, human factors, enabling factors, and environmental considerations. As such, Industry 4.0 focuses on technological innovations, automation, and data-driven efficiency, while Industry 5.0 emphasises sustainability, human-centricity, and societal well-being (Battini et al., 2022). The shift to Industry 5.0 acknowledges the need for industries to operate within ecological limits, reduce environmental impacts, and prioritise the well-being of the workforce and society (Karmaker et al., 2023).

Industry 5.0 aims to govern the digital industrial revolution in line with sustainability goals, addressing societal issues alongside wealth production (Enang et al., 2023; Mukherjee et al., 2023). It seeks to harmonise social progress, environmental conservation, and economic growth (Panagou et al., 2024). Seen as an extension of Industry 4.0, Industry 5.0 focuses on regulating technological advancements and addressing social and environmental flaws (Battini et al., 2022). It integrates disruptive technologies and important techno-functional design concepts (Ivanov, 2023).

Industry 5.0 relies on integrating various technologies, techno-functional concepts, and intelligent components to achieve a sustainable, productive, human-centric, and resilient future (Ivanov, 2023). Emerging technologies like robots and cognitive-like artificial intelligence (CAI) are starting to transform business and industry conventions (van Oudenhoven et al., 2023). The technical and functional design values essential for Industry 5.0 are complex and heavily dependent on its technology components (Modgil et al., 2023). It redefines concepts like horizontal integration, blending stakeholders smoothly, and creating a hyperconnected corporate environment that supports inclusive sustainability (Battini et al., 2022; Ivanov, 2022).

However, Industry 5.0 is still developing, with no consensus on its definition or framework. It balances Industry 4.0's digital revolution rules with the potential rise of a new industrial revolution driven by cutting-edge technologies like AI (Modgil et al., 2023). Moreover, achieving Industry 5.0 requires new economic orientations, supply chain designs, technological goals, policy partnerships, and a human-centric approach (Modgil et al., 2023; Oudenhoven et al., 2023).

2.2.3 Industry 5.0 and its new technologies

Modern advancements like machine vision, augmented and virtual realities, simulations, and AI are crucial for Industry 5.0, enhancing human skills and productivity (Pillai et al., 2021). Additionally, Industry 5.0 leverages both new and evolving technologies, such as generative AI, to foster innovation and create flexible ecosystems (Carayannis et al., 2024).

Industry 5.0 technologies are categorised into core (AI, IoT), supporting (big data, blockchain, cloud computing), and beneficial (digital twins, robotic collaborators) groups, requiring integration for effective operation (Mukherjee et al., 2023). It emphasises human-centric design, seamless connectivity, and sustainability, enhancing industrial performance through intelligent machine-human integration (Ivanov, 2023; Sharma et al., 2022). Meanwhile, cognitive robots in Industry 5.0 adapt to their environment, maintaining productivity while interacting safely with humans (Rožanec et al., 2022; Sharma et al., 2022).

2.2.4 Industry 5.0 and the Triple Bottom Line

Industry 5.0 emphasises the synergy between humans and machines, significantly influencing the mining industry's approach to environmental, social, and economic factors (Ivic et al., 2021; Jämsä-Jounela, 2019; Littleboy et al., 2019; Sánchez & Hartlieb, 2020). Figure 3 shows the relationship between the TBL and Industry 5.0.

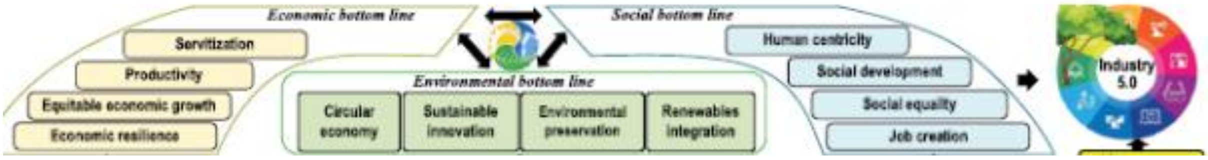

Figure 3. Industry 5.0 - triple bottom line

Source: Pillai et al. (2021)

The diagram shows what makes up the economic bottom line, social bottom line, and environmental bottom line in relation to Industry 5.0.

Advanced technologies like automation and data analytics enhance sustainability by optimising energy use, reducing waste, and improving resource efficiency (Dehran, 2018; Jämsä-Jounela, 2019). However, these technologies can displace jobs, potentially disrupting local communities, so companies must consider these social implications to avoid harming host communities (Jämsä-Jounela, 2019; Littleboy et al., 2019). Industry 5.0 can drive value creation through increased efficiencies and improved safety, though the high initial investment may be a barrier for smaller companies (Littleboy et al., 2019); Sánchez & Hartlieb, 2020).

Research shows Industry 5.0 supports a balanced approach to social, environmental, and economic sustainability (Ivanov, 2023; Pillai et al., 2021; Rodríguez-Espíndola et al., 2022). Technologies aim to enhance production, support local economies, and promote corporate equality (Mukherjee et al., 2023). Industry 5.0 challenges the take-make-waste model, promotes a circular economy and integrates renewable resources to tackle global sustainability issues (Mukherjee et al., 2023). Emphasising human and social aspects, Industry 5.0 focuses on re/upskilling the workforce, improving workplace safety, and enhancing societal resilience against crises (Ivanov, 2023; Mukherjee et al., 2023; Pillai et al., 2021).

2.2.5 Industry 5.0, sustainability and transitions

Industry 5.0 technologies enhance sustainability across environmental, social, and economic dimensions by balancing growth, protecting resources, and leveraging digital technology (Enang et al., 2023; Mukherjee et al., 2023). This transition addresses global sustainability challenges by promoting circular production models, efficient resource use, and renewable integration, supporting the UN's SDGs (Rožanec et al., 2022). It emphasises human-centric innovation, social responsibility, and ethical decision-making, aiming to re/upskill the workforce and enhance societal resilience (Carayannis et al., 2024; Mukherjee et al., 2023).

Despite potential barriers like high initial investments and resistance to change, Industry 5.0 supports sustainable business practices and stakeholder engagement (Littleboy et al., 2019; Sánchez & Hartlieb, 2020). Strategies to overcome these barriers include government support, capacity building, and collaborative ecosystems (Mukherjee et al., 2024). The integration of sustainability into digital transformation facilitates long-term shifts toward sustainable production and consumption (Ivanov, 2023). However, significant upfront investments and reorganisation are required, which may deter some businesses (Mukherjee et al., 2023). The 4C's rule—critical thinking, communication, cooperation, and creativity—plays a crucial role in assessing the value of human capital (Rožanec et al., 2022). Despite some resistance from employees, the shift toward a human-centric approach is essential for meeting Industry 5.0 expectations (Carayannis et al., 2024).

2.2.6 New technology adoption in mining and sustainability transitions

The mining industry has historically been slow to adopt new technologies, often relying on established processes. Taalbi (2017) identifies market competition, skilled labour, and access to financing as key drivers of innovation. Dehran (2018) highlights challenges in the Peruvian mining sector, such as economic and political instability, which hinder technology adoption. Despite resistance, the industry is increasingly recognising the benefits of digitalisation to address challenges like declining ore grades and rising costs (Dehran, 2018).

Gault (2018) notes that the mining industry's approach to innovation varies by company circumstances (Molina, 2018; Navarro, 2018; Taalbi, 2017). Structural barriers, such as worker safety hazards and corporate inertia, further impede technological adoption

(Masucci et al., 2020). The industry prefers status-quo technologies and often lacks capital for new concepts (Molina, 2018; Navarro, 2018).

Research on technology adoption and sustainability transitions emphasises the role of policy mixes in driving innovation (Edmondson et al., 2019; Kivimaa & Kern, 2016). Sustainable entrepreneurship and multi-level perspectives on transitions highlight the need for coordinated efforts across different levels of the socio-technical system (Boons et al., 2013; Meadowcroft, 2011). Politics also plays a crucial role in sustainability transitions, acting as both enablers and obstacles (Meadowcroft, 2011).

The literature on sustainability transitions is expanding, but few studies examine miners' reluctance to adopt new technology (Edmondson et al., 2019). Moreover, the adoption of environmentally friendly technology is crucial for mining sustainability transitions (Kivimaa & Kern, 2016; Musango & Mugabe, 2024).

Industry 5.0 technologies aim to balance economic, environmental, and social values through standardised, disruptive, and emergent technologies, creating human-centricity, sustainability, and resilience in industries. These technologies complement and extend previous industrial revolutions, promoting a TBL approach (Mukherjee et al., 2023). However, the mining industry remains sluggish in adopting these new technologies, highlighting the need for further insights into the Industry 5.0 concept in mining.

2.2.7 Reluctance outcomes in adopting new technologies

The following are the main reluctant outcomes as found in the literature:

2.2.7.1 Economic reluctant outcomes

According to Edmondson et al. (2019), the mining industry frequently has trouble defending the expenses of new technology, especially when the advantages are not readily apparent. This makes people reluctant to spend money on Industry 5.0 technology. According to Enang et al. (2023), mining businesses' reluctance to embrace Industry 5.0 technologies is partly due to the absence of precise financial models for evaluating their economic feasibility. Furthermore, Simboli et al. (2014) contend that the mining sector frequently loses out on possibilities to implement technology that might improve operational efficiency and sustainability due to its cautious attitude to cost concerns.

2.2.7.2 Social reluctant outcomes

The adoption of Industry 5.0 technologies in the mining industry faces various social reluctance outcomes that hinder progress towards sustainable practices. Social reluctance can manifest in several ways, including resistance to change, lack of trust in new technologies, and concerns about job displacement. One of the primary social barriers to adopting Industry 5.0 technologies is the inherent resistance to change within organisations. Brown et al. (2020) opine that employees often exhibit scepticism towards new technologies due to fear of the unknown and potential disruptions to established workflows. This resistance can be exacerbated in the mining sector, where traditional practices are deeply ingrained. The study emphasises the need for effective change management strategies to facilitate smoother transitions.

Trust in the reliability and effectiveness of new technologies is crucial for their adoption. Lee et al. (2023) argue that mining companies must prioritise building trust among employees regarding the integration of Industry 5.0 technologies. The lack of understanding of how these technologies can be integrated sustainably into existing operations often leads to reluctance. The authors suggest that comprehensive training and transparent communication can help alleviate these concerns.

The fear of job loss due to automation and advanced technologies is a significant social concern. Ivanovic (2023) highlights that employees in the mining sector are often apprehensive about the implications of Industry 5.0 technologies on their job security. This fear can lead to resistance against adopting new technologies, as workers may perceive them as threats rather than opportunities for enhancement. The study calls for initiatives that emphasise upskilling and reskilling to mitigate these fears.

Cultural attitudes towards technology and innovation also play a role in social reluctance. Osei et al. (2023) indicate that in some mining communities, there is a cultural preference for traditional methods over modern technologies. This cultural inertia can hinder the adoption of Industry 5.0 technologies, as employees may feel more comfortable with familiar practices. The authors recommend fostering a culture of innovation through leadership support and community engagement. The adoption of Industry 5.0 technologies must also consider social equity and inclusion. Chaudhuri et al. (2024) emphasise that marginalised groups within the mining workforce may face additional barriers to technology adoption. Ensuring that all employees have equal access to training and opportunities related to Industry 5.0 technologies is essential for fostering a more inclusive environment.

2.2.7.3 Environmental reluctant outcomes

Gonzales et al. (2021) discuss the environmental challenges associated with adopting new technologies in the mining sector, emphasising that companies are often hesitant due to fears of exacerbating environmental degradation. Additionally, Smith and Jones (2022) highlight that the unpredictability of environmental impacts from new technologies leads to reluctance among mining companies to adopt Industry 5.0 solutions, as they seek to avoid potential long-term harm to ecosystems. Lee et al. (2023) also argue that mining companies must prioritise environmental sustainability in their technology adoption strategies, as failure to do so can lead to significant reputational and regulatory risks. However, Brown et al. (2020) emphasise that environmental reluctance outcomes are often rooted in a lack of understanding of how new technologies can be integrated sustainably into existing operations.

The rationale behind exploring the Industry 5.0 concept was to understand its new technologies and how they facilitate sustainability transition in industry. In summary, this section has set out the review the key concepts of this study to understand and bring insights into what Industry 5.0 revolution and its technologies mean to industry. Industry 5.0 technologies are shown as an evolving, transformative, adaptive, collaborative process that is aimed at balancing economic, environmental, and social values using standardised, disruptive, and emergent technologies to create human centricity, sustainability, and resilience in industries. Industry 5.0 technologies complement, extend and replace old (1-4) industry revolutions' technologies. Moreover, the Industry 5.0 technologies bring a TBL approach to balance increased production that comes with reduced environmental impact and increased employee and societal concern. Therefore, Industry 5.0 technologies are regarded in the literature as a transition towards resilience that brings sustainability to an organisation to solve current environmental and societal challenges facing nations due to industrialisation. However, the mining industry is reported to be sluggish in its approach to adopting these new technologies, hence the need to gain insights into how the Industry 5.0 concept is understood in mining and its respective reluctant outcomes to the adoption of Industry 5.0 technologies.

2.3 Constraints impacting the adoption of Industry 5.0 technologies in sustainability transitions

2.3.1 Economic constraints/costs

The adoption of Industry 5.0 technologies in the mining sector is crucial for enhancing sustainability and operational efficiency. However, various economic constraints hinder this transition. Economic constraints represent a significant barrier to the adoption of Industry 5.0 technologies in the mining sector, where the financial implications of new technology implementation can be particularly pronounced (Osei et al., 2023).

2.3.1.1 Capital costs

High establishment expenses for novel technologies, including renewable energy, pose significant financial barriers to adoption (Dwivedi & Paul, 2022). The initial capital investment for advanced technologies like automation, AI, and data analytics can be substantial, often reaching millions of dollars, deterring SMEs from pursuing innovative solutions (Rodríguez-Espíndola et al., 2022). The perceived low ROI from sustainable technologies can lead decision-makers to prioritise short-term financial stability over long-term sustainability goals, especially in the cyclical mining industry where economic downturns result in budget cuts and reduced innovation investment (Osei et al., 2023). The uncertainty surrounding ROI for these technologies deters companies from investing, as many mining firms hesitate without clear evidence of long-term economic benefits (Battini et al., 2022).

Access to financing is a significant economic constraint impacting the adoption of Industry 5.0 technologies in mining. Many mining companies, particularly small and medium-sized operations, struggle to secure funding for technology investments due to perceived risks and uncertainties associated with new technologies (Taalbi, 2017). This lack of access to capital can hinder innovation and slow the transition to sustainable practices.

There is ongoing debate regarding the most effective financing models to support the adoption of Industry 5.0 technologies in mining. Some researchers advocate for public-private partnerships (PPPs) to share risks and leverage resources (Horváth & Szabó, 2019). Others argue that traditional financing models, such as loans and equity investments, remain the most viable options for mining companies (Cao et al., 2021). This disagreement underscores the need for further exploration of innovative financing mechanisms that can facilitate technology adoption in the mining sector.

2.3.1.2 Infrastructure costs

The transition to Industry 5.0 technologies often requires significant infrastructure upgrades, as many mining operations rely on outdated systems incompatible with new technologies (Verhoef et al., 2021). This includes investments in digital infrastructure like high-speed internet and data management systems, as well as physical infrastructure improvements (Aheleroff et al., 2022). These costs can be prohibitive, especially for companies in regions with limited access to advanced infrastructure, deterring them from pursuing innovative solutions in a sector with fluctuating commodity prices and profit margins.

Integrating new technologies with legacy systems poses further economic challenges. Many mining companies operate with outdated equipment and processes that may not be compatible with Industry 5.0 technologies. The costs associated with retrofitting or replacing existing systems can be substantial, leading to resistance to adopting new technologies (Carayannis et al., 2024). This highlights a critical research gap in understanding the economic implications of infrastructure integration and the strategies that can be employed to mitigate these costs.

2.3.1.3 Operational costs and efficiency

Operational costs for Industry 5.0 include training personnel, maintaining new technologies, and potential disruptions during the transition (Sharma et al., 2022). Specialised skills required for advanced technologies add to these costs, necessitating extensive training or hiring new talent. Short-term operational costs can increase due to ongoing maintenance, software updates, and employee training (Roberts et al., 2021). These costs may deter mining companies from adopting new technologies if perceived to outweigh the benefits.

Traditional cost-benefit analysis (CBA) methods may not fully capture the benefits of Industry 5.0 technologies, such as improved safety and sustainability (Cao et al., 2021). A more comprehensive CBA, including qualitative factors, is needed to assess economic impacts accurately (Stroh et al., 2023). Cyber-physical systems, the IoT, AI, and digital twins have the potential to contribute to automated and digital manufacturing environments, aiding in the achievement of sustainability in business practices (Jamwal et al., 2021; Sharma et al., 2022). According to Mukherjee et al. (2023), the strategy for Industry 5.0 technologies sustainability focuses primarily on social and ecological variables, such as lowering energy consumption and resource reuse. In a similar vein, Enang et al. (2023) contend that Industry 5.0 is an agenda driven by society that seeks to govern the digital industrial revolution in a manner consistent with sustainability objectives.

Moreover, smart factories powered by Industry 5.0's digital industrial revolution include other smart elements like smart consumers and goods to create a hyperconnected corporate environment that supports inclusive sustainability (Ivanov, 2022). Industry 5.0 technologies not only tackle waste elimination, lower emissions, and improve the efficiency of resources and the integration of renewables at the production as well as distribution levels, but also tackle the growing global sustainability issues like product recyclability, rebound effects, and shorter life cycles (Carayannis et al., 2024; Mukherjee et al., 2023). As such, Mukherjee et al. (2023) state that Industry 5.0 technologies are intended to enhance sustainability in every facet, including the environment, society, and economy.

Horváth and Szabó (2019) argue for process computerisation using robotic systems and drones. Furthermore, the literature shows that large volumes of data may be processed using AI-based algorithms (Shrestha et al., 2019; Trunk et al., 2020). This is comparable to Dehran's (2018) earlier argument that process improvements might be essential to preserving sustainability and competitiveness over the long run. Modern technologies, such as the IoT, machine learning, and AI, build intelligent, networked systems that maximise resource use, minimise waste, and encourage socio-environmentally conscious behaviour (Greco et al., 2021). Additionally, Industry 5.0's real-time data insights facilitate manufacturing process optimisation, leading to more streamlined and effective operations (Mukherjee et al., 2023). Thus, businesses may continuously monitor and optimise their energy and resource use with the help of Industry 5.0 technology (Ivanov, 2023; Pillai et al., 2021; Sharma et al., 2022).

2.3.1.4 Market volatility and economic uncertainty

The mining sector's susceptibility to market volatility and economic uncertainty impacts investment decisions. Fluctuations in commodity prices can reduce profit margins, making it difficult for companies to justify investing in new technologies (Mukherjee et al., 2023). This instability creates a barrier to adopting Industry 5.0 technologies, as companies may prioritise short-term financial stability over long-term advancements. During low-price periods, mining companies often focus on cost-cutting rather than new investments (Asif et al., 2023). Scholars agree that developing economic resilience through diversifying revenue streams, investing in sustainable practices, and adopting efficiency-enhancing technologies can help mining companies navigate market fluctuations and invest in Industry 5.0 technologies, even in challenging conditions (Sharma et al., 2022).

2.3.1.5 Outsourcing costs

In certain organisations, a lack of technical, financial, or human resources makes it necessary for the company to locate a suitable supplier to achieve the intended outcomes, and this outsourcing can be costly (Bag et al., 2021).

Economic limitations, such as elevated capital and infrastructure expenditures, persistent operational costs, and perceived minimal ROI, provide substantial obstacles to the implementation of Industry 5.0 technologies in the mining industry. Confronting these problems necessitates a comprehensive strategy that includes strategic alliances, focused policy measures, and an openness to fostering a culture of ongoing enhancement and innovation.

In summary, this literature review shows that while the economic constraints impacting the adoption of Industry 5.0 technologies in mining sustainability transitions are well-documented, significant research gaps remain. Addressing these gaps through empirical studies, cost-benefit analyses, and sector-specific models will be crucial for facilitating the transition to Industry 5.0 in the mining sector. By understanding and mitigating the economic barriers, mining companies can better position themselves to embrace technological advancements that promote sustainability and operational efficiency.

2.3.2 Environmental constraints/costs

The transition to Industry 5.0 technologies in mining is essential for enhancing sustainability and addressing environmental challenges. However, various environmental constraints hinder this adoption, as highlighted in the literature.

The mining industry is under examination of its ecological consequences, particularly habitat destruction, water contamination, and greenhouse gas emissions. (van Sluisveld et al., 2020). Companies may hesitate to adopt advanced technologies due to fears of exacerbating these issues. Environmental compliance costs, including investments in management systems and remediation efforts, can be significant. The lack of clear guidelines and standards for evaluating the environmental impact of Industry 5.0 technologies complicates decision-making (van Sluisveld et al., 2023; Pillai et al., 2021).

Many new technologies lack development in recycling practices and resource conservation, making reprocessing difficult without sufficient infrastructure (Edmondson et al., 2019; Enang et al., 2023). Aligning integrated assessment modelling with socio-technical transition insights is crucial for developing low-carbon energy scenarios (Shakeel et al., 2020). Industrial ecology aims to address environmental concerns, but more integration of efficiency and sustainable practices is needed (Simboli et al., 2014).

Mining companies may face financial and reputational costs when adopting new technologies that align with sustainability goals. Developing economic resilience through diversifying revenue streams, investing in sustainable practices, and adopting efficiency-enhancing technologies can help navigate these challenges.

2.3.2.1 Regulatory compliance and environmental standards

Complex regulatory frameworks governing environmental compliance are a primary constraint on adopting Industry 5.0 technologies in mining. Stringent regulations aimed at minimising ecological impacts can complicate the integration of new technologies, leading to delays (Friedman & Ormiston, 2022). Additionally, the rapid evolution of environmental standards creates uncertainty, as firms may hesitate to invest in technologies that could soon become obsolete or non-compliant (Cao et al., 2021). This highlights a critical research gap in understanding how regulatory changes influence technology adoption decisions in the mining sector.

2.3.2.2 Environmental Impact Assessments

The requirement for comprehensive Environmental Impact Assessments (EIAs) before implementing new technologies can cause significant delays and costs for mining companies. The lengthy and resource-intensive EIA process can deter firms from pursuing innovative, sustainability-enhancing technologies (Horváth & Szabó, 2019). Additionally, uncertainty surrounding EIA outcomes can foster a risk-averse culture within mining organisations, as companies may fear unfavourable assessments or additional regulatory hurdles (Roberts et al., 2021). This highlights the need for research focused on streamlining EIA processes and understanding their impact on technology adoption.

2.3.2.3 Environmental awareness and Corporate Social Responsibility

Another significant constraint is the varying levels of environmental awareness among stakeholders in the mining industry. While some companies prioritise sustainability and are eager to adopt Industry 5.0 technologies, others may lack the necessary awareness or commitment to environmental stewardship (Stroh et al., 2023). This disparity can hinder collective progress toward sustainability transitions.

Furthermore, the pressure from stakeholders, including investors, communities, and regulatory bodies, can influence the adoption of new technologies. Companies that fail to align their operations with environmental expectations may face reputational risks and financial penalties (Asif et al., 2023). This highlights a research gap in understanding how stakeholder pressures shape technology adoption decisions in the mining sector.

2.3.2.4 Technological compatibility and environmental performance

The compatibility of Industry 5.0 technologies with existing mining practices is another environmental constraint. Many mining operations rely on traditional methods that may not easily integrate with advanced technologies (Mukherjee et al., 2023). The environmental performance of new technologies must be demonstrated to justify their adoption, which can be challenging when existing practices are deeply entrenched.

Moreover, there is often a lack of clear metrics to assess the environmental benefits of adopting Industry 5.0 technologies. Without robust evaluation frameworks, mining companies may struggle to quantify the positive impacts of new technologies on sustainability, leading to hesitance in adoption (Taalbi, 2017). This indicates a need for research focused on developing standardised metrics for evaluating the environmental performance of Industry 5.0 technologies.

In summary, this literature review shows that while the environmental constraints impacting the adoption of Industry 5.0 technologies in mining sustainability transitions are well-documented, significant research gaps remain. Addressing these gaps through empirical studies, streamlined processes, and standardised metrics is crucial for facilitating the transition to Industry 5.0 in the mining sector. By understanding and mitigating the environmental barriers, mining companies can better position themselves to embrace technological advancements that promote sustainability and ecological responsibility.

2.3.3 Social constraints/costs

The transition to Industry 5.0 technologies in the mining sector represents a significant technological and social transformation. While these technologies promise enhanced sustainability and efficiency, they also introduce various social constraints that can impede their adoption.

2.3.3.1 Job losses and workforce displacement

The introduction of collaborative robots and automation technologies raises concerns about job displacement and the erosion of traditional roles within the workforce, leading to resistance from employees (Cao et al., 2021). Advanced technologies like AI and robotics may displace many workers, causing fear and resistance among employees and unions (Mukherjee et al., 2023). The transition to Industry 5.0 requires new skills, but many current employees lack the necessary training, exacerbating job displacement concerns (Friedman & Ormiston, 2022). Effective training and employee engagement are critical to overcoming resistance, with comprehensive programs needed to equip employees with new skills and address job security concerns (Mukherjee et al., 2023). One of the primary social constraints identified in the literature is the resistance to change in the workforce. Many studies indicate that employees may be apprehensive about adopting new technologies due to fears of job displacement, changes in work processes, and the need for new skills (Cao et al., 2021; Stroh et al., 2023). This resistance can slow down the adoption of Industry 5.0 technologies, as companies may face pushback from employees who are not ready to embrace these changes.

2.3.3.2 Community cohesion and social acceptance

Social acceptance is crucial for implementing new technologies in mining. Communities may resist due to fears of losing cultural identity, economic stability, and social networks, viewing these technologies as threats to their livelihoods (Molina, 2018; Navarro, 2018; Stroh et al., 2023). This highlights the need for research on strategies to engage communities and address their concerns during the technology adoption process. The adoption of Industry 5.0 technologies can disrupt local communities, particularly in regions heavily reliant on traditional mining practices. The introduction of new technologies may lead to changes in employment patterns, economic structures, and social dynamics, potentially undermining community cohesion (Asif et al., 2023).

The literature indicates that new technologies in mining can lead to job losses or changes in employment patterns, potentially worsening social inequalities and creating tensions between mining companies and local communities (Asif et al., 2023). The adoption of Industry 5.0 technologies may further exacerbate these inequalities, benefiting those with access to education and training while leaving marginalised groups behind, raising concerns about equitable access, and increased social stratification (Taalbi, 2017).

2.3.3.3 Role of Corporate Social Responsibility

There is a divergence of opinions regarding the role of Corporate Social Responsibility (CSR) in mitigating social costs. Some researchers argue that proactive CSR initiatives can help address community concerns and foster positive relationships between mining companies and local stakeholders (Friedman & Ormiston, 2022). Conversely, others contend that CSR efforts are often insufficient and may serve as a mere public relations tool rather than a genuine commitment to social equity (Horváth & Szabó, 2019). This disagreement highlights the need for further exploration of how CSR can be effectively integrated into the adoption of Industry 5.0 technologies.

2.3.3.4 Machine-human interface dangers

The integration of advanced technologies in mining operations poses significant safety concerns due to the machine-human interface. As machines become more autonomous, the risk of accidents and injuries increases, especially if workers are not professionally trained (Cao et al., 2021). Additionally, working alongside advanced technologies can cause anxiety and stress among employees, potentially decreasing morale, and productivity. This highlights a need for research on the psychological effects of technology adoption in the mining sector and ways to mitigate these impacts (Horváth & Szabó, 2019). The widespread substitution of robots for human labour also raises ethical issues related to employment roles and decision-making processes (Mukherjee et al., 2023). Human-robot co-working may lead to psychological problems due to the absence of social connections (Ivanov, 2023).

2.3.3.5 Cost-benefit analyses

There is a lack of consensus on how to effectively conduct cost-benefit analyses that incorporate social costs. Some researchers advocate for comprehensive frameworks considering both financial and social impacts (Cao et al., 2021). Others argue that such analyses are inherently subjective and may not accurately capture the complexities of social dynamics in mining communities (Stroh et al., 2023). This highlights the need for more robust methodologies to better account for social costs in technology adoption decisions.

2.3.3.6 Cultural factors

Cultural factors play a significant role in adopting new technologies. In some mining communities, there may be a strong attachment to traditional practices and scepticism toward new technologies, hindering the acceptance and integration of Industry 5.0 technologies. Research is needed to address cultural attitudes to facilitate smoother transitions. Within organisations, entrenched cultures may resist integrating new technologies, particularly if they challenge established norms and practices (Taalbi, 2017). This resistance can hinder innovation and slow down the transition to more sustainable practices.

2.3.3.7 Union resistance and concerns

Friedman and Ormiston (2022) emphasise how crucial it is to involve stakeholders in the process of adopting new technologies. They contend that inaction might result in opposition and misconceptions, which will eventually make implementation more difficult. Horváth and Ssabó (2019) note that incorporating new technology might cause confusion among workers and opposition from unions by upending existing roles and duties.

In summary, while adopting Industry 5.0 technologies in the mining sector holds significant promise for enhancing sustainability, various social constraints must be addressed. Job losses, community cohesion, union concerns, machine-human interface dangers, and other social costs present challenges that can impede the transition. By identifying and addressing these constraints through targeted research and engagement strategies, mining companies can better navigate the complexities of technological adoption and foster a more sustainable and socially responsible future.

2.3.4 Regulatory constraints/costs

Regulatory constraints represent a critical barrier to the adoption of Industry 5.0 technologies in mining. The industry is governed by a complex web of regulations related to environmental protection, worker safety, and operational practices. Existing regulations may not adequately address the unique challenges posed by new technologies, creating uncertainty, and deterring investment (Karmaker et al., 2023).

2.3.4.1 Regulatory frameworks and compliance

The complexity and rigidity of existing regulations in the mining industry are significant barriers to adopting Industry 5.0 technologies. Outdated regulatory frameworks do not accommodate rapid technological advancements, making compliance time-consuming and costly (Mukherjee et al., 2023). Researchers agree that regulatory reform is necessary to facilitate the adoption of these technologies. Scholars like Friedman and Ormiston (2022) and Horváth and Szabó (2019) advocate for flexible and adaptive regulations to encourage innovation and investment, supporting sustainability transitions in mining.

2.3.4.2 Environmental regulations

Environmental regulations significantly impact the adoption of Industry 5.0 technologies in mining. While these regulations promote sustainability, they also pose challenges due to their complexity and stringency (Cao et al., 2021). Mining companies often prioritise compliance over innovation, facing difficulties with various local, national, and international laws (Friedman & Ormiston, 2022). Researchers agree that regulatory frameworks need to evolve to encourage innovation while ensuring environmental protection (Mukherjee et al., 2023). However, opinions differ on balancing environmental protection and technological innovation. Some argue that stringent regulations stifle innovation (Taalbi, 2017), while others believe robust regulations are necessary to prevent exacerbating environmental issues (Asif et al., 2023).

For instance, conducting Environmental Impact Assessments (EIAs) is another significant constraint, as they can be time-consuming and costly (Roberts et al., 2021). There is no consensus on the best methodologies for EIAs, with some advocating for dynamic processes and others for traditional frameworks (Cao et al., 2021; Stroh et al., 2023).

Despite initial financial burdens, the long-term environmental benefits of Industry 5.0 technologies can outweigh the costs, encouraging companies to view technology adoption as a strategic investment (Sharma et al., 2022). The maturity of these technologies also affects their adoption, with companies hesitant to invest in unproven innovations (Taalbi, 2017). Opinions vary on the effectiveness of pilot projects in demonstrating environmental benefits, highlighting the need for more empirical studies (Cao et al., 2021; Horváth & Szabó, 2019).

2.3.4.3 Health and safety regulations

Health and safety regulations are crucial in the mining sector, especially with the introduction of new technologies. Stringent requirements can slow down the adoption of Industry 5.0 technologies, as companies must ensure compliance before implementation (Stroh et al., 2023). While maintaining high safety standards is widely supported, some scholars argue that current regulations may not adequately address the challenges posed by new technologies like automation and AI (Horváth & Szabó, 2019). This indicates a need for regulatory updates that consider the implications of Industry 5.0 technologies on worker safety.

2.3.4.4 Licensing and approval processes

The licensing and approval processes for new technologies in the mining sector can be lengthy and bureaucratic, serving as significant regulatory constraints. These delays can discourage companies from pursuing innovative solutions (Mukherjee et al., 2023). While many researchers advocate for streamlining licensing processes to facilitate technology adoption, opinions differ on how to achieve this. Some suggest a collaborative approach between regulators and industry stakeholders for more efficient processes (Friedman & Ormiston, 2022), while others caution that hastening approval without adequate oversight could lead to negative environmental and social outcomes (Asif et al., 2023). This disagreement underscores the complexity of regulatory reform in the mining sector.

In summary, this section shows that researchers have exposed regulatory frameworks, environmental regulations, health and safety regulations, and licensing and approval processes constraints. Most researchers concur new technologies bring about high costs. These new technologies initially come in the absence of substantial regulations, laws, and standards.

2.4 How Industry 5.0 technologies contribute to sustainable mining practices.

2.4.1 Perceived economic benefits

2.4.1.1 Operational efficiency and cost reduction

The integration of Industry 5.0 technologies, such as automation, AI, and IoT, enhances operational efficiency in mining. These technologies optimise processes, reduce downtime, and improve resource allocation, leading to lower operational costs and increased productivity (Carayannis et al., 2024).

For example, AI-powered predictive maintenance minimises equipment failures, translating into higher profit margins and better resource allocation toward sustainable practices. Horváth and Szabó (2019) argue for process computerisation using robotic systems and drones.

Furthermore, literature shows that large volumes of data can be processed using AI-based algorithms (Shrestha et al., 2019; Trunk et al., 2020). This is comparable to Dehran's (2018) earlier argument that process improvements might be essential to preserving sustainability and competitiveness over the long run.

Modern technologies, such as the IoT, machine learning, and AI, build intelligent, networked systems that maximise resource use, minimise waste, and encourage socio-environmentally conscious behaviour (Greco et al., 2021).

Additionally, Industry 5.0's real-time data insights facilitate manufacturing process optimisation, leading to more streamlined and effective operations (Mukherjee et al., 2023). Thus, businesses may continuously monitor and optimise their energy and resource use with the help of Industry 5.0 technology (Ivanov, 2023; Pillai et al., 2021; Sharma et al., 2022).

2.4.1.2 Agreements on long-term cost savings

There is a consensus in the literature that while the initial investment in Industry 5.0 technologies may be high; the long-term cost savings can be substantial. Studies indicate that technologies such as IoT and blockchain can optimise resource management and supply chain processes, resulting in lower operational costs and increased profitability (Roberts et al., 2021). This perspective encourages mining companies to view technology adoption as a strategic investment that can yield significant economic returns over time.

2.4.1.3 Creation of a circular economy

Industry 5.0 technologies promote the development of a circular economy in mining by enabling recycling, waste reduction, and resource recovery. Advanced material recovery techniques reduce the need for virgin materials, lowering extraction costs and minimising environmental impact (Pillai et al., 2021). This shift enhances economic resilience and aligns with global sustainability goals, making mining operations more competitive in an eco-conscious market.

2.4.1.4 Adoption of clean energy solutions

Industry 5.0 technologies can promote the implementation of sustainable energy solutions while enhancing economic advantages. Mining firms can diminish their dependence on fossil fuels and achieve reduced energy expenses and improved energy security by incorporating renewable energy sources like solar and wind into their operations (Horváth & Szabó, 2019).

The enduring financial benefits of adopting clean energy can be significant, enabling organisations to reinvest in sustainable programs and technology that further improve their operational sustainability. Literature findings were clear that Industry 5.0 technologies, such as cyber-physical systems, the IoT, AI, and digital twins, have the potential to contribute to automated and digital manufacturing environments, ultimately aiding in the achievement of sustainability in business practices (Jamwal et al., 2021; Sharma et al., 2022).

According to Mukherjee et al. (2023), the strategy for Industry 5.0 technologies sustainability focuses primarily on social and ecological variables, such as lowering energy consumption and resource reuse. In a similar vein, Enang et al. (2023) contend that Industry 5.0 is an agenda driven by society that seeks to govern the digital industrial revolution in a manner consistent with sustainability objectives. Moreover, smart factories powered by Industry 5.0's digital industrial revolution include other smart elements like smart consumers and goods to create a hyperconnected corporate environment that supports inclusive sustainability (Ivanov, 2022).

Industry 5.0 technologies not only tackle waste elimination, lower emissions, and improve the efficiency of resources and the integration of renewables at the production as well as distribution levels, but also tackle the growing global sustainability issues like product recyclability, rebound effects, and shorter life cycles (Carayannis et al., 2024; Mukherjee et al., 2023). As such, Mukherjee et al. (2023) state that Industry 5.0 technologies are intended to enhance sustainability in every facet, including the environment, society, and economy.

2.4.1.5 Enhanced safety and risk management

The integration of Industry 5.0 technologies can lead to enhanced safety measures in mining operations, which have significant economic implications. Technologies such as drones, remote monitoring, and AI-driven safety systems can reduce workplace accidents and improve compliance with safety regulations (Friedman & Ormiston, 2022).

The economic benefits of improved safety include reduced insurance costs, lower liability risks, and enhanced employee productivity.

There is a general agreement among researchers that investments in safety technologies yield positive economic returns. Studies indicate that companies that prioritise safety through technology adoption often experience lower accident rates and associated costs, leading to improved overall performance (Horváth & Szabó, 2019). This consensus underscores the importance of integrating safety considerations into the economic evaluation of Industry 5.0 technologies.

2.4.1.6 Workforce and human capital development

Industry 5.0 technologies necessitate a skilled workforce capable of operating and maintaining advanced systems. Researchers emphasise that investing in employee training and development is crucial for maximising the economic benefits of technology adoption (Taalbi, 2017). By enhancing workforce skills, mining companies can improve operational efficiency and innovation, leading to better economic outcomes.

While the importance of workforce development is widely acknowledged, there are disagreements regarding the effectiveness of training programs. Some studies suggest that traditional training methods may not adequately prepare employees for the complexities of Industry 5.0 technologies (Molina, 2018). Others argue that tailored training programs that incorporate hands-on experience and continuous learning can significantly enhance employee performance and technology adoption (Navarro, 2018). This divergence highlights the need for further research on effective training strategies in the context of Industry 5.0 technologies.

2.4.2 Perceived environmental benefits

2.4.2.1 Reduction of carbon emissions

The implementation of Industry 5.0 technologies, especially renewable energy sources like solar and wind power, can markedly diminish the carbon footprint of mining activities (Horváth & Szabó, 2019). Researchers emphasise that the use of renewable energy not only reduces environmental impact but also conforms to global sustainability objectives. There is agreement that shifting to renewable energy is essential for minimising the environmental effects of mining, with research indicating significant decreases in greenhouse gas emissions, thereby aiding in climate change mitigation (Carayannis et al., 2024). This highlights the significance of integrating renewable energy into mining as a fundamental component of sustainable operations.

2.4.2.2 Waste management and resource efficiency

Industry 5.0 technologies enhance waste management in mining by using advanced data analytics and IoT to optimise waste sorting and recycling, reducing waste and promoting resource recovery (Sharma et al., 2022). While some argue that high costs and complexity deter adoption (Cao et al., 2021), others believe long-term benefits and regulatory pressures will drive it, with financial incentives aiding the transition (Asif et al., 2023). Further exploration of barriers and enablers is needed.

Furthermore, the integration of IoT devices and sensors allows for real-time tracking of environmental parameters like air and water quality. This enables mining companies to respond swiftly to potential environmental hazards, mitigating risks and enhancing compliance with regulatory requirements, thus reducing the likelihood of fines and reputational damage.

2.4.2.3 Biodiversity and ecosystem protection

Industry 5.0 technologies can mitigate the environmental impact of mining on biodiversity and ecosystems. Remote sensing and environmental monitoring systems help companies manage their environmental footprint more effectively (Friedman & Ormiston, 2022). Real-time ecosystem monitoring allows for measures to minimise habitat destruction and protect biodiversity.

Researchers agree that effective environmental monitoring is crucial for sustainable mining, leading to better compliance with regulations and improved CSR practices (Horváth & Szabó, 2019). According to Carayannis et al. (2024), incorporating smart technology into mining can result in improved environmental management techniques, which are crucial for maintaining biodiversity and guaranteeing sustainable mining operations. Moreover, according to Asif et al. (2023), the application of IoT and sophisticated data analytics in mining improves resource recovery and waste management, which obliquely supports biodiversity conservation by lessening the total environmental effect of mining operations.

This consensus highlights the need for mining companies to invest in monitoring technologies as part of their sustainability strategies.

2.4.2.4 Water management and conservation

Water management is a critical concern in mining. Industry 5.0 technologies, such as smart water management systems and real-time monitoring, can enhance water conservation and management (Taalbi, 2017). These technologies help reduce water consumption, prevent contamination, and ensure sustainable water use. While the benefits are acknowledged, some researchers argue that high costs and technical complexities hinder adoption (Molina, 2018). Others suggest that regulatory frameworks and stakeholder pressure can incentivise adoption, highlighting the role of external factors in driving change (Navarro, 2018). Further research is needed on the interplay between regulatory environments and technology adoption in water management.

2.4.2.5 Alignment with global environmental goals

Industry 5.0 technologies' focus on sustainable resource management corresponds with global environmental objectives, including the United Nations SDGs. By embracing environmental stewardship, mining businesses can improve their company reputation and draw investment from stakeholders who value sustainability.

2.4.3 Perceived social benefits

2.4.3.1 Inclusive and participatory approach

Industry 5.0 technologies promote inclusivity and participation in mining operations. Collaborative tools facilitate communication and knowledge sharing, empowering employees and involving them in decision-making processes. This fosters a sense of ownership, accountability, and job satisfaction, leading to higher retention rates (Sharma et al., 2022).

2.4.3.2 Human-centric approaches

Industry 5.0 technologies emphasise human-centric approaches, integrating human intelligence with advanced technologies to benefit the workforce (Palm, 2022). This leads to improved job satisfaction, employee engagement, and a more inclusive workplace culture. Human-centric design is crucial for successful Industry 5.0 implementation in mining, as technologies designed with end-users in mind are better accepted and utilised by workers (Rožanec et al., 2022). Mining companies should prioritise human factors in technology development and implementation.

Enang et al. (2023) assert that Industry 5.0 technologies consider the primary demands of society and focus on the three areas of progress—resilience, sustainability, and human-centeredness—with a particular focus on the ideas of sustainable growth and improved life quality. Furthermore, Industry 5.0 human-centric technologies may provide employees with significant protective support (Pillai et al., 2021). Additionally, it is believed that the implementation of new Industry 5.0 technology through human-machine interaction would lead to the creation and maintenance of significant jobs (Pillai et al., 2021). Additionally, Battini et al. (2022) proposed that the rise of disruptive technologies is driving the development of human-centric industrial operations, which will lead to improved working conditions for workers, more jobs, and higher productivity (Rožanec et al., 2022).

Industry 5.0 technologies focus on human-robot cooperation and how it may improve safety, ergonomics, and productivity, all of which have a favourable effect on workers' well-being (Aheleroff et al., 2022). Furthermore, sustainability, human-centricity, and societal well-being are thought to be given additional importance by Industry 5.0 and its new technologies (Battini et al., 2022). Sharma et al. (2022) contend that consumers must realise that the industry's transformation is a path to advancement and a rise in the average person's standard of life. By encouraging a sense of empowerment and self-worth, this modification raises employees' overall job satisfaction as well as self-confidence (Battini et al., 2022). Furthermore, modern technologies facilitate simple access to vital information, allowing workers to take on an empowered role and make decisions without continual supervision (Pillai et al., 2021).

2.4.3.3 Employee development and training

Industry 5.0 technologies enhance training and development opportunities for employees by integrating advanced technologies like virtual reality (VR) and augmented reality (AR), which provide immersive learning experiences and improve skill acquisition and retention (Cao et al., 2021). This focus on employee development is crucial for modern mining operations. However, there are disagreements about accessibility and implementation challenges. High costs can limit access, especially for smaller mining companies (Masucci et al., 2020). Some argue that the long-term benefits of investing in training outweigh the initial costs, and financial support from larger corporations can help (Asif et al., 2023). This highlights the need to explore barriers to effective training program implementation in the mining sector.

2.4.3.4 Health and safety improvements

Industry 5.0 technologies can significantly improve health and safety standards in mining operations. Wearable technologies, drones, and real-time monitoring systems enhance safety protocols by providing timely data on hazardous conditions and enabling initiative-taking measures (Friedman & Ormiston, 2022). This focus on safety not only protects workers but also fosters a culture of care and responsibility within organisations.

Researchers agree that adopting Industry 5.0 technologies can lead to improved safety outcomes in mining. Advanced monitoring and communication systems reduce accidents and enhance emergency response capabilities (Horváth & Szabó, 2019). Additionally, automation and robotics reduce worker exposure to hazardous conditions, minimising accidents and injuries, and improving employee morale and productivity (Cao et al., 2021).

Improved worker health, safety, and well-being; lower rates of pain, injuries, stress, mistakes, accidents, and absenteeism; and more workplace sustainability are some of the social benefits of Industry 5.0 technologies (Sharma et al., 2022). Digital and intelligent technology reduces boredom and repetitive work, which motivates employees and increases job satisfaction while protecting their health and safety (Carayannis et al., 2024). The goal of zero harm might be advanced by using Industry 5.0 technology in mine modernisation to improve worker and societal safety and health (De Jager, 2018). Similarly, Industry 5.0 is primarily concerned with human-robot cooperation and how it may improve safety, ergonomics, and productivity (Aheleroff et al., 2022).

By combining a multimodal approach that incorporates smart sensors, real-time monitoring, predictive analytics, and cognitive computing, Industry 5.0 can improve worker safety (Aheleroff et al., 2022). This safety improvement extends to production processes as well, where automation in quality assurance systems reduces workplace risks by ensuring the creation of reliable and secure products (Enang et al., 2023).

2.4.3.5 Community engagement and social licence to operate

Industry 5.0 technologies can enhance community engagement and the social licence to operate for mining companies by promoting transparency and stakeholder engagement, building trust with local communities, and addressing social concerns effectively (Taalbi, 2017). However, there are disagreements about the effectiveness of these strategies. Some researchers argue that technology alone cannot replace genuine human interaction (Molina, 2018), while others suggest that technology can complement traditional engagement methods by providing platforms for dialogue and feedback (Navarro, 2018). Sustainable practices and technologies adopted by mining companies are viewed favourably by local communities, demonstrating social responsibility and environmental stewardship. Transparent communication and community development initiatives build trust and strengthen stakeholder relationships, enhancing the social licence to operate (Friedman & Ormiston, 2022).

In summary, the integration of Industry 5.0 technologies into mining practices offers a multitude of economic, environmental, and social benefits that contribute to the industry's sustainability. By enhancing operational efficiency, promoting circular economy principles, and facilitating clean energy adoption, these technologies can drive significant economic advantages. Simultaneously, the perceived environmental benefits, including reduced emissions and improved resource management, underscore the potential for mining operations to align with global sustainability goals.

Finally, the social benefits associated with enhanced worker safety, community engagement, and CSR highlight the importance of a human-centric approach in fostering a sustainable mining industry. As the sector continues to evolve, embracing Industry 5.0 technologies will be essential for achieving long-term sustainability and resilience.

2.5 Strategies to mediate/overcome resistance to Industry 5.0 technology adoption

The transition to Industry 5.0 technologies in mining presents opportunities and challenges. Resistance often arises from factors like lack of knowledge, insufficient sustainable technology capabilities, inadequate incentives, cultural inertia, lack of technical expertise, financial limitations, and job displacement concerns. Effective strategies are needed to address these barriers and foster innovation and acceptance (Asif et al., 2023; Cao et al., 2021; Masucci et al., 2020). This literature review examines these mediating variables and explores strategies to overcome resistance to adopting Industry 5.0 technologies in mining.

2.5.1 Level of knowledge development

A key barrier to adopting Industry 5.0 technologies is the varying levels of knowledge among stakeholders. Research shows a significant knowledge gap regarding these technologies' functionalities and benefits (Roblek et al., 2021). Mining companies should implement targeted training programs focusing on AI, robotics, and data analytics to enhance technical competencies. Fostering a culture of continuous learning through workshops, online courses, and industry conferences is essential. This investment in knowledge development can empower the workforce to embrace new technologies and reduce resistance due to uncertainty and fear (Aheleroff et al., 2022).

2.5.2 Education and training initiatives

A key strategy to overcome human capital constraints is implementing comprehensive education and training programs. Researchers emphasise updating curricula to include skills relevant to Industry 5.0 technologies, such as data analytics, AI, and human-machine collaboration (Aheleroff et al., 2022). This equips the future workforce with the necessary skills. There is consensus that human capital development is crucial for overcoming barriers to Industry 5.0 adoption, with training and education essential for workforce adaptation and reducing resistance (Aheleroff et al., 2022; Roblek et al., 2021).

Mining companies must invest in training programs to address the lack of skilled labour and technical knowledge (Roblek et al., 2021). Collaborations between educational institutions and mining companies can develop curricula reflecting technological advancements, including internships and apprenticeships (Aheleroff et al., 2022). Promoting lifelong learning through workshops, online courses, and certifications can mitigate resistance and foster a more adaptable workforce (Ceipek et al., 2021).

2.5.3 Change management and organisational culture

To address process and organisational constraints, effective change management strategies are essential. Fostering a culture of innovation and flexibility can facilitate the adoption of new technologies (Pillai et al., 2021). Engaging employees in the change process, promoting open communication, and providing support are crucial. Studies indicate that prioritising cultural change and employee engagement leads to the successful adoption of Industry 5.0 technologies (Pillai et al., 2021). Clear communication and regular updates on technology implementation can alleviate employee concerns (Friedman & Ormiston, 2022). A phased approach to technology adoption, piloting new technologies in specific areas, allows for assessment and adjustment before full-scale rollout, reducing perceived risks (Mukherjee et al., 2023).

2.5.4 Financial support and incentives

Financial constraints in adopting Industry 5.0 technologies can be mitigated through government support, subsidies, and incentives, such as long-term loans with favourable interest rates and tax exemptions, particularly for SMEs (Battini et al., 2022). These incentives can reduce the initial cost burden and promote technology adoption. Internal incentives, like performance bonuses and career advancement opportunities, can also encourage employees to embrace new technologies (Carayannis et al., 2024). However, some researchers argue that financial incentives alone may not suffice without addressing organisational culture and employee engagement (Masucci et al., 2020). Sector-specific strategies are needed, as effective approaches in manufacturing may not apply to mining (Palm, 2022). This highlights the need for nuanced research on the interplay between financial incentives and organisational culture.

2.5.5 Sustainable technology capabilities

The successful adoption of Industry 5.0 in mining requires integrating sustainable technology capabilities. Resistance often arises from a lack of infrastructure and resources for effective sustainable practices. Mining firms should assess their current technological capabilities and identify gaps to address for Industry 5.0 adoption (Palm, 2022). Investing in advanced technologies that promote environmental stewardship and resource efficiency, such as renewable energy sources, waste reduction strategies, and smart monitoring technologies, is essential (Sharma et al., 2022). Demonstrating a commitment to sustainability can alleviate environmental concerns and foster a positive attitude toward new technologies.

2.5.6 Business readiness and leadership commitment

Business readiness to adopt new technologies is crucial in overcoming resistance, encompassing organisational culture, leadership commitment, and operational flexibility. A supportive culture that embraces change, along with change management strategies promoting open communication and employee involvement, can mitigate resistance (Friedman & Ormiston, 2022). Leadership commitment is vital, with executives needing to articulate a clear vision and demonstrate commitment through strategic investments (Ivanov, 2023). Aligning Industry 5.0 adoption with company values and sustainability goals can foster a sense of purpose and commitment among employees (Ivanov, 2023).

2.5.7 Stakeholder engagement

Engaging stakeholders, including local communities, regulatory bodies, and industry partners, is crucial for successful technology adoption. Mining companies should involve these stakeholders in planning and implementation to address concerns and build trust (Mukherjee et al., 2023). Collaborative relationships create a supportive ecosystem for adopting new technologies. Providing concrete examples of how Industry 5.0 technologies enhance operational efficiency, reduce costs, and improve safety, along with case studies and success stories, can motivate employees to embrace change (Horváth & Szabó, 2019).

2.5.8 Risk management and mitigation strategies

Addressing perceived risks associated with technology adoption is essential for reducing resistance (Mukherjee et al., 2023). Companies should develop comprehensive risk management frameworks that identify potential challenges and outline strategies for mitigation (Ivanov, 2023). This may include conducting pilot projects to evaluate new technologies on a smaller scale before full implementation, thereby allowing organisations to assess their effectiveness and address any issues that arise (Horváth & Szabó, 2019).

2.5.9 Encouraging employee involvement

Involving employees in the decision-making process regarding technology adoption can significantly reduce resistance. Companies should create cross-functional teams that include representatives from various departments to assess the potential impact of new technologies and provide input on implementation strategies (Sharma et al., 2022). This participatory approach fosters a sense of ownership and accountability, making employees more likely to support and champion the adoption of new technologies.

2.5.10 Collaborative investment models

Mining companies can also consider collaborative investment models, where multiple organisations pool resources to invest in shared technologies. This strategy mitigates personal financial risk while promoting collaboration and knowledge exchange among industry participants (Carayannis et al., 2024). Through collaboration, companies can use shared skills and resources to surmount financial obstacles to technology adoption.

2.5.11 Fostering a culture of innovation.

Researchers agree on the necessity of fostering a culture that embraces innovation and sustainability (Pillai et al., 2021). Scholars argue that organisations must actively work to shift their cultures to support adopting Industry 5.0 technologies (Friedman & Ormiston, 2022). This includes promoting values such as collaboration, adaptability, and a commitment to sustainability, aligning organisational practices with Industry 5.0 goals (Sharma et al., 2022).

In summary, this section shows there is not much empirical evidence on how industry is addressing challenges. Thus, the discussions are based on theoretical evidence from preliminary research done by scholars on the emergence of the Industry 5.0 revolution. The human capital constraints associated with new technologies are a primary focus for the Industry 5.0 revolution to ensure employee needs are met as humans collaborate with technologies through training and development, educational support, encouraging workers' involvement, and fostering a culture of innovation. Organisational and process constraints can be dealt with by an organisational culture change towards sustainability, reimagining CSR, sound business ethics practices, leadership commitment, change management, financial support, sustainable technology, business readiness, stakeholder engagement, risk management, and collaborative investment models.

2.6 Research gaps

Studies on constraints and strategies to overcome constraints in adoption have been mainly focused on I.1 – I 4.0 technologies (Calzada-Olvera & Iizuka, 2023; Gault, 2018;

Horváth & Szabó, 2019; Jahanmir & Cavadas, 2018; Molina, 2018; Navarro, 2018; Van Oorschot et al., 2018; Yun & Lee, 2015). Numerous researchers have analysed and articulated the various challenges that companies in the hospitality (Pillai et al., 2021), pharmaceutical (Sharma et al., 2022), manufacturing (Aaldering & Song, 2021; Roblek et al., 2021), oil and gas (Robert et al., 2021), construction (Greco et al., 2021; Shojaei & Burgess, 2022), and other industries (Mukherjee et al., 2023) are likely to encounter in adopting Industry 5.0 technologies. However, none of the articles directly address the mining industry and its unique challenges or opportunities in the context of these transformative changes.

The mining industry is often perceived as slow to adapt to new technologies and innovations (Plessis & Pretorius, 2017; Sánchez & Hartlieb, 2020). The articles highlight the importance of embracing technological progress and digital transformation to improve operational efficiency, enhance sustainability, and maintain competitiveness across a range of industries. While these examples provide valuable insights, they do not directly address the specific challenges and opportunities facing the mining industry in the face of these broader trends.

Recent research suggests that the mining industry is also undergoing a digital transformation, with the concept of "Mining 4.0" emerging to encompass advancements in automation, the IoT, and data-driven decision-making (Clausen & Sörensen, 2022; Sánchez & Hartlieb, 2020). However, the existing literature indicates that the mining industry's efforts to adapt to these technological changes must also consider the environmental and social impacts of these innovations to ensure the long-term sustainability of the sector.

By highlighting the common themes of digital transformation and technological innovation across the articles, but acknowledging the lack of direct focus on the mining industry, this research paper aims to explore the unique challenges and opportunities facing the mining sector in the context of these broader industry trends (Clausen & Sörensen, 2022; Sánchez & Hartlieb, 2020).

Studies on constraints and strategies that have been examined in this study have highlighted several important research gaps in the fields of innovation, technology adoption, and the mining sector (Calzada-Olvera & Iizuka, 2023; Gault, 2018; Horváth & Szabó, 2019; Jahanmir & Cavadas, 2018; Molina, 2018; Navarro, 2018; Van Oorschot et al., 2018; Yun & Lee, 2015).

One key gap identified is the need for more system-level and context-incorporating research on the diffusion of innovation in the mining industry. The current literature tends to focus on individual factors or barriers, but there is a lack of holistic, integrated frameworks that consider the complex interplay of various stakeholders, organisational dynamics, and contextual influences (Gruenhagen & Parker, 2020).

Another important gap is the limited understanding of how specific operational demands and requirements in the mining sector can shape innovation patterns and technology adoption. The unique challenges faced by the mining industry, such as capital intensiveness, market volatility, and safety concerns, are not fully accounted for in existing models of innovation (Gruenhagen & Parker, 2020). Additionally, the role of the workforce and organisational culture in driving or impeding innovation in mining remains underexplored.

2.7 Conceptual framework

The conceptual framework in Figure 4 is built based on the literature review conducted above.

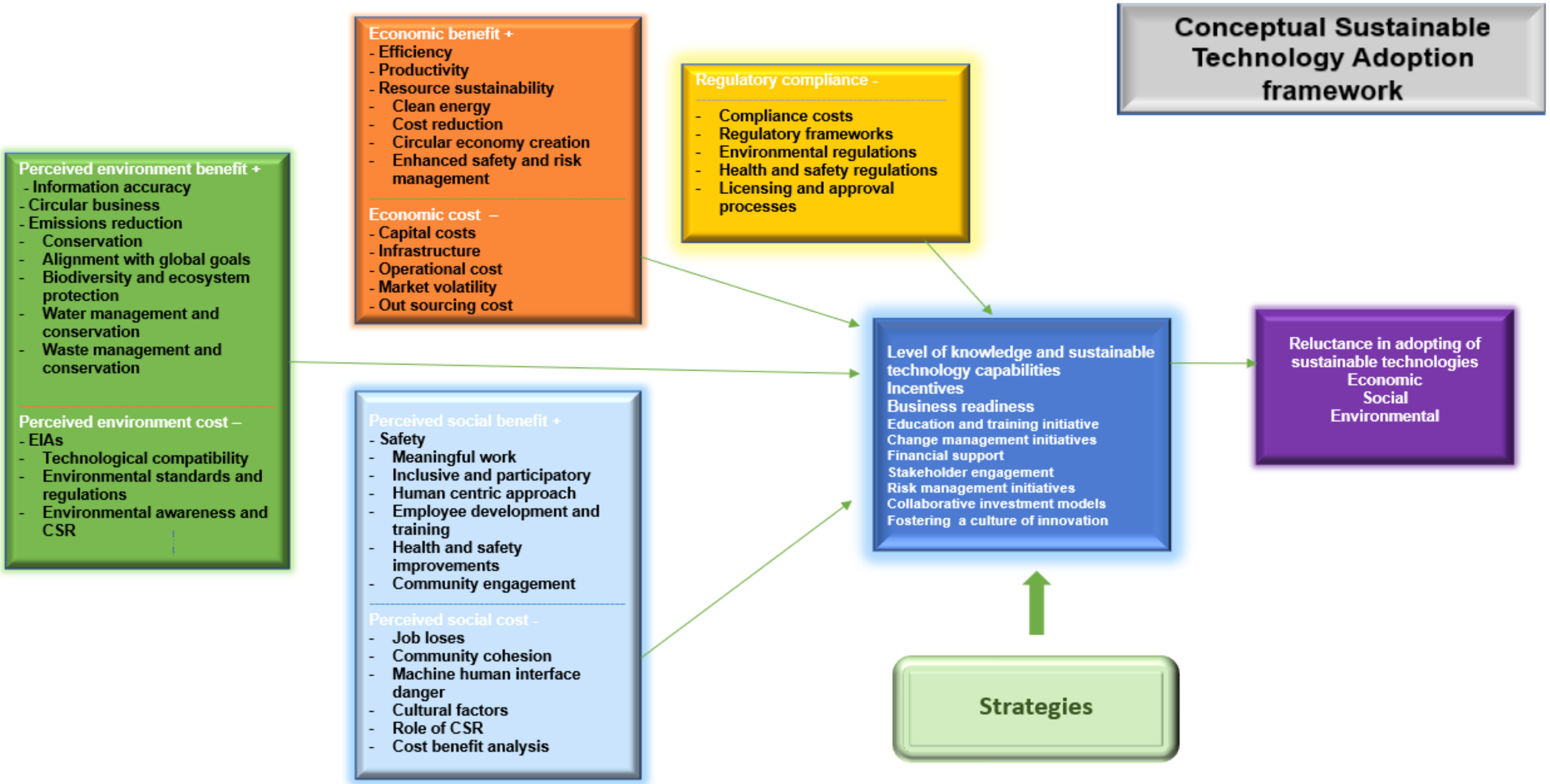

Figure 4. Conceptual framework

This framework shows that sustainable technology adoption in organisations is a complex process influenced by various factors beyond the traditional independent variables of social, environmental, economic, and regulatory considerations. Literature suggests that the success of technology adoption is contingent upon several mediating factors, including project scope clarification, individual commitment, communication, top management support, organisational characteristics, resource availability, government policies, customer and supplier attitudes, and the involvement of external IT consultants (Ansong & Boateng, 2018; Kauffman & Techatassanasoontorn, 2010; Suebsin & Gerdsri, 2009; Tandoğan & Gedikoğlu, 2020).

Organisational readiness has emerged as a particularly significant attribute in technology adoption (Hameed et al., 2012). This encompasses factors such as the organisation's technological infrastructure, financial resources, and the expertise of its IT department. Additionally, the size of the IT department has been found to have a moderately significant relationship with IT innovation adoption (Hameed et al., 2012).

The literature also highlights the importance of aligning technology adoption with the organisation's strategic goals and ensuring clear communication throughout the process (Suebsin & Gerdsri, 2009). Individual commitment and buy-in from employees at all levels can further facilitate the successful integration of new technologies (Suebsin & Gerdsri, 2009).

External variables, including governmental policies and the perspectives of customers and suppliers, significantly influence the adoption of sustainable technologies (Ansong & Boateng, 2018). IT consultants offer essential experience and help organisations manage the intricacies of technology adoption (Ansong & Boateng, 2018).

2.8 Conclusion

In conclusion, mediating resistance to the adoption of Industry 5.0 technologies in the mining sector requires a multifaceted approach that addresses human capital, organisational culture, financial constraints, change management, the communication of benefits, and knowledge gaps. Enhancing sustainable technology capabilities, providing adequate incentives, and ensuring business readiness are also crucial.

By investing in training and education, fostering a culture of innovation, addressing financial barriers, implementing effective change management strategies, and emphasising the benefits of new technologies, mining companies can create an environment conducive to technological adoption. As the industry continues to evolve, these strategies will be essential for ensuring a successful transition to Industry 5.0 and achieving long-term sustainability.

Additionally, engaging stakeholders and addressing perceived risks will further facilitate the transition to Industry 5.0, leading to improved operational efficiency and sustainability in the mining industry. As the sector evolves, these measures will be crucial for facilitating a successful transition to Industry 5.0 and attaining long-term sustainability.

This chapter examined literature pertinent to the research components of Industry 5.0, demonstrating that the idea of Industry 5.0 technologies remains nascent, with most findings being theoretical and conceptual. The literature reviewed showed how industry revolutions are evolving with a human-centric, sustainable, and resilient approach, what Industry 5.0 offers and contributes to industry, and how industries are facing challenges to adopt and implement.

Furthermore, the study showed the strategies to overcome these challenges in the adoption of Industry 5.0 technologies. The next chapter presents the research questions. These questions were developed based on the literature on technology adoption in sustainable transitions.

CHAPTER 3: RESEARCH QUESTIONS

3.1 Introduction

This chapter presents the research questions through a research focus definition in terms of the research problem and the literature reviewed.

The research questions were derived from the literature reviewed in Chapter 2. The literature focused on understanding the concept of Industry 5.0 technologies, reluctance outcomes and their contributions, their movement towards a sustainability transition of industries, and establishing why there are challenges to adopting Industry 5.0 technologies, including establishing strategies to eradicate these challenges to these new technology adoptions.

The literature review process led to the identification of research gaps that informed the research question and its research sub-questions. The main research question is based on Ivanovic's (2023) research gap, which is on exploring Industry 5.0 technology challenges in its adoption, and its impact on sustainability, generating empirical evidence and identifying each industry's unique challenges and opportunities. Further, most past studies have examined constraints to the adoption of new technologies in previous industrial revolutions (1-4) (Calzada Olvera & Iizuka, 2023; Gault, 2018; Horváth & Szabó, 2019; Jahanmir & Cavadas, 2018; Molina, 2018; Navarro, 2018; Van Oorschot et al., 2018; Yun & Lee, 2015).

This study is focused on addressing this literature gap, current academic debate, and the development and evolution of industries into the Fifth Industrial Revolution specifically aimed at achieving more sustainability (Asif et al., 2023; Chaudhuri et al., 2024). Yet other studies had limited scope and delved into specific functions such as supply chain sustainability (Dwivedi & Paul, 2022; Karmaker et al., 2023; Modgil et al., 2023), big data technologies (Bag et al., 2023), AI technologies (Cao et al., 2021; Rožanec et al., 2022), robotics technologies (Panagou et al., 2023), and chain technology (Friedman & Ormiston, 2022) and did not take a holistic approach to all Industry 5.0 technologies.

3.2 Main research question

The main research question is:

"How do mining organisations remain reluctant to implement Industry 5.0 new technologies in their operations?"

In analysing the topic as related to literature, further research gaps and propositions were established, such as the need to better understand how Industry 5.0 technologies are understood in the mining industry and their reluctance outcomes, the main types of constraints that affect mining adoption of Industry 5.0 technologies and the strategies to eradicate these constraints, and how Industry 5.0 technologies contribute to sustainability in the mining businesses.

This led to the development of the following sub-research questions.

3.3 Secondary research questions

3.3.1 Secondary Research Question 1

How do Industry 5.0 technologies contribute to sustainable mining practices?

This sub-research question seeks to help to gain more understanding on how Industry 5.0 contributes towards sustainable mining practices. Various scholars in literature, such as Taalbi (2017), Molina (2018), and Navarro (2018) have proposed various sustainability benefits that are not specifically attributed to the Industry 5.0 technologies but technologies from past industrial revolutions. Various other studies, such as Carayannis et al. (2024), Ivanov (2023), Mukherjee et al. (2023), Palm (2022), Sharma et al. (2022), and Rožanec et al. (2022) were conceptual and theoretical on how Industry 5.0 can contribute towards sustainable practices. Therefore, it is envisaged that the mining professionals, as main actors in the adoption of new technologies, can attest in this study how these new Industry 5.0 technologies benefit sustainable mining practices

3.3.2 Secondary Research Question 2

How do constraints impact the adoption of Industry 5.0 in mining sustainability transitions?

This sub-research question seeks to understand which constraints are specifically encountered in mining industry businesses to the adoption of Industry 5.0 technologies to drive their sustainability transitions. Various scholars in literature, such as Cao et al. (2021), Friedman & Ormiston (2022), Horváth & Szabó (2019), Roberts et al. (2021), and Stroh et al. (2023) have found constraints to the adoption of new technologies in relation to industries that exclude the mining industry. By conducting this study, new understanding can be gained from the mining businesses as a unique industry with finite projects and facing unique constraints that restrict them from adopting new Industry 5.0 technologies based on the insights of mining professionals.

3.3.3 Secondary Research Question 3

What strategies can be employed to overcome these barriers and promote Industry 5.0 technology adoption?

This sub-research question seeks to understand which strategies can address the constraints faced by mining firms when attempting to adopt new Industry 5.0 technologies. Various scholars in literature, such as Aheleroff et al. (2022), Battini et al. (2022), Ceipek et al. (2021), Horváth & Szabó (2019), Roblek et al. (2021), and Sharma et al. (2022), have proposed conceptual and theoretical strategies to overcome constraints to the adoption of Industry 5.0 strategies that are not specifically related to the mining environment. Therefore, by conducting this study on mining professions, they can provide useful strategies based on their experiences as actors involved in the adoption processes of new technologies in mines.

3.3.4 Secondary Research Question 4

What is the understanding of Industry 5.0 technologies and its reluctance outcomes by mining professionals?

The research question seeks to understand and gain fresh insights into how the mining industry understands the role of Industry 5.0 technologies for mining businesses and what the outcomes are of the reluctance to adopt Industry 5.0 technologies. Various scholars have delved into bringing theoretical and conceptual understanding of Industry 5.0 technologies with biases towards a human-centric approach, sustainability, societal wellbeing, environmental stewardship, and resilience (Asif et al., 2023; Battini et al., 2022; Calzada Olvera & Iizuka, 2023; Carayannis et al., 2024; Ivanov, 2023; Karmaker et al., 2023; Mukherjee et al., 2023; Rožanec et al., 2022; Sharma et al., 2022). Literature shows that common reluctance outcomes to adopting new technologies are economic, social, and environmental reluctance outcomes (Edmondson et al. 2019; Enang et al., 2023; Gonzales et al., 2021; Smith and Jones, 2022). However, some of these studies were not directly on Industry 5.0 technologies. Therefore, it is important to gain a better understanding of the experiences of mining professionals and the reluctant outcomes that lead them to not adopt these new technologies.

3.4 Conclusion

In conclusion, this chapter has delineated the research questions that guided this study on the adoption of Industry 5.0 technologies in the mining sector. The formulation of these questions was rooted in a comprehensive literature review that identified significant gaps in understanding the challenges and opportunities associated with Industry 5.0

technology adoption. By focusing on the unique dynamics of the mining industry, the research questions aimed to explore the interplay between technological advancements and sustainability transitions, as well as the factors influencing organisational reluctance to embrace these innovations. This structured enquiry not only set the foundation for the subsequent analysis but also underscored the importance of addressing both theoretical and practical dimensions of Industry 5.0 technologies in achieving sustainable mining practices. The following chapter, Chapter 4, details the methodology employed in this study to collect the empirical data to answer the research questions.

CHAPTER 4: RESEARCH METHODOLOGY

4.1 Introduction

This chapter explains how the research subject was approached, specifically, what is causing mining companies to have trouble or reluctance to use Industry 5.0 technology. The research paradigm, study design, and technique chosen to guide the research process are all part of the research method covered in this chapter. Furthermore, the chapter covers the study's framework, participant strategy, narrative accounts gathering, information processing, rigour and quality, constraints, reflexivity, and ethical issues. The researcher explains and defends the choices by pointing out how they relate to the research topics.

4.2 Research philosophy

The choice of an interpretative paradigm directed the study's investigation. An interpretivism epistemology (nature of knowledge) view points out that the specifics of a situation, reality's particulars, and its specific implications or subjectivity are all parts of an active and creative process that leads to a wide range of social phenomena (Wiesner, 2022). Loftland et al. (2022) assert that the interpretive paradigm relies on individuals' subjective experiences to comprehend the world. Therefore, qualitative research was found to be the most effective method for guiding the study topics and comprehending the subjective experiences of individual participants regarding the challenges faced by mining businesses in implementing new technology in their natural environments.

The interpretivism epistemology promotes an appreciation of the differences between the roles of individuals as "social actors" (Creswell & Guetterman, 2021). The term "social actor" implies that individuals participate in many stages of human existence. Furthermore, the employed interpretative technique allowed the researcher to see an event in authentic and natural environments, thereby creating a clearer picture of the phenomenon (Pervin & Mokhtar, 2022). This method emphasises how important it is to conduct research that respects the diversity between study participants and objects.

Junjie and Yingxin (2022) opine that interpretivism enhances the understanding of individuals as social actors performing their duties to complete the meaning of a situation. Furthermore, interpretivism, according to Creswell and Guetterman (2020), encourages the recognition of human variations in their societal active role to construct socially generated different realities. Furthermore, an interpretative method necessitates viewing social phenomena from the perspective of the participants, not the researcher's (Liamputtong, 2020). Therefore, it was considered appropriate to use subjective interpretations to understand why South African mining businesses are finding it difficult to implement new technology.

4.3 Approach to theory development

Thus, the aim of this interpretive enquiry was not to uncover general, setting-specific knowledge free of value or truth, but rather to attempt to comprehend mining industry professionals' understandings of the adoption of technology in sustainable transitions that they encounter (Kivunja & Kuyini, 2017). Interpretivist researchers sought to construct their ideas about the subject matter through a thorough analysis of the phenomenon they were interested in (Pervin & Mokhtar, 2022). As a result, to understand the phenomenon under investigation and generate theory, the researcher used an inductive method to evaluate the narratives collected in this study. The interpretive paradigm allowed for and was an appropriate match for the exploratory focus of this study, which aimed to understand why mining companies are finding it difficult to embrace cutting-edge technology. The utilisation of structured interviews enabled the researcher to investigate the question being investigated using various participants to generate an evenly balanced report.

The foundation of the interpretive paradigm is observing and deducing, wherein observations are gathering data about events, whereas interpretations are giving that data meaning by making deductions or determining whether the data fits a certain abstract sequence (Pervin & Mokhtar, 2022; Wiesner, 2022). Additionally, the concepts of phenomenology, which emphasise the identification and expression of a phenomenon's basic qualities in its actual existence, form the foundation of interpretive study (Liamputtong, 2020). Interpretive study, on the other hand, focuses on the complete complexity of individual reasoning as the situation arises rather than predefining dependent and independent factors (Borgstede & Scholz, 2021).

According to Loftland et al. (2022), the interpretative approach aims to clarify the subjective reasons and understandings underlying social behaviour. As a result, Creswell and Guetterman (2020) argue that a phenomenological investigation explains how many individuals interpret their lived experiences with a concept or phenomenon. Typically, this means using inductive qualitative research techniques like observations and interviews to collect "deep" data and impressions, then expressing this data and these perspectives from the viewpoint of the respondents.

4.4 Research strategy

The qualitative approach was selected as the research methodology for this investigation. According to Aspers and Corte (2019), the qualitative research approach has a substantial impact on the creation of new theories, therefore influencing our comprehension of theoretical constructs. By applying this process, the issue was understood more thoroughly, and fresh insights were brought to the body of knowledge. As Creswell and Guetterman (2020) contend, this qualitative research possesses the capacity to provide original propositions in the form of the framework outlined in Chapter 2, support established ones, and even modify established ideas to fit novel situations, as was shown by the adjusted framework in Chapter 5.

In addition, Aspers and Corte (2019) assert that the qualitative research technique is suitable since it elucidates the reasoning and methodology by providing the researcher with access to the context, expert viewpoints, and participants' experiences. As a result, this helped the researcher comprehend why it is challenging for mining companies in South Africa to adopt new technologies.

The claim made by Busetto et al. (2020) that qualitative research seeks to investigate and uncover concerns regarding the problem at hand since not much is understood about it, particularly when there are unknowns about its parameters and features, was another benefit of adopting the qualitative methodology. Moreover, Aspers and Corte (2019) assert that the primary objective of qualitative research is to enhance comprehension of individuals, as well as the cultural and social contexts in which they reside. These investigations enable the exploration and representation of the intricacies and distinctions of the worlds under study (Makri & Neely, 2021). By employing this technique, it was possible to gain a deeper grasp of the issue and fresh insights into the reasons why South African mining companies are having trouble implementing new technologies.

4.5 Research design

An exploratory case study (the South African mining industry) approach was used for this study because it was thought to be a suitable method for gaining an understanding of the research question (Yin, 2018). An exploratory strategy is appropriate for attempting to comprehend a phenomenon or obtain clarifications on a condition (Makri & Neely, 2021). In this case, the investigation's goal is to learn more about the factors that prevent South African mining enterprises from using new technology.

The study took the form of exploratory research with an iterative approach. A framework was developed from the literature and adjusted with the findings from the insights developed by the participants. Detailed narratives, deep viewpoints, and a connection among participants are among the advantages of exploratory studies (Yin, 2018).

The questions of “how”, “why”, and “what” are addressed through the exploratory study (Creswell & Guetterman, 2020). When you want a thorough and detailed explanation of a social phenomenon, exploratory studies additionally represent a beneficial choice (Yin, 2018). This research project gathered perspectives as it investigated the barriers preventing South African mining businesses from adopting new technology.

The exploratory approach was particularly suited to the interpretive philosophy because it permitted a reflective examination that made use of the individual subjectivity they have in their natural surroundings (Makri & Neely, 2021). As a result, the exploratory technique fits well in the interpretative paradigm because it enables an insightful study based on people's individual viewpoints in their natural contexts. Furthermore, the application of exploratory design allowed for alternative viewpoints on the topic, which helped to clarify how different points of view on the topic are impeding the adoption of new technologies in South African mining operations (Creswell & Guetterman, 2020). Considering the benefits of uncovering comprehensively the distinct opinions and issues of each person participating in an actual-life scenario, the researcher considered that the exploratory study approach is most suited to this research, considering the interpretive stance chosen in this study as well as the scope of the subject being studied.

Also, according to Chowdhury and Shil (2021), this exploratory design is most suited in situations where it is challenging to discern a phenomenon from its surrounding environment. Due to its methodical approach to data collection, analysis, and reporting, the exploratory study design was determined to be the most suitable approach for this study, considering the interpretive stance adopted and the nature of the research question. This allowed for an in-depth comprehension of a particular problem or situation.

While the study incorporated abductive reasoning by iteratively refining the theoretical framework, it is primarily exploratory in nature because it sought to understand and define the research problem more clearly through initial data collection and analysis. While the study incorporated abductive reasoning by iteratively refining the theoretical framework, it is primarily exploratory in nature because it sought to understand and define the research problem more clearly through initial data collection and analysis.

4.6 Time horizon

When conducting academic research for an MPhil thesis, the choice between a cross-sectional or longitudinal study design can significantly impact the quality and feasibility of the research project. In this case, the researcher opted for a cross-sectional investigation, which offered several compelling advantages that are worth highlighting.

Time efficiency was a key consideration, as cross-sectional studies are typically quicker to conduct than longitudinal studies, as they collect data at a single point in time rather than over an extended period (Moskovicz, 2019). This was particularly beneficial as the researcher was faced with tight timelines, as the technology shifts in this area of study are very quick, and the landscape changes fast (Thomeer et al., 2024).

Additionally, cross-sectional studies tend to be more cost-effective, as they do not require the long-term follow-up with participants that is necessary for longitudinal studies. This was a significant advantage, especially for the researcher with a limited research budget.

Another advantage of the cross-sectional approach is its ability to provide a snapshot of a population at a specific point in time. This was useful for understanding the reluctance of the mining industry to adopt Industry 5.0 technology, which informed the development of hypotheses and will be a guide for future research.

Cross-sectional studies are also generally easier to manage, as they do not require repeated contact with participants, reducing the risk of participant drop-out. Furthermore, the ability to include a large number of participants in a cross-sectional study can make it easier to generalise the findings to a broader population.

4.7 Research population/setting

Purposive sampling is a non-probability sampling technique used in qualitative research, where the researcher selects participants based on specific criteria that align with the objectives of the study. The population from which such participants may be obtained would typically have certain characteristics or knowledge that is relevant to the research topic. These would be, for example, experts or professionals in the field being studied, as they would have in-depth knowledge and experience relevant to the research topic (Abuhassna et al., 2023; Carlos & Ronald, 2020).

Another way to look at them would be as individuals who have directly experienced or been affected by the phenomenon of interest, such as patients, customers, or community members (Abuhassna et al., 2023). The key is that the researcher selects participants who can provide the most valuable and relevant information to address the research objectives (Rout & Aldous, 2016). The purposive sampling approach allows the researcher to intentionally select participants who can offer insights that may not be readily available from a random group of participants of the general population (Etikan, 2016).

However, it is important to note that the purposive sampling method can introduce bias, as the researcher's subjective judgement plays a significant role in the selection of participants (Carlos & Ronald, 2020; Etikan, 2016; Nawawi et al., 2018).

Therefore, to eliminate the effects of sampling bias, the research participants and context consist of individuals capable of providing answers to the study questions. The people who are professionals in mining companies and their technology implementation partners in South Africa who have expertise in or are currently involved in the supply of Industry 5.0 technology to implement sustainable mining, including mining houses, consultants for the mining sector, and original equipment manufacturers (OEMs), are considered the setting for this research.

Data triangulation was made possible by dividing participants into at least four groups and then comparing the in-case and cross-case results from each group according to the important distinctions listed in Table 2 below.

Table 2. Classification of participants

Group of Contributors	Function in technology implementation
Technology suppliers (OEM)	Supplier/developer
Mining Industry	Business and end customer
Engineering/technology Consultants	Advisory and support

Consequently, the target audience consisted of South African mining industry players involved in the implementation of Industry 5.0 technologies within the framework of the sustainable transition in the mining sector. Workers with experience in both the sustainability transition and the implementation of Industry 5.0 technologies were seen to have the most relevant insights to provide. Table 3 shows the profiles of the participants in this study.

Table 3. Profiles of participants

	Code	Participant Group	Role in the Organisation	Highest Qualification	Years of experience	Commodity
1	ME001	Mining Professional	Metallurgical Manager	MBA. B.Sc. Metallurgy	15	Platinum
2	ME002	Mining Professional	Asset Management Exec	PHD- I.4.0	12	Mineral Sands
3	MC003	Consultant	Senior Consultant	Diploma Metallurgy	25+	Various
4	ME004	Mining Professional	Procurement Executive	BSc Engineering GCC	20+	Coal
5	ME005	Mining Professional	Procurement Specialist	Master Supply Chain	20+	Coal
6	TS008	Technology Supply	Sales Executive	Business School	15	Various
7	ME007	Mining Executive	Environmental Expert	M.Sc. Ecology	10	Platinum & Diamonds
8	TS006	Technology Supplier	Process Control Expert	B.Sc. Chemical Eng	17	Various
9	ME009	Mining Executive	Supply Chain VP	PHD Project Management	20	Gold & Platinum
10	MC010	Consultant	Senior Consultant	BSc Chemical Eng	25	Various
11	MC011	Consultant	Consulting Executive	M.Sc. Engineering	18	Various
12	ME012	Mining Professional	Safety Executive	M.Sc. Eng, MBA	27	Platinum
13	TS013	Technology Supplier	Software Application	B Technology	20	Various

4.8 Unit of analysis

Yin (2018, p.23) defines a unit of analysis as "the object or piece of information that is being studied in scientific enquiry and from which conclusions can be formed." Thus, in this study, the unit of analysis was the mining industry profession/associate involved in the Industry 5.0 technology supply chain.

4.9 Sampling strategy

4.9.1 Sampling universe

The interpretivist approach to research emphasises understanding the unique perspectives and experiences of individuals within their social and cultural contexts (Malagon-Maldonado, 2014). In contrast to the positivist focus on objective measurement and generalisation, interpretivists seek to uncover the rich, nuanced meanings that participants ascribe to their lived realities. (McEvoy & Richards, 2006)

When it comes to sampling, interpretivists typically employ purposive or theoretical sampling techniques, selecting participants based on their relevance to the research question and their ability to provide in-depth, information-rich data. The sampling universe, then, is not defined by the need to represent a broader population but rather by the specific goals and objectives of the qualitative enquiry (Mohd Ishak & Abu Bakar, 2014).

Yin (2018) suggests that in qualitative research, participants are selected based on their relevance to the subject matter, rather than their representativeness of the entire population. The sampling frame, in this view, serves as a functional architecture for recruiting samples that can shed light on the phenomenon of interest, rather than as a means of statistical generalisation.

Hence, for this research, the sampling universe was defined as South African mining industry professionals, consultants, and technology suppliers, and network sampling was used as it was more appropriate for the research than probability-based techniques. The emphasis was on depth of understanding rather than breadth of representation, with the researcher actively seeking out the perspectives of participants who may not be considered "typical" or "representative".

4.9.2 Sampling method

The researcher used purposive sampling, a kind of non-probability sampling, to select participants. Non-probabilistic, according to Creswell and Guetterman (2020), denotes that there is no assurance of an equal and known probability when selecting a component from the overall population. Finding individuals or groups with experience or knowledge relevant to the topic under study was part of the process of purposeful sampling (Yin, 2018).

Purposive sampling, according to Creswell and Creswell (2017), facilitates effective discovery and the selection of subjects with a richness of information when resources are limited. Therefore, the researcher considered this type of sample to be relevant for the study, focusing on employees whose roles directly involved implementing new technology at the mine while eliminating those whose roles did not directly involve it.

This method also worked well for giving the researcher the freedom to use independent judgment when selecting the study participants who would be most suited for it. Thus, the researcher could pick the ideal study participants by employing purposive sampling and relying on their judgment and experience (Yin, 2018). Purposive sampling had the benefit of being a rapid, simple, quick, and affordable method of choosing respondents for data collection (Creswell & Creswell, 2017). This was therefore believed to have been the most efficient method of selecting appropriate study subjects.

4.9.3 Sampling size

The researcher calculated that 13 respondents, which include participants from each of the following categories: original equipment suppliers (OEMs), engineering and supply chain departments in the mining sector, and technology consultants. While the intention had been to have an equal number per segment, it did not turn out as such. This depth of understanding was thought to be enough for comprehending the study question from an external, independent, and internal perspective.

Additionally, the researcher carefully considered the data saturation threshold when selecting this sample size. Data saturation, according to Hennink and Kaiser (2022), is the point in a study where no new data emerges and further data collection becomes redundant. Therefore, Hennink and Kaiser's (2022) 9–17 participant criterion for determining a qualitative depth of understanding deemed the selected participants for this study sufficient.

Data triangulation was made possible by dividing the participants into four groups according to the main difference, as shown in Table 4 below, and then comparing the research results (within and between cases) of each group.

Table 4. Categorisation of participant groups

Category	OEM/Technology suppliers	Mining Engineering group	Technology Consultants
	3	8	2

4.10 Narrative gathering method.

Only structured interviews with open-ended questions from a group of participants of the mining organisation's personnel were conducted by the researcher to collect insights into the adoption of new technologies. As per Yin's (2018) perspective, interviews comprised an array of assessments to distinguish perceptions from reality and verify veracity. The interviewer used a set of prepared interview questions to verbally collect information during the conversation.

As a result, interviews produced highly targeted and helpful recommendations because the interviewer concentrated on specific issues. To gather information on the adoption of new technologies in mining companies, the researcher conversed with 13 participants via Teams. The interviews were done in an organised fashion, using a series of open-ended questions to extract comprehensive information from participants about their viewpoints, intentions, beliefs, and opinions of the study. The benefit of conducting interviews for the current investigation was that it allowed for direct communication with strategists and implementers of new technologies, providing thorough information about the research concerns. The flexibility of the interviews allowed the researcher the ability to ask additional questions to elicit more information from the participants and obtain more comprehensive responses to the investigation's questions.

Using professional networks of mining personnel, the researcher collected contact information of possible participants. After the participants gave their consent, the researcher emailed a list of chosen people to invite them to participate in the interviews. With consent for both video and audio recording of the interview, each of the selected candidates took part in a structured interview, lasting 45 minutes to an hour, conducted online using the Microsoft Teams platform. The record functions as the researcher's memoir, enabling them to hear, see, feel, and think back on the conducted interview (Creswell & Creswell, 2017). However, to adhere to ethical consideration guidelines, the respondents provided their permission to be recorded. After every interview, the recordings were stored on a secured hard drive and labelled with letters and numbers for upkeep.

4.11 Narrative gathering instrument

The structured interviews were built on pre-set, open-ended interview questions. Yin (2018) opines that an interview guide is a set of memory questions for an investigation that helps someone learn about the personal lives of others (see Appendix D, Interview Guide). The main idea of the research questions and the findings of the completed literature analysis informed the development of the open-ended questions in the interview guide (Creswell & Creswell, 2017). The study employed open-ended questions due to their ability to elicit extensive data from participants. According to Aspers and Corte (2019), a qualitative researcher is curious about what individuals have to convey as well as how individuals communicate among themselves. The most effective way to achieve this is through interviews with open-ended questions that permit as many detailed answers as feasible (Charmaz & Thornberg, 2021).

The researcher ensured that no subject topic in the interview guide was a double-barrelled question but rather a subordinate enquiry to the main study problem. Yin (2018) believes that allowing individuals to take the lead and employing double-barrelled questions could diminish the reliability of the results due to potential distortions. According to Chowdhury and Shil (2021), pretesting an interview guide helps determine the estimated duration of the interview, identify errors for repair, and avoid lengthy periods of time that could tire participants. Therefore, the interview questions were pilot-tested on three mining executives to refine the phrasing and applicability of the questions to the research. This approach corrected incorrect questions and errors before a more powerful research tool was used to conduct the full-scale examination.

4.12 Data analysis method

All 13 interviews were professionally transcribed with the assistance of a professional transcriber for accuracy and speed.

The researcher employed Braun and Clarke‘s (2021) thematic analysis, a flexible and widely used method for identifying, analysing, and reporting patterns (themes) within data. Although the original framework outlined six phases, the researcher adapted it to highlight two inductive and two deductive steps, thereby streamlining the data analysis process (Bonsteel, 2012).

Initially, the researcher concentrated on the inductive steps. During the familiarisation phase, there was immersion in the data, reading and re-reading it to gain a comprehensive understanding of its depth and breadth (Brown, 2018). This step was crucial as it allowed them to become intimately familiar with the content, nuances, and context of the data. Subsequently, initial codes were generated by systematically identifying features of the data that were interesting and meaningful. Relevant data for each code were collated, which facilitated the organisation of information in a structured manner (Dawadi, 2020). This process was supported using ATLAS.ti, and the generated codes are detailed in Appendix F.

Upon completing the inductive steps, the researcher proceeded to the deductive steps. In the theme-searching phase, the codes were organised into potential themes, gathering all relevant data for each candidate theme. This involved grouping similar codes and identifying overarching patterns. Finally, in the theme-reviewing phase, these themes were refined to ensure they accurately represented the data. The themes were reviewed in relation to the coded data and the entire data set ensured coherence and distinctiveness.

The data analysis process revealed that data saturation had been achieved, as no new codes emerged from subsequent interviews. This saturation began to manifest after approximately 10 interviews, signalling a comprehensive capture of the data's richness. Figure 5 below provides a detailed summary of the hybrid coding process with four steps of data analysis and the resulting codes, illustrating the meticulous and exhaustive nature of the research process.

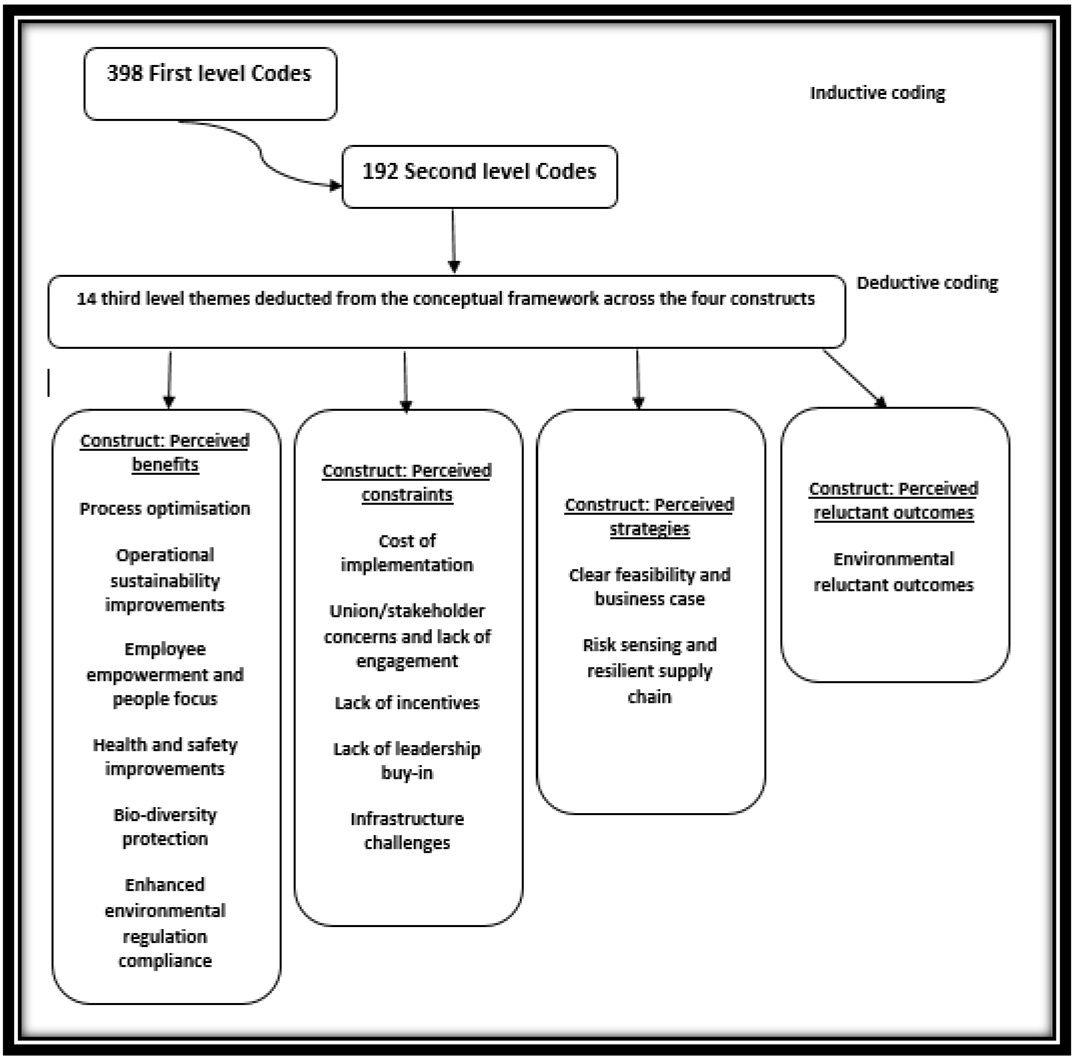

Figure 5. Hybrid coding process

By adhering to these meticulously crafted steps, the researcher conducted a thorough and systematic analysis of the data, culminating in a set of coherent and meaningful themes that illuminated the research topic with newfound clarity. From this rigorous process, a total of 36 themes emerged, each contributing to a deeper understanding of the subject matter from these 14 were selected for discussion according to the over arching constructs. The conceptual framework, enriched with these themes and subthemes, is presented in Chapter 5, offering a comprehensive and insightful narrative that underscores the significance of the findings.

4.13 Research quality and rigour

The researcher used various approaches to determine the validity, credibility, transferability, and dependability of the results. To accomplish quality control, this qualitative study employed a trustworthy method of assessing the quality of the research, based on the four elements of confirmability, dependability, transferability, and credibility (Yin, 2018).

Confirmability evaluated how much other research in the same field could support the findings (Creswell & Creswell, 2017). This suggested that the focus was mostly on the collected data and its interpretation, rather than the researcher's creativity. Additionally, the researcher's reflexivity or sensitivity to influence the study was neutralised by capitalising on, explaining, and acknowledging it (Francisco et al., 2023). Consequently, the researcher maintained confirmability by presenting the connection between the data collected, the conclusions reached, and the results obtained.

To ensure dependability, the researcher considered the consistency of the study approach employed (Yin, 2018). According to Creswell and Creswell (2017), a study technique needs to be repeatable to have a more dependable outcome. Therefore, to ensure integrity in the data gathering, organisation, analysis, and dissemination processes, the researcher meticulously documented each step of the process. Furthermore, the research ensured that the results were grounded in several perspectives on the same subjects from supply chain executives, supply chain senior managers, and supply chain operations managers.

To guarantee that the investigation's findings were both legitimate and credible, the researcher considered the degree of assurance and authenticity associated with them (Creswell & Creswell, 2017). According to Yin (2018), credibility is established if the investigation's conclusions fairly reflect the original and genuine facts as seen by the participants. As a result, the study used ATLAS.ti to analyse interview recordings and assess the qualitative data acquired. Moreover, an audit trail proved the use of mechanisms for oversight to ensure that the findings were based on the viewpoints of the participants and countered any charges of bias due to the researcher's interpretive paradigm.

To ensure that the results were transferable, the researcher considered to what extent they could be applied to a different environment with different participants (Creswell & Creswell, 2017). Keeping a comprehensive narrative and audit trail was one of the strategies employed in the investigation to ensure transferability and provide proof that the conclusions originated from the participants. Additionally, the study supported the systematic approach and provided in-depth information on the institutional context. Being aware of own biases, the researcher ensured that the participants' opinions—rather than the researcher's own—determined the investigation's conclusions.

4.14 Limitations of the study

Despite the best efforts to maintain rigour, the researcher's time and capacity constraints, and resource limitations all affected the study process. Additionally, because the research relied on structured interviews to gather data, interrogator influences might have introduced bias into the results (Braun & Clarke, 2021). Using a qualitative method, the research attempted to present a complete picture of why South African miners were having trouble implementing modern technology.

Limitations are defined as "research biases that are unknowing or can be controlled, which could negatively influence the research findings" (Creswell & Creswell, 2017, p. 42). Selecting participants in the adoption of new technologies was limited to platinum, diamond, and gold mines in South Africa, which was one of the study's two drawbacks. Thus, restricting the collection of data to a limited number of instances could make it less likely that the findings could be applied generally (Yin, 2018). Rather than being generalised, the findings were intended to open the door to more in-depth future investigations.

Conducting research was a complex and multifaceted endeavour that required a deep understanding of various methodological approaches and data analysis.

Another limitation of the study, conducted by this novice researcher, was the development of interview skills and designing and conducting effective interviews. The researcher at times struggled to establish rapport with participants, asking probing questions, and managing the interview dynamics, which could have affected the quality and depth of the data collected.

4.15 Ethical considerations

The study followed clear ethical guidelines as provided by the institution, including obtaining respondents' informed consent, respecting their privacy, and preventing abuse. This bolstered the argument put forth by Creswell and Guetterman (2020) that ethical concerns are essential to reducing or eliminating difficulties in research. Consequently, the researcher guaranteed the subjects' voluntary participation and refrained from identifying them or subjecting them to any form of coercion.

Each participant received and signed an informed consent form before the start of the study, which contained information about the study and outlined their rights and expectations. Respondents were allowed to withdraw from the research at any time or to refuse to participate. It was not anticipated that the research participants would face any harm. During the discussions, participants' responses to the interview questions were not disclosed and confidentiality was maintained. Anonymity was ensured and at no time were the identities of the participants or their organisations used in the study. The results were arranged so that no specific respondent could be linked to them. Data collection started only after the GIBS Ethical Committee had granted clearance for the study to proceed.

4.16 Conclusion

Chapter 4 outlined the research methodology employed to investigate the challenges and reluctance faced by mining companies in adopting Industry 5.0 technologies. It detailed the research paradigm, study design, and data collection techniques, emphasising the importance of a structured approach to understanding the complexities of technology adoption in the mining sector. The chapter also addressed ethical considerations, participant strategies, and the rigour of the research process, ensuring that the findings were credible and relevant. Overall, the methodology established a solid foundation for the subsequent analysis and discussion of the research findings, highlighting the critical factors influencing the integration of Industry 5.0 technologies in mining operations.

CHAPTER 5: FINDINGS

5.1 Introduction

This chapter delineates the findings derived from the data obtained through interviews, evaluated under the study methods outlined in Chapter 4. The findings are organised per the secondary research questions described in Chapter 3. To facilitate a clear understanding of the participants' perspectives, a colour key is employed for the efficient identification of participants in the data presentation: Mining Executives, Mining Consultants and Technology Suppliers.

The 13 interview transcripts were classified into three categories and analysed with ATLAS.ti, facilitating cross-tabulation of the data based on the viewpoints of each group. Despite the challenges faced during the data processing, the utilisation of this qualitative data analysis software markedly optimised the procedure and enriched the depth of findings.

ATLAS.ti provides an extensive array of capabilities, rendering it a versatile and effective instrument for qualitative researchers. One of the key advantages of using ATLAS.ti is its capacity to manage and analyse extensive amounts of unstructured data, encompassing text, audio, and video. ATLAS.ti facilitated both inductive and deductive coding methodologies, enabling the researcher to employ any strategy as required for the study. Additionally, ATLAS.ti offered a variety of sophisticated analytical capabilities, including network creation, relationship visualisation, and the execution of intricate queries.

5.2 Research Question 1

How Industry 5.0 technologies contribute to sustainable mining practices

The themes to answer this question were guided by the conceptual framework mapping of perceived economic benefits, perceived environmental benefits, perceived social benefits, and perceived regulatory benefits.

5.2.1 Perceived economic benefits

This section discusses the themes related to the perceived economic advantages of Industry 5.0 technology in promoting sustainable mining operations. Four topics were delineated as illustrated in Table 5 from the thematic analysis. However, only two themes or structures that yielded fresh insights are presented and analysed.

Table 5. Perceived economics benefits themes

Theme	Similarities Existing theme	Differences New theme	Discussed Yes/No
Efficiency and effectiveness	X		No new insights
Process optimisation		X	Yes, insights
Better risk control	X		No fresh insights
Operational sustainability improvements		X	Yes, insights

The themes of efficiency, effectiveness, and risk management were previously identified in literature, echoing the arguments presented by the participants. In contrast, process optimisation and operational sustainability have arisen as novel concepts not previously addressed in literature. These new themes offer fresh ideas on proactiveness, enhanced output, and human-machine collaboration, articulated as economic advantages.

Table 6 below is a summary of the frequency of the theme mentioned by each group, their differences in thoughts and the main topics that were exemplified.

Table 6. Frequency of perceived economic benefits themes

Theme	Mining Executives	Mining Consultants	Technology Suppliers
Process optimisation	Many- Proactiveness, support for human intervention,	Few- Increase output	Few- Collaboration between technology and humans
Operational sustainability improvements	Few- Future predictions Supplier audits	Few- ESG reporting	None

5.2.1.1 Theme 1: Process optimisation

The theme of process optimisation was mentioned by many mining executives and mining consultants, plus a few technical suppliers' participants. Table 7 below presents the evidence.

5.2.1.1.1 Evidence of theme 1: Process optimisation

Table 7. Evidence of process optimisation theme

Research Question 1, Theme 1: Process optimisation
"You can proactively look at your process to see how you can optimise going forward because your information base is a little bit more accurate." Participant ME4
"The other factor will be the view of managing risk, how well your operation views the management of risk and how proactive we are." Participant ME12
"With real-time data analytics, we can continuously optimise our processes and make adjustments on the fly." Participant ME1
"The technology has been used to make a human intervention list." Participant ME5
"If we looked after your flotation circuit we could improve your recoveries.....". Participant MC003
AI can do a hundred times better than any human, although the human still needs to have a look at it and act upon it." Participant MC003
As a person who sells services and equipment, you would know this, right? The main thing that the business was worried about was how applying digital get me more work does?" Participant MC010
"Even when you were like, …., to throw stuff away, like I said, some stuff has to be thrown away... So, I think technology…..," Participant TS006

5.2.1.1.2 In-case and cross-case analysis of the evidence of Theme 1: Process optimisation

The insights obtained from the three participant groups indicate both commonalities and divergences in their views regarding process optimisation as a perceived economic advantage of implementing Industry 5.0 technology. For instance, Participant ME4 underscores the need for a precise information foundation, asserting that, "one can proactively examine the process." This underscores the significance of data accuracy in facilitating initiative-taking decision-making and process optimisation. Effective data analysis enables mining operations to pinpoint inefficiencies and enact improvements, resulting in increased production and cost reductions.

Conversely, Participant ME12 introduces the notion of risk management into the discourse, asserting that Industry 5.0 technologies entail an initiative-taking approach to risk management. This viewpoint emphasises that process optimisation encompasses not only efficiency but also the comprehension and mitigation of risks linked to mining operations. Initiative-taking risk management fosters steady and predictable operations, crucial for sustained economic advantages.

Additionally, Participant ME1 reinforced the concept of process optimisation via technology by asserting that “real-time data analytics can perpetually enhance processes and implement adjustments instantaneously.” This observation highlights the dynamic characteristics of Industry 5.0 technologies, enabling ongoing monitoring and modification of operations. The capacity for real-time modifications can improve operating efficiency and adaptability to evolving circumstances, therefore optimising economic advantages.

Moreover, Participant ME5 enhances the discourse by stating that “the technology has been utilised to create a human intervention list.” This signifies that although technology is essential for process optimisation, it also highlights areas requiring human control. The equilibrium between automation and human involvement is essential for the smooth and efficient functioning of activities.

From the viewpoint of the mining consultants, participant MC003 elucidated how the flotation circuit might enhance recovery rates. This underscores the consultants’ emphasis on operational domains where Industry 5.0 technologies can yield measurable enhancements in performance. The focus on improving the flotation circuit indicates that specific interventions can produce substantial economic advantages.

However, another mining consultant (Participant MC010) presented an alternative perspective and expressed a practical issue regarding the challenges businesses face in implementing new digital technology to enhance productivity. This illustrates a prevalent concern among enterprises about the concrete advantages of implementing digital technologies. This emphasises the direct influence of technology on workload and operational efficiency, a crucial factor for mining businesses.

Finally, Participant TS006 from the technical suppliers' group provided a comprehensive viewpoint, asserting that the interaction between technology and human behaviour is crucial for achieving optimal results in mining operations.

The insights obtained from the three participant groups indicate both commonalities and divergences in their views regarding process optimisation as a perceived economic advantage of implementing Industry 5.0 technology. For instance, Participant ME4 underscores the need for a precise information foundation, asserting that “one can proactively examine the process”. This underscores the significance of data accuracy in facilitating initiative-taking decision-making and process optimisation. Effective data analysis enables mining operations to pinpoint inefficiencies and enact improvements, resulting in increased production and cost reductions.

Conversely, Participant ME12 introduces the notion of risk management into the discourse, asserting that Industry 5.0 technologies entail a proactive approach to risk management. This viewpoint emphasises that process optimisation encompasses not only efficiency but also the comprehension and mitigation of risks linked to mining operations. Proactive risk management fosters steady and predictable operations, crucial for sustained economic advantages.

Additionally, Participant ME1 reinforced the concept of process optimisation via technology by asserting that “real-time data analytics can perpetually enhance processes and implement adjustments instantaneously.” This observation highlights the dynamic characteristics of Industry 5.0 technologies, enabling ongoing monitoring and modification of operations. The capacity for real-time modifications can improve operating efficiency and adaptability to evolving circumstances, therefore optimising economic advantages.

Moreover, Participant ME5 enhances the discourse by stating that “the technology has been utilised to create a human intervention list.” This signifies that although technology is essential for process optimisation, it also highlights areas requiring human control. The equilibrium between automation and human involvement is essential for the smooth and efficient functioning of activities.

From the viewpoint of the mining consultants, participant MC003 elucidated how the flotation circuit might enhance recovery rates. This underscores the consultants’ emphasis on operational domains where Industry 5.0 technologies can yield measurable enhancements in performance. The focus on improving the flotation circuit indicates that specific interventions can produce substantial economic advantages.

However, another mining consultant (Participant MC010) presented an alternative perspective and expressed a practical issue regarding the challenges businesses face in implementing new digital technology to enhance productivity. This illustrates a prevalent concern among enterprises about the concrete advantages of implementing digital technologies. This emphasises the direct influence of technology on workload and operational efficiency, a crucial factor for mining businesses.

Finally, Participant TS006 from the technical suppliers' group provided a comprehensive viewpoint, asserting that the interaction between technology and human behaviour is crucial for achieving optimal results in mining operations.

5.2.1.1.3 Conclusion on Theme 1: Process optimisation

The interactions with mining executives, consultants, and technical suppliers indicated a complex comprehension of process optimisation as an economic advantage of implementing Industry 5.0 technology. Mining executives underscored the significance of precise data, risk management, real-time analytics, and the equilibrium between automation and human involvement. Consultants emphasised specific operational enhancements and the practical ramifications of technology implementation, whereas technical vendors underscored the necessity for a culture transformation in conjunction with technological progress. These results highlighted that process optimisation in the mining sector involves a complex interaction of technology, human behaviour, and strategic management, all essential for optimising economic gains in the advancing context of Industry 5.0.

5.2.1.2 Theme 2: Operational sustainability improvements

The issue of operational sustainability enhancements surfaced as a significant finding for discussion due to the varied perspectives presented in the case, as illustrated in Table 8 below. The diverse experiences of mining executives and consultants offered valuable insights into the research issue, enhancing the comprehension of the phenomenon under investigation.

5.2.1.2.1 Evidence of Theme 2: Operational sustainability improvements

Table 8. Evidence of operational sustainability improvement theme

Research Question 1, Theme 2: Operational sustainability improvements
"...AI helping with basically being more power efficient. Better adoption of AI by those sorts of smaller guys would actually improve their operation a whole lot and collectively together improve the sustainability of mining as a whole." Participant ME12
"If we could use technology to predict climate change, that will go a long way in assisting us to deal with sustainability challenges. There has been much development around solar, wind and renewables" Participant ME9
"You cannot operate nowadays without talking about ESG. We also do audits on our suppliers around ESG. Again, you could utilise technology to gain that info to be informed." Participant ME9
"So, look, sustainability, I think, has become obviously more and more important over the past couple of years, especially the ESG side of things. And I think it has been pushed quite hard. I think technology obviously enables a lot of the sustainability stuff, but again, it still comes down to, I think, based on lots of stuff I've seen in the mining industry. For the junior guys, it's, you know, sustainable sustainability is important because that gives you funding, but it can't be done at any cost." Participant MC011
"I mean, the ESG topic is broad, right? So I think there's a few different elements in that. If I just think of the g part of ESG, just the governance, I think the reporting burden on mining companies is

going to increase significantly if they want to comply with the agendas or the ESG agenda of today." Participant MC010

5.2.1.2.2 In-case and cross-case analysis of the evidence of Theme 4: Operational sustainability improvements

The investigation of operational sustainability enhancements, viewed as economic advantages of using Industry 5.0 technology in mining, uncovered a complex array of perspectives from mining executives and consultants. The insights provided by Participants ME12 and ME9 from the mining executive group, along with Participants MC011 and MC010 from the mining consultants group, underscore both shared themes and divergent perspectives on the role of technology in advancing sustainability.

Participant ME12 highlighted the capacity of AI to improve energy efficiency in mining operations. This perspective posits that the use of AI technologies can enhance energy efficiency and promote the sustainability of mining operations. Moreover, ME12 observed that increased adoption of AI by smaller entities will significantly enhance their operations and collectively bolster the sustainability of the mining sector. This underscores the notion that even minor mining enterprises may use innovative technologies to improve their sustainability initiatives, therefore generating a cumulative effect throughout the industry.

In a complementary manner, participant ME9 emphasised the significance of employing technology to anticipate and tackle climate change issues. This viewpoint emphasises the anticipatory function of technology in mitigating environmental effects and promoting sustainable practices. ME9 also referenced progress in renewable energy sources, including solar and wind, signifying a comprehensive commitment to incorporating sustainable energy solutions into mining operations.

Participant ME9 underscored the paramount importance of Environmental, Social, and Governance (ESG) concerns in contemporary mining operations, asserting that “mines cannot function today without addressing ESG”. This feeling indicates an increasing acknowledgement of the significance of ESG compliance in obtaining operational legitimacy and financing. Thus, Participant ME9 emphasised the significance of technology in the collection and analysis of ESG-related data, proposing that technological instruments can improve transparency and accountability in supply chain management.

From the consultants' viewpoint, participant MC011 recognised the growing significance of sustainability, especially with ESG considerations. The comments indicate a pragmatic approach to sustainability, with financial viability as a primary issue. Sustainability measures are crucial for attracting investment, but they must be weighed against operating expenses and economic conditions, especially for junior mining firms. Additionally, Participant MC010 elaborated on the governance dimension of ESG, emphasising the growing reporting obligations imposed on mining enterprises. This observation highlights the difficulties mining firms encounter in fulfilling regulatory and stakeholder demands related to sustainability reporting. The focus on governance indicates that, although technology can enhance data gathering and reporting, the intricacies of compliance may provide considerable hurdles for the business.

5.2.1.2.3 Conclusion on Theme 4: Operational sustainability improvements

In conclusion, the interviews with mining executives and consultants indicated a consensus on the pivotal role of Industry 5.0 technologies in improving operational sustainability in the mining industry. Mining executives underscored the promise of AI and predictive technology to enhance energy efficiency and combat climate change, while consultants underlined the financial ramifications of sustainability projects and the growing governance requirements related to ESG compliance. Collectively, these findings emphasised the necessity of merging sophisticated technologies with a strategic sustainability approach that harmonises economic viability with environmental and social obligations. The changing mining landscape requires a cooperative approach to use technology for sustainable practices, ensuring the industry meets operational and societal expectations in the future.

5.2.2 Perceived environmental benefits

This section discusses the themes related to the perceived environmental benefits of Industry 5.0 technologies as they contribute to sustainable mining practices. Five topics were recognised in the thematic analysis and examined, as illustrated in Table 9. Nonetheless, only a single theme that embodies novel ideas is offered and examined.

Table 9. Perceived environmental benefits themes

Theme	Similarities Existing theme	Differences New theme	Discussed Yes/No
Resource conservation	X		No new insights
Biodiversity protection	X		Yes, new insights
Climate resilience	X		No new insights
Waste management improvements	X		No new insights
Carbon emission reduction	X		No new insights

Table 10. Frequency of perceived environmental benefits themes

Theme	Mining Executives	Mining Consultants	Technology Suppliers
Biodiversity protection	Many Efficient land use planning Real-time monitoring and habitat conservation	Many	None

5.2.2.1 Theme 1: Biodiversity protection

The protection of biodiversity surfaced as a theme in the examination of the contributions of Industry 5.0 technologies to sustainable mining. Only members of the mining executive and technical supplier groups articulated their experiences about this issue. Table 11 below underscores the evidence pertaining to this issue.

5.2.2.3.1 Evidence of Theme 1: Biodiversity protection

Table 11. Biodiversity protection theme

Research Question 1, Theme 1: Biodiversity protection
"Industry 5.0 technologies allow us to monitor and protect local biodiversity." Participant ME9
"By using Industry 5.0 technologies, we can better assess the impact of our operations on local ecosystems, which helps in protecting biodiversity." Participant ME1
"The advanced monitoring systems allow us to track environmental changes and take action to mitigate any negative effects on biodiversity." Participant ME5
"With the integration of smart technologies, we can minimise our footprint and ensure that we are not disrupting local wildlife habitats." Participant ME9
"The implementation of Industry 5.0 technologies has allowed us to better manage our mining activities, which is crucial for habitat preservation." Participant ME1
"By utilising smart technologies, we can monitor the health of habitats in real-time and respond quickly to any threats." Participant ME12
"We are now able to implement practices that prioritise habitat preservation, thanks to the capabilities of new technologies" Participant ME7
"With the help of advanced technologies, we can plan our land use more effectively, ensuring minimal disruption to the surrounding environment." Participant ME5
. "By focusing on sustainable land use, we can ensure that our mining operations do not lead to irreversible damage to the landscape." Participant ME9
"Industry 5.0 technologies allow us to optimise land use by identifying areas that can be mined sustainably without compromising ecological integrity." Participant MC011
"One of the key advantages of adopting these technologies is the ability to implement practices that safeguard biodiversity in mining areas." Participant MC010

5.2.2.3.2 In-case and cross-case analysis of the evidence of Theme 2: Biodiversity protection

The perspectives obtained from mining executives and consultants concerning biodiversity protection as a recognised environmental advantage of implementing Industry 5.0 technologies indicate a robust agreement on the beneficial effects of these technologies in monitoring and preserving local ecosystems. For example, Participant ME9 asserted that “Industry 5.0 technologies facilitate the monitoring and safeguarding of local biodiversity,” highlighting the essential function of technology in biodiversity conservation. Similarly, Participant ME1 articulated that “utilising Industry 5.0 technologies enables mines to more effectively evaluate the effects of mining activities on local ecosystems, thereby aiding in the preservation of biodiversity.” Consequently, both participants emphasised the significance of monitoring as an essential initial measure in comprehending and alleviating the effects of mining operations on biodiversity.

Building on this, Participant ME5 elaborated on this issue, asserting that “advanced monitoring systems enable us to track environmental changes and implement measures to mitigate any adverse effects on biodiversity.” This proactive monitoring strategy corresponded with the perspective of Participant ME12, who observed that “by employing smart technologies, we can assess habitat health in real-time and swiftly address any threats.” Consequently, both parties underscored the necessity of real-time data to guide decision-making and facilitate prompt responses for biodiversity protection.

The incorporation of intelligent technologies was a prevalent motif in the responses. Participant ME9 stated that “the integration of smart technologies allows us to reduce our footprint and prevent disruption to local wildlife habitats.” In addition, participant ME1 asserted that the emphasis on reducing environmental impact is enhanced by the adoption of Industry 5.0 technologies, which facilitates improved management of mining operations essential for habitat protection. Consequently, both participants acknowledged that proficient management of mining operations is crucial for safeguarding local environments and biodiversity.

Furthermore, Participant ME7 contributed to this conversation with a different insight by asserting that advancements in technology have facilitated the implementation and prioritising of habitat preservation. This viewpoint corresponded with the assertions of Participant MC010, who contended that “a primary benefit of adopting these technologies is the capacity to implement practices that protect biodiversity in mining regions.” Both participants underscored the initiative-taking strategies that may be implemented to safeguard habitats and biodiversity through the implementation of Industry 5.0 technologies.

Land use planning is another significant unique insight emphasised by the participants. Participant ME5 asserted that “through the utilisation of advanced technologies, mines can optimise land use while minimising disruption to the adjacent environment.” Similarly, Participant MC011 expressed that Industry 5.0 technologies facilitate the optimisation of land use by pinpointing places suitable for sustainable mining without jeopardising ecological integrity. Consequently, both contributors underscored the significance of strategic land use planning in reducing the ecological impact of mining activities.

Finally, Participant ME9 addressed this issue, asserting that "by prioritising sustainable land use, mines can guarantee that mining activities do not result in irreversible harm to the landscape." This viewpoint underscored the necessity of responsible land use for safeguarding biodiversity and preserving ecological equilibrium.

5.2.2.3.3 Conclusion on Theme 1: Biodiversity protection

The results from the mining executives and consultant participants indicate a robust agreement on the anticipated environmental advantages of implementing Industry 5.0 technology for biodiversity conservation. The insights indicate the necessity of monitoring and evaluating the effects of mining activities on local ecosystems, along with the imperative for efficient land use planning to mitigate disturbances to wildlife habitats. Although there were subtle distinctions in the focus on certain elements, such as real-time monitoring and habitat conservation, the overarching theme highlights a dedication to sustainable mining techniques that prioritise the protection of biodiversity. The incorporation of Industry 5.0 technologies was regarded as a crucial advancement towards realising these objectives, resulting in more sustainable and ecologically aware mining practices.

5.2.3 Perceived social benefits

This section discusses the themes related to the perceived social benefits of Industry 5.0 technologies as they contribute to sustainable mining practices. Four themes were found in the thematic analysis and examined, as indicated in Table 12. Nevertheless, only two themes providing novel insights into the study are presented.

Table 12. Perceived social benefits themes

Theme	Similarities Existing theme	Differences New theme	Discussed Yes/No
Employee empowerment and people focus	X		Yes, insights
Health and safety improvements	X		Yes, insights
Community engagement	X		No new insights

Table 13. Frequency of perceived social benefits themes

Theme	Mining Executives	Mining Consultants	Technology Suppliers
Employee empowerment and people focus	Many Start new business Job enlargement New job creation Workplace development	Few Proficient personnel capable Interpersonal skills in managing sophisticated technologies	Few Upskilling Job retention Training opportunities
Health and safety improvements	Many Reduce facilities. Reduce accidents. New safety risks	Few Remote operating capabilities	Few Utilisation of large language models (LLMs) for training personnel

5.2.3.1 Theme 1: Employee empowerment and people focus

Employee empowerment and a focus on individuals emerged as a prominent theme from the participants' varied experiences on the capacity of INDUSTRY 5.0 technologies to enhance the skillsets and competencies of mining employees. The theme was chosen to provide fresh insights and comprehension of the research topic at hand. Table 14 presents the participants' perspectives on this issue.

5.2.3.1.1 Evidence of Theme 1: Employee empowerment and people focus

Table 14. Evidence of employee empowerment and people focus theme.

Research Question 1, Theme 1: Employee empowerment and people focus
"Empowerment is very big, right? In my view, you shouldn't be employing people to do the same thing for the rest of their lives. We should be empowering people to go from one level to the next level in one way or the other. You should be also empowering people out of your business. That makes sense. You should be empowering people to start their own businesses, to provide a service to you." Participant ME4
"So it also created some employment creation which has brought bread on other people's tables." Participant ME12
"I think the first one is the one which I highlighted at the beginning of our discussion that there is the issue around employment creation……." Participant ME9
"Instead of just focusing on efficiency, we're looking at the social side, the social benefit, we're looking at the environmental benefits. What is now important is for the worker to have meaningful work." Participant ME9
"People are going to be replaced by people who know about AI. The human resources... are the ones who decide... The human impact is still required." Participant ME9
"You need the human interface, you need the skillset to identify... you can have the best drone technology... but if you don't know how to mine it, mining will be nothing its own." Participant MC010
"You still need to utilise and signal that machine. It's the human interface that signals a machine." Participant MC011
"It's enhancing especially your more inexperienced or your novices and graduate engineers. It's a massive help to them. The LLMs is a potential enabler for that, to reverse that trend... upskilling." Participant TS008
"LLMs is a potential enabler for it because it's like having a specialist on your computer. The people that had access to the LLM, chatbot job retention went up by 80%." Participant TS008
"They are key. They are key. They are enablers... The co-pilot is assisting the guy who's actually doing the flying of the airplane." Participant TS006
"The mining houses are starting to push their people out at the age of 55... these guys are using their best skills at the age of 55. All that money is going back to consultation. He's not going back and teach and train the people and actually responding to jobs." Participant TS013

5.2.3.1.2 In-case and cross-case analysis of the evidence of Theme 1: Employee empowerment and people focus.

The insights obtained from mining executives, consultancy firms, and technical suppliers demonstrated a sophisticated comprehension of the social advantages of implementing Industry 5.0 technologies in mining, especially regarding employee empowerment and a human-centric approach. Despite significant disparities in viewpoints among the groups, certain shared themes arose, underscoring the significance of human capital in the changing mining scenario.

For instance, participant ME4 underscored the need for empowerment, advocating that employees ought not to be restricted to monotonous jobs during their careers. The emphasis should be on facilitating individuals' advancement to higher positions within the firm or enabling them to establish their own enterprises. Participant ME12 echoed this sentiment differently, by observing that the implementation of new technology has resulted in employment development, thereby yielding economic advantages for individuals and their families.

Furthermore, Participant ME9 emphasised a fresh insight into the necessity of job creation as a vital component of technological adoption, suggesting that the societal advantages of Industry 5.0 technologies extend beyond simply efficiency improvements. Participant ME9 elaborated on the social aspect of technological adoption, emphasising the significance of meaningful employment for employees. He, however, also points out that "People are going to be replaced by people who know AI," which brings into focus the knowledge deficiency that a lot of the respondents spoke of. However, this viewpoint corresponded with the overarching idea of employee empowerment, indicating that technology should not merely augment productivity but also enhance the individual work experience.

Recognising human influence in the mining industry is essential, as it highlights the necessity for proficient personnel capable of effectively engaging with sophisticated technologies. This insight was corroborated by the consultancy participants, with Participant MC010 asserting that despite technical developments, human interaction is vital for effective mining operations.

The technical suppliers' group offered further insights regarding technology's significance in improving employee capabilities. Participant TS008 asserted that Industry 5.0 technologies, especially Large Language Models (LLMs), are essential in enhancing the skills of inexperienced engineers. This viewpoint emphasised technology's capacity to serve as a mentor, facilitating substantial enhancement of competencies for less experienced personnel. In addition, Participant TS006 supported this notion by comparing the function of technology to that of a co-pilot, aiding employees in their duties and augmenting their abilities.

Nonetheless, there are apprehensions surrounding the treatment of seasoned employees within the sector. Participant TS013 observed that mining businesses are progressively dismissing personnel aged fifty-five and above, despite these individuals possessing significant skills and expertise. This trend prompts enquiries regarding knowledge transfer and the possible erosion of competence within the industry. The inability to utilise the expertise of older workers may impede the overall efficacy of Industry 5.0 technologies, as these individuals frequently possess essential insights for successful application.

5.2.3.1.3 Conclusion on Theme 1: Employee empowerment and people focus.

The conclusions from the diverse participants underscored a collective acknowledgement of the significance of personnel and employee empowerment in the adoption of Industry 5.0 technologies within the mining sector. Mining executives highlighted the importance of professional advancement and purposeful employment, whereas consultancy participants underscored the essentiality of people skills in managing sophisticated technologies. Technical suppliers emphasised the capacity of technology to improve skill development while simultaneously expressing concerns on the treatment of elderly labour. The conclusions indicate that a balanced strategy prioritising both technology progress and human capital is crucial for maximising the societal advantages of Industry 5.0 technologies in the mining industry. Empowering personnel, promoting skill development, and facilitating knowledge transfer will be essential for navigating the future of mining in an increasingly automated environment.

5.2.2.2 Theme 2: Health and safety improvements

The theme of health and safety improvements was mentioned by a few participants from the three participating groups. The evidence is shown in Table 15 below.

5.2.2.2.1 Evidence of Theme 2: Health and safety improvements

Table 15. Evidence of health and safety improvement theme

Research Question 1, Theme 2: Health and safety improvements
"So I think safety is the one of the mitigating driver in this whole thing. And then obviously the other thing is like production. I mean, productivity is something that we really trying to maximise each and every time." Participant ME1
"With the use of advanced sensors and AI, we can now predict equipment failures that could lead to safety incidents, which is a game changer for our operations." Participant ME3
"The automation of hazardous tasks not only protects our workers but also enhances their overall well-being by reducing their exposure to dangerous environments." Participant ME5
"By leveraging advanced analytics, we can continuously improve our safety standards, making data-driven decisions that prioritise the well-being of our workforce." Participant ME9
"But at the same time, the industry might be trying to push in that direction in order to reduce the fatalities in the industry. From the safety perspective. But at the same time run the risk of exposure of people to other risks. So there is a give and take there." Participant ME12
"You need the human interface, but with technology, we can ensure that workers are not placed in harm's way, which is a fundamental shift in our safety culture." Participant MC010
"So I think safety, as I say, I think safety. It's, I think very much front and centre in terms of the mining industry. I think the technology there certainly is, you know, you will use the technology or the latest technology to try and assist with that. But again, it all comes down to it being a tool rather than an end goal. Let's call it that." Participant MC011
"The ability to remotely operate machinery means that our workers can stay safe while still being productive, which is a significant advancement in our safety measures." Participant MC011
"By utilising LLMs, we can train our staff on safety procedures more effectively, ensuring that they are well-prepared to handle emergencies." Participant TS008
"Decisions that you have to make that is driven by legislation, that is driven by safety, which is driven by different environmental factors, and then you get decisions that is driven by monetary value, sustainability, market demand." Participant TS013

5.2.2.2.2 In-case and cross-case analysis of the evidence of Theme 2: Health and safety improvements

The implementation of Industry 5.0 technologies in mining has been a central topic of discourse among diverse stakeholders, especially regarding enhancements in health and safety. Perspectives from mining executives, consultants, and technical providers indicate both commonalities and distinctions regarding the impact of these technologies on safety standards and overall worker welfare.

Mining executives underscored the simultaneous emphasis on safety and productivity as essential motivators for the use of Industry 5.0 technology. Participant ME1 emphasised that safety is a crucial mitigating element in technological adoption, intimately linked to the objective of optimising output. Participant ME3 observed that modern sensors and AI facilitate predictive maintenance, thereby averting equipment failures that could result in safety accidents. This proactive safety strategy is seen as a "game changer" for operations, reflecting a firm conviction in technology's capacity to improve safety results.

Furthermore, Participant ME5 elaborated on the protective advantages of automation, asserting that automating perilous duties not only protects workers but also enhances their overall well-being by reducing their exposure to hazardous settings. This viewpoint corresponded with Participant ME9, who underscored the significance of advanced analytics in perpetually enhancing safety standards via data-driven decision-making. Consequently, both panellists emphasised the significance of technology in fostering safer work settings, indicating a consensus among executives regarding the beneficial effects of Industry 5.0 technologies on health and safety.

Participant ME12 presents a nuanced perspective, recognising that although the industry seeks to diminish deaths via technological innovations, there are intrinsic hazards linked to these modifications. This acknowledgement of a "give and take" relationship underscores the intricacy of integrating recent technologies in mining, where enhancements in safety must be weighed against possible new hazards.

Conversely, mining consultants offered another viewpoint, emphasising the human aspect in the incorporation of technology. Participant MC010 claimed that although technology is vital, human interaction is crucial for safeguarding workers from potential harm. This comment indicates a significant transformation in safety culture, underscoring that technology should augment, not supplant, human supervision. Additionally, Participant MC011 emphasised that safety is a paramount concern in the mining sector, with technology functioning as an instrument to facilitate the attainment of safety objectives. This perspective coincided with the executives' focus on safety while introducing a note of prudence, indicating that technology should be regarded not as a final objective but as a tool to enhance safety results. Furthermore, MC011 underscores the importance of remote operating capabilities, enabling personnel to sustain output while reducing their exposure to perilous conditions.

Technical vendors provided significant insights, especially concerning training and compliance. Participant TS008 indicated the utilisation of large language models (LLMs) for training personnel on safety protocols, hence assuring their preparedness for crises. This emphasis on training corresponds with the perspectives of executives and consultants regarding the significance of human factors in safety. Moreover, Participant TS013 examines the decision-making processes shaped by legislation, safety, environmental factors, and financial reasons. This viewpoint highlights the complex nature of safety enhancements, indicating that although technology is essential, it must be incorporated within a wider context of regulatory and market requirements.

5.2.2.2.3 Conclusion on Theme 2: Health and safety improvements

The findings indicate a robust agreement among mining executives, consultants, and technical providers regarding the significance of Industry 5.0 technologies in improving health and safety standards within the mining sector. Executives prioritised the immediate advantages of technology in incident prevention and enhancing worker welfare, but experts underscored the importance of preserving a human component in safety protocols. Technical vendors emphasised the need for training and compliance in the proper implementation of safety enhancements. The observations indicate that Industry 5.0 technologies provide substantial prospects for improving safety; however, a balanced strategy that accounts for both technology and human elements is crucial for attaining lasting advancements in health and safety standards within mining operations.

5.2.4 Perceived regulatory benefits

The themes of the perceived regulatory benefits derived from Industry 5.0 technologies as contribution of sustainable mining practices are discussed in this section. One theme was identified and discussed, as highlighted in Table 16.

Table 16. Perceived regulatory benefits themes

Theme	Similarities Existing theme	Differences New theme	Discussed Yes/No
Enhanced environmental regulation compliance	X		Yes, insights

Table 17. Frequency of perceived regulatory benefits themes

Theme	Mining Executives	Mining Consultants	Technology Suppliers
Enhanced Environmental regulation compliance	Few Air quality regulations	Few ESG reporting	None

5.2.4.1 *Theme 1: Enhanced environment regulations compliance*

Compliance with enhanced environmental standards emerged as a significant lesson from the different experiences of mining executives and mining consultants regarding the transformative impact of Industry 5.0 technologies on the skillsets and competencies of mining employees. The theme was chosen to provide fresh insights and comprehension regarding the research topic under consideration. Table 18 presents the participants' perspectives on this issue.

5.2.4.1.1 Evidence of Theme 1: Enhanced environmental regulations compliance

Table 18. Evidence of enhanced environmental regulations compliance theme

Research Question 1, Theme 1: Enhanced environment regulations compliance
"With Industry 5.0 technologies, we can automate compliance reporting, making it easier to meet regulatory standards." Participant ME1
"The transparency provided by advanced analytics helps us demonstrate compliance to regulators effectively." Participant ME3
"Using data analytics, we can make informed decisions that align with regulatory requirements." Participant ME5
"Predictive analytics can foresee compliance issues before they arise, allowing us to address them proactively." Participant ME9
"In terms of environmental adoption of technologies to have a positive impact on the environment, I think the industry has been forced because of the regulations, especially on air quality. The penalty is actually what is now pushed people to say, what can we do differently in order not to get these penalties." Participant ME12
"In terms of environmental adoption of technologies to have a positive impact on the environment, I think the industry has been forced because of the regulations, especially on air quality." Participant ME12
"I mean, the ESG topic is broad, right? So I think there's a few different elements in that. If I just think of the g part of ESG, just the governance, I think the reporting burden on mining companies is going to increase significantly if they want to comply with the agendas or the ESG agenda of today." Participant MC10
"Real-time data collection allows us to monitor compliance continuously, reducing the risk of violations." Participant MC010

> “Automated checks ensure that we are always in line with the latest regulations, reducing human error." Participant MC011

5.2.4.1.2 In-case and cross-case analysis of the evidence of Theme 1: Environmental regulations compliance

Perspectives from mining executives and consultants demonstrated a sophisticated comprehension of how these technologies aid in adhering to environmental standards, emphasising both commonalities and distinctions in their viewpoints. Mining executives, including Participant ME1, highlighted the automation of compliance reporting as a significant advantage of Industry 5.0 technologies, contending that automation streamlines the process of adhering to regulatory norms, thus alleviating the administrative strain on mining firms. Participant ME3 echoed this sentiment, noting that enhanced analytics improve transparency, facilitating compliance demonstration to authorities. This emphasis on automation and transparency reflected a collective acknowledgement among executives that Industry 5.0 technologies may enhance compliance processes, resulting in more efficient operations.

Alongside automation, mining executives emphasised the significance of data analytics in facilitating informed decision-making. Participant ME5 observed that data analytics facilitates enterprises in efficiently aligning their operations with regulatory mandates. Participant ME9 reinforced this proactive strategy by addressing the capability of predictive analytics to anticipate compliance issues prior to their emergence. This progressive viewpoint highlighted a prevalent theme among executives that the capacity to utilise technology is not only for adherence to current rules but also to foresee and alleviate future compliance issues.

There is a significant disparity in the perspectives of mining executives concerning the reasons for embracing these technologies. Participant ME12 indicated that the industry has been necessitated to implement environmental technologies chiefly due to governmental demands, especially regarding air quality. This viewpoint emphasised a reactive approach when adherence is motivated by the apprehension of sanctions rather than a proactive dedication to sustainability. This opinion diverges from the more hopeful perspectives of some executives who regard Industry 5.0 technologies as instruments for improving operational efficiency and sustainability. There is a current drive by the South African government against pollution and climate change that affects mining houses operating in South Africa. Most of these sentiments were made by older mining executives than younger executives who have been in the industry for a long time.

Conversely, mining experts offered a comprehensive perspective on the ramifications of Industry 5.0 technologies for compliance. Participant MC10 highlighted the escalating reporting obligations for mining firms as they endeavour to comply with the advancing Environmental, Social, and Governance (ESG) frameworks. This recognition of the intricacies associated with ESG compliance indicated that whereas Industry 5.0 technologies can aid in compliance, they simultaneously provide novel issues with governance and reporting. These viewpoints from the consultants originate from the aggressive drive by big, listed mining houses to engage consulting firms to ensure ESG compliance.

Mining advisors echoed the different opinions of mining executives over the advantages of real-time data collection. Participant MC010 emphasised that ongoing compliance monitoring mitigated the risk of infractions, consistent with the proactive compliance measures articulated by executives. Moreover, Participant MC011 emphasised the significance of automated verifications in maintaining compliance with current standards, thus reducing human error. However, the collective focus on real-time monitoring and automation demonstrated agreement among internal and external stakeholders regarding the operational benefits of Industry 5.0 technologies.

5.2.4.1.3 Conclusion on Theme 1: Environmental regulation compliance

The findings indicate a complex relationship between the perceived advantages of Industry 5.0 technologies and the incentives for their adoption in the mining industry. Mining executives mostly perceived these technologies as facilitators of efficiency and proactive compliance while also recognising the regulatory requirements that necessitate their adoption. Conversely, mining consultants offer a comprehensive viewpoint on the escalating intricacies of ESG compliance, emphasising the necessity for strong governance structures in conjunction with technology progress. Both parties acknowledge the potential of Industry 5.0 technologies to improve compliance with environmental regulations, albeit from slightly different perspectives, highlighting the necessity of balancing operational efficiency with the changing requirements of regulatory frameworks.

5.2.5 Conclusions to Research Question 1: Perceived benefits

The findings from the responses to RQ1 underscored the complex landscape of adopting Industry 5.0 technologies in the mining sector. Key insights revealed diverse perspectives on technology adoption, with a general acknowledgement of benefits like process optimisation, operational sustainability improvements, enhanced biodiversity protection, employee empowerment and people focus, health and safety improvements, and enhanced environmental compliance. However, significant concerns persisted regarding the operational complexities and financial implications of these technologies. The role of regulatory compliance emerged as a crucial motivator, while the necessity for strategic integration and robust leadership support is highlighted as essential for successful implementation. Overall, a balanced approach that aligns technological advancements with economic viability, sustainability goals, and stakeholder expectations is imperative for navigating the challenges of Industry 5.0 adoption in mining.

5.3 Research Question 2

Constraints that impact the adoption of Industry 5.0 technologies in mining sustainability transitions.

The topics addressing this subject were informed by the conceptual framework delineating perceived economic, environmental, social, and regulatory constraints.

5.3.1 Perceived economic constraints

The themes of the perceived economic constraints hindering the adoption of Industry 5.0 technologies are discussed in this section. One theme was identified in the thematic analysis and discussed, as highlighted in Table 19.

Table 19. Perceived economic constraints themes

Theme	Similarities Existing theme	Differences New theme	Discussed Yes/No
Cost of implementation	X		Yes - insights

Table 20. Frequency of perceived economic constraints themes

Theme	Mining Executives	Mining Consultants	Technology Suppliers
Cost of implementation	Few High maintenance and initial costs	Few Cost conservative nature	Few- Overestimation of benefits

5.3.1.1 *Theme 1: Cost of implementation*

The cost of implementation emerged as a key theme from the mining executive participants' diverse experiences on how Industry 5.0 technologies can transform mining employees' skillsets and competencies. The theme was chosen to provide fresh insights and comprehension regarding the research topic under consideration. Table 21 shows the evidence of the participants' views on this theme.

5.3.1.1.1 Evidence of Theme 1: Cost of implementation

Table 21. Cost of implementation theme

Research Question 2, Theme 1: Cost of implementation
"The upfront costs of implementing Industry 5.0 technologies are significant, making it hard to justify." Participant ME1
"We struggle to quantify the ROI of these technologies, which makes it difficult to secure funding." Participant ME3
"What you call battery-driven, it was the change out of the batteries. How long does it change, take to change out the batteries as well? So the inventory of those batteries, it's, it's just a massive cost and if you don't keep them" Participant ME1
First and foremost is always the cost, right. As an industry, we very often... struggle to articulate... the benefit outside of production." Participant ME7
"So the cost, the driver about cutting costs also, I think, becomes a deterrent in adopting the technology, but in terms of maintenance, actually the initial uptake, maintenance thereof, of that technology." Participant ME12
"The conservative nature of the mining industry in terms of what is the cost, does kick in." Participant MC003
"So I think, I mean the first one is cost... " Participant MC010
"The new stuff and the value that it adds is grossly overestimated." Participant TS008
"Now so much data gets logged. We meant we overshot in terms of - now there's just too much information, probably." Participant TS008

5.3.1.1.2 In-case and cross-case analysis of the evidence of Theme 1: Cost of implementation

The investigation of the perceived economic limitations related to the cost of the implementation of Industry 5.0 technologies in mining uncovers a multifaceted array of perspectives among several stakeholder groups, including mining executives, consultants, and technical suppliers. The primary theme is the substantial expenses linked to the implementation of these technologies, regarded as a significant obstacle to acceptance.

Participant ME1 underscored the considerable initial expenditure necessary for Industry 5.0 technologies, asserting that "the upfront expenses of implementing Industry 5.0 technologies are enormous, rendering justification difficult." ME12 echoed another sentiment, observing that the expenses related to maintenance and initial implementation also hinder the adoption of innovative technologies. Participant ME3 emphasised yet a different insight: the challenge of measuring the return on investment (ROI) for these technologies, hence complicating the financing acquisition process. ME7 further elaborated on this topic, stating differently that "the mining industry often struggles to articulate the benefits of new technologies beyond production." This highlighted a more extensive problem within the sector about the capacity to exhibit the financial feasibility of Industry 5.0 technologies. ME1 also articulated unique apprehensions over the financial implications of battery-operated technologies, especially the costs involved with battery stockpiling and replacement. This underscored the intricate financial ramifications of implementing technologies within the overarching framework of Industry 5.0.

Participant MC003 highlighted the conservative tendencies of the mining industry regarding cost considerations, indicating that this mentality may impede the integration of innovative technologies. This corresponded with the executives' apprehensions about the elevated expenses and the challenges in rationalising them. MC010 also emphasised that cost is a primary concern, underscoring that financial limitations are a substantial obstacle to the implementation of Industry 5.0 technologies in mining.

Participant TS008 provided a critical viewpoint, asserting that the new technical offering and its added value are significantly exaggerated. This indicated a disparity between the expectations established by suppliers and the actual perceived value by mining businesses, potentially leading to reluctance to embrace new technologies. TS008 addressed the concern of data overload, highlighting that the enormous quantity of information produced by emerging technology might be daunting. The apprehension regarding data management and interpretation introduces a new dimension to economic limitations, suggesting extra expenses associated with data administration and analysis.

5.3.1.1.3 Conclusion on Theme 1: High implementation costs

The conversations revealed to several participant groups that the substantial implementation costs of Industry 5.0 technologies pose a severe economic barrier in the mining sector. Mining executives articulated apprehensions regarding the significant initial expenditures and the difficulties in measuring ROI, which hinder financing endeavours. Consultants' viewpoints highlighted the industry's conservative characteristics, whilst technical vendors emphasised the possible overvaluation of the benefits these technologies offer, in addition to the difficulties associated with data management.

The findings indicated a multifaceted interaction of financial apprehensions, industrial conservatism, and the necessity for more explicit communication regarding the advantages of Industry 5.0 technologies. Mitigating these economic restraints will be essential for promoting the use of novel technologies in the mining sector, as players aim to reconcile the necessity for modernisation with the imperatives of financial justification.

5.3.2 Perceived environmental constraints

The themes of the perceived environmental constraints hindering the adoption of Industry 5.0 technologies are discussed in this section. Two themes were identified as highlighted in Table 22. However, these themes are not discussed since they do not offer any fresh insights to the study.

Table 22. Perceived environmental constraints theme

Theme	Similarities Existing theme	Differences New theme	Discussed Yes/No
Environmental regulations	X		No new insights

5.3.3 Perceived social constraints

The themes of the perceived social constraints hindering the adoption of Industry 5.0 technologies are discussed in this section. Four themes were identified in the thematic analysis as highlighted in Table 23 below. However, only two themes offered fresh insights and are subsequently presented and discussed.

Table 23. Perceived social constraints themes

Theme	Similarities Existing theme	Differences New theme	Discussed Yes/No
Skills and training gap	X		No new insights
Job security and work transition	X		No new insights
Union/stakeholder concerns/resistance and lack of engagement	X		Yes, insights

Table 24. Frequency of social constraints themes

Theme	Mining Executives	Mining Consultants	Technology Suppliers
Union/stakeholder concerns/resistance and lack of engagement	Many Emerging technologies as detrimental to workers' employment Scepticism and apprehension inside union ranks Insufficient communication and involvement	Few Lack of genuine stakeholder participation	Few Lack of perceived value of technology to the end-users

5.3.3.1 Theme 1: Union/stakeholder concerns/resistance and lack of engagement

Union apprehensions and opposition surfaced as a prominent element in the examination of impediments that contribute to the hesitance in using Industry 5.0 technologies in mining. Numerous participants from the mining executive sector, together with other individuals from the consultancy and technical supplier groups, articulated their experiences about this issue. Table 25 underscores the evidence pertaining to this issue.

5.3.3.1.1 Evidence of Theme 1: Union/stakeholder concerns/resistance, lack of engagement

Table 25. Evidence of union/ stakeholder concerns/ resistance, lack of engagement

Research Question 2, Theme 3: Union/stakeholder concerns/resistance and lack of engagement
"The unions are going to say... they're reducing employment if we have more remote [control]." Participant ME9
“The moment you start talking about your automation, your organised labour is already up in arms that the comrades are going home." Participant ME9
"Unions are often resistant to change, especially when they perceive that new technologies might threaten jobs." Participant ME6
"If there’s a hint that you’re going to be laying off people because you’re implementing this new technology, obviously you’re going to have pushback in a big way from unions." Participant ME12
"The unions are always concerned about how technology will affect employment levels, and that creates a barrier to adoption." Participant ME4

"I think that the industry per se and the government and the organised labour, I think they haven't workshopped this thing properly. Everyone is sitting on the fence..." Participant ME12
"...you just need to properly communicate why this change is happening to all stakeholders. I must say, our MOC process, our management of change, if that is done properly, then you identify all the risks, the positives, the negatives. And then again, like I said, you just need to properly communicate why this change is happening to all stakeholders." Participant ME5
"You also need to engage other stakeholders like the government." (How would you handle unions? You got to find a way of ensuring that... even if you're going to reduce your labour force because of technology, you find an alternative for them." Participant ME9
"There's often a disconnection between the technology developers and the end-users in the mining sector, which leads to a lack of effective implementation." Participant ME3
"Without proper engagement with all stakeholders, including the workforce, the adoption of new technologies can face significant hurdles." Participant ME7
"The lack of communication between management and the workers creates resistance to new technologies." Participant ME10
"If we don't involve the unions and the workers in the conversation, we risk facing backlash when we try to implement new systems." Participant ME12
"There's a lot of scepticism from union representatives about the benefits of new technologies, which complicates negotiations." Participant ME5
"We need to ensure that all parties are on board; otherwise, the technology will not be utilised to its full potential." Participant MC005
"Many companies face significant pushback from unions when trying to implement new technologies, as they fear job losses." Participant MC011
"Stakeholder engagement is crucial; if the miners don't see the value in the technology, they won't use it." Participant TS002
"If there's a hint that, you know, you're going to be laying off people because you're implementing this new technology, obviously you're going to have pushback in a big way from unions." Participant TS008

5.3.3.1.2 In-case and cross-case analysis of the evidence of Theme 1: Union/stakeholder concerns/resistance and lack of engagement

The insights obtained from diverse participant groups about union/stakeholder apprehensions/opposition and lack of engagement, viewed as a social restriction affecting the use of Industry 5.0 technologies in mining sustainability transitions, indicate both commonalities and divergences in viewpoints. The union view was combined with other stakeholder engagement as it was expected to bring out specific nuances that are unique to South Africa and its history. The mining executives, consultants, and technical suppliers each offer significant perspectives that enhance the knowledge of the issues presented by the Union and other stakeholder dynamics amid technological innovation.

The mining executives articulate a distinct apprehension about the correlation between automation and employment. Participant ME9 concisely expresses that unions perceive emerging technologies as detrimental to workers' employment. This underscores a common apprehension among union leaders regarding the potential for job losses due to heightened automation, a different sentiment echoed by Participant ME6, who observes that "unions are frequently resistant to change, particularly when they believe that new technologies could jeopardise employment."

The executives underscored that the mere discourse on automation can elicit swift opposition from organised labour, as evidenced by Participant ME9's assertion, "The moment you begin discussing automation, your organised labour is already in an uproar that the comrades are departing." This indicates a profound scepticism and apprehension inside union ranks concerning the ramifications of technological progress. This is commonly expected in South Africa with a history of past labour uprisings during and post-apartheid era. This has led to the existence of strong labour unions and legislative support to constantly push for mineworkers’ employment rights.

Moreover, Participant ME12 corroborates this idea by indicating that resistance from the union is anticipated if there are indications of staff layoffs resulting from the implementation of recent technologies. This viewpoint highlights the executives' acknowledgement of the unions' safeguarding position on their members' employment stability, which constitutes a considerable obstacle to the implementation of modern technology. Participant ME4 asserts that "unions are consistently apprehensive regarding the impact of technology on employment levels, which constitutes an impediment to adoption." The shared perspective among executives highlights a recurring theme: the apprehension of job displacement is a significant obstacle to technological advancement.

Mining executives also articulated significant apprehension about the insufficient communication and involvement among many stakeholders, including government entities, organised labour, and technology developers. Participant ME12 emphasised that "the industry, government, and organised labour have not collaborated effectively to implement Industry 5.0 technologies, suggesting a perceived deficiency in cooperative planning and communication." Participant ME5 echoed a different opinion, underscoring the necessity of a systematic Management of Change (MOC) process and asserting that effective communication among stakeholders is essential for successful change implementation. This underscores a collective recognition among leaders that effective communication is vital to reduce opposition and enable more seamless transitions.

The mining consultants acknowledged the executives' concerns while underscoring the need for diversity in the engagement process. Participant MC005 emphasised the necessity of securing consensus among all stakeholders to fully actualise the potential of the new technology. This underscores the consultants' emphasis on the practical ramifications of a lack of genuine stakeholder involvement, indicating that the absence of thorough buy-in jeopardises the viability of innovative technology.

The mining consultants also reinforced the executives' sentiments, highlighting the difficulties presented by union opposition. Participant MC011 indicated that mining businesses may encounter substantial opposition from unions when attempting to adopt new technologies due to concerns over potential job losses. This closely matches with the executives' perceptions, underscoring the notion that the fear of job loss is a prevalent concern shared by both groups. The consultants' viewpoint enhances comprehension of the wider ramifications of union opposition, indicating that it transcends individual enterprises and is a systemic concern impacting the entire mining industry in South Africa, emanating from its historical apartheid background.

From the viewpoint of technical suppliers, the focus was on the perceived value of technology to the end-users. Participant TS002 stated that stakeholder participation is essential, and miners will not adopt technologies they perceive as lacking value. This statement highlights the necessity of communicating the advantages of modern technologies to the workforce, which corresponds with the executives' apprehensions over communication and engagement.

All participating groups clearly acknowledge differently the significance of stakeholder involvement in the effective implementation of Industry 5.0 technology. The mining executives prioritised organised communication and proactive interaction with labour unions, while advisors underscored the need to involve all stakeholders in the process. Technical vendors emphasised the necessity of explaining the advantages of technology to the miners. Nevertheless, a significant distinction exists in the focus on the responsibilities of various parties. Executives prioritised the internal dynamics of the organisation and the necessity for management to connect effectively with employees and unions. Conversely, consultants and suppliers prioritised the comprehensive involvement of all stakeholders, encompassing external groups such as governmental organisations.

5.3.3.1.3 Conclusion on Theme 1: Union/stakeholder concerns/resistance and lack of engagement

The findings indicate robust viewpoints among mining executives, consultants, and technical suppliers about the impact of union concerns and resistance as major social impediments to the implementation of Industry 5.0 technologies. The apprehension regarding job loss is a predominant issue that resonates with all participant groups, demonstrating a collective awareness of the difficulties presented by organised labour in the realm of technological progress. The executives offer direct views into the immediate effects of union resistance, while the consultants and technical vendors corroborate these observations, emphasising the systemic aspect of the problem. This collective viewpoint emphasises the necessity for mining corporations to collaborate with unions and other stakeholders proactively and genuinely, addressing their concerns and illustrating the potential advantages of new technologies to enable more seamless transitions to sustainable practices within the industry.

While there are differences in focus—executives on internal communication and consultants and suppliers on broader inclusivity—the consensus is clear: without effective engagement and communication, the transition to innovative technologies in the mining sector will face significant challenges. Addressing these concerns through structured engagement processes and demonstrating the value of technology to all stakeholders is essential for successful sustainability transitions in the industry.

5.3.4 Perceived regulatory constraints

This section discusses the themes regarding the perceived regulatory obstacles impacting the deployment of Industry 5.0 technology. Three themes were discovered in the thematic analysis, as noted in Table 26. Nevertheless, only a singular theme with novel insights was introduced and examined.

Table 26. Perceived regulatory constraints themes

Theme	Similarities Existing theme	Differences New theme	Discussed Yes/No
Prohibitive policies	X		No data
Lack of incentives	X		Yes, insights
Privacy and confidentiality concerns	X		No data

Table 27. Frequency of perceived regulatory constraints themes

Theme	Mining Executives	Mining Consultants	Technology Suppliers
Lack of incentives	Few Lack of incentives to prioritise digitisation that yield EIAS compliance	Few Absence of a definitive return on investment or incentive framework	None

5.3.4.1 Theme 1: Lack of incentives

The issue of "lack of incentives" was chosen to get insights into legislative restrictions that contribute to the hesitance in adopting Industry 5.0 technologies inside mining enterprises. The evidence is shown in Table 28 below.

5.3.4.2.1 Evidence of Theme 1: Lack of incentives

Table 28. Evidence of lack of incentives theme

Research Question 2, Theme 1: Lack of incentives
"The only incentive for environmental stuff is the retaining of your EIAS and your licenses that go with that. Right. So, it's about continuation of operation. I haven't seen any major incentives beyond that for environmental side." Participant ME4
"No incentives that I'm aware of now, I know we get skills ready back for training certain employees in certain skills, but I'm not sure if any of those four in that bracket where we get something back, but from the mining side." Participant ME5
"When there are no incentives tied to the adoption of new technologies, it's hard to get buy-in from the workforce." Participant ME12
"Many companies are hesitant to invest in new technologies because they don't see a clear return on investment or incentive structure." Participant MC011

5.3.4.2.2 In-case and cross-case analysis of the evidence of theme 1: Lack of incentives

The interviews with mining executives and consultants indicate a common apprehension about the absence of incentives as a major regulatory obstacle hindering the implementation of Industry 5.0 technologies in mining sustainability transitions. The participants' views reveal both commonalities and divergences in their viewpoints, especially with the perceived efficacy of current incentives and the overall influence on technological adoption.

Mining executives' perspectives are featured. Participant ME4, who expressed a critical perspective on the existing incentive framework, asserted that "The sole motivation for environmental digitisation is the preservation of EIAs and licences required for operational continuity and nothing beyond that." This statement highlights a common belief among mining executives that current incentives prioritise compliance over the promotion of innovation. The focus on preserving Environmental Impact Assessments (EIAs) and operational licences indicates that the legal framework prioritises the maintenance of existing conditions above fostering proactive technical innovations.

Participant ME5 echoed this sentiment by highlighting the absence of incentives. This remark underscores a deficiency in clarity over the incentives for adopting new technologies. The participant expressed doubt over the relevance of some skills-related incentives to wider technological improvements in mining. This uncertainty indicates a systemic problem in which the incentives are misaligned with the strategic objectives of using Industry 5.0 technology.

Participant ME12 underscored the difficulties arising from the absence of incentives, asserting that "without incentives linked to the adoption of new technologies, securing workforce buy-in is challenging." This viewpoint emphasises the essential function of incentives in encouraging employees to adopt change. In the absence of a definitive incentive framework, the workforce may oppose the adoption of new technology, hence obstructing overall advancements in sustainability transitions.

According to the mining consultants, Participant MC011 offers a unique perspective, asserting that “numerous mining companies are reluctant to invest in new technologies due to the absence of a definitive ROI or incentive framework.” This observation can be likened to the apprehensions expressed by mining executives, underscoring that the lack of a definitive incentive system constitutes an impediment to investment in novel technology. The focus on ROI signifies that firms seek not only compliance incentives but also concrete financial advantages that can validate the expenses incurred in adopting innovative technologies.

Both sides agree that the existing incentive systems are insufficient for encouraging the use of Industry 5.0 technology. Mining executives differently articulated their dissatisfaction with the narrow focus of current incentives, which predominantly emphasise compliance instead of fostering innovation. This sentiment is corroborated by the consultants, who emphasised the reluctance of mining businesses to engage in modern technology owing to the absence of a definitive ROI or incentive framework.

Nevertheless, a significant distinction is in the emphasis of the dialogues. Mining executives focused on legal considerations and operational continuity, whilst consultants highlighted the wider financial ramifications and the necessity for a definitive business case for technology implementation. The executives, as internal stakeholders, reflected on their day-to-day digitisation issues. This distinction indicates that both groups acknowledge the absence of incentives as a limitation, although they address the matter from differing perspectives—executives from a compliance and operational standpoint and consultants from a financial and strategic position. The consultant as an external stakeholder reflected a long-term and strategic perspective, which often makes up their engagement with mines.

5.3.4.2.3 Conclusion on Theme 1: Lack of incentives

The interviews with mining executives and consultants reveal a critical worry about the absence of incentives as a legislative barrier hindering the use of Industry 5.0 technologies in the transition towards mining sustainability. The executive participants reflected on their insights that the existing incentive frameworks are insufficient, especially emphasising compliance above the promotion of innovation. Whereas the consulting participants' viewpoint was that the absence of incentives diminishes corporate investment in innovative technology and impedes staff engagement, hence retarding advancements in sustainable mining practices. Rectifying these incentive deficiencies will be essential for enabling the transition to Industry 5.0 and improving the sustainability of mining operations.

5.3.5 Perceived organisational constraints

This section discusses the themes related to perceived organisational restrictions that impede the deployment of Industry 5.0 technology. Four themes were delineated from the thematic analysis as illustrated in Table 29. Nevertheless, only two themes providing novel insights to the investigation were addressed.

Table 29. Perceived organisational constraints

Theme	Similarities Existing theme	Differences New theme	Discussed Yes/No
Lack of leadership buy-in	X		Yes, insights
Infrastructure challenges	X		Yes, insights
Resistance to change culture	X		No new insights
Lack of internal capacity	X		No new insights

Table 30. Frequency of organisational constraints themes

Theme	Mining Executives	Mining Consultants	Technology Suppliers
Lack of leadership buy-in	Many Deficiency of excitement and motivation at the upper echelons Leadership culture is a substantial barrier A risk-averse mentality that obstructs innovation	Few Lack of a definitive vision to adopt new technologies	None
Infrastructure challenges	Many Lack of data integration Lack of systems Technical complexities Connectivity challenges	None	None

5.3.5.1 Theme 1: Lack of leadership buy-in

Lack of leadership buy-in emerged as a key theme from the mining executives and consultants' diverse experiences on constraints leading to the lack of adopting Industry 5.0 technologies in mines. The theme was thus selected to bring fresh insights and understanding to the research subject under discussion. Table 31 shows the evidence of the participants' views on this theme.

5.3.5.1.1 Evidence of Theme 1: Lack of leadership buy-in

Table 31. Evidence of lack leadership buy-in

Research Question 2, Theme 1: Lack of leadership buy-in
"The leadership in my view, those that I've worked with are actually listening to where the wind is blowing, if you know what I mean. But in terms of the enthusiasm required and the drive, I feel that we are not at the highest level." Participant ME2
"The biggest issue when it comes to technology and new interventions is the leadership culture. It's the leadership risk opportunity of us." Participant ME4
"Without strong leadership support, any initiative to adopt new technologies is likely to falter." Participant ME9
"If the leaders are not on board, it creates a significant barrier to implementing any new technology." Participant ME12
"Leadership needs to be fully committed to the vision of integrating advanced technologies; otherwise, it becomes just another project that lacks momentum." Participant MC006
"It's crucial for leaders to champion these changes; otherwise, the workforce remains sceptical and disengaged." Participant MC010
"The lack of buy-in from top management can derail even the best-planned technology adoption strategies." Participant MC010

5.3.5.1.2 In-case and cross-case analysis of the evidence of Theme 1: Lack of leadership buy-in

The insights obtained from mining executives and consultants concerning the absence of leadership endorsement as a perceived organisational impediment affecting the adoption of Industry 5.0 technologies in mining sustainability transitions indicate both commonalities and divergences in their viewpoints. Participant ME2 from the mining executives group articulated a nuanced perspective on leadership, indicating that although leaders recognise industry trends and changes, there is a deficiency of excitement and motivation at the upper echelons. This signifies an acknowledgement of the necessity for leaders to be proactive and involved in the transition to new technology. Conversely, Participant ME4 identifies a systemic issue, asserting that the leadership culture is a substantial barrier, specifically emphasising a risk-averse mentality that obstructs innovation.

This viewpoint indicates that the issue extends beyond individual leaders to encompass a wider cultural problem within the business that dissuades risk-taking related to the adoption of new technologies. Participant ME9 emphasised the essential importance of leadership, stating that without robust backing from leaders, endeavours to adopt new technology are prone to failure. Participant ME12 articulated that the lack of leadership endorsement presents significant obstacles to the adoption of innovative technology. Both panellists emphasise the direct influence of leadership involvement on the success of technological initiatives, demonstrating an agreement among executives that robust leadership is crucial for surmounting organisational stagnation.

The mining consultants group provides further insights that clarify the difficulties arising from insufficient leadership support. Participant MC006 emphasised the imperativeness for leaders to be dedicated to the vision of incorporating innovative technology, cautioning that without such dedication, initiatives may devolve into stagnant projects devoid of the requisite impetus for success. This corresponds with the executives' perspectives on the significance of leadership involvement while introducing an element of urgency around the necessity for a definitive vision. Participant MC010 expressed sentiments that it is essential for leaders to advocate for changes, otherwise, the workforce remains doubtful and disengaged. This underscores the essential role of leadership endorsement and the necessity for leaders to aggressively champion new technology to cultivate a culture of acceptance and enthusiasm among employees. Participant MC010 emphasises that insufficient support from top management can undermine even the most meticulously devised technology adoption strategy, underscoring that leadership endorsement is not merely advantageous but crucial for successful execution.

The results from both groups highlight the significance of leadership endorsement in the adoption of Industry 5.0 technologies within the mining sector. The executives underscore the importance of proactive involvement and a transformation in leadership culture, whilst the consultants stress the essentiality of commitment and advocacy from leaders to guarantee workforce alignment and project momentum. The shared viewpoints among both groups indicate an agreement on the essential function of leadership in facilitating technological adoption. The distinctions reside in the prioritisation of cultural versus individual leadership attributes, with executives concentrating on the overarching organisational culture as internal stakeholders and consultants as external stakeholders highlighting the necessity for individual leaders to demonstrate initiative.

5.3.5.1.3 Conclusion on Theme 1: Lack of leadership buy-in

The absence of leadership endorsement constitutes a major impediment to the implementation of Industry 5.0 technologies in the mining industry. Mining executives and consultants concur that robust, dedicated leadership is crucial for surmounting obstacles to innovation and facilitating effective sustainability transitions. Resolving this issue necessitates a unified endeavour to cultivate a culture of creativity and risk-taking, along with the proactive involvement of leaders at every level.

5.3.5.2 Theme 2: Infrastructure challenges

The theme of infrastructure challenges was mentioned by many mining executive participants. This theme was selected to understand insights into constraints leading to the reluctance to adopt Industry 5.0 technologies in mines. The evidence is shown in Table 32 below.

5.3.5.2.1 Evidence of Theme 2: Infrastructure challenges

Table 32. Evidence of infrastructure challenges theme

Research Question 2, Theme 2: infrastructure challenges
"The mining industry is not ready in that it is still not integrating the data it gets from the operation to supply chain. What I'm saying is there isn't one role player that is amalgamating everyone else to work as a team." Participant ME2
"Imagine if were to have some sort of an integral, let's call it a central person, not really person, but some sort of a cloud-based, you know, technology which would sort of be unique to an operation, including it all supplies." Participant ME2
"...a second one, which was a minor one, it was about getting all these systems to talk to each other and to have a simplified way how to report on all this data." Participant ME5
"In my view, in general, the mining industry is quite rich in terms of data...but every other end of that, I think we are very poor in terms of the information which we extract from the data to have informed decision-making." Participant ME12
"So, one of the challenges could be temperature that we experience it. And we found that the sensors, they are not actually working properly in a very dusty environment to start with. And then also the delivery times of these sensors, if they break or if you have an incident in the pit or in underground, they take long to actually be delivered as well because you can't get them off shelves in Africa." Participant ME1
"Mining is behind because of the challenges that the technology presents. The challenges are what we call temperature, particularly for underground workings and also harsh conditions for plants. The challenges are what we call temperature, particularly for underground workings and also harsh conditions for plants. So that is our biggest challenge. There is a fear of, look, we might lose a job if we automate everything." Participant ME2
"Internet connectivity is also an issue in some of our areas where you got remote operations." Participant ME4

"A lot of that conversation has been in the environmental space... around being able to have your devices almost be connected and generate that data in real-time." Participant ME7

5.3.5.2.2 In-case and cross-case analysis of the evidence of Theme 2: Infrastructure challenges

The mining executives' comments on infrastructure problems, viewed as organisational restrictions affecting the adoption of Industry 5.0 technologies in mining sustainability transitions, highlight both shared themes and unique viewpoints among the participants.

Participant ME2 expressed a critical worry about the mining industry's preparedness to embrace innovative technologies, highlighting the absence of operational data integration with the supply chain. This participant emphasises the lack of a central function or mechanism to integrate diverse stakeholders for joint efforts, indicating that a unified strategy is crucial for optimal data utilisation. Participant ME2 offered a cloud-based solution that might function as a distinct operational hub, integrating all suppliers and data sources, highlighting the necessity for a centralised infrastructure to enhance communication and collaboration.

Participant ME5 also highlighted the difficulty of achieving efficient communication between disparate systems. The participant emphasised the need for a streamlined reporting system to handle the generated data, pointing out that the existing infrastructure is disjointed and lacks the necessary interoperability for effective data management. This view corresponds with ME2's advocacy for a more cohesive strategy, emphasising a collective acknowledgement of the necessity for enhanced systems connectivity.

Participant ME12 contributed to the discourse by recognising that although the mining sector possesses abundant data, it faces challenges in deriving significant insights for informed decision-making. This observation indicates that the current infrastructure may be insufficient for properly processing and analysing data, which is essential for harnessing the capabilities of Industry 5.0 technologies. The focus on the disparity between data accessibility and actionable insights highlights a wider apprehension regarding the sufficiency of existing systems to facilitate sophisticated technology applications.

Conversely, Participant ME1 identified significant operational issues associated with environmental conditions, especially the efficacy of sensors in dusty settings. This participant emphasised that the severe conditions in mining operations can impede the efficacy of technology, which is a crucial factor when assessing infrastructure capacities. Furthermore, ME1 highlighted the logistical challenges associated with the delivery of replacement sensors, suggesting that the supply chain for technological components lacks the resilience necessary for prompt maintenance and updates.

Participant ME4 expressed concerns regarding infrastructure by highlighting internet connectivity challenges in remote operations. This underscores a critical obstacle to the implementation of Industry 5.0 technologies, as dependable connectivity is vital for real-time data creation and communication. The reference to remote operations highlights the geographical obstacles encountered by the mining sector, which can hinder the adoption of innovative technologies. Finally, Participant ME7 emphasised the significance of interconnected devices for generating real-time data, especially in the environmental sector. This viewpoint underscores the necessity for infrastructure that facilitates uninterrupted data flow and monitoring, essential for sustainability efforts in mining.

5.3.5.2.3 Conclusion on Theme 2: Infrastructure challenges

The mining executives' conclusions indicate a consensus on the significant infrastructure obstacles that impede the implementation of Industry 5.0 technologies in sustainable mining transitions. Principal topics encompass the demand for enhanced data integration and system interoperability, the significance of managing environmental factors that influence technology performance, and the imperative for dependable connectivity in remote operations. Despite variations in emphasis—from the necessity for centralised data administration (ME2) to particular operational difficulties (ME1)—the predominant theme is evident: the existing infrastructure in the mining sector is insufficient to adequately facilitate the transition to modern technologies. Resolving these infrastructure difficulties is crucial for the mining sector to capitalise on the advantages of Industry 5.0 and attain its sustainability objectives.

5.3.6 Conclusions to Research Question 2: Perceived constraints

The findings from this section emphasised the lack of incentives for the critical role of real-time monitoring in maintaining environmental compliance, a key benefit of Industry 5.0 technologies. However, there were significant concerns about the potential for increased operational complexity, genuine stakeholder engagement, and the financial implications of adopting these technologies. A cautious, risk-averse approach was prevalent among mining leaders not as supportive of technology adoption, reflecting broader economic uncertainties and infrastructure challenges. Strong governance structures were deemed essential to manage the complexities of ESG compliance, and there was a view of the need to balance operational efficiency with regulatory requirements. Overall, these insights highlighted the necessity for a strategic and well-governed approach to integrating Industry 5.0 technologies in the mining sector.

5.4 Research Question 3

Strategies employed to overcome these constraints and promote Industry 5.0 technology adoption.

The themes of the strategies that can be employed to overcome constraints hindering the adoption of Industry 5.0 technologies are discussed in this section. Five themes were identified from the thematic analysis as highlighted in Table 33. However, only two themes with fresh insights were selected for further discussion.

Table 33. Potential strategies themes

Theme	Similarities	Differences	Discussed Yes/No
ICT upskilling and training	X		No new insights
Culture of innovation	X		No new insights
Clear communication and transparency strategy	X		No new insights
Clear feasibility and business case	X		Yes, new insights
Risk sensing and resilient supply chain	X		Yes, new insights

Table 34. Frequency of potential strategies themes

Theme	Mining Executives	Mining Consultants	Technology Suppliers
Clear feasibility and business case	Many Technology that is specifically aligned with operational requirements Data-driven strategy A persuasive business case	Few Avoid overselling technologies and concentrate on cost-effective solutions Grounded in business rationale rather than individual inclinations	Few- Long-term planning for infrastructure ten to fifteen years
Risk sensing and resilient supply chain	Many Foresight to implement pre-	Few	None

	emptive digitisation measures Proactive approach to digitisation risk management Technological solutions must be weighed against possible human safety issues	Technology that improves our risk-sensing capabilities Detect risks in real-time can enhance our response times and overall supply chain resilience	

5.4.1 Theme 1: Clear feasibility and business case

Clear feasibility and business case emerged as a prevalent theme in the research of methods to address the obstacles contributing to reluctance to use Industry 5.0 technologies in mining operations. Representatives from the mining executive, consulting, and technical supplier sectors provided elucidations of their perspectives on this topic. Table 35 underscores the evidence pertaining to this theme.

5.4.1.1 Evidence of Theme 1: Clear feasibility and business case

Table 35. Evidence of clear feasibility and business case theme

Research Question 3, Theme 1: Clear feasibility and business case
"The key thing is you need to make it and choose the best way for your operation. There's a lot of things in the market that the guys are selling, which sounds fantastic, but you need to properly investigate and ensure that you commit to a line of technology that is effective and best suited for your operation." Participant ME5
"The feasibility of implementing new technologies must be backed by data and a clear understanding of the benefits they bring to the operation." Participant ME9
"To promote Industry 5.0, we must present a compelling business case that illustrates how these technologies can drive efficiency and innovation." Participant ME10
"Tell the vendors to stop over-selling... and let's come up with cost-effective solutions that do actually work and will make a difference." Participant MC003
"Every technology we consider must have a structured business case that outlines its impact on productivity and cost savings." Participant MC011
"Yeah, I think there's, firstly, I think it must make business sense, right. I think often we find technologies are implemented with, you know, someone's pet project or, you know, someone has just got this bee in their bonnet." Participant MC010
"If you build a mine, you need to think 10 to 15 years ahead in terms of infrastructure." Participant TS013

5.4.1.2 In-case and cross-case analysis of the evidence of Theme 1: Clear feasibility and business case

The viewpoints of mining executives, consultants, and technical suppliers on the feasibility and business case as tactics for addressing obstacles and facilitating the adoption of Industry 5.0 technologies exhibit both commonalities and divergences. Insights from the mining executives' group include Participant ME5, who underscored the significance of choosing technology that is specifically aligned with operational requirements. This perspective emphasises a prudent strategy, endorsing comprehensive examination prior to the use of any technology. The focus is on guaranteeing that the selected technology is efficient and appropriate for the operation, which corresponds with the overarching issue of feasibility.

Participant ME9 emphasised that the adoption of recent technologies necessitates data assistance and a comprehensive comprehension of the advantages. This viewpoint emphasises the importance of a data-driven methodology to assess the viability of technology implementation, guaranteeing that decisions are grounded in concrete advantages rather than conjectures. Participant ME10 emphasised the necessity for a persuasive business case to advocate for Industry 5.0 technology. This assertion conveys a strategic perspective, indicating that a clearly-articulated business case is essential for illustrating how emerging technologies can improve efficiency and foster innovation in the mining industry.

The comments from the mining consultants group include Participant MC003, who urged vendors to avoid overselling technologies and to concentrate on cost-effective solutions that yield tangible results. The consultants’ sales background explains why this exaggeration occurs when technology suppliers are marketing new technologies. This viewpoint aligns with the executives' prudent approach, underscoring the necessity for practicality and efficacy in technology selection.

Participant MC011 echoed the sentiments of the mining executives by noting that every technology evaluated must possess a comprehensive business case detailing its effects on productivity and cost reduction. This alignment signifies a mutual comprehension between both groups concerning the imperative for a systematic method of technology assessment. Participant MC010 emphasised a different insight: that technology adoption must be grounded in business rationale rather than individual inclinations or "pet projects." This insight underscores the necessity of integrating technological projects with organisational objectives, emphasising the requirement for a definitive business case.

Yet, Participant TS013, a mining technical supplier, asserted a unique insight that offering a long-term perspective necessitates planning for infrastructure 10 to fifteen years in advance. This insight incorporates a strategic foresight component, indicating that feasibility evaluations must also account for future operational requirements and technological progressions.

Consequently, throughout the three participant groups, there is a significant agreement on the necessity of a definitive feasibility and business case for technology adoption. However, viewpoints from mining executives and consultants underscore the necessity for systematic assessments and data-informed decision-making. The executives emphasise the appropriateness of technology for certain processes, whilst the consultants underscore the importance of cost-efficient solutions and compatibility with corporate goals. Nonetheless, the technical vendors provide a distinctive viewpoint by highlighting long-term planning and infrastructure factors, thus enriching the discourse on feasibility. This foresight is essential in the mining sector, where technological expenditures must account for future operational requirements and possible innovations.

5.4.1.3 Conclusion on Theme 1: Clear feasibility and business case

The interview findings indicate a robust consensus among mining executives, consultants, and technical suppliers on the importance of explicit feasibility and business case tactics for facilitating the implementation of Industry 5.0 technologies. The focus on data-driven decision-making, systematic assessments, and alignment with operational requirements highlights a shared comprehension of the challenges and opportunities within the mining industry. By prioritising these tactics, stakeholders may adeptly manage the intricacies of technology adoption, guaranteeing that investments produce concrete advantages and foster innovation within the industry.

5.4.2 Theme 2: Risk sensing and resilient supply chain

Risk sensing and resilient supply chains emerged as key strategies that can be used to overcome the constraints in adopting Industry 5.0 technologies. The theme was thus selected to bring fresh insights and understanding to the research subject under discussion. Table 36 shows the evidence of the participants' views on this theme.

5.4.2.1 *Evidence of Theme 2: Risk sensing and resilient supply chain*

Table 36. Evidence of risk sensing and resilient supply chain

Research Question 3, Theme 1: Risk sensing and resilient supply chain
"Elements around risk sensing, I want to be able to know things before they happen so that I can do something today." Participant ME9
You want to sense risk... You want to be able to use technology to predict what could happen." Participant ME9
"Securing supply, having a resilient... supply chain is important, and technology plays a big role around that." Participant ME9
"A resilient supply chain is not just about reacting to risks but proactively identifying them and mitigating their impact." Participant ME7
But at the same time run the risk of exposure of people to other risks. So, there is a give and take there." Participant ME12
We don't want to...to get into a risk where you end up with the white elephant at your operation." Participant ME12
So, the inventory of those batteries, it's, it's just a massive cost and if you don't keep them, you're running a risk because you don't know when these people can actually sleep and not change out as quick as possible." Participant ME1
"Investing in technology that enhances our risk sensing capabilities is essential for maintaining a resilient supply chain." Participant MC006
"The ability to sense risks in real-time can significantly improve our response times and overall supply chain resilience." Participant MC010

5.4.2.2 *In-case and cross-case analysis of the evidence of Theme 2: Risk sensing and resilient supply chain*

The views obtained from mining executives and consultants concerning risk sensing and resilient supply chains as solutions to mitigate limits and facilitate the implementation of Industry 5.0 technologies indicate both commonalities and divergences in their viewpoints. Insights from the mining executives group include Participant ME9, who underscored the significance of possessing the foresight to implement pre-emptive digitisation measures. This proactive risk-sensing strategy is further emphasised by Participant ME9, who expressed the intention to "utilise technology to forecast the future." This underscores a proactive mentality that values preparation over-reaction, essential in the ever-changing mining sector. Participant ME7 stated an insight that “a resilient supply chain involves not only responding to risks but also proactively identifying and mitigating their effects.” This perspective corresponds with ME9’s emphasis on technology’s role in ensuring supply and bolstering resilience. Both participants emphasised the need for a proactive approach to risk management, indicating that resilience is developed through foresight and preparation.

Participant ME12 presented a sophisticated viewpoint by recognising the reciprocal nature of risk management. In the pursuit of a robust supply chain, there exists an inherent risk of exposing humans to novel hazards. This underscores the intricacy of risk management in mining, where the quest for technological solutions must be weighed against possible human safety issues. Additionally, Participant ME1 expressed a pragmatic worry about inventory management, notably highlighting the “substantial expense” related to sustaining a stock of batteries. This phrase illustrates the operational difficulties encountered in maintaining supply chain resilience while controlling expenses. The potential depletion of essential supplies is a significant worry that highlights the necessity for efficient inventory management systems.

Insights from the group of mining consultants include Participant MC006, who emphasised that “investing in technology that improves our risk sensing capabilities is crucial for sustaining a resilient supply chain.” This corresponds with the executives’ perspectives on the essential function of technology in risk management. The consultants emphasised that technical investment is fundamental to successful risk sensing. Furthermore, Participant MC010 emphasised that “the capacity to detect risks in real-time can greatly enhance our response times and overall supply chain resilience.” This assertion supports the executives’ emphasis on proactive risk management, indicating that real-time data and analytics are essential for improving responsiveness and adaptability in supply chains.

Both groups exhibit a robust agreement on the significance of risk sensing and resilience in supply chain management. The mining executives underscore proactive methods and the significance of technology in risk anticipation, while the consultants bolster these concepts by promoting technical investments and real-time risk detection capabilities. However, the executives present a more intricate discourse on the complexity of risk management, specifically addressing the equilibrium between technical solutions and human safety considerations. This component is less emphasised in the consultants’ comments, which concentrate more on the technical and operational advantages of risk-sensing technology. Additionally, the executives offer pragmatic insights into the operational difficulties of sustaining a robust supply chain, including inventory management and cost factors. The consultants emphasise the strategic significance of technology in improving risk-sensing skills.

5.4.2.3 *Conclusion on Theme 2: Risk sensing and resilient supply chain*

The findings indicate a consensus among mining executives and consultants on the need for risk sensing and robust supply chains for facilitating the deployment of Industry 5.0 technology. Both parties endorse proactive tactics and technological investments to improve risk management. Nevertheless, the executives present a more sophisticated viewpoint that acknowledges the intricacies of reconciling technical solutions with human safety and operational expenses. This thorough perspective highlights the necessity for an integrated approach to risk management in the mining industry, where technology is essential for enhancing resilience and adaptability in supply chains.

5.4.3 Conclusion to Research Question 3: Perceived strategies

The research outlines several strategies to overcome constraints and promote the adoption of Industry 5.0 technologies in the mining sector. Key approaches include developing a clear business case to justify investments, implementing risk sensing and resilient supply chain management to navigate uncertainties, and engaging stakeholders through effective communication. Additionally, investing in upskilling and training programs, fostering a culture of innovation, and exploring various financing options are crucial for addressing financial concerns. These strategies collectively aim to create a supportive environment for the successful integration of Industry 5.0 technologies, ensuring that the adoption process is both feasible and sustainable.

5.5 Reluctance outcomes to the adoption of Industry 5.0

The participants were asked how they understood the adoption of the Industry 5.0 concept in the mining sector and its reluctance outcomes. Their responses were analysed to reveal the themes of the reasons behind the reluctance to adopt Industry 5.0 technologies that are discussed in this section. Three themes were identified as highlighted in Table 37. However, only one theme with fresh insights was discussed.

Table 37. Reluctance outcomes themes

Theme	Similarities	Differences	Discussed Yes/No
Economic reluctance outcomes	X		No new insights
Social reluctance outcomes	X		No new insights
Environmental reluctance outcomes	X		Yes, insights

Table 38. Frequency of reluctance outcomes themes

Theme	Mining Executives	Mining Consultants	Technology Suppliers
Environmental reluctance outcomes	Many Emerging technologies may not sufficiently mitigate the environmental repercussions of mining activities Need for comprehensive compliance testing Fear of hidden environmental compliance costs associated with new technologies Industry 5.0 technologies may complicate resource management procedures	Few Compliance with environmental regulations can be costly Emerging technologies may not sufficiently mitigate the environmental repercussions of mining activities	None

5.5.1 Research theme 1: Environmental reluctance outcomes

Environmental reluctance outcomes emerged as a key reluctance outcome leading to the lack of Industry 5.0 technology adoption in the mining sector. The theme was thus selected to bring fresh insights and understanding to the research subject under discussion. Table 39 shows the evidence of the participants’ views on this theme.

5.5.1.1 *Evidence of Theme 1: Environmental reluctance outcomes*

Table 39. Evidence of environmental reluctance outcomes

Research Question 4, Theme 1: Environmental reluctance outcomes
“We need to understand the environmental impact of these new technologies and how they work. For now, we are not sure and there’s a fear that rushing into new technologies could lead to unsustainable practices that harm the environment long-term." Participant ME2
"Some technologies can be seen as adding to the environmental burden rather than alleviating it. The unpredictability of climate change impacts makes it difficult to commit to new technologies that may not perform well under extreme conditions. We are cautious about adopting Industry 5.0 technologies because we need to ensure they are resilient to the effects of climate change." Participant ME5
"The mining industry is under pressure to reduce its environmental footprint, and not all Industry 5.0 technologies align with that goal. There’s a fear that new technologies may not effectively manage resources, leading to waste and inefficiency." Participant ME1
"Environmental regulations can create hesitance to adopt new technologies that may not have been fully tested for compliance." Participant ME4
“There’s a concern that adopting Industry 5.0 technologies could complicate our resource management processes." Participant ME2
“There’s a concern that new technologies might not adequately address the environmental impacts of mining operations." Participant MC010
"We often question whether adopting Industry 5.0 technologies will genuinely contribute to future environmental sustainability." Participant ME1
"The fear of hidden environmental compliance costs associated with new technologies can lead to reluctance in their adoption." Participant ME1
"The complexity of environmental regulations can make it challenging to implement new technologies effectively. Many companies fear that new technologies may not comply with existing environmental regulations, leading to potential fines." Participant ME12
"Compliance with environmental regulations can be expensive, and companies are wary of adding more costs through new technologies. Environmental regulations are constantly changing, and this uncertainty makes companies cautious about new technology adoption." Participant MC010
“Navigating the regulatory landscape is daunting, and companies often hesitate to adopt technologies that might complicate compliance.” Participant MC010

5.5.1.2 *In-case and cross-case analysis of the evidence of Theme 1: Environmental reluctance outcomes*

The hesitation to implement Industry 5.0 technologies in the mining sector is profoundly shaped by environmental apprehensions, as expressed by numerous mining executives and consultants. The findings from these participants disclose both commonalities and divergences in their viewpoints concerning the environmental rationale for this hesitance.

Participant ME2 underscored the necessity for a thorough comprehension of the environmental ramifications of emerging technology, asserting that "mines must grasp the environmental impact of these new technologies and their operational mechanisms." This sentiment indicates a prudent stance towards the adoption of Industry 5.0 technologies, motivated by the apprehension that rapid implementation may result in unsustainable practices detrimental to the environment over time.

Participant ME5 articulated the fear that "some technologies may exacerbate the environmental burden instead of mitigating it." However, both participants expressed a mutual concern regarding the possible adverse effects of emerging technologies on the environment, underscoring the necessity for comprehensive assessment prior to deployment. Participant ME1 further brings fresh insight and emphasises the industry's imperative to diminish its environmental impact, stating that "not all Industry 5.0 technologies correspond with that objective." This issue corresponds with Participant MC010's opinion that "there is apprehension that emerging technologies may not sufficiently mitigate the environmental repercussions of mining activities." Both participants underscore the necessity of ensuring that new technologies proficiently manage resources to prevent waste and inefficiency, indicating a shared recognition that the integration of Industry 5.0 technologies with environmental sustainability objectives is essential for their acceptance in the mining industry.

The intricacy of environmental legislation is a notable element contributing to hesitance. Participant ME4 asserted that "environmental regulations can induce reluctance to embrace new technologies that may not have undergone comprehensive compliance testing." Participant ME12 asserted that "the intricacy of environmental regulations can hinder the effective implementation of new technologies." Thus, both participants underscore the formidable challenge of regulatory compliance, indicating that the apprehension of potential penalties and concealed expenses linked to non-compliance dissuades mining companies from adopting new technologies.

Participant ME1 highlighted a significant concern regarding the apprehension of concealed environmental compliance expenses, asserting that "the fear of hidden environmental compliance costs associated with new technologies can result in hesitance towards their adoption." This issue corresponds with Participant MC010's statement that "compliance with environmental regulations can be costly," reflecting mutual anxiety regarding the financial ramifications of using Industry 5.0 technologies. The continual alterations in environmental regulations intensify this uncertainty, prompting corporations to exercise caution in adopting new technology that may fail to satisfy changing compliance criteria.

Participant ME2 articulated a fear that the implementation of Industry 5.0 technologies may complicate resource management procedures, asserting that, "there is a concern that adopting Industry 5.0 technologies could complicate our resource management processes." This perspective emphasises the possible operational difficulties that emerging technologies can present, hence exacerbating the hesitance to embrace them. Participant MC010 articulated this attitude by underscoring the necessity for organisations to be cautious about incurring additional expenses through new technology, highlighting that financial and operational complications significantly influence the decision-making process.

5.5.1.3 Conclusion on Theme 2: Environmental reluctance outcomes

The findings indicate an agreement among mining executives and consultants concerning the environmental apprehensions linked to the implementation of Industry 5.0 technologies. The collective apprehensions over environmental consequences, regulatory compliance, and the possibility of elevated expenses underscore the intricacies companies encounter in the implementation of new technologies. The concerns over the compatibility of Industry 5.0 technologies with sustainability objectives, along with apprehensions about concealed expenses and regulatory obstacles, highlight the necessity for a comprehensive evaluation and understanding of these technologies before their extensive deployment. Addressing these environmental issues will be crucial for promoting a more positive disposition towards the implementation of Industry 5.0 technologies in the mining industry.

5.5.2 Conclusion to Research Question 4: Reluctance outcomes

The section identified several key reluctance outcomes related to the adoption of Industry 5.0 technologies in the mining sector. Environmental concerns include potential negative impacts on resource management and regulatory compliance, leading to fears of unforeseen consequences. Economic reluctance is driven by high initial costs and potential increases in operational expenses, causing financial hesitance. Social reluctance stems from resistance to change within organisational culture, fears of job displacement, and a lack of understanding of Industry 5.0 benefits. Addressing these environmental, economic, and social reluctance outcomes is crucial for fostering a more favourable attitude towards the adoption of advanced technologies and achieving sustainability goals in the mining industry.

5.6 Updated conceptual framework

Figure 6 illustrates a conceptual framework derived from the deductive and inductive investigation detailed in Chapter 4, highlighting 14 fresh insights (in bold) and 21 themes (text strikethrough) that were referenced but lack new ideas.

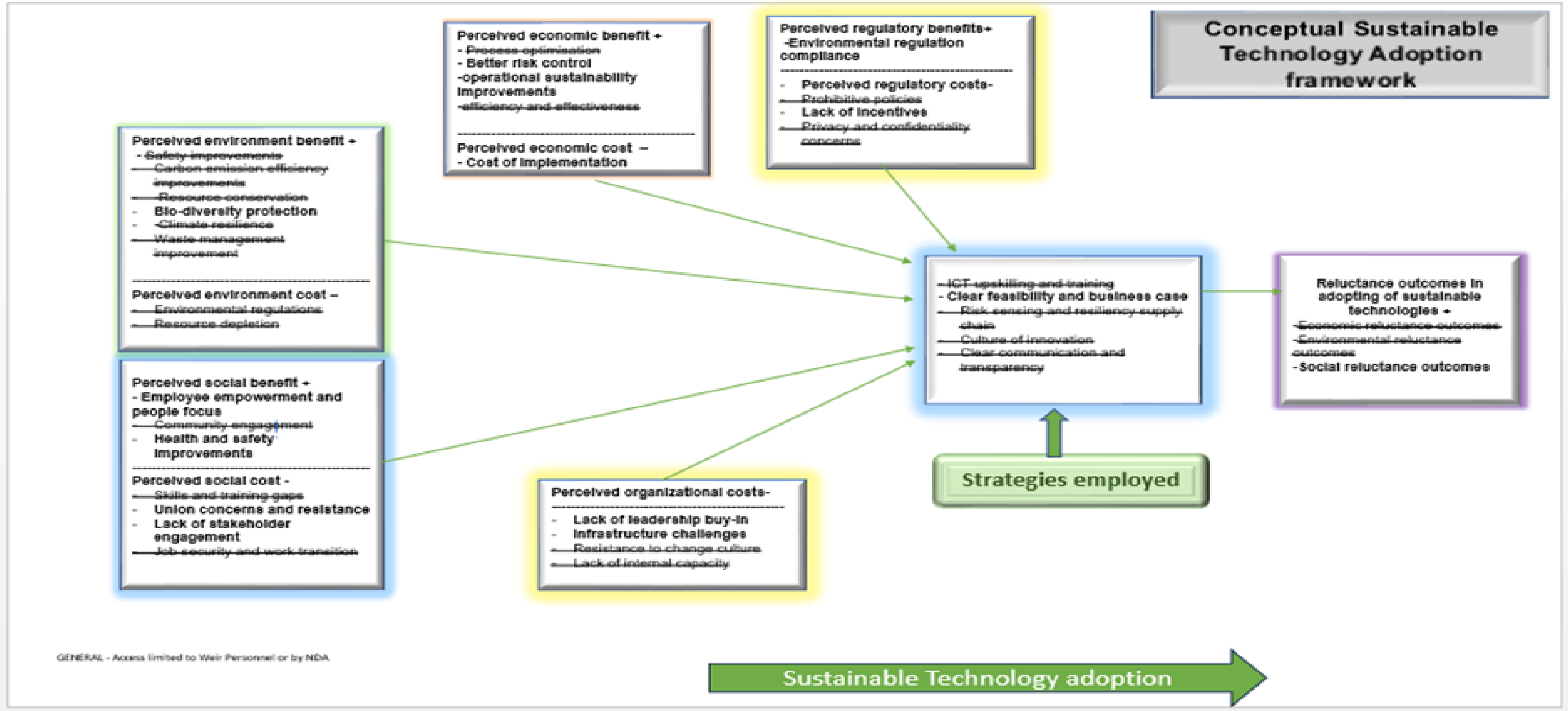

Figure 6. New conceptual framework

Figure 6 illustrates an updated framework depicting the complex interrelationship among many perceived costs, benefits, procedures, and adverse outcomes associated with the implementation of Industry 5.0 technology as extrapolated from the findings. The subsequent significant elements are highlighted: This encompasses investment expenses, potential long-term savings or income increases, and other financial factors related to the implementation of Industry 5.0 technology.

This analysis encompasses all facets of the workforce and corporate culture, including modifications to work processes, alterations in employee satisfaction and productivity, and the potential for job displacement.

This document addresses issues related to resource management, regulatory compliance, and the overall environmental footprint concerning the environmental impact of Industry 5.0 technologies. Enhancing infrastructure, delivering training, and overseeing change exemplify internal costs linked to the utilisation of Industry 5.0 technologies.

Figure 6 illustrates an updated framework depicting the complex interrelationship among various perceived costs, benefits, procedures, and adverse outcomes associated with the implementation of Industry 5.0 technology. Key elements highlighted include investment expenses, potential long-term savings or income increases, and other financial factors.

The analysis covers all aspects of the workforce and corporate culture, such as modifications to work processes, changes in employee satisfaction and productivity, and the potential for job displacement. Additionally, the document addresses issues related to resource management, regulatory compliance, and the overall environmental footprint of Industry 5.0 technologies. Internal costs, such as enhancing infrastructure, delivering training and overseeing change are also considered.

The figure further illustrates the interaction between perceived benefits and costs with strategies designed to facilitate the adoption of Industry 5.0 technologies. These strategies address internal resistance to change, concerns around job displacement, and an inability to comprehend the benefits of Industry 5.0 technology. It also highlights concerns regarding elevated initial expenses, potential increases in operational costs, and the difficulties of resource management and its potential adverse environmental impacts.

Strategies to mitigate reluctance and facilitate the successful use of Industry 5.0 technologies must be devised, considering the perceived costs and benefits. This approach underscores the importance of undertaking this within the framework of sustainable transitions.

5.7 Chapter conclusion

The findings suggest that several critical factors are crucial for the successful adoption of Industry 5.0 technologies in the mining sector. Firstly, fostering innovation is essential for enhancing sustainability. Additionally, addressing organisational constraints such as leadership buy-in and infrastructure challenges is crucial. Moreover, developing clear business cases and implementing risk management strategies, including resilient supply chain management, are necessary to justify investments and navigate uncertainties.

Furthermore, upskilling and training programs are vital to bridge the skills gap, and fostering a culture of innovation encourages openness to new technologies. However, financial considerations remain a significant barrier, necessitating the exploration of various financing options to secure investments. Overall, these elements are key to enabling a transition toward more sustainable and technologically advanced mining practices. The next chapter discusses the findings of the research.

CHAPTER 6: DISCUSSION OF FINDINGS

6.1 Introduction

This chapter discusses the results presented in Chapter 5, meticulously comparing them with the insights gathered from the literature review. The discussions are structured around the research questions and the 14 themes identified in Chapter 5, ensuring a coherent and systematic analysis.

To facilitate a comprehensive comparison, a systematic approach is employed, leveraging a keyword search technique to juxtapose the newly identified themes with the existing literature. This method ensures that the analysis is both thorough and precise. The search is initially confined to top articles on the key themes. However, in instances where past empirical evidence is sparse, the search is broadened to encompass additional literature. This expanded search utilises the keyword technique across top academic databases, including Google Scholar, JSTOR, Elsevier, Core and Emerald, with a particular focus on the technologies and implications of the Industry 5.0 revolution.

The newly identified literature, uncovered through this rigorous search process, is incorporated into this chapter as part of the process analysis. This approach ensures that the discussion remains current and relevant, integrating the latest academic insights without altering the foundational literature review presented in Chapter 2.

Table 40. Summary of research questions, theoretical constructs, selected themes, and literature review main authors

<table>
<tr><th>Research Question</th><th>Theoretical construct</th><th>New or adapted themes</th><th>Literature review authors</th></tr>
<tr><td rowspan="7">RQ1: How Industry 5.0 technologies contribute to sustainable mining practices</td><td rowspan="2">Perceived economic benefits</td><td>Process optimisation</td><td rowspan="7">Enang et al. (2023)
Greco et al. (2021)
Horváth & Ssabó (2019)
Ivanov (2023)
Mukherjee et al. (2023)
Pillai et al. (2021)
Sharma et al. (2022)
Shrestha et al. (2019)
Trunk et al. (2020)</td></tr>
<tr><td>Operational sustainability improvements</td></tr>
<tr><td rowspan="2">Perceived social benefits</td><td>Employee empowerment and people focus</td></tr>
<tr><td>Health and safety improvements</td></tr>
<tr><td>Perceived environmental benefits</td><td>Bio-diversity protection</td></tr>
<tr><td>Perceived regulatory benefits</td><td>Enhanced environmental regulation compliance</td></tr>
<tr></tr>
<tr><td>RQ2: Constraints that impact the</td><td>Perceived economic constraints</td><td>Cost of implementation</td><td>Cao et al. (2021)</td></tr>
</table>

adoption of Industry 5.0 technologies in mining sustainability transitions	Perceived social constraints	Union concerns and resistance	Friedman & Ormiston (2022) Horváth & Szabó (2019) Roberts et al. (2021) Stroh et al. (2023)
		Lack of stakeholder engagement	
	Perceived environmental constraints	NIL	
	Perceived regulatory constraints	Lack of incentives	
	Perceived organisational constraints	Lack of leadership buy-in	
		Infrastructure challenges	
RQ3: Strategies employed to overcome constraints and promote Industry 5.0 technology adoption		Clear feasibility and business case	Aheleroff et al. (2022) Battini et al. (2022) Ceipek et al. (2021) Horváth & Szabó (2019) Roblek et al. (2021) Sharma et al. (2022)
		Risk sensing and resilient supply chain	
RQ4: Outcomes to the reluctance to adopt Industry 5.0 technologies	Economic reluctance outcomes	NIL	Brown et al. (2020) Gonzales et al. (2021) Lee et al. (2023) Smith and Jones (2022)
	Social reluctance outcomes	NIL	
	Environmental reluctance outcomes	Environmental reluctance outcome	

The discussion of the findings is per research question and theme. This ensured alignment with the original intent to investigate the constraints to Industry 5.0 technology adoption in sustainable transitions.

6.2 Research Question 1: How Industry 5.0 technologies contribute to sustainable mining practices

This research question was formulated to provide new insights and understanding on the benefits derived from Industry 5.0 technologies in mining companies. Table 41 shows the main selected themes derived from the findings.

Table 41. Key themes on perceived benefits of adopting Industry 5.0 in mining organisations

Research Question	Theoretical Construct	New Themes	Literature review authors
RQ1: How Industry 5.0 technologies contribute to sustainable mining practices	Perceived economic benefits	Process optimisation	Enang et al. (2023) Greco et al. (2021), Horváth & Ssabó (2019), Ivanov (2023), Mukherjee et al. (2023) Pillai et al. (2021), Sharma et al. (2022), Shrestha et al. (2019), Trunk et al. (2020),
		Operational sustainability improvements	
	Perceived social benefits	Employee empowerment and people focus	
		Health and safety improvements	
	Perceived environmental benefits	**Bio-diversity protection**	
	Perceived regulatory benefits	Enhanced environmental regulation compliance	

6.2.1 RQ1: Theme 1: Process optimisation

The search term "process optimisation" prior to juxtaposing it with the findings.

6.2.1.1 Process optimisation: Summary of key findings

Contributions from mining executives, consultants, and technical vendors revealed a nuanced understanding of process optimisation as an economic benefit of adopting Industry 5.0 technology. Mining executives emphasised insights on the importance of accurate data, risk management, real-time analytics, and the balance between automation and human participation. Consultants highlighted particular operational improvements and the tangible effects of technology adoption, while technical providers stressed the importance of cultural transformation with technological advancement particularly the trust deficit between technology and humans. The results underscored that process optimisation in the mining sector entails a complex interplay of technology, human behaviour, and strategic management, all crucial for maximising economic benefits in the evolving landscape of Industry 5.0.

6.2.1.2 Process optimisation: Summary of key literature

Horváth and Szabó (2019) argue for process computerisation using robotic systems and drones. Furthermore, literature shows that large volumes of data may be processed using AI-based algorithms (Shrestha et al., 2019; Trunk et al., 2020). This is comparable to Dehran's (2018) earlier argument that process improvements might be essential to preserving sustainability and competitiveness over the long run. Modern technologies, such as the IoT, machine learning and AI build intelligent, networked systems that maximise resource use, minimise waste and encourage socio-environmentally conscious behaviour (Greco et al., 2021). Additionally, Industry 5.0's real-time data insights facilitate manufacturing process optimisation, leading to more streamlined and effective operations (Mukherjee et al., 2023). Businesses may continuously monitor and optimise their energy and resource use with the help of Industry 5.0 technology (Ivanov, 2023; Pillai et al., 2021, Sharma et al., 2022). Thus, the literature shows that Industry 5.0 technologies have process optimisation capabilities in other industries and will likely do the same in the mining industry.

6.2.1.3 Process optimisation: Comparison of findings vs literature Theme 1

Literature and industry professionals both show that Industry 5.0, the latest phase of the industrial revolution, has ushered in a new era of process optimisation driven by advanced technologies such as AI, the IoT and real-time data analytics. These innovative tools have empowered organisations to enhance operational efficiency, reduce costs, and improve sustainability, offering significant economic and operational benefits.

Insights from industry professionals, including mining executives, consultants, and technical suppliers, highlight the practical implications of process optimisation in this context. They emphasise the importance of precise data, effective risk management, and the strategic implementation of real-time analytics to drive decision-making. Additionally, they stress the need to strike a balance between automation and human involvement, recognising the critical role of cultural transformation in ensuring the successful adoption of these technologies.

The academic literature in chapter 2 provides a more theoretical perspective, discussing the specifics of emerging technologies and their broader impacts. Studies (Trunk et al., 2020; Shrestha et al., 2019) have examined the potential of robotic systems, drones, AI-based algorithms, and the IoT in enhancing process optimisation, underscoring their ability to improve sustainability, resource utilisation, and socio-environmental behaviour in other industries such as manufacturing. Based on the participants’ insights, Industry 5.0 technologies will optimise mining processes.

6.2.1.4 Conclusion

In conclusion, the adoption of Industry 5.0 technologies in the mining sector presents significant opportunities for process optimisation needed in sustainability transitions. The findings from the research align with existing literature, underscoring the critical role of data, real-time analytics, and the interplay between automation and human involvement. However, the findings highlight differences in the importance of addressing human and organisational factors to fully leverage these technologies. As the mining industry continues to evolve, embracing these insights will be essential for achieving sustainable and efficient operations required to fulfil sustainability transitions.

6.2.2 RQ1: Theme 2: Operational sustainability improvements

6.2.2.1 Operational sustainability improvements: Summary of key findings

The main findings regarding operational sustainability enhancements were predicated on the growing governance requirements associated with ESG compliance, the potential of AI and predictive technology to improve energy efficiency and fight climate change, which has financial implications for sustainability of mining projects. Sophisticated technology and a deliberate sustainability strategy that balances commercial viability with social and environmental responsibilities make this feasible. Such a collaborative approach is necessary to use technology for sustainable practices in the ever-changing mining landscape, guaranteeing that the sector can fulfil future operational and social demands. Among the main benefits of Industry 5.0 technologies are resource efficiency, which reduces waste, accidents, and health hazards; more effective material usage; safer working conditions; and employee empowerment, which results in a sustainable organisational culture that is required in the current sustainability transitions. There is however a significant focus on compliance as observed by the participants at the expense of sustainability perse.

6.2.2.2 Operational sustainability improvements: Summary of key literature

Literature findings were clear that Industry 5.0 technologies, such as cyber-physical systems, the Internet of Things, artificial intelligence, and digital twins, have the potential to contribute to automated and digital manufacturing environments, ultimately aiding in the achievement of sustainability in business practices (Jamwal et al., 2021; Sharma et al., 2022). According to Mukherjee et al. (2023), the strategy for Industry 5.0 technologies sustainability focuses primarily on social and ecological variables, such as lowering energy consumption and resource reuse. In a similar vein, Enang et al. (2023) contend that Industry 5.0 is an agenda driven by society that seeks to govern the digital industrial revolution in a manner consistent with sustainability objectives. Moreover, smart factories powered by Industry 5.0's digital industrial revolution includes other smart elements like smart consumers and goods to create a hyperconnected corporate environment that supports inclusive sustainability (Ivanov, 2022). Industry 5.0 technologies not only tackle waste elimination, lower emissions, efficiency of resources, and integration of renewables at the production as well as distribution levels, but also tackle the growing global sustainability issues like product recyclability, rebound effects, and shorter life cycles (Carayannis et al., 2024; Mukherjee et al., 2023). As such, Mukherjee et al. (2023) state that Industry 5.0 technologies are intended to enhance sustainability in every facet, including the environment, society, and economy. Thus, these studies collectively illustrate that the adoption of Industry 5.0 technologies can lead to substantial improvements in operational sustainability, reinforcing the findings of the current research.

6.2.2.3 Comparison of findings vs literature Theme 2

Industry 5.0 is gaining attention for its potential to enhance operational sustainability across various industries (Ali et al., 2022; Jamwal et al., 2021; Sharma et al., 2022). Both academic and industry sources highlight the role of Industry 5.0 technologies, such as AI, cyber-physical systems, and predictive analytics, in improving resource efficiency and reducing waste (Jamwal et al., 2021; Sharma et al., 2022; Carayannis et al., 2024; Ivanov, 2022; Mukherjee et al., 2023). These technologies are seen as transformative, driving significant sustainability improvements in industrial processes.

Academic literature provides a broad view of Industry 5.0’s sustainability benefits, exploring various dimensions and methods for enhancing outcomes. In contrast, industry insights focus on practical implications and governance, particularly within the mining sector. The emphasis on governance in industry findings may be due to the declining state of mining in South Africa, where the increasing depth of gold extraction and the pressure on mining corporations to maximise assets make governance a priority over future sustainability. This practical perspective highlights the challenges and opportunities associated with implementing AI and predictive analytics in the mining industry.

6.2.2.4 Conclusion

In conclusion, the mining sector is poised to benefit significantly from the adoption of Industry 5.0 technologies for improved operational sustainability. This research corroborates prior studies, emphasising the crucial importance of employee empowerment, health and safety, and resource efficiency. The findings underscore the importance of addressing organisational and human problems for the effective utilisation of these technologies. Embracing these ideas will be essential as the mining sector evolves to attain the sustainable and ethical practices required for sustainability transitions. However, there are constraints related to the end-of-mine-life issues in the South African mining sector that hinder more robust applications.

6.2.3 RQ1: Theme 3: Employee empowerment and people focus.

6.2.3.1 Employee empowerment and people focus: Summary of key findings

The primary findings on employee empowerment and a focus on individuals highlight the importance of interpersonal skills in managing complex technology, facilitating professional growth, meaningful engagement, skill enhancement, and knowledge sharing. Research shows that Industry 5.0 technology significantly boosts worker empowerment and promotes a people-centric approach in mining enterprises. Key findings include skill enhancement, optimised job functions, and community engagement. Participants noted that Industry 5.0 technologies enable staff upskilling, allowing interaction with more complex systems and procedures, leading to professional advancement and increased job satisfaction. Job roles may shift from monotonous tasks to more engaging and meaningful ones, enhancing both productivity and employee morale. The focus on individuals extends to community engagement, where mining companies use technology to strengthen connections with local communities and enhance social responsibility.

The study showed the challenge and scepticism that accompanied the empowerment effort and the differences in the views across the employee groups. However, the findings also reveal a significant knowledge gap at lower employment levels, characterised by poor foundational computing skills, which limits job advancement opportunities.

6.2.3.2 Employee empowerment and people focus: Summary of key literature

Enang et al. (2023) assert that Industry 5.0 technologies address society’s primary demands by focusing on resilience, sustainability, and human-centeredness, aiming for sustainable growth and improved life quality. Industry 5.0 human-centric technologies provide significant protective support for employees (Pillai et al., 2021). Literature indicates that implementing Industry 5.0 technology through human-machine interaction creates and maintains significant jobs (Pillai et al., 2021). Battini et al. (2022) suggest that disruptive technologies drive the development of human-centric industrial operations, leading to better working conditions, more jobs, and higher productivity (Rožanec et al., 2022).

Industry 5.0 emphasises human-robot cooperation to enhance safety, ergonomics, and productivity, positively impacting workers' well-being (Aheleroff et al., 2022). Industry 5.0 and its innovative technologies prioritise sustainability, human-centricity, and societal well-being (Battini et al., 2022). Sharma et al. (2022) argue that industry transformation leads to advancement and improved living standards. This transformation fosters employee empowerment and self-worth, boosting job satisfaction and self-confidence (Battini et al., 2022). Modern technologies also facilitate easy access to vital information, enabling workers to make decisions independently (Pillai et al., 2021). Collectively, these studies demonstrate that Industry 5.0 technologies significantly enhance worker empowerment and promote a people-centred culture in mining operations.

6.2.3.3 Comparison of findings vs literature Theme 3

Literature highlighted the importance of Industry 5.0 technologies in empowering employees and promoting a people-centric approach to organisational growth. Both literature and data emphasise employee well-being, skill enhancement, and job satisfaction, facilitated by Industry 5.0 technologies, which improve interactions between individuals and complex systems, leading to better working conditions and productivity.

The literature provided a theoretical framework for the human-centric benefits of Industry 5.0, such as improved safety, ergonomics, and productivity through human-robot collaboration (Battini et al., 2022; Pillai et al., 2021). In contrast, research findings offered practical insights, particularly in the mining sector, emphasising skill enhancement, job satisfaction, and community engagement.

Future workplaces will be worker-centric, tailoring jobs to individual skills and experiences, thus enhancing production efficiency. The mining sector must adapt to sustainability trends by addressing environmental, economic, and social challenges, with a focus on the human factor (Battini et al., 2022; Pillai et al., 2021). This may be at odds with the South African mining business model that relies on a large pool of inexpensive unskilled workers and is structured to maintain this condition.

Active employee engagement in job design and task balancing can improve knowledge, skills, and organisational performance. Industry 5.0 technologies can restructure job responsibilities, making roles more engaging and boosting morale. Younger employees are generally more receptive to these changes than older ones, who may see new technologies as a threat to their established roles.

In South Africa, poor basic education and expertise among the labour force hinder the benefits of Industry 5.0 technologies. This issue is compounded by the country's history of apartheid, which has led to significant opposition from unions.

6.2.3.4 Conclusion

In conclusion, adopting Industry 5.0 technology in the mining sector empowers workers and promotes a human-centric approach. The research highlights the importance of skill development, job progression, and community engagement, urging firms to prioritise human capital. This approach is crucial for creating a more engaged and proficient workforce. The study also notes that job redesign and skills development are more beneficial for younger employees with longer career trajectories. In developing nations, historical factors may hinder technological advancement and human progress. There remains a significant gap between practice and theory which is exacerbated by unique local conditions and circumstances.

6.2.4 RQ1: Theme 4: Health and safety improvements

6.2.4.1 Health and safety improvements: Summary of key findings

Industry 5.0 technologies significantly enhance health and safety in mining by preventing incidents and improving worker welfare. Key benefits include remote operation, advanced safety measures, and effective training. These technologies reduce accidents, protect workers, and ensure continuous operations. For instance, remote control of machinery minimises exposure to dangerous situations, while sophisticated safety systems and surveillance enhance overall safety conditions. Training with technologies like large language models (LLMs) ensures employees are well-prepared for crises. The findings also highlight the need for a cultural shift in the mining industry, making safety a core organisational value and addressing the complexities of adopting Industry 5.0 technologies to improve safety. Given the hazard level in South African mining the participants agreed more could be done with regards to safety but economics remained an impendent.

6.2.4.2 Health and safety improvements: Summary of key literature

The literature speaks to creating human-centric innovation ecosystems is crucial for leveraging Industry 5.0 technologies while prioritising human needs (Shakeel et al., 2020). These technologies improve worker health, safety, and well-being, reduce stress and accidents, and enhance job satisfaction (Carayannis et al., 2024; Sharma et al., 2022). Industry 5.0 advances the goal of zero harm in mining by enhancing safety through human-robot cooperation and smart technologies (Aheleroff et al., 2022 De Jager, 2018). Automation in quality assurance also reduces workplace risks (Enang et al., 2023). Overall, Industry 5.0 adoption leads to significant health and safety improvements in the mining industry.

6.2.4.3 Comparison of findings vs literature Theme 4

Industry 5.0 technologies offer new opportunities to enhance workplace health and safety. Both practical insights and theoretical literature (Aheleroff et al., 2022; Shakeel et al., 2020; Sharma et al., 2022) suggest that integrating advanced technologies like remote operating capabilities, smart sensors, and predictive analytics can significantly prevent incidents and improve worker well-being.

In mining, Industry 5.0 technologies have led to advanced safety protocols, remote operations, and effective safety training, reducing accidents and empowering workers. For example, drones and robots in hazardous areas prevent fatalities and injuries, increasing efficiency and accuracy.

Theoretically, Industry 5.0 establishes human-centric innovation ecosystems, enhances worker well-being, and reduces repetitive tasks. However, in South Africa, these benefits are not fully realised as safety is viewed more as a statutory requirement than a cultural norm, common in developing nations with high unemployment rates. While a lot has improved in South African mining, the human cost to economic cost ratio still seems not favour wholesale automation of operations.

6.2.4.4 Conclusion

In summary, the mining industry can greatly benefit from Industry 5.0 technologies, particularly in enhancing health and safety. The research aligns with previous studies, emphasising the importance of incident prevention and thorough training. It highlights the need for businesses to prioritise health and safety in their technology strategies. Remote operating capabilities improve mineworkers’ safety in hazardous environments, reducing mortality and injury rates. Adopting these insights is essential for creating a more secure and sustainable workplace as the mining sector evolves, even though these remain unreleased due to economic trade-offs.

6.2.5 RQ1: Theme 5: Bio-diversity protection

6.2.5.1 Bio-diversity protection: summary of findings

Biodiversity, while important, often takes a backseat to immediate operational goals in mining, as highlighted by one participant. Industry 5.0 technologies offer significant advantages in monitoring and assessing mining impacts on ecosystems and in effective land use planning to mitigate wildlife habitat disruptions. Research shows that Industry 5.0 technologies enhance biodiversity protection through improved monitoring, evaluation, and proactive measures. These technologies help mining companies assess and mitigate environmental impacts, preserve habitats, and reduce ecological disturbances. Strategic land use planning supported by Industry 5.0 is crucial for minimising the ecological footprint of mining activities. The findings emphasise integrating biodiversity considerations into mining operations and decision-making to prevent lasting ecological damage.

6.2.5.2 Bio-diversity protection: Summary of key literature

Friedman and Ormiston (2022) highlight the role of remote sensing and environmental monitoring systems in managing the environmental footprint of mining operations, emphasising that real-time monitoring can mitigate habitat destruction and protect biodiversity. Other studies support these findings, showing that Industry 5.0 technologies enhance biodiversity protection in mining. Carayannis et al. (2024) note that smart technology improves environmental management techniques, crucial for maintaining biodiversity and ensuring sustainable mining operations. Asif et al. (2023) add that IoT and advanced data analytics improve resource recovery and waste management, indirectly supporting biodiversity conservation by reducing the overall environmental impact of mining. Collectively, these studies demonstrate that Industry 5.0 technologies can significantly enhance biodiversity conservation in the mining industry.

6.2.5.3 Comparison of findings vs literature Theme 4

The mining sector faces the challenge of balancing operational needs with the protection of fragile ecosystems and biodiversity. Industry 5.0 technologies offer a solution, as both research and practical observations (Asif et al., 2023; Carayannis et al., 2024) highlight their role in enhancing sustainable mining practices. These technologies, including remote sensing, environmental monitoring systems, and the Internet of Things, enable real-time assessment of mining's environmental impacts, improving ecosystem understanding and facilitating proactive, data-driven measures to preserve biodiversity.

While both literature, which has by far the greater emphasis, and practical findings agree on the benefits of Industry 5.0 technologies for biodiversity conservation, there are differences in focus. Research suggests that biodiversity often takes a backseat to operational priorities due to mining's cyclical nature, making it a marginal consideration in decision-making. Despite the recognised advantages, the impact of these technologies remains limited within the South African context.

6.2.5.4 Conclusion

In conclusion, there are significant advantages for biodiversity conservation when Industry 5.0 technologies are implemented in the mining industry. The findings of the research are consistent with current studies, highlighting the vital role that pre-emptive measures, efficient land management, and monitoring have in preserving regional ecosystems. The study does, however, also draw attention to the usefulness of these technologies, highlighting the necessity for mining firms to give biodiversity preservation a priority in their operational plans which is currently not the case. Adopting these findings will be crucial as the mining sector develops to support sustainable practices that preserve biodiversity and advance ecological balance.

6.2.6 RQ1: Theme 6: Enhanced environmental regulation compliance

6.2.6.1 Enhanced environmental regulation compliance: Summary of key findings.

The key finding regarding enhanced environmental regulation compliance is that Industry 5.0 technologies facilitate efficiency and proactive compliance, necessitating their adoption alongside robust governance structures. The study shows that Industry 5.0 technologies significantly improve mining operations' adherence to environmental regulations through continuous compliance monitoring, real-time monitoring, automated verification, and proactive measures. These technologies help mining businesses monitor environmental indicators, reduce regulatory violations, and lessen administrative burdens by automating data collection and processing. They also improve compliance reporting accuracy and reduce human error. However, there remains a significant gap in fully utilising these technologies for environmental regulatory compliance in mining operations.

6.2.6.2 Enhanced environmental regulation compliance: Summary of key literature.

The findings about improved environmental regulation compliance through Industry 5.0 technologies in mining are supported by literature. Industry 5.0 technologies can automate regulatory report creation, enhancing transparency and compliance tracking (Mukherjee et al., 2023). Sharma et al. (2022) highlight how IoT and advanced data analytics enable real-time data collection, allowing quick responses to environmental hazards and reducing compliance risks. Cao et al. (2021) note that despite high initial costs, the long-term benefits of better compliance and lower regulatory risks make Industry 5.0 technologies attractive. Asif et al. (2023) emphasise that smart technology improves continuous environmental monitoring, essential for legal compliance and sustainable practices. Horváth and Ssabó (2019) add that clean energy solutions reduce carbon emissions and meet sustainability regulations. Overall, these studies show that

Industry 5.0 technologies can significantly enhance environmental regulation compliance in the mining industry.

6.2.6.3 Comparison of findings vs literature Theme 6

The incorporation of Industry 5.0 technologies can be crucial for improving compliance with environmental regulations in mining. This research highlights the synergies between Industry 5.0 technology and environmental compliance, emphasising practical insights and theoretical perspectives. The findings reveal a significant need for environmental compliance due to the extensive degradation caused by mining activities.

Practical insights and literature (Mukherjee et al., 2023; Sharma et al., 2022) underscore the importance of using Industry 5.0 technologies for continuous monitoring, automated verification, and proactive compliance strategies. These technologies enable real-time monitoring and quicker responses to regulatory violations, though full utilisation has not yet been realised. Continued efforts are needed to integrate these technologies into often bureaucratic compliance frameworks.

Technologies like the Internet of Things, real-time monitoring, and automated verification improve compliance reporting accuracy, reduce regulatory infractions, and foster sustainability. While Industry 5.0 technologies are recognised for their potential, significant barriers to their comprehensive use remain, including cultural, organisational, and economic factors. Theoretical perspectives highlight the abstract advantages of Industry 5.0, such as automated regulatory reports and real-time data acquisition, emphasising the long-term benefits of enhanced compliance and reduced regulatory risks.

6.2.6.4 Conclusion

The mining industry can boost compliance with environmental regulations by adopting Industry 5.0 technology. The study highlights the importance of proactive strategies, automated verification, and real-time monitoring to meet environmental standards, reducing administrative burdens. It emphasises the need for mining companies to prioritise compliance in their operations. Embracing these technologies is essential for sustainable practices and legal adherence as the industry evolves.

The discussion on RQ1 provided a comparative analysis of the findings and reviewed literature, highlighting both similarities and discrepancies. While the literature supports the benefits of Industry 5.0 technologies, the mining sector faces unique challenges that theoretical frameworks may not fully address. The next section, RQ2, explores the constraints to the adoption of Industry 5.0.

6.3 Research Question 2: Constraints impacting adoption of Industry 5.0 technologies in mining sustainability transitions

This research question was formulated to provide new insights and understanding on the constraints that impact the adoption of Industry 5.0 technologies in mining sustainability transitions. Table 42 shows the main themes derived from the findings highlighting the lack of incentives for environmentally compliant technologies and environmentally unfriendly technologies as a potential new theme.

Table 42. Key themes on perceived constraints to adopting Industry 5.0 technologies in mining organisations

Research Question	Theoretical construct	New themes	Literature review authors
RQ2: constraints that impact the adoption of Industry 5.0 technologies in mining sustainability transitions	Perceived economic constraints	Cost of implementation	Cao et al. (2021) Friedman & Ormiston (2022) Horváth & Ssabó (2019) Roberts et al. (2021) Stroh et al. (2023).
	Perceived social constraints	Union/stakeholder concerns and lack of engagement	
	Perceived environmental constraints	NIL	
	Perceived regulatory constraints	**Lack of incentives**	
	Perceived organisational constraints	Lack of leadership buy-in	
		Infrastructure challenges	

6.3.1 RQ2: Theme 1: Cost of implementation

Cost of Industry 5.0 technologies implementation is a theme that was found in the literature but the findings brought out nuances worth exploring.

6.3.1.1 Cost of implementation: Summary of key findings

The study highlights that high implementation costs are a significant barrier to adopting Industry 5.0 technologies in the mining sector. These costs include substantial initial expenses, overestimated benefits, and challenges in calculating return on investment (ROI). The conservative nature of the mining industry further complicates financial concerns. Insights from mining professionals, particularly those in platinum mines, underscore the unique, finite nature of mining projects and the severe financial pressures from low commodity prices and demand deflation. Consequently, the cost-benefit analysis is crucial before adopting new technologies.

Survey participants noted that significant upfront expenses, maintenance, and operating costs are major concerns. Continuous maintenance expenses also pose a barrier, making it harder to justify the financial investment in Industry 5.0 technologies. Calculating ROI is particularly challenging, as the mining sector often struggles to demonstrate the benefits of new technology beyond initial productivity gains, complicating funding efforts for their adoption.

6.3.1.2 Cost of implementation: Summary of key literature

Research indicates that high implementation costs are a significant barrier to adopting new technologies (Aaldering & Song, 2021; Greco et al., 2021; Mukherjee et al., 2023; Roblek et al., 2021; Shojaei & Burgess, 2022). Many organisations believe that the high infrastructure costs and perceived low economic returns make adopting new sustainability technologies expensive and detrimental to performance (Verhoef et al., 2021). Additionally, the fifth industrial revolution’s technologies pose adaptation challenges for older workers and other groups, increasing training costs (Enang et al., 2023).

Van Sluisveld et al. (2023) highlight the financial implications of adopting advanced technologies in mining, noting that high initial and ongoing maintenance costs hinder sustainable practices. Edmondson et al. (2019) point out that the mining industry struggles to justify the expenses of new technology, especially when benefits are not immediately apparent, leading to reluctance to invest in Industry 5.0 technologies. Enang et al. (2023) also mention the lack of precise financial models for evaluating the economic feasibility of these technologies as a barrier. Simboli et al. (2014) argue that the mining sector’s cautious approach to cost concerns often results in missed opportunities to enhance operational efficiency and sustainability. Collectively, these studies underscore that implementation costs remain a major obstacle to the adoption of Industry 5.0 technologies in the mining industry.

6.3.1.3 Comparison of findings vs literature Theme 1

The results and previous research highlight the high upfront costs of deploying Industry 5.0 technology as the main barrier in mining businesses. This mutual understanding draws attention to the financial obstacles mining firms confront while implementing new technology. A recurring topic is the worry over continuing maintenance expenditures, which both literature and the participants acknowledge might discourage businesses from pursuing technical developments. Nonetheless, the results offer particular qualitative perspectives from industry players, describing their individual experiences and opinions about the financial ramifications of Industry 5.0 technologies. On the other hand, the literature (Aaldering & Song, 2021, Greco et al., 2021, Mukherjee et al., 2023; Roblek et al., 2021; Shojaei & Burgess, 2022) frequently offers a generalised view that using Industry 5.0 technology has the hefty upfront expenses. This reciprocal understanding highlights the financial challenges mining companies face when introducing new technology. However, the findings include specific qualitative viewpoints from industry participants, including their own experiences and thoughts on the financial implications of Industry 5.0 technologies and show that the finite nature of mining activities makes it difficult to uptake Industry 5.0 technologies without evaluating costs and benefits issues in relation to the life span of the mine. In South Africa mining is in its lifecycle sunset, deep, and complex in extraction and regulation which provides a unique set of circumstances. The literature does not address this added financial dynamic which encourages a more timid approach to technology adoption.

6.3.1.4 Conclusion

In conclusion, one major barrier to the mining industry's adoption of Industry 5.0 technologies is the expense of implementation. The results of this research are consistent with current studies, highlighting the issues associated with large upfront costs, continuing maintenance expenses, and ROI measurement. According to both sources, mining firms must create more transparent financial models and explanations for their Industry 5.0 technology investments. The financial dynamics that present in South Africa may however be unique and present boundary conditions that challenge theory.

6.3.2 RQ2: Theme 2: Union/stakeholder concerns and lack of engagement

Union/stakeholder concerns and lack of engagement is a theme that had limited coverage in the literature. A search in the existing literature was insufficient, leading to additional new searches in academic databases using the search words union/stakeholder concerns and lack of engagement. The literature focuses on a generalised view of stakeholders but is limited to organised labour.

6.3.2.1 *Union/stakeholder concerns and lack of engagement: Summary of key findings*

The study highlights that stakeholder and union concerns significantly hinder the adoption of Industry 5.0 technologies in mining companies. The communities around mining operations were viewed as more influential than other stakeholders in the technological adoption debate or any other change related to mining operations. A major issue is the lack of participation in the adoption process, which fuels fears of job loss among employees. Participants noted that unions and stakeholder groups are particularly resistant to new technologies due to concerns about potential job displacement. This resistance is exacerbated when these groups are not meaningfully involved in the technology adoption process, leading to feelings of exclusion from important discussions. The findings suggest that overcoming this resistance requires a holistic approach that includes legislative support and active stakeholder engagement to address the concerns of unions and other stakeholders effectively.

6.3.2.2 *Union/stakeholder concerns and lack of engagement: Summary of key literature*

The literature (Cao et al., 2021; Friedman & Ormiston, 2022; Horváth & Ssabó, 2019; Roberts et al., 2021; Stroh et al., 2023) identifies employee and manager attitudes, resistance to change, and fear of job loss as major barriers to adopting new technologies. Integrating AI into decision-making processes can disrupt the current division of labour, leading to resistance and uncertainty among employees (Trunk et al., 2020). Therefore, implementing Industry 5.0 requires a holistic approach that includes technological advancements, stakeholder participation, legislative support, and the creation of human-centric innovation ecosystems (Bag et al., 2018).

Cao et al. (2021) highlight the impact of employee attitudes and resistance to change, emphasising that fears of job loss can lead to strong opposition from unions and workers. Friedman and Ormiston (2022) stress the importance of involving stakeholders in the adoption process to prevent opposition and misconceptions. Horváth and Ssabó (2019) note that new technology can cause confusion and resistance by disrupting existing roles and duties. Stroh et al. (2023) advocate for a human-centric approach to technology adoption, addressing workers' concerns and ensuring their involvement in decision-making. Collectively, these studies show that union and stakeholder concerns, along with a lack of engagement, are significant barriers to adopting Industry 5.0 technologies in the mining sector.

6.3.2.3 Comparison of findings vs literature Theme 2

The results and previous research (Trunk et al., 2020) highlight that employees' primary concern is the fear of job loss. This shared understanding emphasises the psychological and emotional barriers that can hinder the adoption of new technologies. Both sources stress the importance of stakeholder/employee engagement, recognising that effective participation in the adoption process is crucial to mitigating opposition. While the literature (Bag et al., 2018; Stroh et al., 2023) thoroughly addresses the need for employee engagement, the findings offer new insights into the necessity of involving unions and communities when considering new technologies. An important distinction between the literature and findings is the organised nature of the employees' responses.

In the highly unionised South African mining sector, any strategies that could lead to job displacement are a significant concern and can be resisted by trade unions. Additionally, communities around mining operations have become increasingly militant, demanding involvement in decision-making processes, a legacy of the fight against apartheid. These perspectives are unique to the mining industry's adoption of Industry 5.0 technologies and may not apply to other sectors. Although existing research discusses the general effects of resistance to change, the findings specifically highlight that a lack of genuine involvement exacerbates resistance, a point that may not be as thoroughly covered in current studies.

6.3.2.4 Conclusion

In conclusion, stakeholder and union concerns, along with a lack of participation, significantly hinder the mining industry's adoption of Industry 5.0 technologies. The research aligns with current studies, highlighting challenges such as fears of job loss and the need for genuine stakeholder involvement. While the literature focuses on worker engagement, the findings emphasise the importance of involving unions and mining communities. Both sources underscore the necessity of a comprehensive strategy that addresses these issues and promotes cooperation among all stakeholders. Overcoming these obstacles is crucial for the mining sector to transition to more sustainable practices.

6.3.3 RQ2: Theme 3: Lack of incentives

Lack of incentives is an interesting theme that brings new insights to the debate in that South Africa is one of the most regulated developing countries with extensive mining operations.

6.3.3.1 Lack of incentives: Summary of key findings

The main findings indicate that insufficient incentives significantly hinder the adoption of environmentally sustainable technologies in the mining industry. The lack of comprehensive incentive frameworks discourages corporate investment and employee participation. Participants noted that the primary incentive for environmental compliance is maintaining Environmental Impact Assessments (EIAs) and required permits, which does not encourage the broader use of advanced technologies.

Mining executives and consultants highlighted that the absence of a clear return on investment (ROI) or incentive structure makes businesses hesitant to invest in new technology. This financial disincentive hampers the adoption of Industry 5.0 technologies. The study emphasises that existing incentive programs are inadequate and primarily focused on compliance rather than fostering innovation. Participants stressed the need for stronger incentive structures to promote investment in innovative technologies.

Given the rigorous environmental regulations in the mining sector, addressing the lack of incentives is crucial. Current programs do not sufficiently encourage creativity and the adoption of Industry 5.0 technologies, slowing the development of sustainable mining practices.

6.3.3.2 Lack of incentives: Summary of key literature

The literature supports the conclusion that a lack of incentives is a major barrier to adopting Industry 5.0 technologies. Gault (2018) discusses how insufficient incentives can deter businesses from adopting new technologies, particularly in high-risk sectors like mining. Horváth and Ssabó (2019) note that the absence of incentives for sustainable technology can stall innovation. Roberts et al. (2021) highlight that prioritising short-term compliance over long-term innovation, due to a lack of financial incentives, can significantly hinder the transition to sustainable practices. Bag et al. (2018) argue that incentive programs promoting advanced technologies that enhance sustainability while meeting legal requirements are crucial. Collectively, these studies indicate that the lack of incentives remains a significant obstacle to the mining industry’s adoption of Industry 5.0 technologies.

6.3.3.3 Comparison of findings vs literature Theme 3

The results and previous research (Gault, 2018; Horváth & Ssabó, 2019) highlight the crucial role of incentives in promoting the adoption of new technologies. In the high-risk mining industry, the lack of incentives is a significant concern that hinders the uptake of

Industry 5.0 technologies. Both findings and literature agree that businesses are less likely to invest in new technology without sufficient financial incentives. The findings also note that current incentive frameworks often prioritise regulatory compliance over innovation, emphasising compliance as the main motivator.

Participants shared their experiences and opinions about the lack of incentives, suggesting that the perceived costs outweigh the benefits of adopting Industry 5.0 technologies. The results emphasise the need for a comprehensive incentive framework tailored to the specific challenges of the mining sector. While the literature addresses the general effects of inadequate incentives, the findings highlight the necessity of a detailed incentive framework for technology-environmental compliance, which may not be as thoroughly covered in existing studies. In the South African context to further the disincentive has a particularly bureaucratic approach to regulation and high penalties but does not have any incentives for some of the perceived benefits of the introduction of Industry 5.0 technology.

6.3.3.4 Conclusion

In conclusion, the lack of incentives for environmental regulatory compliance is a major barrier to adopting Industry 5.0 technology in the mining industry. The study's findings align with current research, highlighting the need for stronger incentive structures to encourage innovation and investment in new technologies while ensuring compliance. Promoting environmentally friendly technologies that meet legal requirements is essential for the mining sector to transition to more sustainable practices. Overcoming these obstacles is crucial for progress.

6.3.4 RQ2: Theme 4: Lack of leadership buy-in

Lack of leadership buy-in is a theme that was found in the literature to a certain extent. A search in the existing literature was insufficient, leading to additional new searches in academic databases using the search words lack of leadership buy-in.

6.3.4.1 Lack of leadership buy-in: Summary of key findings

The primary finding is that the adoption of new technologies is severely hindered by the lack of leadership support. Strong, committed leadership is essential for overcoming barriers to innovation and enabling successful sustainability transitions. The research shows that a lack of leadership buy-in is a major obstacle to adopting Industry 5.0 technologies in mining enterprises. Participants noted that efforts to implement new technology often fail without strong support from senior management. This lack of commitment and strategic direction results in missed opportunities for innovation and increased sustainability. Effective leadership is crucial for fostering an innovative culture and facilitating the necessary adjustments for technology adoption. The absence of leadership involvement is highlighted as one of the main obstacles to advancing sustainable mining practices.

6.3.4.2 Lack of leadership buy-in: Summary of key literature

The literature highlights that top management support is crucial for the successful adoption of new technologies (Ansong & Boateng, 2018; Tandoğan & Gedikoğlu, 2020). Ansong and Boateng (2018) emphasise that leadership commitment is essential for driving change and fostering an organisational culture that embraces innovation. They note that in sectors undergoing significant change, leadership buy-in is vital for technology adoption. Tandoğan and Gedikoğlu (2020) add that leadership involvement significantly impacts employee motivation and the overall success of innovation projects. Without strong leadership backing, organisations struggle to adopt new technologies effectively, causing innovation initiatives to stall. These studies collectively indicate that the absence of leadership buy-in remains a major obstacle to the mining industry's adoption of Industry 5.0 technologies.

6.3.4.3 Comparison of findings vs literature Theme 4

The literature (Ansong & Boateng, 2018; Tandoğan & Gedikoğlu, 2020) emphasises the importance of leadership buy-in for fostering an organisational culture that supports innovation and technology integration, focusing on senior management's role in facilitating change. The findings highlight unique challenges in the mining sector, such as managing limited resources and regulatory complexities, which can hinder technology adoption.

While the literature often overlooks middle management, the findings reveal their crucial role in translating upper management's vision into actionable strategies and engaging frontline employees. Resistance to change in the mining industry is linked to job security concerns and the need for union involvement, influenced by the sector's socio-economic context.

The findings also provide practical insights on enhancing leadership buy-in, such as promoting open communication and involving leaders at all levels. External factors significantly impact leaders' willingness to invest in new technologies, highlighting the importance of understanding the operational environment of mining executives.

These differences underscore the need for a more contextualised understanding of leadership buy-in in the mining sector, combining theoretical insights with practical experiences from industry stakeholders.

6.3.4.4 Conclusion

In conclusion, a major barrier to the mining industry's adoption of Industry 5.0 technologies is the absence of leadership buy-in. The research's findings, which highlight the difficulties caused by a lack of leadership support and the requirement for strong top management endorsement, are consistent with previous literature. Both sources emphasise how important it is to promote an innovative culture and a dedication to technology adoption. For the mining sector to make the shift to more sustainable methods, these obstacles must be removed.

6.3.5 RQ2: Theme 5: Infrastructure challenges

Infrastructure challenges is a theme related to the inherent capacity of the organisation to execute Industry 5.0 and is fundamentally important in mining as new projects tend to start in remote locations.

6.3.5.1 Infrastructure challenges: Summary of key findings

Key findings indicate that infrastructural obstacles hinder the implementation of Industry 5.0 technologies in mining companies. These include data integration issues, system connectivity challenges, environmental concerns, and a lack of centralised management. Participants noted difficulties in integrating data from various activities and ensuring effective communication across systems. One executive highlighted the need for better data reporting methods due to poor system integration.

Environmental conditions such as dust, extreme heat, darkness, water, noise, and hard surfaces pose significant challenges to technology used in mining. This underscores the need for robust infrastructure. A key deficiency identified was the lack of a centralised mechanism to oversee data and technology integration. Participants recommended a cloud-based solution to improve data management and streamline operations.

6.3.5.2 Infrastructure challenges: summary of key literature

Mukherjee et al. (2024) identified infrastructure as a major barrier to Industry 5.0 in developing nations, particularly in South African mining. Leng et al. (2022) noted increased cyberattack risks with Industry 5.0, while Sharma et al. (2022) and Ivanov (2023) highlighted their focus on integration and intelligent components.

Calsada-Olvera and Iisuka (2023) emphasised that poor infrastructure hampers technology adoption. Gault (2018) and Horváth and Ssabó (2019) discussed challenges from outdated systems in mining. Molina (2018) added that a lack of investment in infrastructure prevents leveraging new technologies. Collectively, these studies show infrastructure is a key barrier to Industry 5.0 in mining.

6.3.5.3 Comparison of findings vs literature Theme 4

The implementation of Industry 5.0 technologies in South Africa faces unique challenges. Local environmental factors like dust, extreme temperatures, and rugged terrain significantly affect technology performance.

The literature often overlooks the historical context of South African mining, including the legacy of apartheid and its impact on worker relations and infrastructure. Strong labour unions and past uprisings influence current infrastructure investment and technology adoption, adding pressure on mining companies to balance technological progress with workforce stability.

Financial constraints and economic instability complicate the integration of new technologies, as highlighted by Horváth and Ssabó (2019), Molina (2018), and Mukherjee et al. (2024). These challenges are particularly relevant in South Africa, where economic difficulties can affect funding for technology implementation.

The lack of centralised governance frameworks in South African mining companies also hinders effective infrastructure and technology management, especially given the dispersed nature of mining activities.

These factors underscore the need to consider South Africa’s unique socio-economic, environmental, and regulatory context when addressing infrastructure challenges related to Industry 5.0 technologies. Chapter 5’s findings provide a localised perspective on the specific challenges faced by the South African mining sector, which may not be fully covered in the broader literature.

Additionally, organisational constraints, including leadership, culture, internal capacity, and infrastructure limitations, should be viewed as a separate construct influencing the adoption of Industry 5.0 technology, as discussed in Chapter 2.

6.3.5.4 Conclusion

In conclusion, the adoption of Industry 5.0 technologies in the mining industry faces significant challenges due to infrastructural issues and environmental impacts. The study highlights the need for substantial infrastructure investments to support advanced and eco-friendly technologies. Organisational costs are also a key factor in adopting Industry 5.0 technologies. Addressing these obstacles is crucial for sustainable mining practices.

Research Question 2 identified major barriers such as high implementation costs, societal resistance, and lack of incentives for environmentally compliant technologies. Tailored solutions like better communication, financial support, and training are essential to overcome these challenges. Overcoming these barriers is vital for promoting sustainable mining and ensuring long-term industry viability. Strategies to address these issues are discussed in response to RQ3.

6.4 Research Question 3: Strategies employed to overcome constraints and promote Industry 5.0 technology adoption in mining organisations

This research question was formulated to provide new insights and understanding on strategies employed to overcome constraints and promote Industry 5.0 technology adoption. Table 43 shows the main themes derived from the findings.

Table 43. Key themes on perceived strategies employed to overcome constraints and promote Industry 5.0 technology adoption in mining organisations

Research Question	New themes	Literature review authors
RQ3: strategies employed to overcome constraints and promote Industry 5.0 technology adoption	Clear feasibility and business case	Aheleroff et al. (2022) Battini et al. (2022) Ceipek et al. (2021) Horváth and Ssabó (2019) Roblek et al. (2021) Sharma et al. (2022)
	Risk sensing and resilient supply chain	

6.4.1 RQ3: Theme 1: Clear feasibility and business case

6.4.1.1 Clear feasibility and business case: Summary of key findings

The key findings indicate that the lack of clear feasibility and business cases hampers the adoption of new technologies in mines. Emphasising data-driven decision-making, systematic assessments, and alignment with operational needs helps stakeholders manage technology adoption effectively, ensuring investments yield tangible benefits and foster innovation. These insights mainly come from platinum miners who are currently facing viability challenges due to falling commodity prices.

The research underscores the importance of establishing clear feasibility and business cases to overcome constraints in adopting Industry 5.0 technologies. Participants highlighted the necessity of well-defined business cases to justify investments in new technologies, emphasising their impact on productivity and cost savings. They also stressed the importance of considering long-term implications when investing in technology and presenting compelling business cases to stakeholders. The current profitability pressures on platinum miners heighten their focus on the cost-benefit analysis of new technologies.

6.4.1.2 Clear feasibility and business case: Summary of key literature

The literature underscores the importance of a clear feasibility and business case for adopting Industry 5.0 technologies. Mukherjee et al. (2024) and Sharma et al. (2022) emphasise that without a well-articulated feasibility study, organisations may struggle to justify investments. Ivanov (2023) and Leng et al. (2022) highlight that understanding business implications and developing robust business cases can mitigate stakeholder resistance and facilitate smoother transitions.

Calsada-Olvera and Iisuka (2023) and Gault (2018) stress the need for structured approaches to evaluating feasibility, particularly in mining. Aaldering and Song (2021) and Roblek et al. (2021) argue that clear business cases addressing potential risks and benefits are essential. Collectively, these studies illustrate that establishing a clear feasibility and business case is crucial for adopting Industry 5.0 technologies in the mining sector.

6.4.1.3 Comparison of findings vs literature Theme 1

Both the findings and current literature (Leng et al., 2022; Mukherjee et al., 2024; Sharma et al., 2022) highlight the crucial role of a well-defined feasibility and business case in justifying investments in new technologies. They agree that systematic evaluations are essential for effective decision-making and emphasise the importance of long-term planning and assessing future impacts of technological investments.

Chapter 2's literature stresses the need for a clear feasibility and business case for technology adoption. However, the findings offer a more nuanced, sector-specific perspective, highlighting the unique challenges faced by the mining industry, the necessity of risk management, and the impact of organisational culture on business case development. A localised understanding is vital for navigating the complexities of deploying Industry 5.0 technologies in the mining sector, influenced by commodity prices and prevalent end-of-life mining practices in South Africa.

6.4.1.4 Conclusion

In conclusion, a clear feasibility and business case is essential for adopting Industry 5.0 technologies in mining. The research aligns with existing literature, emphasising data-driven decision-making, structured assessments, and long-term planning. Mining companies must develop tailored business cases to address operational complexities and enhance efficiency.

6.4.2 RQ3: Theme 2: Risk sensing and resilient supply chain

6.4.2.1 Risk sensing and resilient supply chain: Summary of key findings

The key findings emphasise the importance of proactive risk management and technological investments in mining operations to enhance resilience and adaptability in supply chains. These strategies help reconcile technical solutions with human safety and operational costs.

Risk sensing and resilient supply chains are crucial for adopting Industry 5.0 technologies in mining. Key points include proactive risk management, technology for risk prediction, supply chain resilience, and real-time data utilisation. Participants stressed anticipating risks, using technology for prediction, and maintaining a resilient supply chain. Real-time data and analytics are essential for improving responsiveness and adaptability, especially in financially risky mining businesses.

6.4.2.2 Risk sensing and resilient supply chain: Summary of key literature

Literature shows that technologies like machine cognition, sensing technologies, and virtual training help workers adjust to Industry 5.0 (Leng et al., 2022). A key feature of Industry 5.0 is enhancing business process resilience (Carayannis et al., 2024; Ivanov, 2023; Mukherjee et al., 2023; Panagou et al., 2023; Sharma et al., 2022).

Kumar et al. (2022) highlight that advanced analytics and IoT improve risk sensing and decision-making in mining. Shang et al. (2021) emphasise resilient supply chains for managing uncertainties, advocating for technology integration. Choi and Cheng (2020) stress the need for robust risk-sensing frameworks to mitigate disruptions. Mishra et al. (2023) note that resilient supply chains, supported by real-time data analytics, enhance responsiveness to risks, facilitating smoother technology adoption. These studies collectively show that effective risk sensing and resilient supply chains are crucial for adopting Industry 5.0 technologies in mining.

6.4.2.3 Comparison of findings vs literature Theme 2

The analysis of risk perception and supply chain resilience in South Africa's mining industry reveals unique challenges. Political and economic turmoil, such as labour strikes and economic fluctuations, significantly impact supply chains. Recognising these risks is crucial for maintaining resilience, allowing organisations to adjust strategies proactively.

Effective risk assessment must include monitoring labour relations and union activities to anticipate disruptions. Environmental risks like droughts, floods, and climate-related events also necessitate incorporating environmental monitoring into risk sensing to mitigate natural disasters' impact on supply chains.

The South African mining sector is increasingly adopting advanced technologies to enhance operational efficiency. Risk sensing technologies, such as IoT and data analytics, bolster supply chain resilience by facilitating real-time risk assessment and quick responses to potential disruptions.

These unique aspects underscore the need for tailored measures that consider the local context. Chapter 5 highlights the importance of proactive risk management, community engagement, and technological innovation in addressing the challenges faced by the South African mining industry.

Recent literature (Ivanov, 2023; Mukherjee et al., 2023; Panagou et al., 2023; Sharma et al., 2022) supports the importance of risk sensing in proactive risk management and using technology for risk prediction to improve operational efficiency. Both the findings and literature emphasise supply chain resilience in managing uncertainties and promoting technology adoption. However, the findings specifically highlight the mining industry's need for customised risk management solutions to address operational complexities.

6.4.2.4 Conclusion

In conclusion, risk sensing and resilient supply chains are crucial for adopting Industry 5.0 technologies in mining. The research and recent literature highlight the need for proactive risk management, technology for risk sensing, and supply chain resilience to enhance operational efficiency.

Research Question 3 identified key measures to mitigate barriers, such as developing a clear business case, improving stakeholder involvement, and allocating resources for training. These strategies help mining businesses address challenges and promote sustainable practices. Research Question 4 will focus on the consequences of hesitating to embrace Industry 5.0 technology.

6.5 Research Question 4: Outcomes of reluctance to adopt Industry 5.0 technologies

This research question was formulated to provide new insights and understanding of outcomes to the reluctance to adopt Industry 5.0 technologies. Table 44 shows the main themes derived from the findings.

Table 44. Key themes on outcomes to the reluctance to adopt Industry 5.0 technologies in mining organisations

<table>
<tr><th>Research Question</th><th>Theoretical Construct</th><th>New Themes</th><th>Literature Review Authors</th></tr>
<tr><td rowspan="3">RQ4: Outcomes to the reluctance to adopt Industry 5.0 technologies</td><td>Economic reluctance outcomes</td><td>NIL</td><td rowspan="3">Brown et al. (2020)
Gonsales et al. (2021)
Lee et al. (2023)
Smith and Jones (2022)</td></tr>
<tr><td>Social reluctance outcomes</td><td>NIL</td></tr>
<tr><td>Environmental reluctance outcomes</td><td>Environmental reluctance outcome</td></tr>
</table>

6.5.1 RQ4: Theme 1: Environmental reluctance outcome

6.5.1.1 Environmental reluctance outcome: Summary of key findings

The key findings on environmental reluctance outcome was the concerns over the compatibility of Industry 5.0 technologies with sustainability objectives, along with apprehensions about concealed expenses and environmental regulatory obstacles.

The research findings indicate that environmental reluctance outcomes significantly contribute to the reluctance to adopt Industry 5.0 technologies in mining businesses with key evidence which includes concerns over environmental impact, unpredictability of climate change, and fear of unsustainable practices. Environmental impacts is a critical area of management in mining businesses and the reason the participants shared sentiments on unpredictability of climate change, and fear of unsustainable practices. Participants expressed apprehension regarding the environmental implications of new technologies and reflected a cautious approach to adopting technologies perceived as potentially harmful to the environment. The findings also suggest that there is a prevalent fear among mining executives that the adoption of Industry 5.0 technologies could lead to practices that are not environmentally sustainable, further contributing to their reluctance to embrace these innovations.

6.5.1.2 Environmental reluctance outcome: Summary of key literature

Literature highlights the environmental challenges of adopting new technologies in mining. Gonzales et al. (2021) note that companies hesitate due to fears of worsening environmental degradation. Smith and Jones (2022) emphasise the unpredictability of environmental impacts, leading to reluctance to adopt Industry 5.0 solutions to avoid long-term ecosystem harm. Lee et al. (2023) argue that prioritising environmental sustainability in technology adoption is crucial to avoid reputational and regulatory risks. Brown et al. (2020) suggest that environmental reluctance often stems from a lack of understanding of how new technologies can be sustainably integrated into existing operations.

6.5.1.3 Comparison of findings vs literature Theme 1

Both the findings and existing literature (Brown et al., 2020; Lee et al., 2023; Smith & Jones, 2022) emphasise the critical role of environmental concerns in the reluctance to adopt Industry 5.0 technologies. Mining executives commonly fear the environmental impact of new technologies, unsustainable practices, and the unpredictability of climate change. While the literature discusses general principles of environmental sustainability and technology adoption, the findings highlight the unique challenges faced by the mining industry, such as regulatory pressures and the need for technologies that align with sustainability goals.

6.5.1.4 Conclusion

In conclusion, environmental concerns significantly hinder the adoption of Industry 5.0 technologies in mining. Addressing these concerns and ensuring new technologies meet sustainability goals can reduce reluctance and support successful integration.

Research Question 4 highlighted that sustainability and compliance issues are major barriers. Addressing these is essential for adopting new technologies and aligning with industry sustainability objectives.

6.6 Update to conceptual framework

The updated conceptual sustainable technology adoption framework is presented below.

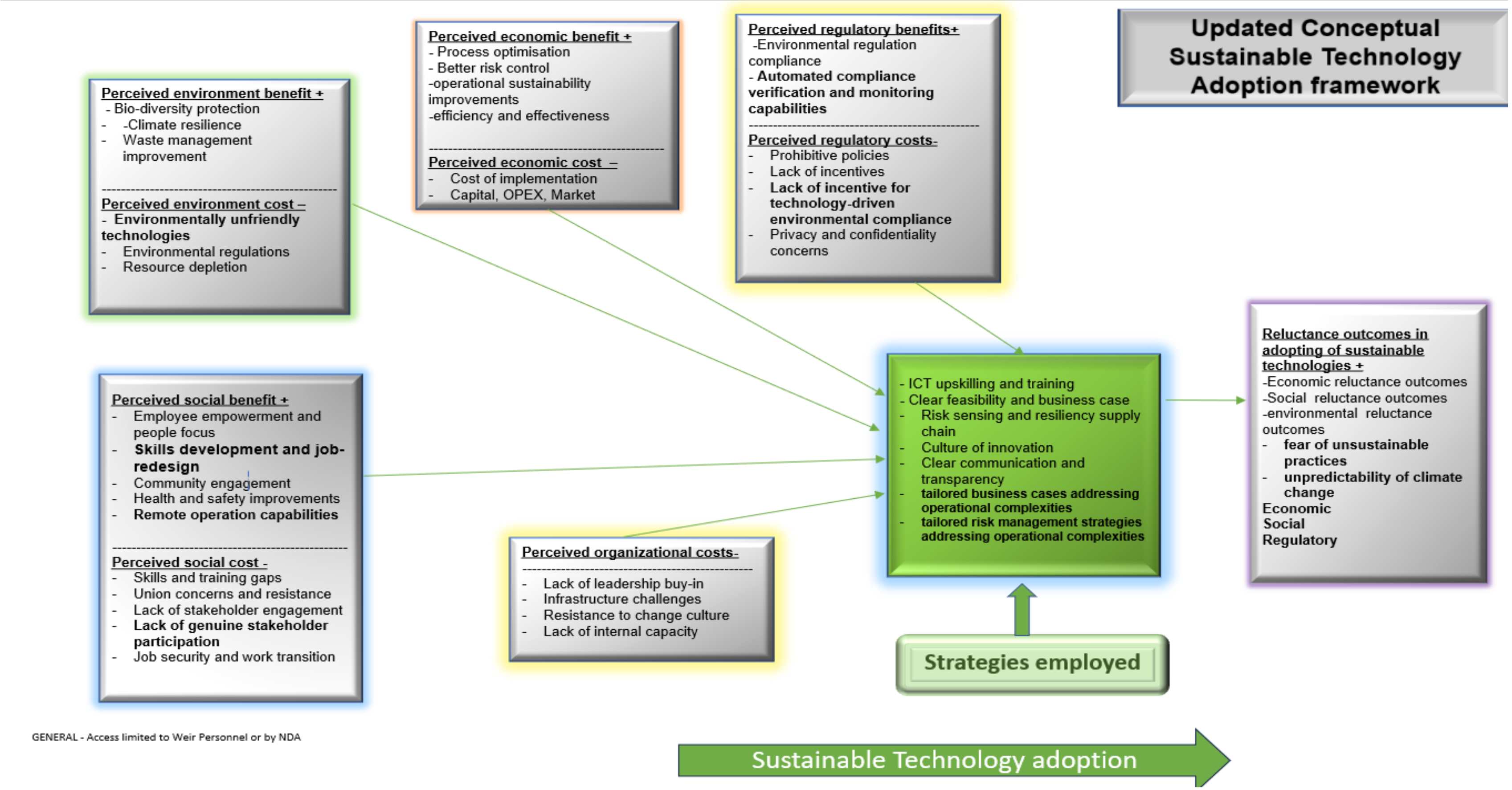

Figure 7. Updated conceptual sustainable technology adoption framework

The analysis yielded an improved framework tailored to the findings and the South African context. Figure 7 above encapsulates the revised theoretical framework. The redesigned framework notably includes perceived organisational costs as a novel component. The data, along with further literature, substantiate this perspective. The framework encompasses the primary issues of leadership, culture, and internal capability. Infrastructure, once categorised solely as an economic cost, is now recognised as part of an organisation's perceived cost due to its intrinsic connection to the organisation's capabilities.

Figure 7, however, fails to illustrate the significant impact that economic benefits or their absence exert on the other drivers and restrictions affecting the adoption of I.5.0 technologies in mining, despite their relative perceived importance.

6.7 Conclusion

Leadership support is crucial for fostering a creative culture and implementing Industry 5.0 technology. Both research and participants agree that lack of leadership endorsement is a major obstacle and stress the need to involve stakeholders, such as employees and unions, to reduce resistance and facilitate adoption. They also recognise cultural reluctance in the mining sector to adopt new technologies, highlighting psychological and emotional barriers.

While the literature focused on employee participation, participants emphasised the importance of including unions and mining communities, reflecting the unionised nature of the South African mining sector. Participants identified operational and regulatory challenges not well-covered in the literature, indicating a gap in understanding the sector’s unique obstacles.

Chapter 6 highlights further discrepancies, noting infrastructural issues like data integration and system compatibility, and the impact of ambient conditions on technology performance, which are not extensively addressed in the literature. This suggests a need for theoretical discussions to better consider the mining sector’s unique operational environment.

Participants also provided insights on financial challenges, emphasising the need for innovative financing solutions tailored to the mining sector. They expressed concerns about the insufficient use of data for decision-making and job security, reflecting the socio-economic conditions of the mining industry, especially in unionised areas.

These disparities underscore the need to incorporate practical industry stakeholder views into theoretical frameworks to fully understand the challenges and opportunities of adopting Industry 5.0 technologies in the mining sector.

Chapter 7 presents the study's conclusions, suggests further research avenues, and provides targeted recommendations for the South African mining sector regarding Industry 5.0 adoption in the context of a sustainable transition.

CHAPTER 7: CONCLUSION AND RECOMMENDATIONS

This research highlights the transformative potential of Industry 5.0 technologies in the mining sector, particularly for enhancing sustainability. It began with an introduction to Industry 5.0 technologies and their relevance, emphasising the need to understand their challenges and opportunities.

The literature review provided an overview of existing studies, highlighting contributions to sustainability and identifying research gaps. These gaps informed the research questions, focusing on the challenges of adopting Industry 5.0 technologies and their impact on sustainability in mining.

Using a detailed methodology, the study gathered and analysed data, revealing both benefits and hurdles in adopting Industry 5.0 technologies. The findings were connected back to the literature, showing how Industry 5.0 can drive process optimisation and sustainability, and identifying new themes and sub-themes.

The concluding chapter discusses the academic lessons from the study, highlighting contributions to existing knowledge, gaps in the literature, and differences from initial research questions. It also addresses study limitations and provides practical recommendations for mining sector management, emphasising strategies for implementing Industry 5.0 technologies to optimise processes and enhance sustainability.

7.1 Principal theoretical conclusions

The principal theoretical conclusions that can be drawn from this research regarding the adoption of Industry 5.0 technologies in the mining sector, particularly in the context of South Africa for each research question, are set out in this section.

The primary research question was" Why do organisations remain reluctant to implement Industry 5.0 technologies in mining operations?" which was answered by addressing the four sub-questions. In short, mining is constrained by economic cost, social costs, environmental costs and a newly added construct of organisational cost in its implementation of Industry 5.0. The discussion of the conclusions shows that even in a changing world with sustainability at its core economic considerations far out way perceived social and environmental considerations and are heavily influenced by structural and cultural issues within individual organisations.

7.1.1 Conclusions on RQ1: How Industry 5.0 technologies contribute to sustainable mining practices

The first research question examined how Industry 5.0 technologies support sustainable mining. Understanding their benefits can encourage adoption for sustainability.

Chapter 7 covers seven themes from Chapter 6: process optimisation, operational sustainability, employee empowerment, health and safety, and biodiversity protection. Five themes match existing literature, while three are new sub-themes.

Findings highlight the importance of precise data and real-time analytics in mining (Rodríguez-Espíndola et al., 2022). Optimal results need a human-machine balance (Mukherjee et al., 2023). The study also emphasises the human aspects of process optimisation, like organisational culture and staff training in developing economies, and the need for strategic management to fully utilise Industry 5.0 technologies.

The literature and findings highlight waste reduction and resource efficiency as key sustainability benefits of Industry 5.0 technologies (Pillai et al., 2021). Health and safety enhancements are also emphasised, showcasing technology's role in creating safer, long-term working conditions (Horváth & Szabó, 2019).

Industry 5.0 technologies empower employees through skill development and job redesign, particularly noted by younger, less experienced participants. Executive mining professionals emphasised this strategic imperative. Automation transforms repetitive tasks into more engaging work, boosting both production and morale.

Training and continuous learning are more suitable for younger employees, especially for operating sophisticated equipment. However, a significant knowledge gap exists at lower employment levels due to poor foundational computing skills, limiting job advancement opportunities. Redesigning jobs to combine human skills with automation can enhance operational efficiency.

Industry 5.0 technologies enable automated compliance with environmental laws through advanced monitoring systems that track environmental indicators in real time (Carayannis et al., 2024). These systems reduce human error in compliance reporting, ensuring accurate data submission and reducing legal risks. Automated compliance processes streamline operations, allowing companies to focus on core activities while maintaining regulatory standards.

The research highlights job advancement and skill development as key social benefits of Industry 5.0 technologies. It also emphasises social responsibility and community involvement, showing how these technologies empower employees through skill development and job redesign. The findings reveal differing sentiments between younger and older generations regarding new technologies in mining.

Both Friedman & Ormiston (2022) and the research stress the importance of monitoring mining's impact on ecosystems. Industry 5.0 technologies aid in this process, emphasising strategic land use to minimise ecological disturbance and protect biodiversity.

The results and Carayannis et al. (2024) emphasise the importance of automated systems and real-time monitoring for adhering to environmental laws. These technologies ensure compliance, reduce legal risks, and support sustainable mining by minimising the ecological footprint. However, in South Africa, their use is often limited to regulatory compliance due to financial and resource constraints.

The findings also highlight how Industry 5.0 technologies support biodiversity conservation in mining, though economic priorities often overshadow these efforts. Automated verification and real-time monitoring improve environmental standards, and remote operations enhance health and safety.

In conclusion, the research shows that Industry 5.0 technologies are crucial for sustainable mining. There is agreement between literature and the research findings that there are economic, social and environmental benefits to adopting Industry 5.0 technology in mining. There are however local conditions that limit some of these benefits including the age of the workforce in mining, regulatory compliance levels and knowledge levels of employees.

7.1.2 Conclusions on RQ2: Constraints to adoption of Industry 5.0 technologies in mining sustainability transitions

Research question 2 aimed to understand the constraints impacting the adoption of Industry 5.0 technologies in mining sustainability. The constraints reviewed included economic, social, environmental, and organisational costs. While the literature and findings generally aligned, themes such as implementation differences, costs, union and stakeholder concerns, inadequate engagement, lack of incentives, leadership support, and infrastructural barriers required further discussion.

Significant initial costs were a major challenge for mining companies. Concerns about ROI and ongoing maintenance costs deterred adoption, despite studies highlighting long-term savings (Roberts et al., 2021) and efficiency enhancements (Carayannis et al., 2024; Mukherjee et al., 2023). Mining executives often expressed scepticism about immediate financial benefits, leading to a cautious investment approach.

Unions and stakeholders worried about job security and the impact of new technology, leading to resistance. This aligns with concerns about job displacement in the literature (Ghobakhloo et al., 2023). Fear of the unknown created a contradiction between potential benefits and perceived risks.

Lack of employee and management engagement in the adoption process led to scepticism and resistance. Effective communication and change management were often recognised but poorly executed was echoed by participants and agreed with Brown (2020).

The absence of clear incentives hindered progress. Without tangible benefits, organisations were reluctant to invest. Some recognised the need for incentives but failed to establish effective reward systems.

Strong leadership support and buy-in is crucial (Sansel et al., 2020) and echoed by the findings that inadequate support from top management posed significant challenges, despite executives' dedication to innovation. A mismatch between strategic vision and practical backing often stalls initiatives.

The constraints to adoption of Industry 5.0 in mining are agreed between literature and the participants as being broadly economic costs, social constraints, regulatory constraints and organisational constraints. Of note was the importance of organisational constraints discussed in the themes of leadership and infrastructure which was highlighted by the participants. The study showed that while literature shows a greater influence of social and environmental cost, in the South African setting economics still played a significant role, however, influenced, it seems, by leadership.

7.1.3 Conclusion RQ3: Strategies to overcome constraints/promote Industry 5.0 technology adoption in mining organisations

Research Question 3 explored techniques to alleviate constraints and promote the adoption of Industry 5.0 technologies in mining. There is general agreement between literature and the participants that ICT skilling, the culture of innovation, and communication, amongst other strategies, are necessary to mitigate against the constraints to the adoption of Industry 5.0 technology. The focus was, however, on the themes of clear feasibility, business justification, risk sensing, and robust supply chain, while recognising the role of stakeholders and staff competencies.

The research found that developing a strong feasibility and business case was crucial for success. This is similarly echoed in literature amplifying the need for mining organisations to specify tangible benefits like cost reductions, efficiency improvements, and sustainability outcomes to justify investments, this could be done incrementally (Horváth & Szabó, 2019). Data-driven decision-making and systematic assessments were key to successful adoption, but many participants pointed out that many organisations lacked adequate analysis and communication regarding ROI, causing stakeholder reluctance.

Mukherjee et al. (2023) emphasised robust risk management, while the participants looked to resilient supply chains as a way to manage risk (Kumar et al. (2022). The capabilities of Industry 5.0 technologies as risk-sensing tools were emphasised by the participants as a strategy for adoption. Mining companies need to identify and mitigate risks (risk sense) to ensure operational continuity (Choi & Cheng, 2020). Proactive risk management was more effective, but many companies remained reactive, unlike sectors with thorough risk management systems.

Techniques to promote Industry 5.0 adoption in mining focused on clear feasibility, business cases, risk detection, and supply chain resilience. While similar to current research, inconsistencies highlighted challenges in applying these strategies. Stakeholder engagement, training, and governance structures were also crucial for effective technology adoption.

7.1.4 Conclusion RQ4: Outcomes of reluctance to mining businesses adopting Industry 5.0 technologies in sustainability transitions

Research Question 4 examined the consequences of reluctance to adopt Industry 5.0 (I5.0) technologies in mining sustainability transitions, focusing on environmental outcomes.

Participants feared that unsustainable practices and the unpredictability of climate change impacts are main reason for reluctance, highlighting a cautious approach to technology adoption in the mining sector. Mining companies feared new technologies might not align with sustainability goals or could worsen environmental issues. Stringent regulations in mining regions heightened these concerns. Jones (2022) also highlights that the unpredictability of environmental impacts from technologies leads to reluctance to adopt. This was a counter-intuitive outcome for the researcher and provides potential for further investigation. Reputational damage (Lee et al. 2023) which is important in literature did not feature prominently with the participants this may be because the research was carried out in a developing economy as opposed to developed economies.

Economic reluctance and social reluctance outcomes are viewed similarly in literature and participants. The economic outcomes remain significant given that the technology is in its infancy but as in previous industrial revolutions, the economics is expected to improve rapidly.

7.1.5 Principal theoretical conclusions: Final conceptual framework on reluctance to adopt Industry 5.0 technologies in mining sustainability transitions

Figure 8 below presents the final conceptual framework, summarising the main theoretical conclusions. It highlights differences and similarities between existing literature and the study, with differences marked in bold as potential refinements.

The framework outlines perceived benefits, constraints, strategies to overcome constraints, and reluctance outcomes related to adopting Industry 5.0 technologies. It provides new insights into why mining businesses are reluctant to adopt Industry 5.0 technologies during sustainability transitions.

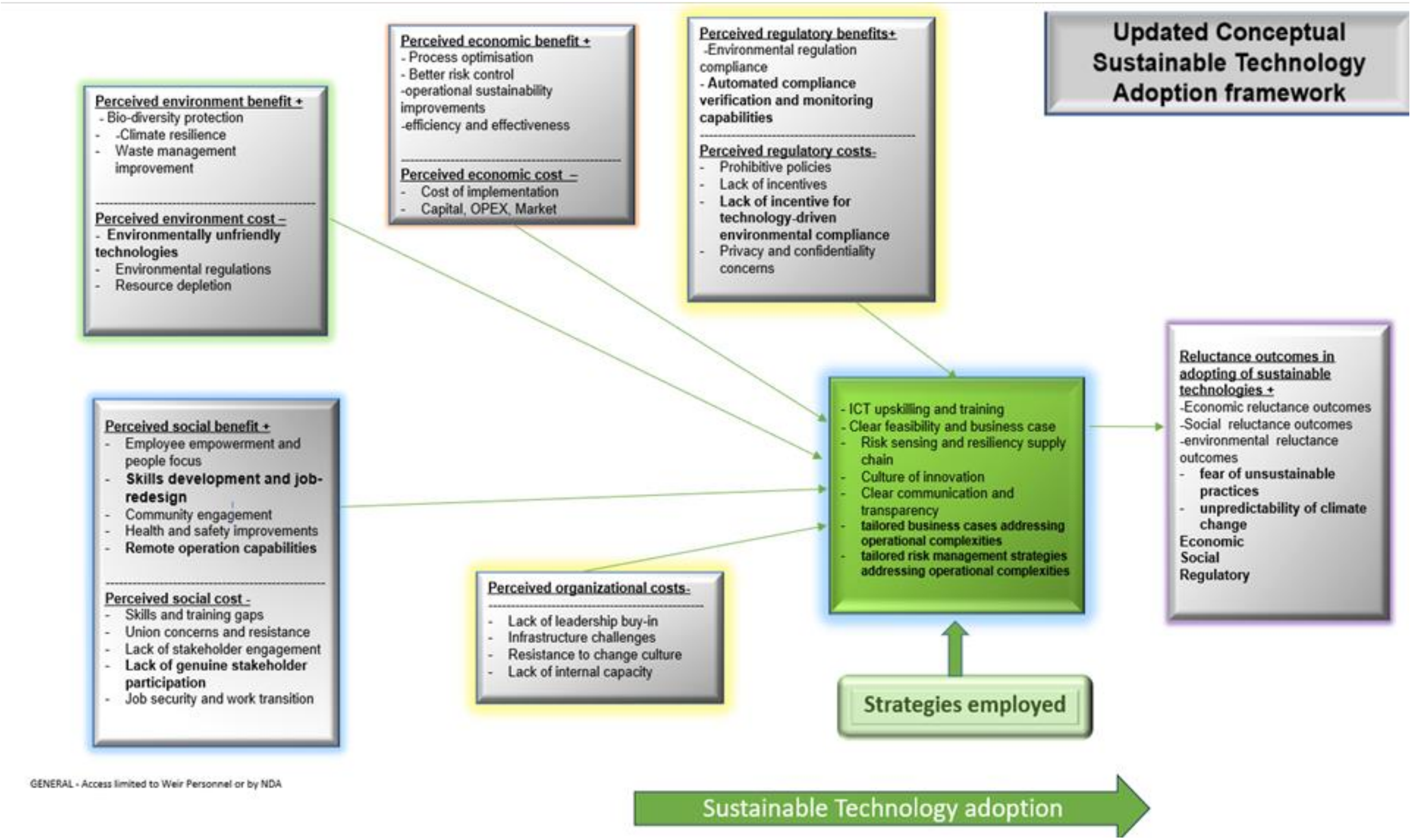

Figure 8. Final conceptual framework of reluctance in adopting Industry 5.0 technologies

The research concluded that perceived "organisational costs" should be viewed as a separate construct. The framework shows that organisational leadership buy in and culture are important in this transition which is intuitive given the human-centric orientation of Industry 5.0 and sustainability as a philosophy. This observation is important as it puts a spotlight on leadership and its role when such fundamental change is required or revolutions are taking effect.

7.2 Research contribution

This study offers a potential contribution by identifying similarities to literature that may add to the body of knowledge. Further, this study identifies the nuanced literature differences that contribute to potential refinements to theory (Crane et al., 2016).

7.2.1 Similarities between the study and literature: Adding to the body of knowledge

The study concludes with several themes similar to theoretical literature, summarised in the final conceptual framework in Figure 8. Perceived benefits include increased efficiency through automation and data analytics (Aheleroff et al., 2022; Roblek et al., 2021) and sustainability improvements through better environmental practices (Brown et al., 2020; Lee et al., 2023).

Perceived constraints involve high initial costs, with the financial burden of new technologies being a significant barrier (Sharma et al., 2022; Horváth & Szabó, 2019), and regulatory challenges, where navigating complex frameworks is a noted constraint (Battini et al., 2022; Ceipek et al., 2021).

Perceived strategies to overcome constraints include stakeholder engagement, emphasising the importance of involving stakeholders in decision-making (Aheleroff et al., 2022; Gonzales et al., 2021), and developing a clear business case, a recurring theme for technology adoption (Roblek et al., 2021; Smith & Jones, 2022).

Reluctance outcomes are driven by economic and social concerns, well-documented in the literature (Brown et al., 2020; Gonzales et al., 2021) and environmental concerns, with apprehension about the impact of new technologies being significant (Lee et al., 2023; Smith & Jones, 2022).

7.2.2 Differences between the study and literature: Refinement to the body of knowledge

Five potential refinements to literature were identified in the study and discussed in Chapter 6, included in the conceptual framework in Figure 7 with bold lettering.

The study identified unique benefits not extensively covered in existing literature, such as enhanced employee empowerment. While operational efficiency is discussed, the study emphasises Industry 5.0 technologies' role in skill development and job redesign, particularly for younger, educated workers (Ivanov, 2023; Mukherjee et al., 2023). This leads to higher job satisfaction and productivity.

The study introduced "environmental reluctance," referring to the hesitance of mining companies to adopt technologies perceived as environmentally harmful (Crane et al., 2016; Shrestha et al., 2019). Harsh environmental conditions in mining can degrade equipment and reduce the effectiveness of Industry 5.0 technologies, deterring adoption.

The study highlighted the importance of developing resilient supply chains and risk-sensing capabilities, strategies not commonly emphasised in the literature (Pillai et al., 2021; Trunk et al., 2020). Tailored risk management strategies can mitigate operational complexities, ensuring smoother implementation and compliance with regulations.

The study provided a nuanced understanding of reluctance outcomes, detailing the interplay between economic pressures and environmental concerns, which is often oversimplified in existing research (Greco et al., 2021; Jamwal et al., 2021). Uncertainty about climate change impacts can lead to a risk-averse attitude, hindering the adoption of new technologies.

7.3 Recommendations for management and stakeholders

This study developed a conceptual framework to assist companies to understand how mining companies are reluctant in adopting Industry 5.0 technologies. Each construct in the conceptual framework is intended to provide improved understanding to assist mining managers and other new technologies stakeholders as they navigate into the adoption of Industry 5.0 technologies to achieve technology-driven sustainability transitions.

7.3.1 Enhance stakeholder engagement.

Understanding perceived constraints helps managers engage stakeholders to address concerns about adopting Industry 5.0 technologies. Effective engagement leads to better decision-making and increased buy-in (Battini et al., 2022; Crane et al., 2016). Open communication reduces resistance, making it easier to implement new technologies. Inclusive strategies involving stakeholders and unions are essential.

Early engagement builds support for technology adoption. Involving employees, suppliers, and community members' lead to greater acceptance and collaboration

(Aheleroff et al., 2022; Freeman, 1984). Managers should create forums for feedback and involve stakeholders in decision-making.

7.3.2 Investment in tailored training programs

To bridge the skills gap, managers should invest in tailored training programs. Upskilling enhances employee capabilities and fosters a culture of innovation (Aheleroff et al., 2022; Mukherjee et al., 2023). Equipping employees with necessary skills facilitates smoother transitions to Industry 5.0 technologies. Training programs and continuous learning are essential for operating and maintaining advanced equipment.

7.3.3 Creation of clear and compelling technology adoption business case

Managers should create clear business cases outlining the economic and environmental benefits of Industry 5.0 technologies. Well-articulated cases help justify investments and alleviate cost concerns (Enang et al., 2023; Horváth & Szabó, 2019). Demonstrating long-term value gains support from stakeholders and decision-makers. Clear business cases provide justification for investment and help gain buy-in from stakeholders and unions by addressing their concerns.

7.3.4 Implementation of robust new technologies risk management framework

Managers should implement a robust risk management framework to address uncertainties in Industry 5.0 technology adoption. Identifying and mitigating potential risks enhances resilience and adaptability (Ivanov, 2023; Jamwal et al., 2021). Proactive risk management reduces negative outcomes and ensures smoother implementation. Tailored strategies help maintain regulatory compliance and avoid legal and financial penalties. These strategies should include plans for managing technological failures, environmental impacts, and safety concerns.

7.3.5 Establishment of incentive programs for technology-driven sustainable practice

Managers should collaborate with policymakers to establish incentives that reward sustainable practices. Financial incentives significantly influence technology adoption in mining (Jamwal et al., 2021; Pillai et al., 2021). Aligning incentives with sustainability goals motivates stakeholders to embrace new technologies. Enhanced incentive programs are needed to reward innovation in environmental practices. Policymakers should consider reforms to provide better incentives for adopting advanced, environmentally sustainable technologies.

7.4 Limitations of the study

The research focused on South African gold and platinum mines, which may not reflect challenges in other countries like the DRC, Ghana, or Zimbabwe. The study mainly involved executives and internal stakeholders, lacking external viewpoints from suppliers and consultants. Including union members and lower-level staff could provide a broader perspective.

Structured interviews may introduce biases, and the qualitative nature limits generalisability. The findings aim to open avenues for further investigation rather than being universally applicable. Time constraints and the researcher's capacity may have affected the depth of the study, leading to incomplete insights.

Unintentional biases from the researcher's perspectives or participant selection could influence the findings. These limitations suggest caution in interpreting the results and highlight areas for future research. Section 4.14 details the research design and method limitations.

7.5 Areas for further research

Future studies could include mining operations in countries like the DRC, Ghana, and Zimbabwe to understand the adoption of Industry 5.0 technologies across different contexts. Research should involve a wider range of participants, including union members, lower-level staff, and policymakers, to gain insights into barriers and facilitators of technology adoption.

Incorporating quantitative methods, such as surveys and statistical analyses, could validate qualitative findings and provide a broader understanding of reluctance to adopt new technologies. Research could also focus on how regulatory frameworks influence technology adoption, offering valuable insights for policymakers and industry leaders.

Further studies could explore the relationship between organisational constraints in particular leadership buy in and economic cost of Industry 5.0 technology adoption. This is an area that could bring interesting dynamic interplay in the implementation of industry 5.0 technology.

Further studies could explore specific Industry 5.0 innovations and identify best practices for their implementation in mining. This research would help develop strategies to overcome reluctance and enhance sustainability, contributing to a deeper understanding of the complexities in adopting Industry 5.0 technologies in the mining sector.

7.6 Conclusion

In conclusion, this study explores the adoption of Industry 5.0 technologies in the South African mining sector, highlighting unique challenges and opportunities. The findings emphasise the importance of human-centric approaches, fostering innovation, and enhancing stakeholder engagement for successful Industry 5.0 implementation.

By addressing barriers and implementing recommended strategies, the mining industry can improve operational efficiency, sustainability, and competitiveness in a digital landscape. This study identifies key areas for future research, particularly policy interventions and financial incentives to support sustainable practices. The economic in particular, social, regulatory and organisational costs remain impediments to the adoption of Industry 5.0 technology despite the perceived benefits.

REFERENCES

Abuhassna, H., Busalim, A., Yahaya, N., Aman Zahiri Megat Zakaria, M., & Abdul Latif Latif, A. (2023). Study from Home! The Antecedents and Consequences of Collaborative Learning on Malaysian University Students. *Journal of Information Technology Education: Research*, *22*, 071–095. https://doi.org/10.28945/5074

Afolalu, S. A., Ikumapayi, O. M., Abdulkareem, A., Soetan, S. B., Emetere, M. E., & Ongbali, S. O. (2021). Enviable roles of manufacturing processes in sustainable fourth industrial revolution – a case study of mechatronics. *Materials Today: Proceedings*, *44*, 2895–2901. https://doi.org/10.1016/j.matpr.2021.01.099

Aheleroff, S., Huang, H., Xu, X., & Zhong, R. Y. (2022). Toward sustainability and resilience with Industry 4.0 and Industry 5.0. *Frontiers in Manufacturing Technology*, *2*. https://doi.org/10.3389/fmtec.2022.951643

Ahmed, T., Karmaker, C. L., Nasir, S. B., Moktadir, Md. A., & Paul, S. K. (2023). Modeling the artificial intelligence-based imperatives of industry 5.0 towards resilient supply chains: A post-COVID-19 pandemic perspective. *Computers & Industrial Engineering*, *177*, 109055. https://doi.org/10.1016/j.cie.2023.109055

Ansong, E., & Boateng, S. L. (2023). Reaching for the "Cloud." *International Journal of E-Business Research*, *19*(1), 1–17. https://doi.org/10.4018/IJEBR.319324

Asif, M., Searcy, C., & Castka, P. (2023). ESG and Industry 5.0: The role of technologies in enhancing ESG disclosure. *Technological Forecasting and Social Change*, *195*, 122806. https://doi.org/10.1016/j.techfore.2023.122806

Aspers P, & Corte U. (2019). What is qualitative research? *Qualitative Sociology*, *7*, 139–160.

Bag, S., Pretorius, J. H. C., Gupta, S., & Dwivedi, Y. K. (2021). Role of institutional pressures and resources in the adoption of big data analytics powered artificial intelligence, sustainable manufacturing practices and circular economy capabilities. *Technological Forecasting and Social Change*, *163*, 120420. https://doi.org/10.1016/j.techfore.2020.120420

Battini, D., Berti, N., Finco, S., Zennaro, I., & Das, A. (2022). Towards industry 5.0: A multi-objective job rotation model for an inclusive workforce. *International Journal of Production Economics*, *250*, 108619. https://doi.org/10.1016/j.ijpe.2022.108619

Bonsteel, S. (2012). APA PsycNET. *The Charleston Advisor*, *14*(1), 16–19. https://doi.org/10.5260/chara.14.1.16

Borgstede, M., & Scholz, M. (2021). Quantitative and Qualitative Approaches to Generalization and Replication–A Representationalist View. *Frontiers in Psychology*, *12*. https://doi.org/10.3389/fpsyg.2021.605191

Braun, V., & Clarke, V. (2021). Can I use TA? Should I use TA? Should I not use TA? Comparing reflexive thematic analysis and other pattern-based qualitative analytic approaches. *Counselling and Psychotherapy Research*, *21*(1), 37–47. https://doi.org/10.1002/capr.12360

Brown, N. (2018, July). *Evaluating the Usefulness of the Adapted Thematic Analysis in the Process of Design*. https://doi.org/10.14236/ewic/HCI2018.145

Brown, T., Smith, J., & Jones, R. (2020). Understanding resistance to change in the mining sector: A case study of technology adoption. *Journal of Mining and Environmental Science*, *6*(2), 45–58.

Busetto, L., Wick, W., & Gumbinger, C. (2020). How to use and assess qualitative research methods. *Neurological Research and Practice*, *2*(1), 14. https://doi.org/10.1186/s42466-020-00059-z

Calzada Olvera, B., & Iizuka, M. (2024). The mining sector: Profit-seeking strategies, innovation patterns, and commodity prices. *Industrial and Corporate Change*, *33*(4), 986–1010. https://doi.org/10.1093/icc/dtad020

Cao, G., Duan, Y., Edwards, J. S., & Dwivedi, Y. K. (2021). Understanding managers' attitudes and behavioral intentions towards using artificial intelligence for organisational decision-making. *Technovation*, *106*, 102312. https://doi.org/10.1016/j.technovation.2021.102312

Carayannis, E. G., Canestrino, R., & Magliocca, P. (2024). From the dark side of Industry 4.0 to Society 5.0: Looking "Beyond the Box" to developing human-centric innovation ecosystems. *IEEE Transactions on Engineering Management*, *71*, 6695–6711. https://doi.org/10.1109/TEM.2023.3239552

Carlos, N., & Ronald, M. O. (2020). Analyzing effect of alternative banking channels on financial performance of Burundi commercial banks: Evidence from Kenya Commercial Bank in Burundi. *Asian Journal of Advanced Research and Reports*, 1–11. https://doi.org/10.9734/ajarr/2020/v10i430247

Ceipek, R., Hautz, J., De Massis, A., Matzler, K., & Ardito, L. (2021). Digital transformation through exploratory and exploitative Internet of Things innovations: The Impact of family management and technological diversification. *Journal of Product Innovation Management*, *38*(1), 142–165. https://doi.org/10.1111/jpim.12551

Charmaz, K., & Thornberg, R. (2021). The pursuit of quality in grounded theory. *Qualitative Research in Psychology*, *6*, 305–327.

Chaudhuri, R., Chatterjee, S., Mariani, M. M., & Wamba, S. F. (2024). Assessing the influence of emerging technologies on organisational data-driven culture and innovation capabilities: A sustainability performance perspective. *Technological Forecasting and Social Change*, *200*, 123165. https://doi.org/10.1016/j.techfore.2023.123165

Chowdhury, A., & Shil, N. C. (2021). Thinking ‘qualitative’ through a case study: homework for a researcher. *American Journal of Qualitative Research*, *5*(2 (In Progress)), 190–210. https://doi.org/10.29333/ajqr/11280

Clausen, E., & Sörensen, A. (2022). Required and desired: breakthroughs for future-proofing mineral and metal extraction. *Mineral Economics*, *35*(3–4), 521–537. https://doi.org/10.1007/s13563-022-00328-0

Creswell, J. W., & Creswell, J. D. (2017). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches* (4th ed.). Sage.

Creswell, J. W., & Guetterman, T. C. (2021). *Educational Research: Planning, Conducting and Evaluating Quantitative and Qualitative Research* (6th ed.). Pearson.

Dawadi, S. (2020). Thematic analysis approach: A Step-by-Step guide for ELT research practitioners. *Journal of NELTA*, *25*(1–2), 62–71. https://doi.org/10.3126/nelta.v25i1-2.49731

De Jager, K. (2018). Safety and health leadership: A concise “storyline” to achieve zero harm. *The Southern African Institute of Mining and Metallurgy*, 431–438.

Dehran, S., Agrawal, P., & Midha, P. S. (2018). Digital applications in metals and mining industry. *Semantic Scholar*, 1–13.

Du Plessis, M. J., & Pretorius, M. W. (2017). Towards a better understanding of the key elements driving the innovativeness of the mineral resources industry: A literature review. *TechnologyManagementforInterconnectedWorld*.

Dwivedi, A., & Paul, S. K. (2022). A framework for digital supply chains in the era of circular economy: Implications on environmental sustainability. *Business Strategy and the Environment*, *31*(4), 1249–1274. https://doi.org/10.1002/bse.2953

Edmondson, D. L., Kern, F., & Rogge, K. S. (2019). The co-evolution of policy mixes and socio-technical systems: Towards a conceptual framework of policy mix feedback in sustainability transitions. *Research Policy*, *48*(10), 103555. https://doi.org/10.1016/j.respol.2018.03.010

Enang, E., Bashiri, M., & Jarvis, D. (2023). Exploring the transition from techno centric industry 4.0 towards value centric industry 5.0: A systematic literature review. *International Journal of Production Research*, *61*(22), 7866–7902. https://doi.org/10.1080/00207543.2023.2221344

Etikan, I. (2016). Comparison of convenience sampling and purposive sampling. *American Journal of Theoretical and Applied Statistics*, *5*(1), 1. https://doi.org/10.11648/j.ajtas.20160501.11

European Commission (EC). (2021). Industry 5.0: Towards a more sustainable, resilient and human-centric industry. *Research and innovation*. https://research-and-innovation.ec.europa.eu/knowledge-publications-tools-and-data/publications/all-publications/industry-50-towards-sustainable-human-centric-and-resilient-european-industry_en

Friedman, N., & Ormiston, J. (2022). Blockchain as a sustainability-oriented innovation?: Opportunities for and resistance to blockchain technology as a driver of sustainability in global food supply chains. *Technological Forecasting and Social Change*, *175*, 121403. https://doi.org/10.1016/j.techfore.2021.121403

Gault, F. (2018). Defining and measuring innovation in all sectors of the economy. *Research Policy*, *47*(3), 617–622. https://doi.org/10.1016/j.respol.2018.01.007

Ghobakhloo, M., Iranmanesh, M., Foroughi, B., Tseng, M.-L., Nikbin, D., & Khanfar, A. A. A. (2023). Industry 4.0 digital transformation and opportunities for supply chain resilience: a comprehensive review and a strategic roadmap. *Production Planning & Control*, 1–31. https://doi.org/10.1080/09537287.2023.2252376

Greco, M., Grimaldi, M., Locatelli, G., & Serafini, M. (2021). How does open innovation enhance productivity? An exploration in the construction ecosystem. *Technological Forecasting and Social Change*, *168*, 120740. https://doi.org/10.1016/j.techfore.2021.120740

Gruenhagen, J. H., & Parker, R. (2020). Factors driving or impeding the diffusion and adoption of innovation in mining: A systematic review of the literature. *Resources Policy*, *65*, 101540. https://doi.org/10.1016/j.resourpol.2019.101540

Hameed, M. A., Counsell, S., & Swift, S. (2012). A conceptual model for the process of IT innovation adoption in organisations. *Journal of Engineering and Technology Management*, *29*(3), 358–390. https://doi.org/10.1016/j.jengtecman.2012.03.007

Horváth, D., & Szabó, R. Zs. (2019). Driving forces and barriers of Industry 4.0: Do multinational and small and medium-sized companies have equal opportunities? *Technological Forecasting and Social Change*, *146*, 119–132. https://doi.org/10.1016/j.techfore.2019.05.021

Ivanov, D. (2023). The Industry 5.0 framework: viability-based integration of the resilience, sustainability, and human-centricity perspectives. *International Journal of Production Research*, *61*(5), 1683–1695. https://doi.org/10.1080/00207543.2022.2118892

Jahanmir, S. F., & Cavadas, J. (2018). Factors affecting late adoption of digital innovations. *Journal of Business Research*, *88*, 337–343. https://doi.org/10.1016/j.jbusres.2018.01.058

Jämsä-Jounela, S.-L. (2019). Future automation systems in context of process systems and minerals engineering. *IFAC-PapersOnLine*, *52*(25), 403–408. https://doi.org/10.1016/j.ifacol.2019.12.570

Jamwal, A., Agrawal, R., Sharma, M., & Giallanza, A. (2021). Industry 4.0 technologies for manufacturing sustainability: A systematic review and future research directions. *Applied Sciences*, *11*(12), 5725. https://doi.org/10.3390/app11125725

Jayashree, S., Reza, M. N. H., Malarvizhi, C. A. N., & Mohiuddin, M. (2021). Industry 4.0 implementation and Triple Bottom Line sustainability: An empirical study on small and medium manufacturing firms. *Heliyon*, *7*(8), e07753. https://doi.org/10.1016/j.heliyon.2021.e07753

Junjie, M., & Yingxin, M. (2022). The discussions of positivism and interpretivism. *Global Academic Journal of Humanities and Social Sciences*, *4*(1), 10–14. https://doi.org/10.36348/gajhss.2022.v04i01.002

Karmaker, C. L., Bari, A. B. M. M., Anam, Z., Ahmed, T., Ali, S. M., de Jesus Pacheco, D. A., & Moktadir, A. (2023). Industry 5.0 challenges for post-pandemic supply chain sustainability in an emerging economy. *International Journal of Production Economics*, *258*, 108806. https://doi.org/10.1016/j.ijpe.2023.108806

Kauffman, R. J., & Techatassanasoontorn, A. A. (2010). New theoretical perspectives on technology adoption. *InformationTechnologyManagement*, 157–160.

Kivimaa, P., & Kern, F. (2016). Creative destruction or mere niche support? Innovation policy mixes for sustainability transitions. *Research Policy*, *45*(1), 205–217. https://doi.org/10.1016/j.respol.2015.09.008

Kivunja, C., & Kuyini, A. B. (2017). Understanding and applying research paradigms in educational contexts. *International Journal of Higher Education*, *6*(5), 26. https://doi.org/10.5430/ijhe.v6n5p26

Lee, H., Park, S., & Kim, J. (2023). Building trust in technology adoption: The case of Industry 5.0 in mining. *Journal of Cleaner Production*, *295*, 126–138.

Liamputtong, P. (2020). *Qualitative Research Methods* (5th ed.). Oxford University Press.

Liao, Y., Deschamps, F., Loures, E. de F. R., & Ramos, L. F. P. (2017). Past, present and future of Industry 4.0 - a systematic literature review and research agenda proposal. *International Journal of Production Research*, *55*(12), 3609–3629. https://doi.org/10.1080/00207543.2017.1308576

Littleboy, A., Keenan, J., Ordens, C. M., Shaw, A., Tang, R. H., Verrier, B., Vivoda, V., Yahyaei, M., & Hodge, R. A. (2019). A sustainable future for mining by 2030? Insights from an expert focus group. *The Extractive Industries and Society*, *6*(4), 1086–1090. https://doi.org/10.1016/j.exis.2019.11.005

Lofland, J., Snow, D., Anderson, L., & Lofland, L. H. (2022). *Analysing Social Settings: A Guide to Qualitative Observation and Analysis*. Waveland Press.

Lumandi, V. W., & Nyasha, S. (2024). Technology and growth in the South African mining industry: An assessment of critical success factors and challenges. *Journal of the Southern African Institute of Mining and Metallurgy*, *124*(2), 163–172.

Makri, C., & Neely, A. (2021). Grounded theory: a guide for exploratory studies in management research. *International Journal of Qualitative Methods*, *20*. https://doi.org/10.1177/16094069211013654

Malagon-Maldonado, G. (2014). Qualitative research in health design. *HERD: Health Environments Research & Design Journal*, *7*(4), 120–134. https://doi.org/10.1177/193758671400700411

Masucci, M., Brusoni, S., & Cennamo, C. (2020). Removing bottlenecks in business ecosystems: The strategic role of outbound open innovation. *Research Policy*, *49*(1), 103823. https://doi.org/10.1016/j.respol.2019.103823

McEvoy, P., & Richards, D. (2006). A critical realist rationale for using a combination of quantitative and qualitative methods. *Journal of Research in Nursing*, *11*(1), 66–78. https://doi.org/10.1177/1744987106060192

Meadowcroft, J. (2011). Engaging with the politics of sustainability transitions. *Environmental Innovation and Societal Transitions*, *1*(1), 70–75. https://doi.org/10.1016/j.eist.2011.02.003

Mineral Council of South Africa. (2021). *Modernisation towards the mine of tomorrow*. Mineral Council of South Africa.

Mining Review Africa. (2023). *Mining and Extraction sector trends 2023-2024*. Mining Review Africa.

Modgil, S., Singh, R. K., & Agrawal, S. (2023). Developing human capabilities for supply chains: an industry 5.0 perspective. *Annals of Operations Research*. https://doi.org/10.1007/s10479-023-05245-1

Mohd Ishak, N., & Abu Bakar, A. Y. (2014). Developing sampling frame for case study: Challenges and conditions. *World Journal of Education*, *4*(3). https://doi.org/10.5430/wje.v4n3p29

Molina, O. (2018). Innovation in an unfavorable context: Local mining suppliers in Peru. *Resources Policy*, *58*, 34–48. https://doi.org/10.1016/j.resourpol.2017.10.011

Moskovicz, A. (2019). Financial qualitative research: A comprehensive guide for case study usage. *Financial Markets, Institutions and Risks*, *3*(4), 106–116. https://doi.org/10.21272/fmir.3(4).106-116.2019

Mukherjee, A. A., Raj, A., & Aggarwal, S. (2023). Identification of barriers and their mitigation strategies for industry 5.0 implementation in emerging economies. *International Journal of Production Economics*, *257*, 108770. https://doi.org/10.1016/j.ijpe.2023.108770

Musango, J. K., & Ouma-Mugabe, J. (2024). A generic technology assessment framework for sustainable energy transitions in African contexts. *Technological Forecasting and Social Change*.

Navarro, L. (2018). The world class supplier program for mining in Chile: Assessment and perspectives. *Resources Policy*, *58*, 49–61. https://doi.org/10.1016/j.resourpol.2017.10.008

Nawawi, S. Bin, Roslin, R. B. M., & Hamid, N. B. A. (2018). The importance of friends' and family members' influence and subjective norm in propelling individuals intention to purchase Halal personal care products. *International Journal of Academic Research in Business and Social Sciences*, *8*(11). https://doi.org/10.6007/IJARBSS/v8-i11/5565

Osei, M. B., Papadopoulos, T., Acquaye, A., & Stamati, T. (2023). Improving sustainable supply chain performance through organisational culture: A competing values framework approach. *Journal of Purchasing and Supply Management*, *29*(2), 100821. https://doi.org/10.1016/j.pursup.2023.100821

Palm, A. (2022). Innovation systems for technology diffusion: An analytical framework and two case studies. *Technological Forecasting and Social Change*, *182*, 121821. https://doi.org/10.1016/j.techfore.2022.121821

Panagou, S., Neumann, W. P., & Fruggiero, F. (2024). A scoping review of human robot interaction research towards Industry 5.0 human-centric workplaces. *International Journal of Production Research*, *62*(3), 974–990. https://doi.org/10.1080/00207543.2023.2172473

Pervin, N., & Mokhtar, M. (2022). The Interpretivist research paradigm: A subjective notion of a social context. *International Journal of Academic Research in Progressive Education and Development*, *11*(2). https://doi.org/10.6007/IJARPED/v11-i2/12938

Pillai, S. G., Haldorai, K., Seo, W. S., & Kim, W. G. (2021). COVID-19 and hospitality 5.0: Redefining hospitality operations. *International Journal of Hospitality Management*, *94*, 102869. https://doi.org/10.1016/j.ijhm.2021.102869

PWC. (2023). *SA Mine 2023: Adapt and thrive*. Price Waterhouse Coppers.

Roberts, R., Flin, R., Millar, D., & Corradi, L. (2021). Psychological factors influencing technology adoption: A case study from the oil and gas industry. *Technovation*, *102*, 102219. https://doi.org/10.1016/j.technovation.2020.102219

Roblek, V., Meško, M., Pušavec, F., & Likar, B. (2021). The role and meaning of the digital transformation as a disruptive innovation on small and medium manufacturing enterprises. *Frontiers in Psychology*, *12*. https://doi.org/10.3389/fpsyg.2021.592528

Rodríguez-Espíndola, O., Cuevas-Romo, A., Chowdhury, S., Díaz-Acevedo, N., Albores, P., Despoudi, S., Malesios, C., & Dey, P. (2022). The role of circular economy principles and sustainable-oriented innovation to enhance social, economic and environmental performance: Evidence from Mexican SMEs. *International Journal* *of Production Economics*, *248*, 108495. https://doi.org/10.1016/j.ijpe.2022.108495

Rout, C. C., & Aldous, C. (2016). How to write a research protocol. *Southern African Journal of Anaesthesia and Analgesia*, *22*(4), 101–107. https://doi.org/10.1080/22201181.2016.1216664

Rožanec, J. M., Novalija, I., Zajec, P., Kenda, K., Tavakoli Ghinani, H., Suh, S., Veliou, E., Papamartzivanos, D., Giannetsos, T., Menesidou, S. A., Alonso, R., Cauli, N., Meloni, A., Recupero, D. R., Kyriazis, D., Sofianidis, G., Theodoropoulos, S., Fortuna, B., Mladenić, D., & Soldatos, J. (2023). Human-centric artificial intelligence architecture for industry 5.0 applications. *International Journal of Production Research*, *61*(20), 6847–6872. https://doi.org/10.1080/00207543.2022.2138611

Sánchez, F., & Hartlieb, P. (2020). Innovation in the mining industry: Technological trends and a case study of the challenges of disruptive innovation. *Mining, Metallurgy & Exploration*, *37*(5), 1385–1399. https://doi.org/10.1007/s42461-020-00262-1

Sansel Tandogan, N., & Gedikoglu, H. (2020). Socio-economic dimensions of adoption of conservation practices: What is needed to be done? In *Organic Agriculture*. IntechOpen. https://doi.org/10.5772/intechopen.93198

Shakeel, J., Mardani, A., Chofreh, A. G., Goni, F. A., & Klemeš, J. J. (2020). Anatomy of sustainable business model innovation. *Journal of Cleaner Production*, *261*, 121201. https://doi.org/10.1016/j.jclepro.2020.121201

Sharma, M., Sehrawat, R., Luthra, S., Daim, T., & Bakry, D. (2024). Moving towards Industry 5.0 in the pharmaceutical manufacturing sector: Challenges and solutions for Germany. *IEEE Transactions on Engineering Management*, *71*, 13757–13774. https://doi.org/10.1109/TEM.2022.3143466

Shojaei, R. S., & Burgess, G. (2022). Non-technical inhibitors: Exploring the adoption of digital innovation in the UK construction industry. *Technological Forecasting and Social Change*, *185*, 122036. https://doi.org/10.1016/j.techfore.2022.122036

Shrestha, Y. R., Ben-Menahem, S. M., & von Krogh, G. (2019). Organisational decision-making structures in the age of artificial intelligence. *California Management Review*, *61*(4), 66–83. https://doi.org/10.1177/0008125619862257

Simboli, A., Taddeo, R., & Morgante, A. (2014). The conservative approach of the mining industry towards cost considerations and its impact on sustainability. *Journal of Environmental Management*.

Sonia, C. R., & Lakonawa, P. (2021). SCRIBEES: BINUS University's platform for student services in the age of disruption. *IOP Conference Series: Earth and Environmental Science*, *747*(1), 012081. https://doi.org/10.1088/1755-1315/747/1/012081

Stroh, T., Mention, A.-L., & Duff, C. (2023). The impact of evolved psychological mechanisms on innovation and adoption: A systematic literature review. *Technovation*, *125*, 102759. https://doi.org/10.1016/j.technovation.2023.102759

Suebsin, C., & Gerdsri, N. (2009). Key factors driving the success of technology adoption: Case examples of ERP adoption. *PICMET ’09 - 2009 Portland International Conference on Management of Engineering & Technology*, 2638–2643. https://doi.org/10.1109/PICMET.2009.5261818

Taalbi, J. (2017). What drives innovation? Evidence from economic history. *Research Policy*, *46*(8), 1437–1453. https://doi.org/10.1016/j.respol.2017.06.007

Tate, W. L., & Bals, L. (2018). Achieving shared triple bottom line (TBL) value creation: toward a social resource-based view (SRBV) of the firm. *Journal of Business Ethics*, *152*(3), 803–826. https://doi.org/10.1007/s10551-016-3344-y

Thomeer, M. B., Brantley, M., & Hernandez, E. M. (2024). Using mixed methods approaches to study families and relationships. *Journal of Marriage and Family*, *86*(5), 1374–1392. https://doi.org/10.1111/jomf.12974

Trunk, A., Birkel, H., & Hartmann, E. (2020). On the current state of combining human and artificial intelligence for strategic organisational decision-making. *Business Research*, *13*(3), 875–919. https://doi.org/10.1007/s40685-020-00133-x

van Oorschot, J. A. W. H., Hofman, E., & Halman, J. I. M. (2018). A bibliometric review of the innovation adoption literature. *Technological Forecasting and Social Change*, *134*, 1–21. https://doi.org/10.1016/j.techfore.2018.04.032

van Oudenhoven, B., Van de Calseyde, P., Basten, R., & Demerouti, E. (2023). Predictive maintenance for industry 5.0: Behavioural inquiries from a work system perspective. *International Journal of Production Research*, *61*(22), 7846–7865. https://doi.org/10.1080/00207543.2022.2154403

van Sluisveld, M. A. E., Hof, A. F., Carrara, S., Geels, F. W., Nilsson, M., Rogge, K., Turnheim, B., & van Vuuren, D. P. (2020). Aligning integrated assessment modelling with socio-technical transition insights: An application to low-carbon energy scenario analysis in Europe. *Technological Forecasting and Social Change*, *151*, 119177. https://doi.org/10.1016/j.techfore.2017.10.024

Verhoef, P. C., Broekhuizen, T., Bart, Y., Bhattacharya, A., Qi Dong, J., Fabian, N., & Haenlein, M. (2021). Digital transformation: A multidisciplinary reflection and research agenda. *Journal of Business Research*, *122*, 889–901. https://doi.org/10.1016/j.jbusres.2019.09.022

Wiesner, C. (2022). Doing qualitative and interpretative research: reflecting principles and principled challenges. *Political Research Exchange*, *4*(1). https://doi.org/10.1080/2474736X.2022.2127372

Yin R.K. (2018). *Case study research design and methods* (5th ed.). Sage.

Yun, S., & Lee, J. (2015). Advancing societal readiness toward renewable energy system adoption with a socio-technical perspective. *Technological Forecasting and Social Change*, *95*, 170–181. https://doi.org/10.1016/j.techfore.2015.01.016

APPENDICES

APPENDIX A: ETHICAL CLEARANCE

Decision:

Approved

REC comments:

Good luck with your research

Date: 31 Jul 2024

Gordon Institute of Business Science
University of Pretoria

Ethical Clearance Approved

[redacted]

Please be advised that your application for Ethical Clearance has been approved.

You are therefore allowed to continue collecting your data.

We wish you everything of the best for the rest of the project.

Ethical Clearance Form

Kind Regards

This email has been sent from an unmonitored email account. If you have any comments or concerns, please contact the GIBS

APPENDIX B: CERTIFICATE OF ADDITIONAL SUPPORT

(Additional support retained or not – to be **completed by all students**.)

I hereby certify that (please indicate which statement applies):

I RECEIVED *additional/outside assistance (that is, statistical, transcriptional, thematic, coding, and/or editorial services) on my research report:*

I RECEIVED ADDITIONAL SUPPORT...

If any additional services were retained, ***please indicate below which:***

- □ ***Statistician***
- □ ***Coding (quantitative and qualitative)***
- □ ***Transcriber -***
- □ ***Editor***

Please provide the name(s) and contact details of all retained:

NAME: Eve Armstrong
EMAIL ADDRESS: audtranscriber@gmail.com
CONTACT NUMBER: ....
TYPE OF SERVICE: Transcribing service

NAME: Cheryl Thomson (EDITOR)
EMAIL ADDRESS: cherylthomson2@gmail.com
CONTACT NUMBER: 082 685 9545
TYPE OF SERVICE: Language and technical editing

I hereby declare that all *interpretations (statistical and/or thematic) arising from the analysis and write-up of the results of* **my study were completed by myself without outside assistance**.

STUDENT NUMBER:

23023504

APPENDIX C: EDITOR'S LETTER

Napier

7270

Overberg

Western Cape

22 November 2024

LANGUAGE & TECHNICAL EDITING

Cheryl M. Thomson

CONSTRAINTS LEADING TO THE RESISTANCE IN THE ADOPTION OF INDUSTRY 5.0 IN MINING SUSTAINABILITY TRANSITIONS

This is to confirm that I, Cheryl Thomson, executed the language and technical editing of the above-titled thesis of **MUFARO MUZVONDIWA, student no. 23023504,** at the **Gordon Institute of Business Science,** in preparation for submission of this thesis for assessment.

Yours faithfully

CHERYL M. THOMSON

Email: cherylthomson2@gmail.com

Cell: 0826859545

APPENDIX D: INTERVIEW GUIDE

RESEARCH QUESTION	INTERVIEW GUIDE QUESTIONS
Demographics	Qualifications: Managerial level: Position: Areas of speciality and expertise: Level of involvement in technology adoption processes:
What is the understanding of Industry 5.0 technologies and their adoption reluctance outcomes amongst mining professionals?	1. What have been your experiences with technological advancements and their applications in the mining sector? 2. Can you describe any of the new technologies and their application in the past five years? 3 Have you played a role in the implementation of such technologies and if so, can you share some of your experiences
How do constraints impact the adoption of Industry 5.0 technologies in mining sustainability transitions?	4. This brings us to the next question – where I would like you to share the challenges and/or barriers that may have hindered the successful implementation of such technologies – be elaborate and as detailed as possible. 5. What organisational factors do you think might hinder the adoption of Industry 5.0 technologies in the mining industry? 6. How well-prepared do you feel in terms of skills and knowledge to work with the new technologies?
What strategies can be employed to overcome these constraints and promote Industry 5.0 technology adoption to drive sustainability transition?	7. What training or upskilling opportunities would you find valuable to facilitate the adoption of these technologies? 8. If you had it your way what strategies or initiatives would you employ to overcome any impediments you may have experienced or witnessed in the implementation of the technologies under discussion? 9. How do you see the role of human workers in the integration of these technologies? 10. What strategies can be employed to ensure a smooth transition while considering the well-being of employees and society?
How does Industry 5.0 technologies contribute to sustainable mining practices?	11. A topical issue today is sustainability – have you found there to be a link between these new technologies and sustainability? Elaborate please. 12. In your opinion, have they contributed to sustainable mining practices and resource efficiency? 13. Are there any concerns about the environmental impact of such technologies in mining? If any.
Concluding Question	14. What do you understand from the term Industry 5.0?

APPENDIX E: CONSISTENCY MATRIX

Constraints leading to the resistance to the adoption of Industry 5.0 in mining sustainability transitions

RESEARCH QUESTIONS	LITERATURE	DATA COLLECTION	ANALYSIS TECHNIQUE
How does Industry 5.0 technologies contribute to sustainable mining practices?	Horváth & Ssabó (2019), Trunk et al. (2020), Shrestha et al. (2019), Ivanov (2023), Pillai et al. (2021), Sharma et al. (2022), Greco et al. (2021), Mukherjee et al. (2023) and Enang et al. (2023	Semi-structured interviews with Mining Professionals	Thematic analysis of transcribed scripts
How do constraints impact the adoption of Industry 5.0 technologies in mining sustainability transitions?	Cao et al. (2021), Friedman & Ormiston (2022), Horváth & Szabó (2019), Roberts et al. (2021) and Stroh et al. (2023).	Structured interviews with Mining Professionals	Thematic analysis of transcribed scripts
How can strategies be employed to overcome these constraints and promote Industry 5.0 technology adoption?	Aheleroff et al. (2022), Battini et al. (2022), Ceipek et al. (2021), Horváth & Szabó (2019), Roblek et al. (2021) and Sharma et al. (2022)	Semi-structured interviews with Mining Professionals	Thematic analysis of transcribed scripts
What is the understanding of Industry 5.0 technologies and its adoption reluctant outcomes amongst mining professionals?	Gonzales et al. (2021); Smith and Jones (2022; Brown et al. (2020; Lee et al. (2023)	Semi-structured interviews with Mining Professionals	Thematic analysis of transcribed scripts

APPENDIX F: CODE BOOK ATLAS.ti

Code	First Level	Grand Total
Accuracy	1	1
Addressing Concerns	1	1
Addressing concerns and resistance to change among employees	1	1
Addressing concerns	1	1
Adoption of cyber-physical systems - Frequency	1	1
Advanced analytics	1	1
Advancements in ESG reporting in Europe	1	1
Advancements in technologies	1	1
AI	1	1
AI and Emerging Technologies	1	1
AI Assistance	1	1
AI for predictive maintenance	1	1
AI for process optimization	1	1
AI for safety improvements	1	1
AI for security enhancements	1	1
AI technologies for analysis	1	1
AI: 4	1	1
Assessing and rating suppliers using technology	1	1
Automated PO processing	1	1
Automated responses to environmental issues	1	1
Automation	1	1
Automation	1	1
Automation	1	1
Automation and Robotics	1	1
Automation Benefits	1	1
Automation Challenges	1	1
Automation:	1	1
Battery-Driven Equipment	1	1
Battery-Related Challenges	1	1
Benefits and detriments of dry technology	1	1
Big Data and AI in Mining	1	1
Building a resilient supply chain through technology	1	1
Business case	1	1
Business Impact	1	1
Buyback Period	1	1
Calibration	1	1
Capital Outlay	1	1
Carbon Reduction	1	1
Change management and adoption support	1	1
Change Management and Upskilling	1	1

Change story	1	1
Change story	1	1
Changing Job Market	1	1
Changing Skillsets	1	1
Chatbots for supplier interaction	1	1
Clear Communication	1	1
Clear Performance Expectations	1	1
Coal disposal facilities and risks	1	1
Coal Reduction	1	1
Code: Advancements in process control algorithms	1	1
Code: Agility and openness to innovation in smaller companies	1	1
Code: AI as a game changer	1	1
Code: AI support for inexperienced engineers	1	1
Code: AI's impact on engineers and developers	1	1
Code: Automation as a natural progression	1	1
Code: Challenges in adopting new systems	1	1
Code: Challenges in preparing for and adopting new tech	1	1
Code: Change management in mining operations	1	1
Code: Company culture and innovation	1	1
Code: Cost of excessive data	1	1
Code: Data logging and historical importance	1	1
Code: Data logging and information overload	1	1
Code: Enhanced communication protocols	1	1
Code: Financial constraints and responsibility	1	1
Code: Fleet management and data utilization	1	1
Code: Gradual progression, not a step change	1	1
Code: Impact of LLMs on different job roles	1	1
Code: Impact of LLMs on job satisfaction and retention	1	1
Code: Importance of a solid foundation for new tech	1	1
Code: Improved sensors	1	1
Code: Instilling a culture of innovation from the top	1	1
Code: Limited benefit for experienced specialists	1	1
Code: Need for foundational requirements for optimization	1	1
Code: Neural networks and LLMs -	1	1
Code: People's attitudes towards new technology	1	1
Code: Plant readiness for new technologies	1	1
Code: Sustainability through work environment enhancement	1	1
Code: Task team evaluation for leveraging LLMs	1	1
Code: Time required to train a metallurgist	1	1
Code: Underestimation of change management efforts	1	1
Collaboration	3	3
Collaboration with OEMs	1	1
Collaboration with suppliers and other stakeholders	1	1
Collaboration	1	1

Collaborative Decision-Making	1	1
Collision Avoidance	1	1
Communication	1	1
Communication	1	1
Communication	1	1
Company Benefit	1	1
Company Norms	1	1
Competency	1	1
Competition	1	1
Complexity of technology	1	1
Compliance	1	1
Computer literacy	1	1
Concerns about job security due to AI and automation	1	1
Condition Monitoring	1	1
Condition Monitoring	1	1
Connected devices and data generation	1	1
Connectivity	1	1
Continuous improvement	1	1
Cost	1	1
Cost Concerns	1	1
Cost of implementation	1	1
Cost Reduction	1	1
Cost reduction	1	1
Cost reduction	1	1
Cost understanding and benefit articulation	1	1
Cost-Benefit Analysis	2	2
Creating a culture of innovation and technology acceptance	1	1
Culture	1	1
Curriculum	1	1
Data Analysis	1	1
Data analysis frequency	1	1
Data analysis limitations	1	1
Data Analytics	2	2
Data availability and understanding	1	1
Data sciences and analytics	1	1
Data utilization	1	1
Data utilization for compliance	1	1
Data-Driven Decision Making	2	2
Data-intensive technologies	1	1
Decision-Making	1	1
Decision-making	1	1
Developing self-correcting and self-aware systems - Frequency	1	1
Development	1	1
Digital skills	1	1

Digital Strategy	1	1
Digital strategy	1	1
Digital Transformation	1	1
Digital twins	1	1
Digitization	1	1
Digitization/ICT	1	1
Drones	1	1
Dust and water ingress	1	1
Early detection of potential disruptions	1	1
Education and Knowledge Sharing	1	1
Education and training	1	1
Educational Trends	1	1
Efficiency	1	1
Efficiency and Productivity	1	1
Efficiency and Waste Reduction	1	1
Efficiency	1	1
Electronic systems for sourcing events	1	1
Elimination of physical tender submissions	1	1
Employee Morale	1	1
Encouraging employees to adapt to new technologies	1	1
Energy Conservation	1	1
Energy Efficiency	1	1
Energy Monitoring	1	1
Ensuring data privacy and confidentiality	1	1
Environmental considerations	1	1
Environmental focus of conversations	1	1
Environmental Impact	1	1
Environmental Impact of Mining	1	1
Environmental Impact Reduction	1	1
Environmental impact	1	1
Environmental Management	1	1
ESG and Industry 5.0	1	1
ESG compliance	1	1
ESG compliance	1	1
ESG factors	1	1
Establishing dedicated research and innovation teams	1	1
Experimental mindset	1	1
Faster and more accurate task completion	1	1
Fear of Failure	1	1
Fear of job losses	1	1
Filter press technologies for dry co-disposal	1	1
Flotation Circuits	1	1
Focus on environmental interaction and sustainability	1	1
Focus on numbers and risk aversion	1	1

Fragility and durability of technology	1	1
Future of Work in Mining	1	1
Global mining sector lagging behind global counterparts in other industries	1	1
Gradual Adoption	1	1
Grinding Circuits	1	1
Habit and Culture	1	1
Harsh environmental conditions	1	1
Human Resource Challenges	1	1
Human-Machine Collaboration	2	2
Human-machine interface	1	1
Human-Machine Partnerships	1	1
Human-robot interface	1	1
Impact Assessment	1	1
Impact on Jobs	1	1
Impact on water quality	1	1
Implementation costs	1	1
Importance of fallback plans in case of technology failure	1	1
Incentives	2	2
Incremental implementation	1	1
Industry 4.0 Adoption	1	1
Industry 4.0 Challenges	1	1
Industry 5.0	1	1
Industry 5.0 Opportunities	1	1
Information extraction	1	1
Injury Reduction	1	1
Innovation	1	1
Innovation mindset	1	1
Integrating data across departments	1	1
Integration	1	1
Integration and Interoperability Issues	1	1
Integration with ERP systems like SAP	1	1
Integration	1	1
Interoperability	1	1
Interoperability Challenges	1	1
Investing in research and development	1	1
Investment	1	1
Investment Strategy	1	1
Job Displacement	1	1
Job Displacement Concerns	1	1
Job Loss Fears	1	1
Job losses	1	1
Job Market Change	1	1
Job Security	1	1
Labor Relations	1	1

Lack of clarity/examples	1	1
Lack of enthusiasm and drive from leadership	1	1
Lack of future-oriented skills development	1	1
Lack of proper laws and regulations for ESG reporting in South Africa	1	1
Lack of robust network infrastructure	1	1
Lack of understanding and skills	1	1
Lack of understanding of data-driven technologies	1	1
Lack of workforce preparedness	1	1
Lagging behind in data-driven technologies	1	1
Lagging behind in digital technology adoption compared to other sectors	1	1
Leadership	2	2
Leadership Buy-in	1	1
Leadership needs to embrace and promote technology adoption	1	1
Leadership	1	1
Learning from past failures of other companies	1	1
Life of Mine Increase	1	1
Limited buy-in from senior management	1	1
Maintaining AI Systems	1	1
Maintenance	1	1
Maintenance and Support	1	1
Management of Change (MOC)	1	1
Managing egos and politics within departments	1	1
Managing expectations and offering opportunities to suppliers	1	1
Mass information filtering	1	1
Mechanized mining	1	1
Mixed approaches to technological advancements	1	1
Monitoring suppliers and their sub-suppliers	1	1
Motivation	1	1
Need for further research on the environmental impact of technologies	1	1
Need for research on the social impact of technology	1	1
Need for Smaller Solutions	1	1
Need for the mining industry to learn from other sectors	1	1
New Functionality	1	1
New Skills	1	1
NPV Analysis	1	1
Online advertising and bid submission	1	1
Online Analysis	1	1
Operator Behaviour	1	1
Optimization	1	1
Optimizing energy consumption	1	1
Overlap with Industry 4.0	1	1
Partnering with research institutions	1	1
Passive and active water treatment	1	1
Perception of Technology	1	1

Personnel Involvement	1	1
Potential for job losses as technology replaces human tasks	1	1
Potential for remote mining operations in different locations	1	1
Potential impact of new technologies on carbon emissions	1	1
Potential of big data services	1	1
Predicting climate change patterns and preparing for droughts	1	1
Predicting spare part consumption	1	1
Predictive Maintenance	1	1
Problem-solving/analytical skills	1	1
Process automation for improved turnaround times	1	1
Processes	1	1
Productivity: 3	1	1
Productivity: 4	1	1
Profitability	1	1
Programming and autonomous systems	1	1
Promoting innovation and upskilling initiatives	1	1
Proper Analysis	1	1
Protecting systems and data from cyber threats in the mining industry	1	1
Providing training on new technologies	1	1
Real-time data generation and filtering	1	1
Real-time data	1	1
Real-time Monitoring	1	1
Real-time monitoring of emissions	1	1
Recycling	1	1
Reduced Labor	1	1
Reducing costs by optimizing processes and eliminating human error	1	1
Reducing reliance on human intervention	1	1
Regulations	1	1
Relationship and SOA	1	1
Reliability	1	1
Reliance on manual tasks	1	1
Remote Control	1	1
Remote Management	1	1
Remote operating centers	1	1
Remote operation of machinery	1	1
Remote Operations	2	2
Renewable energy	2	2
Reputation and premium benefits	1	1
Research and development for 5IR technologies - Frequency	1	1
Resistance to Change	3	3
Resistance to change - Frequency	1	1
Resistance to Change	1	1
Resistance to change	1	1
Resistance to change	1	1

Resistance	1	1
Resource Management	1	1
Resource Optimization	1	1
Responding to disruptions and ensuring supply continuity	1	1
Retraining	1	1
Return on Investment	1	1
Return on Investment	1	1
Risk aversion	1	1
Risk Identification	1	1
Risk management and technology implementation	1	1
Risk of cyberattacks on technology systems	1	1
ROI	1	1
Safety	1	1
Safety Measures	1	1
Safety	1	1
Safety	1	1
Self-preservation	1	1
Shift Towards Technology	1	1
Silos	1	1
Silos	1	1
Skills Development	2	2
Skills Gap	3	3
Skills gap	2	2
SOA	1	1
Solutions	1	1
South Africa's Position in the Transition	1	1
Stakeholder engagement	1	1
Stakeholder Understanding	1	1
Startup Capital	1	1
Streamlining processes and reducing turnaround times	1	1
Strong link and opportunity	1	1
Sustainability	1	1
Sustainability technologies and value protection	1	1
Sustainable Development in South Africa	1	1
Sustainable Mining Practices	2	2
Sustainable Practices	1	1
System Integration	1	1
Systems	1	1
Technological adoption	1	1
Technological Advancement	1	1
Technological Advancements	1	1
Technological Challenges	1	1
Technological innovation	1	1
Technology Adoption	1	1

Technology can lead to cost reduction	1	1
Technology Cost	1	1
Technology improves efficiency and effectiveness of processes	1	1
Temperature sensitivity of sensors	1	1
Training	2	2
Training	1	1
Training and Development	1	1
Training and Re-skilling	1	1
Training Need	1	1
Training: 2	1	1
Training: 4	1	1
Tricky to translate to bottom line	1	1
Trust and linkages to past experiences	1	1
Trust deficit: 3	1	1
Trust: 3	1	1
Understanding Change	1	1
Upskilling and reskilling the workforce	1	1
Upskilling need	1	1
Use cases	1	1
Use of bots for automating tasks	1	1
Use of data and AI for prediction	1	1
Use of drones for dangerous areas	1	1
Using data to predict asset health	1	1
Using technology for risk sensing in the supply chain	1	1
Using technology to address sustainability challenges	1	1
Value add and decision-making	1	1
Values and principles	1	1
Waste Minimization	1	1
Water management technologies	1	1
Wi-Fi	1	1
Workforce Training	1	1
Zero carbon	1	1
Grand Total	**398**	**398**